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# Implementing Watershed-Based Green Infrastructure for Stormwater Management: Case Study in Blacksburg, Virginia

By

Meredith Pavlick Warren
Tamim Younos
John Randolph

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## Disclaimer



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Virginia Water Resources Research Center
210 Cheatham Hall (0444)
Virginia Tech
Blacksburg, VA 24061
(540)231-5624
FAX: (540)231-6673
E-mail: water@vt.edu
Website: http://www.vwrrc.vt.edu

Virginia WATER RESOURCES Research Center

Stephen Schoenholtz, Director

# Summary


Conventional stormwater management in the U.S. consists of moving runoff away from development as quickly as possible. This practice has many negative and widely-known side-effects including higher than normal peak flows, stream channel degradation and contribution of high pollutant loads to receiving water bodies. USEPA regulatory requirements now mandate comprehensive management of stormwater runoff. To address stormwater runoff problems and USEPA regulatory requirements, many municipalities are exploring alternative stormwater management approaches.

Two alternative approaches to conventional stormwater management are watershed-based planning and green infrastructure. Watershed-based planning aims to manage stormwater beyond the site or subdivision level. The planning process considers the hydrology of an entire watershed and how it may be affected by both short and long-term development. In the context of stormwater management, green infrastructure can be defined as open space and infiltration-promoting stormwater management practices which in turn can reduce peak flows and pollutant loads in surface waters. Examples of green infrastructure for stormwater management include grass swales, natural wetlands, open space conservation and stream channel buffer protection. Green infrastructure can be implemented on the site, subdivision or watershed scale.

The objectives of this paper are to review approaches for watershed-based stormwater management and green infrastructure and develop an integrated watershed-based green infrastructure planning and implementation process for a case study watershed. The case study watershed is the Toms Creek watershed in Montgomery County, southwest Virginia. The watershed encompasses part of the Town of Blacksburg, in Montgomery County. Land use in the watershed is mainly rural but faces high development pressure and increased urbanization in coming decades. Currently, Blacksburg’s zoning ordinance requires significant preservation of open space when development occurs. This combined with Town’s stormwater management requirements make the watershed a good candidate for implementing a watershed-based green infrastructure plan. The developed framework can be used as a model for implementing integrated watershed-based green infrastructure plan in similar geographic environments.

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# 1. Introduction

Urban stormwater management is undergoing a transformation. Historically, stormwater management involved diverting runoff to ditches, retention ponds, pipes and culverts which transported it away from development and to the nearest surface water body as quickly as possible. Stormwater control measures were designed to accommodate runoff and prevent flooding on an individual site or within a subdivision. Minimal consideration was given to pre-existing or proposed development when new stormwater control measures were installed. As an area was built out, the impacts of traditional stormwater control practices and neglecting stormwater volumes from surrounding development began to surface. For example, in the 1980s retention ponds were the control measures of choice, yet flooding become an even bigger issue in areas where they were widely used (NRC 2008).

Historic stormwater control practices also had minimal effect on protecting water quality, stream channel stability and aquatic species habitat. An increasing number of surface waters exhibiting quality impairment due to land development prompted numerous studies of stormwater runoff effects in the 1960s through the 1980s (ASCE and WEF 1998). The early studies discovered a direct connection between land use, namely impervious cover, stormwater quality and quantity and water body impairment. As an area is developed and impervious cover increases, land loses its ability to absorb water and assimilate pollutants. Receiving water bodies, in turn, are unable to handle the increase in flow and pollutants which often transforms streams into runoff ditches, supporting little to no flow between rain events and scarce aquatic life.

In response to the findings of early studies, and the scale of the problem, the United States Environmental Protection Agency (USEPA) promulgated federal stormwater management regulations under the National Pollution Discharge Elimination Program (USEPA 2000). Today, urban stormwater control measures (SCMs) are expected to meet these federal regulations, as well as address public safety issues, minimize water resource impacts and meet the public's desire to protect environmental quality. To achieve this, local governments and developers are incorporating alternative SCMs into new development and retrofit projects which are designed to reduce or eliminate common urban stormwater runoff impacts. Alternative measures, which include rain gardens, vegetated swales and pervious pavement, address the sources of stormwater and stormwater pollution, not just the volume of runoff moving offsite. Promoting infiltration and keeping water onsite is also achieved through a number land development practices, including conservation subdivisions, where structures are clustered to reduce impervious cover, conserve large tracts of land and create stream buffers. However, these alternative SCMs still share a common thread with traditional methods: runoff is addressed on a site-by-site or subdivision basis.

Today, the literature calls for a more comprehensive approach to stormwater runoff reduction and control – watershed-based stormwater management. Watershed-based approaches have been successfully applied in natural resource and pollutant management programs, but have not been widely utilized for stormwater management. A watershed-based approach for stormwater management makes sense from a hydrologic standpoint. Stream flow and water quality are influenced not only by land development in one subdivision, but by all land uses throughout an entire watershed. The minimal application of this approach may be the result of limited research completed on this topic. However, available research findings provide extensive information on the successes that can be achieved using various stormwater control measures and land development tools. There is agreement in the literature that this information can be applied on watershed scale, but comprehensive planning including the assessment of projected short and long-term land use changes, locally adaptable stormwater control measures, zoning limitations, desired water quality goals and public support will be required.

In addition to watershed-based management, the concept of green infrastructure planning is also receiving increased attention in the areas of water resource protection and stormwater management. Green infrastructure planning evolved out of the land conservation movements of the early twentieth century. Up until the 1980s, conserved lands were often afterthoughts, comprised mainly of land remaining after development had been completed (Ducham 2000). In many locations the land was often mediocre in terms of habitat, water quality or recreation benefits. More recently, municipalities, regional governments and states are prioritizing areas for conservation before development takes place via green infrastructure plans. These plans guide development in order to conserve areas deemed necessary for protecting ecosystems health and other natural amenities. The green infrastructure movement, originally promoted as a way to protect habitat, has exhibited water quality benefits that can be adapted to controlling stormwater runoff. Specifically, impervious areas promote infiltration, reducing peak runoff volumes, assimilate pollutants and promote evapotranspiration.

This paper analyzes the environmental impacts of stormwater runoff and the evolution of stormwater management controls. Focus is placed on stormwater control measures which are becoming more common place to address both runoff quantity and quality. The concept of watershed-based stormwater management will then be reviewed. This paper will also review the concepts of green infrastructure including how it evolved from early approaches to land conservation, key components of green infrastructure plans and examples of planning at the state, regional and local level. Lastly, the techniques and examples of green infrastructure and watershed-based stormwater management controls which are discussed will be utilized to create a planning process for establishing a watershed-based green infrastructure to manage stormwater in the Toms Creek Watershed in Virginia.

# 2. Urban Stormwater: Impacts, Regulation and Management

## *2.1. Overview*

Stormwater runoff is a natural component of the water cycle, created by excess rain or snowmelt that runs overland and eventually reaches a river, stream, lake, ditch or pipe. However, stormwater runoff should be considered in two contexts. The first is the general term already described, excess water running overland that eventually reaches a surface water body (NRC 2008). The water may reach the water body shortly after a rain or snowmelt event or infiltrate and enter a surface water body via interflow, water moving just below the surface of the ground, after the event has passed. Stormwater runoff can also be viewed from a regulatory standpoint where runoff is generated from an urban environment and flows through an engineered pipe or canal and is discharged into a water body at a specific point (NRC 2008). This second definition is the focus of this paper and herein will be referred to as "urban stormwater".

Urban stormwater has increasingly damaging effects as land is developed from a rural state to an urbanized state. While the connections between urbanization and stormwater runoff generation have been known for some time, initially the main concern from a regulatory standpoint was flood control (USEPA 1983). In the 1960s the U.S. Geologic Survey (USGS) started to quantify the impacts of urban stormwater on water quality by assessing the chemical constituents in runoff and streams, discovering excess nutrients, heavy metals, and pesticides

(ASCE and WEF 1998). These findings prompted the USEPA in the 1970s to require regional planning agencies regulated under section 208 of Clean Water Act to study urban stormwater characteristics and its impacts on water quality (ASCE and WEF 1998). The studies were ultimately unsuccessful due to lack of experience in how to collect stormwater data (ASCE and WEF 1998).

Following the 1970s studies, the USEPA implemented the National Urban Runoff Program (NURP) (ASCE and WEF 1998; USEPA 1983). NURP was not designed to be a research initiative; instead it aimed to serve as a support mechanism for 28 local water planning initiatives (USEPA 1983). The USEPA intended to use the results of the planning efforts to assist other jurisdictions with water quality management plans (USEPA 1983). One of the most notable facts about the NURP is that the USEPA understood proper stormwater management planning across agencies could prevent some effects of stormwater runoff at the lowest cost.

NURP and other early studies made great strides in identifying the urban stormwater pollutants that cause water quality problems. The issues identified lead to a new body of literature focused on quantifying the levels of pollutants and the thresholds of watersheds for assimilating pollutants and accepting larger runoff volumes. The extensive research findings promoted the adoption and implementation of federal stormwater regulations by the USEPA which will be discussed in Section 1.3.

## *2.2. Urban Stormwater: Impacts on Water Resources*

Research has identified impervious surfaces, including driveways, roads, rooftops and sidewalks, as the most important factor contributing to urban stormwater volumes and pollution (Arnold and Gibbons 1996; Schueler and Holland 2000a). At the parcel level, the impact of impervious surfaces many not be easily noticed, however as the scale is increased from a lot to a subdivision or a watershed the impacts become more apparent. The correlation between the percent of watershed impervious cover and runoff quantity, expressed as runoff coefficient (Rv), is well understood (Figure 1). As impervious surfaces in a watershed increase, the land area that can absorb rain and/or snow melt decreases, thus less infiltration and increased runoff. The runoff coefficient (Rv) is commonly used to appropriately apportion SCMs for specific storm sizes given the high correlation in this relationship.

Research has consistently shown that stream health is also directly related to the amount of impervious cover in a watershed. If the impervious cover in a watershed is less than 10 percent a stream is considered protected, between 10 percent and 30 percent a stream is considered mildly impaired and above 30 percent a stream is severely impaired (Arnold and Gibbons 1996). A similar relationship has been observed with wetland impairment in urbanized watersheds (Arnold and Gibbons 1996).

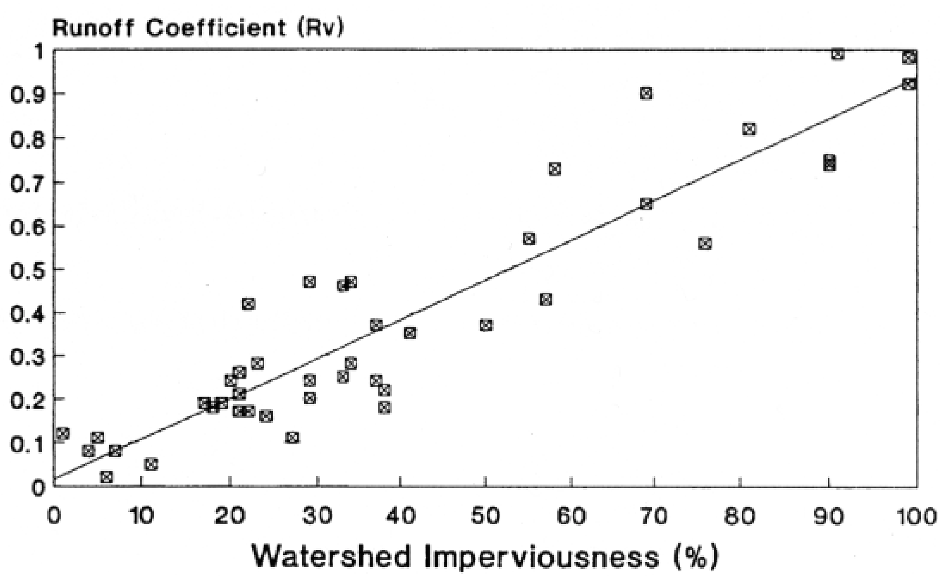


**Figure 1: Relationship between Watershed Imperviousness and the Runoff Coefficient (Rv)**
*Source: Scheuler and Holland 2000a.*

Urban stormwater contributes high levels of pollutants to surface waters, typically on the order of one to two magnitudes greater, than runoff from an undeveloped watershed (ASCE and WEF 1998). Impervious surfaces accumulate detritus, trash, sediment, oils, salts, nutrients and toxic compounds. These materials are easily picked up by runoff and carried to surface waters. Pollutant characteristics associated with stormwater runoff change over time as a developed area ages. In the initial development phase, surface water collects sediment created by land disturbances during construction (ASCE and WEF 1998). As the disturbed land stabilizes, pollutants originate from impervious areas and are washed off during rain and snow melt events (ASCE and WEF 1998).

In urbanized areas, the hydrology and channel geomorphology of streams changes due to increased impervious surfaces, as well as altered drainage paths and the enclosure of headwater streams. Impervious surfaces and hydrologic changes cause runoff to enter streams at a much faster rate, producing larger peak flow volumes and high flow velocities (ASCE and WEF 1998; NRC 2008). As an area develops, water entering streams is increasingly from surface runoff and less from baseflow, discharge from groundwater aqifers, or interflow (ASCE and WEF 1998). Subsequently, urban streams experience an increase in the frequency of peak flows and downstream flooding (ASCE and WEF 1998; NRC 2008; Scheuler and Holland 2000a). The large volumes of urban runoff also scour stream banks causing stream channels to widen and incise, sometimes several meters below the original stream bed level (NRC 2008). The scouring and incising lead to increased sediment loads downstream and changes in stream bed composition and structure which alters or destroys aquatic habitat resulting in decreased biodiversity (NRC 2008). For example, it has been observed that stream macroinvertebrate diversity decreased as impervious cover increased in a watershed (Scheuler and Holland 2000a).

Urbanization and urban runoff also impact wetlands, groundwater recharge and lake water quality. Wetlands, like streams, will receive increased pollutant loads and experience hydrologic changes (ASCE and WEF 1998). In some instances wetlands may even disappear due to changes in stream channel morphology or removal during development. Groundwater recharge by rainfall and snow is often decreased because impervious surfaces reduce local infiltration (ASCE and WEF 1998; Scheuler and Holland 2000a). Lakes do not experience the hydrologic impacts as severe as streams, but are affected by runoff volume and increased pollutant loads. Lakes do not flush like streams, but instead act as sinks for nutrients and other pollutants which can create eutrophic conditions (ASCE and WEF 1998).

The cumulative changes that occur in surface waters as a result of urban stormwater have lasting effects. Many waterways within and downstream of urban areas no longer meet their use designations due to violations of water quality standards (Figure 2). If water quality violations are frequent, a surface water body may be included on the 303(d) list of impaired waters. A 303(d) listing will require the development of a Total Maximum Daily Load (TMDL) report which could create additional load limitations on point and potentially nonpoint sources of pollution, depending on the pollutant requiring reductions.

## *2.3. Stormwater Regulation*

In the 1970s local zoning ordinances started to appear across the U.S. requiring management of urban stormwater generated by certain rainfall depths occurring within a 24 hour period (NRC 2008). Many local jurisdictions began utilizing detention basins for runoff management using these criteria. However, shortcomings of these SCMs were soon apparent including improper sizing, basin location and overuse (NRC 2008). In the 1980s, both the U.S.

Congress and USEPA began to take notice of the limitation of regulations to address the pervasive problems created by urban stormwater. In 1987, Congress amended the

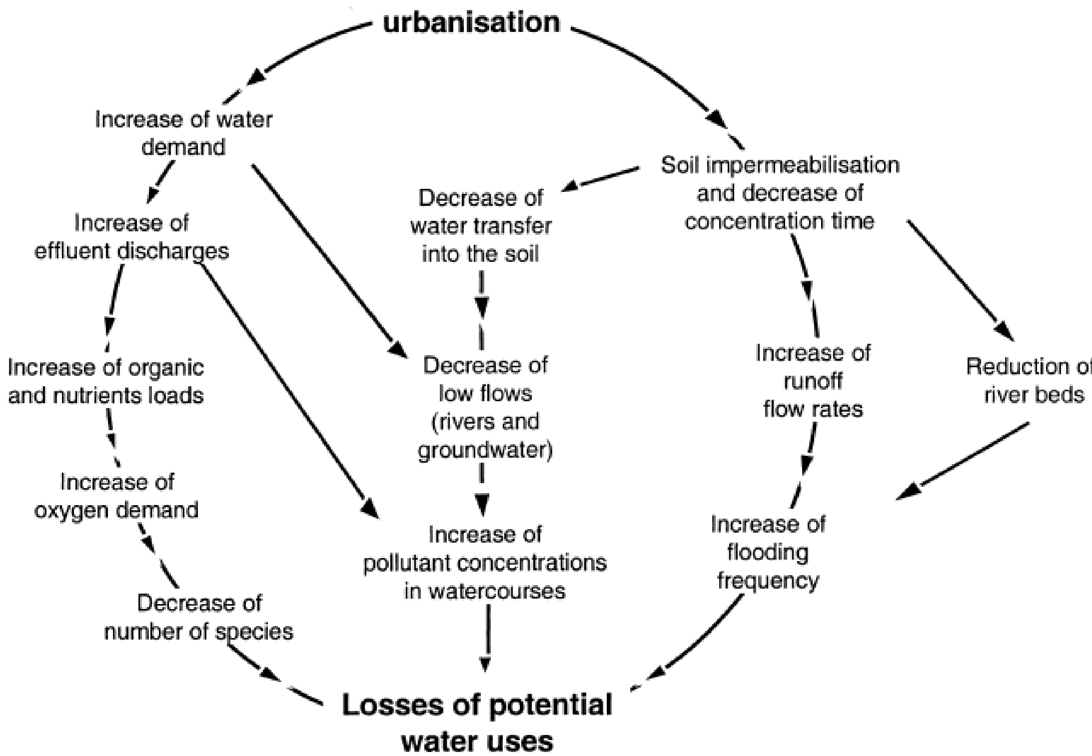


**Figure 2. Impacts of Urbanization on Aquatic Environments**
*Source: Bertrand-Kranjewski 2000 from Chocat, ed. 1997*

Clean Water Act to include Section 402(p). The amendment requires the management of certain stormwater discharges. Section 402(p) directs the USEPA to regulate municipal, industrial and construction site stormwater discharges under a National Pollution Discharge Elimination System (NPDES) program (NRC 2008).

In 1990, the USEPA published the NPDES permit application requirements (USEPA 2000; NRC 2008; ASCE and WEF 1998). The USEPA split the implementation of the program in two phases. Phase I covers cities with a municipal separate storm sewer system (MS4) and a population greater then 100,000 people, construction sites disturbing more than five acres, and ten different industrial sectors (EPA 2000; NRC 2008). Phase II covers smaller MS4 communities and construction sites between one and five acres (EPA 2000; NRC 2008). There are two major differences between the stormwater NPDES program and the NPDES program managing other point source discharges. Under stormwater NPDES program, USEPA does not establish discharge limits for pollutants prior to permit approval, or require stringent monitoring of effluent for specific pollutants (NRC 2008). The USEPA made these changes recognizing that pollutants are site specific and will require site specific control measures, leaving control measure decisions up to the permit holders (NRC 2008).

## 2.4. Stormwater Control Measures

Up until the 1970s, SCMs in the U.S. were aimed at moving water away from development as quickly as possible to address safety concerns associated with local flooding (Arnold and Gibbons 1996; Chocat, et al. 2001; ASCE and WEF 1998; NRC 2008). Urban stormwater was managed using structural controls including curb and gutter, pipes and detention basins. Contrary to what was trying to be achieved with these SCMs, this approach resulted in frequent downstream flooding. This issue was partially addressed with widened, reinforced stream channels which proved to be inadequate at mitigating the emerging urban stormwater pollutant issues (NRC 2008). Today flooding issues, coupled with emerging data on pollutants and the promulgation of the stormwater NPDES program, has changed the way developers and local governments approach stormwater management. SCMs are now comprised of a multitude of structural and nonstructural controls, designed to mitigate the water quantity and quality impacts of urban stormwater on receiving water bodies (Table 1) (NRC 2008). Structural controls including infiltration basins, vegetated filter strips, bioretention structures, constructed wetlands, and riparian buffers are being modified and designed to facilitate infiltration as well as convey runoff offsite (NRC 2008; Young et al. 2009). Nonstructural controls, including low impact development techniques and public education, are aimed at promoting infiltration, changing public behavior and developing long-term management programs.

**Table 1. Overview of Current Stormwater Control Measures**

| Category | Common approaches | Structural vs. Nonstructural |
|---|---|---|
| Policies and source controls | Public education, land use planning, material management and spill prevention, street and stormwater control facilities maintenance, prevention of illicit connections and dumping | Non-structural |
| Lot-level source controls | Green roofs, local storage/detention, stormwater harvesting, local infiltration, impervious cover reduction | Structural |
| Community level stormwater control measures | Community infiltration facilities, stormwater management ponds, constructed wetlands or natural wetland enhancement, extended detention (dry basins) treatment trains | Structural |
| Watershed level measures | Manages water on a natural versus political boundaries, establishes water quality goals and use designation protection, considers cumulative impacts, protects resources valuable in controlling runoff, supports and directs land use decisions, and assists in siting of stormwater control measures, employ the ecosystem approach, assists in the development of more detailed plans | Structural and Non-structural |

*Source: ASCE and WEF 1998; Marsalek and Chocat 2002; NRC 2008.*

Vegetated filter strips provide areas for pollutant removal and infiltration between developed areas and waterways. These filter strips can be used as a stand alone SCMs or as part of a series of SCMs (treatment train) (Young et al 2009). Vegetated filter strips should consist of at least turf, but provide even greater benefit if a variety of vegetation is present, including trees and shrubs, to promote retention and evapotranspiration (Young et al 2009). Vegetated filter strips work most effectively when receiving water from an area of five acres or less (Young et al. 2009).

Bioretention structures serve to improve stormwater through retention, infiltration and uptake. These SCMs are sometimes limited, as with other infiltration SCMs, by shallow groundwater and soil type (Young et al. 2009). Bioretention structures can be either on-line, meaning they are located in other SCMs including vegetated filter strips, or off-line, meaning water is directed to a specific area (Young et al. 2009).

Infiltration basins are impounded areas that collect urban stormwater and allow infiltration using existing soil media and promote evapotranspiration with local vegetation (Young et al. 2009). Infiltration basins are typically limited to a catchment area of about 50 acres and can only be installed in certain soils (Young et al 2009). Infiltration basins provide a significant amount of treatment of suspended and soluble pollutants (Young et al 2009).

Constructed wetlands are designed to provide water treatment through uptake and infiltration. This SCM is generally not used for runoff or flood control because the fluctuations in water levels can place stress on the wetland and upland vegetation planted for pollutant removal (Young et al. 2009). Constructed wetlands are used to treat runoff from an area greater than ten acres and must be placed in an area with adequate baseflow or shallow groundwater to assure a constant supply of water to the wetland (Young et al. 2009).

Riparian buffers are zones of vegetation along a waterbody that can protect water quality and stream structure, biodiversity benefits and promote infiltration. In an agricultural setting, riparian buffers have been shown to provide substantial pollutant removal when treating sheet flow (NRC 2008). However, in an urban setting, stream buffers may receive concentrated flow, or be bypassed completely by a stormwater conveyance pipe which discharges directly into a stream (NRC 2008). Giving consideration to runoff flow direction and areas of concentration during runoff events can improve the ability for buffers to increased pollutant remove and decrease infiltration. Riparian buffers also protect biodiversity and habitat by stabilizing stream structure and proving shelter for aquatic species (NRC 2008; Scheuler and Holland 2000d).

Public education, low impact development (LID) strategies and other nonstructural controls address the sources of urban stormwater. Public education programs are typically designed to explain how urban stormwater is created and outline changes in behavior that can benefit water quality and reduce runoff volume. These programs often promote limiting fertilizer use on lawns, disconnecting downspouts from storm drains and installing rain barrels to collect rain water for irrigation (NRC 2008). The goal of LID strategies is to reduce impervious surfaces, by reducing road widths, clustering development and minimizing site disturbance (EPA 2007; Scheuler and Holland 2000e). A study in the state of Washington found that a ten to twenty percent reduction in runoff was reasonable if these practices are implemented (Scheuler and Holland 2000e). Utilizing LID strategies can be challenging if local zoning ordinances or emergency vehicle access requirements do not allow for certain practices (Scheuler and Holland 2000e). Taking the time to work through regulatory conflicts could ease the process of adopting and including LIDs in future development.

While nonstructural and modified structural SCMs are being used more regularly, qualitative information about their impact on downstream water quality is still limited (Chocat, et al. 2001; Marsalek and Chocat 2002; NRC 2008). Fortunately, knowledge of links between impervious surfaces, runoff volumes and watershed impairment, effectiveness of specific SCMs and options for increasing onsite infiltration are encouraging many jurisdictions to think outside of traditional stormwater management approaches. But, even with the increased utilization of modified SCMs nationally, the trend within many jurisdictions is to use prescribed methods of stormwater management at the lot or subdivision level (NRC 2008). However, the state of knowledge about stormwater generation and control should enable stormwater management planning to occur on a watershed level where the environment, local economy, social demands and climate change are all considered (Marsalek and Chocat 2002; NRC 2008). In fact, the literature is now encouraging this type of urban stormwater management.

## *2.5. Watershed-Based Urban Stormwater Management*

Utilizing watersheds as the foundation for stormwater management is completely logical. Within a watershed, water quality and flow volumes at a given point along a stream will be affected by all land use and human activities located upstream. Unfortunately, watershed boundaries are often bisected by political or structural stormwater conveyance system boundaries which may include only a portion of a watershed. Water quality and urban stormwater volumes, especially in politically defined management areas, have the potential to be negatively impacted by land use and regulations in adjacent jurisdictions in the same watershed. If a watershed serves as management boundary, focus can be placed on protecting watershed resources as a whole and issues originating in one particular jurisdiction may be avoided.

From a stormwater management perspective, watershed-based planning is being touted by many as a way to address the underlying causes of stormwater runoff, rather than managing the symptoms (ACSE and WEF 1998; Marsalek and Chocat 2002; NRC 2008). A watershed-based approach for resource management has been used in flood and erosion control for many years (ASCE and WEF 2008). The EPA has been promoting watershed-based resource management for the last decade, most recently for its NPDES program (EPA 2003). The push from EPA is due to the potential financial and environmental benefits that can be realized with this approach (EPA 2003; NRC 2008).

Even with extensive application of watershed-based management, the process for developing a watershed-based stormwater management plan is still mainly empirical because very few studies have addressed the subject (Marsalek and Chocat 2002). Yet, enough is known about the hydrologic cycle and runoff generation, that if properly planned and implemented, a watershed-based approach has the potential to achieve desired water quality goals (ASCE and WEF 1998; Marsalek and Chocat 2002). One component of watershed-based management that is limited in the literature is the cost associated with this type of approach. However, information about the cost savings related to specific stormwater control measures is beginning to appear in the literature, and many cite anecdotal evidence that cost savings can be realized when stormwater management decisions are made before development (EPA 2007; Marsalek and Chocat 2002; NRC 2008).

Watershed-based planning may make the most sense in areas currently being developed, more specifically in suburban areas (NRC 2008). Since the watershed-based approach considers SCMs from the site scale up to, and including, the entire watershed, developing areas allow for more flexibility in SCMs selection, and costs could potentially be much lower versus retrofitting SCMs post-development. Upfront development of SCMs also places a majority of the costs associated with SCMs onto the home buyer versus the community as a whole, the entity typically funding retrofitting projects (NRC 2008).

## 2.6. Watershed-Based Stormwater Management Process

The literature has outlined a number of ways to implement a watershed-based stormwater management program. The steps outlined below provide one option for developing a watershed-based stormwater management plan based on these numerous sources (ASCE and WEF 1998; EPA 2003; Marsalek and Chocat 2002; NRC 2008). The steps will be defined in some detail in the following subsections and explained further in Section 4.

1. Identify stakeholders
2. Define objectives
3. Data collection

4. Data analysis
5. Implement program
6. Evaluate effectiveness

### 2.6.1. Identify Stakeholders

Watershed planning for stormwater management should be implemented by a broad-based committee compromised of citizens, local government, quasi-governmental agencies, nonprofit organizations, and local developers (ASCE and WEF 2008). Involving stakeholders from the beginning and including all effected parties will allow ownership of a plan to develop, improving the chance of success. If the watershed crosses multiple jurisdictions, intergovernmental cooperation may be necessary to achieve desired outcomes (ASCE and WEF 2008).

### 2.6.2. Define Objectives

The first step in developing the actual management plan is to determine the objectives of stormwater management. Stakeholders need to determine what aspect of surface water (and potentially groundwater) resources should be protected. Most of the literature alludes to the protection of beneficial uses, but communities may want to elaborate by aiming to control flooding, prevent violation of specific water quality standards or improve baseflow between storm events.

One major consideration in goal setting is cost of implementation (Figure 3). The cost of achieving certain water quality goals will be determined by local conditions. Stakeholders need to be careful not to set a management plan up for failure by setting goals that cannot be achieved due to cost restrictions (NRC 2008). For example, if a watershed already contains a high percentage of impervious cover, it may be more realistic to protect the current conditions, versus trying to restore water quality to pre-development conditions (NRC 2008). In a relatively

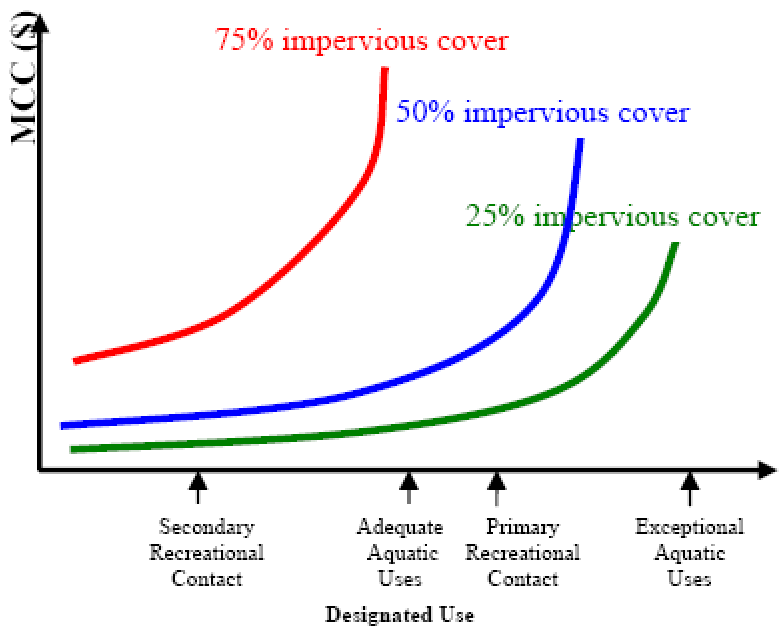


**Figure 3. Cost of Achieving Designated Uses in a Hypothetical Urban Watershed**
*Source: NRC 2008.*

undeveloped watershed (low percentage of impervious cover) where water quality is still supporting a healthy aquatic population, protecting a stream at or near its current state is likely to be more financially feasible in the long-term (NRC 2008).

### 2.6.3. Data collection

The data collection and analysis phase is one of the most critical. Stakeholders need to consider all potential stressors and assets of local water quality (ASCE and WEF 1998; NRC 2008). Available data will be determined by local conditions, but some of the major pieces of information to review include:

- Current and future land use (land use land cover data, comprehensive plan and zoning ordinances)

- Locally applicable SCMs
- Federal, state and local regulations (land use, environmental, public health)
- Potential water quality stressors other than stormwater (point and nonpoint)
- Available water quality data (monitoring, TMDLs, watershed plans)
- Existing programs (land conservation, water quality protection, etc.)
- Valuable natural resources (wetlands, floodplains)
- Meteorological data
- Responsible management entities
- Conserved lands
- Educational resources
- Physical constraints for SCMs (karst, high water tables, steep slopes)
- SCMs maintenance options (public and private)
- Financing options.

### 2.6.4. Data analysis

Data analysis should result in the development of the stormwater management plan and will include, but is not limited to, defined water resource goals, a list of relevant and locally applicable SCMs, regulatory and non-regulatory implementation tools, specific financing components and evaluation methods and criteria (ASCE and WEF 1998). The data analysis should also result in an outline of uncertainties with data and should provide for alternative implementation methods if evaluations find specific components of the plan are not functioning as anticipated.

One of the most important components of data analysis is determining which SCMs will be the most effective in achieving the objectives of the plan (Marsalek and Chocat 2002; NRC 2008). The SCMs selected should be applicable to local conditions and experience, and should include those that can be used at the site, subdivision, and subwatershed level. The selection of SCMs should also include guidance and performance criteria, if the goal of the plan is water quality protection, as well as maintenance requirements (NRC 2008).

### 2.6.5. Implement Program

Program implementation can occur one of three ways: incorporating the plan into an existing program, using the plan to start a new program or employing the plan to implement a pilot study to assess implementation costs and potential problems (ASCE and WEF 1998). Adding on to an existing program may be the most feasible in MS4 communities or other areas where a municipal or regional management program has been established. Conducting a pilot study may be the best option in areas where not enough information exists to make long-term management decisions (ASCE and WEF 1998).

### 2.6.6. Evaluate Effectiveness

Evaluation of a watershed-based program could be challenging given the limited amount of studies completed on the subject. The literature recommends evaluating effectiveness of a plan through ongoing assessment of stream health to determine what adjustments, if any, are necessary to achieve the goal of the plan (ASCE and WEF 1998). Two important components of this type of evaluation include assessing the ecological conditions of the receiving waterbody to assure habitat and aquatic life are stable, and water quality monitoring to assure standards are not being violated and beneficial uses are met (ASCE and WEF 1998). Additional evaluation may be necessary, including public surveys, monitoring of stormwater runoff discharges and assessment of receiving water before, during and after a storm (ASCE and WEF 1998). A pilot study may be the best approach to developing the most applicable evaluation techniques (ACSE and WEF 1998).

# 3. Green Infrastructure

## *3.1. Overview and History*

Green infrastructure is a term that typically portrays the naturally-linked components within and surrounding the built-environment. Green infrastructure is most commonly defined as a structure of interconnected greenways (trails, stream corridors) and green hubs (forests, farms, parks) located throughout a region to protect wildlife diversity, ecological processes, air and water quality and recreation opportunities (Benedict and McMahon 2002, 2006). The term green infrastructure can also represent a systematic process, the decision making and planning for the purpose of developing an infrastructure framework to achieve specific conservation or resource management objectives (Benedict and McMahon 2002, 2006).

Green infrastructure as a physical structure or a process is not a new idea. However, the approach and motivation for its establishment have morphed over time. Since the mid-nineteenth century, landscape architects, starting with Frederick Law Olmstead, have frequently organized major developments and cities around central "*greenspaces*" for a number of social and environmental purposes (Bryant 2006; Little 1990; Randolph 2004; Wamsley 2006). Olmstead's initial approaches to greenspace development included designing parks for major metropolitan areas which early on also included the Parkway concept. Parkways are green corridors designed to mentally prepare the individual as they approached the park to enhance a visitors experience once inside (Little 1990). Olmstead also utilized the "*greenbelt*" concept where parks and parkways and/or greenways were linked in a linear design (Little 1990; Randolph 2004). The practice of developing greenspaces with natural and cultural significance lasted through the 1980s.

In the 1980s the approach to land conservation shifted and began to include the conservation of farmland, urban forests and greenways planning (Table 2) (Benedict and McMahon 2002, 2006; Gangloff 2003; Randolph 2004). In the 1990s “sustainability” became an international topic of discussion (Benedict and McMahon, 2006). The public at large became increasingly aware of the impacts of land development on natural resources including habitat fragmentation, water resource contamination and water availability. The public also started to understand the ecological, social and financial benefits of conserving land in contiguous networks. Greenspace and greenways concepts morphed into a more holistic “green infrastructure” approach where public and private land conservation and development patterns were driven not only by social and recreational benefits, but also the protection of biodiversity, ecosystem function, property values, improved stormwater management and reducing the impacts of land development on natural resources (Benedict and McMahon 2002, 2006; Randolph 2004; Wamsley 2006).

**Table 2. Evolving Nature of Local Government Land Conservation in the United States**

| Period | Type | Conservation Tools | Primary Objectives |
|---|---|---|---|
| <1980 | Parks and Recreation Planning | Land acquisition, park planning and management | Active recreation, scenic amenity |
| 1980s | Open Space Planning | Land acquisition and easement; park planning and management | Active recreation, scenic amenity, farmland protection , urban forestry |
| 1990s | Greenways and Open Space Planning | Land acquisition, easement, floodplain zoning, park and greenway planning and management | Active and passive recreation, scenic amenity, farmland protection, urban forestry, urban wildlife |
| 2000 | Green Infrastructure | Land acquisition, easement, floodplain management, Smart Growth management tools, conservation land development, partnerships with landowners, land trusts | Hubs and links for active and passive recreation, scenic amenity, farmland protection, urban forestry urban wildlife, regional and state ecological systems, integration of conservation and growth management. |

*Source: Randolph 2004.*

While green infrastructure originally evolved from greenways planning there are some significant differences between the two as noted by Benedict and McMahon (2002):

- "Ecology vs. Recreation—Green infrastructure emphasizes ecology, not recreation
- Bigger vs. Smaller—Green infrastructure includes large, ecologically important hubs, as well as key landscape linkages.
- Framework for Growth—Green infrastructure can shape urban form and provide a framework for growth. It works best when the framework pre-identifies both ecologically significant lands and suitable development areas" (p.13).

These key comparisons help explain why land conservation planning is now based more on conservation biology, hydrology, social science and land use planning principles as opposed to just natural and cultural significances (Benedict and McMahon 2006).

The "green infrastructure" concept gained high visibility in 1999 when it was recognized by The President's Council for Sustainable Development as a key approach for achieving sustainable land development (Benedict and McMahon 2002; The Council on Sustainable Development 1999). Since 1999, the green infrastructure concept has been advanced by several organizations, such as the Trust for Public Land and The Conservation Fund, and states including Maryland and Florida (Benedict and McMahon 2006; Randolph 2004). Each year, an increasing number of cities and states are adopting green infrastructure plans to protect valuable open spaces (Benedict and McMahon 2006; Ducham 2000; Wamsley 1995).

## *3.2. Water Resources Benefits of Green Infrastructure*

Benefits associated with green infrastructure include but are not limited to, biodiversity protection, preservation of wildlife corridors, carbon sequestration, protection of ecological functions of terrestrial and aquatic environments, stormwater and flood control, water quality protection, increased property values, improved public health and tourism (Benedict and McMahon 2006; The Trust for Public Land 2002). Land development, more specifically impervious surfaces, can dramatically alter the water cycle by increasing stormwater runoff volumes. Land development, road construction and other anthropogenic activities associated with urbanization, including fertilization of lawns and littering, also increase the levels of pollutants contributed to local water bodies. Green infrastructure helps control runoff quantity and quality entering water bodies from developed land, thus reducing the occurrence of floods, stream channel erosion caused by high flow rates, water quality degradation and impacts on stream baseflow and temperature (Benedict and McMahon 2004; Scheuler and Holland 2000b, 2000c).

Green infrastructure reduces water resource impacts by promoting infiltration, pollutant catchment, plant pollutant uptake and evapotranspiration (Benedict and McMahon 2006). Vegetated surfaces and forests allow for increased infiltration, water uptake by plants and evapotranspiration. Water uptake by trees alone is significant. According to one study, woodlands absorb up to 60 times more water than grazed land (Benedict and McMahon 2006). Protected floodplains provide swelling rivers room to overflow without damaging built property or down-cutting stream channels (Scheuler and Holland 2000a). Wetlands are areas normally saturated with water for all or a significant portion of the year due to standing surface water or shallow groundwater depths (USEPA 2009). Wetland vegetation, and in some areas the soil, have a high affinity for water. Wetlands readily absorb stormwater runoff and the hydrophilic vegetation and soils release the water at a much slower rate (Scheuler and Holland 2000a).

## 3.3. Planning and Network Design

Green infrastructure planning and development is successful when approached in a similar manner to the planning and development that occurs for built infrastructure (ex. roads, water and sewer systems). Green infrastructure plans should be based on a conservation vision, strategically and holistically designed to assure connection of valuable lands, planned and implemented with public input, funded upfront to assure timely development and serve as the framework for development (The Trust for Public Land 2002; Wamsley, Mednick and Benedict 2002). The green infrastructure planning that has occurred across the U.S. and abroad has led to the understanding of some key principles to succeed in the process (Figure 4) (Benedict and McMahon 2006). These principles should be considered when a green infrastructure plan is being developed.

**Ten Principles of Green Infrastructure**

1. Connectivity is key.
2. Context matters.
3. Green infrastructure should be grounded in sound science and land-use planning theory and practice.
4. Green infrastructure can and should function as the framework for conservation and development.
5. Green infrastructure should be planned and protected before development.
6. Green infrastructure is a critical public investment that should be funded up front.
7. Green infrastructure affords benefits to nature and people.
8. Green infrastructure respects the needs and desires of landowners and other stakeholders.
9. Green infrastructure requires making connections to activities within and beyond the community.
10. Green infrastructure requires long-term commitment.

**Figure 4. Ten Principles of Green Infrastructure**
*Source: Benedict and McMahon 2002,2006.*

The blueprint of a green infrastructure plan is ultimately determined by local conditions and the goals of stakeholders. Each local, regional or state plan will place more value on some desired benefits and outcomes versus others. However, it is important the infrastructure utilize the basic underlying principle that green infrastructure systems operate much more efficiently when whole rather than fragmented. Generally, green infrastructure is constituted of hubs (large, contiguous areas of open space), links (greenways, river and stream corridors) and sites (smaller hubs of open space) (Benedict and McMahon 2006) (Figure 5). The hubs promote biodiversity, carbon and other air pollutant sequestration, water infiltration and urban forestry. Links promote wildlife migration, recreation and help protect water quality. Sites are often recreation amenities that can provide additional local wildlife and water quality benefits (Benedict and McMahon 2006).

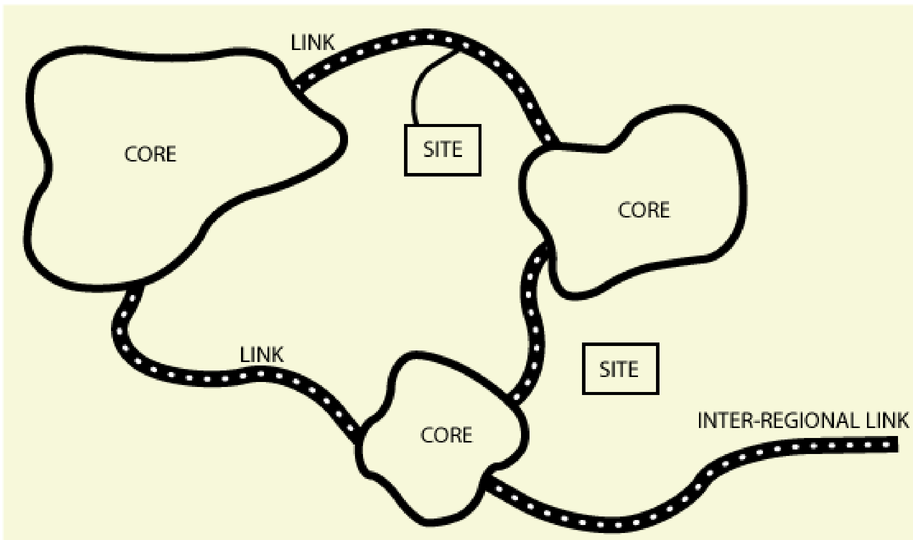


**Figure 5. Basic green infrastructure network design**
*Source: Green Infrastructure Center 2009.*

### *3.4. State and Regional Green Infrastructure*

Since the 1990s several state and local governments have initiated green infrastructure plans. The State of Maryland, one of the first to develop a state-wide program, implemented the so called GreenPrint Program from 2001 to 2006 (State of Maryland 2009). The program evolved from a greenways initiative implemented in 1991, by then governor William Donald Schaefer, though land conservation has been a priority in Maryland since 1969 under Program Open Space (Benedict and McMahon 2006; The Conservation Fund 2004). The initial greenways initiative was very successful, but eventually the focus had shifted from protecting ecosystems to expanding greenways and trails (Benedict and McMahon 2006; The Conservation

Fund 2004). The Maryland Department of Natural Resources, Maryland Greenways Commission and Baltimore County Department of Environmental Protection and Resource Management helped the state refocus its efforts by utilizing geographic information systems (GIS) mapping technology to identify critical unprotected lands, develop natural linkages between them, and ultimately promote the protection of the green infrastructure through an organized conservation effort (Benedict and McMahon 2006; Randolph 2004). The mapped land, over 2 million acres, now serves as the framework for land conservation efforts in the State of Maryland (Benedict and McMahon 2006; Randolph 2004; State of Maryland 2009).

The State of Virginia does not have a comprehensive state-wide green infrastructure plan as of yet, but has made significant progress to support green infrastructure planning processes with the establishment of the Virginia Conservation Lands Needs Assessment (VCLNA) program. The VCLNA, a joint effort by the Virginia Department of Conservation and Recreation, Virginia Coastal Zone Management Program, Virginia Land Conservation Foundation and the Virginia Commonwealth University, uses GIS mapping to target and prioritize lands for conservation, a similar approach to Maryland program (VA-DCR 2009).

The process of developing Virginia's VCLNA program began in 2006 with a series of Advisory Workgroup meetings organized by the lead organizations (Ciminelli 2006). The workgroup met on three different occasions to discuss the concept and process of developing green infrastructure in Virginia. The workgroup identified data needs for green infrastructure planning, identified and explored available GIS datasets and discussed long-term conservation activities (VA-DCR 2009). The outcome of the meetings was the development of a series of GIS datasets and models to support the analysis and development of specific components of a green infrastructure including:

- Virginia Natural Landscape Assessment – a network of natural lands
- Cultural Model – ranks cultural value of lands including archeological and architecture sites and American Indian Lands
- Forest Economics Model – ranks economic value of viable forests
- Agricultural Model – ranks value of agricultural areas based on suitable, prime farmland soils and historic farm resources
- Recreation Model – ranks recreation opportunity of publically owned lands
- Watershed Integrity Model – ranks land based on contribution to water quality and watershed integrity
- Vulnerability Model – a composite of three models (Virginia Urban Vulnerability Model, Virginia Suburban Vulnerability Model, and Virginia Vulnerability beyond the Urban Fringe Model) that ranks lands based on their threat of urban or suburban development (VA-DCR 2009).

The GIS datasets and models were completed on a state-wide scale so accuracy and detail may not be appropriate for local decision-making. Dataset and models should be modified to incorporate local knowledge and data, such as projected land use and recently conserved lands, if the datasets are utilized for local green infrastructure planning activities.

On a regional scale, the New River Valley Planning District Commission (NRVPDC) is currently developing a green infrastructure plan for the New River Valley which includes the counties of Montgomery, Floyd, Radford, Pulaski and Giles and the City of Radford (NRVPDC, 2009a). This project, when completed, would facilitate natural resource planning and conservation in the New River Valley region (NRVPDC, 2009a). The project has six green infrastructure network targets, most of which are similar to the green infrastructure components considered valuable for the VCLNA: water, forest and farming lands, natural hazard areas, habitat and ecosystem diversity, recreation and health, and cultural heritage. The datasets being developed by the New River Valley Green Infrastructure Committee are in various stages of completion, with a target completion date of September 2009 (NRVPDC 2009a, 2009b).

### 3.5. Local Green Infrastructure

At the local level, governments, developers and citizens can utilize a number of techniques to conserve land or develop green infrastructure at the subdivision scale. Better site design, commonly referred to as conservation subdivisions, is one of the most common techniques used today (Scheuler and Holland 2000b, 2000c). Better site design serves to reduce stormwater runoff and protect sensitive environments by reducing the amount of impervious cover and conserving large parcels of open space for passive recreation, stormwater control and habitat conservation by clustering homes on the site (Scheuler and Holland 2000b, 2000c). Additional benefits, including improved habitat and water quality, can potentially be realized with better site design when conserved open spaces adjoin conserved lands on adjacent parcels and high quality land and habitats are given preference for conservation.

The U.S. Green Building Council (USGBC) has developed the Leadership in Environmental Energy and Design Neighborhood Development (LEED ND) program. LEED ND encourages builders to locate and design developments in a manner that reduces the impact on environmental, energy and financial resources (USGBC 2008). The USGBC also encourages local governments to adopt the LEED ND principles, with a few already encouraging the application of the program through fast tracking and financial incentives (USGBC 2008). As with other LEED programs, developments are certified under the LEED ND program based on the USGBC's scoring criteria. The program has been implemented on a small number of pilot projects and the supporting scoring documentation is undergoing public review. At this time LEED ND focuses on three main characteristics of development: smart location and linkage, neighborhood pattern & design and green infrastructure and buildings (USGBC 2009). Developments can earn a higher LEED ND rating if they are enhanced with open space and wetland conservation, protected steep slopes, innovative stormwater management and connectivity to adjacent natural resources (USGBC 2009).

## *3.6. Enhancing Stormwater Management with Green Infrastructure*

Watershed-based stormwater management could potentially be enhanced by green infrastructure given the significant amount of overlap in the goals of the two resource management tools. Green infrastructure has been shown to protect water quality and promote infiltration, which is why it is commonly utilized to protect the health of high quality water resources (Benedict and McMahon 2006; Scheuler and Holland 2000d). The incorporation of green infrastructure into a watershed-based stormwater management plan could potentially reduce urban stormwater volumes and pollutant loads, the common goal in stormwater management. Green infrastructure may also lower maintenance costs associated with stormwater management in the long-term due to reduced pollutant and flow volumes passing through structural controls (EPA 2007; NRC 2008).

Many nonstructural SCMs, including conservation subdivisions, LID techniques and wetland conservation, are often utilized as components of green infrastructure (NRC 2008). The incorporation of these and similar SCMs could help reduce the size of structural SCMs, which in turn would reduce the amount of land and financial resources required to construct structural facilities, and improve their effectiveness in treating or controlling runoff (NRC 2008). Watershed-based stormwater management could be further enhanced by the inclusion of large, undeveloped tracts of land such as stream buffers and headwater protection areas which are commonly utilized in green infrastructure. The inclusion of large tract conservation in a stormwater management plan could help protect areas that would pose risks to water quality if developed, as well as require clustering of development to reduce impervious cover.

# 4. Case Study: Toms Creek Watershed, Blacksburg

## *4.1. Overview and Purpose*

Federal and state regulations are requiring local jurisdictions to take an active role in urban stormwater management and water resource protection. Implementing traditional stormwater management practices may not be enough to meet current and future regulations. Local jurisdictions are considering alternative, low impact and more comprehensive approaches to stormwater management. The integration of green infrastructure and watershed-based stormwater management has the potential to provide local jurisdictions with a more holistic approach to reducing stormwater volumes and preventing pollutants from entering surface water bodies.

The literature indicates the application of watershed-based stormwater management and green infrastructure planning is realistically applicable in areas where there is limited development, is experiencing growth pressure and is subject to state and federal MS4 stormwater regulations. The Toms Creek watershed exhibits such characteristics and therefore was selected as the case study. Toms Creek is a relatively high quality stream. A significant portion of the Toms Creek watershed is facing growth pressure from the Town of Blacksburg (Blacksburg), Virginia. Blacksburg is subject to state and federal MS4 stormwater regulations, and the Town is addressing urban stormwater through a local ordinance. The case study described in this paper outlines a planning and implementation approach for developing a watershed-based green infrastructure for managing stormwater in the Toms Creek watershed.

### *4.2. Watershed and Land Use Description*

This case study site for this paper is Toms Creek Watershed located in Montgomery County, Virginia. The watershed encompasses the northern section of the Town of Blacksburg (Blacksburg) which covers about 40 percent of the Toms Creek watershed (Figure 6). The remaining 60 percent is in the unincorporated area of Montgomery County, including a very small section of the George Washington-Jefferson National Forest (Figure 7).

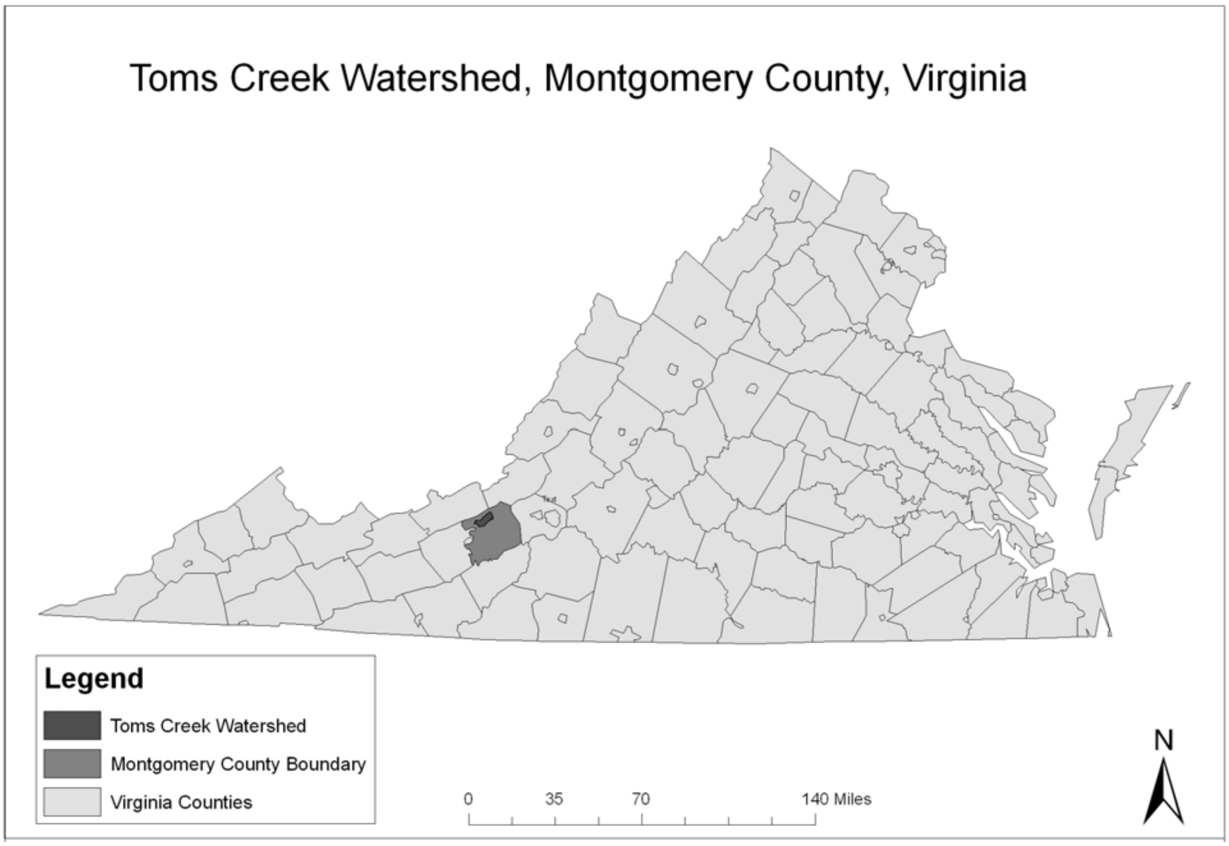


**Figure 6. Location of Toms Creek Watershed in Montgomery County, Virginia**
*Source: USDA 2009a; Toms Creek Watershed Boundary developed using ArcHydro and RU 2009.*

Blacksburg is bisected by US Route 460 which runs from the southwest to the northeast section of the town. The south and southeastern sections of Blacksburg are mainly developed, containing the downtown core and Virginia Polytechnic Institute and State University (Virginia

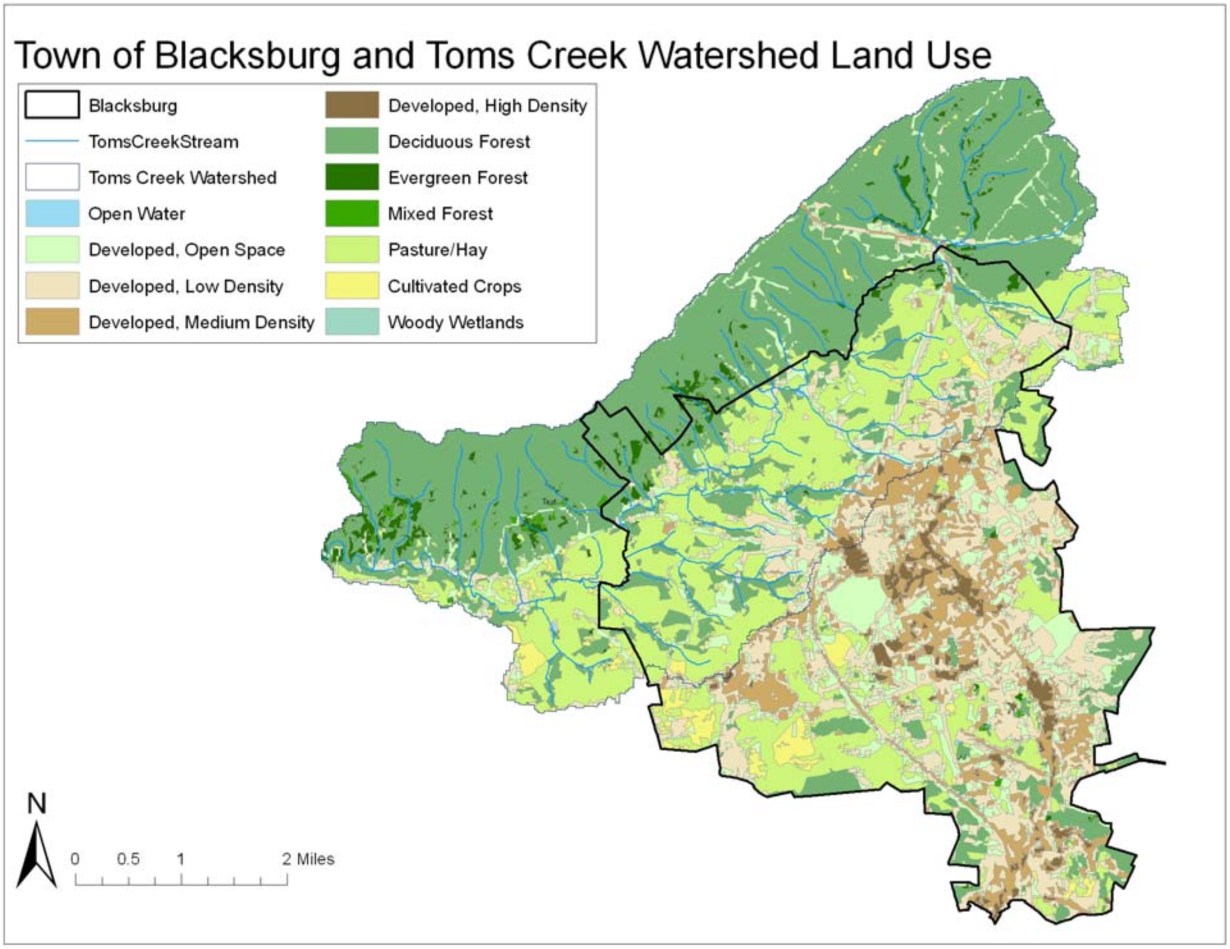


**Figure 7. Land Use and Land Cover in Blacksburg, VA and Toms Creek Watershed**
*Source: TOB 2009a; USDA 2009b; USGS 2009. Toms Creek Watershed Boundary developed using ArcHydro and RU 2009.*

**Table 3. Land Use and Land Cover in the Toms Creek Watershed within Blacksburg**

| Land Use/Land Cover | Acres | Percent |
|---|---|---|
| Open Water | 5.0 | 0.08 |
| Developed, Open Space | 553.3 | 9.01 |
| Developed, Low Density | 1065.9 | 17.36 |
| Developed, Medium Density | 467.1 | 7.61 |
| Developed, High Density | 41.5 | 0.68 |
| Deciduous Forest | 1267.9 | 20.65 |
| Evergreen Forest | 97.6 | 1.59 |
| Mixed Forest | 15.2 | 0.25 |
| Pasture/Hay | 2505.4 | 40.81 |
| Cultivated Crops | 118.9 | 1.94 |
| Woody Wetlands | 0.9 | 0.01 |
| **Total** | **6138.7** | **100.00** |

*Source: USDA 2009b.*

Tech). The north and northwestern sections of Blacksburg, located mainly within the Toms Creek watershed, contain a small percentage of high density development and large tracks of pasture, crop lands and undeveloped forestland (Figure 7 and Table 3).

The Toms Creek watershed as a whole is generally undeveloped with most of the land north of the main tributary in forest cover, pasture and cultivated crops. The watershed is also adjacent to the George Washington-Jefferson National Forest (not shown on Figure 7) which runs parallel to the watershed to the north. The high quality of water in the Toms Creek allowed it to serve as a suitable reference stream for sediment load analysis for the Upper Stroubles Creek TMDL report (VT-BSE 2006). The limited amount of development has enabled Toms Creek to maintain high water quality, but development pressures in the headwaters pose a risk to the current conditions.

The 2006-2046 Blacksburg Comprehensive Plan outlines the land use vision for the Town. Blacksburg is divided into eight sectors for the purpose of visioning. The majority of the Toms Creek watershed within Blacksburg's jurisdiction is covered by the Northwest and North End sectors (TOB 2007). The vision for the Northwest section includes the preservation of the "rural character" and the viewshed provided by Brush Mountain, and protecting the water quality and natural amenities of Toms Creek (TOB 2007). Rural character is defined as having large, preserved open spaces, development set away from the road and limited street lighting (TOB 2007). The North End sector contains mixed land use including Rural Residential (one to two units per acre) and Commercial development (TOB 2007). The vision for this sector is to protect the headwaters of the Toms Creek Watershed by leaving areas undeveloped and through adequate stormwater controls (TOB 2007).

Within the Town of Blacksburg, Toms Creek is mainly zoned Rural Residential (RR-1), Planned Residential (PR) and Low Density Residential (R-4) at 62, 13 and 8 percent of the watershed, respectively. A significant portion of the land encompassed by the Planned Residential and Low Density Residential has already been developed (Figure 8). A characteristic summary of each of these zoning districts can be found in Table 4 (Section 4.2).

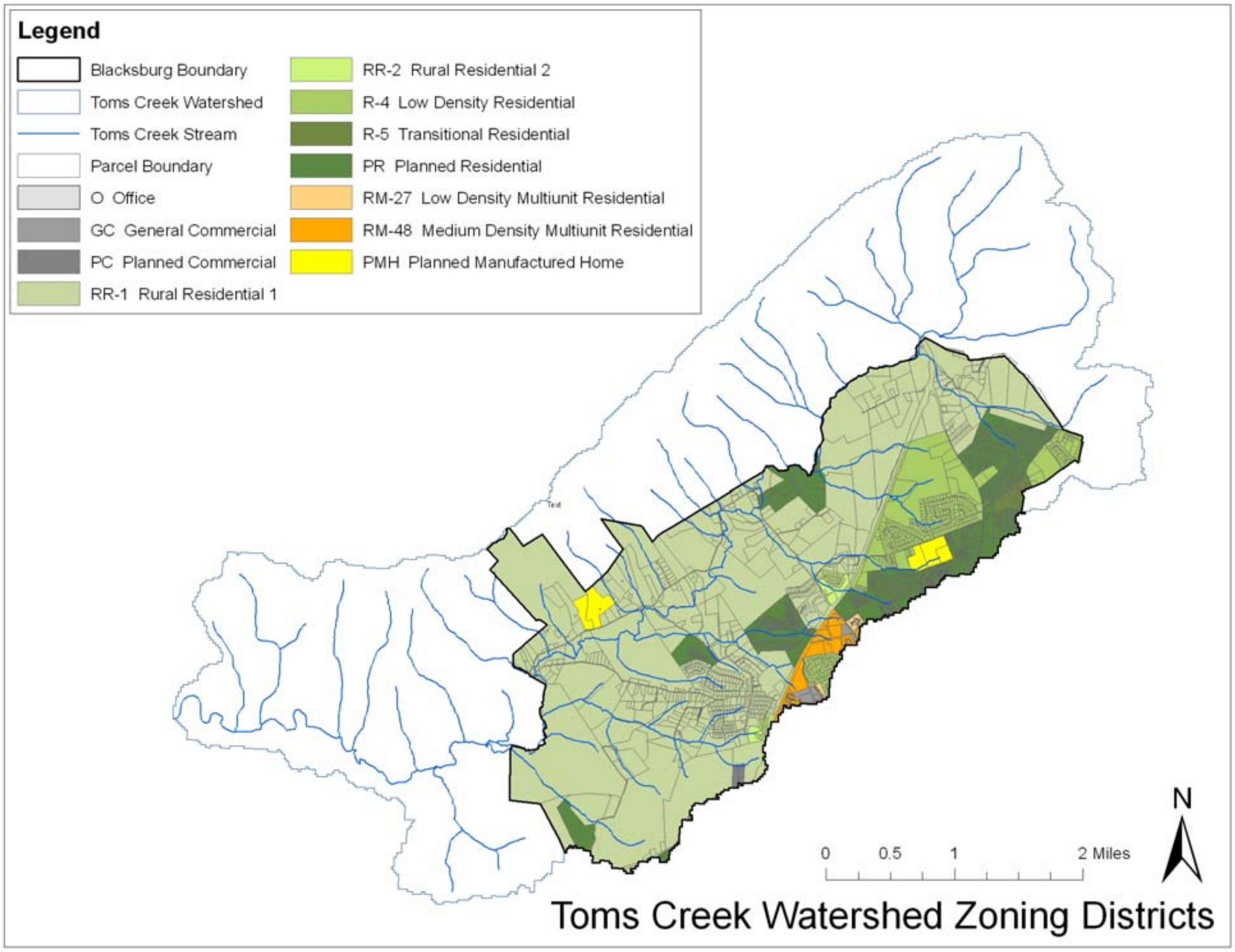


**Figure 8. Toms Creek Watershed Zoning Districts**
*Source: TOB 2009d; Toms Creek Watershed Boundary developed using ArcHydro and RU 2009.*

## *4.3. Stormwater Regulation and Management*

Blacksburg's stormwater runoff and discharges are permitted under Virginia's Phase II MS4 program. Phase II permits require the reduction of pollutants to the "maximum extent practicable" (40 CFR 122.34; EPA 2000). This is achieved by developing a stormwater control program that incorporates the permits' six minimum control measures:

1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit discharge detection and elimination
4. Construction site stormwater runoff control
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operations (40 CFR 122.34).

**Table 4. Major Zoning Districts of the Toms Creek Watershed**

| Zoning District | Purpose | Development Restrictions | Example Permitted Uses |
|---|---|---|---|
| RR-1 Rural Residential 1 | Develop at a scale that will protect the rural character of the area (clustered homes surrounded by agricultural and forest land), conserve unified open space, allows for flexibility in subdivision design to promote land conservation. | One dwelling unit per acre, minimum of 50 percent open space | Agriculture<br>Stables<br>Single family dwelling – detached or attached<br>Townhomes<br>Community recreation<br>Open space<br>Bed and breakfasts |
| PR Planned Residential | Developments include a range of housing options, commercial and office uses, and efficiency to help reduce building costs | District must be at least one acre of contiguous land, minimum of 30 percent open space conservation | Multi and single family Dwellings<br>Townhomes<br>Gas station<br>Restaurant |
| RR-4 | Low density development allowed, preventing the intrusion of nonresidential development. | Minimum lot size 10,000 sq ft | Single family detached<br>Home occupations<br>Open space<br>Community recreation |

*Source: TOB 2009b.*

On March 11, 2008, Blacksburg adopted Ordinance 1483 to establish comprehensive stormwater management regulations and a stormwater management plan review fee of $1,000 (TOB 2009c). The ordinance will help the Town meet minimum control measure five of the NPDES permit.

Ordinance 1483 requires developed land over a specified acreage to install post-construction SCMs that meet specified quantity and quality criteria and provide for long-term SCM maintenance (TOB 2009c). The Ordinance outlines allowable SCMs to meet the Town's water quality requirements, but provides developers the flexibility to install alternative measures.

An alternative SCM can be implemented if it is approved by the Virginia Department of Conservation and Recreation director or its performance has been demonstrated and certified, and also meets Virginia's standards for phosphorus removal (TOB 2009c). Finally, Ordinance 1483 requires a management entity be put in place to maintain specific SCMs (TOB 2009c). This responsibility is placed on developers, homeowner associations and Blacksburg tax payers.

## *4.4. Watershed-Based Green Infrastructure and Toms Creek*

The final section of this paper will outline a planning process for developing a watershed-based green infrastructure to manage stormwater in Toms Creek (herein referred to as "Watershed Plan"). Existing characteristics, complementary practices and potential implementation challenges will be outlined as well as recommendations for developing the Watershed Plan. The planning process will be developed utilizing the watershed-based stormwater management and green infrastructure planning processes previously discussed.

### 4.4.1. Existing Characteristics and Green Infrastructure Planning Gaps

Large tracts of undeveloped land, projected future land use, zoning districts characteristics, comprehensive plan goals, existing water resources, land conservation practices and stormwater management requirements of Blacksburg make the Toms Creek watershed a great candidate for implementing a watershed-based, green infrastructure for stormwater management. The land use and land cover of Toms Creek includes large, extensive tracts of undeveloped land in the watershed. The literature points out that green infrastructure and watershed-based management for stormwater is more realistic in areas with limited existing development that experience new growth (Benedict and McMahon 2006; NRC 2008). Blacksburg is projecting Low Density Residential land use (two to four units per acre) to increase from 14 percent of the Town's total land area in 2006 to 24 percent in 2046 (TOB 2007). Agricultural land is expected to reach zero percent of total land area by 2046 from 25 percent in 2006 (TOB 2007). The projected change in agricultural land use alone indicates growth will be occurring in the Toms Creek watershed over the next 40 years.

Current zoning and existing land use practices provide a good foundation for developing green infrastructure in Toms Creek. The zoning within the Town of Blacksburg, as previously described, requires up to 50 percent open space conservation when land is developed. Blacksburg zoning also includes a Creek Valley Overlay and Open Space Overlay district. The Creek Valley Overlay district restricts the development within the 100-year floodplain; slopes over 25 percent adjacent to the 100-year flood plain or commencing within 50 feet of Toms Creek; land 50 feet from the Toms Creek channel not included in the first two categories and all wetlands contiguous to the 100-year floodplain; and 50-foot creek buffer or protected steep slopes (Figure 9) (TOB 2009b). The Open Space Overlay district requires 30 percent of development land be conserved as open space (TOB 2009b). It applies to the R-4, R-5, RM-27 and RM-48 zoning districts of the Toms Creek Watershed (see Figure 8) (TOB 2009b).

Green infrastructure may be further enhanced by Agricultural and Forestal Districts and the Town of Blacksburg Greenway Trail Plan. Agricultural and Forestal districts are created at a landowners request and, as described in Blacksburg Town Code, must contain a core of at least 200 acres for one or more contiguous parcels (TOB 2009e). Parcels not adjacent to the core must be within a mile of the core boundary (TOB 2009e). Parcels under consideration for a district will be reviewed for certain criteria including current use of the land and environmental benefits of retaining the land in agricultural or forest production before receiving approval (TOB 2009e). The Toms Creek watershed presently contains parcels dedicated to Agricultural and

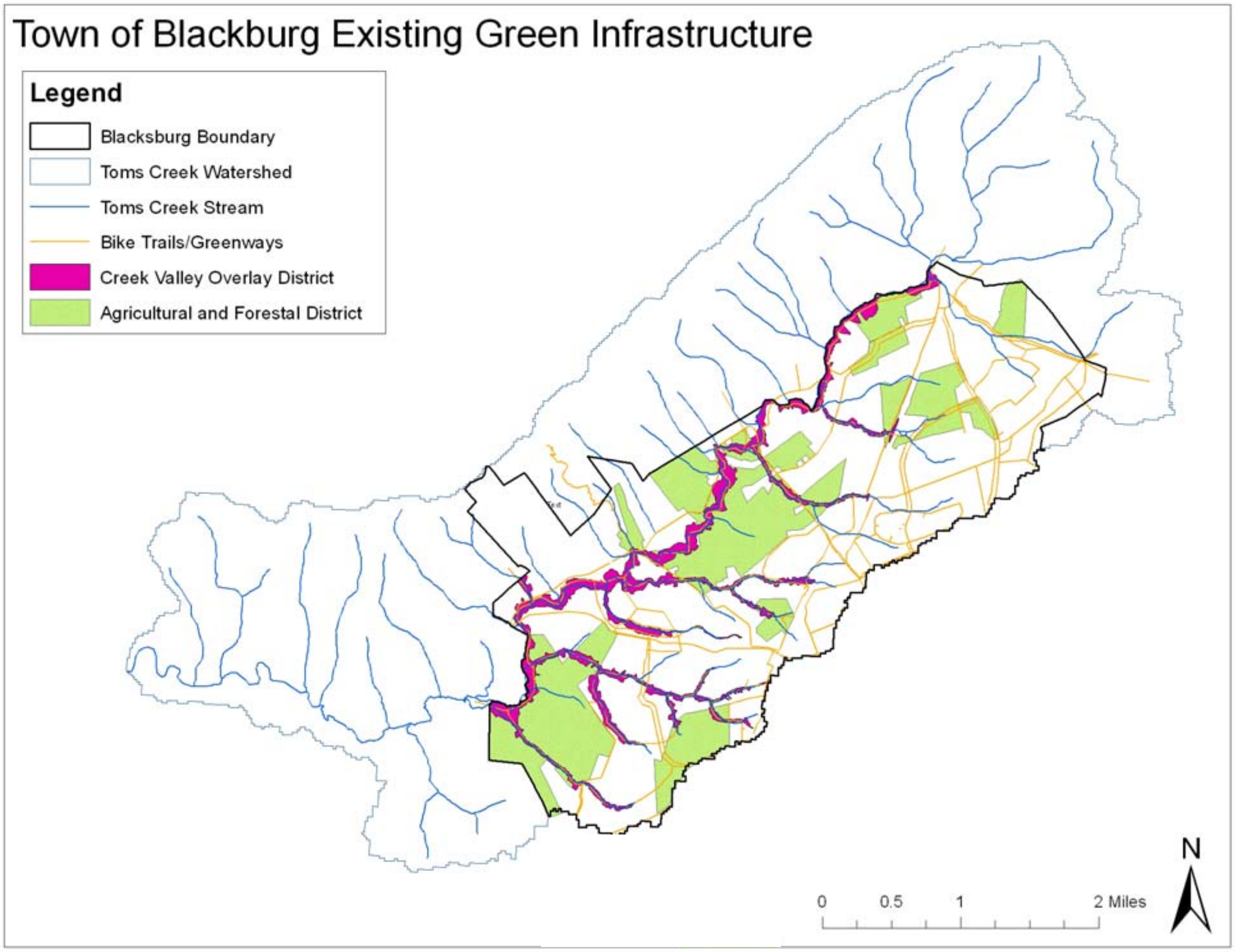


**Figure 9. Town of Blacksburg Existing Green Infrastructure**
*Source: TOB 2009f; TOB 2009g; TOB 2009h.*

Forestal Districts (Figure 9). The Town of Blacksburg Greenway Plan, as described in the Blacksburg Comprehensive Plan, promotes the development of natural recreation amenities in and around Blacksburg (TOB 2007). Existing and planned greenways are being developed in conjunction with Blacksburg bikeways. Greenways developed throughout the Toms Creek watershed will only serve to enhance green infrastructure (Figure 9).

While policies and programs described above aim to protect and enhance environmental resources within town limits, no other land development practices, outside of the Creek Valley Overlay district, preserve predetermined areas for the specific purpose of reducing urban stormwater impacts on Toms Creek. For example, the location of land conserved as part of a development project is typically determined by the developer who is likely not thinking about protecting water quality, rather placing the open space in areas not suitable for development. Additionally, the 2006-2046 Blacksburg Comprehensive Plan verbalizes the community's desire to protect the natural resources of the Toms Creek watershed, but often does not provide specific tools for accomplishing this goal (TOB 2007). Finally, most of the existing green infrastructure components do not extend beyond town limits. Green infrastructure for Toms Creek should extend beyond the political jurisdictions of the Blacksburg and into Montgomery County.

In all fairness, the development of a comprehensive plan for managing stormwater in Toms Creek has likely not been developed because the need and/or benefits have not been fully realized. Toms Creek's water quality has not been impaired by stormwater pollutants due to the limited development. Federal and state stormwater regulations governing development and stormwater runoff in Blacksburg have only been in place for the past decade, and only in the past year has the Town adopted a local stormwater ordinance. However, as previously discussed, comprehensive management is being viewed by many in the literature as the next step in controlling urban stormwater impacts. The following subsections address the process for developing a watershed-based green infrastructure for Toms Creek watershed.

### 4.4.2. Identifying Stakeholders

Blacksburg faces some challenges in pulling together stakeholders for Toms Creek watershed since a significant portion of the watershed is located outside of Town's jurisdiction. Working collaboratively with Montgomery County should be top priority so that development and land use occurring outside of Blacksburg's jurisdiction does not negatively impact water quality. Local developers and landowners should also be major stakeholders in the Watershed

Plan development process since a significant portion of the green infrastructure will exist on private land both in Blacksburg and Montgomery County. Land developers and land owners will likely be valuable resources in helping Blacksburg and others shape land use planning tools necessary for developing green infrastructure on private land.

Blacksburg should also include the following stakeholders into the planning process: US Forest Service, watershed organizations, Virginia Tech, Virginia Outdoors Foundation, land trusts, homeowners associations, Virginia Department of Conservation and Recreation and Virginia Department of Environmental Quality. The Town of Blacksburg should also coordinate activities with the NRVPDC. As previously discussed, the NRVPDC has initiated a green infrastructure planning process which has brought together local stakeholders. The Watershed Plan could benefit from the relationships developed by the NRVPDC process.

### 4.4.3. Define Objectives

Given local conditions, it is recommended the Watershed Plan include the following objectives: (1) protect water quality, (2) maintain rural character, and (3) maintain low SCM maintenance costs. The protection of water quality should be a top priority considering Toms Creek's existing water quality and the likelihood of surface water impairment resulting from extensive development as evident in the adjacent Upper Stroubles Creek watershed (VT-BSE 2006). The water quality protection objective could be as general as meeting a specific designated use at certain built-out levels, or more defined with specific maximum pollutant loads permitted in runoff entering Toms Creek, an objective inline with the Blacksburg stormwater ordinance and state regulations. Establishing a water quality protection goal may also prove beneficial if, in the future, the EPA or State of Virginia require certain pollutant loads or apply water quality criteria to stormwater outfalls in Blacksburg.

The zoning district requirements and comprehensive plan vision for Toms Creek all indicate the community's desire to protect rural character, open space and local water quality. Including an objective of "maintaining rural character" in the Watershed Plan would provide Blacksburg with an additional tool for meeting the community's vision of protecting existing land use characteristics while enabling the development of a green infrastructure. Blacksburg will have to work with Montgomery County to assure a similar development pattern, and land use vision, will be applicable to the rest of Toms Creek in the long term.

The Blacksburg stormwater ordinance requires ongoing maintenance of SCMs installed within town limits. Green infrastructure and watershed-based stormwater management has been shown to provide upfront cost benefits, lower SCM maintenance costs and reduced size of structural SCMs (EPA 2007; NRC 2008). Maintaining low maintenance costs would be a realistic objective of the Watershed Plan to assure financial savings for the community and financial stability within Blacksburg's stormwater management program. The savings associated with SCM installation could also apply to any new development in Montgomery County.

### 4.4.4. Data collection

A significant amount of data exists for assessing the conditions of Toms Creek and developing the Watershed Plan. GIS data, a key piece of information for designing the green infrastructure and determining build-out potential in the watershed, is available from a number of sources including the Virginia Department of Conservation and Recreation, Town of Blacksburg, Montgomery County and Virginia Tech (Table 5). Stakeholders will also have to consider which SCMs will be utilized to meet the goals of the plan. A large knowledge base of SCMs exists in the literature, as well as locally. Virginia Tech recently developed a Virginia-specific stormwater management model to determine the effectiveness of SCMs scenarios, which includes green infrastructure-based SCMs (Young et al. 2009). This model could be used for assessing the best SCMs for the Toms Creek watershed. Additional information on the success and failures of specific SCMs could potentially be obtained from local developers utilizing non-traditional SCMs, such as open space preservation, in their development projects. One example is Tom's Creek Investors L.C., developer of the Village at Tom's Creek, a planned unit development located in the watershed (Village at Tom's Creek 2009).

Other relevant information includes state and local stormwater management regulations, Blacksburg Comprehensive Plan, Blacksburg and Montgomery County zoning ordinances, New River Valley green infrastructure programs, relevant state land use and development regulations (fire protection, Department of Transportation road requirements, etc.) that may have an impact on the use of non-traditional SCMs, historic water monitoring data for Toms Creek, known pollutant sources in the watershed (point and nonpoint) and funding options for program implementation.

**Table 5. Overview of available GIS datasets applicable to green infrastructure development**

| Dataset | Source |
|---|---|
| VCLNA data | VA-DCR |
| Land Use and Land Cover | National Dataset and Blacksburg |
| Conserved lands, private and public | Virginia Outdoors Foundation, VA-DCR (VCLNA) |
| Zoning | Town of Blacksburg GIS, Montgomery County GIS |
| Ag and Forestal Districts | Town of Blacksburg GIS |
| Creek Valley Overlay District | Town of Blacksburg GIS |
| Wetlands | USGS, Town of Blacksburg, |
| Karst areas and sink holes | Town of Blacksburg Comprehensive Plan and GIS |
| Existing SCM | Town of Blacksburg GIS |
| Soils | Town of Blacksburg, USDA-NRCS |

### 4.4.5. Data analysis

The data analysis should ultimately culminate into the draft Watershed Plan. The foundation of the Watershed Plan should be the green infrastructure principles with emphasis on the following: 1) use available scientific research and local land use planning policies, 2) green infrastructure should serve as the framework for development, preventing afterthought conservation 3) program funding should be identified and potentially secured in the beginning and 4) connections should be made beyond the immediate community (Benedict and McMahon 2002, 2006).

There are at least five analyses that will have to be completed to assure the objectives the Watershed Plan are achieved: GIS dataset development and analysis, review of locally applicable SCMs, assessment of local land use planning constraints, assessment of applicable funding sources, consideration of non regulatory versus regulatory implementation measures and determination of the responsible management entities. The GIS dataset development and analysis process should be completed in the same manner as other green infrastructure programs previously discussed given the success of these approaches (NRVPDC 2009a; State of Maryland 2009a; VA-DCR 2009a). Available GIS datasets will likely have to be modified to improve data resolution and reflect any land use changes that may have taken place since each dataset was developed.

Stakeholders will have to determine the best locally applicable SCMs for the Toms Creek watershed, measures that will facilitate development of green infrastructure, protect water quality and function in karst regions (TOB 2007). Locally applicable SCMs may include better site design, LID techniques, LEED ND, constructed wetlands, wetland conservation, vegetated filter strips, bioretention structures, infiltration basins, riparian buffers and public education. Each of these SCMs can facilitate the network design of green infrastructure, as well as improve infiltration and pollutant assimilation of stormwater to protect water quality (NRC 2008; Scheuler and Holland 2000a; USGBC 2008; Young et al. 2009).

Local land use planning regulations will have to be fully analyzed to determine which SCMs can be legally implemented and where green infrastructure can be implemented. Current Blacksburg zoning regulations provide for one of the key components of green infrastructure - conservation of a large percentage of developed parcels (TOB 2009b). However, it is anticipated zoning ordinances will require amendments to accommodate for flexibility in urban design to promote the linkage of the green infrastructure components across the watershed. For example, Blacksburg and Montgomery County could provide incentives in the zoning code for developers who adhere to a pre-determined green infrastructure design and SCM recommendations.

The literature notes that funding of SCMs and green infrastructure is more realistic when these components are implemented during development versus retrofitting them into existing development (NRC 2008). The limited development within the Toms Creek watershed could lead to lower Watershed Plan implementation costs for both the citizens and local governments since a significant portion of the costs will likely be paid by the home buyer. Stakeholders will have to determine the financial responsibility of long term maintenance of SCMs and cost-sharing to install SCMs for managing water from large areas. The Blacksburg stormwater ordinance could serve as the foundation for determining maintenance responsibility. Funding of large SCMs, either structural or nonstructural, will likely face financing challenges. However, some funding options exist including pay-as-you go funds created through development fees, general obligation bonds secured by Blacksburg or Montgomery County, special tax districts or assessment bonds, developer-constructed improvements required under development agreements with Blacksburg or Montgomery County, in-lieu fees paid by developers opting out of certain stormwater management or green infrastructure requirements and Community Development Block Grants (ASCE and WEF 1998).

Non-regulatory and regulatory implementation tools should be defined after the bulk of the data analysis is completed since the objectives and data analysis results will directly determine which tools are best suited for the Watershed Plan.  It is anticipated, the Watershed Plan will be implemented using both non-regulatory (voluntary) and regulatory tools.  Non-regulatory tools may include educational programs informing land owners about the benefits of reducing onsite pervious cover to increase the application of LIDs.  Regulatory controls will likely affect land use regulations.  For example, Blacksburg or Montgomery County may implement a zoning overlay district to restrict development in areas deemed valuable for the installation of community SCMs or in areas with wetlands and sensitive habitat.

Finally, the data analysis phase should also identify which entity (or entities) will guide the management and implementation of the program (see Section 4.3.6) and identify uncertainties in the Watershed Plan's ability to achieve the objectives. Indentifying uncertainties will be valuable determining how implementation will be phased and for developing evaluation and assessment methodologies.

### 4.4.6. Implement Program

It is recommended that the Watershed Plan be implemented in one of two options described below.  First, the Watershed Plan could be implemented under Blacksburg's stormwater management program in partnership with the NRVPDC's Green Infrastructure Initiative.  Blacksburg's stormwater management program is already established and working toward implementing Ordinance 1483.  The NRVPDC Green Infrastructure Initiative planning process will be complete in the fall of 2009.  Utilizing both agencies would place responsibility of implementation on at least one entity within each major political jurisdiction. This could help reduce or eliminate political conflict generated by an entity trying to govern land use outside of its jurisdiction.

The second implementation option is a pilot study. Given the uncertainties that will likely exist due to data gaps and limited information available in the literature regarding the implementation of this type of stormwater management plan, a pilot project many be the best option for understanding the physical and political constraints of the Watershed Plan. A pilot study would also provide opportunity for the stakeholders to confirm or dispute uncertainties and evaluate the likelihood of the Watershed Plan components meeting the core objectives.

### 4.4.7. Evaluate Effectiveness

Determining the success of the Watershed Plan will require a carefully detailed monitoring and evaluation plan. The Watershed Plan evaluation components should encompass at least three areas; natural resources, funding and public participation. The natural resource evaluation should include ecological monitoring to assess the condition of stream habitat, water quality monitoring of stormwater runoff and instream water quality characterization. Both the ecological and water quality monitoring will require baseline data for comparison in the long-term. Any existing data for the Toms Creek watershed should be collected and checked for quality assurance and quality control (ASCE and WEF 1998). Gaps in existing water quality data should be complimented by baseline monitoring before and after a range of stream flow and storm conditions. If enough baseline data is available, the stakeholders could potentially use the data to develop a Toms Creek model for planning purposes.

Evaluation of funding needs will be necessary to determine if available sources are being efficiently utilized and/or developed. It will also be valuable to monitor the expenses associated with installing non-traditional SCMs to educate developers about the most cost-effective measures. Evaluating public participation will likely include nonconventional monitoring such as surveys of public opinion and program participation levels (ASCE and WEF 1998). The collection of nonconventional monitoring data will be beneficial in gauging public acceptance of non-traditional stormwater management, challenges faced by land owners and developers in meeting the Watershed Plan objectives and the success of non-regulatory activities initiated by the Watershed Plan.

# 5. Conclusion

The connection between land development and water quality is highly understood. Land development severely disrupts the hydrologic cycle, placing the burden of excess runoff on surface water bodies. As evident in the promulgation of federal stormwater regulations, the problem of urban runoff is widespread and detrimental to the environment. Recognizing the management mistakes of the past, many government entities, private businesses and non profit organizations are trying to address the issue of urban stormwater with innovative solutions aimed at preventing the source of the problem rather than treating the symptoms.

This paper presents a combination of two water resource management tools to meet the goal of stormwater management today, green infrastructure and watershed-based planning. These tools, while not widely used, show promise in addressing the water resource protection needs in developing and urbanizing areas. Watershed-based planning considers the hydrology of the entire watershed, not just a subdivision, home site or a political jurisdiction, allowing for more comprehensive decision making when developing local and regional SCMs. Green infrastructure promotes and allows for the one of the most important stormwater management goals – infiltration. In combination, these resource management tools have the potential to improve the level of water quality protection associated with common stormwater management practices.

The Toms Creek watershed case study site is one example where a watershed-based, green infrastructure implementation may be suitable for stormwater management. Currently, the watershed is relatively undeveloped, but is expected to be built out by 2046 (TOB 2007). Blacksburg is already engaged in developing components of green infrastructure in Toms Creek through the Town Code and Comprehensive Plan. Blacksburg is in a good position to take stormwater management planning to a more comprehensive level. Adopting a watershed-based approach to management could save Blacksburg and Montgomery County money both in the development of SCMs and maintaining the water quality of Toms Creek. Other local governments striving for solutions to stormwater management issues, and already proactively engaged in natural resource management and green infrastructure development, could find great success in the marrying of green infrastructure and watershed-based planning.

Finally, it should be noted the planning process described in this paper is one option for developing a long-term stormwater management plan. However, it is not a guarantee for achieving all resource management or protection goals. Stakeholders will have to be committed to ongoing evaluation and modifications if their planning efforts are going to be successful. The most notable gap in the literature is case studies on the success and failures of green infrastructure-based stormwater management. Communities willing to take the risk and learn from their mistakes will provide valuable information to those facing similar challenges as they develop their watershed-based management programs.

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