Stormwater Management

A Plan for the Basins from Tanyard Creek to Lilly Branch on the North Oconee River

by

CAROL JEAN MYERS FLAUTE

B.S., The Ohio State University, 2000

M.S., The University of Georgia, 2007

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STORMWATER MANAGEMENT: A PLAN FOR THE BASINS

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CAROL JEAN MYERS FLAUTE

Major Professor: John Crowley

Committee: Jon Calabria
Mark Risse
Ryan Eaves

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Chapter 1: Introduction

This section begins with a discussion of conventional and sustainable stormwater control, explores reasons for planning for stormwater on a watershed scale, and concludes with information about the stormwater plan that is presented in this report.

Organization

Context

An interdisciplinary team, consisting of faculty, staff, and students from the University of Georgia (UGA) and the Athens-Clarke County government (ACC), received a one year Section 319(h) Nonpoint Source Implementation Grant from the Georgia Environmental Protection Division to create a nine-element watershed plan for the watersheds of three tributaries of the North Oconee River in Athens, GA. Two of the watersheds, Lilly Branch and Tanyard Creek, span parts of the UGA campus as well as some of the surrounding community. The third watershed, the physical plant drainage (PPD), is small and contained entirely on the UGA campus. This report describes a system-wide suitability analysis for potential Stormwater Control Measures (SCMs) within these three watersheds, which will help address one component of the overall watershed planning effort.

Stormwater control

Stormwater runoff is water that flows across the surface of land after a rain event, rather than soaking into the ground where it falls. As it travels, runoff collects pollutants and carries them towards streams; in contrast, water that infiltrates the ground before reaching a stream is filtered naturally by the soil particles it passes through. Impervious surfaces, like parking lots and buildings, reduce opportunities for soil infiltration (Urbonas and Doerfer 2005). As a result, under conventional development, urbanization tends to result in increased runoff, flooding, and pollution and decreased groundwater flow (Urbonas and Doerfer 2005; Vick et al. 2012). In addition, increased stormwater runoff causes accelerated channel erosion, incision, widening and other changes in the geomorphic patterns of natural waterways, as well as changes in terrestrial and aquatic habitats (Urbonas and Doerfer 2005).

Stormwater control measures (SCMs) are structures or practices that are put into place in an attempt to control and manage stormwater by promoting infiltration and groundwater recharge, protecting or improving surface water quality, minimizing the use of potable water, and capturing runoff for reuse (Vick et al. 2012). Most SCMs are structural, but there are also nonstructural SCM practices like educational campaigns, street and parking lot maintenance, and the adoption of local criteria and standards (Urbonas and Doerfer 2005). While SCMs are also commonly referred to as Best Management Practices (BMPs), "SCM" is preferred here because it is a more value-neutral term.

Traditional stormwater management attempts to control flooding from stormwater runoff by limiting the rate at which stormwater enters receiving waters (i.e. the peak flow rate). Large, detention-based systems are the primary tools used to control peak flow rate. Detention-based stormwater control structures, such as regional detention ponds, are structures that are designed to hold water for an extended period of time before releasing it to receiving waters at a controlled rate. The goal of traditional stormwater management is to prevent stormwater flow from exceeding the pre-development peak flow rate (Vick et al. 2012).

Detention-based systems are designed to control the rate at which stormwater enters receiving waters, rather than to reduce the total stormwater volume. Because traditional stormwater management efforts reduce peak flow rate without reducing flow volume, receiving waters experience extended peak flow, meaning that after it rains, water moves through receiving water bodies at a high rate for a much longer period of time than it would in a natural state. Extended peak flow can lead to downstream flooding, especially as water from multiple detention systems combines downstream. In addition, because detention-based systems do not encourage infiltration, their use can lead to the gradual dewatering of the landscape. Finally, while large, regional detention structures can be designed to reduce pollution, erosion, stream bed scouring, and siltation immediately downstream of their outfalls, they cannot protect small, headwater streams (Vick et al. 2012).

Instead of focusing solely on maintaining a pre-development peak flow rate, sustainable stormwater development attempts to mimic the entire pre-development water cycle, including infiltration, evapotranspiration, and total peak flow volume. To accomplish its goals, sustainable stormwater management uses small, distributed systems that retain runoff (Vick et al. 2012). Some examples include rain gardens and bioretention areas, green roofs, vegetated swales, rain barrels and cisterns, permeable pavement, and impervious surface reduction and disconnection (Zhen et al. 2006). These and other SCMs are described in Chapter 3. Unlike regional detention systems, which merely slow the release of water, the retention-based SCMs of sustainable stormwater management aim to reduce the total amount of runoff water that reaches receiving waters by enabling it to evaporate, transpire, or soak into the ground (Vick et al. 2012).

By reducing both the volume and flow rate of surface water, sustainable SCMs reduce flooding, peak storm duration, and associated effects like erosion, stream siltation, and streambed scouring. Streams with low base flow problems can be restored as infiltration-based SCMs encourage infiltration to replenish the groundwater that supports the streams. Many SCMs also reduce thermal and nonpoint source pollution. Finally, the shallow, vegetated nature of many retention-based SCMs can create opportunities for wildlife habitat and enhanced aesthetic appeal, as well as a reduced need for maintenance in the form of mowing (Vick et al. 2012).

In summary, in a natural, undeveloped system, most rainfall is intercepted by vegetation, where some water undergoes evapotranspiration, some infiltrates the soil and recharges groundwater, and some becomes runoff. Both surface runoff and subsurface flow pass to a network of ephemeral, intermittent, and perennial drainages, which carry it through riparian areas and into receiving waters. A distributed, sustainable stormwater system in a developed area cannot rely on these natural processes alone. Instead of relying on natural vegetative interception alone, a sustainable stormwater system also intercepts rainfall with landscaping, vegetated roofs, rainwater harvesting, and the permeable surfaces offered by many SCMs. In addition, while sustainable stormwater management does require manmade structures to convey runoff, conveyance occurs at the surface, and the structures used are built to slow flow rate and encourage evapotranspiration and infiltration. In contrast, with a conventional stormwater system, much of the rain falls on hard surfaces, from where a manmade network of pipes bypasses the natural drainage network, carrying runoff to rate-controlled detention facilities. From there, it is sent directly to receiving waters, bypassing the riparian zone and the stormwater management benefits that it offers (Vick et al. 2012). The problem with conventional management strategies is not that detention-based systems are necessarily bad in all situations. It is that these systems are typically used alone, bypassing opportunities for a more natural flow path. Conventional and sustainable stormwater strategies can be used together to achieve desired outcomes.

Stormwater planning sometimes does requires the use of large, downstream regional treatment facilities, such as constructed wetlands or large retention ponds, but distributing smaller SCMs throughout a watershed when possible is beneficial. A distributed stormwater management approach has a greater ability to establish flow similar to predevelopment conditions. When SCMs are dispersed throughout the system, pollutants also remain dispersed, rather than accumulating in one large regional treatment facility (Lloyd, Wong, and Porter 2002). In addition, using small, distributed SCMs creates redundancy, reducing the chance of overall system failure (Vick et al. 2012). Distributing aesthetically pleasing SCMs, such as rain gardens, stormwater wetlands, and vegetated swales, provides aesthetically pleasing landscape elements throughout the watershed. A distributed approach can also have lower capital and maintenance costs than a regional approach (Lloyd, Wong, and Porter 2002).

While both traditional and sustainable stormwater strategies attempt to manage stormwater, they differ in their objectives and outcomes. This report focuses on the small, distributed, retention-based SCMs employed by sustainable stormwater management. Its focus on small, distributed SCMs is due, in part, to the advantages of sustainable stormwater management strategies described above. Another reason why this practicum does not examine conventional detention-based systems is that a recent report for the ACC government has already thoroughly examined several potential sites for regional detention ponds within the Tanyard Creek watershed (Tetra Tech 2012). These sites are shown on the recommendations maps in chapter 7. Evaluating potential detention sites in the Tanyard Creek watershed now would be an unnecessary duplication of effort.

Watershed-wide stormwater planning

Urbonas and Doerfer (2005) issued recommendations for master planning for stream protection. A master plan provides guidance for the future as land-use changes occur or funds become available. It also provides coherence of function so that each SCM provides the needed function to make the entire system work. While the authors stressed that planning for surface drainage should be integrated early into the urban layout, their basic principles should also apply to stormwater control planning in already developed areas. The four principles are:

1. When lands urbanize or redevelop, include SCMs for volume reduction whenever possible.
2. Treat residual runoff through the use of a water quality capture volume sufficient in size to capture the most frequent storm events, then release the captured water to receiving streams slowly.
3. Stabilize the natural waterways that receive runoff.
4. Prevent contaminated commercial and industrial runoff and contaminated spills from reaching receiving waters (Urbonas and Doerfer 2005).

On-site SCMs are now commonly implemented during new development to control the stormwater runoff generated on an individual development project; however, adding on-site SCMs to previously developed areas is more challenging, as property owners are not required to retroactively manage runoff from existing structures. In previously-developed areas, it can be especially beneficial to evaluate potential SCMs as an interconnected system, rather than as individual structures. Doing so may require the inclusion of regional SCMs that capture water from far beyond the property they are located on, as well as consideration of how SCMs can work together in series (Villarreal, Semadeni-Davies, and Bengtsson 2004). Sequencing structural SCMs to achieve optimal flow management and pollutant removal is sometimes referred to a as a "treatment train" (Lloyd, Wong, and Porter 2002). Treatment trains are described in more detail on page 77.

A system-wide assessment of a previously developed area was prepared for Augustenborg, an inner suburb of Malmö, Sweden. Model simulations showed that a combination of green roofs, open channels, and detention basins could work together to control stormwater, and that the position of each SCM within the watershed and relative to the other SCMs mattered. For example, green roofs were most effective for small storms but became saturated during heavier rain evens, whereas detention and retention ponds can capture flow from large storms and regulate flow from these storms into receiving waters. Placing these and other SCMs in series allows each structure to help control the water that is not retained or detained by structures upstream (Villarreal, Semadeni-Davies, and Bengtsson 2004).

Another area-wide analysis was completed for the residential complex located at the former site of the Beijing Olympic Village. When the Beijing Olympic Village was constructed, a variety of SCMs were included, but each facility was designed individually without taking the larger context into account. Using a computer model, the study compared the stormwater impacts of three alternatives: the existing SCM scheme, a plan that aimed at improving landscape features, and a plan that included additional and modified SCMs based on low impact development (LID) design principles. Examples of LID principles used include rerouting roof runoff through green spaces rather than directly to rain barrels, increasing stormwater detention times, and using properly designed bioretention. When compared to the existing SCM scheme, the third scenario was predicted to reduce total runoff volume and peak flow rate by 27% and 21% respectively (Jia et al. 2012). These two stormwater planning examples illustrate the benefits of planning for the watershed as a whole and considering interactions between SCMs.

Different types of structural SCMs have different strengths and weaknesses, so no one SCM type can remove all pollutant types or control all stormwater flow (Lloyd, Wong, and Porter 2002). For example, Barrett (2008) used data from the International Stormwater Best Management Practice Database (BMP Database, *http://www.bmpdatabase.org/*) to compare the water quality improvement performance of retention ponds, extended detention basins, vegetated swales, and sand filters. While vegetated swales and retention ponds tended to perform best overall among the four SCMs compared, which SCM was best for specific circumstances varied depending on the pollutant of interest and specific site conditions, such as rainfall patterns (Barrett 2008). Because different SCMs target different stormwater management issues, a variety of SCMs working together should be included in a stormwater plan (Lloyd, Wong, and Porter 2002).

Site overview

Lilly Branch, Tanyard Creek, and the PPD are tributaries of the North Oconee River, which ultimately flows to the Atlantic Ocean via the Altamaha River. The headwaters of Lilly Branch and Tanyard Creek begin in Athens-Clarke County to the west of the campus, while the PPD watershed is entirely contained within UGA's main campus (Figure 1-1). Tanyard Creek drains an area of 0.92 square miles. About half of the stream length is piped (Herbert et al. 2003). The Lilly Branch watershed is 0.62 square miles, and approximately two-thirds of Lilly Branch is enclosed in pipes or culverts. The PPD watershed is 0.14 square miles. While not recognized as a perennial or intermittent stream by the National Hydrography Dataset, the PPD stream is daylit from the railroad tracks to its confluence with the North Oconee River. West of the railroad tracks, the watershed is entirely paved over and piped.

All three watersheds have been impacted negatively by urbanization in terms of both hydrology and water quality. As a result of its impairment, Lilly Branch has commonly been referred to as Stinky Creek for some time (e.g. Carroll and Rasmussen 2005). Tanyard Creek and its tributary, Cloverhurst Branch, are both listed on Georgia's 303(d) list for fecal coliform impairment. Lilly Branch and the PPD are too small to be assessed by the state, but the reach of the North Oconee River into which they both flow is also listed as failing to meet fecal coliform criteria (GA DNR 2010). Ongoing water quality sampling within the study area reveals elevated levels of fecal coliform and several other contaminants within all three drainages (Brown and Caldwell 2011, 2012). A more detailed overview of these three watersheds, including water quality data, can be found in the site inventory (Chapter 2).

Site overview

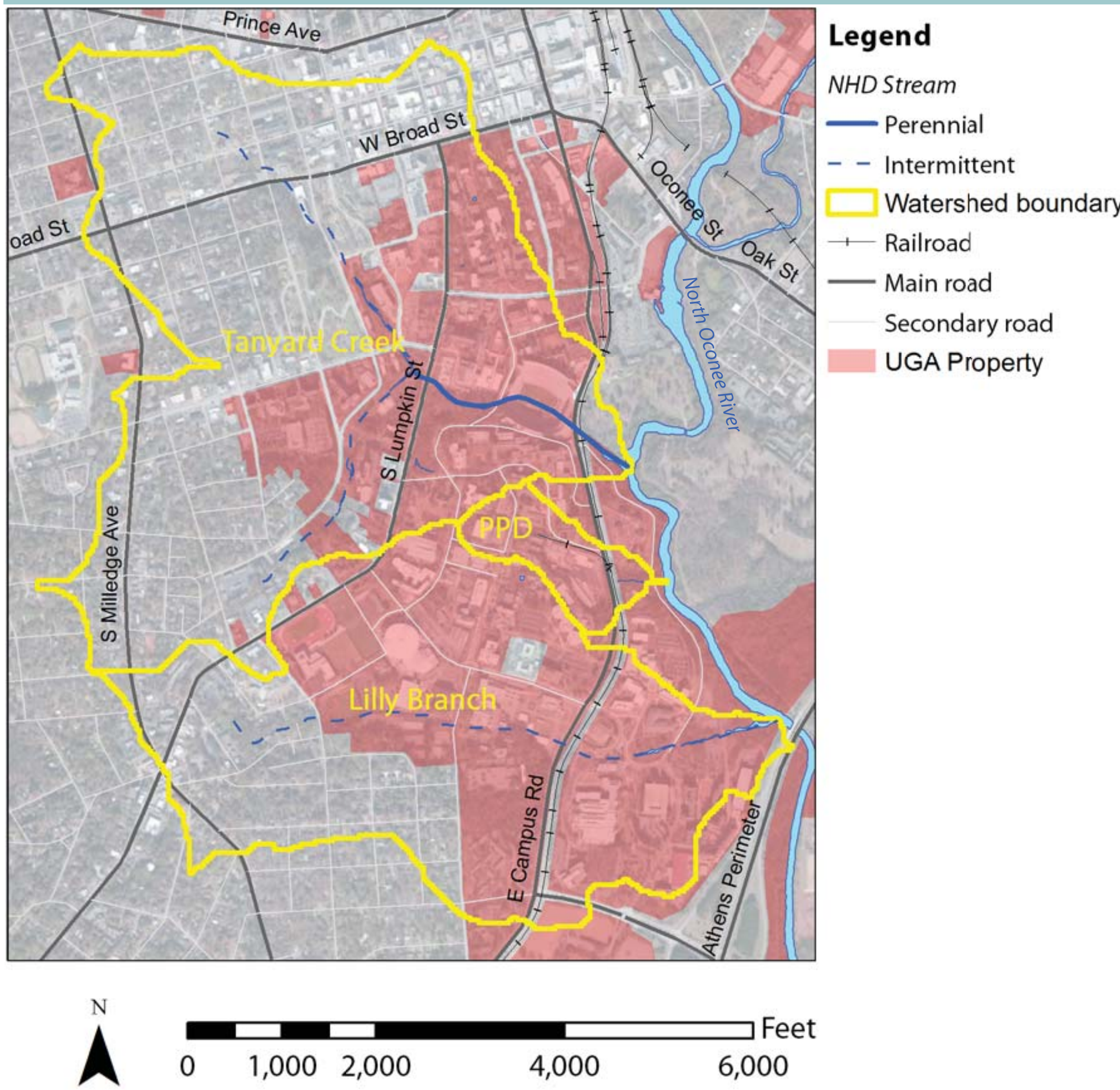

Figure 1-1. This stormwater control suitability analysis focuses on three watersheds in Athens-Clarke County, Georgia. The headwaters of Lilly Branch and Tanyard Creek begin within the Athens community, mostly on privately held land, but all three drainages flow through the University of Georgia campus before reaching the North Oconee River.

There two additional areas that drain to this section of the North Oconee River from the UGA campus that were not included in this plan. They are visible on the map north and south of the PPD watershed. They were excluded from analysis because they drain directly into the North Oconee River, rather than into one of the three target streams.

Project overview

This stormwater control plan centers around a suitability analysis for future SCMs in the Lilly Branch, Tanyard Creek, and PPD watersheds. Because it examines the study area at a watershed scale, it does not present exact locations or design specifications for individual SCMs. Instead, it highlights regions within the three target watersheds where SCMs are most needed and suggests the types of SCMs that may be most appropriate within those regions. Recommendations are based on several weighted overlay analyses, using ArcGIS. Regions in need of stormwater control were determined by taking into account impervious surfaces, physical site conditions, and water pollution. Locations suggested as suitable for specific SCMs were determined by correlating site conditions with design criteria for each type of SCM. Land ownership was also taken into account regarding the feasibility of installing SCMs on a given property. The objective of this watershed plan is to highlight locations within these three watersheds where SCMs are most suitable, feasible, and needed, so that future SCMs can be located where they are most effective. Information about SCM function, both in general and as it relates to specific water quality goals, is also included to assist with future stormwater control decisions.

Chapter 2: Site Inventory

This section presents an inventory of site conditions that were taken into consideration during the development of this stormwater control plan.

Organization

The data within this site inventory were used for this plan's analyses and recommendations. The inventory begins with an overview of the site's context, including aerial imagery, transportation, and university-owned property boundaries. It then procedes to show streams and surface water, watershed and catchment delineation, and the location of flood zones. Next, surface and soil characteristics are presented, followed by UGA's existing stormwater infrastructure (both conventional structures and SCMs). Manmade boundaries and structures, including parcel data and impervious surfaces, are also included. The largest and final portion of this inventory chapter presents water quality monitoring data for several pollutants of interest.

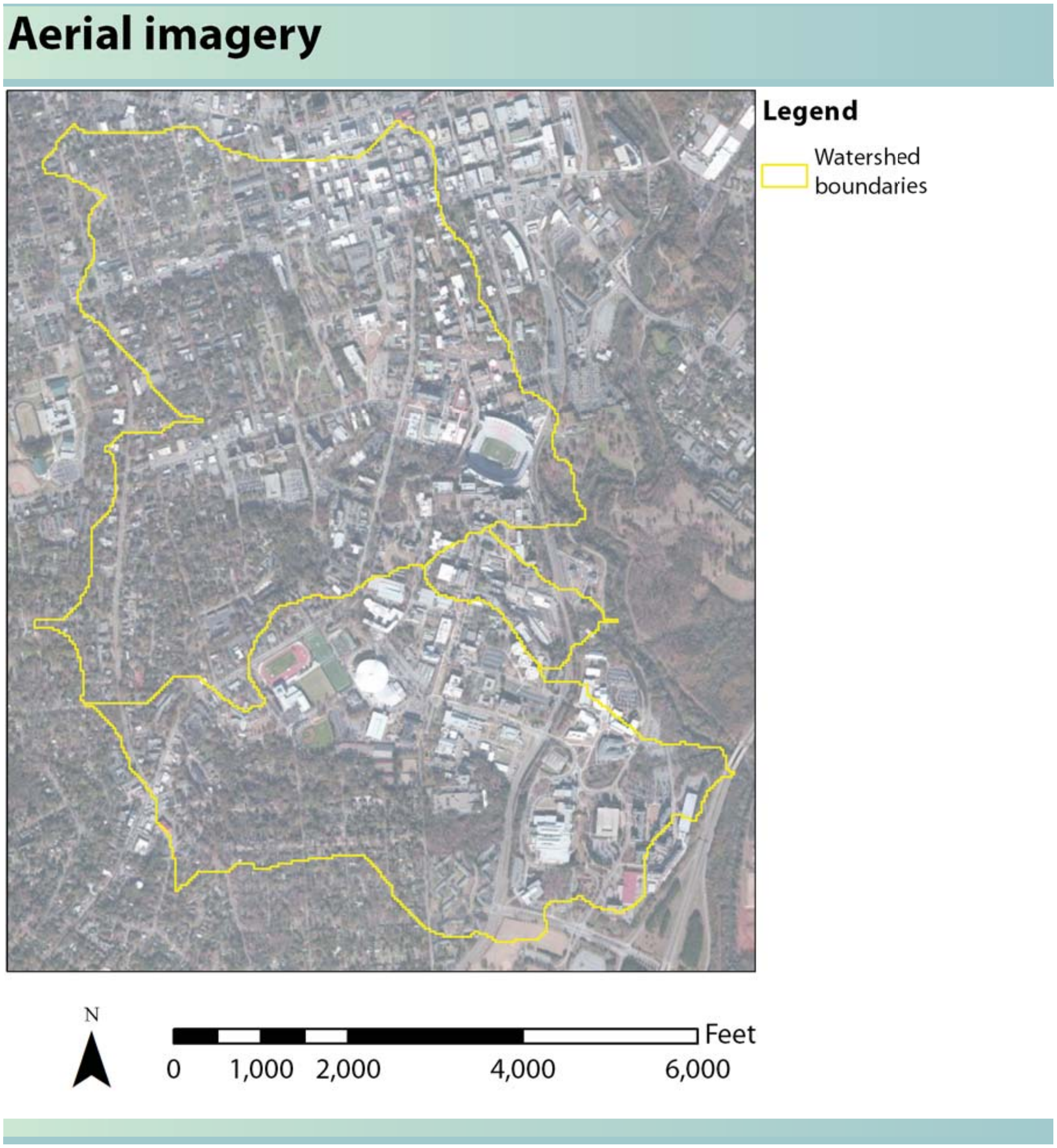

Figure 2-1. Aerial image of target area.

The aerial image is from Bing Maps, Microsoft Corporation, 2010, and was accessed through ArcMap's built-in base map function.

Roads and rail

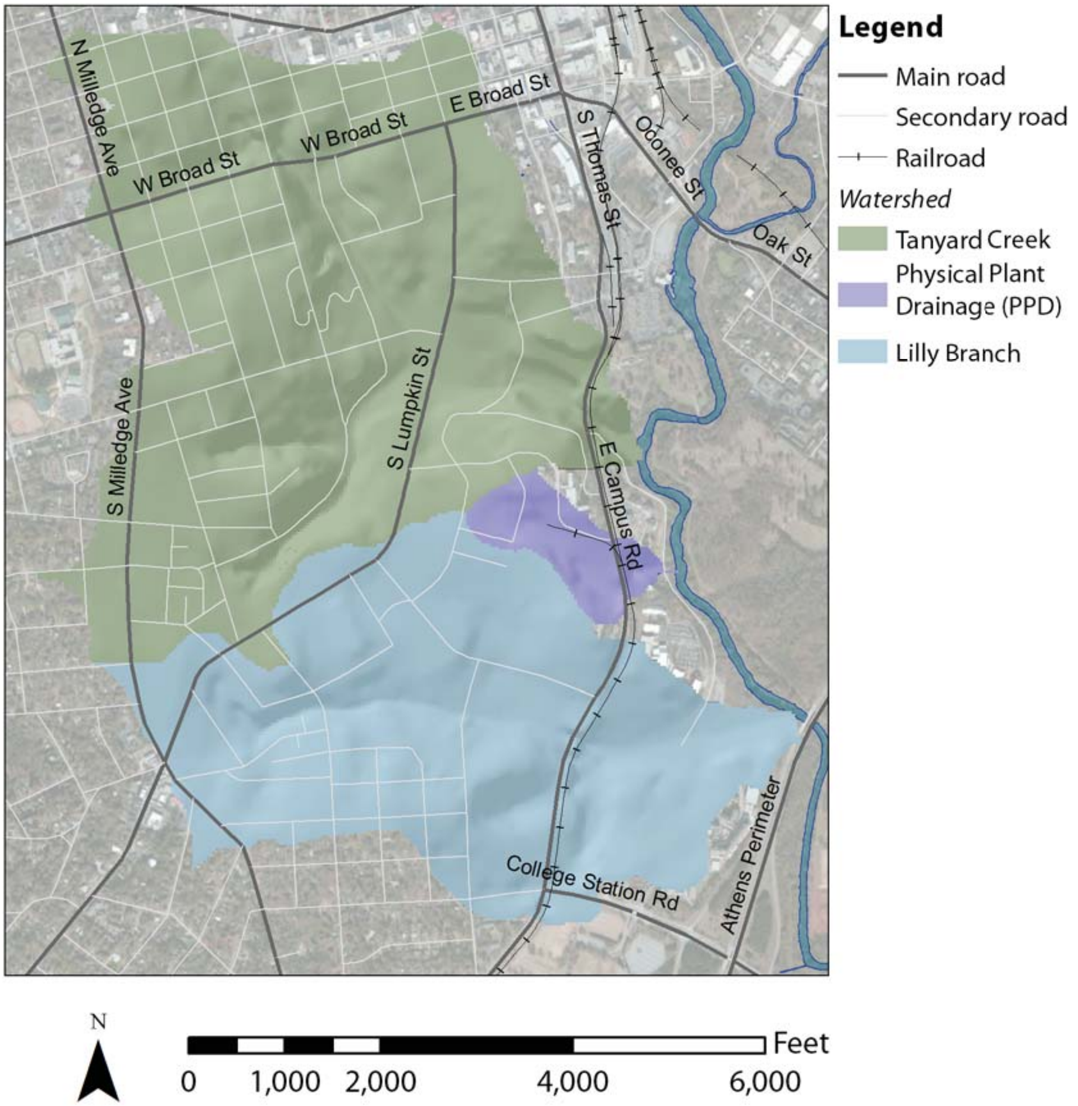

Figure 2-2. Transportation infrastructure (roads and railroads).

The road and rail shapefiles were obtained from Athens-Clarke County.

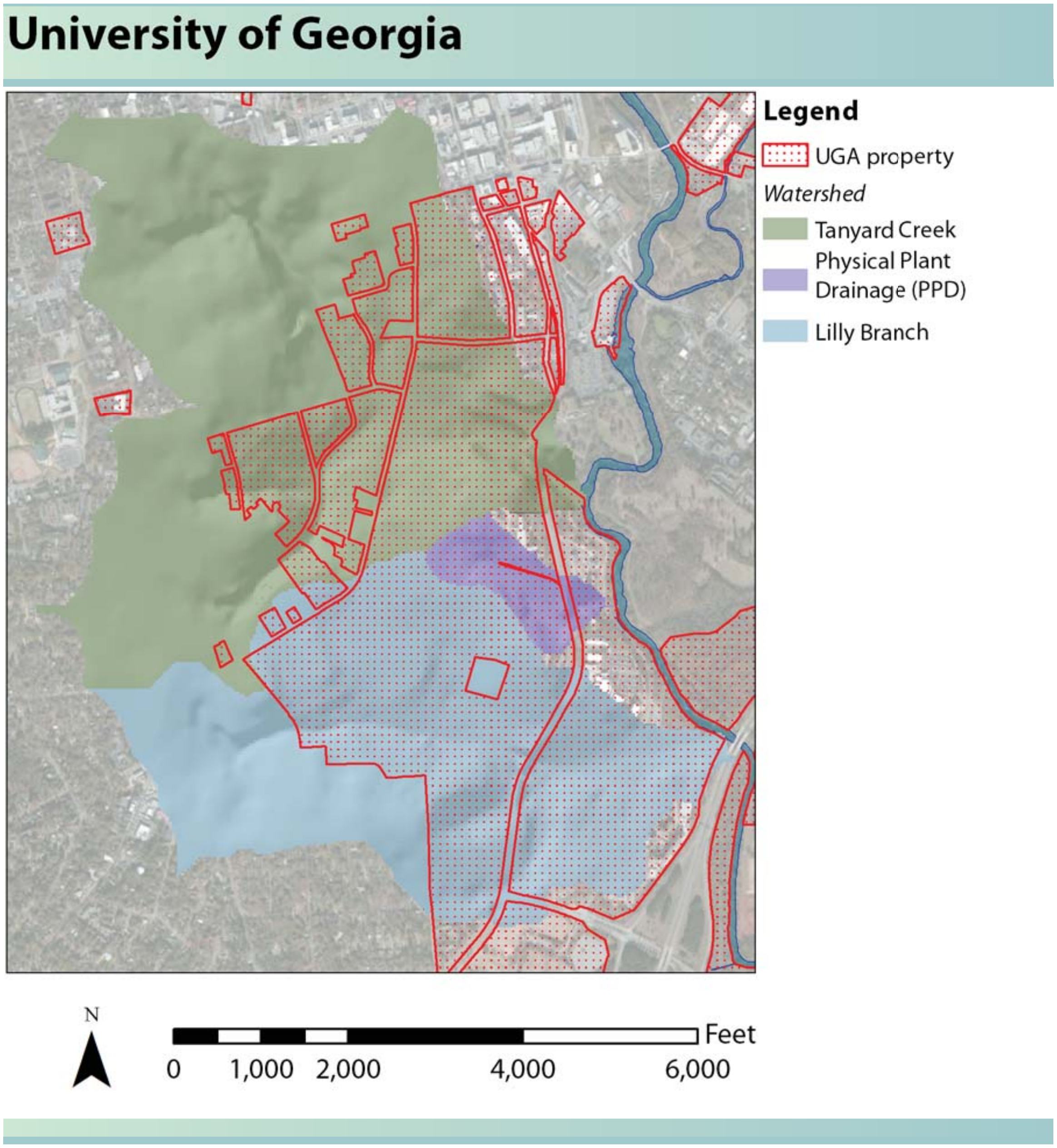

Figure 2-3. Property owned by the University of Georgia.

The property boundary shapefile was obtained from the UGA Office of University Architects.

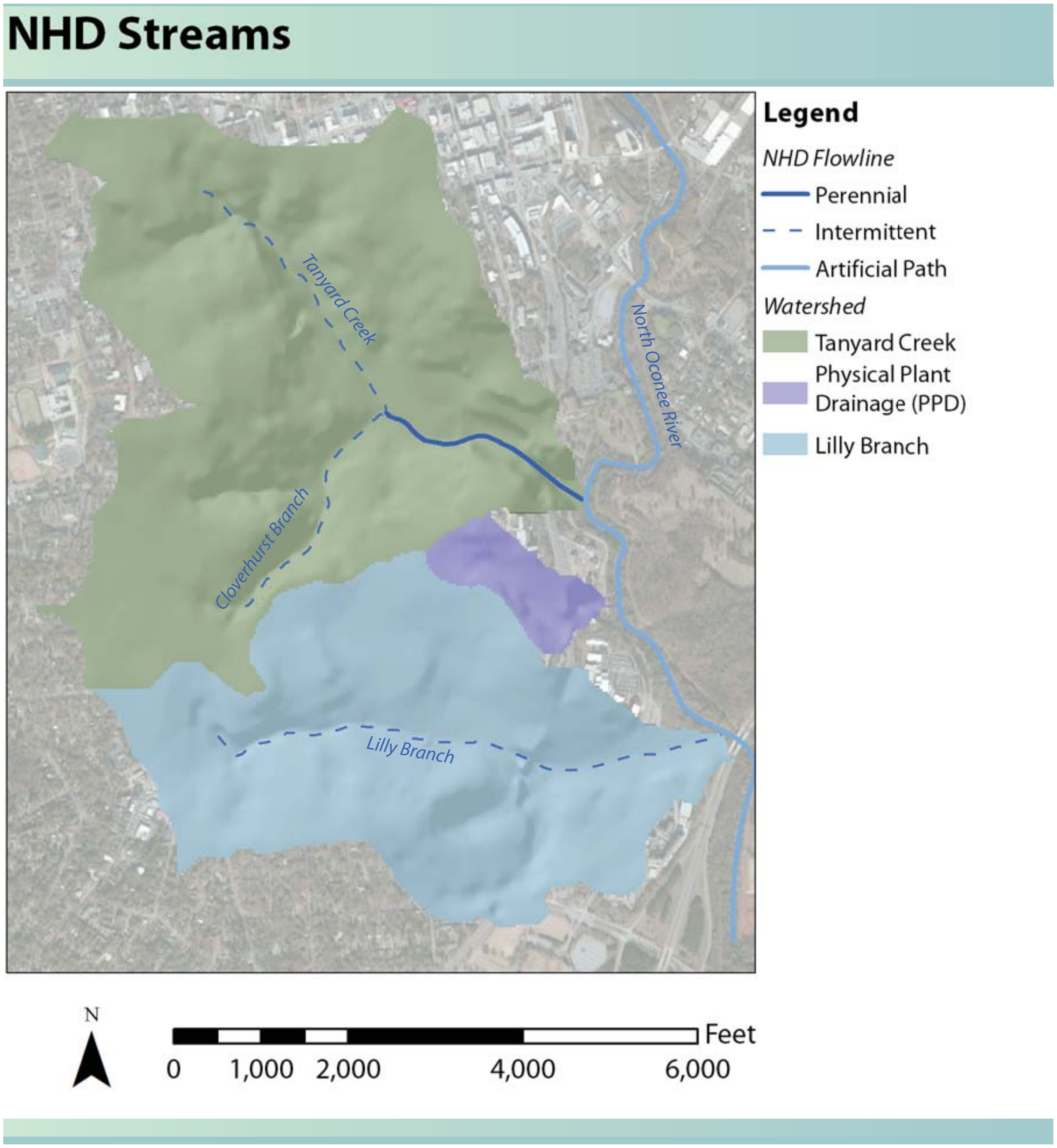

Figure 2-4. Streams (National Hydrography Dataset).

This image shows the streams that are included within the National Hydrography Dataset (USGS 2012b).

Flow path

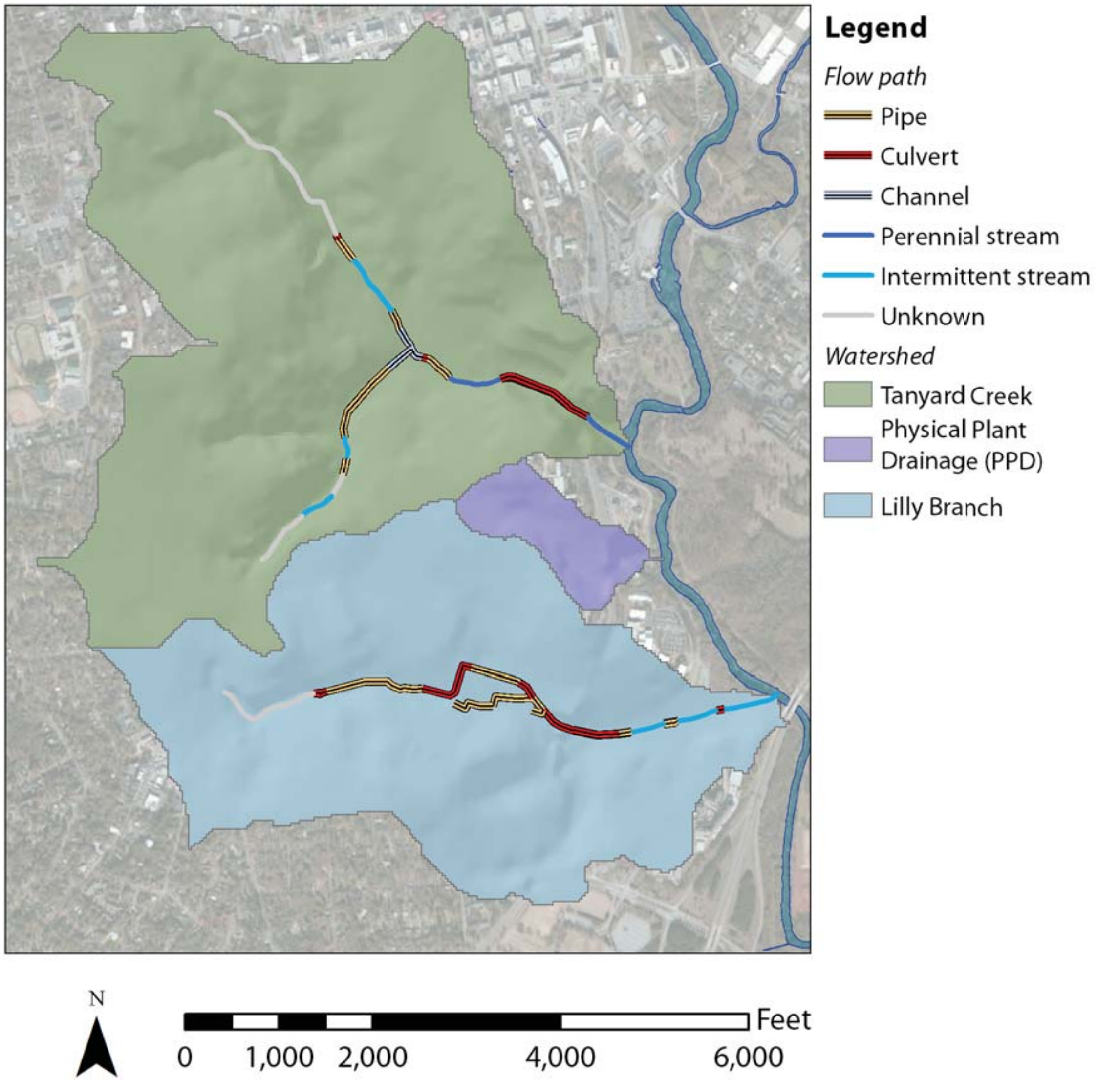

Figure 2-5. Pathway followed by NHD streams.

The pathway followed by NHD streams was found by visually comparing the NHD streams (Figure 2-4), UGA stormwater lines (Figure 2-19), UGA hydrography (Figure 2-6), and aerial imagery GIS layers (Figure 2-1). Sections of these streams marked as "unknown" are beyond the UGA campus. The "unknown" sections are all classified as intermittent in the NHD, but without stormwater infrastructure data from Athens-Clarke County, it is not clear whether these sections flow naturally or through manmade infrastructure.

Surface water

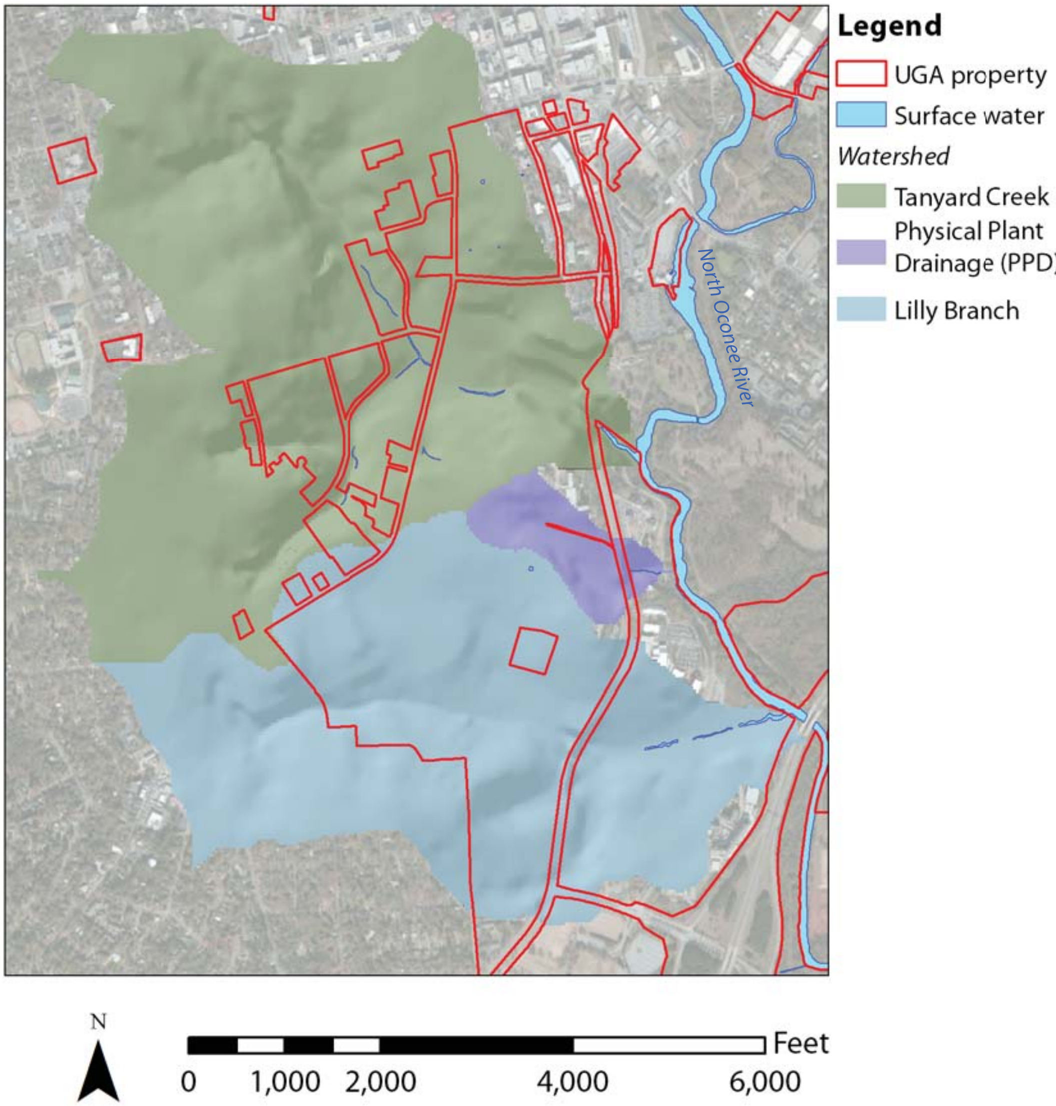

Figure 2-6. Surface water bodies (UGA only).

Water bodies shown are those from the University of Georgia's Hydrography shapefile, excluding swimming pools. Because of the source of these data, only the North Oconee River and water bodies on the University of Georgia campus are included. No information about the presence or absence of surface water is given for the portion of the study area that lies beyond the University of Georgia campus.

Catchment boundaries

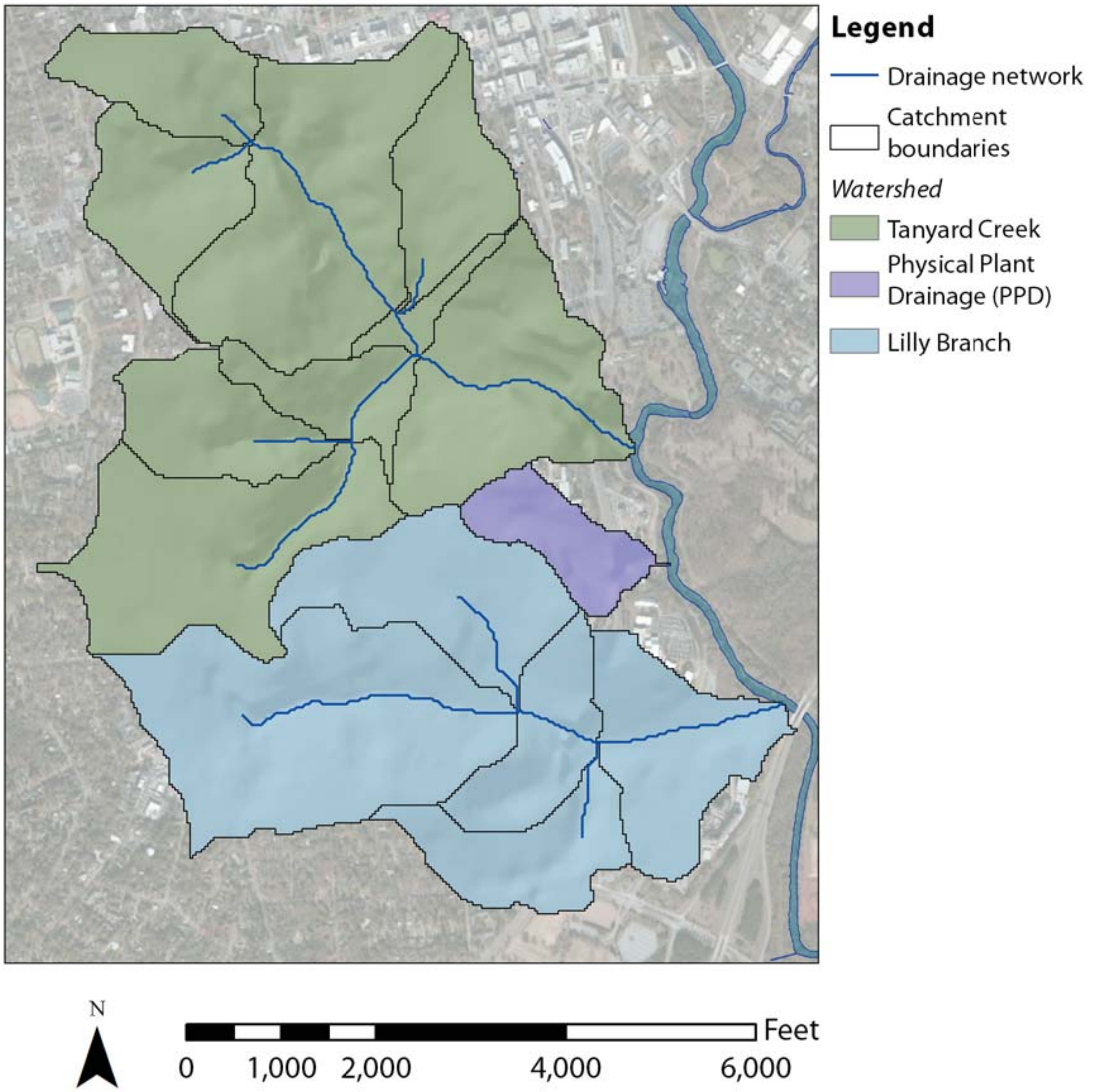

Figure 2-7. Delineated catchments and watersheds.

For the purposes of this analysis, "catchment" refers to all land that drains to a specific point (in this case, to a single stream junction), while "watershed" includes all of the catchments that drain to a perennial or intermittent stream. While the Physical Plant drainage includes no NHD recognized streams, it is treated as a separate watershed because water from it drains directly to the North Oconee River through a short daylit section of stream, without first passing through either of the other two watersheds.

Catchments and watersheds were delineated based on the flow direction, flow accumulation, and drainage network shown on page 19, which are all derived from a NED digital elevation model (Figure 2-12) with 1/3 arc second (31.06 ft.) cell resolution.

As stormwater runoff from opposite sides of a stream can experience very different conditions, catchments were further subdivided by the drainage network layer, allowing land on each side to be examined separately in suitability analyses. For details about this process, please see the appendix.

Catchment delineation - intermediate steps

Flow direction is based on a NED digital elevation model (Figure 2-12) with NHD stream locations (Figure 2-4) imposed on it.

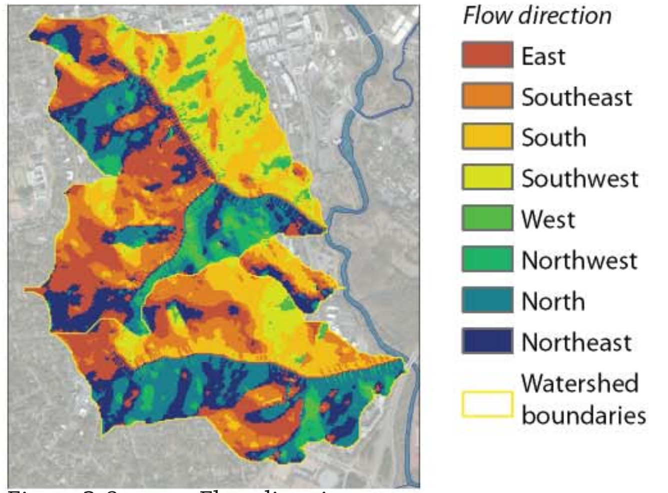

Figure 2-8. Flow direction.

From this image, one can see the watershed's drainage pattern, including ephemeral streams. Flow accumulation values represent the number of raster cells (each is approximately 31 ft., squared) that drain to each location, based on flow direction (Figure 2-8).

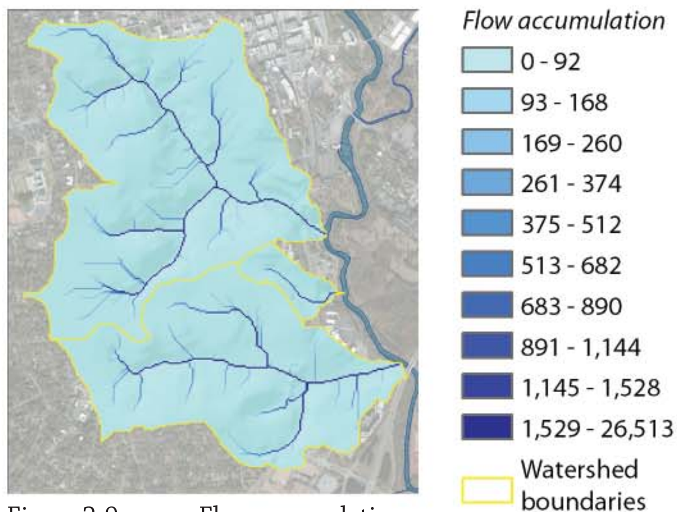

Figure 2-9. Flow accumulation.

The primary drainage network includes all perennial and intermittent streams (Figure 2-4), as well as some important ephemeral drainages. These streams are those with a flow accumulation greater than 1528 cells, which is the value that allowed the PPD watershed to be delineated as single catchment.

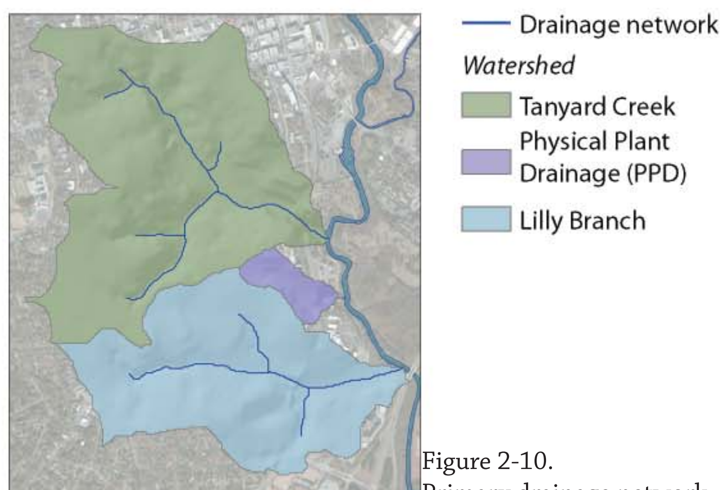

Figure 2-10.
Primary drainage network

Flood zones

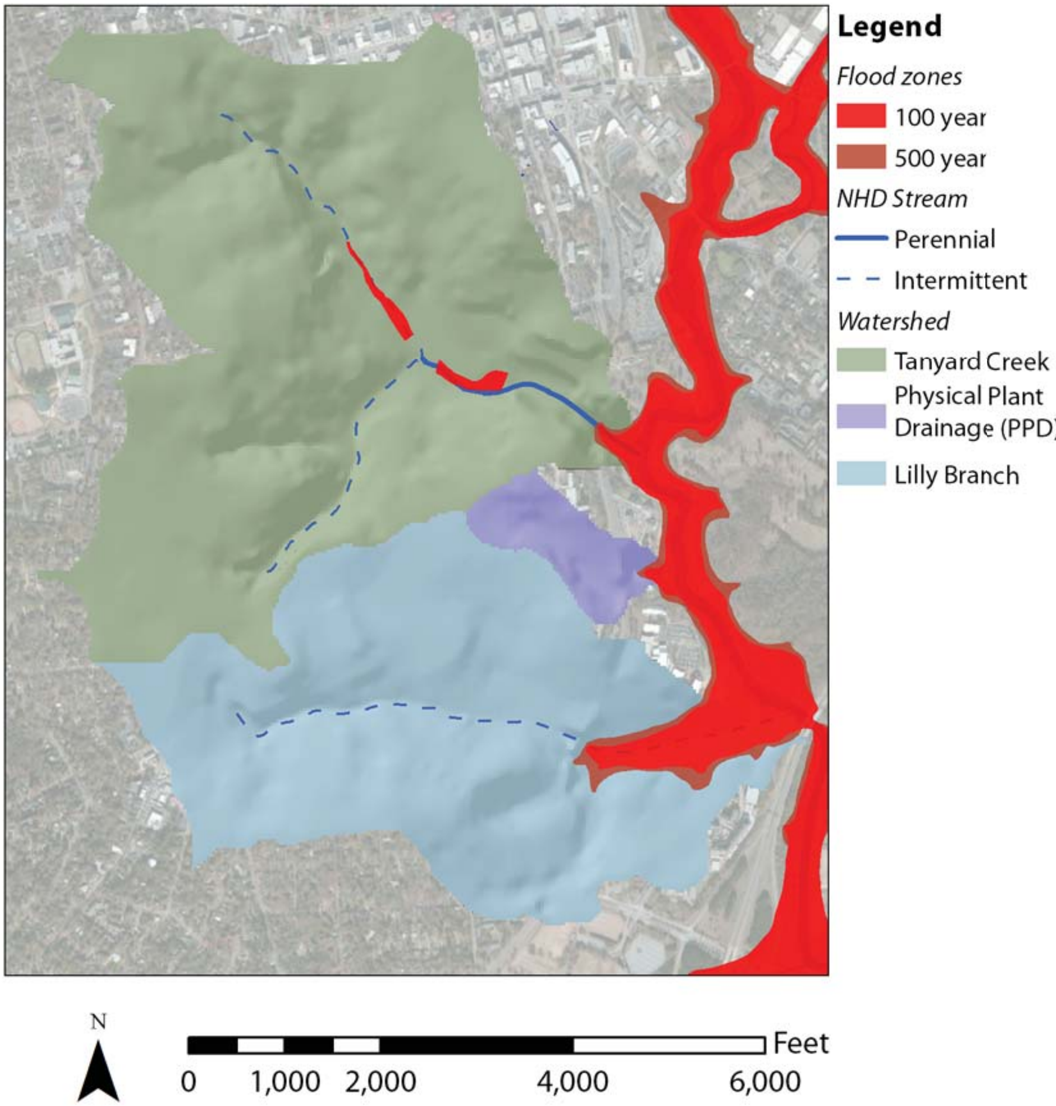

Figure 2-11. Flood hazard zones.

Flood zone information from the Federal Emergency Management Agency's Digital Flood Insurance Map Database (FEMA 2009).

Elevation

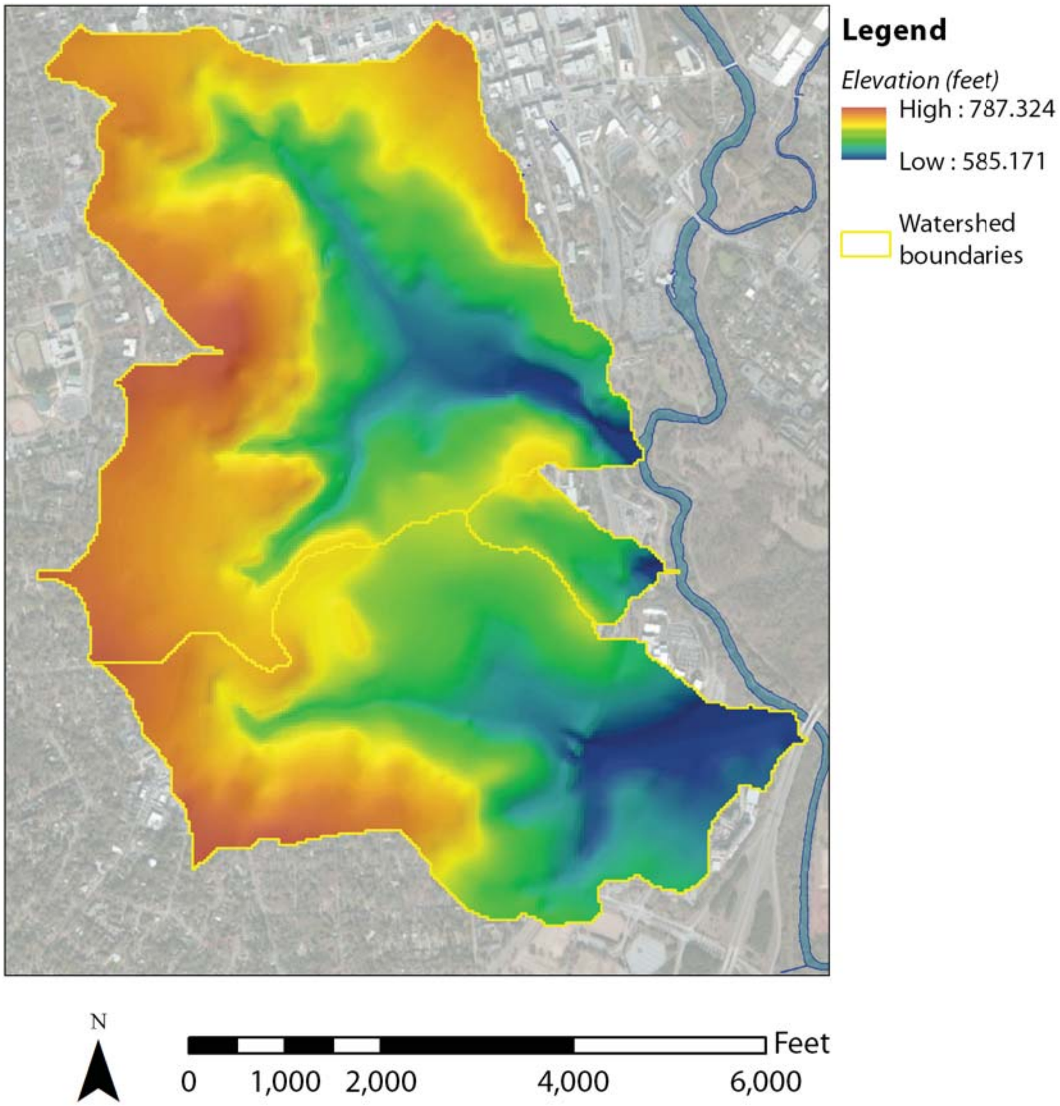

Figure 2-12. Elevation in feet.

This information was extracted from a digital elevation model from the National Elevation Dataset (1/3 arc-second) (USGS 2012a).

Contours

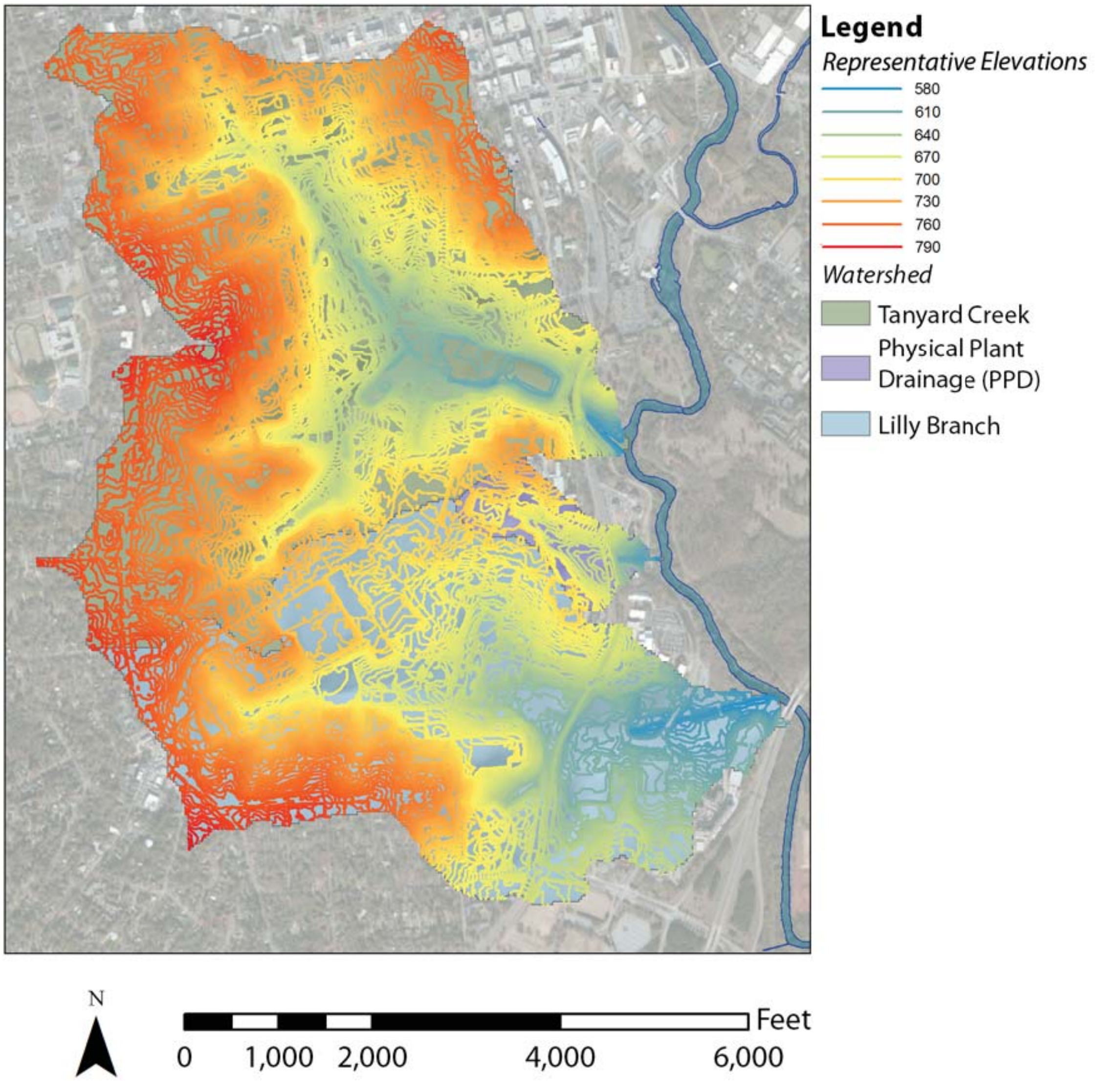

Figure 2-13. Contours (2 ft. intervals).

Contour interval shapefiles (2 ft. and 10ft). were obtained from Athens-Clarke County.

Slope

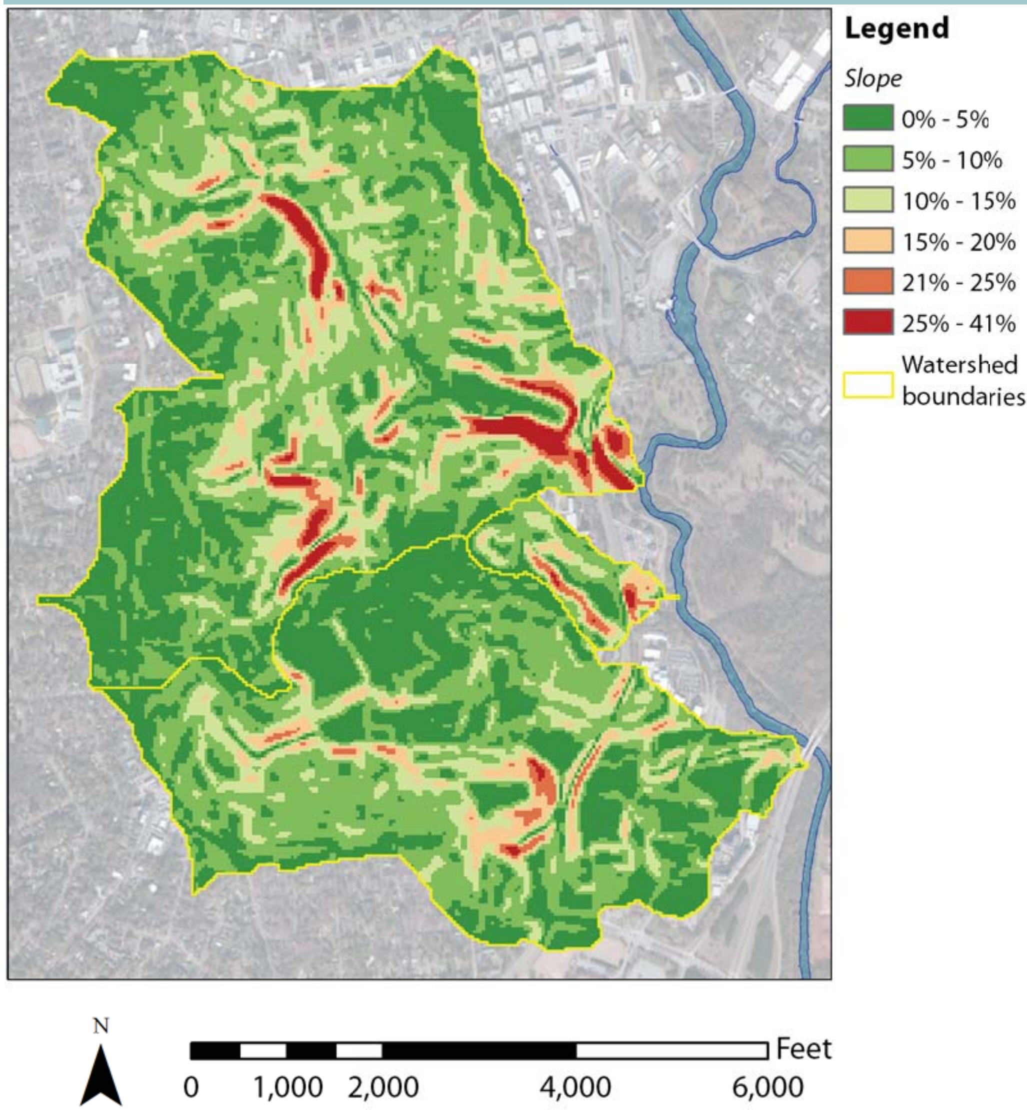

Figure 2-14. Slope (percent).

Slope was calculated from 2 foot contour intervals (Figure 2-13). For more information on this process, please see the the appendix.

Soil type

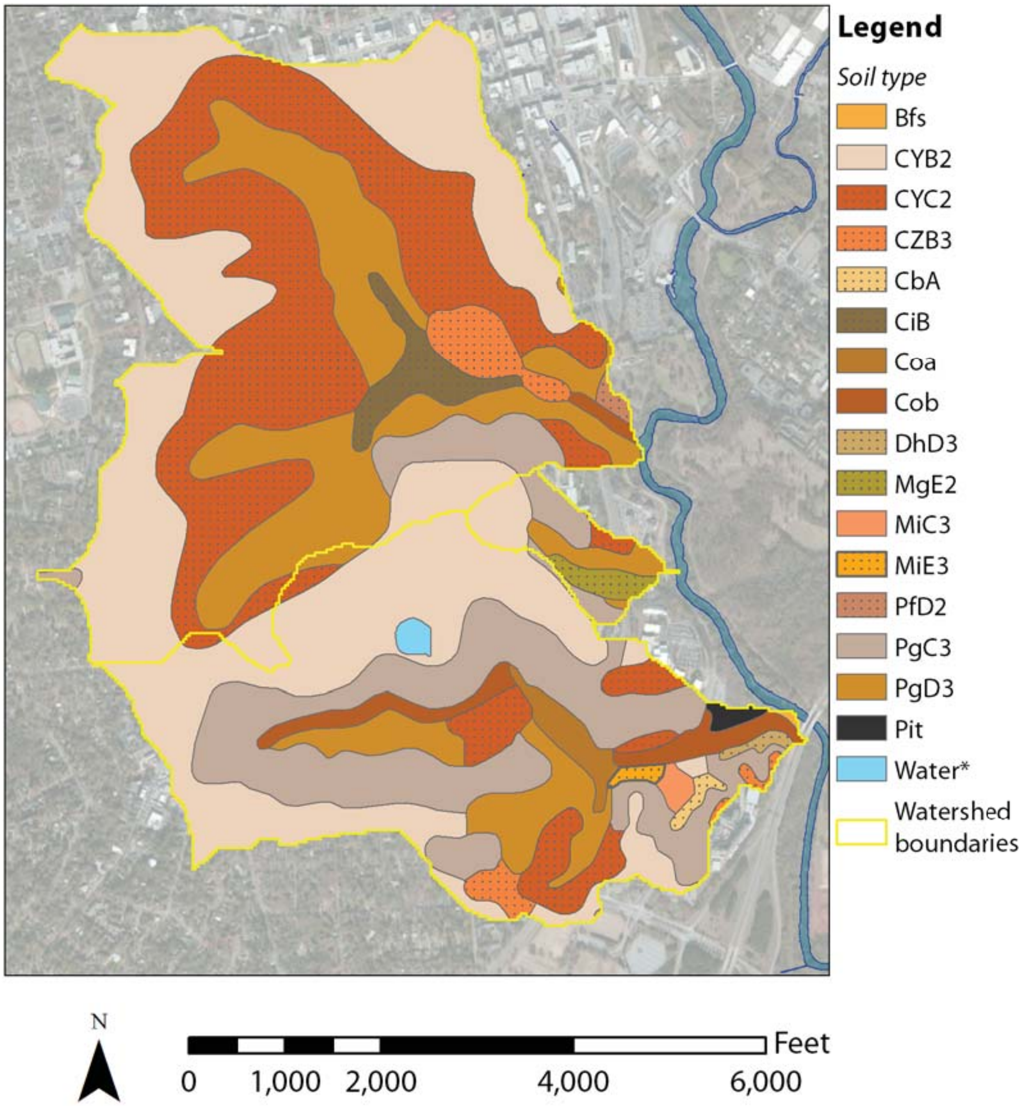

Figure 2-15. NRCS soil type.

The original soil shapefile was downloaded from the National Resource Conservation Service's Soil Data Mart (Soil Survey Staff). Descriptions of each soil type are found on the following page.

*Note that the area identified as "Water" on the map was incorrectly identified in the source data. It is actually the roof of the UGA Coliseum.

Table 2-1. NRCS soil type descriptions (Soil Survey Staff).

Code	Description
Bfs	Buncombe loamy sand
CbA	Cecil soils, 0 to 2 percent slopes, overwash
CiB	Colfax sandy loam, 2 to 6 percent slopes
Coa	Congaree soils and alluvial land
Cob	Chewacla soils and alluvial land
CYB2	Cecil sandy loam, 2 to 6 percent slopes, eroded
CYC2	Cecil sandy loam, 6 to 10 percent slopes, eroded
CZB3	Cecil sandy loam, 2 to 6 percent slopes, severely eroded
DhD3	Davidson clay loam, 10 to 15 percent slopes, severely eroded
MgE2	Madison sandy loam, 15 to 25 percent slopes, eroded
MiC3	Madison sandy clay loam, 6 to 10 percent slopes, severely eroded
MiE3	Madison sandy clay loam, 10 to 25 percent slopes, severely eroded
PfD2	Pacolet sandy loam, 10 to 15 percent slopes, eroded
PgC3	Pacolet sandy clay loam, 6 to 10 percent slopes, severely eroded
PgD3	Pacolet sandy clay loam, 10 to 15 percent slopes, severely eroded

Hydrologic soil group

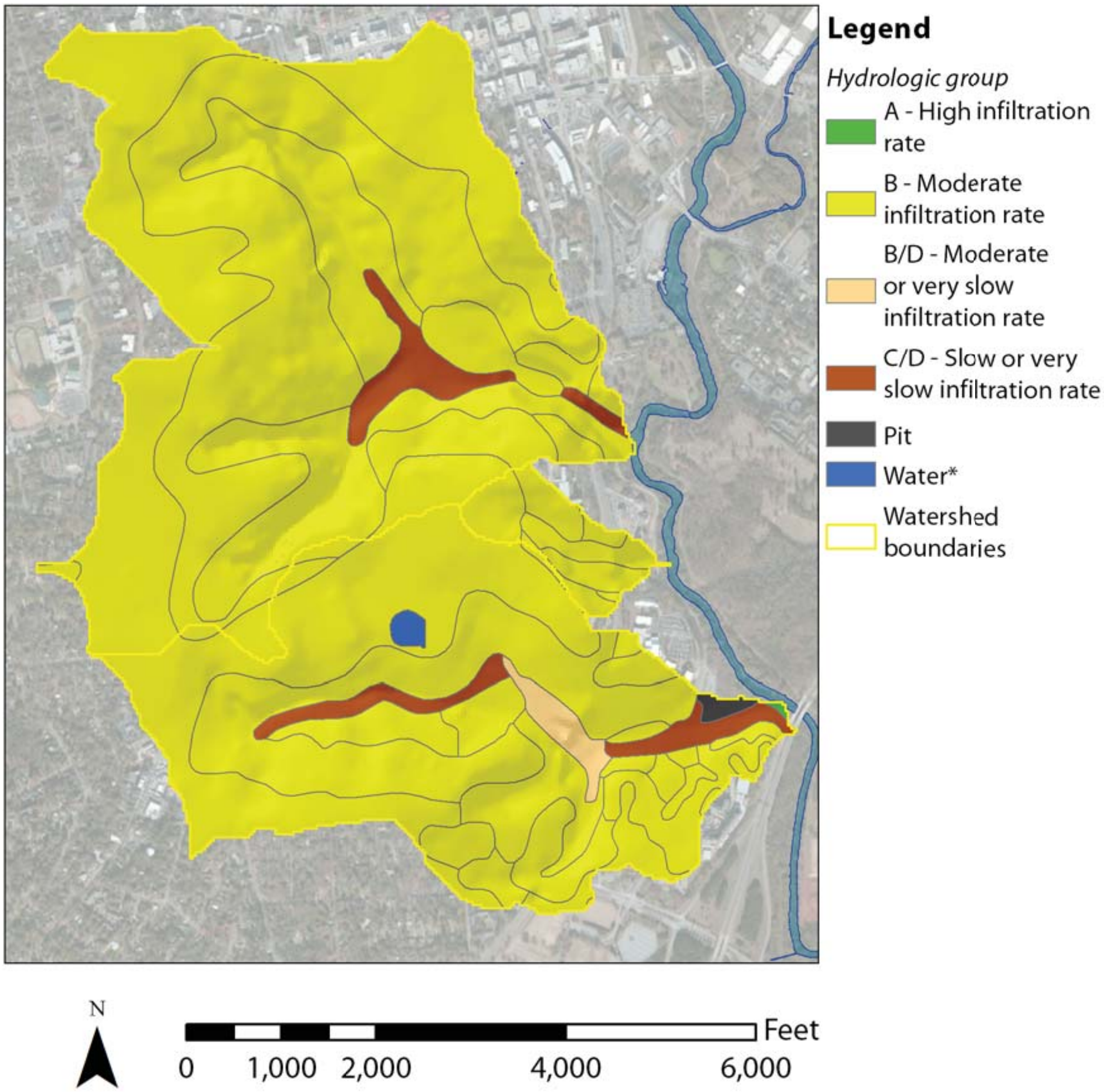

Figure 2-16. NRCS soil hydrogroup.

When more than one hydrologic group is indicated in the legend above (e.g. B/D), the first group given applies to drained soils, while the second applies to undrained soils.

The original soil shapefile (Figure 2-15) was downloaded from the National Resource Conservation Service's Soil Data Mart. Each soil type was then correlated with its hydrologic group according to the Water Features report, which is also part of the Soil Data Mart (Soil Survey Staff).

*Note that the area identified as "Water" on the map was incorrectly identified in the source data. It is actually the roof of the UGA Coliseum.

Soil erodibility

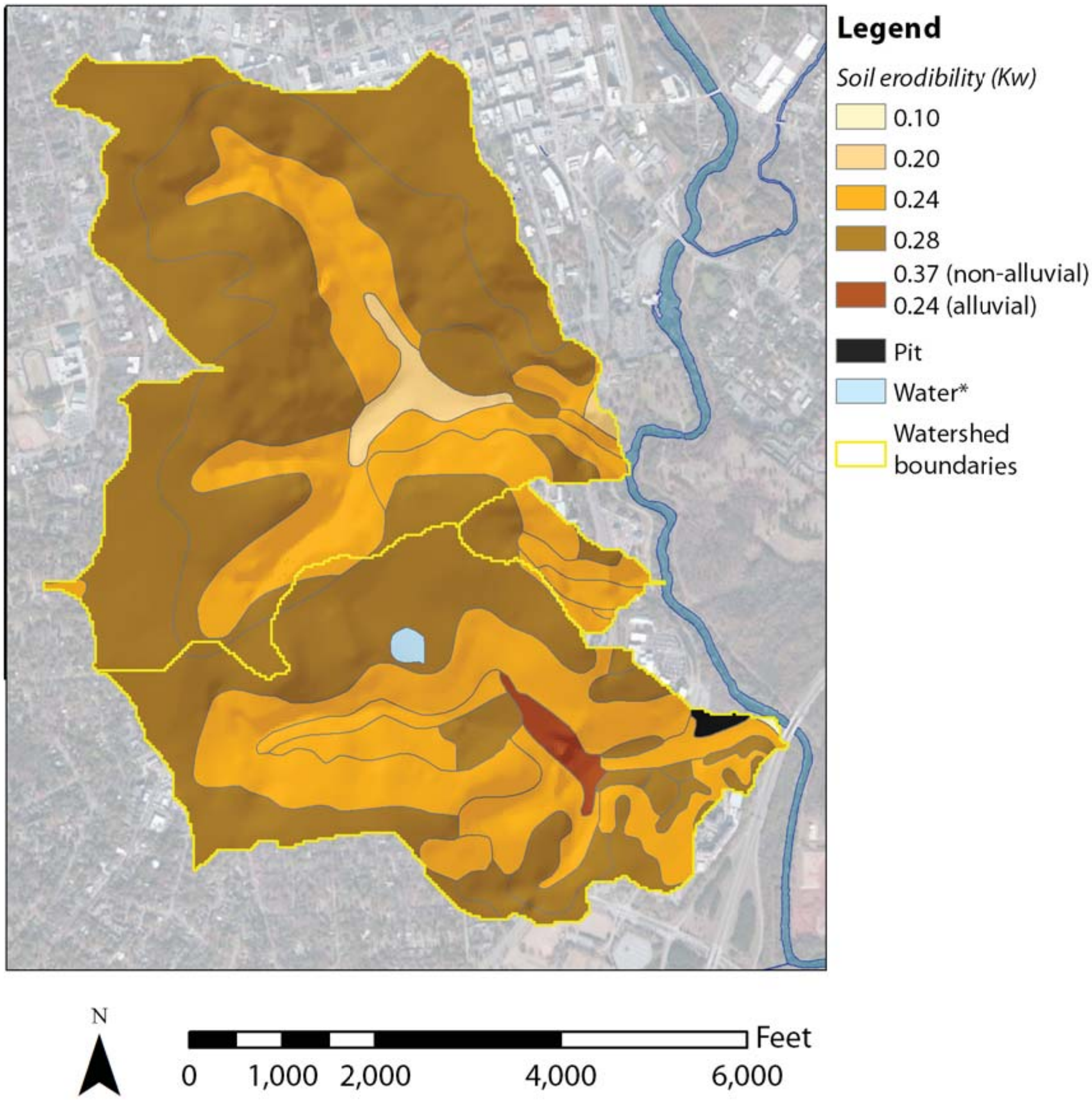

Figure 2-17. Soil erodibility (Kw).

The original soil shapefile (Figure 2-15) was downloaded from the National Resource Conservation Service's Soil Data Mart. Each soil type was then correlated with its erosion factor (Kw) at shallow depths (0-3" or 0-6" depending on the soil group), according to the NRCS's Physical Soil Properties report, which is also part of the Soil Data Mart (Soil Survey Staff).

*Note that the area identified as "Water" on the map was incorrectly identified in the source data. It is actually the roof of the UGA Coliseum.

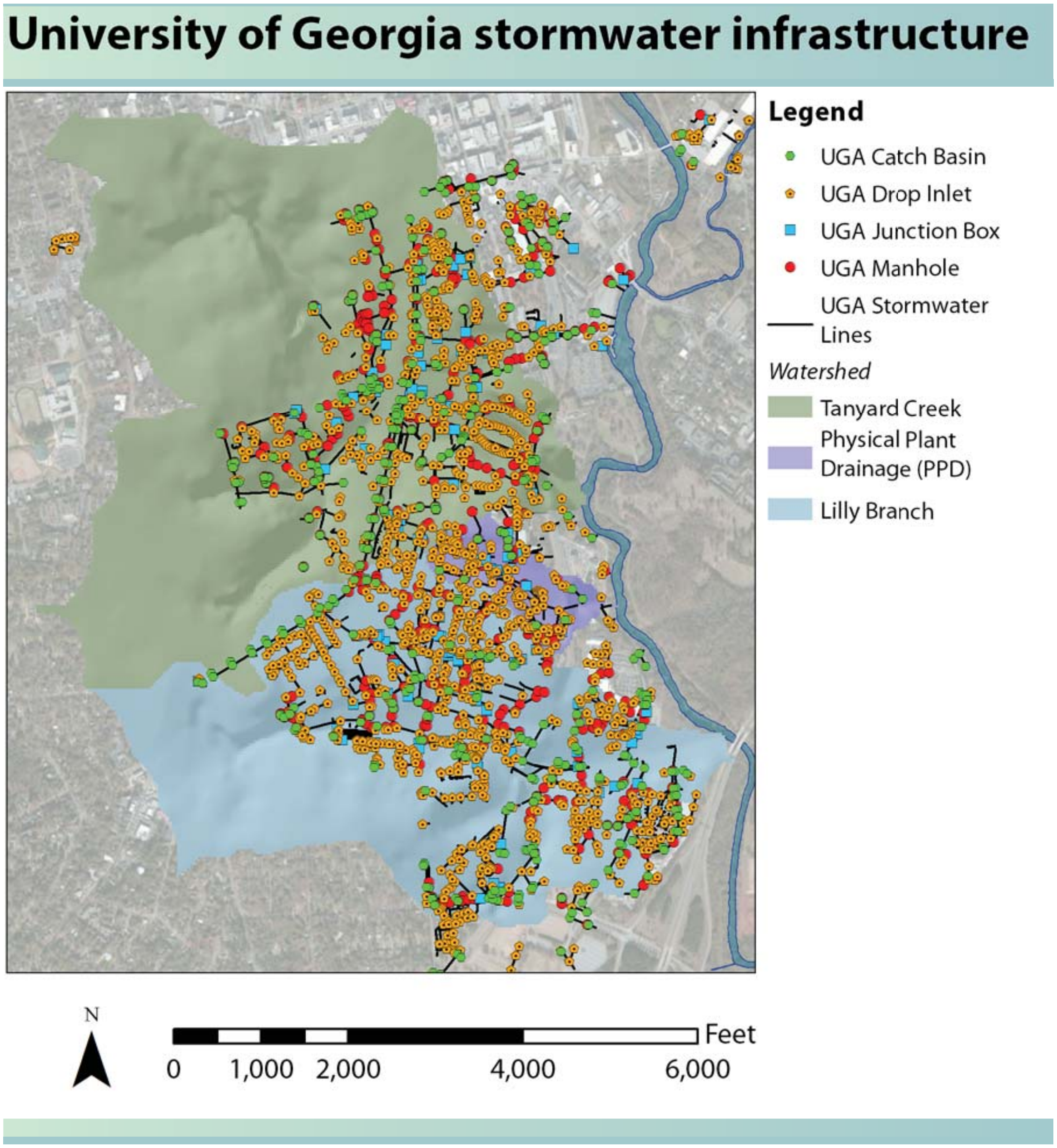

Figure 2-18. Conventional stormwater infrastructure (UGA property only).

Stormwater infrastructure shapefiles were provided by the UGA Office of University Architects. More specific information about the network of stormwater pipelines is available on the following page.

Similar GIS data for the portions of the target watersheds that lie beyond UGA property are not currently available.

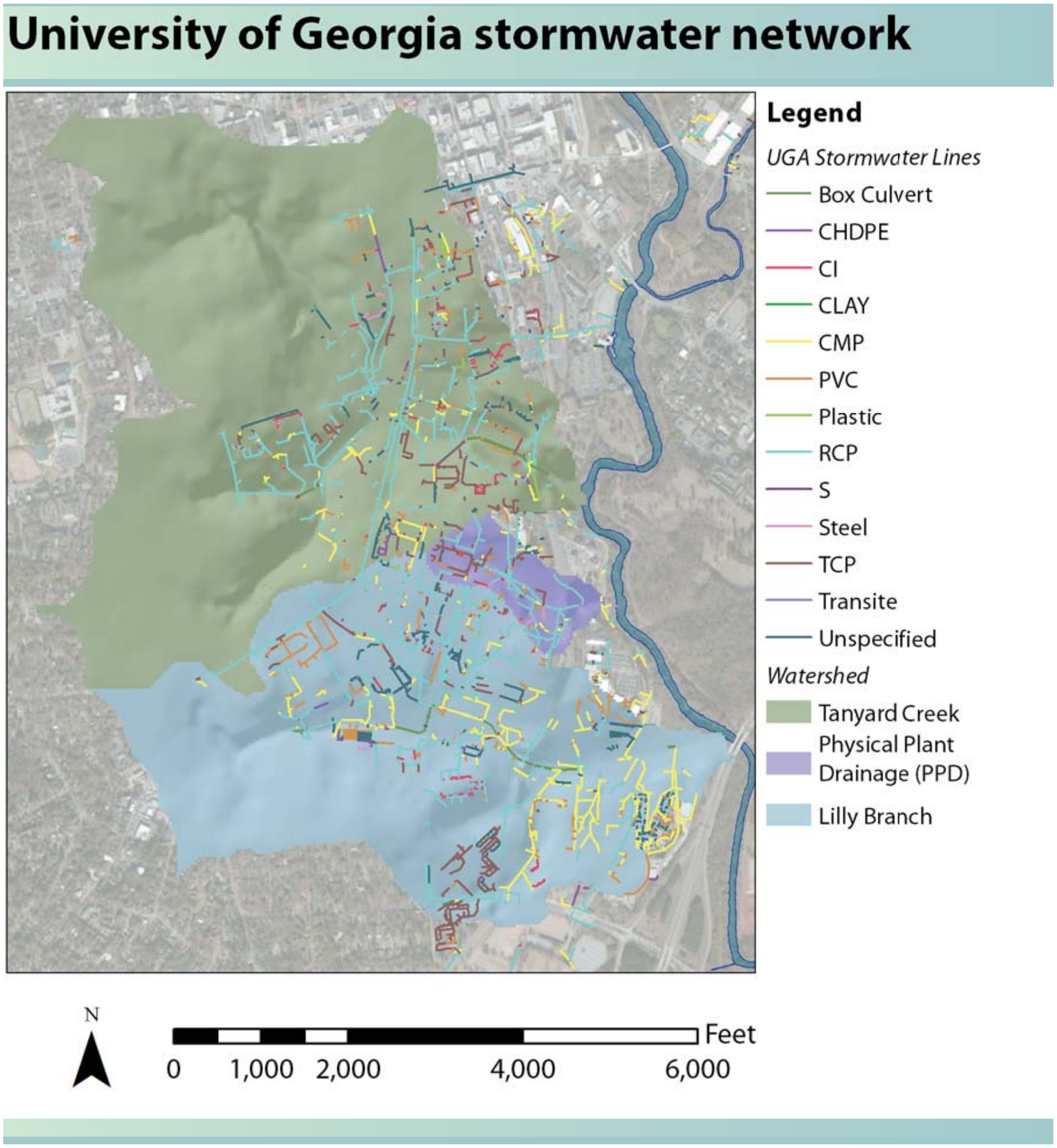

Figure 2-19. Stormwater pipelines that form UGA's conventional stormwater network (UGA property only).

The storm lines shapefile was provided by the UGA Office of University Architects.

Similar GIS data for the portions of the target watersheds that lie beyond UGA property are not currently available.

UGA existing SCMs

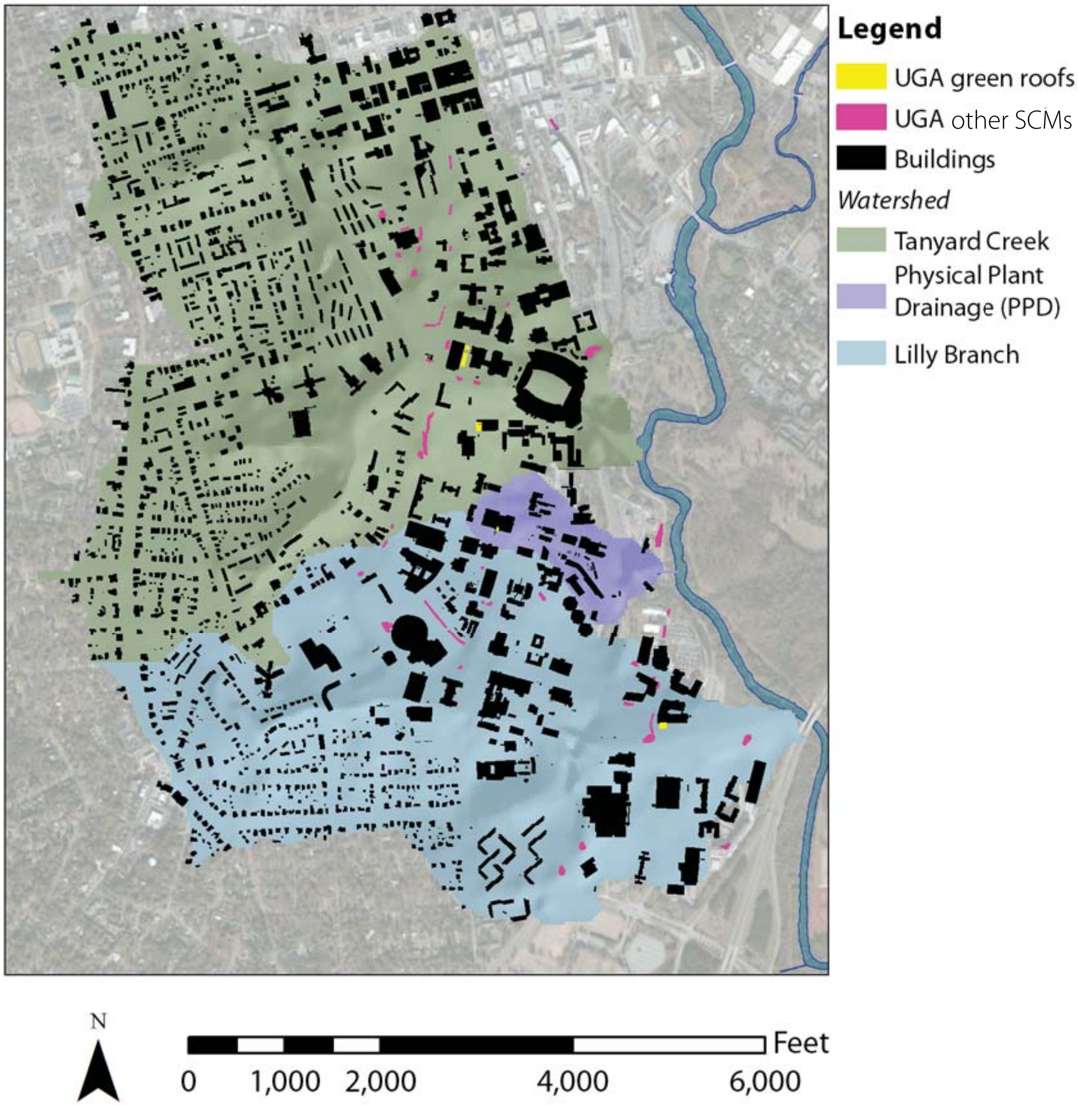

Figure 2-20. Existing SCMs, excluding cisterns (UGA property only)

“Other SCMs” refers mostly to rain gardens, but also includes other SCMs like porous pavement. This category excludes cisterns, which are shown on page 32. Locations of existing SCMs were surveyed by UGA’s Grounds Department in May 2012 for this project. UGA has 48 SCMs (excluding cisterns and green roofs) within the target watersheds, ranging in size from less than 0.01 acres to 0.23 acres.

UGA’s green roofs were traced from aerial photography using ArcMap’s Editor toolbar. The four green roof locations shown are on the Lamar Dodd School of Art, at the Climate Research Lab on the Geography/Geology building, on the expansion to the Tate Center (Tate II), and at the trial green roof on the Science Library.

Athens-Clarke County does not maintain an inventory of SCMs, so no information on green roofs or other SCMs is available for the portions of the target watersheds that are beyond UGA's borders. The County's Stormwater Coordinator indicated that there were few if any SCMs within the non-UGA portions of the target watersheds.

University of Georgia existing cisterns

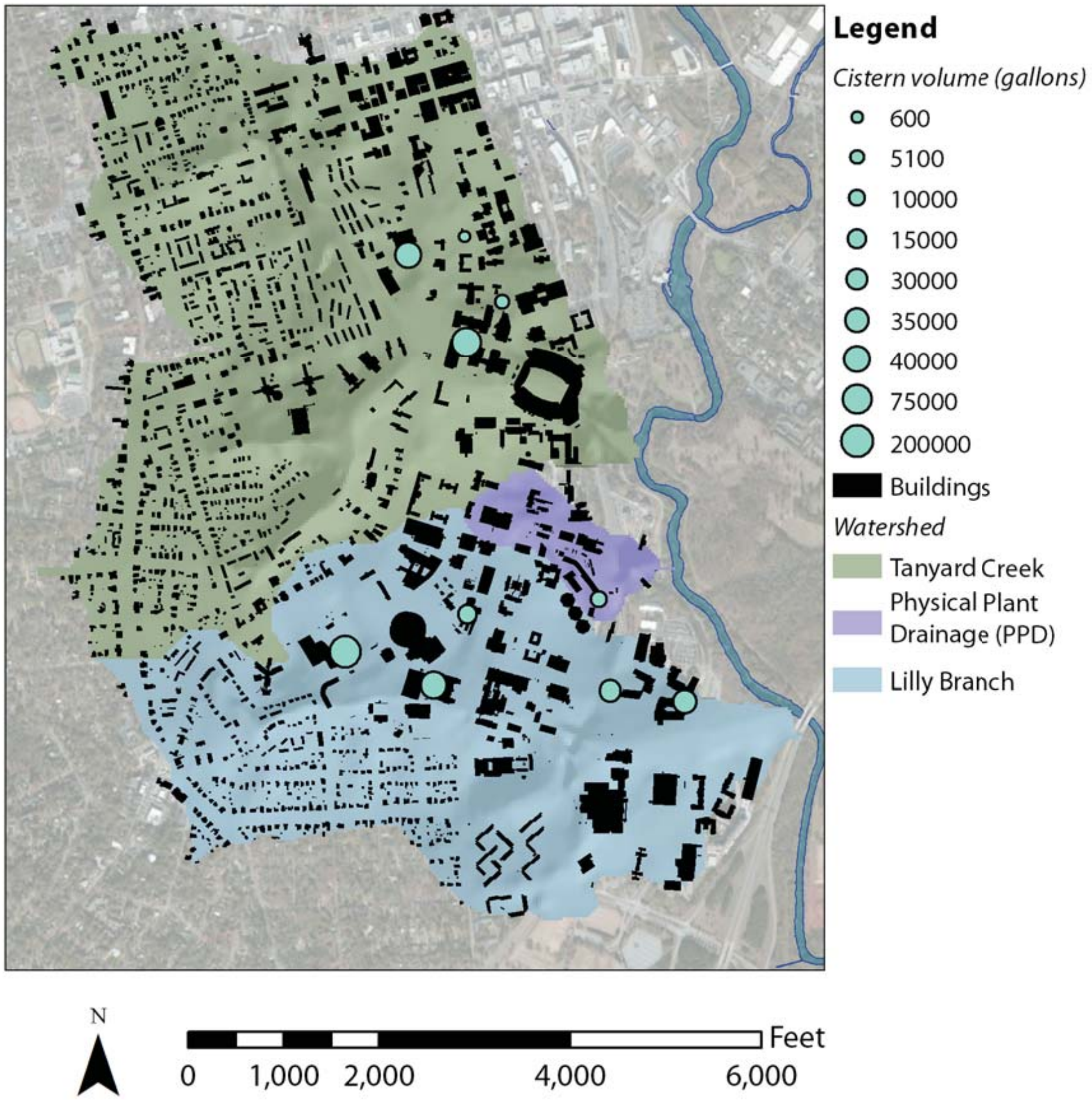

Figure 2-21. Existing cisterns (UGA property only).

Points shown represent approximate cistern locations only. Markers were sited based on verbal descriptions of cistern locations and approximate volumes. UGA Office of Sustainability (UGA Office of Sustainability 2012). The size of each marker indicates relative cistern volume, not actual size.

Some cisterns are used for rainwater harvesting only, while others collect water from other sources, such as air conditioner condensate.

Zoning, by parcel

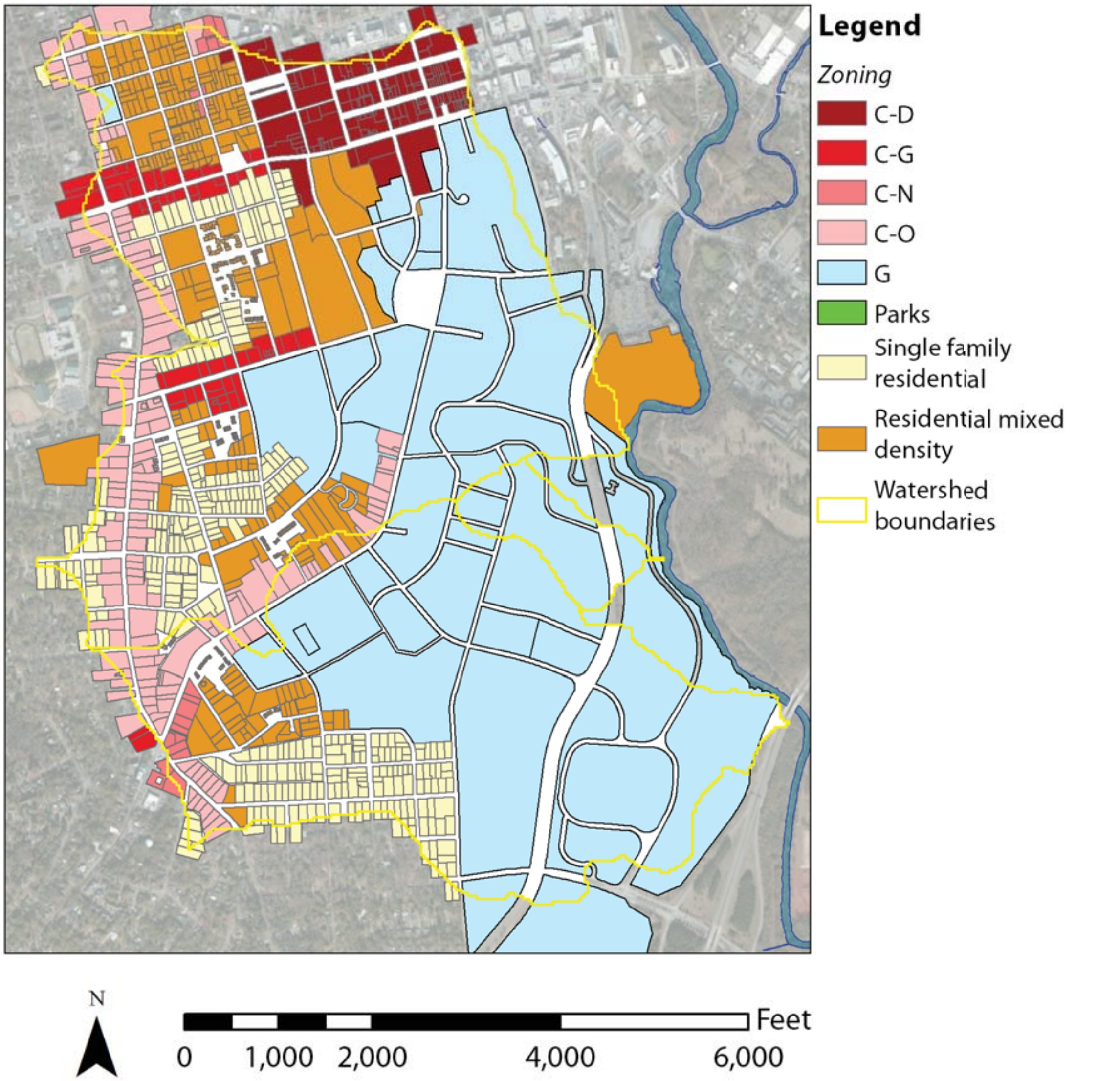

Figure 2-22. Zoning, by parcel.

Zoning information was obtained from Athens-Clarke County's zoning shapefile. Zones beginning with a C- are zoned for commercial use (Commercial-Downtown, Commercial-General, Commercial-Neighborhood, and Commercial-Office). Zone G is government; within the target watersheds, most parcels zoned for government use belong to UGA.

Ownership, by parcel

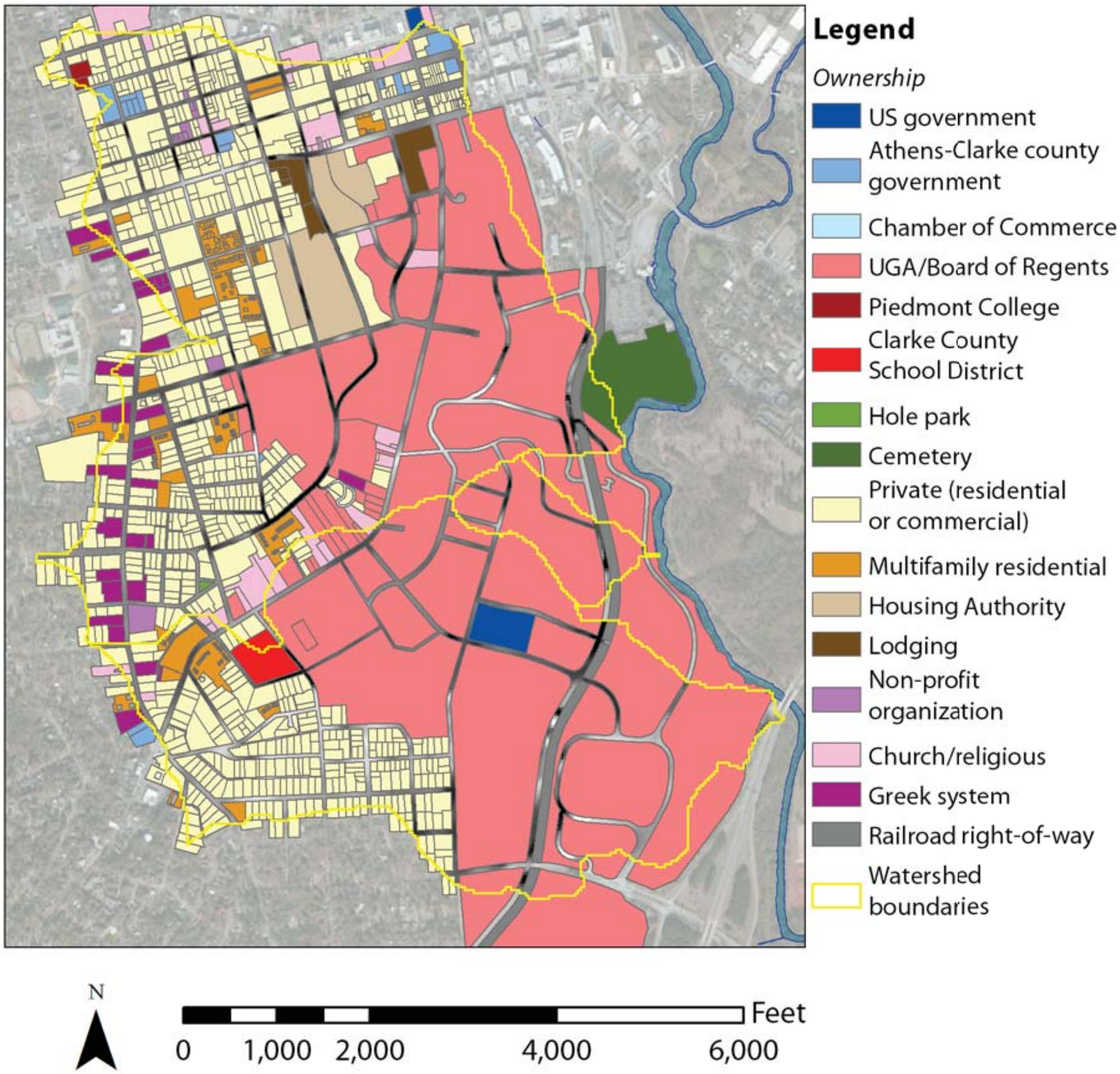

Figure 2-23. Property ownership, by parcel.

Property ownership categories were derived from Athens-Clarke County's parcel shapefile. The file gave owner names, which were sorted into categories.

Residential and commercial ownership was combined because it was often impossible to tell from the name which of the two categories was appropriate for a given property. Multifamily residential properties were identified by searching for owner names indicative of condominiums, apartments, or rentals, as well as by visual inspection of the parcel layer for shared common areas. In addition, Athens-Clarke County had some properties specifically identified as condominiums. Where none of these clues were apparent, some multifamily residential properties may have been identified as private (residential or commercial). Similarly, it is possible that some other ownership types, such as lodging, may have been identified as private (residential or commercial) if there were no clues within the owner's name to identify it as belonging to a more specific category.

Impervious surfaces

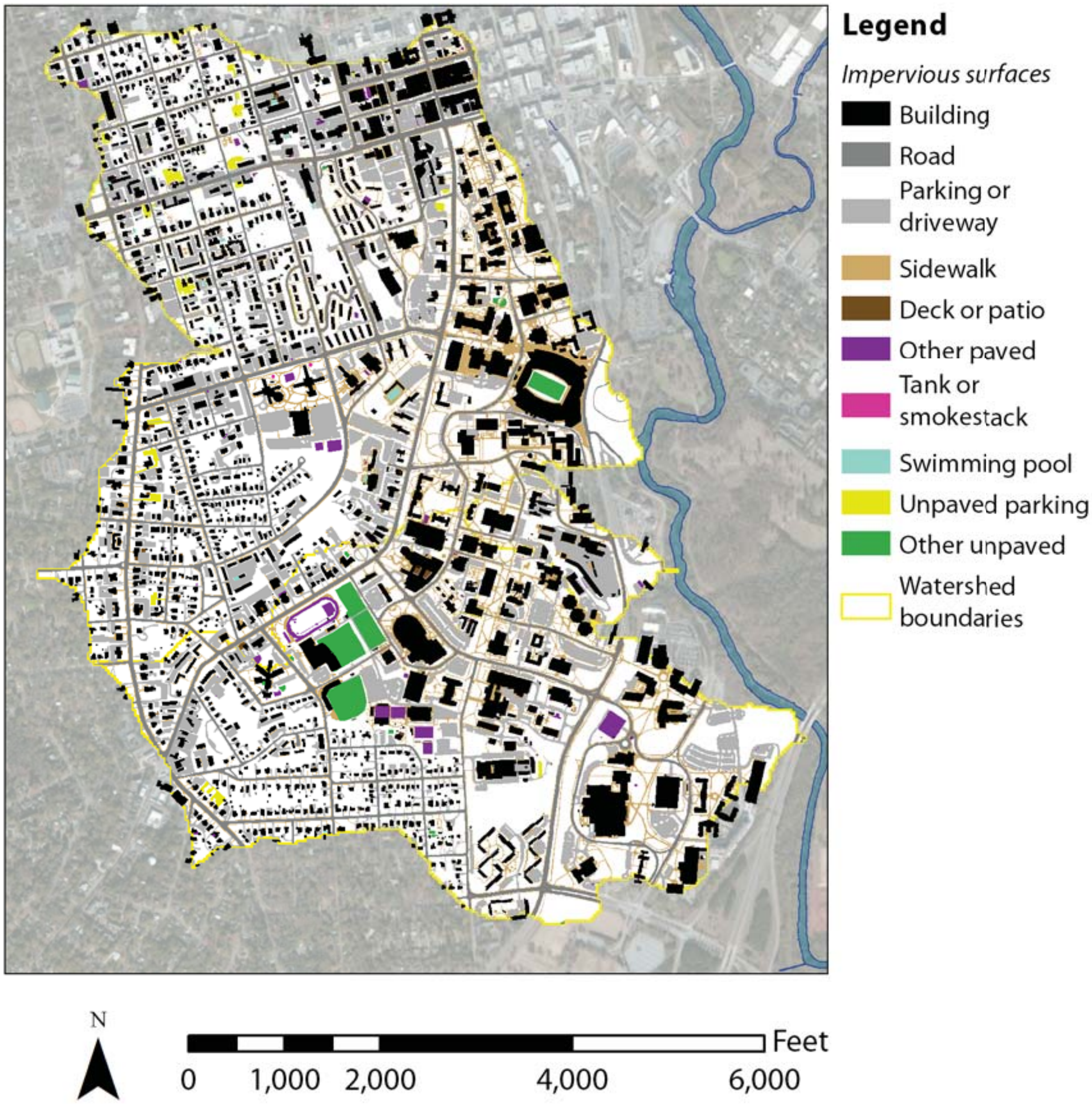

Figure 2-24. Impervious surfaces.

Impervious surface shapefiles were obtained from both Athens-Clarke County and UGA's Office of University Architects. The Athens-Clarke County data included all of the impervious surface categories shown in this map, while the UGA data were separated among buildings, parking areas, and sidewalks layers. The Athens-Clarke County data covered the entire target area, whereas the UGA data were limited to UGA property; however, the UGA data were more up to date. For this reason, the impervious surface layer used in suitability analyses was created from a combination of the two data sources. For buildings, parking areas, and sidewalks, UGA data were used for UGA property and Athens-Clarke County data were used for all other areas. For all other categories of impervious surfaces, Athens-Clarke County data were used throughout.

Roads were manually edited in the area of the new Special Collections Libraries Building, with the assistance of aerial imagery, to reflect the changes that accompanied construction. For more information about this process, please see the appendix.

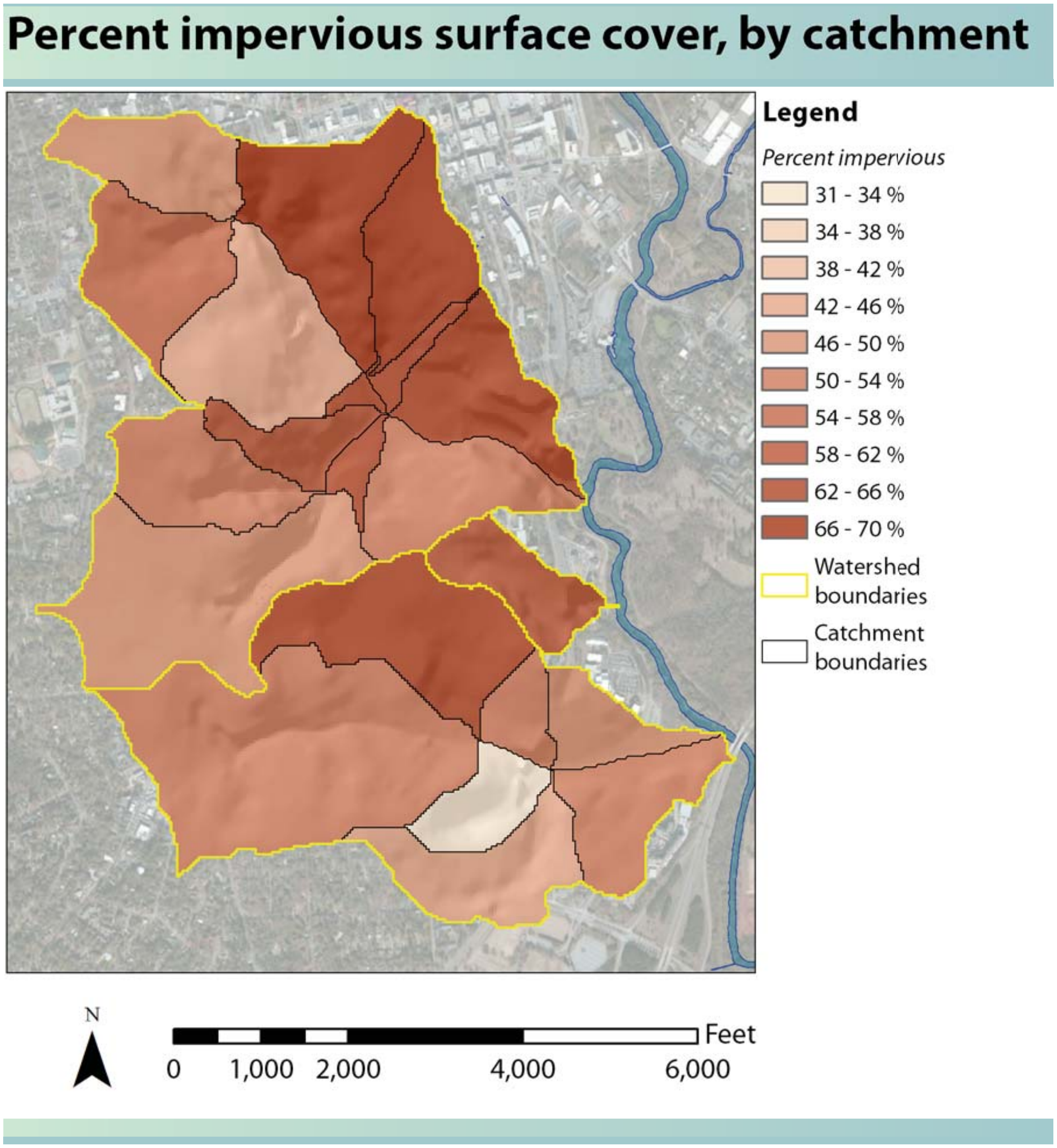

Figure 2-25. Percent impervious surface cover, by catchment.

Percent impervious surface cover was calculated in ArcMap for each catchment based on the impervious surface data shown on page 36. For information about this process, please see the appendix.

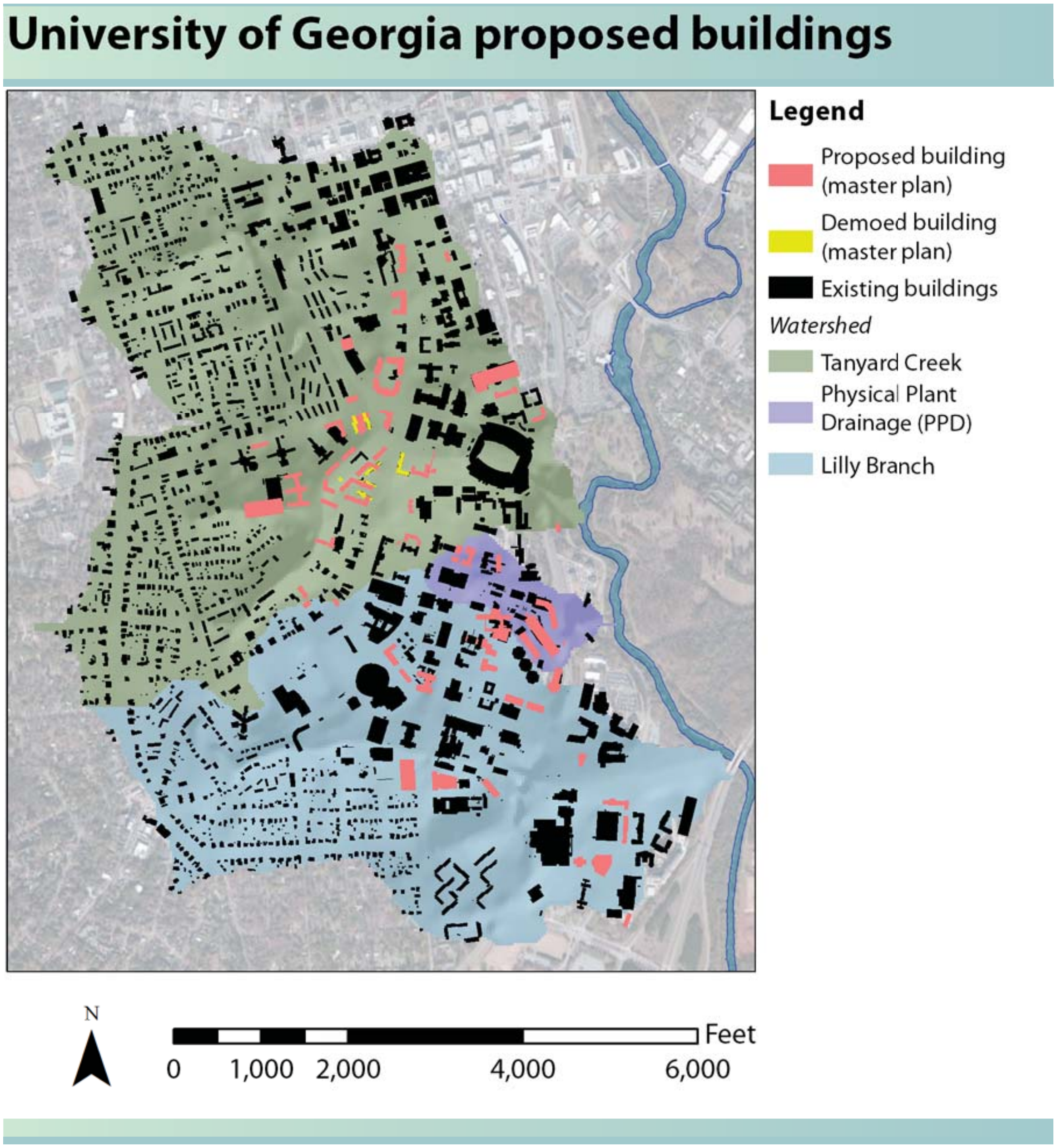

Figure 2-26. Buildings proposed in the University of Georgia master plan.

Buildings shown are the proposed parking decks, housing, and academic and support buildings. The proposed and proposed-to-be-demolished (demoed) building information was obtained as a shapefile from the UGA Office of University Architects. Some proposed buildings in this shapefile have been updated relative to what is shown in the 2008 Physical Master Plan (UGA University Architects for Facilities Planning 2008).

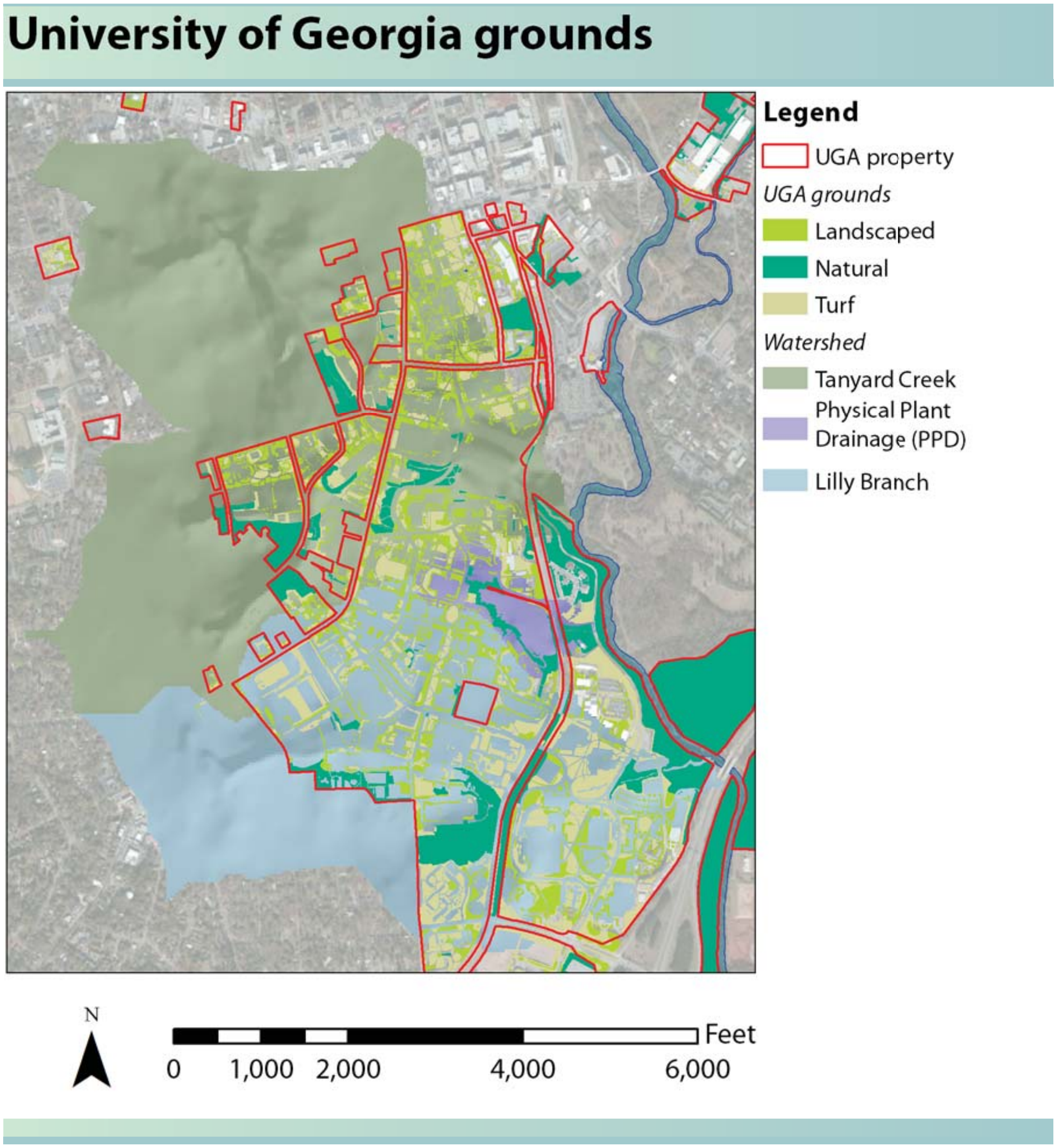

Figure 2-27. Land cover of UGA's grounds.

The grounds shapefile was obtained from UGA's Grounds Department.

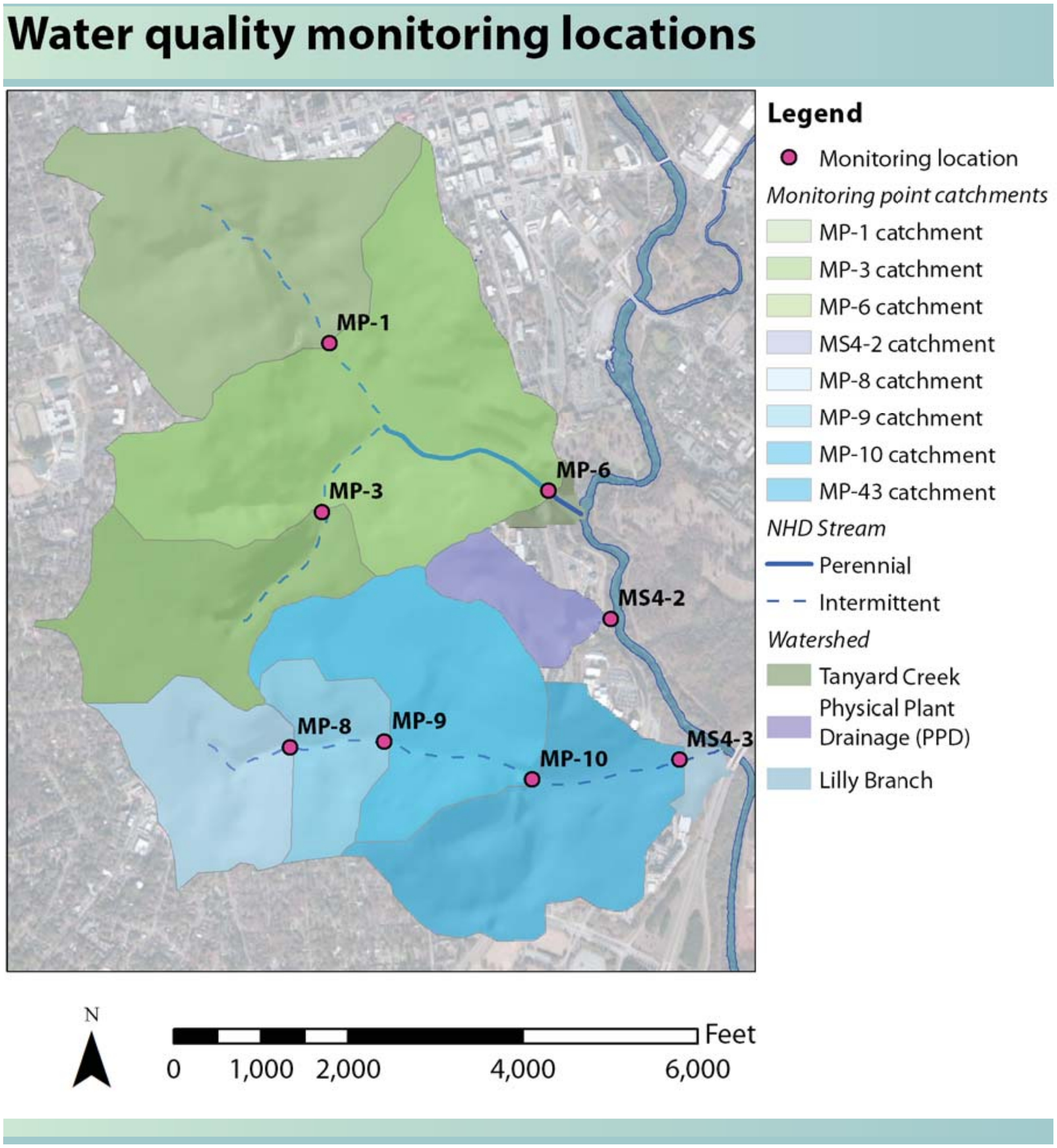

Figure 2-28. Brown and Caldwell water quality monitoring locations.

These sites indicate water quality monitoring points used for this analysis. All data collection was carried out by the consulting firm Brown & Caldwell for the University of Georgia (Brown and Caldwell 2011, 2012).

The specific water quality parameters included in this report are those that Brown & Caldwell indicated were high (or low, in the case of pH) at one or more sampling point within the target watersheds. Specifically, fecal coliform bacteria, total nitrogen (TN), total phosphorus (TP), lead, copper, total suspended solids (TSS), turbidity, conductivity, and pH are included. Hydrocarbons are also a concern within the study area, but were excluded here because, as they are believed to have resulted from leaking service station tanks, they are not stormwater related (Byers 2010).

For most of the contaminants and water quality indicators considered in this analysis, only three sites in the Tanyard Creek watershed (MP-1, MP-3, and MP-6), one site in the PPD watershed (MP4-2), and two sites in the Lilly Branch watershed (MP-8 and MS4-3) were sampled. Two additional sampling points in the Lilly Branch watershed (MP-9 and MP-10) were regularly sampled for fecal coliform bacteria, pH, conductivity, and turbidity. Five additional sites were sampled for fecal coliform bacteria in Lilly Branch; however, these five sites were excluded from this analysis for two reasons. First, they only underwent dry sampling, and only during a single sampling period (the first quarter of 2011). Second, they were located within piped areas away from the main streams, making it difficult to accurately determine the catchment draining to any of those five sampling points.

Data used were collected in 2010, 2011, and the first quarter of 2012 (the most recent data available). Inclusion of these three years ensured that each calculated average was the result of at least three samples (exception: under warm, wet conditions, site MS4-2 was only sampled twice during these three years). Data older than 2010 were excluded, as older data are less likely than more recent data to reflect current conditions in the watershed . For example, some leaks and contaminated sites may have been fixed or cleaned up, while new construction may have created new problems in some areas.

Besides the monitoring points shown above, additional locations have been sampled by Brown & Caldwell, as well as by Athens-Clarke County, the Upper Oconee Watershed network, and by students in the Environmental Law Practicum at UGA. Most of these additional data were excluded due to lack of sufficiently repeated sampling during the 2010-2012 time frame. The Athens-Clarke County sampling sites were excluded because the data did not distinguish between wet and dry sampling, making comparisons with other data difficult.

The monitoring point catchments shown were delineated using the ArcHydro Tools plugin for GIS, using the process outlined on page 19, with the exception that the water quality monitoring points (Figure 2-28) were used as pour points instead of the intersections of the primary drainage network (Figure 2-10). See the appendix for more information. Upstream catchments are nested within downstream catchments; for example, the catchment for site MS4-3 includes the catchments for MP-8, MP-9, and MP-10.

Water quality data are presented on pages 43 through 63 and summarized beginning on page 64.

Fecal coliform bacteria, wet sampling

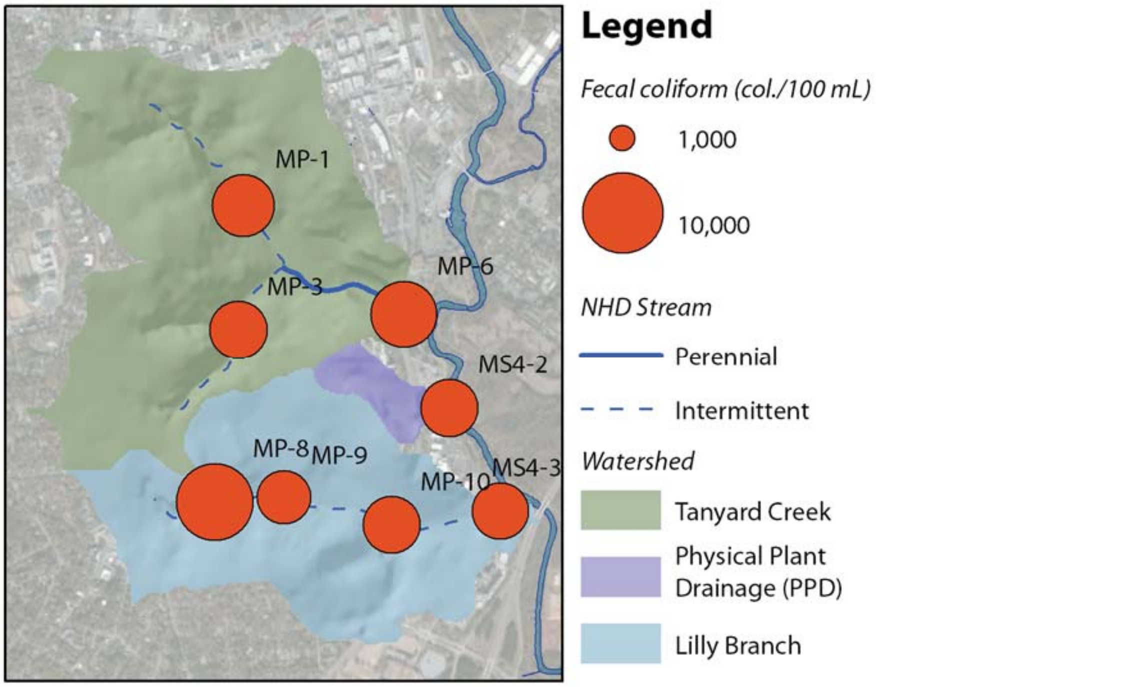

Figure 2-29. Geometric mean of fecal coliform bacteria (colonies per 100 mL) from warm season samples (May-October) collected during rain events, 2010-2012.

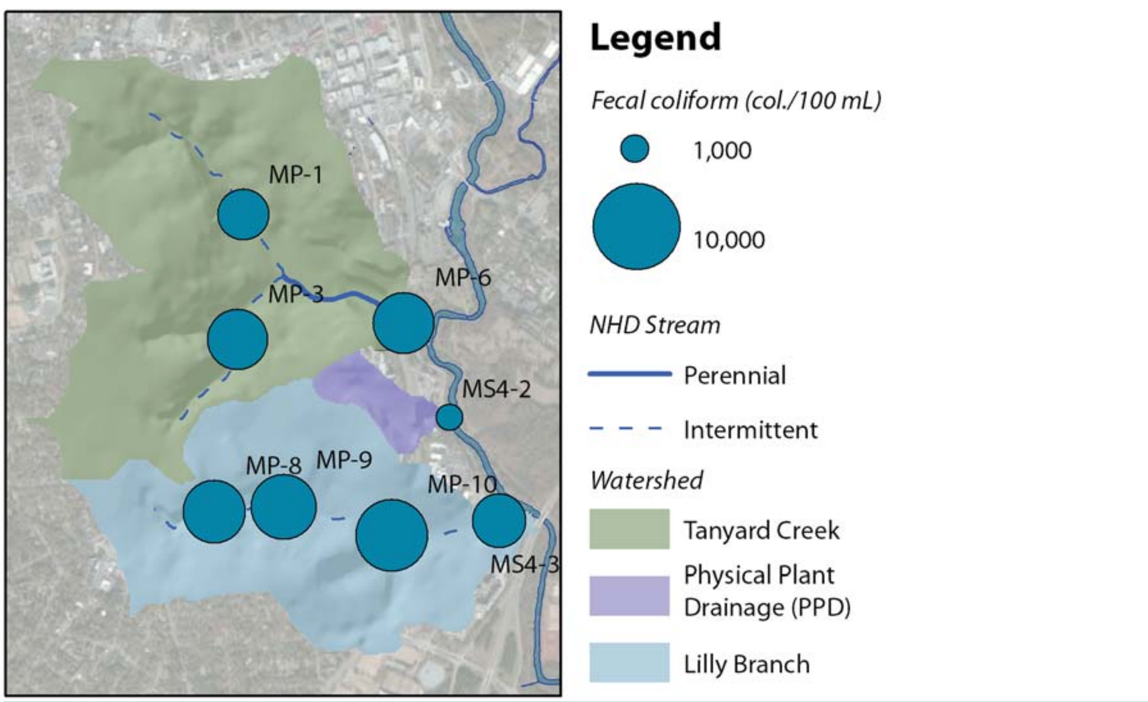

Figure 2-30. Geometric mean of fecal coliform bacteria (colonies per 100 mL) from cool season samples (November-April) collected during rain events, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Fecal coliform data are summarized on page 46.

Fecal coliform bacteria, dry sampling

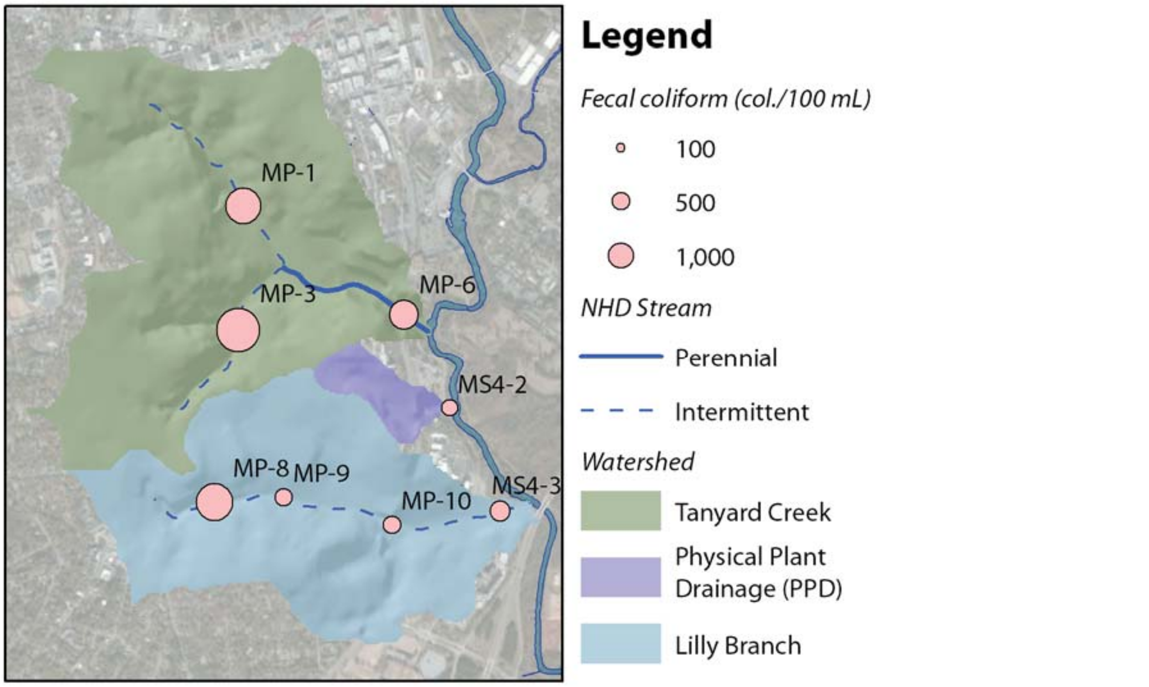

Figure 2-31. Geometric mean of fecal coliform bacteria (colonies per 100 mL) from warm weather samples (May-October) collected during dry weather, 2010-2012.

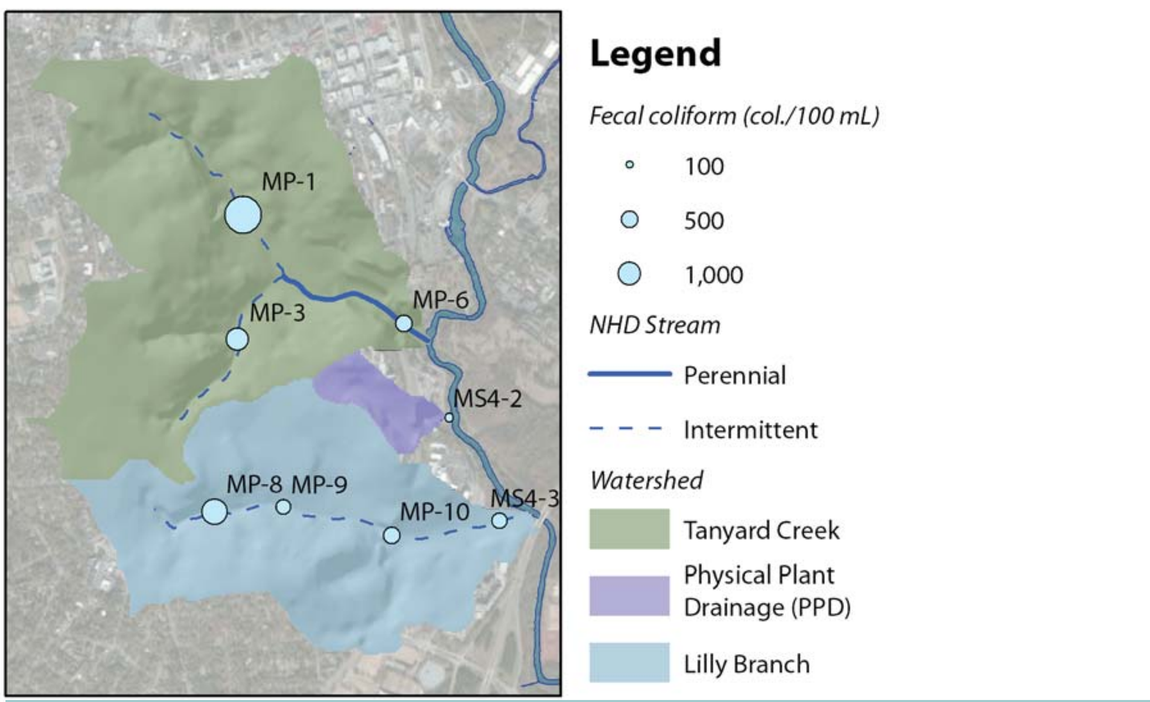

Figure 2-32. Geometric mean of fecal coliform bacteria (colonies per 100 mL) from cool weather samples (November-April) collected during dry weather, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Fecal coliform data are summarized on page 46.

Fecal coliform bacteria, summary

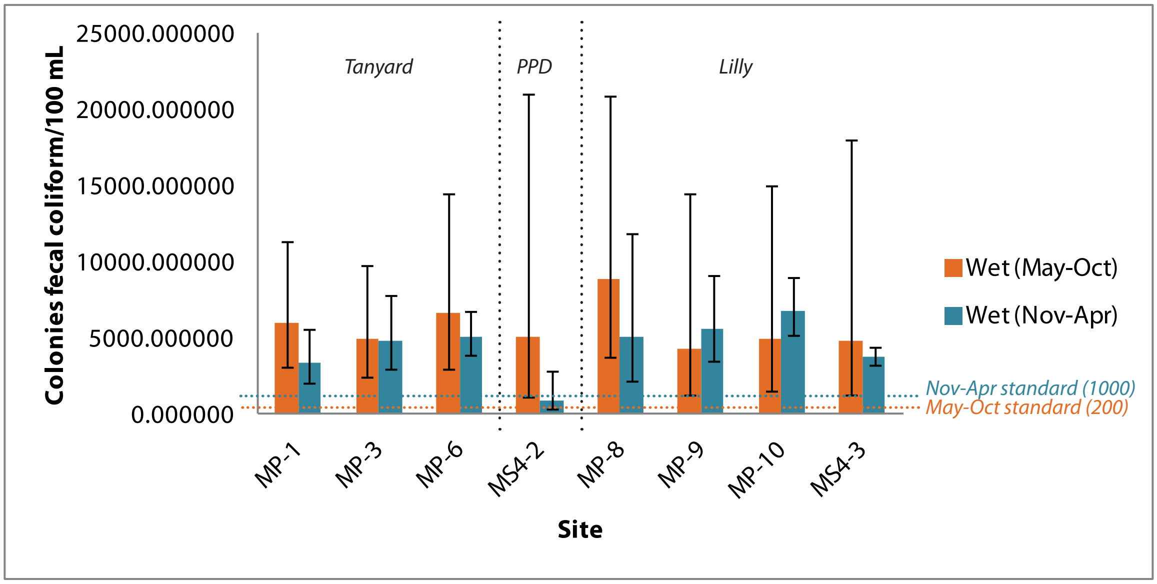

Figure 2-33. Geometric mean of fecal coliform bacteria samples taken during rain events, 2010-2012. Error bars represent standard error of the geometric mean. May-Oct: n=2 for site MS4-2 and n=3 for all other sites. Nov-Apr: n=4 for MP-8, MP-9, and MP-10 and n=5 for all other sites. Please see page 41 for site locations and other details about these data.

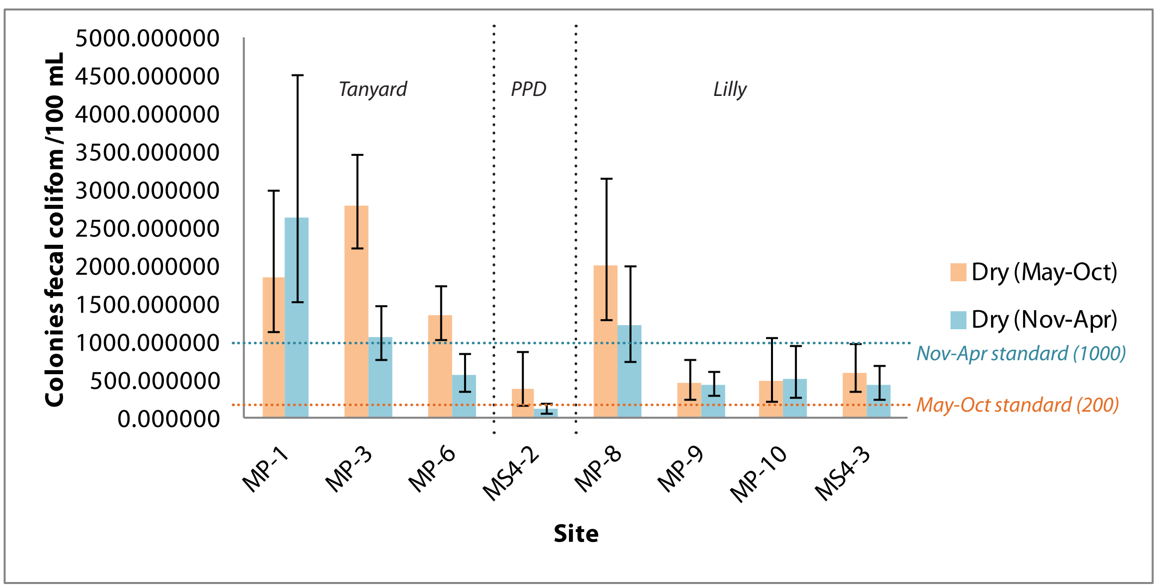

Figure 2-34. Geometric mean of fecal coliform bacteria samples taken during dry weather, 2010-2012. Error bars represent standard error of the geometric mean. May-Oct: n=3 for site MS4-2 and n=5 for all other sites. Nov-Apr: n=9 (sites MP-1, MP-3, MP-6), n=7 (site MSC4-3), n=5 (site MS4-2), and n= 6 for all other sites. Please see page 41 for site locations and other details about these data.

Standards are set by Georgia DNR (GA DNR 2011). All water quality data are from Brown and Caldwell (2011, 2012). Data are summarized on the following page.

Recent fecal coliform sampling (2010-2012) revealed elevated fecal coliform levels during base flow (dry sampling) in the headwaters of both the Lilly Branch and Tanyard Creek watersheds (sampling points MP-8, MP-1, and MP-3) when compared to downstream locations and the PPD watershed. Under dry conditions, these three sites exceeded water quality standards in both warm and cool sampling periods, while all other sites exceeded the warm weather standard only (Figure 2-34).

Values from wet weather sampling were much more variable at each individual site, revealing fewer apparent differences among sites. Under wet conditions, all locations except site MS4-2 (PPD watershed) failed to meet water quality standards during both warm and cool sampling periods; site MS4-2 only failed to meet water quality standards during warm weather sampling (Figure 2-33).

Please see page 84 for information about using SCMs for fecal coliform reduction.

Total nitrogen

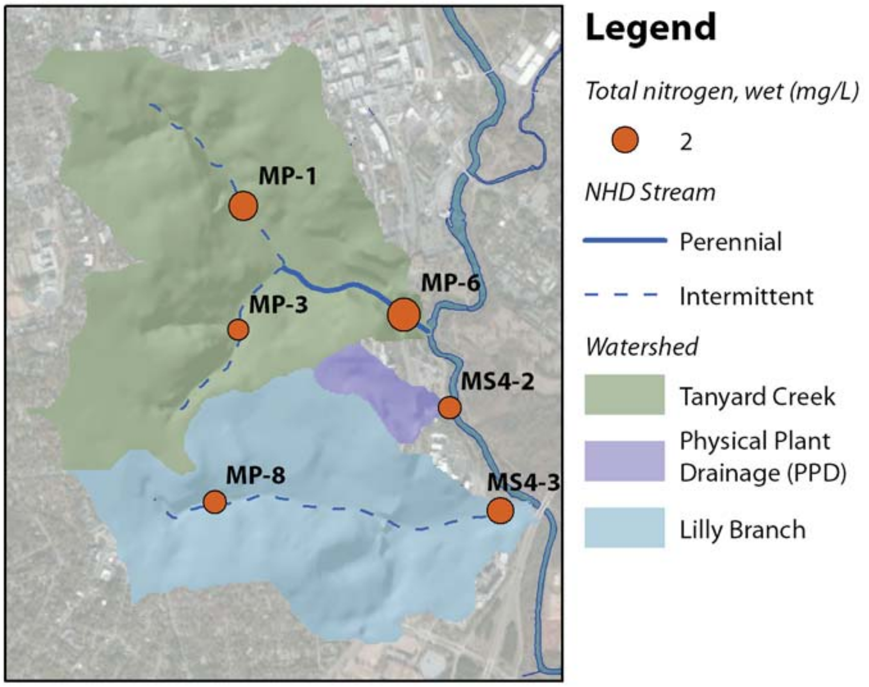

Figure 2-35. Mean of total nitrogen (mg/L), sampled during rain events, 2010-2012.

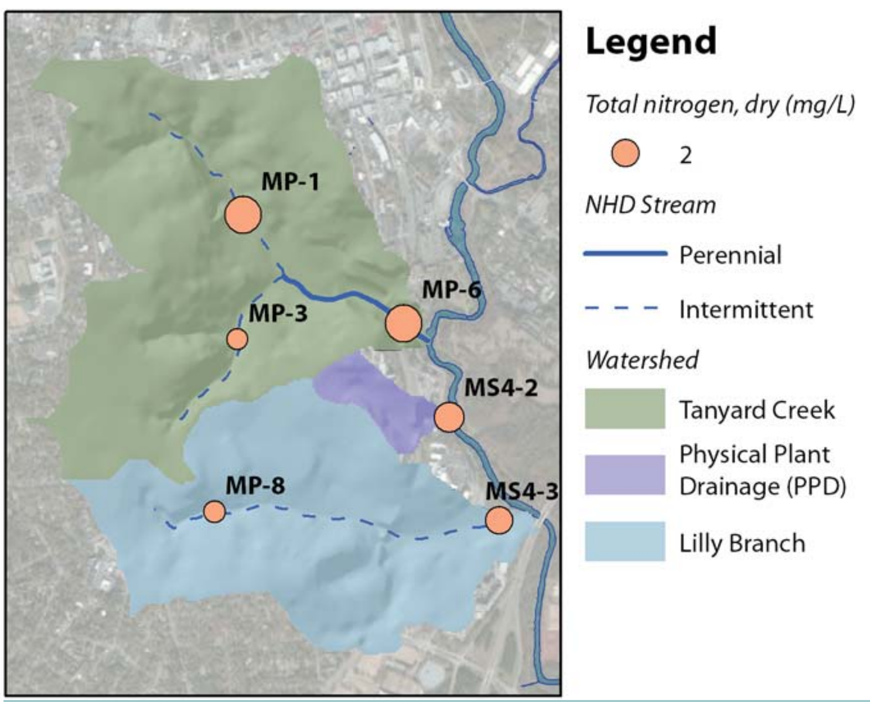

Figure 2-36. Mean of total nitrogen (mg/L), sampled during dry weather, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Total nitrogen data are summarized on the following page.

Total nitrogen, summary

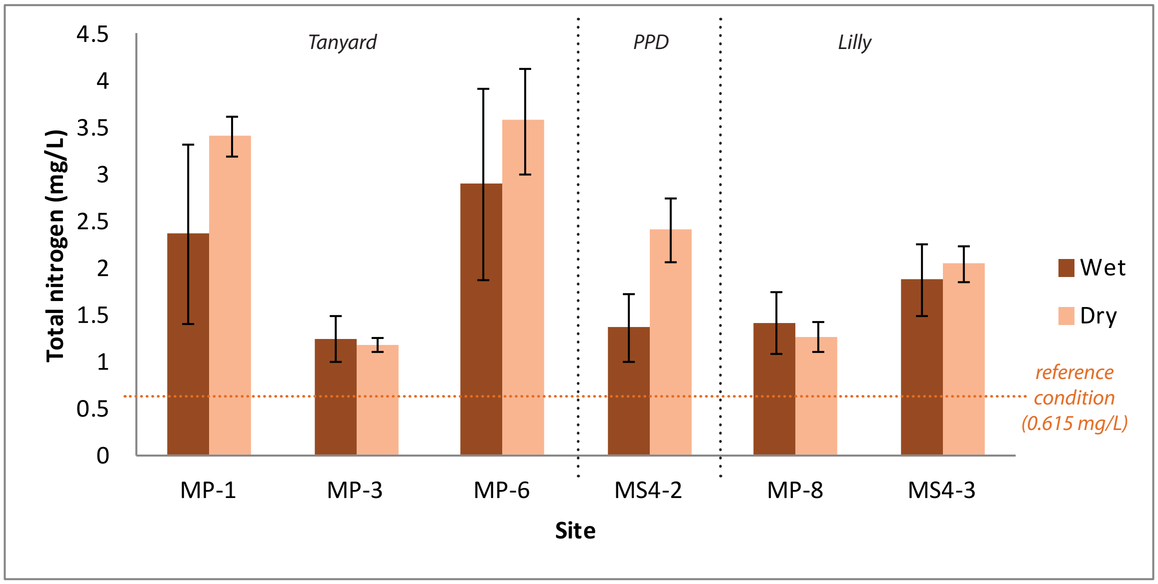

Figure 2-37. Mean of total nitrogen in water quality monitoring samples, 2010-2012.
Error bars represent standard error. Wet: n=6 for site MP-8 and n=7 for all other sites. Dry: n=7 for MP-8 and n=8 for all other sites. Please see page 41 for site locations and other details about these data.

No total nitrogen (TN) standards exist for Georgia streams (GA DNR 2011); however, the US EPA has issued reference concentrations for each ecoregion. Reference conditions represent the 25th percentile of all nutrient data given for streams within a given ecoregion. Streams below the reference condition are considered pristine or minimally impacted. Reference conditions are not equivalent to standards, as standards are based on the boundary between safe and unsafe or impaired and nonimpaired conditions, whereas reference conditions indicate the highest or most natural condition attainable at this time (US EPA 2000). The reference condition for streams in the target watersheds (Level II Ecoregion IX, level III Ecoregion 45) is shown in Figure 2-37.

During recent sampling (2010-2012), all monitoring sites within these three watersheds exceeded reference conditions for TN. It appears that TN was somewhat higher downstream in Lilly Branch (site MS4-3) than upstream (site MP-8). Recorded values were higher in Tanyard Creek (sites MP-1 and MP-6) than in Cloverhurst Branch (site MP-3). The two Tanyard Creek sites also appeared to be more highly variable, especially during wet sampling, than the other monitoring points (Figure 2-37). Brown and Caldwell noted that during the 2010-2011 sampling period, TN measurements at most sites were consistent with historical values, with the exception of site MS4-3, where some improvement over historical values was observed (Brown and Caldwell 2011).

Please see page 85 for information about using SCMs for nutrient reduction.

Total phosphorus

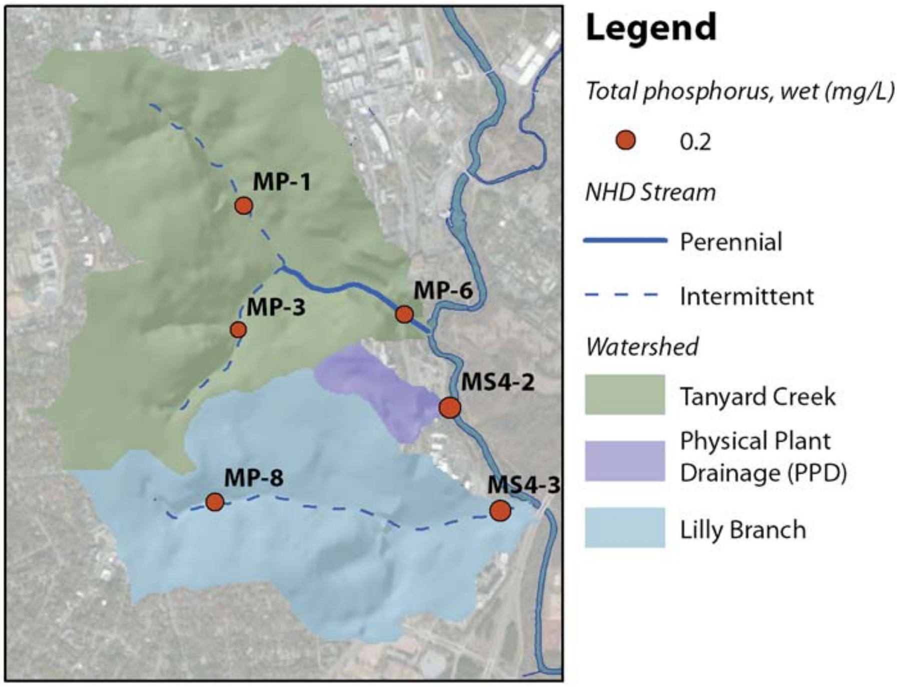

Figure 2-38. Mean of total phosphorus (mg/L), sampled during rain events, 2010-2012.

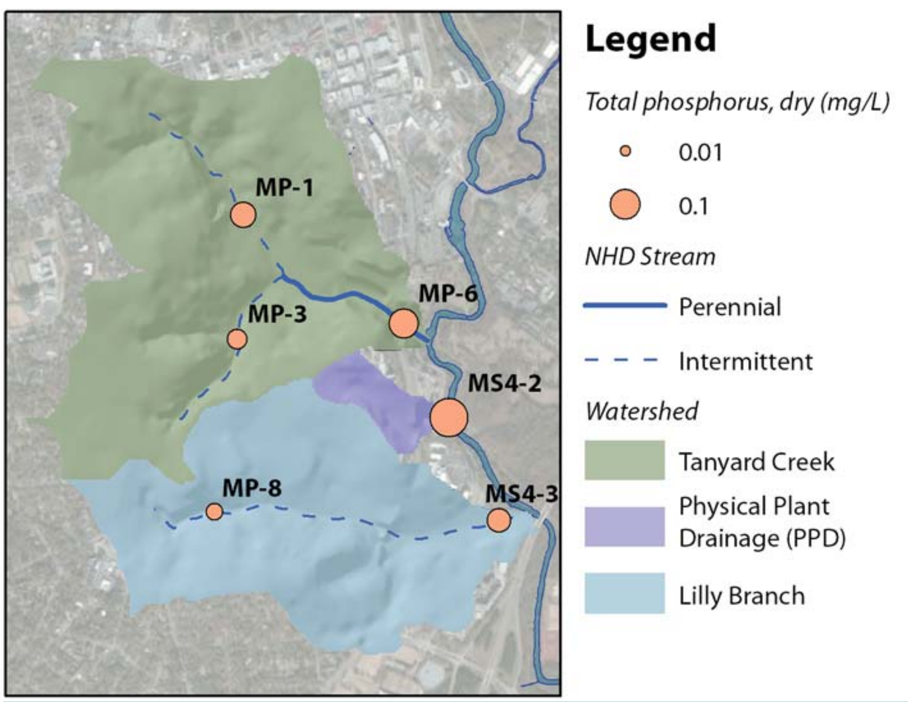

Figure 2-39. Mean of total phosphorus (mg/L), sampled during dry weather, 2010-2012.

All water quality data are from Brown and Caldwell (2011 and 2012). Total phosphorus data are summarized on the following page.

Total phosphorus, summary

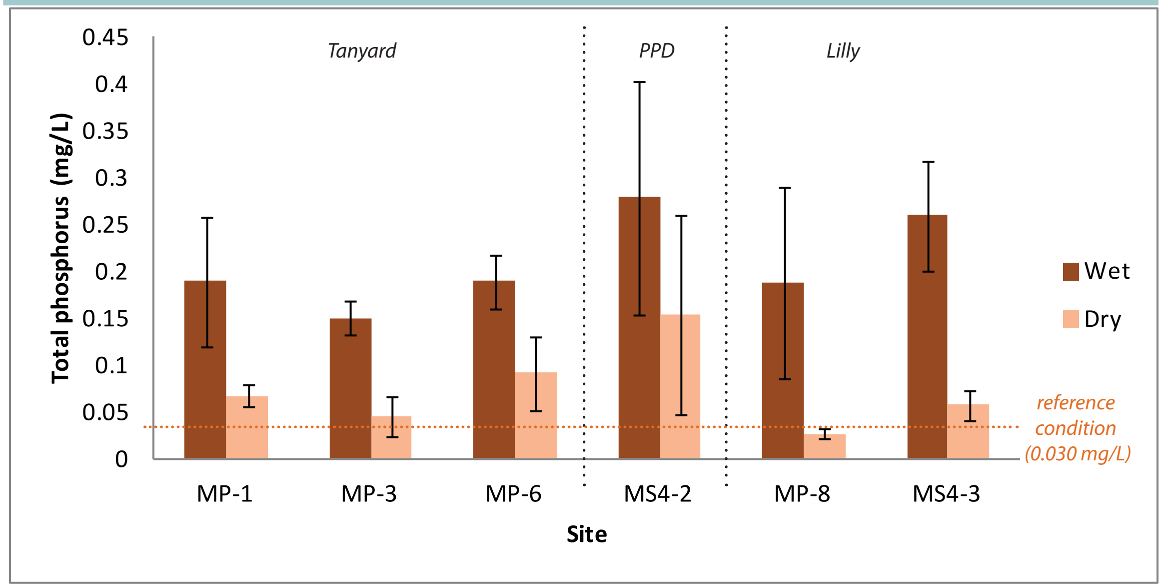

Figure 2-40. Mean of total phosphorus in water quality monitoring samples, 2010-2012. Error bars represent standard error. Wet: n=6 for site MP-8 and n=7 for all other sites. Dry: n=7 for MP-8 and n=8 for all other sites. Please see page 41 for site locations and other details about these data.

No total phosphorus (TP) standards exist for Georgia streams (GA DNR 2011); however, the US EPA has issued reference concentrations for each ecoregion (US EPA 2000; see discussion of reference concentrations, page 48). The reference condition for streams in the target watersheds (Level II Ecoregion IX, level III Ecoregion 45) is shown in Figure 2-40.

During recent sampling (2010-2012), all monitoring sites within these three watersheds exceeded reference conditions for TP, with the exception of the headwaters of Lilly Branch (site MP-8) during base flow (dry) conditions. TP was higher at all sites during wet sampling than during dry sampling (Figure 2-40). Brown and Caldwell has noted improvements in TP throughout these three watersheds when compared with historical values, based on 2010-2011 data (Brown and Caldwell 2011).

Please see page 85 for information about using SCMs for nutrient reduction.

Lead

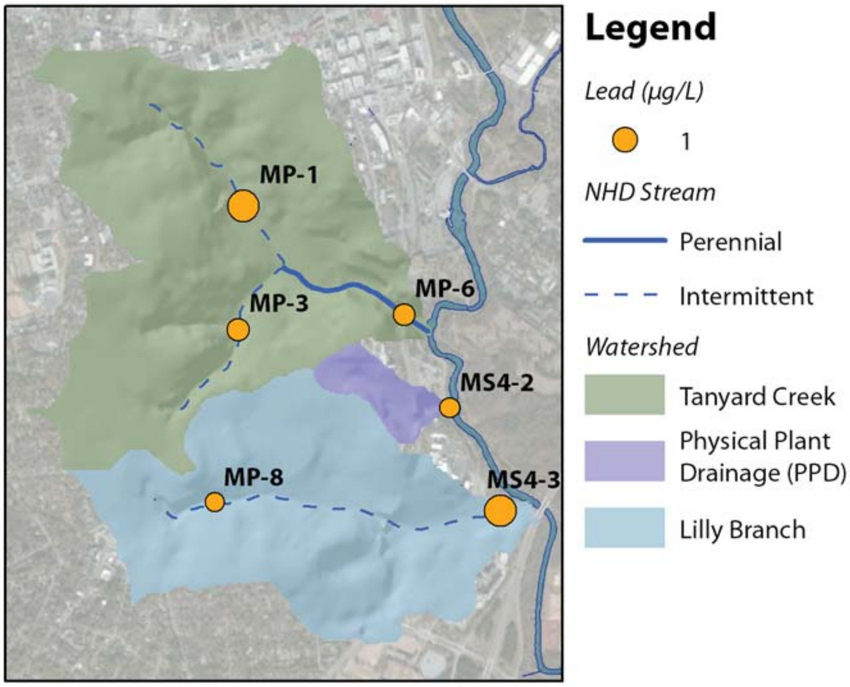

Figure 2-41. Mean concentration of lead (µg/L) in wet weather water samples, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Lead data are summarized on the following page.

Lead, summary

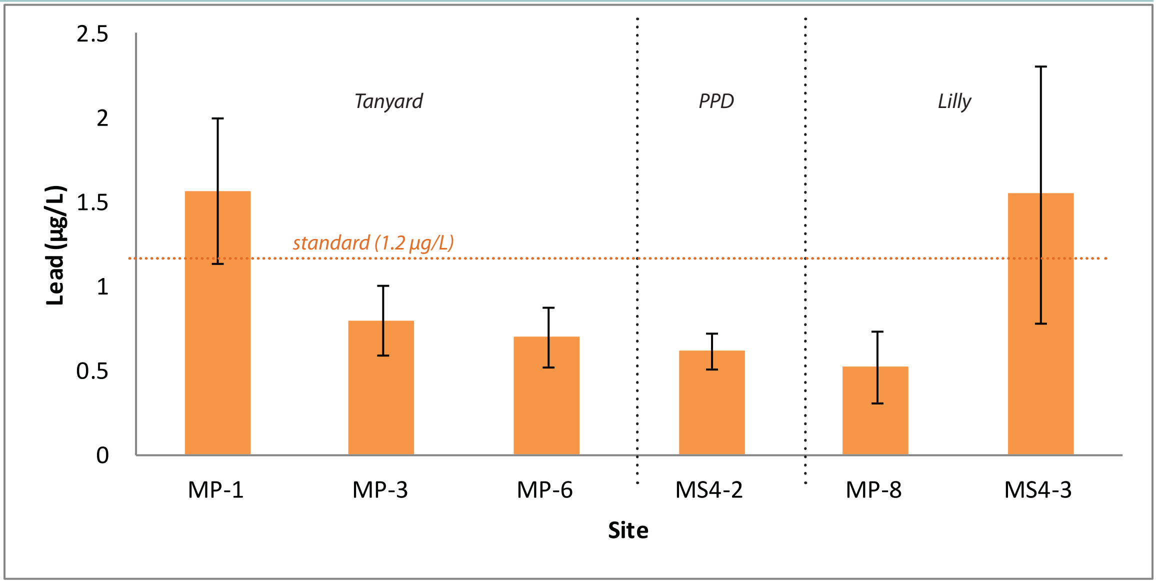

Figure 2-42. Mean concentration of lead in water sampled during wet weather, 2010-2012. Error bars represent standard error. N=4 for all sites. Please see page 41 for additional information about these data.

During recent wet weather sampling (2010-2012), lead concentrations were highest in the headwaters of the Tanyard Creek main stem (site MP-1) and at the downstream end of Lilly Branch (site MS4-3). Average measurements for all other sites were within the water quality standard for lead (GA DNR 2011) for this sampling period (Figure 2-42); however, exceedances were noted for some individual samples at all sites (Brown and Caldwell 2011).

Please see page 89 for information about using SCMs for lead removal.

Copper

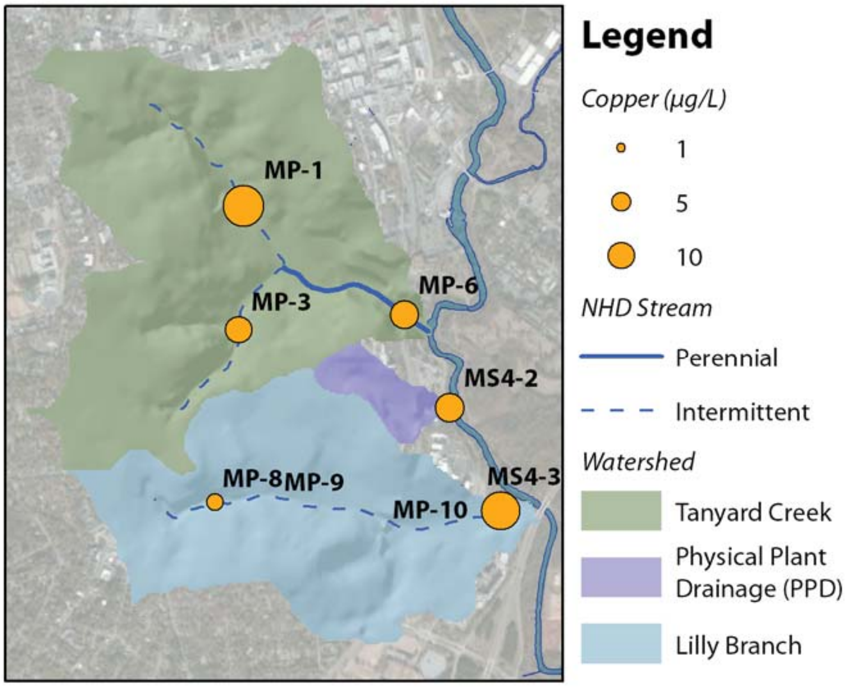

Figure 2-43. Mean concentration of copper (µg/L) in wet weather water samples, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Copper data are summarized on the following page.

Copper, summary

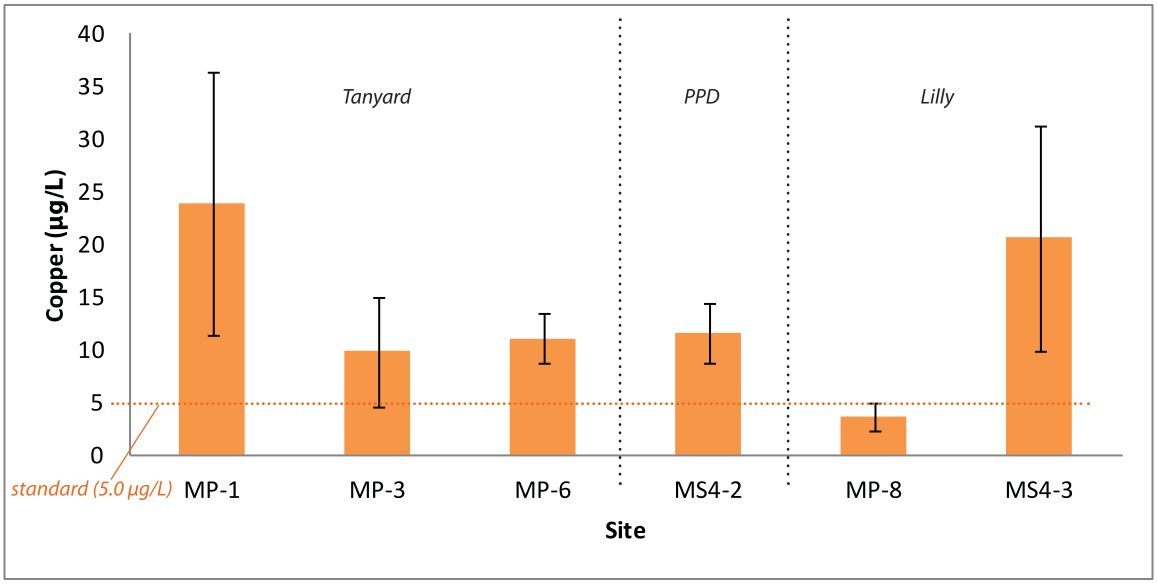

Figure 2-44. Mean concentration of copper in water sampled during wet weather, 2010-2012. Error bars represent standard error. N=4 for all sites. Please see page 41 for additional information about these data.

During recent wet weather sampling (2010-2012), copper concentrations were highest in the headwaters of the Tanyard Creek main stem (site MP-1) and at the downstream end of Lilly Branch (site MS4-3). Average measurements for all sites except site MP-8 (Lilly Branch headwaters) exceeded the water quality standard for copper (GA DNR 2011) for this sampling period (Figure 2-44); however, exceedances were noted for some individual samples taken at all sites (Brown and Caldwell 2011).

Please see page 89 for information about using SCMs for copper removal.

Total suspended solids

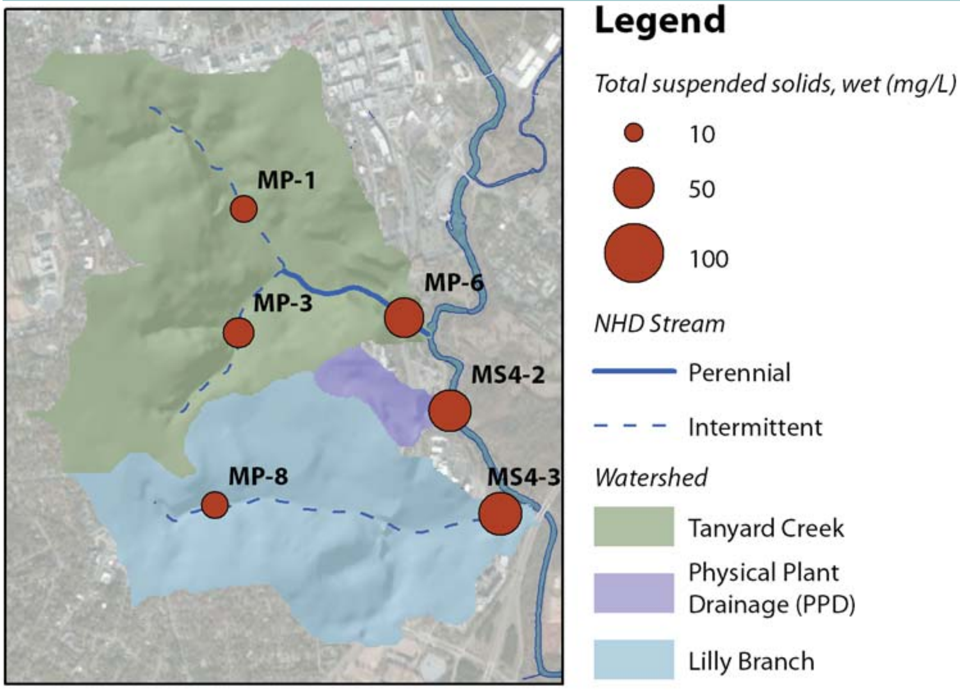

Figure 2-45. Mean concentration of total suspended solids (mg/L) in wet weather water samples, 2010-2012.

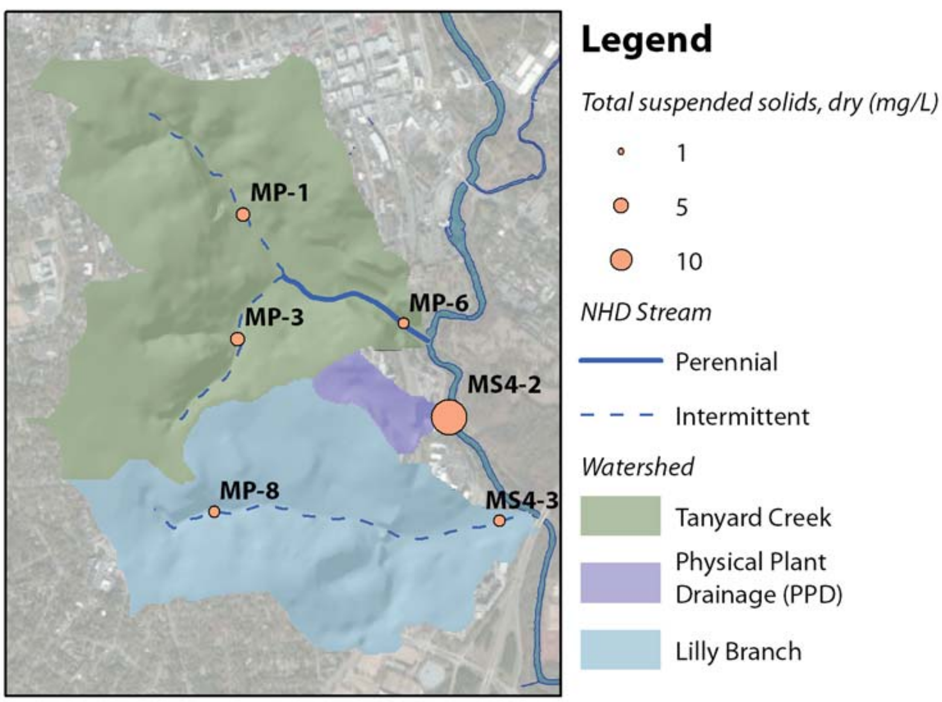

Figure 2-46. Mean concentration of total suspended solids (mg/L) in dry weather water samples, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Total suspended solids data are summarized on the following page.

Total suspended solids, summary

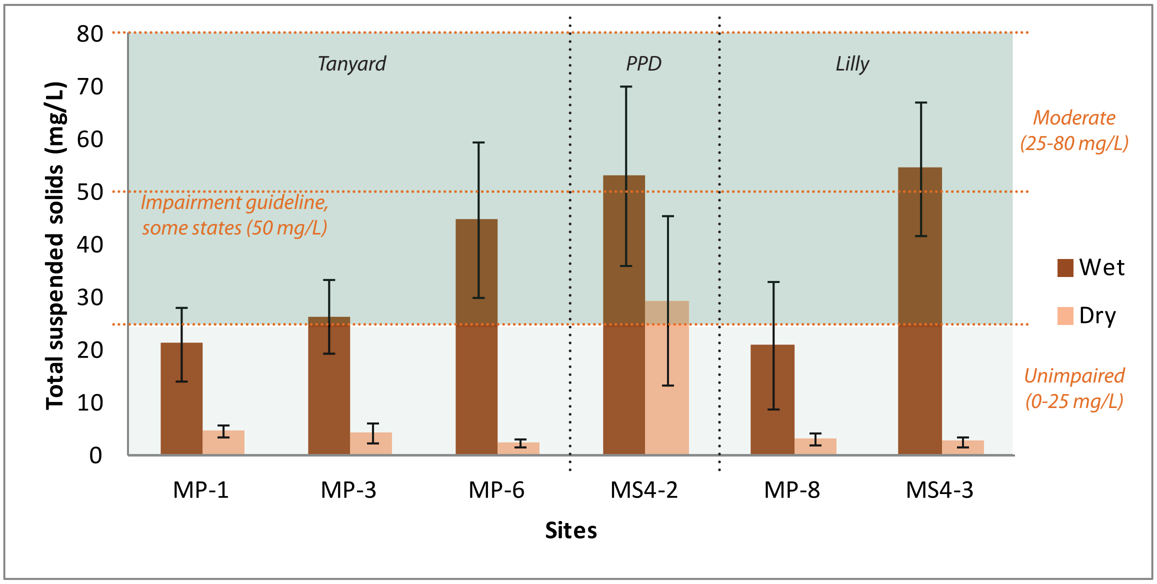

Figure 2-47. Mean concentration of total suspended solids in water samples, 2010-2012. Error bars represent standard error. Wet: n=6 for site MP-8 and n=7 for all other sites. Dry: n=7 for site MP-8 and n=8 fo all other sites. Please see page 41 for additional information about these data.

Total suspended solids (TSS) is a measure of the amount of sediment that is suspended in the water column (Geosyntec Consultants and Wright Water Engineers 2011). Georgia has no water quality standard for TSS (GA DNR 2011). Some guidelines have been suggested for unimpaired (0-25 mg/L) and moderate (25-80 mg/L) streams based on average TSS. Some other states use 50 mg/L as an indicator of potential impairment (GA EPD 2001).

Recent sampling (2010-2012) revealed higher TSS levels were higher during wet weather events than during base flow (dry weather). This is to be expected: during rain events, sediment is likely to increase due to erosion and likely to become suspended in the water column due to high water velocities and volumes, while slower water during dry events allows sediments time to settle out. TSS averages were low during dry weather at all sampling points except MS4-2 (PPD watershed), where it was considerably higher. During wet weather, TSS appeared to increase going downstream in both the Lilly Branch and Tanyard Creek watersheds. TSS in the PPD watershed was comparable to the highest TSS, furthest downstream monitoring locations in Lilly Branch and Tanyard Creek (Figure 2-47).

Please see page 91 for information about using SCMs for sediment control.

Turbidity

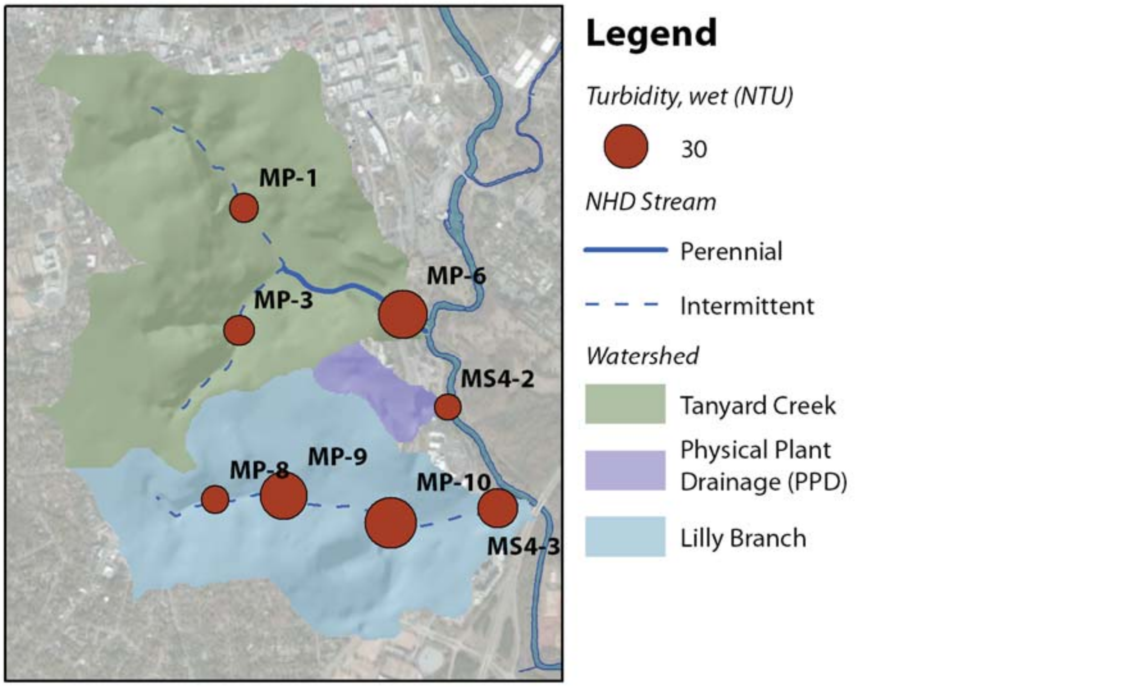

Figure 2-48. Mean turbidity (NTU) in wet weather water samples, 2010-2012.

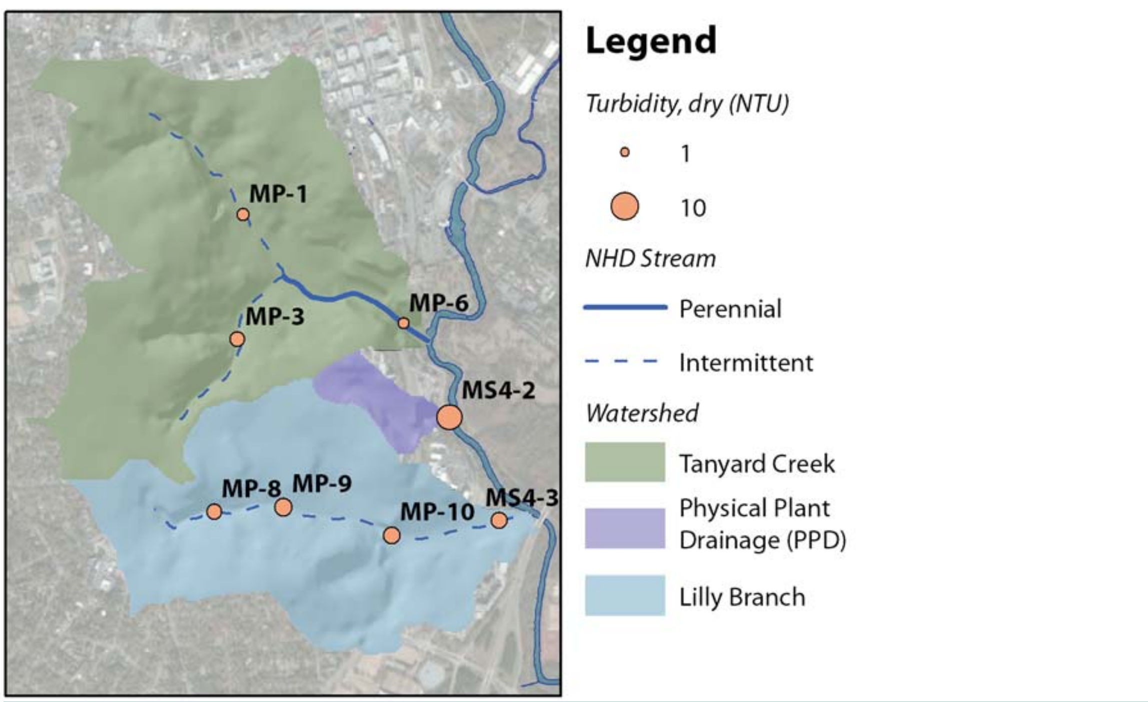

Figure 2-49. Mean turbidity (NTU) in dry weather water samples, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Turbidity data are summarized on the following page.

Turbidity, summary

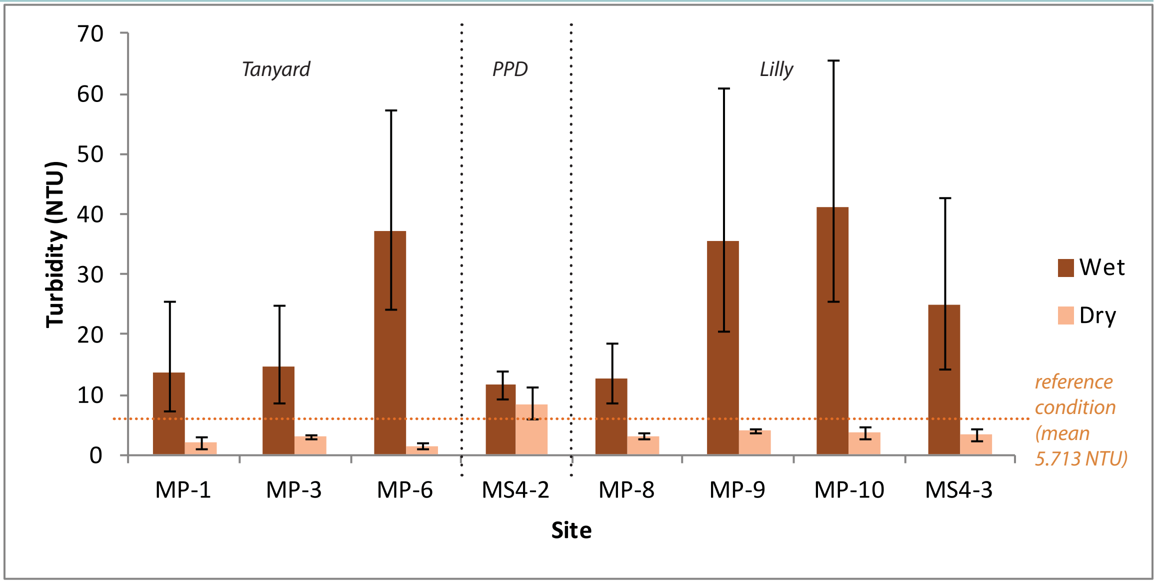

Figure 2-50. Geometric mean of turbidity in water samples, 2010-2012.
Error bars represent standard error of the geometric mean. Wet: n=9 (site MS4-2), n=8 (sites MP-1, MP-3), n= 6 (site MP-6) and n=7 for all other sites. Dry: n=19 (sites MP-1, MP-6), n=17 (site MP-9), n=9 (site MS4-3), and n=16 for all other sites. Please see page 41 for information about these data.

Turbidity is a measure of light scattering ability, which is increased by both suspended sediments and organic matter (Geosyntec Consultants and Wright Water Engineers 2011). No turbidity standards exist for Georgia streams (GA DNR 2011); however, the US EPA has issued reference concentrations for each ecoregion (US EPA 2000; see discussion of reference concentrations, page 48). The reference condition for streams in the target watersheds (Level II Ecoregion IX, level III Ecoregion 45) is shown in Figure 2-50. Please note that the reference condition represents an arithmetic mean, while values shown in the figure were calculated as geometric mean, due to the high amount of variability in the monitoring data under wet conditions. The geometric mean is always lower than the arithmetic mean for the same data set.

During recent sampling (2010-2012), only site MS4-2 (PPD watershed) clearly exceeded the reference condition for turbidity under dry conditions (Figure 2-50). Elevated turbidity in the PPD watershed under dry conditions, relative to all other sites, correlates with elevated TSS at the same site (page 56). All sites exceeded the reference condition under wet conditions, with turbidity highest at downstream Tanyard Creek (site MP-6), midstream Lilly Branch (sites MP-9 and MP-10), and, to a lesser extent, downstream Lilly Branch (site MS4-3) (Figure 2-50). This pattern is similar to the observed pattern of increasing TSS downstream after rain events, although the downstream trend is less pronounced for turbidity than for TSS (page 56).

Please see page 91 for information about using SCMs for sediment control.

Conductivity

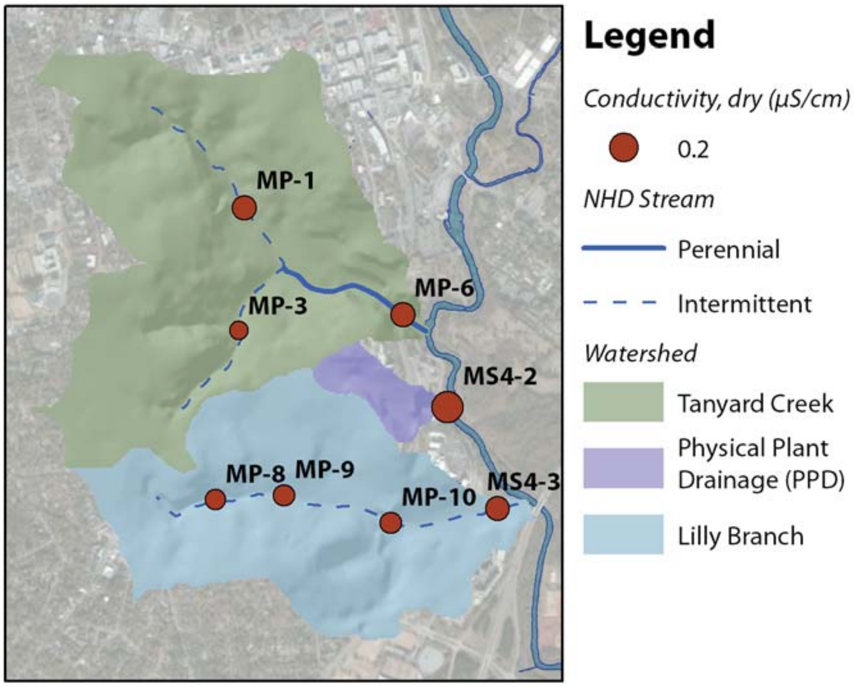

Figure 2-51. Mean conductivity (µS/cm) of wet weather water samples, 2010-2012.

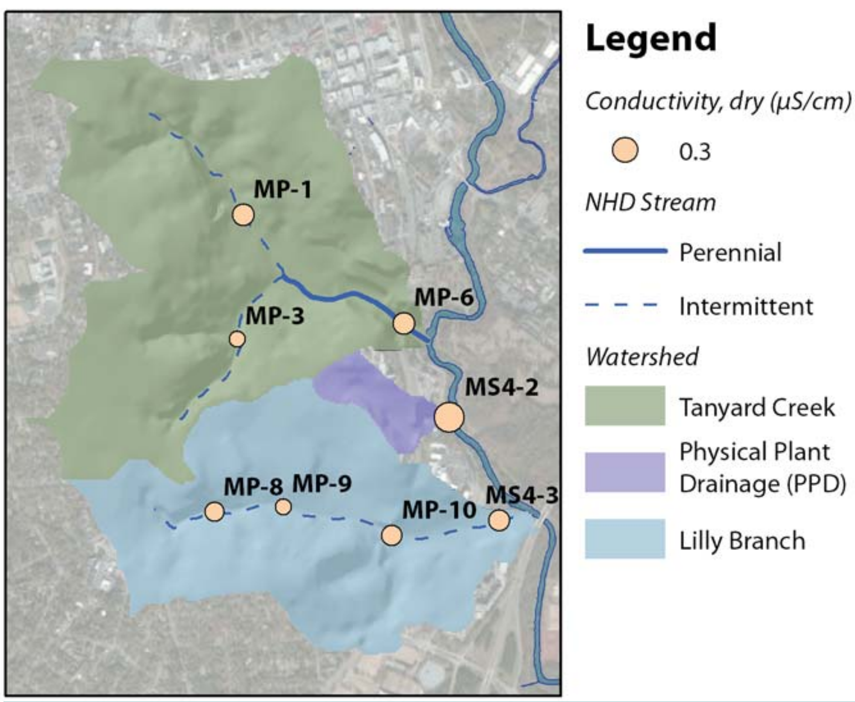

Figure 2-52. Mean conductivity (µS/cm) of dry weather water samples, 2010-2012.

All water quality data are from Brown and Caldwell (2011, 2012). Conductivity data are summarized on the following page.

Conductivity, summary

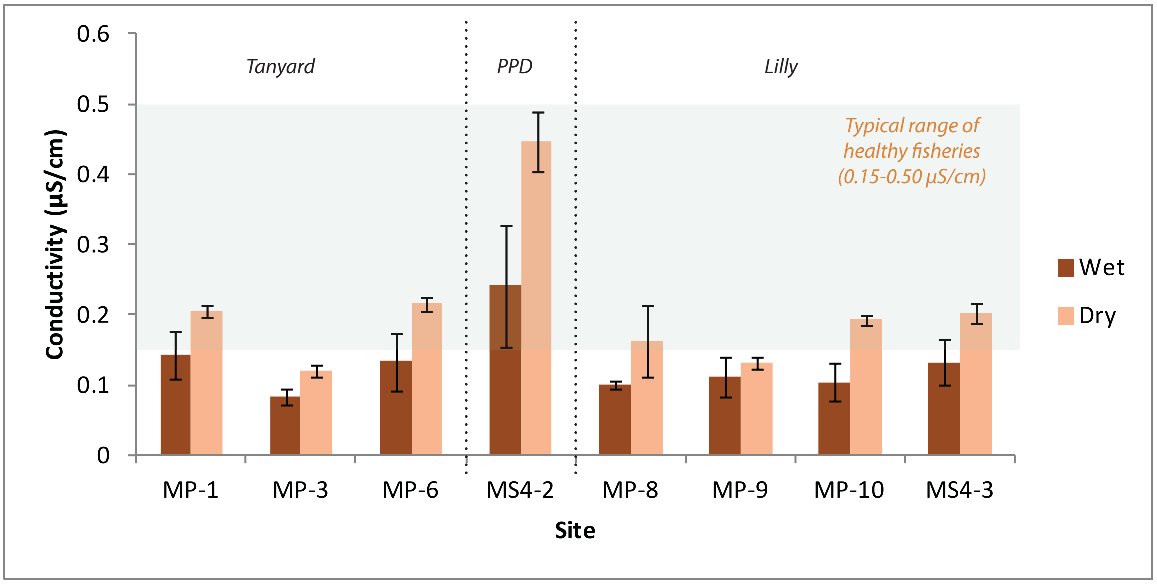

Figure 2-53. Mean conductivity (µS/cm) in water samples, 2010-2012. Error bars represent standard error. Wet: n=8 (site MS4-2), n=7 (sites MP-1, MP-3), and n=6 for all other sites. Dry: n=19 (sites MP-1, MP-6), n=16 (site MS4-3), n=15 (site MP-3), n=9 (site MS4-2), and n=17 for all other sites. Please see page 41 for site locations and other details about these data.

Conductivity measures water's ability to carry an electrical current (US EPA 2012). There is no state conductivity standard in Georgia with which to compare these conductivity measurements (GA DNR 2011). Conductivity in streams supporting healthy fisheries tend to fall within a range of 0.15 to 0.50 µS/cm, but this is a national average and may not reflect local conditions (US EPA 2012). The average conductivity (2010-2012) of all sampling points within the target watersheds was below 0.50 µS/cm, with many points falling below 0.15 µS/cm (Figure 2-53). Values below the range given for typical healthy fisheries do not necessarily indicate poor stream health, as they may be indicative of granite or other components of local geology. Conductivity is not a unidirectional indicator of water quality, in that certain pollutants raise conductivity while others decrease it, making a simple interpretation of conductivity data difficult (page 91).

What is apparent from these data (Figure 2-53) is that conductivity was considerably higher in the PPD watershed during this period (2010-2012) than in the other two watersheds, during both wet and dry sampling, which may indicate a conductivity-related problem in the PPD. Conductivity was higher in the main stem of Tanyard Branch (sites MP-1 and MP-6) than in its tributary, Cloverhurst Branch (site MP-3). For 2010-2011, conductivity in sites MP-1 and MP-6 were higher during base flow (i.e. dry sampling) than has been typical for these sites historically (Brown and Caldwell 2011), which suggests a recent change in the water chemistry of inputs upstream of site MP-

1. In addition, conductivity during the 2010-2012 period appears to have been slightly higher at the downstream sampling points MP-10 and MS4-3 than further upstream at MP-9 during dry sampling.

Please see page 91 for information about using SCMs to improve conductivity.

pH

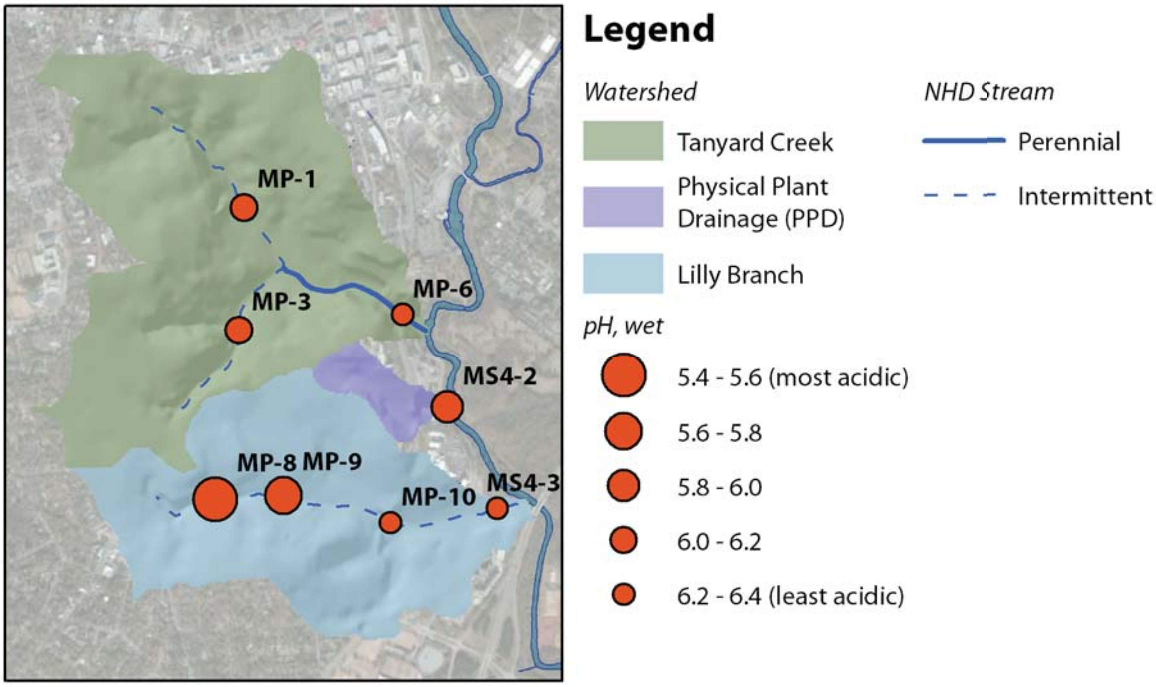

Figure 2-54. Mean** pH in wet weather water samples, 2010-2012.

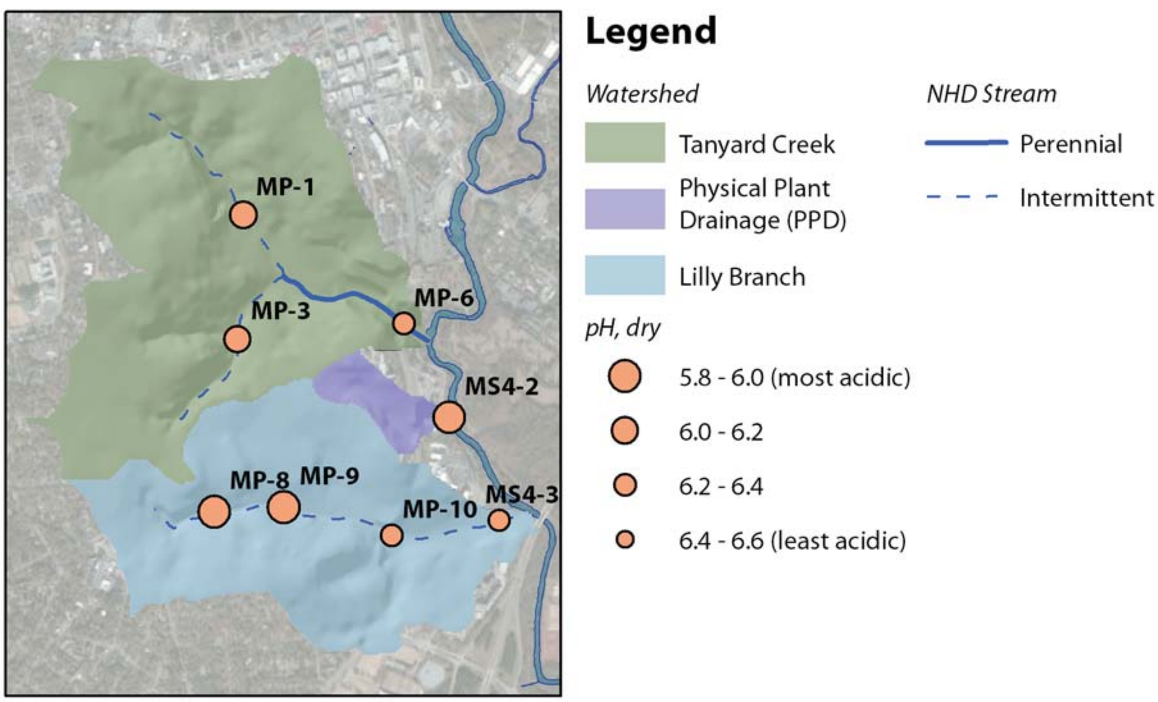

Figure 2-55. Mean** pH in dry weather water samples, 2010-2012.

Asterisks (**) in these figures are explained in the caption for Figure 2-56. All water quality data are from Brown and Caldwell (2011, 2012). PH data are summarized on the following page.

pH, summary

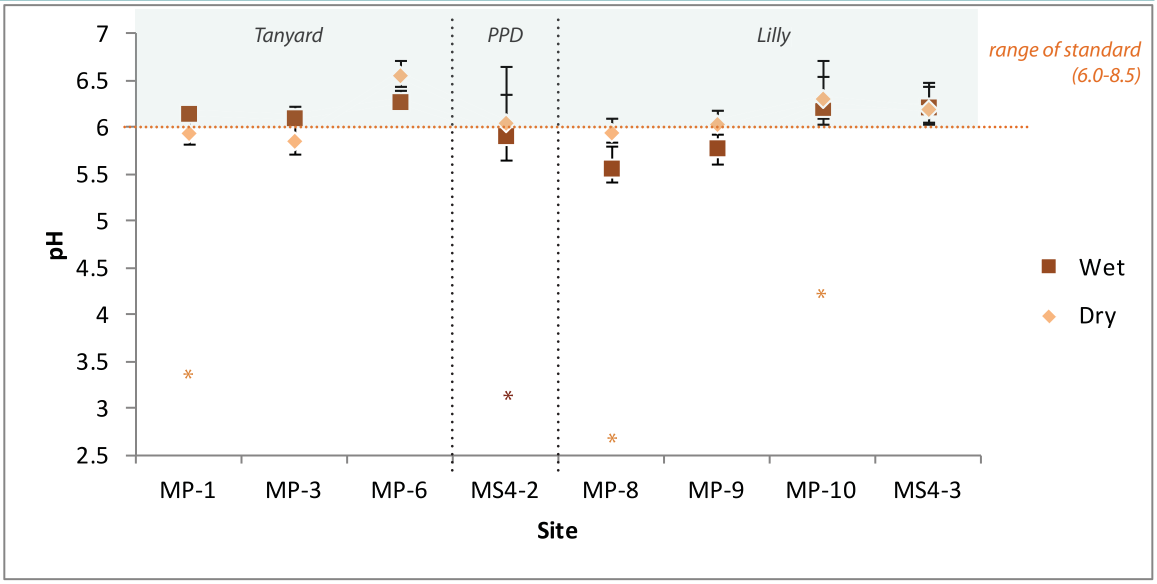

Figure 2-56. Mean** pH of water samples, 2010-2012.
Error bars represent standard error**. Wet: n=8 (sites MP-1, MP-3), n= 6 (site MS4-2) and n=7 for all other sites. Dry: n=20 (site MP-6), n=19 (site MP-1), n=17 (site MP-9), n=10 (site MS4-2), and n=16 for all other sites. Single asterisks (*) represent very low pH values that were excluded as outliers at four sites. Please see page 41 for site locations and other details about these data.

**Because pH is a logarithm ($-\log_{10}[H+]$), the mean and standard error shown were calculated for hydrogen ion concentration, rather than pH units, then converted back to pH for display.

The water quality standard in Georgia for pH is 6.0 to 8.5 (GA DNR 2011). All sampling points within the target watersheds are somewhat acidic (pH less than 7.0), though during recent sampling (2010-2012) there appears to have been trend towards decreasing acidity moving downstream in both the Lilly Branch and Tanyard Creek watersheds. The most acidic average pH overall was found at the upstream end of Lilly Branch (sites MP-8 and MP-9), during wet weather sampling (Figure 2-56).

Please see page 92 for information about the relationship between SCMs and pH.

Water quality summary

Taking all water quality data into consideration together (pages 41 through 63), no one sampling point or group of points can be identified as the most polluted overall; however, several patterns do emerge. This information can help inform SCM selection by identifying treatment targets within these watersheds.

1. *Higher in the headwaters than downstream:*
    - Fecal coliform bacteria (dry sampling conditions only)
    - Lead* (Tanyard Creek main stem only)
    - Copper* (Tanyard Creek main stem only)
    - Acidic conditions* (indicated by lower pH)

2. *Higher moving downstream:*
    - Total nitrogen* (Lilly Branch only, small possible increase)
    - Lead* (Lilly Branch only)
    - Copper* (Lilly Branch only)
    - Total suspended solids*
    - Turbidity* (wet sampling conditions only, especially in the Tanyard Creek watershed)
    - Conductivity (dry sampling conditions only, Lilly Branch only, excluding upstream point MP-8)

3. *Higher in the Tanyard Creek main stem than in its tributary, Cloverhurst Branch:*
    - Conductivity*
    - Total Nitrogen*

4. *Higher in the PPD watershed than elsewhere:*
    - Total suspended solids* (especially during dry sampling)
    - Turbidity (dry sampling conditions only; under wet conditions, this site had among the lowest levels)
    - Conductivity* (especially during dry sampling)

5. *Lower in the PPD watershed than elsewhere:*
    - Fecal coliform bacteria* (cool season, wet sampling conditions only)

6. *Above water quality standard or reference condition at all sites, with no clear pattern among sites:*
    - Fecal coliform bacteria* (warm season, wet sampling conditions only)
    - Total phosphorus* (exception: site MP-8 under dry conditions)

* Dry sampling conditions indicate water quality at baseflow, whereas wet weather samples are more strongly influenced by pollution carried by stormwater. Pollutant patterns marked with an asterisk are the results of wet weather sampling.

Chapter 3: Stormwater Control Measures

This section describes how stormwater control measures can be used to help meet stormwater management goals.

Organization

Stormwater control measures (SCMs) are structures or practices that are put into place in an attempt to control and manage stormwater. The small, distributed structural SCMs favored by sustainable stormwater management promote infiltration and groundwater recharge, protect or improve surface water quality, minimize the use of potable water, and capture runoff. Non-structural SCMs, such as education and local ordinances, also help promote watershed health (Vick et al. 2012); however, the focus of this analysis is on structural SCMs.

Different SCMs have different strengths and weaknesses (Lloyd, Wong, and Porter 2002; Barrett 2005, 2008). For example, some are good at removing certain kinds of pollution but poor at reducing runoff volume or encouraging evaporation, while others' strengths may be just the opposite. In addition, each SCM is suitable for a specific range of site conditions, such as slope, soil infiltration rate, and water table depth. Making appropriate SCM selection choices depends on understanding how each type of SCM fits a site's conditions and stormwater improvement goals.

This chapter begins with an overview of the ways in which SCMs can be used to achieve stormwater goals. Next, background information about specific SCMs is provided. This section includes, but is not limited to, design considerations that factor into the suitability analyses for individual SCMs. Note that role of SCMs in achieving specific water quality targets is included in a separate chapter. Finally, treatment trains, which combine multiple SCMs in series, are discussed.

How SCMs support healthy watersheds

Low-Impact Development (LID) is a design and planning strategy that seeks to mimic the natural hydrologic regime of a site. LID is defined by five fundamental concepts: using hydrology as the integrating framework of development, managing stormwater on a small scale, controlling stormwater near its source, using simple, nonstructural methods when possible, and creating a landscape that can serve multiple purposes (Prince George's County 1999). Within this framework, SCMs are tools LID uses to move a site towards emulating a natural hydrologic regime. Each SCM manages stormwater in one or more of the following ways: reducing runoff, mitigating runoff through the encouragement of infiltration and evapotranspiration, conveying runoff from larger rain events, and protecting or restoring natural areas and receiving water bodies (Vick et al. 2012). A combination of these tactics can work together to meet stormwater management goals.

In natural landscapes, 10-30 percent of the rainfall becomes runoff, with the rest infiltrating or evapotranspiring to the atmosphere; in contrast, development can lead to over 50 percent runoff (Prince George's County 1999). Runoff can be reduced in developed areas by reducing the impervious surfaces that cause runoff, conserving natural areas, increasing surface permeability to encourage water to infiltrate the soil, and collecting and reusing water from runoff that does occur (Vick et al. 2012).

Impervious surfaces are hard barriers that prevent water from soaking into the ground. The more area that is covered by impervious surfaces, the more water becomes available for runoff. Connected impervious surfaces create a pathway over which runoff collects and moves quickly towards receiving waters (Hunt 1999). In fact, conventional stormwater management depends on a network of hard infrastructure (e.g. pipes, curbs) to drain rainwater quickly and efficiently (Prince George's County 1999). Fast moving, high volume runoff leads to high peak flows, and increased erosion potential. In addition, because impervious surfaces prevent groundwater from being replenished through infiltration, the base flow of streams during dry weather is reduced (Hunt 1999). Reducing impervious surfaces and other hard elements reduces runoff by increasing opportunities for the natural processes of evaporation, filtration, and infiltration (Vick et al. 2012).

The greatest source of imperviousness in developed areas is the traffic network: roads, sidewalks, driveways, and parking lots, so managing these areas an important step towards managing runoff (Prince George's County 1999). Some techniques for reducing the area covered by the traffic network include reducing road lengths and widths, downsizing parking lot stalls and aisle width, and taking advantage of opportunities for shared parking. In addition, the runoff potential of these areas can be reduced by using permeable pavement, especially in low-traffic areas. Eliminating curbs and gutters from the transportation network and disconnecting these surfaces as much as possible allows runoff generated by these areas to be directed into adjacent SCMs , high infiltration soils, and vegetated areas (Vick et al. 2012). Adjacent vegetation should be preserved as more natural vegetation types (e.g. trees, meadows, and woodlands) in lieu of turf grasses when possible. When new impervious surfaces must be constructed, it is recommended that they be sited on the least pervious soils (Prince George's County 1999). Together, these techniques reduce the total amount of transportation-related impervious surface cover, increase the permeability of these surfaces, and reduce the chances that runoff generated by them will flow directly to storm sewers and surface waters. Buildings are also large contributors to increased runoff. Multi-story buildings have a smaller roof area than single-story buildings, and so generate less runoff. Green roofs decrease runoff and encourage evapotranspiration (Vick et al. 2012). Roof drains should be disconnected from storm sewers; instead, as with roads and parking lots, runoff from roofs can be directed into vegetation, permeable soils, and SCMs (Prince George's County 1999).

In addition to reducing impervious surfaces, runoff can also be reduced by conserving natural areas. Under LID, identifying and preserving sensitive areas that affect hydrology is the first step of integrating hydrology into the planning process (Prince George's County 1999). Stormwater-related target conservation areas include streams, their vegetated riparian areas, groundwater recharge areas, high infiltration soils, wetlands, floodplains, and steep slopes (Vick et al. 2012; Prince George's County 1999). Conserved land should serve multiple purposes; for example, a site can provide recreation opportunities and aesthetic appeal in addition to preserving hydrologic function (Vick et al. 2012).

Where excess runoff is generated by impervious surfaces, it can be intercepted by harvesting SCMs, such as cisterns, rain barrels, and dry wells. Collected water can be reused for nonpotable uses, such as irrigation, cooling, and toilet flushing (Vick et al. 2012). Water harvesting is discussed further within the description of cisterns and rain barrels.

Runoff can be mitigated using SCMs that replicate the natural hydrological processes of infiltration and evapotranspiration. During infiltration, water at the surface seeps into the soil, promoting groundwater recharge. Evapotranspiration occurs when water moves into the air through either evaporation or plant transpiration. SCMs that encourage these processes are those that slow stormwater down and spread it out into holding areas where it can sit for an extended period of time. Some examples include green roofs, rain gardens, pervious pavement, and many of the other infiltration-based SCMs described below (Vick et al. 2012). These devices are most effective at mitigating runoff when they fit within the LID concepts of managing stormwater on a small scale (treatment of a 1 acre drainage area or smaller) and controlling stormwater near its source (Vick et al. 2012; Prince George's County 1999).

During large, infrequent storms, runoff volume may be higher than retention-based SCMs are designed to accommodate (see discussion of SCM size on page 83). For these occasions, excess stormwater must be diverted and conveyed downgradient to existing regional detention systems or directly to receiving waters (Vick et al. 2012). Conventional stormwater management uses hard, usually enclosed infrastructure elements like pipes to convey water as quickly as possible; in contrast, the conveyance SCMs of sustainable stormwater management attempt to mimic natural water transport by using open systems where vegetation, soil, rock, and water can interact (Prince George's County 1999; Vick et al. 2012).

Receiving water bodies can be damaged from incoming stormwater runoff, particularly if it enters as a high velocity, concentrated stream of water. Level spreaders are an SCM that can help protect receiving waters by converting concentrated runoff to slow, shallow sheet flow over the surface of the land (Prince George's County 1999). Riparian buffers and stormwater wetlands are additional SCMs that can protect streams from incoming runoff (Vick et al. 2012).

Developed areas produce more runoff than natural areas, but a combination of SCMs that reduce, mitigate, convey, or protect receiving waters from runoff can be used to manage stormwater in developed areas by emulating natural hydrologic processes. Some specific SCMs that fall within these design approaches and the LID framework are described below, followed by information on how they can work together within a watershed.

Categories of SCMs

The following overviews of specific SCM types are arranged based on whether they are intended to reduce the amount of runoff generated by manmade structures (permeable pavements, green roofs), harvest the excess runoff that is generated by structures (cisterns and rain barrels), encourage filtration, infiltration, or evapotranspiration (bioretention areas and rain gardens, wet ponds, sand filters, vegetative filter strips, stormwater wetlands), convert or convey runoff flow (level spreaders, swales), or involve the protection of existing natural features (vegetation, riparian buffers, natural drainage pathways). The information provided includes considerations that should be taken into account when SCMs are selected and explains the reasoning behind some of the design considerations that were used in this report's suitability analyses.

Permeable pavements

Permeable pavements produce less runoff than traditional pavements because they allow water to pass through them. Water enters the pores in the surface, collects in underlying storage areas, and then either infiltrates the soil directly or is released slowly to an underdrain system (Hunt 2011). Benefits include runoff volume reduction, peak flow reduction and delay, pollutant sequestration, and groundwater recharge (Vick et al. 2012; Hunt 2011; Hunt and Collins 2008; Hunt and Szpir 2006). Because water drains instead of collecting on the surface, puddles are avoided and glare and tire spray are reduced (Vick et al. 2012). Some systems also have high albedo, or light reflectivity, and some reduce thermal pollution of runoff (Hunt 2011; Hunt and Collins 2008). Permeable pavements can remove metals (including zinc and copper), motor oil, sediment (though clogging is a risk), and possibly some nutrients . In addition, they have been shown to buffer pH, which is believed to be due to the presence of calcium carbonate and magnesium carbonate in pavement and aggregate materials (Hunt and Collins 2008; Hunt and Szpir 2006).

Despite the benefits of permeable pavements, they are not suitable everywhere. They are most appropriate for areas with low vehicular traffic volume, such as sidewalks, patios, residential parking pads, driveways, fire lanes, overflow parking areas, and some daily parking areas, such as those with infrequent turnover (Hunt and Szpir 2006). Permeable pavements on flat slopes tend to reduce runoff better than those on steeper slopes (Hunt and Szpir 2006); furthermore, construction on flat slopes is easier and less expensive as permeable pavements on steeper slopes require internal berms (Hunt 2009). Permeable pavements may be used on clay soils like those within the three target watersheds, but usually require an underdrain system because of slow infiltration. To avoid the need for an underdrain system, soils should have an infiltration rate of at least 0.5 inches per hour (Hunt and Szpir 2006).

The main concerns about permeable pavements are clogging and potential groundwater contamination. Groundwater contamination risk is low, and can be minimized by ensuring a separation of at least 1 foot (preferably 2 feet) above the seasonally high water table (Hunt and Collins 2008). The most frequent cause of permeable pavement failure is sediment accumulation from surrounding areas (Hunt 2011). Because of the risk of clogging, permeable pavements should not be used to filter sediments; in addition, potential sediment sources such as adjacent landscaping should drain away from the pavement (Vick et al. 2012). Overhanging vegetation also presents a clogging risk. To enable proper function, frequent inspection and maintenance are necessary (Hunt 2011). Other SCMs may be used in series with permeable pavements to help prevent clogging.

There are five types of permeable pavement: permeable concrete, permeable asphalt, permeable interlocking concrete pavers, concrete grid pavers, and plastic reinforced grass pavement (also known as plastic reinforced grid pavers or geocells). The latter two pavements include relatively large openings that may be filled with aggregate, sand, or grass (Hunt and Szpir 2006; Hunt and Collins 2008). These two pavements temporarily store water nearer the surface than permeable concrete, asphalt, or interlocking concrete pavers, which is believed to encourage the release of more water by evaporation (Hunt and Collins 2008), especially when they are filled with sand (Hunt 2009). There is no difference in total runoff reduction among the different permeable pavement types; however, as underdrains are usually necessary in clay soils due to poor infiltration (Hunt and Collins 2008), it seems likely that pavement systems that encourage more evaporation through shallower water storage would produce less outflow from the underdrain system. The Georgia Stormwater Manual recommends against the use of permeable asphalt in Georgia, because the high temperatures experienced in the summer can melt asphalt, potentially eliminating the pavement's porous properties (Atlanta Regional Commission 2001). Ultimately, pavement selection depends on the anticipated traffic load and on desired outcomes such as water storage capacity (Vick et al. 2012).

Green roofs

A green, or vegetated, roof consists of waterproofing and drainage mats, a lightweight growing media, and plants suitable for climate extremes (Hunt and Szpir 2006). They may be intensive or extensive. Intensive green roofs are more garden like, being able to carry pedestrian traffic and having much thicker growing media (6-8 inches or more) that can support trees and shrubs (Vick et al. 2012; Windhager, Simmons, and Blue 2012; Hunt and Szpir 2006). Extensive green roofs have shallow (2-5 inches thick) growing media that is capable of supporting low-lying vegetation (Hunt and Szpir 2006; Vick et al. 2012). Extensive green roofs are more common for runoff control, while intensive green roofs are used when pedestrian accessibility and rooftop landscaping are also desired. Green roofs are especially advantageous in high-density urban environments, where there is limited land available for other SCMs (Hunt and Szpir 2006).

Extensive green roofs can reduce annual runoff volumes by 50-90 percent (Vick et al. 2012), returning much of the retained water to the atmosphere via evapotranspiration

(Hunt 2009). They can also reduce peak flows. In addition to hydrologic cycle benefits, green roofs also prolong roof life, reduce roof temperature, reduce energy costs within a building, and reduce the urban heat island effect (Hunt and Szpir 2006). Depending on plant selection, green roofs can provide a range of wildlife benefits, including cover for insects and nesting birds and nectar for pollinators (Vick et al. 2012).

When considering installation of a green roof, the following should be taken into account. They are suitable for a roof pitch up to 8 percent, but are most manageable on flat roofs (Hunt 2009). For stormwater benefits, they should hold at least 0.5 inches of rainfall, which must be supported by the roof structure where they are located (Vick et al. 2012). Plants selected should be ecological generalists that can tolerate both very wet and very dry conditions, a variety of sun exposure levels, high heat, low maintenance, and shallow soil. Sedums have been the preferred choice for some time, but studies suggest that some grasses, forbs, and shrubs may perform better where stormwater retention and water cooling are priorities (Windhager, Simmons, and Blue 2012). Finally, green roofs can be net exporters of nutrients (Hunt and Szpir 2006), so where nutrient levels are a concern, their outflow may need to be directed into other SCMs for nutrient removal.

Rain barrels and cisterns

Excess water generated by roofs and other hard surfaces can be collected and reused for nonpotable uses such as irrigation, cooling, vehicle washing, and toilet flushing (Vick et al. 2012; Hunt and Szpir 2006). Water harvesting provides owners with a water supply without potable water fees (Hunt and Szpir 2006). Two SCMs that can be used for rainwater harvesting include rain barrels and cisterns. Rain barrels are typically above ground, small (holding less than 100 gallons), and are frequently used to harvest water from the roofs of small buildings such as residences. They are a good demonstration tool and promote awareness, but because of their small size, they rarely reduce runoff significantly (Hunt and Szpir 2006). Cisterns are larger and can be located above or below ground. Cisterns should have at least a 500 gallon capacity to reduce runoff measurably, though they can be large enough to hold hundreds of thousands of gallons of water (Hunt 2009).

In addition to the runoff volume reduction described above, water harvesting can have a moderate impact on runoff frequency and peak discharge, as well as a small impact on water quality (Prince George's County 1999). Captured water is potentially nutrient-rich. It is often high in atmospheric nitrogen, and some surfaces like green roofs may be nutrient exporters. Water reuse for irrigation is spread out where it can infiltrate the ground and provide these nutrients to irrigated plants (Hunt and Szpir 2006).

To maximize stormwater benefits, rain barrels and cisterns should be emptied between storms to prevent rainfall from bypassing the rain capture system. If it is anticipated that supply will regularly exceed demand, cisterns can be built with a leak for slow water release (Hunt and Szpir 2006). Another consideration is that some impervious surfaces are more appropriate for rainwater harvesting than others. Clean, smooth roof surfaces, such as steel, slate, or terra cotta, are preferable to surfaces like asphalt shingles and parking lots that may produce more pollution (Vick et al. 2012).

Bioretention areas and rain gardens

Some sources use the terms “bioretention “ and “rain garden” interchangeably (e.g. Hunt 2009), while others distinguish between them. For example, the Sustainable Sites Handbook describes a rain garden as a small, shallow (6 to 8 inches deep) depressed area that encourages water to collect and infiltrate, differentiating a bioretention area as a shallow, upland basin that uses vegetation and permeable soils to filter and infiltrate runoff. A distinguishing factor for those who differentiate between them is that bioretention is more likely to include an underdrain system (Vick et al. 2012). For the purposes of this watershed analysis, bioretention areas and rain gardens will be considered together, with the understanding that site conditions and desired stormwater outcomes will determine the need for an underdrain, soil permeability, and size.

Bioretention and rain gardens provide several important hydrologic functions: interception, depression storage, infiltration, groundwater recharge, runoff volume and frequency reduction. They can also have a moderate effect on peak discharge and restoration of stream base flow (Prince George’s County 1999). In addition to their hydrologic benefits, they can serve a dual function as a landscaping element (Prince George’s County 1999). They also remove nutrients and other pollutants and can cool water to reduce thermal pollution (Hunt and Lord 2006).

They are most effective at pollution reduction when designed to treat specific pollutants. For example, metal removal occurs in shallow soil, so no more than 18 inches of soil is needed for this purpose. Likewise, bacteria are more likely to die at the surface, where they are exposed to air and sunlight (Hunt and Lord 2006). On the other hand, thermal pollution is best controlled with a feature depth of 4 feet or more (Vick et al. 2012). Nitrogen removal is high in all soil conditions, but phosphorus loads may be increased or decreased depending on the P-index of fill soils used. Bacteria die off is higher when plant density is low, but plants are needed to sequester metals (Hunt and Lord 2006), with herbaceous species most likely being better suited for sequestration and adsorption than woody species (Vick et al. 2012).

Other design considerations include soil infiltration rates, sunlight, catchment size, water table depth, and proximity to buildings. Soil should be permeable enough to drain these SCMs within 48 hours, but drain slowly enough to allow treatment to occur. Wetland and other low-infiltration soils should be avoided, although moderately slow-draining soils can be overcome with underdrains (Vick et al. 2012; Prince George’s County 1999). Full sunlight is preferred. As with all small, retention-based SCMs, rain gardens and bioretention areas should be distributed across an area to maximize their effectiveness. Rain gardens are most appropriate in the headwaters of a catchment;

bioretention areas should drain an area less than an acre in size and their size is typically 5 to 10 percent of their catchment area (Vick et al. 2012). Both should be located at least 10 feet downgradient of buildings (Prince George's County 1999). There should be at least 2 feet of separation between the seasonally high water table and the bottom of infiltration-based SCMs like rain gardens and bioretention areas (Hunt 2009).

Clogging is a concern with rain gardens and bioretention areas. They should not be used to treat high sediment levels, as initial removal of suspended solids is high but will rapidly lead to system failure due to clogging (Hunt 1999). Pretreatment devices can be used to prevent premature clogging, or a forebay may be included for this purpose (Hunt and Lord 2006).

Sand filters

Sand filters are small, infiltration-based SCMs that function as a two-tiered system. First, debris settles out in a sedimentation chamber. Then, stormwater treatment occurs as the water flows through a sand chamber. Sand chambers can be highly effective at removing suspended solids (around 80 percent removal) and associated sediment-adsorbed pollutants (Hunt 1999); however, they clog easily, so regular maintenance is needed to keep removal rates high (Prince George's County 1999). To avoid clogging, they can be used to treat water from parking lots and other highly impervious areas that do not generate much sediment (Hunt 1999). In addition to removing suspended solids well, sand filters have high metal removal rates, but they are net exporters of nitrate nitrogen (Prince George's County 1999). They have high maintenance needs and can be very expensive, but they take up a very small amount of land at the surface (Hunt 1999). As a result, they are most well-suited for highly urbanized areas where land costs are high or little land is available for other treatment options (Prince George's County 1999). In addition, they are preferred over infiltration based SCMs when the water table is high or groundwater pollution is a concern (US EPA 1999b).

Vegetative filter strips

A filter strip is an area of closely planted vegetation, usually grass, onto which runoff is directed for filtration. Filter strips are commonly used as pretreatment devices for other SCMs or to treat stormwater before it enters receiving water bodies (Prince George's County 1999). They are often used in combination with level spreaders (Winston and Hunt 2010). Vegetative filter strips provide many hydrologic functions, including interception, depression storage, and base flow and stream quality maintenance. There is also moderate infiltration and groundwater recharge, as well as some control of runoff volume and runoff frequency (Prince George's County 1999). In several studies of level spreader-vegetative filter strip systems in North Carolina, runoff flow volume was reduced by 28 to 92 percent, and peak flow rate was reduced by 23 to 89 percent. These ranges are wide, with the highest reductions occurring at sites with low slopes, dense vegetation and small drainage area to filter strip ratios (Winston and Hunt 2010).

Two factors common to vegetative filter strips may introduce additional nutrient pollution into stormwater. First, it can be tempting to use fertilizer on the grass, but fertilizer should not be used after vegetation is established due to the risk of putting fertilizer directly into the runoff stream. Second, vegetative filter strips can be attractive as dog walking areas. Signage may be required to alert pet owners that their dogs should avoid the filter strip because it is a water treatment system (Winston et al. 2010).

Infiltration basins and trenches

Infiltration basins and trenches are SCMs that use shallow cells, typically filled with porous media (e.g. riprap), to enable infiltration (Hunt 2009). They do not have underdrains, so they should be located where soil permeability is at least 0.5 inches per hour (Vick et al. 2012). Like other infiltration-based SCMs, they should be located at least 10 feet downgradient of buildings (Prince George's County 1999), and there should be at least 2 feet between the bottom of the basin or trench and the top of the seasonally high water table (Hunt 2009). Infiltration trenches perform best with an upgradient drainage area slope less than 5 percent and a downgradient slope less than 20 pecent (US EPA 1999a). These SCMs provide several hydrological services, including infiltration, groundwater recharge, runoff volume reduction, and protection of water and stream quality. They also offer moderate improvements to depression storage, peak discharge, and runoff frequency (Prince George's County 1999). Small infiltration basins, distributed throughout a site and each treating a drainage area of less than 1 acre each, are preferred (Vick et al. 2012). They are well suited to small urban watersheds (Prince George's County 1999).

Infiltration trenches and basins are more effective and durable when some form of pretreatment is used. They are susceptible to clogging, so entering water should be sediment free (Vick et al. 2012). In addition, pretreatment should be used to remove grease and other floatable organic materials, where these pollutants are a concern (Prince George's County 1999). As infiltration basins and trenches may introduce pollutants to groundwater, they should not be used in areas of high pollution (Vick et al. 2012).

Stormwater wetlands

They are designed to maximize stormwater's flow path (Hunt 1999), with a retention time of at least 48 hours to allow ample time for water treatment (Hunt et al. 2007). They consist of deep pools, shallow water sections that connect the pools, temporary inundation areas that are inundated only during large storms, and transitions between these three areas and between the wetland and its surroundings (Hunt et al. 2007). Vegetation includes early succession wetland plants (Vick et al. 2012). Because stormwater wetlands require slowly moving water that remains at the surface for an extended period of time, they depend on a reliable water source (Hunt and Doll 2000). As such, they should intersect the seasonally high water table and can also intersect the seasonally low water table (Hunt 2009). In areas with high water tables, they are one of the most efficient pollutant removal SCMs available (Hunt et al. 2007). Because water must move slowly through stormwater wetland systems, they should be located on relatively flat land (Hunt and Doll 2000).

Stormwater wetlands are very effective at pollutant removal (Prince George's County 1999). Sedimentation and filtration help remove suspended solids, debris, soil bound phosphorus, and some soil-bound pathogens. Total suspended solid removal is very high, with nearly 80 percent removal (Hunt 1999). Dissolved metals and soluble phosphorus adhere to soil particles. Nitrification and denitrification reduce nitrogen, pathogens, and organic pollutants. Plants take up nutrients. Finally, sunlight and dryness in shallow areas kills pathogens (Hunt and Doll 2000). Stormwater wetlands also mitigate temperatures, reducing thermal pollution (Hunt et al. 2007). In addition to pollution control benefits, stormwater wetlands also enhance flood control, wildlife habitat, and education and recreation opportunities (Hunt and Doll 2000).

Stormwater wetlands can be beneficial when built either in-line with natural ephemeral drainages or off-line, though in-line wetlands perform better (Hunt et al. 2007). The catchment area for a stormwater wetland should be no larger than 5 acres, and a wetland's size tends to be 5 to 10 percent of its catchment area. Floodplain areas that lie the farthest from streams are often the most suitable location (Vick et al. 2012).

While stormwater wetlands are more tolerant of sediment than infiltration-based SCMs, they can become filled with sediment over time, so pretreatment is recommended (Hunt and Doll 2000). Other limitations include their dependency on a reliable water source, their large size relative to many other SCMs, and the relatively high costs of excavation, construction, and wetland plants. Public opinion may negatively associate the word "wetland" with swamp-like conditions (Hunt 1999). Because stormwater wetlands are inundated with water, they may present a drowning hazard (Hunt and Doll 2000). Finally, if large storm events exceed the capacity of the wetland, a bypass system will be required to avoid damage from excess flow (Hunt et al. 2007).

Level spreaders

A level spreader is an SCM that converts a concentrated runoff stream to slow, shallow sheet-flow (Prince George's County 1999). Spreading slow-moving flow evenly across the land enables infiltration and some evapotranspiration (Hunt 2009). It is often used as a precursor to another SCM, and is especially common in conjunction with vegetative filter strips and riparian buffers. Research indicates that level spreaders may be more effective outside riparian buffers than within them, as wooded riparian areas have a tendency to reconcentrate flow (Winston et al. 2010). They are one of the most effective

SCMs in areas with high water tables, though their usefulness is limited in where slopes are steep (Hunt 2009).

Level spreaders are relatively simple to construct and require little space, but they can easily become overwhelmed by flow volumes if size requirements are underestimated (Hunt 1999). As long level spreaders are more difficult to construct, these devices are best suited for small watersheds. Infrequent, large storms can reduce infiltration and water quality treatment by saturating the soil, so large storms should be redirected to bypass the system (Winston et al. 2010).

Vegetated swales and bioswales

Swales are used to convey runoff using an open drainage system, which alleviates flooding and reduces the need for conventional stormwater infrastructure (Hunt 1999). Vegetated swales are often planted with turf grass, though densely planted native plants with fibrous roots are preferred (Vick et al. 2012; Hunt 2009). Grass covered swales have some pollutant removal ability, which can be improved using modifications such as turf reinforcement matting and check dams. Check dams detain water, allowing it to infiltrate the ground (Hunt 1999).

Fast moving channel flow can be avoided by increasing surface roughness, using wide, relatively flat channels, and keeping a shallow gradient along the length of the swale. A longitudinal gradient of 1 to 6 percent is recommended. Sheet flow should be maintained when possible (Prince George's County 1999). High water velocities often lead to erosion within swales. Where slopes are steep enough to produce fast-moving water, a swale may need to be lined with rip-rap rather than vegetation. Turf-reinforced mats can also provide some protection (Hunt 1999). Another variation that can be used where scouring is a concern is a swale that includes step pools (Vick et al. 2012).

While most infiltration-based SCMs should not intersect the water table, a vegetated swale can do so. In that situation, wetland vegetation must be used. A wetland swale most likely has better nutrient removal capabilities than a grass swale, due to the use of wetland plants (Hunt 2009). Another variation on a vegetated swale is a bioswale. Bioswales incorporate engineered soil and underdrains like a bioretention area to promote infiltration (Vick et al. 2012). Because a bioswale's function depends on infiltration, there should be a minimum clearance of 2 feet between the bottom of the bioswale and the top of the seasonally high water table (Hunt 2009).

Natural areas and riparian buffers

As described on page 67, preserving certain natural areas provides multiple stormwater control benefits. Three priority protection areas will be discussed here in more detail: natural drainage ways, large tracts of contiguous vegetation, and riparian buffers.

Natural drainage ways include ephemeral, intermittent, and perennial streams, as well as terraces, floodplains, and wetlands (Vick et al. 2012). Identifying these patterns reveals where water will concentrate. Knowing natural drainage patterns enables them to be protected by vegetated buffers. When possible, existing drainage ways can be preserved and used to convey water, avoiding the expense of artificial drainage infrastructure; however, natural drainage pathways also need protection against potential flooding or scouring from runoff (Prince George's County 1999).

Trees and other vegetation increase surface roughness and increase the flow path of water. Preserving them protects the many stormwater-related services they provide. Natural vegetation slows runoff velocity, helps maintain infiltration capacity, helps prevent erosion by holding soil in place, shields soil from the impact of rain, and provides some sediment filtration (Prince George's County 1999).

While all patches of vegetation can provide these services, riparian buffer preservation is especially important for stream protection. Riparian buffers are grass covered or forested areas adjacent to a stream (Hunt 2009). They provide protection from stormwater impacts by intercepting sediment and sediment-bound pollutants, slowing and dispersing runoff flows, and providing some infiltration. Vegetated buffers protect sensitive areas and help to reduce stormwater impacts by trapping sediment and sediment-bound pollutants, providing some infiltration, & slowing and dispersing flows (Hunt 1999).

A level spreader can be used to disperse sheet flow throughout a buffer to increase its effectiveness (Hunt 1999); however, the natural draws and channels within a buffer tend to quickly reconcentrate flow (Winston and Hunt 2010). Another limitation of riparian buffers is that they require large amounts of land relative to other SCMs (Hunt 1999). Finally, a riparian buffer with a steep slope (greater than 6 percent for wooded buffers or 8 percent for vegetated buffers) should not be depended on to reduce peak flows, as water velocity will be too rapid. Other SCMs, such as bioretention and stormwater wetlands, should be used when these slopes are exceeded (Hunt 2009).

Summary

The appropriate SCM for a given location depends on site conditions. Some design considerations for SCM selection are summarized in Table 3-1.

Treatment trains

A treatment train is a series of SCMs that are designed to work together to achieve stormwater management goals. Using SCMs in series provides redundancy in the overall stormwater control system and facilitates optimal flow management and pollutant removal (Lloyd, Wong, and Porter 2002). This section provides examples of how SCMs can be used together.

Table 3-1. SCM design considerations (Prince George's County 1999; Hunt and Collins 2008; Hunt 2009; Vick, Calabria et al. 2012).

Design consideration	Description	SCMs
Catchment size	< 1/4 acre	• Above ground cisterns
	< 1 acre	• Infiltration basins • Below-ground cisterns • Sand filters • Bioretention/rain gardens
	< 5 acres	• Stormwater wetlands • Level spreaders • Infiltration basins • Swales
Soil	Best on tighter soils, such as clay	• Stormwater wetlands
	Best on permeable soils	• Bioretention/bioswales * • Infiltration basins/trenches • Permeable pavements * *Less permeable soil types may be overcome with an underdrain system
	Perform better on permeable soils, but soil type is not a limitation	• Swales (except bioswales) • Vegetative filter strips
	Function well regardless of soil type	• Cisterns/rain barrels • Sand filters
Water table	At least 2 feet of separation between the bottom of the SCM and the top of the seasonally high water table	• All infiltration-based SCMs except as otherwise noted
	Should intersect the seasonally high water table, and preferably the seasonally low water table	• Stormwater wetlands • Wetland swales
	Good for when other options are limited by high water tables	• Vegetative filter strips
Slope	Best on flat slopes	• Permeable pavements
	Minimum slope 1 %, maximum downstream slope 15 % (up to 50 feet)	• Level spreaders
	Longitudinal slope 1-6%	• Swales
	Requires some minimum gradient	• Bioretention with underdrains
	Requires upstream pretreatment when slope exceeds 6% (wooded) or 8% (vegetated)	• Riparian buffer
Land use intensity (most to least)	High	• Stormwater wetlands • Bioretention
	Moderate	• Infiltration basins • Infiltration trenches
	Low	• Swales • Level spreaders • Vegetated filter strips
	Potentially occupy no useable land if buried underground	• Cisterns • Sand filters
	Cover a large area, but use space that would be otherwise occupied by impervious surfaces	• Green roofs • Permeable pavement
Distance from buildings	> 10 ft, located downslope (to protect basements/ crawl spaces)	• All infiltration based SCMs

Certain SCMs produce outflow that may require further treatment by downgradient SCMs. Permeable pavement, for example, does enable more infiltration than conventional pavement; nevertheless, it still does produce some runoff, having a curve number[1] ranging from 45 to 89. Stormwater runoff originating from permeable pavement may need to be treated by another SCM just as runoff from conventional parking would be (Hunt 2009). While over half of the annual rainfall that lands on a green roof is returned to the atmosphere via evapotranspiration, some runoff is generated. This runoff may contain pollution in the form of nutrients and organic material, so further treatment is required where these pollutants are a concern (Vick et al. 2012). A specific scenario in which a system may be intentionally designed to pair multiple SCMs together is when water is contaminated with multiple pollutants. A treatment train made up of multiple SCMs designed to target different contaminants can be more effective than attempting to remove all contaminants with an individual device (Wright Water Engineers and Geosyntec Consultants 2011). In a more general sense, additional treatment may be needed for water leaving any SCM that produces overflow, generates runoff, or is a net exporter of a pollutant.

Any SCM that is designed to target a pollutant or other problem not thoroughly addressed by upslope SCMs may be used for further treatment; however, certain systems are better suited for this purpose than others. For example, as riparian buffers are, by definition, located adjacent to streams, a treatment train can be designed with a buffer as the final water quality improvement tool. A level spreader-vegetative filter strip combination can be used to treat outflow from other treatment systems, such as infiltration devices and retention ponds (Winston et al. 2010; Prince George's County 1999). Rain gardens are suitable for the collection of stormwater from a variety of surfaces, including outflow or overflow from other SCMs such as cisterns and green roofs (Vick et al. 2012).

Many infiltration-based SCMs are very prone to clogging. Clogging is such a concern for sand filters that they are primarily used to treat runoff from parking lots and other highly impervious surfaces that generate little sediment (Hunt 1999). The water entering permeable pavement, infiltration basins, and infiltration trenches must also be sediment free (Vick et al. 2012). Many infiltration devices, including bioretention areas, rain gardens, and bioswales, initially perform very well at filtration functions like sediment removal, but they last longer and are more effective over time when pretreatment is included (Hunt 1999; Prince George's County 1999). Stormwater wetlands are less sensitive to clogging than the SCMs listed above, so it may be suitable for them to precede other, more sensitive SCMs; however, they will eventually fill up with sediment, so protection from sediment is preferred (Hunt 2009; Vick et al. 2012). Cisterns are even less susceptible to clogging than stormwater wetlands, and so can likewise precede more sediment-sensitive SCMs, but even so, runoff should be screened or filtered before it enters a cistern (Vick et al. 2012; Hunt 2009). While riparian buffers are not especially vulnerable to clogging, they may require pretreatment in the form of level spreaders or other SCMs like bioretention and stormwater wetlands when

1 A curve number is an indication of the amount of runoff generated by a surface. Curve numbers run from 0 to 100. A completely impervious surface, where all rain that falls is converted to runoff, has a curve number of 100.

concentrated or high velocity flow is a concern, especially when their slopes are steep (Hunt 2009).

There are several options for protecting sensitive SCMs from sediment. The vegetation in swales and vegetative filter strips provides filtration without becoming clogged (Vick et al. 2012; Prince George's County 1999). A barrier around the perimeter of certain SCMs like bioretention cells can be created using a thin gravel verge and sod. The entrance of these SCMs can also be protected using forebays, which are areas of slow-moving water where sediment settles out of the influent water stream before it proceeds to the clogging-sensitive portions of an SCM (Hunt and Lord 2006).

Certain SCM categories are needed in treatment trains to convey, redirect, or convert stormwater flow to protect other SCMs and enable them to function properly. Swales and preserved natural drainage pathways can be used to convey stormwater to and from other SCMs. Some swales can also provide some pretreatment (Vick et al. 2012). Other devices that modify stormwater flow include flow splitters and level spreaders. Level spreaders are precursors to other SCMs and are used to convert concentrated runoff to sheet flow. They are described in more detail on page 75.

A flow splitter is a device that directs the flow of water, ensuring that the first flush of runoff reaches an SCM for treatment while stormwater in excess of the design volume bypasses the structure (Vick et al. 2012). Redirecting excess water flow prevents erosion and other damage to SCMs that are not built to accommodate high flow, such as riparian buffers and level spreaders (Hunt 2009). Large storms also represent a threat downstream, as they can flush out sediments, organic matter, and associated pollutants from where they have built up on the bottom of stormwater wetlands and other vulnerable SCMs (Hunt and Doll 2000). Because they must accommodate high speed water, overflow swales should be reinforced with riprap or turf matting (Hunt 2009).

This overview of treatment trains is summarized in Figure 3-1. Information is categorized as either treatment trains in general, treatment trains specifically related to clogging risk, or SCMs that can be used in a treatment train to modify the flow of stormwater. Arrows indicate the direction of water flow within each category. The three categories are not independent of one another; stormwater may flow in either direction among them.

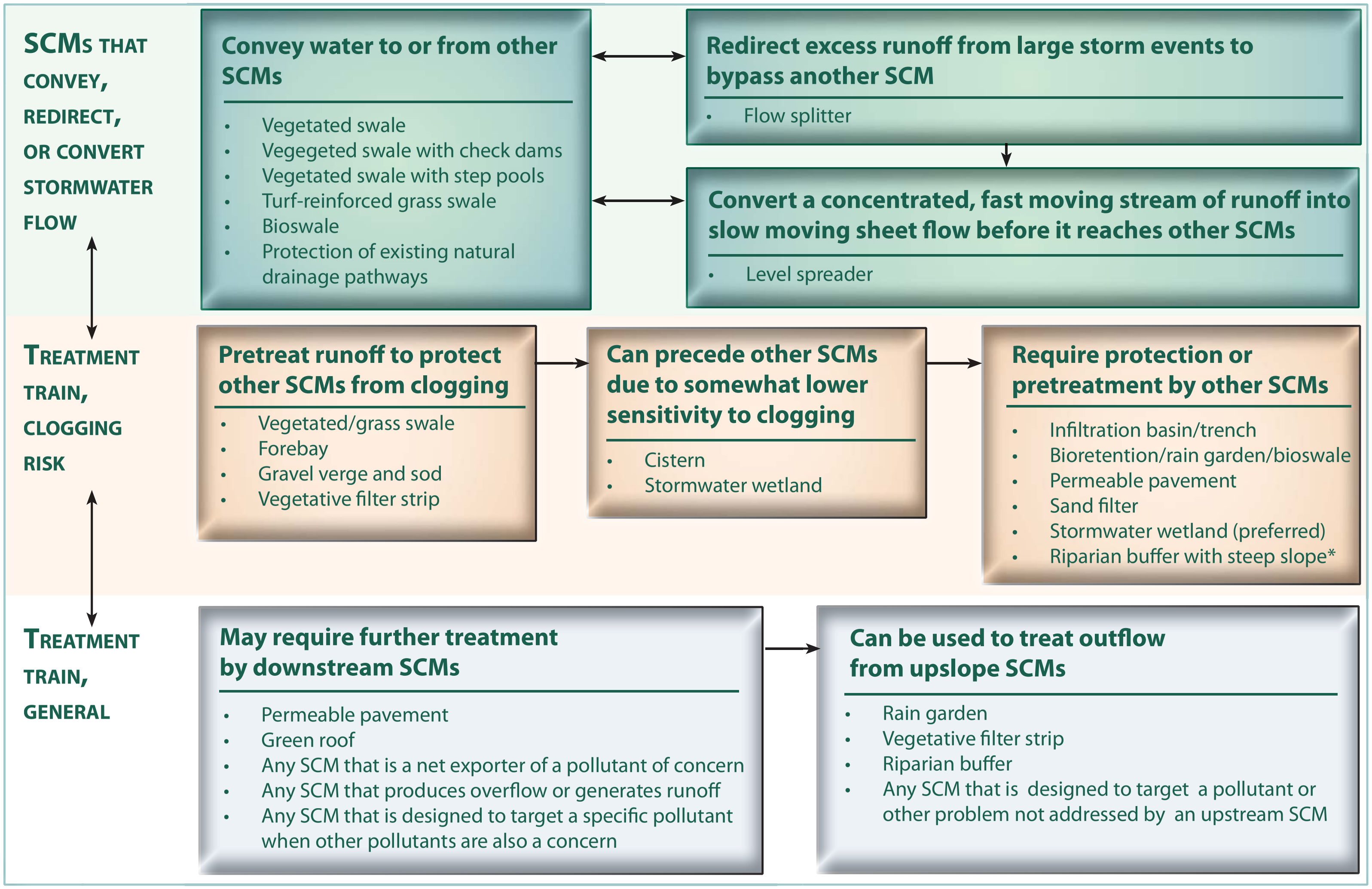

Figure 3-1. Treatment trains use multipe SCMs in series for improved stormwater control. This figure summarizes the information presented in the text beginning on page 77. Arrows indicate the direction of water flow; water flows are shown within each category (conveyance, clogging risk, and general), but SCMs from each category may precede or follow SCMs from each of the other two cateogries.

Chapter 4:
SCMs and Water Quality

This section discusses the sizing and selection of SCMs used for water quality improvement goals.

Organization

In addition to providing many services related to mimicking the predevelopment hydrologic cycle of a developed watershed, SCMs can also be effective tools for reaching other water quality improvement goals. This chapter begins with a brief overview the appropriate size of SCMs, which is related to treating pollution from the majority of storm events within a watershed. The rest of the chapter concerns the use of SCMs to reach specific water quality goals.

Sizing SCMs for water quality

Throughout this report, conventional and sustainable stormwater management strategies have been contrasted in regard to the size of the stormwater control structures they favor. Conventional management depends on regional detention systems described as "large", whereas the distributed SCMs of sustainable stormwater management are "small." What do large and small mean in this context, and how is size determined under each strategy?

Conventional stormwater detention systems are large for two reasons. First, they must be large because they are usually regional, end-of-pipe systems, so the catchment of land from which they capture runoff is extensive. Second, they are usually sized to accommodate all of the runoff from relatively large storm events; they are typically designed for a 1- or 2-year storm (meaning the size of storm that can be expected to occur only once every 1 or 2 years, on average), but on occasion may even be large enough to accommodate a 10- or even 100-year storm (Hunt 2009).

Most rainfall events are much smaller than the ones conventional stormwater systems are built to accommodate. In Athens, 90% of all storms produce less than 1.5 inches of rainfall (Carter 2006); in contrast, the rainfall depth of the 1-year (24 hour) storm is 3.2 inches (Atlanta Regional Commission 2001). Because most rain events are small and contain the most pollution, an emphasis can be placed on capturing and treating the first flush of runoff from frequent small rain events (Vick et al. 2012). Up to 90 percent of all runoff pollution can be treated by SCMs designed for relatively small storms (Hunt 2009). In Georgia, the first flush required to be captured and treated onsite is 1.2 inches, based on the 85th percentile rain event (Atlanta Regional Commission 2001), although for federal projects, on site retention of the 95th percentile event is required (Vick et al. 2012). The Sustainable Sites Handbook recommends that first flush pollution be diverted by first directing runoff into small, distributed retention facilities to encourage evaporation, with the excess volume from small storms overflowing into infiltration-based SCMs. The excess volume from large, infrequent storms can be diverted downstream (Vick et al. 2012). In previously developed areas with existing conventional stormwater infrastructure, like the three watersheds in this analysis, diverted flow from these infrequent events will take advantage of existing storm sewers and regional detention systems.

Selecting SCMs for pollutant removal

Tanyard Creek, its tributary (Cloverhurst Branch), and the reach of the North Oconee River into which Lilly Branch and the PPD flow are listed as impaired on Georgia's 303(d) list due to high levels of fecal coliform bacteria (GA DNR 2010). Ongoing water quality sampling within the three target watersheds has identified potential problems with the following water quality parameters: fecal coliform bacteria, total nitrogen (TN), total phosphorus (TP), lead, copper, total suspended solids (TSS), conductivity, turbidity, and pH (Brown and Caldwell 2011, 2012). Recent water quality data for these parameters are presented on pages 41 through 64. Lilly Branch is also polluted with hydrocarbons, but as this is due to leaking underground storage tanks from old service stations in the Five Points neighborhood, it is not runoff related (Byers 2010).

This section presents information about using SCMs to treat specific water quality issues. Much of what is known comes from comparisons drawn from the International Stormwater Best Management Practice Database (BMP Database, *http://www.bmpdatabase.org/*), a collection of several hundred BMP studies and performance analysis results. Many of the recommendations below are based on conclusions their project team has drawn from the database's assembled data.

General principles

Sediment, debris, and particulates can be removed during initial infiltration, using certain SCMs , including green roofs, rain gardens, bioswales, and constructed wetlands. Most contaminants adhere to fine soil particles during slow infiltration, so most will be trapped with the sediment to which they adhere. Groundwater contamination can be a concern with infiltration-based SCMs, but most contaminants can be prevented from reaching groundwater if stormwater is properly retained and pretreated with sedimentation or filtering (Vick et al. 2012).

The effectiveness of an SCM at removing a contaminant can be measured in either concentration or load. The effect of an SCM on contaminant concentration is determined by comparing the concentration of the water flowing into the SCM (influent) with the water that leaves it (effluent). Pollutant load, on the other hand, is the total amount of a pollutant that enters receiving waters. It is possible for an SCM to reduce stormwater volume to the extent that contaminant concentration increases but the total pollutant load it delivers to a receiving stream decreases (Wright Water Engineers 2010).

Fecal coliform

Fecal coliform bacteria are not a human health hazard, but its presence indicates contamination for fecal material from warm blooded mammals, which may contain dangerous pathogens. Sources can include leaking sewers and septic tanks, waterfowl and other animals defecating directly in surface bodies, or animal waste from the surface being transported by runoff. There is generally a positive correlation between indicator bacteria concentration in streams and the proportion of impervious cover within their watersheds (Hathaway and Hunt 2008).

As part of the overall nine-element watershed plan, the project team is working on determining specific sources of fecal coliform within the watershed. At this time, it is believed that leaking underground sanitary sewers and septic systems are a major source, but that above ground sources like dumpsters and pet feces may also contribute. Until more is known about what proportion of fecal coliform contamination is from above ground sources, it is unclear whether SCMs would have a measurable impact on fecal coliform concentration in the streams. The following information pertains to the potential for fecal coliform removal from stormwater by SCMs.

Bacteria can be removed by sedimentation and filtration, and so may be removed by SCMs (Hathaway and Hunt 2008). Based on the limited research that is available so far, there is evidence that some retention ponds, media filters, and bioretention cells may help reduce bacteria concentrations to some extent, but overall, SCMs do not appear to reduce fecal coliform concentrations from influent to effluent enough to meet water quality targets (Wright Water Engineers 2010). Bacteria may survive to pass through or even increase in SCMs with most soils and available nutrients, which are suitable growing conditions for bacteria, or when SCMs attract wildlife that can contribute additional feces (Hathaway and Hunt 2008). An SCM is considered a net exporter of fecal coliform if fecal coliform concentration is higher in water leaving the SCM than in incoming water. Examples include grass swales, grass strips, and detention basins. Nevertheless, even SCMs that are net exporters can reduce the overall fecal coliform load delivered to streams if they reduce water volume sufficiently (Wright Water Engineers 2010). The potential of specific SCMs to reduce fecal coliform concentration is summarized in Table 4-1. Because of the poor ability, in general, for SCMs to reduce fecal coliform concentrations, the BMP Database's Project Team recommends that those who want to reduce fecal coliform focus on source controls and on SCMs that reduce fecal coliform load via water volume reduction (Wright Water Engineers 2010). Volume reduction is discussed on page 92.

Nutrients (total nitrogen and total phosphorus)

Phosphorus removal is affected by whether it is bound to particles and if so, to what size particles it is bound. Particle-bound phosphorus is primarily removed through sedimentation and filtration. Most phosphorus in a system can be located on the dominant size of soil particle in that system, so for effective phosphorus removal, SCMs should be designed to remove particles at least as small as the dominant size. Care should be taken periodically to remove captured particles if possible, as variations in pH, oxidation-reduction potential, and bacterial community composition in the surrounding water can reintroduce captured particles by transforming sediment-bound phosphorus into soluble phosphorus. In SCMs with underdrains, care should be taken

Table 4-1. Potential of SCMs to reduce fecal coliform bacteria concentration in stormwater.

SCM category	Fecal coliform removal potential	Theoretical fecal coliform removal mechanisms / reasoning behind proposed removal potential
Bioretention	**High** (Hathaway and Hunt 2008) **Medium** (Wright Water Engineers 2010)	Drying, sun exposure, sedimentation, filtration; no exposed standing water to attract waterfowl and wildlife (Hathaway and Hunt 2008)
Sand filter / media filter	**High** (Hathaway and Hunt 2008) **Medium** (Wright Water Engineers 2010)	Drying, sedimentation, filtration; no exposed standing water to attract waterfowl and wildlife (Hathaway and Hunt 2008)
Grass swale / grass filter strip	**Low** - potential net exporter (Wright Water Engineers 2010; Hathaway and Hunt 2008)	Sedimentation, sun exposure, drying; attractive to dogs, do not necessarily dry out between storms, little sediment sequestration (Hathaway and Hunt 2008)
Stormwater wetland	**Medium** (Hathaway and Hunt 2008)	Sun exposure, sedimentation, some drying (Hathaway and Hunt 2008)
Wet retention pond	**Medium** (Wright Water Engineers 2010; Hathaway and Hunt 2008)	Sun exposure, sedimentation (Hathaway and Hunt 2008)
Dry detention basin	**Medium** (Hathaway and Hunt 2008) **Low** - potential net exporter (Wright Water Engineers 2010)	Drying, sun exposure, sedimentation (Hathaway and Hunt 2008)

with underdrain placement to avoid anoxic or anaerobic conditions, as these can result in the release of phosphorus that is bound to media (Geosyntec Consultants and Wright Water Engineers 2010).

Soluble phosphorus can be removed through the encouragement of adsorption and precipitation via contact with reactive media and soils as well as manipulation of pH. In general, phosphorus is less soluble at a neutral pH than under acidic conditions. Soluble phosphorus can also be taken up by plants, which should be harvested periodically to remove captured phosphorus from the system (Geosyntec Consultants and Wright Water Engineers 2010).

The three dominant forms of nitrogen in stormwater are, in order from highest concentration to lowest, nitrogenous organic solids (leaves and other organic debris), nitrate, and ammonia. Nitrogenous organic solids can be removed by physical separation methods or transformed by ammonification. The success of the former depends on the proportion of nitrogen existing in particulate forms. Nitrate can be removed by plant uptake, requiring periodic harvesting to remove excess nitrogen from the system, or transformed by denitrification. Ammonia can be removed through volatilization or transformed by nitrification. Ammonification, denitrification, and nitrification processes only take place within certain pH ranges (neutral or slightly basic, depending on the process), temperature ranges, and bacterial community compositions (Geosyntec Consultants and Wright Water Engineers 2010).

Table 4-2. Effects of SCMs on nitrogen concentration in stormwater.

SCM category	Effects on nitrogen	Mechanisms and notes
Permeable pavements	• Studies of nutrient removal have mixed results (Hunt and Collins 2008)	
Green roofs	• Increased nitrogen (Hunt and Szpir 2006)	• Likely due to composition of soil media (Hunt and Szpir 2006)
Water harvesting (cisterns/ rain barrels)	• Capture and reuse nitrogen (Hunt and Szpir 2006)	• Roof runoff is potentially rich is atmospheric nitrogen; can be reused for irrigation (Hunt and Szpir 2006)
Bioretention/ rain gardens	• Total nitrogen removal high, but nitrate nitrogen may increase (Hunt 1999) • Bioretention can significantly reduce total nitrogen (Geosyntec Consultants and Wright Water Engineers 2010)	
Sand filters	• Media filters in general show no significant effect on total nitrogen (Geosyntec Consultants and Wright Water Engineers 2010) • Nitrate creators (Hunt 1999)	
Stormwater wetlands	• Remove nutrients more efficiently than wet ponds, including nitrate (Hunt et al. 2007; Hunt 1999) • Wetland basins and channels show no significant change in total nitrogen concentration (based on small number of studies) (Geosyntec Consultants and Wright Water Engineers 2010)	• Microbial processes • Plant uptake (Hunt and Doll 2000) • Volatilization of ammonia • May be rereleased to effluent as plants decay (Geosyntec Consultants and Wright Water Engineers 2010) • Microbes residing in habitat provided by plants remove more nutrients than direct plant update does (Hunt 1999)
Bioswales	• No significant change in total nitrogen concentration (based on small number of studies) (Geosyntec Consultants and Wright Water Engineers 2010)	
Riparian buffers	• Remove nitrate (Hunt 1999)	• Nitrate converted to nitrogen gas by soil microbes (Hunt 1999)
Retention (wet) ponds	• Can significantly reduce total nitrogen (Geosyntec Consultants and Wright Water Engineers 2010)	
Detention (dry) ponds	• Tend to increase total nitrogen (based on small number of studies) (Geosyntec Consultants and Wright Water Engineers 2010)	

Table 4-3. Effects of SCMs on phosphorus concentration in stormwater.

SCM category	Effects on phosphorus	Mechanisms and notes
Permeable pavements	• Studies of nutrient removal have mixed results (Hunt and Collins 2008)	
Green roofs	• Do not show a significant effect on total phosphorus concentration (Geosyntec Consultants and Wright Water Engineers 2010) • Increased phosphorus (Hunt and Szpir 2006)	• Likely due to composition of soil media (Hunt and Szpir 2006)
Bioretention/ rain gardens	• Phosphorus loads increase or decrease (Hunt and Lord 2006) • Do not show a significant effect on total phosphorus concentration (Geosyntec Consultants and Wright Water Engineers 2010)	• Phosphorus loads increase with high P-index fill soils and decrease with low P-index fill soils (Hunt and Lord 2006)
Sand filters	• Very effective at removing sediment adsorbed phosphorus (Hunt 1999) • Media filters in general appear to reduce median total phosphorus (Geosyntec Consultants and Wright Water Engineers 2010)	
Vegetative filter strips	• Do not show a significant effect on total phosphorus concentration (Geosyntec Consultants and Wright Water Engineers 2010)	
Stormwater wetlands	• Remove nutrients more efficiently than wet ponds (Hunt et al. 2007; Hunt 1999) • Appear to reduce median total phosphorus (Geosyntec Consultants and Wright Water Engineers 2010)	• Sedimentation and filtration - soil bound phosphorus • Adsorption - soluble phosphorus • Plant uptake - soluble phosphorus (Hunt and Doll 2000) • Microbes residing in habitat provided by plants remove more nutrients than direct plant update does (Hunt 1999)
Bioswales	• Increase median phosphorus concentration (Geosyntec Consultants and Wright Water Engineers 2010)	• Particulate phosphorus resuspension • Nutrient leaching from soils or applied fertilizers (Geosyntec Consultants and Wright Water Engineers 2010) • Presumably, fill soil selection may influence phosphorus output as with bioretention
Riparian buffers	• Remove phosphorus (Hunt 1999)	• Soil adsorbed phosphorus trapped as buffer vegetation slows water flow • (Hunt 1999)
Retention (wet) ponds	• Appear to reduce median total phosphorus (Geosyntec Consultants and Wright Water Engineers 2010)	
Detention (dry) ponds	• Appear to reduce median total phosphorus, though effluent concentrations are not as low as for other options (Geosyntec Consultants and Wright Water Engineers 2010)	

SCM selection for nitrogen removal depends on the proportion of nitrogen existing in each form. As organic debris is usually the predominant form of nitrogen in stormwater, settling and filtration can be very effective. Biological mechanisms that reduce organic nitrogen depend on aerobic conditions. In contrast, nitrate is best removed under anaerobic conditions, such as can occur stormwater wetlands. Ammonia removal relies on using SCMs with long residence times, where volatilization and microbial processes can occur. Stormwater wetlands are recommended for nitrogen removal, due to long residence times and variable depth zones that allow a variety of microbial processes to occur. More generally, vegetated SCMs are recommended, especially those with permanent pools (Geosyntec Consultants and Wright Water Engineers 2010).

The effectiveness and removal mechanisms of specific SCMs are outlined in Table 4-2 and Table 4-3. In summary, SCMs with sedimentation and filtration processes, as well as those with permanent pools, are recommended for total phosphorus removal; however, resuspension of captured particles and leaching of phosphorus from captured particles, building materials, or landscaping materials can introduce phosphorus into the effluent stream. Nitrogen removal appears to be more complicated, as some devices reduce total nitrogen while increasing organic nitrogen (e.g. retention ponds and wetlands), while others do the opposite (e.g. biofilters and media filters). Because of this, multiple treatment practices using different nitrogen removal mechanisms, one immediately following another, may be more effective at total nitrogen removal than either one in isolation. For both phosphorus and nitrogen treatment, periodic vegetation removal is recommended (Geosyntec Consultants and Wright Water Engineers 2010).

Metals (lead and copper)

The two metals which have exceeded water quality standards during ongoing water quality sampling in the target watersheds are lead and copper (Brown and Caldwell 2011). Common sources of copper in stormwater include building materials, paints, wood preservatives, algaecides, and brake pads; sources of lead include paint, batteries, and gasoline, especially from before the lead gasoline phase-out. In general, pavement is usually the primary source of elevated metal concentrations (Wright Water Engineers and Geosyntec Consultants 2011a). To reduce metals, SCMs should target runoff from pavement.

Metals can exist in dissolved or particulate form. A significant portion of copper exists in the dissolved form (especially under acidic conditions), but most metal in stormwater is associated with organic debris, such as that found on rooftops and pavement. Reducing particulates from the water stream, which is primarily done by sedimentation and filtration -- can reduce lead substantially and copper somewhat. Unlike nutrients, metals appear likely to remain strongly bound to sediments when trapped within SCMs for extended periods of time. Increased retention times are correlated with reduced metal toxicity. Dissolved metals can be removed by sorption and precipitation processes. Soluble metals such as copper can also be taken up by plants, though it appears that copper tends to remain in roots rather than moving to foliage, making

Table 4-4. Metal removal from stormwater by SCMs

SCM category	Metal removal abilities	Mechanisms and notes
Permeable pavements	• Remove heavy metals (Hunt and Collins 2008) • Reduce total copper and total lead (Wright Water Engineers and Geosyntec Consultants 2011a)	
Bioretention areas	• Remove metals (Hunt and Lord 2006) • Reduce total lead and total copper (Wright Water Engineers and Geosyntec Consultants 2011a)	• Metal removal occurs in top 18 inches or less of fill soil (Hunt and Lord 2006)
Sand filters	• High metal removal (Hunt 1999) • Media filters in general reduce total copper, total lead, and dissolved lead (Wright Water Engineers and Geosyntec Consultants 2011a)	
Vegetative filter strips	• Reduce total copper, dissolved copper, total lead, and dissolved lead (Wright Water Engineers and Geosyntec Consultants 2011a)	
Stormwater wetlands	• Remove metals (Hunt and Doll 2000) • Wetland basins reduce total copper • Wetland channels appear to reduce total copper, but not statistically significant • Wetland basins and channels reduce total lead (Wright Water Engineers and Geosyntec Consultants 2011a)	• Adsorption to soil particles (Hunt and Doll 2000) • Plant uptake of dissolved copper (Wright Water Engineers and Geosyntec Consultants 2011a)
Bioswales	• Reduce total lead and total copper (Wright Water Engineers and Geosyntec Consultants 2011a)	
Grass swales	• Can reduce metal concentrations, but captured metals may be reintroduced to effluent (Wright Water Engineers and Geosyntec Consultants 2011a)	• Reduction mechanisms: sedimentation, infiltration, biological uptake • Reintroduction via scouring (Wright Water Engineers and Geosyntec Consultants 2011a)
Retention (wet) ponds	• Reduce total copper, dissolved copper, and total lead (Wright Water Engineers and Geosyntec Consultants 2011a)	
Detention (dry) ponds	• Reduce total copper, dissolved copper, and total lead (Wright Water Engineers and Geosyntec Consultants 2011a)	

removal from the system difficult (Wright Water Engineers and Geosyntec Consultants 2011b). Table 4-4 presents a summary of metal removal by SCMs.

Total suspended solids and turbidity

Suspended solids are sediment that is suspended in the water column. Turbidity, which is an indication of light scattering, is influenced by both suspended sediment and organic matter. Most SCMs provide significant removal of sediments through filtration and settling. Every SCM category for which data exists in the BMP Database was found to be effective at reducing both total suspended solids and sediment (Geosyntec Consultants and Wright Water Engineers 2011). One cautionary note: many SCMs are effective at reducing suspended sediments initially but are susceptible to clogging in the long term. Please see page 79 for an overview of protecting vulnerable SCMs from the risk of clogging.

While numerous options for sediment removal exist, the following recommendations may improve sediment removal. First, filtration and sedimentation based SCMs must be well designed, installed, and maintained. Second, sediment removal is expected to improve by increasing the amount of time water remains in the SCM to be treated. Residence time can be increased in wetlands and ponds by lengthening the flow path using berms, baffles, and dense vegetation. Once sediment is captured, scour and resuspension of solids should be minimized or sediments will be carried downstream during large storm events (Geosyntec Consultants and Wright Water Engineers 2011).

Conductivity

Conductivity indicates water's ability to pass an electrical current. It is influenced by inorganic dissolved solids and organic compounds within the water column. Inorganic compounds raise conductivity. Some ions that can positively affect a conductivity measurement include chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron, and aluminum. In contrast, organic compounds like oil do not carry an electrical current well, so they decrease conductivity (US EPA 2012).

Because some pollutants increase conductivity while others decrease it, it is difficult to specify a target conductivity range for healthy streams. In addition, conductivity is highly dependent upon the geology of an area; for example, streams with a lot of granite tend to have low conductivity. Rather than using conductivity as an absolute measure of stream health, more information can be gained by comparing individual sampling events and locations within a stream to a baseline determined by repeated sampling of that stream. Such a comparison can provide information about whether pollution inputs to a stream have changed over time or whether an individual location varies from the stream as a whole (US EPA 2012).

While these conductivity differences may indicate concerns about water quality inputs in some stream locations, they do not directly reveal the nature of the potential problems. Recommendations for SCMs to treat conductivity issues in these areas cannot be made unless more is known about the cause of elevated conductivity. For example, different treatment emphasis may be appropriate for elevated nitrate than elevated metal ions, but both types of inputs increase conductivity.

pH

PH indicates whether water is acidic or basic. Neutral water has a pH of 7, with lower pH values indicating acidity. PH can be reduced by minerals in the soils or building materials over which it flows, including concrete (Wright Water Engineers and Geosyntec Consultants 2011a). Permeable pavement can buffer pH, likely due to minerals in the paving materials and aggregate (Hunt and Collins 2008). Presumably, other SCMs that use similar aggregate and other materials could have a similar affect.

Knowing the pH of water in an area can affect treatment choices related to the removal of other pollutants. For example, under acidic conditions (low pH), most metals are more likely to be found in dissolved forms rather than in particulates. As pH increases, metals are increasingly likely to become adsorbed to particles (Wright Water Engineers and Geosyntec Consultants 2011a). Similarly, phosphorus is more than 80 percent soluble at a pH of 6 but less than 1 percent soluble at a pH of 8, so it tends to precipitate onto particles at a high pH (Geosyntec Consultants and Wright Water Engineers 2010). For settling to be an effective removal mechanism for metal or phosphorus pollution in an acidic water stream, it may be necessary to first reduce the water's acidity. Other pollutants are best removed at in a certain pH range in all forms. Nitrogen removal processes (denitrification, ammonification, volatilization, and nitrification) occur at optimal rates under neutral or slightly basic conditions (Geosyntec Consultants and Wright Water Engineers 2010). On the other hand, bacteria tend to thrive near neutral conditions (pH 6.5 to 7.5) (Wright Water Engineers 2010), so exposure to low pH may be beneficial for bacteria removal.

Given these pH ranges, one could imagine a hypothetical treatment train targeting pH, bacteria, metals, and nutrients. It would begin with SCMs that target bacteria and dissolved forms of metal and phosphorus, next introduce materials that can neutralize the water, and finally use SCMs that encourage nitrogen removal processes as well as settling and filtration to remove particulate metals and phosphorus.

Runoff volume

While runoff volume reduction as part of restoring the predevelopment hydrologic cycle of a watershed is an important function of SCMs on its own, it has the added benefit of assisting with water quality improvement, as well. As previously indicated, reducing stormwater volumes can reduce the pollutant load delivered to receiving waters, even in some cases when pollutant concentration increases after passing through an SCM. This function of volume reduction is especially important for pollutants like fecal coliform for which SCMs offer limited concentration removal options (Wright Water Engineers 2010).

The BMP Database project team offered the following recommendations for reducing stormwater volumes. First, normally-dry vegetated SCMs (filter strips, vegetated swales, bioretention, and grass lined detention basins) have substantial potential for volume reduction on a long term basis. These SCMs also provide better volume reduction for small storms, which occur more frequently than large storms. On the other hand, permanently wet SCMs like retention ponds and wetland basins and channels do not provide substantial volume reduction and so should not be used to fulfill volume reduction objectives. Finally, site conditions play a significant role in volume reduction performance. For example, soils with poor infiltration can result in lower volume reductions than what is typical for a certain SCM type (Wright Water Engineers 2011).

Conclusion

The information above presents a qualitative overview of SCM pollutant removal abilities. For quantitative information about the amount of pollution that existing SCMs have removed, please see the BMP Database's performance summary table (Wright Water Engineers and Geosyntec Consultants 2011b) and the technical papers referenced within each section above.

Chapter 5:
Watershed Characterization Analyses

This section includes analyses that rank potential stormwater management needs and opportunities throughout the three target watersheds.

Organization

Analysis overview

The recommendations given in chapter 7 are based on several weighted overlay analyses conducted using ArcMap. The first two analyses, described in this chapter, are those which characterize the target watersheds in ways that apply to all SCMs. The potential SCM needs analysis identifies regions where site characteristics are indicative of potential stormwater problems. The second analysis indicates opportunities for SCM installation based on property ownership. SCM specific suitability and prioritization analyses are described in the following chapter.

This chapter provides an overview of each analysis, including the data used, weighting factors when combining data, and the reasoning behind each decision. Specific technical details are given in the appendix.

The analysis zones that are indicated on maps throughout this and subsequent chapters are based on the results of the needs analysis output. These zones form the organizational structure of chapter 7, where stormwater management recommendations are given.

All raster analyses use a 1/3 arcsecond grid cell size (approximately 31 feet), except where otherwise noted. This size was determined by the finest resolution digital elevation model available from the National Elevation Dataset, which underlies all flow accumulation calculations and catchment boundaries used for these analyses.

Potential SCM needs

The potential SCM needs overlay combines five factors: two indicators of impervious surface coverage, slope, soil erodibility, and water quality. These five factors were given equal weight in the analysis. Giving the five layers equal weight, when two of the layers relate to impervious surface coverage, results in impervious surfaces influencing this analysis twice as much any of the other three factors. The double weight given to impervious surfaces in the analysis is reasonable, given that the presence of impervious surfaces is what disrupts the hydrologic cycle and generates excess stormwater runoff. Also, impervious surfaces are the source of metal pollution, which is a known concern in the target watersheds. Each of the layers in the potential SCM needs analysis is described below.

Percent impervious

The percent of impervious surface coverage was calculated for each catchment in the study area Figure 2-7, based on all impervious surface types shown in Figure 2-24 (see appendix). For this layer, values were assigned on a scale of 1 to 10, with 10 indicating the catchments with the highest percentage of impervious surface cover.

Percent impervious	Overlay value	Percent impervious	Overlay value
31-34	1	50-54	6
34-38	2	54-58	7
38-42	3	58-62	8
42-46	4	62-66	9
46-50	5	66-70	10

Flow-weighted distance from impervious surfaces

The second impervious surface layer is a combination of two separate measurements: the distance of every cell on the map from the nearest impervious surface, and the flow accumulation of the drainage network where it intersects those surfaces.

Including distances from the nearest impervious surface reflects the emphasis that LID places on controlling stormwater near its source, or in other words, near impervious surfaces. Distances, up to 100 feet, were assigned values from 1 to 10, with 10 indicating land at or near an impervious surface.

Distance (feet)	Overlay value	Distance (feet)	Overlay value
0-10	10	50-60	5
10-20	9	60-70	4
20-30	8	70-80	3
30-40	7	80-90	2
40-50	6	90-100	1

Flow accumulation (Figure 2-9) was taken into account based on the assumption that impervious surfaces within natural drainage ways are more likely to disrupt the natural hydrologic cycle. In addition, existing conventional stormwater infrastructure (e.g. catch basins and drop inlets, (Figure 2-18), which are usually located on or along side existing impervious surfaces, are located where they were needed historically for stormwater control due to high flow volumes. The final opportunity to treat stormwater before it is taken directly to the stream by storm sewers is through the installation of SCMs immediately upstream of these conventional inlets.

Assigning flow accumulation values to impervious surfaces was a multistep process (see appendix for technical details). First, flow accumulation was assigned values from 1 to 10, with 10 indicating flow accumulation above the primary drainage cutoff that was used for catchment delineation (Figure 2-10), and all other values determined using a geometric interval. Second, a layer was created that included all impervious surfaces except roads and sidewalks. Roads and sidewalks were excluded due to their length and linear nature -- a given road or sidewalk could cover a long distance and cross the drainage network at many locations, making it hard to assign meaningful flow accumulation values to these features. Third, impervious surfaces were spatially joined with flow accumulation data, resulting in each surface being assigned the highest flow

Flow accumulation (cells)	Overlay value	Flow accumulation (cells)	Overlay value
0-92	1	513-682	6
93-168	2	683-890	7
169-260	3	891-1144	8
261-374	4	1145-1528	9
375-512	5	> 1528	10

accumulation value (from 1 to 10) that intersects it. Next, a 100 foot buffer was created around each surface, to account for the fact that most SCMs are near impervious surfaces, rather than on them. The 100 foot buffer was assigned the same flow accumulation value as the surface it surrounds. Finally, these data, including impervious surfaces and their buffers, were converted to a raster for use in a weighted overlay. Where multiple data points overlapped a single cell, the highest flow accumulation value encountered was used for that cell.

Note that exclusion of roads and sidewalks from the second step in the previous paragraph does not exclude them entirely from the flow-weighted distance analysis; it only excludes them from being assigned a flow accumulation overlay value based on the streams they intersect, since their highest flow accumulation intersecting drainage could be hundreds of feet or even over a mile away. Instead, due to the combination of the distance and buffer functions described above, assigned flow accumulation overlay values will vary along the length of a road or sidewalk based on drainages intersected by other impervious surfaces (e.g. buildings, parking lots) within a 100 foot radius.

These two data sets were combined in a weighted overlay (equal weight). Any area missing data on either layer (i.e. locations further than 100 feet from an impervious surface) were assigned a value of 1 on both layers to avoid holes in the resulting raster. The resulting raster had values ranging from 1-10. A value of 10 indicates a location that is very close to an impervious surface that intersects a drainage with high flow; in contrast, a value of 1 indicates a location that is relatively far from impervious surfaces (at least 90 feet) and where nearby impervious surfaces intersect areas of very low flow accumulation. The combined layer (distance from impervious surfaces, weighted by flow accumulation) makes up one fifth of the potential SCM needs overlay.

Slope

Slope was included in the potential SCM needs analysis because steep slopes lead to high water velocity, which increases the risk of erosion and reduces the ability of runoff to infiltrate the soil. Slope was calculated based on 2 foot contour intervals (Figure 2-14). Several sources categorized slopes above 15 percent as steep and from 7 to 15 percent as moderately steep (e.g. Hunt 2009), so those ranges were used as a guideline for assigning overlay values. Overlay values ranged from 1 to 10, with 10 indicating a slope greater than 15 percent. Slopes less than 15 percent were divided equally into the remaining overlay values.

Slope (percent)	Overlay value	Slope (percent)	Overlay value
0-1.67	1	8.33-10.0	6
1.67-3.33	2	10.0-11.67	7
3.33-5.0	3	11.67-13.33	8
5.0-6.67	4	13.33-15.0	9
6.67-8.33	5	> 15.0	10

In addition to being calculated for individual cells, slope was also averaged for each catchment, and then reclassed using the same values above. Then, the two slope layers were combined using a weighted overlay with equal influence. This combination layer is what was used in the overall potential SCM needs analysis.

Soil erodibility

Soil erodibility is based on the erosion factor (Kw) identified by the NRCS for each soil type within the study area (Figure 2-17). There are a total of 14 Kw values. Overlay values from 1 to 10 were assigned to all 14 possible Kw values as shown. Kw values that exist within the target watersheds are starred(*). The small area within the target watersheds identified by the NRCS as a pit or quarry was assigned an overlay value of 1, assuming low erodibility. The area misidentified as water (the UGA Coliseum) was assigned a moderate overlay value of 5 to avoid a hole in the resulting data, in the absence of other information.

Kw	Overlay value	Adjusted overlay value	Kw	Overlay value	Adjusted overlay value
0.02	1	--	0.28*, 0.32*	6	8
0.05	2	--	0.37*, 0.43*	7	10
0.10*	3	2	0.49	8	--
0.15	4	--	0.55	9	--
0.20*, 0.24*	5	6	0.64	10	--
No Kw (pit*)	1	1	No Kw (water*)	5	6

Within the target watershed, the most erodible soils have a Kw of 0.43 (overlay value 7), and the least erodible soils have a Kw of 0.10 (overlay value 3). These overlay values were adjusted to emphasize differences among sites. The overlay value for the most highly erodible soils within the target watersheds (Kw = 0.37, 0.43) was adjusted upward from 7 to 10. The relative spacing between this and lower overlay values was maintained, but the magnitude of the difference was doubled. For example, the one step difference between the original overlay values 7 and 6 became a two step difference between the adjusted overlay values 10 and 8. The overlay value for the area labeled as a pit was not adjusted, because 1 is already the lowest possible value and the reasoning behind assigning a value of 1 still holds after adjustment of the other values.

Water Quality

Many of the specific water pollution sources within the three target watersheds are unknown. The campus watersheds team is working on identifying pollution sources as part of its watershed improvement plan. As a result, the water quality layer included in the potential SCM needs analysis does not indicate specific pollution sources. Instead, it reflects the water quality values recorded during ongoing stream monitoring at all downslope sampling points, weighted by the inverse of the distance from each. The distance weighting can be thought to reflect the relative influence a particular point has on water quality at downstream sampling locations. A high pollutant level value on the water quality layer indicates that a given location is part of a catchment that is producing high levels of pollution, and that treating pollution problems if they are found at that location would help address water quality issues at problem areas downstream. The technical details of this process are described in the appendix.

While all of the water quality data presented in chapter 2 were considered for final treatment recommendations (chapter 7), only fecal coliform, copper, lead, total suspended solids (TSS), and pH were included in the analysis of potential SCM needs. Four of these parameters (fecal coliform, copper, lead, and pH) were included because water quality standards are available to provide a benchmark against which measured values can be compared. In addition, while there is no TSS standard in the state of Georgia, meaningful ranges for TSS concentration have been suggested in a Georgia EPD report (GA EPD 2001).

On the other hand, while reference conditions are available for total nitrogen (TN), total phosphorus (TP), and turbidity, reference conditions are not the same as water quality standards (page 48). They correspond with the conditions that have been measured in the 25th percentile stream within each ecoregion for each water quality parameter, rather than to a biologically meaningful pollutant concentration (US EPA 2000). Reference conditions do provide a benchmark for comparison, but may not provide enough information to confidently identify pollution severity (i.e. not just which sites are most polluted for TN, TP, or turbidity, but how polluted are they compared to the severity of other pollutants within the study area?). Conductivity was also excluded from the SCM needs analysis due to lack of water quality standards, and also because its interpretation is nonlinear, in that it can increase or decrease in response to increased pollution, depending on the type of pollution (page 60).

For the five water quality parameters that were included in the potential SCM needs analysis (fecal coliform, copper, lead, TSS, and pH), only the results of wet weather sampling were used. Wet sampling results are more likely to be influenced by stormwater, whereas dry weather sampling is more likely to indicate ongoing water quality problems such as ground water contamination or persistent leaks. Finally, while cold season fecal coliform measurements were used in the analysis, warm season fecal coliform data were not. Warm season, wet weather measurements were excluded because recorded values were both very high and highly variable across all sites; as every site would have received an overlay value of 10, inclusion of warm season fecal coliform data would have failed to add any information to distinguish among sites.

Overlay values for the five pollutants were determined separately, then combined into one water quality layer using a weighted overlay, with equal weight given to each pollutant (see appendix). The resulting water quality layer had overlay values of 6, 7, and 8, indicating moderate to moderately high impairment throughout the target watersheds. This pattern is as expected, for two reasons. First, with the exception of fecal coliform bacteria, the water quality measurements used indicated unimpaired to moderately impaired streams. Second, different pollutants followed different patterns within the watershed (page 64). Some pollutants were high at the same sampling points where others were low.

TSS, wet (mg/L)	Overlay value	Explanation
20 - 25	5	not impaired (division size is one fifth the impairment indicator, as with the other four contaminants)
25 - 50	6	moderate impairment, below the impairment indicator used by some other states
50 - 80	7	moderate impairment, above the impairment indicator used by some other states

Fecal coliform, cold/wet (colonies per 100 mL	Total copper, wet (µg/L)	Total lead, wet (µg/L)	pH*, wet	Overlay value	Explanation
0 - 200	--	--	--	1	Below the water quality standard, divisions are each one fifth of the standard.
200 - 400	--	--	6.40 - 6.70	2	
400 - 600	--	0.48 - 0.72	6.22 - 6.40	3	
600 - 800	3 - 4	0.72 - 0.96	6.10 - 6.22	4	
800 - 1000	4 - 5	0.96 - 1.20	6.00 - 6.10	5	
1000 - 2000	5 - 10	1.20 - 2.40	5.55 - 6.00	6	Above the water quality standard, divisions are multiples of the standard.
2000 - 3000	10 - 15	--	--	7	
3000 - 4000	15 - 20	--	--	8	
4000 - 5000	20 - 25	--	--	9	
> 5000	> 25	--	--	10	

*pH divisions were calculated based on hydrogen ion concentration, relative to pH 7 (neutral water).

To emphasize differences among locations, overlay values for the combined water quality layer were adjusted using a similar process to that used for soil erodibility (page 98). The highest overlay value was changed to 10. The relative interval between groups was maintained, but the magnitude was increased. In this case, the magnitude of differences was tripled, resulting in a minimum adjusted overlay value of 4, which still indicates moderate overall water quality -- not highly impaired overall, but not pristine. Two small areas within the Lilly Branch and Tanyard Creek watersheds, closest to the North Oconee River, contribute only to the stream sections that fall downstream of all monitoring points. These locations were assigned an adjusted overlay value of 5, so that they would be included in the final SCM needs analysis without strongly influencing it.

Combined water quality overlay value	Adjusted overlay value
6	4
7	7
8	10
No Data	5

Result

The two water quality layers, slope, soil erodibility, and water quality were combined in a weighted overlay, with equal influence. Because the objective of this process was to identify general target zones, rather than precise locations, majority filter and boundary clean processes were used to smooth zone edges (see appendix). In addition to simplifying visual interpretation of the resulting map, these processes also make sense from a stormwater management perspective, as SCMs may be more suitable upslope or downslope of a potential problem area rather than within it. Potential SCM needs are shown in Figure 5-1.

Interpreting potential SCM needs

An area shown in Figure 5-1 as having high potential SCM needs has or is near a location with the a high combination of steepness, percent impervious surface coverage (catchment-wide), proximity to impervious surfaces that intersect the natural drainage pattern, soil erodibility, and water pollution (catchment-wide), relative to other locations. SCMs used to address these problems may be located within these target areas where site conditions permit, but in some cases, it may be necessary to treat stormwater runoff either before it enters or after it leaves these areas.

Six analysis zones were identified visually based on stream locations, watershed and catchment boundaries, and the pattern of potential SCM needs (Figure 5-2). These analysis zones are shown on maps throughout the remainder of the analysis section and are used as the organizing feature of the recommendations chapter (chapter 7). The analysis zones with the highest overall potential SCM needs are North Campus/Downtown, PPD, and Lilly West. Zones with relatively low potential SCM needs include West Broad, Central, and Lilly East.

Potential SCM needs

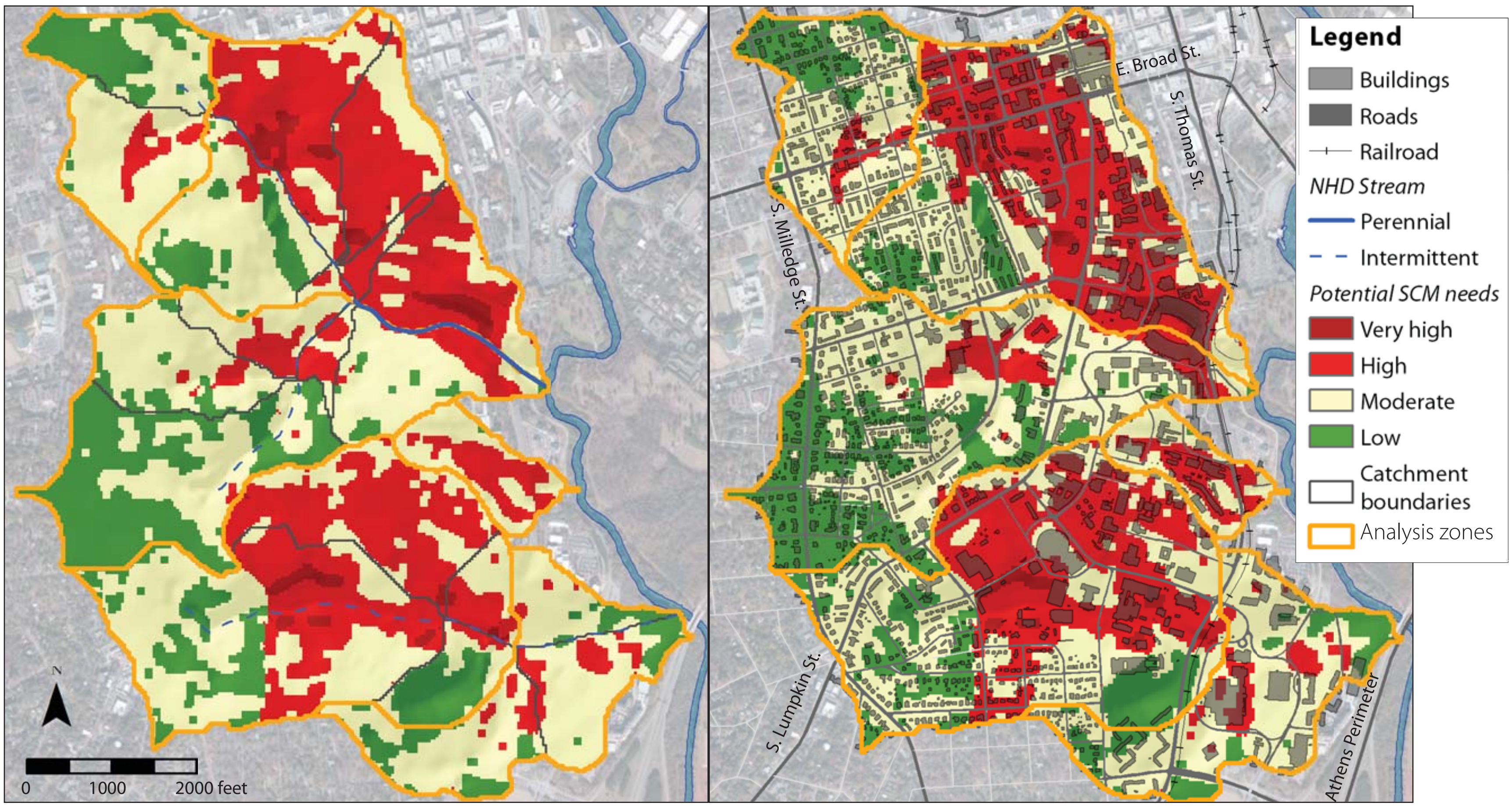

Figure 5-1. Potential SCM needs, based on slope, impervious surface cover, soil erodibility, and water quality. The process by which potential SCM needs were calculated is described beginning on page 95 . The analysis zones shown were identified visually based on catchment boundaries and distinct high need areas. These analysis zones were used for the recommendations in chapter 7.

Analysis zones

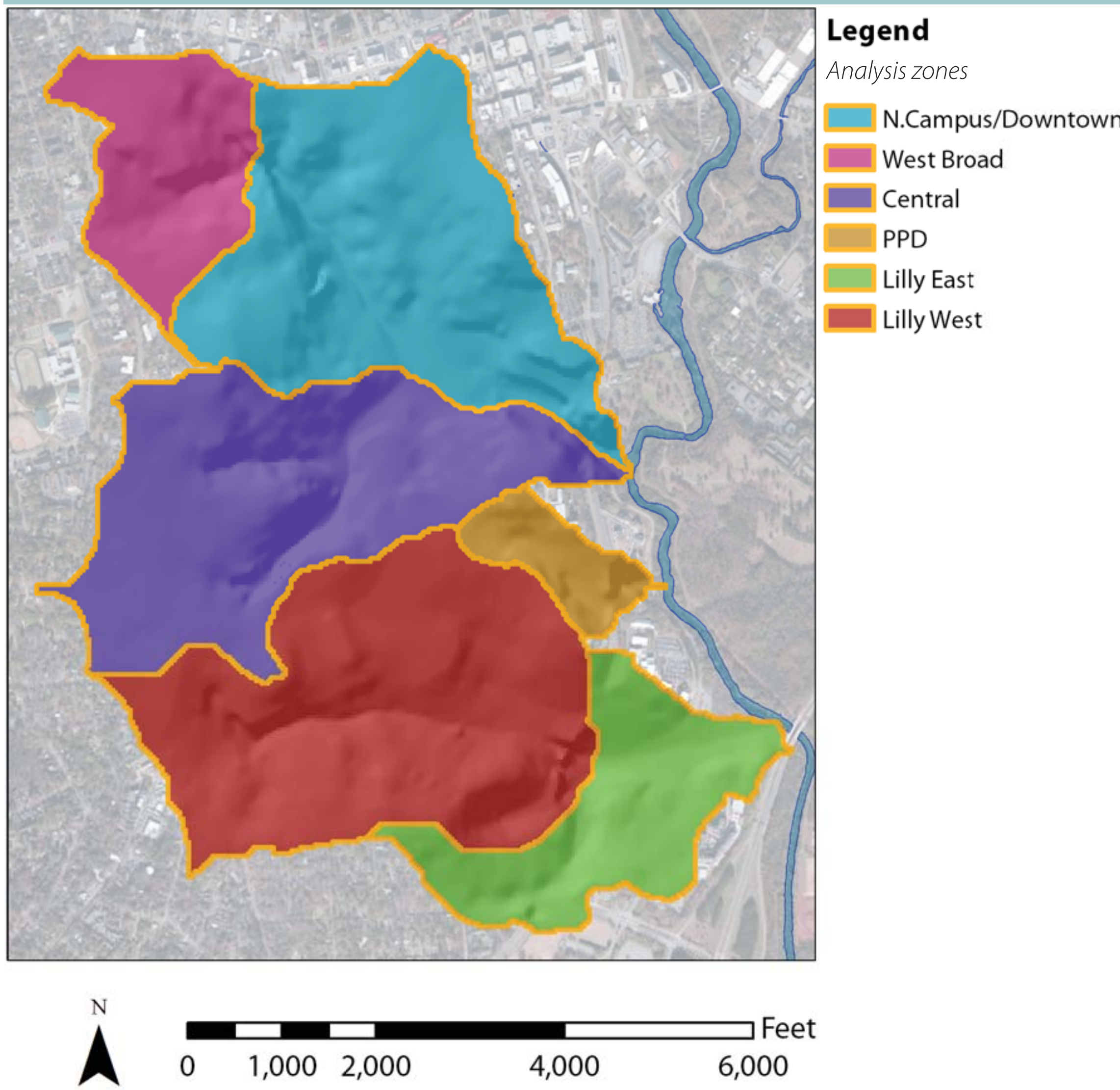

Figure 5-2. Analysis zones.

These analysis zones are used throughout the analysis and recommendations sections of this report (chapters 6 and 7). Zones were determined visually based on catchment and watershed boundaries, stream locations, and the results of the potential SCM needs analysis (Figure 5-1).

Opportunities for SCM installation

The opportunities layer (Figure 5-3) reflects the feasibility of installing SCMs within the watershed, based on property ownership and zoning. Properties owned by organizations with representatives on the campus watersheds team (UGA and Athens-Clarke County) were considered to be most feasible. Parcels not owned by these organizations, but where collaboration opportunities may be high were assigned moderate overlay values. Private property was considered to have the lowest opportunity for installation, not because SCMs necessarily physically difficult to install there, but that installation may depend on educational outreach or other interactions with individual small landholders. Details about and rationale for assigned overlay values are given on the following page. A high opportunities overlay value indicates relatively few obstacles to and high opportunities for SCM installation. Areas with low opportunities overlay values may present more challenges or require more effort, but they should not be entirely eliminated from consideration.

Areas of high SCM opportunity are primarily located on the eastern half of the study site, which is covered by the UGA main campus. Ownership based opportunities are lower on the western half of the study area and downtown, as these areas are primarily held in private ownership.

Parcel information	Overlay value	Rationale
No Data (e.g. roads)	1	SCMs cannot be installed in the middle of a road.
Cemetery	2	Few locations within a cemetery are suitable for soil disturbance
Lodging; private property (except as indicated below)	3	SCM installation on these parcels will depend on private property owner participation, requiring some combination of education, outreach, collaboration, and incentives.
Private property (residential zones RS-, RM-, and RG-6, except as indicated below)	4	SCM installation on these parcels will depend on private property owner participation, requiring some combination of education, outreach, collaboration, and incentives. Individual residents may be more amenable to these types of property improvements than for-profit business owners.
Multifamily residential	5	The same private property challenges exist here as described above; however, parcels containing apartments and other multifamily units sometimes include unused common areas that are unsuitable for building or parking lot construction and that are currently unused for other purposes. Owners may be open to the installation of aesthetically pleasing SCMs as an added amenity to their complexes.
Railroad right-of-way; Housing Authority	6	Land exterior to the rail line but within the right-of-way usually has no current use except as a buffer around the rail road. The owner of the existing right-of-way has indicated openness to stormwater management in the past (personal communication, Dexter Adams, UGA Grounds Director). The Housing Authority has a public interest, and outside funding opportunities may be available based on the low-income demographic served by the Housing Authority; however, SCM installation will affect open areas where the residents live, which may invite opposition.
Nonprofit organization; religious institution; Greek system	7	These organizations may be open to collaboration (including potential volunteer labor) due to their public interest and community affiliations. In addition, outside funding opportunities may be available to these organizations.
US Government; Piedmont College; Clarke County School District	8	These organizations are not part of the campus watersheds team, but are likely to be open to collaboration based on their government affiliation and/or public interest.
University of Georgia/Board of Regents; Athens-Clarke County	9	The campus watersheds advisory committee consists of representatives from the University of Georgia and Athens-Clarke County.
Hole park	10	The hole park parcel within the target watersheds is an open space affiliated with no private property owner with no current land use.

SCM installation opportunities

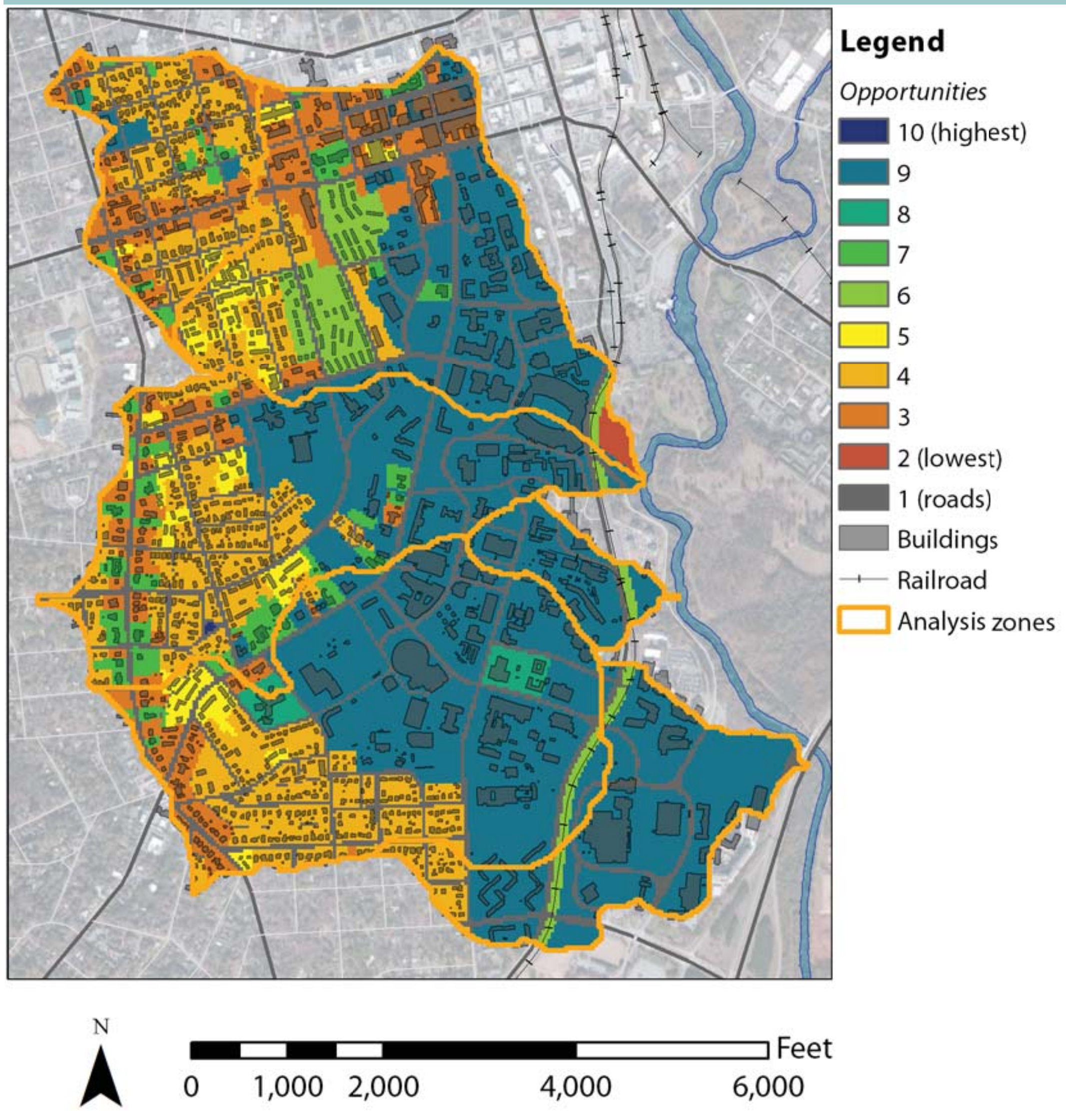

Figure 5-3. SCM installation opportunities, based on property ownership and zoning for each parcel. For more information, please see page 104.

Chapter 6:
SCM-Specific Watershed Analyses

This section includes analyses that rank suitability and priority areas for each SCM category.

Organization

Analysis overview

The recommendations given in chapter 7 are based on several weighted overlay analyses conducted using ArcMap. The first two analyses, potential SCM needs and opportunities, are presented in the previous chapter. This chapter describes two kinds of analyses that are specific to each SCM type. The account of each SCM type begins with an overview its site condition suitability analysis and concludes with its priority areas map, which is the combined result of the potential needs, opportunities, and suitability analyses.

This chapter provides an overview of each analysis, including the data included, weights used when combining data, and the reasoning behind each decision. Specific technical details are given in the appendix.

Suitability and prioritization

Each SCM category has a unique set of design considerations that influence where it can and should be installed, so the suitability of each was analyzed in ArcMap with a separate weighted overlay analysis. Parameters were given equal weight within each suitability analysis.

The results of prioritization analyses indicate where to focus attention when looking for potential sites for each type of SCM, based on where is most likely to be suitable, feasible, and needed. Prioritization maps are the result of a weighted overlay combining SCM suitability (45% weight), potential SCM needs (45% weight) and opportunities (10% weight) layers.

Most SCMs are constructed in the landscape near runoff sources, rather than directly on them. For these types of SCMs (e.g. bioretention, stormwater wetlands), the desired outcome from prioritization analyses was to identify general priority zones. For these types of SCMs, generalization procedures (majority filter and boundary clean) were used to smooth edge zones, reducing image noise. On the other hand, for analyses for which the desired outcome was the identification of specific suitable structures (e.g. rooftop water harvesting, green roofs, porous pavement), these generalization procedures were not used.

Interpreting suitability and prioritization

The objective of the suitability analyses is the identification of general areas where suitable sites for specific SCM types are most likely to be found. Similarly, these prioritization analyses are intended to identify general areas where SCM installation would be most needed, feasible, and suitable. The results of these analyses are not precise enough to identify exact sites for SCMs, nor are they intended to be.

Please bear the following in mind when examining the suitability and prioritization maps on the following pages. First, the images shown in these analyses have a cell resolution of approximately 31 feet, squared. They represent the average condition for each cell. Furthermore, results were geographically generalized in some analyses using majority filter and boundary clean processes as described in the previous section. A label of "unsuitable" or "low suitability" does not rule out the possibility of small, suitable locations within an otherwise unsuitable area. For example, a cell identified as having a steep slope may be steep throughout, but it may also consist of a flat area adjacent to a retaining wall. Likewise, not all sites within an area identified as "high suitability" are necessarily best suited for a given SCM. Interpret suitability recommendations as the relative likelihood of finding suitable sites within a given location, rather than as absolute suitability or unsuitability. Priority area zones should be interpreted in a similarly general manner.

In addition, these suitability and subsequent prioritization analyses do not include all relevant design considerations, either because appropriate data were not available or because those conditions need to be measured or evaluated on an individual site basis (e.g. water table depth, soil infiltration rate, traffic volume). Omitted considerations are listed after each suitability analysis.

Finally, many of the following analyses are depended upon catchment area in acres, which is derived from flow accumulation (Figure 2-9). These catchment areas are approximations, based on the National Elevation Dataset (Figure 2-12). Because of the data source, the data resolution is coarse (approximately 31 feet, squared). In addition, as flow accumulation and catchment area calculations are based on surface elevations, they do not take conventional stormwater infrastructure into account.

Analysis overviews and results

The following pages present a summary of the suitability and prioritization analyses for each SCM type considered. Summaries of suitability analyses begin with a figure displaying analysis results, followed by a list of weighted overlay values, and concluding with a list of site-level design considerations that were not included in the analysis. Each suitability analysis summary is followed immediately by the results of the corresponding prioritization analysis.

Please note that no suitability or prioritization analyses were done for level spreaders. Level spreaders are usually used in combination with other SCM. They are used most often with vegetative filter strips or riparian buffers, but can precede any SCM where conversion of concentrated runoff to sheet flow is desired. As a result, level spreader placement will depend on the location of the SCMs they precede.

Suitability, permeable pavement (conversion of existing parking)

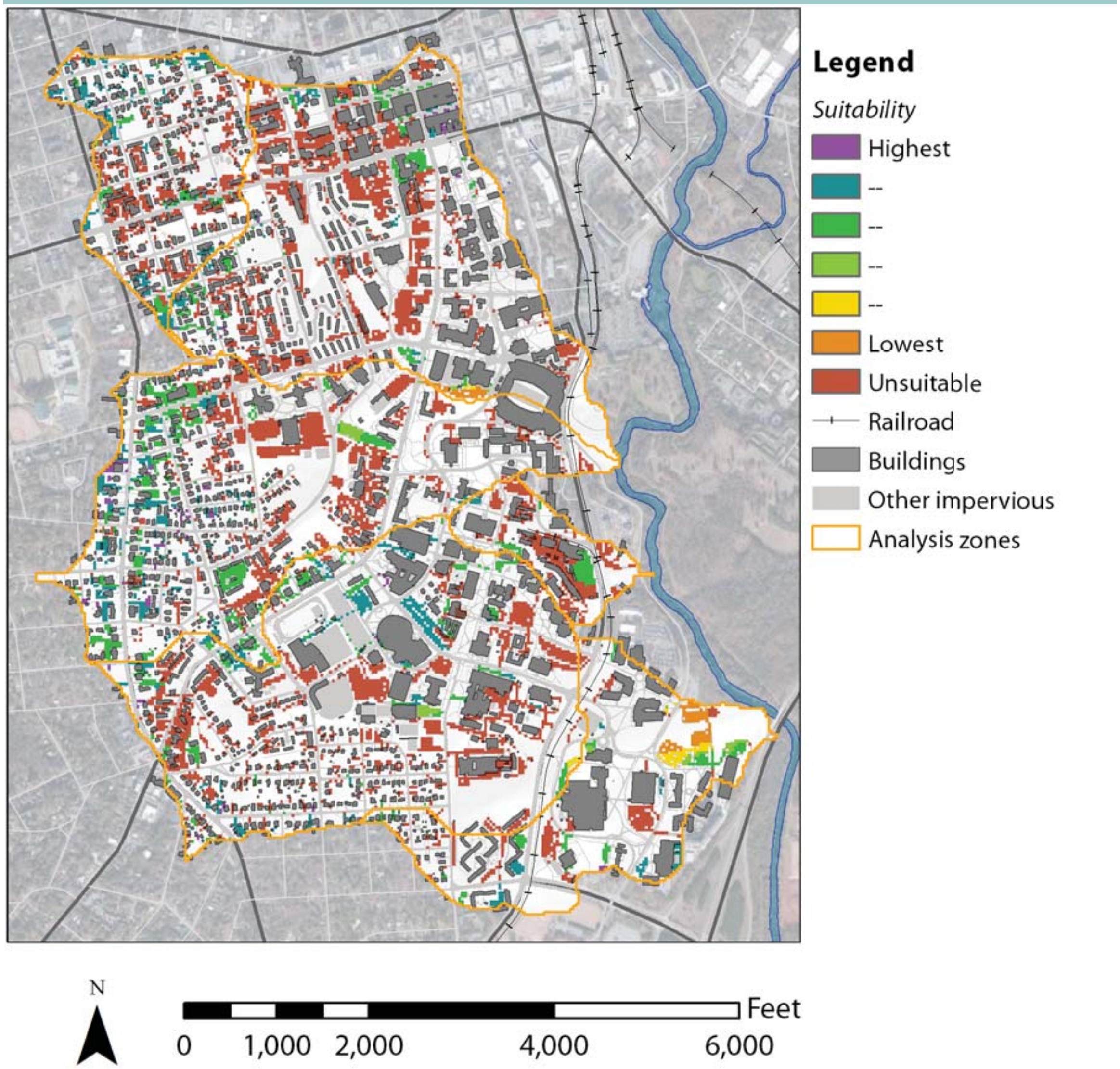

Figure 6-1. Suitability of converting existing parking lots and driveways to permeable pavement, based on site conditions.

Permeable pavement overview: page 69

Conditions included in suitability analysis:

- Slope
- Current status (paved or unpaved)
- Hydrologic soil group
- Flood zone

Weighted overlay values:

Average slope, existing parking lot (percent)	Overlay value	Explanation
0 - 0.5	10	Permeable pavement functions best on flat land. Slopes greater than 5 percent are unsuitable.
0.5 - 1.0	9	
1.0 - 1.5	8	
1.5 - 2.0	7	
2.0 - 2.5	6	
2.5 - 3.0	5	
3.0 - 3.5	4	
3.5 - 4.0	3	
4.0 - 4.5	2	
4.5 - 5.0	1	
> 5.0	Restricted	

Status (from ACC impervious surface data)	Overlay value	Explanation
Unpaved	10	Unpaved parking areas may present opportunities for conversion to permeable pavement if they are paved at a later date, as they will already be under construction.
Paved	6	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	10	Slower draining soil is less suitable for infiltration based SCMs. The NRCS label "pit" (included in "other") encompasses both pits and quarries, so low infiltration was assumed.
B (moderate)	6	
B/D (moderate/very slow)	4	
C/D (slow/very slow)	2	
Other	1	

Flood zone	Overlay value	Explanation
100 year flood zone	2	Flood zone data are used as a partial surrogate for water table depth, in that the water table is likely to be high within a flood zone.
500 year flood zone	4	
Outside of flood zone	10	

Considerations omitted from suitability analysis: When considering potential pavement conversion projects, the following additional design considerations should be evaluated at the site level.

- Soil infiltration rate
- Traffic volume, traffic speed, turnover rate, and the type (weight) of vehicles that are most likely to park or drive there
- Water table depth, especially if an underdrain system is needed

- The presence of overhanging vegetation or upslope sediment sources, due to clogging risk
- Future plans for each parking area (e.g. is it scheduled for removal?)
- The location of water pollution sources, especially for pollution concerns that can be improved with permeable pavement (e.g. copper, lead, pH)

Priorities, permeable pavement (conversion of existing parking)

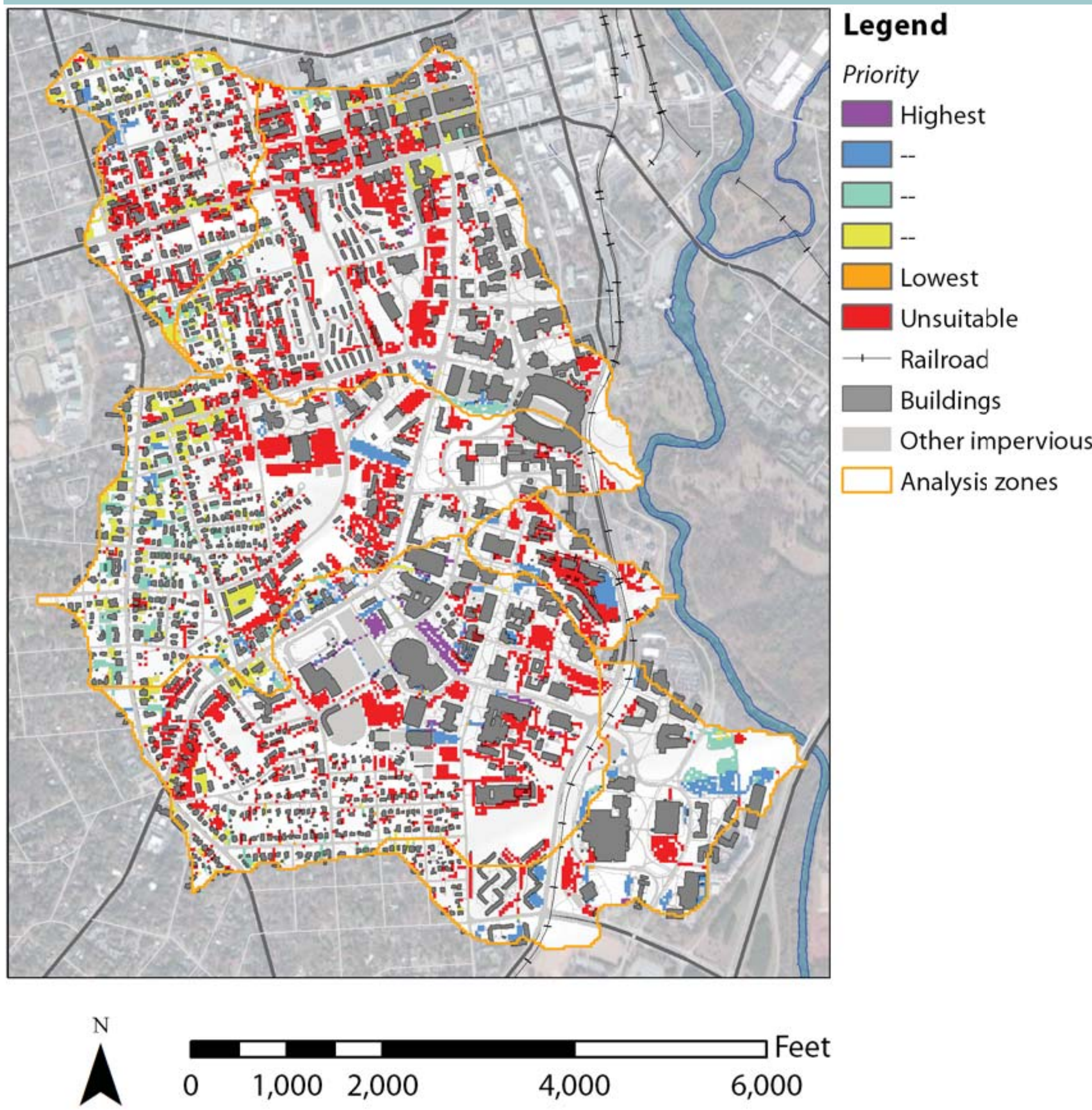

Figure 6-2. Priority areas for converting existing parking lots and driveways to permeable pavement, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where conversion to permeable pavement is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, permeable pavement (general)

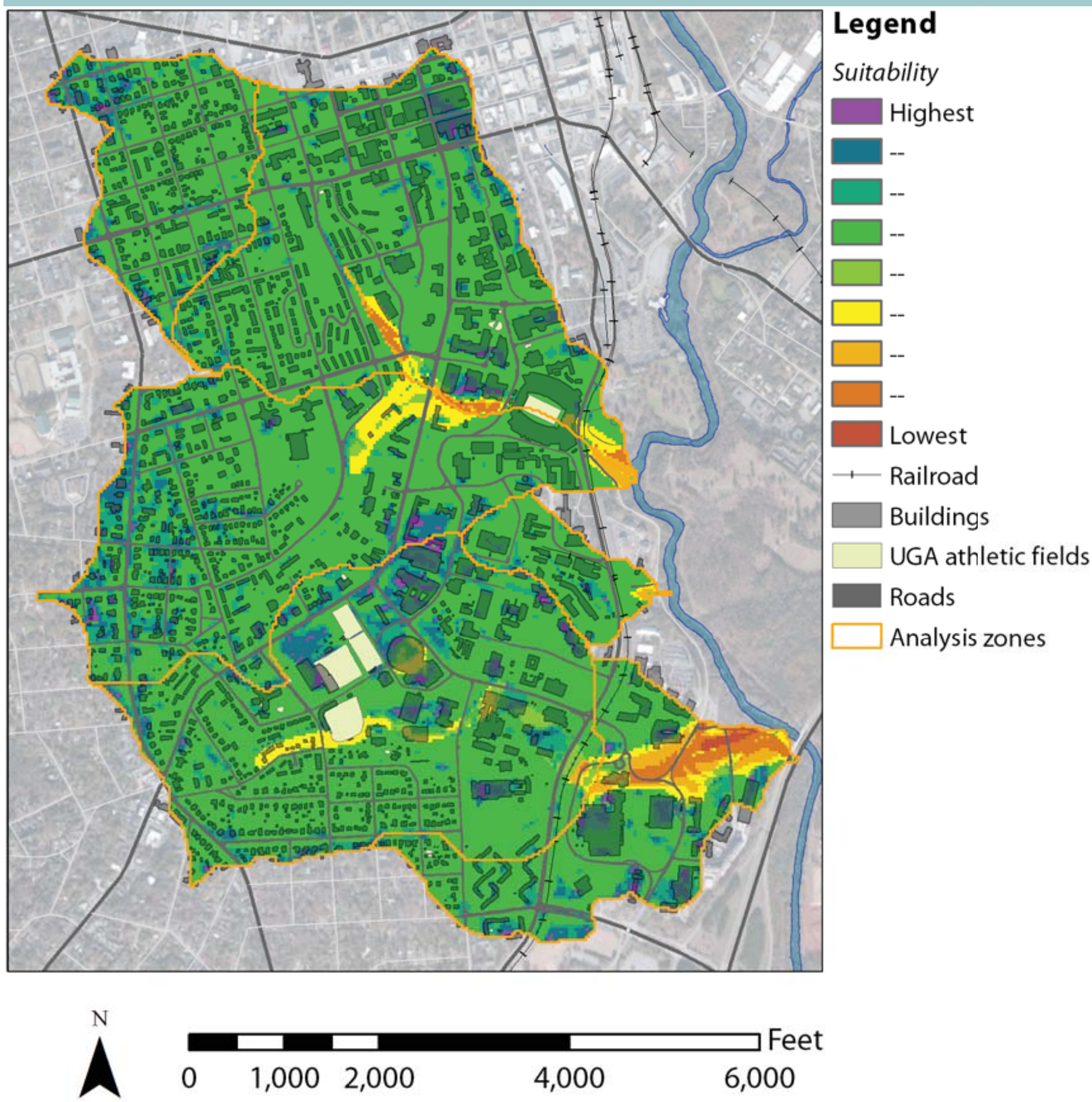

Figure 6-3. Suitability of installing permeable pavement, based on site conditions.

Permeable pavement overview: page 69

Conditions included in suitability analysis:

- Slope
- Hydrologic soil group
- Flood zone

Weighted overlay values:

Average slope, existing parking lot (percent)	Overlay value	Explanation
0 - 0.5	10	Permeable pavement functions best on flat land, up to 5 percent slope. In contrast with the previous analysis, slopes steeper than 5 percent were given the lowest overlay value instead of being restricted as unsuitable. This difference is to allow for the possibility of small, flat areas (smaller than the cell resolution of approximately 31 feet, squared) within overall steep areas, where small permeable pavement projects like sidewalks or patios may be appropriate.
0.5 - 1.0	9	
1.0 - 1.5	8	
1.5 - 2.0	7	
2.0 - 2.5	6	
2.5 - 3.0	5	
3.0 - 3.5	4	
3.5 - 4.0	3	
4.0 - 4.5	2	
> 4.5	1	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	10	Slower draining soil is less suitable for infiltration based SCMs. The NRCS label "pit" (included in "other") encompasses both pits and quarries, so low infiltration was assumed.
B (moderate)	6	
B/D (moderate/very slow)	4	
C/D (slow/very slow)	2	
Other	1	

Flood zone	Overlay value	Explanation
100 year flood zone	2	Flood zone data are used as a partial surrogate for water table depth, in that the water table is likely to be high within a flood zone.
500 year flood zone	4	
Outside of flood zone	10	

Considerations omitted from suitability analysis: When considering potential permeable pavement projects, the following additional design considerations should be evaluated at the site level.

- Soil infiltration rate
- Traffic volume, traffic speed, turnover rate, and the type of traffic (e.g. vehicular, pedestrian)
- Water table depth, especially if an underdrain system is needed
- The presence of overhanging vegetation or upslope sediment sources, due to clogging risk
- The location of water pollution sources, especially for pollution concerns that can be improved with permeable pavement (e.g. copper, lead, pH)

Priority areas, permeable pavement (general)

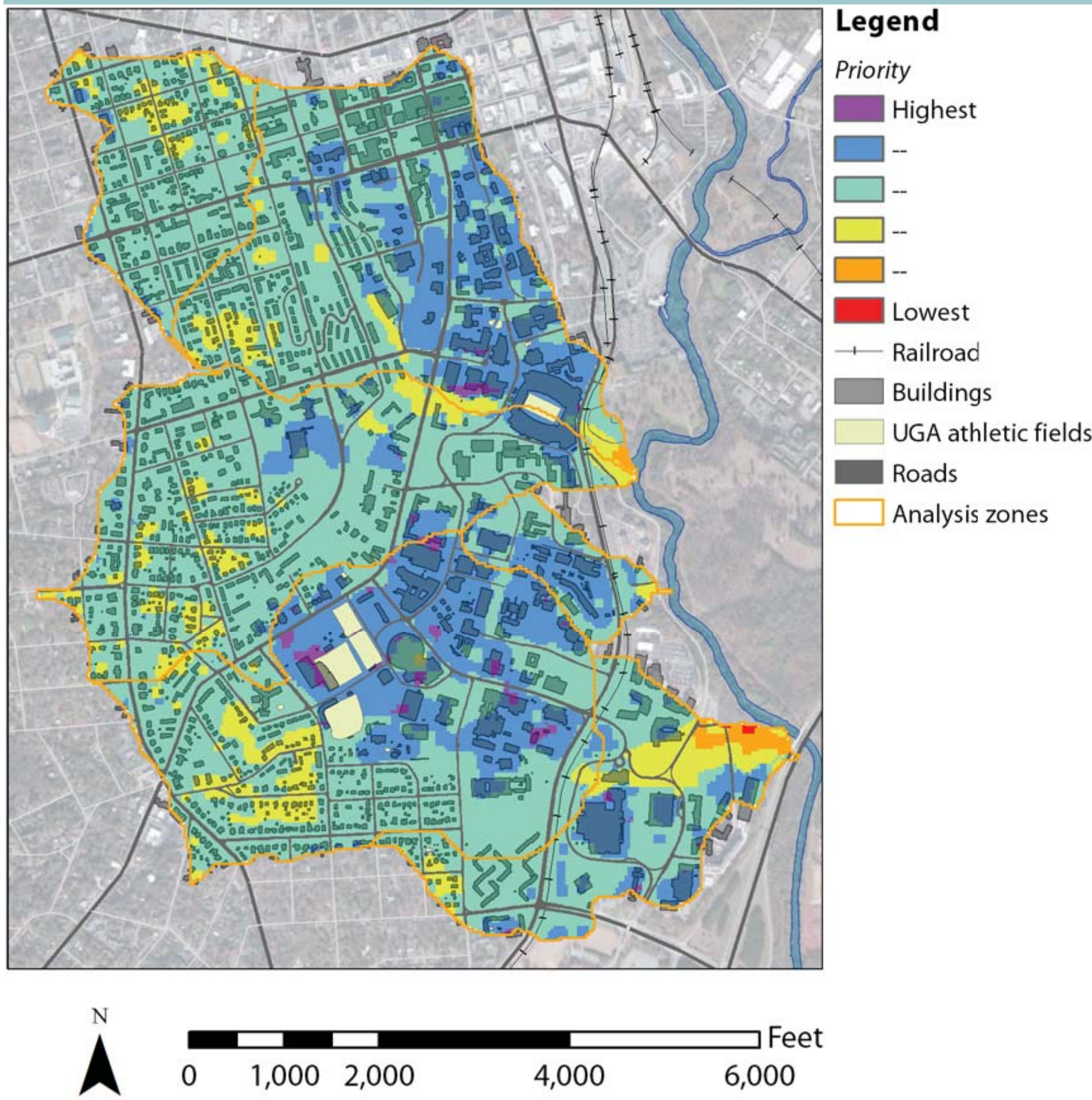

Figure 6-4. Priority areas for installation of permeable pavement, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, green roofs

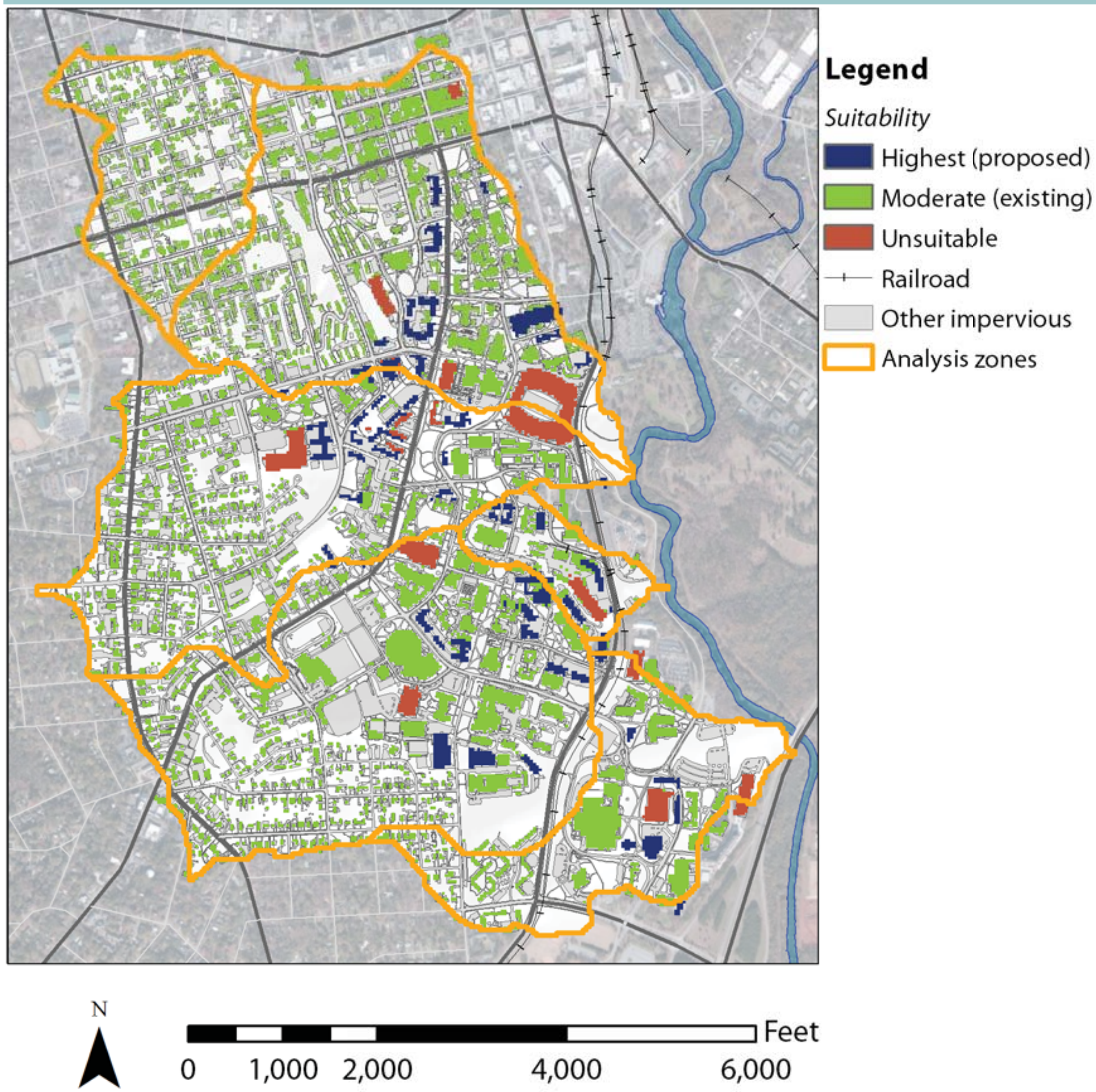

Figure 6-5. Suitability of existing and proposed buildings for the installation of a green roof.

Green roof overview: page 70

Conditions included in suitability analysis:

- Building status (existing, proposed (UGA master plan), or planned demolition (UGA master plan))
- Whether or not a roof is already in use for a purpose that would conflict with a green roof

Weighted overlay values:

Building status	Overlay value	Explanation
Proposed	10	It is easier to construct a new building to accommodate for a green roof than to retrofit an existing structure. It is not worth the investment to install a green roof on a building that is scheduled to be demolished.
Existing	6	
Demoed	Restricted	

Roof already in use	Overlay value	Explanation
No	10	Restricted uses include rooftop parking and stadium seating.
Yes	Restricted	

Considerations omitted from suitability analysis: When considering potential green roofs, the following additional design considerations should be evaluated at the site level.

- Roof slope
- Age/replacement schedule of existing roof
- Life expectancy of building
- Load bearing capacity of building supports
- Location relative to existing pollution problems, especially for pollutants that may be increased by green roofs (e.g. nutrients, organic matter)
- Historic or architectural significance of the structure, such that a green roof would be inappropriate

Priorities, green roofs

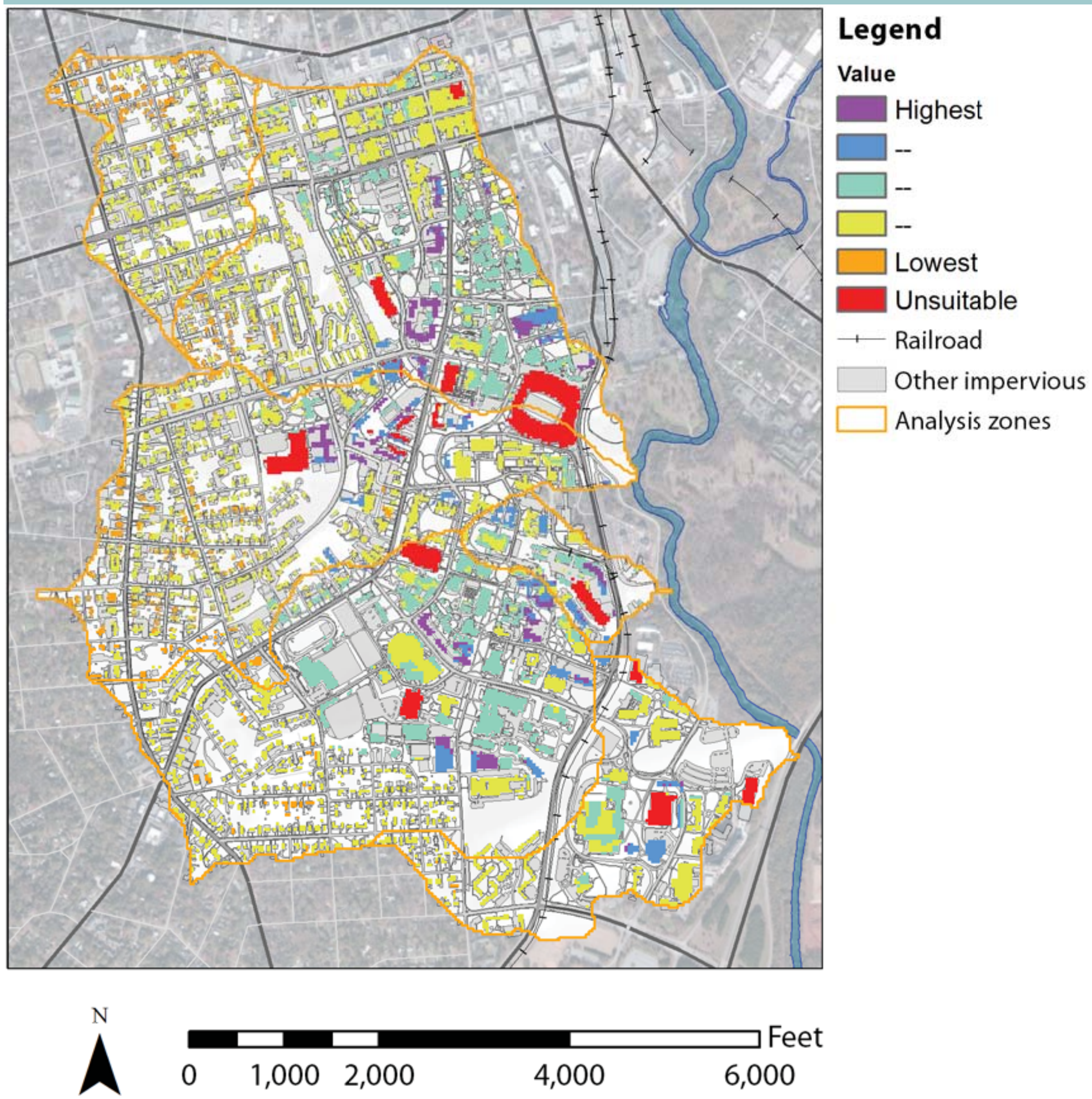

Figure 6-6. Priority areas for installation of green roofs, based on site suitability, opportunity, and overall potential SCM needs. Both existing and proposed (UGA Master Plan) buildings are included.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, water harvesting (buildings)

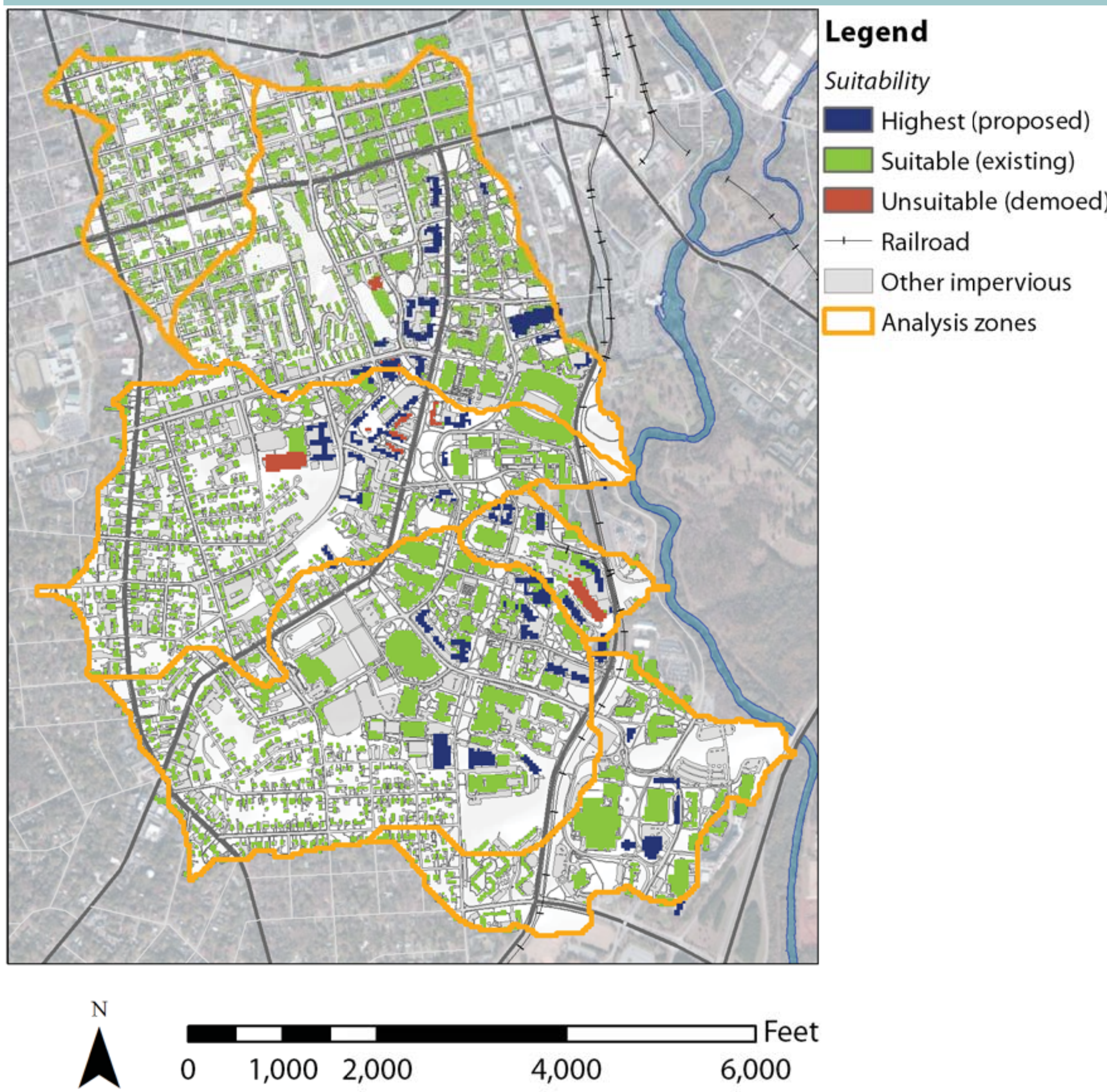

Figure 6-7. Suitability of existing and proposed buildings as a source for water harvesting.

Cistern and rain barrel overview: page 71

Condition included in suitability analysis:

- Building status (existing, proposed (UGA master plan), or planned demolition (UGA master plan))

Weighted overlay values:

Building status	Overlay value	Explanation
Proposed	10	Soil disturbance during new construction facilitates the installation of below-ground cisterns. It may not be worth the investment to install water harvesting system for a building that is scheduled to be demolished.
Existing	6	
Demoed	Restricted	

Considerations omitted from suitability analysis: When considering potential water harvesting projects, the following additional design considerations should be evaluated at the site level.

- Catchment area/expected water harvest volume
- Nearby opportunities to use harvested water
- Potential rate of harvested water use
- Roofing material (potential pollution source)
- Location relative to existing water pollution problems, especially nitrogen

Priorities, water harvesting (buildings)

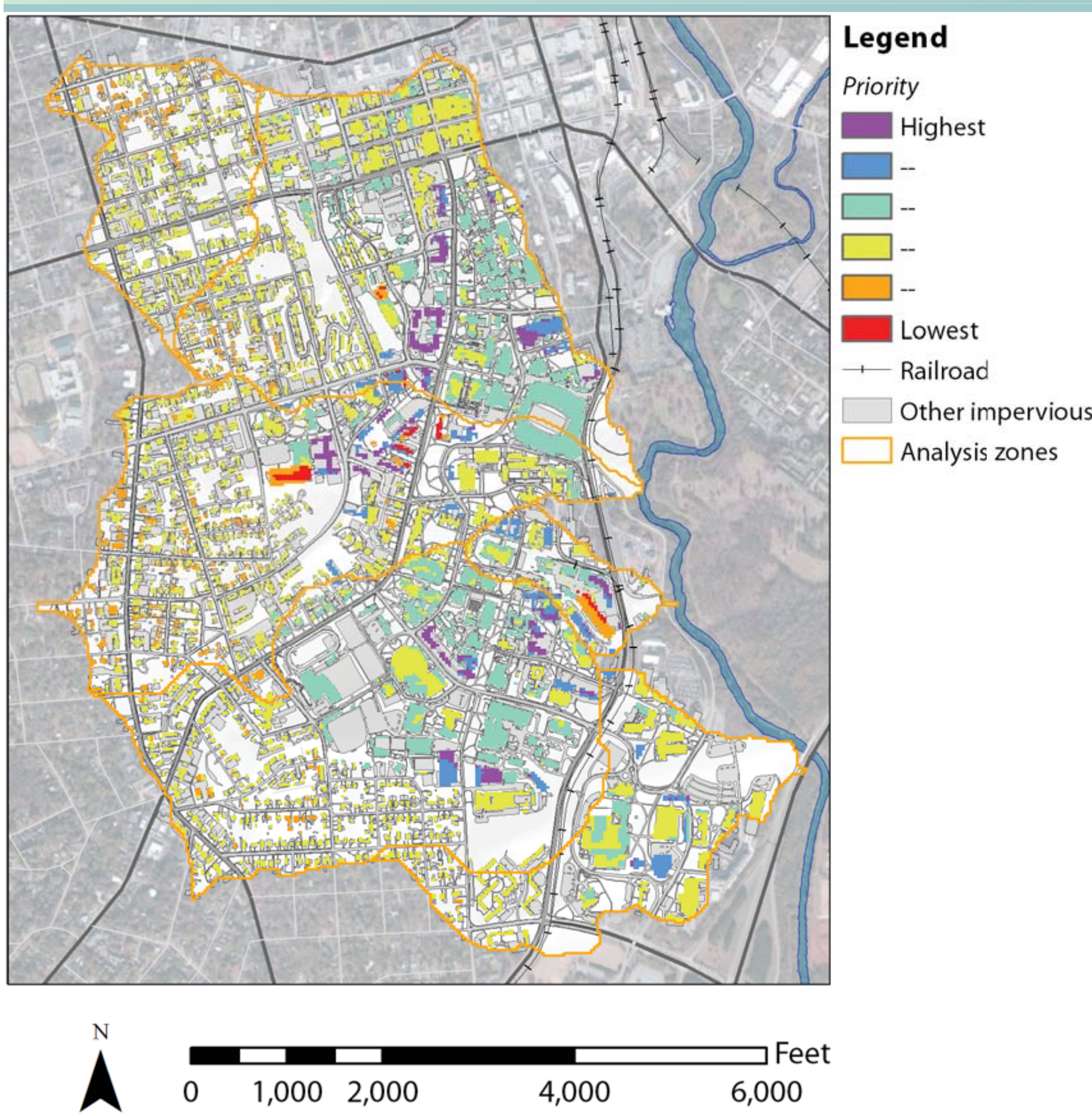

Figure 6-8. Prioritization of existing and proposed buildings for water harvesting, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, water harvesting (other)

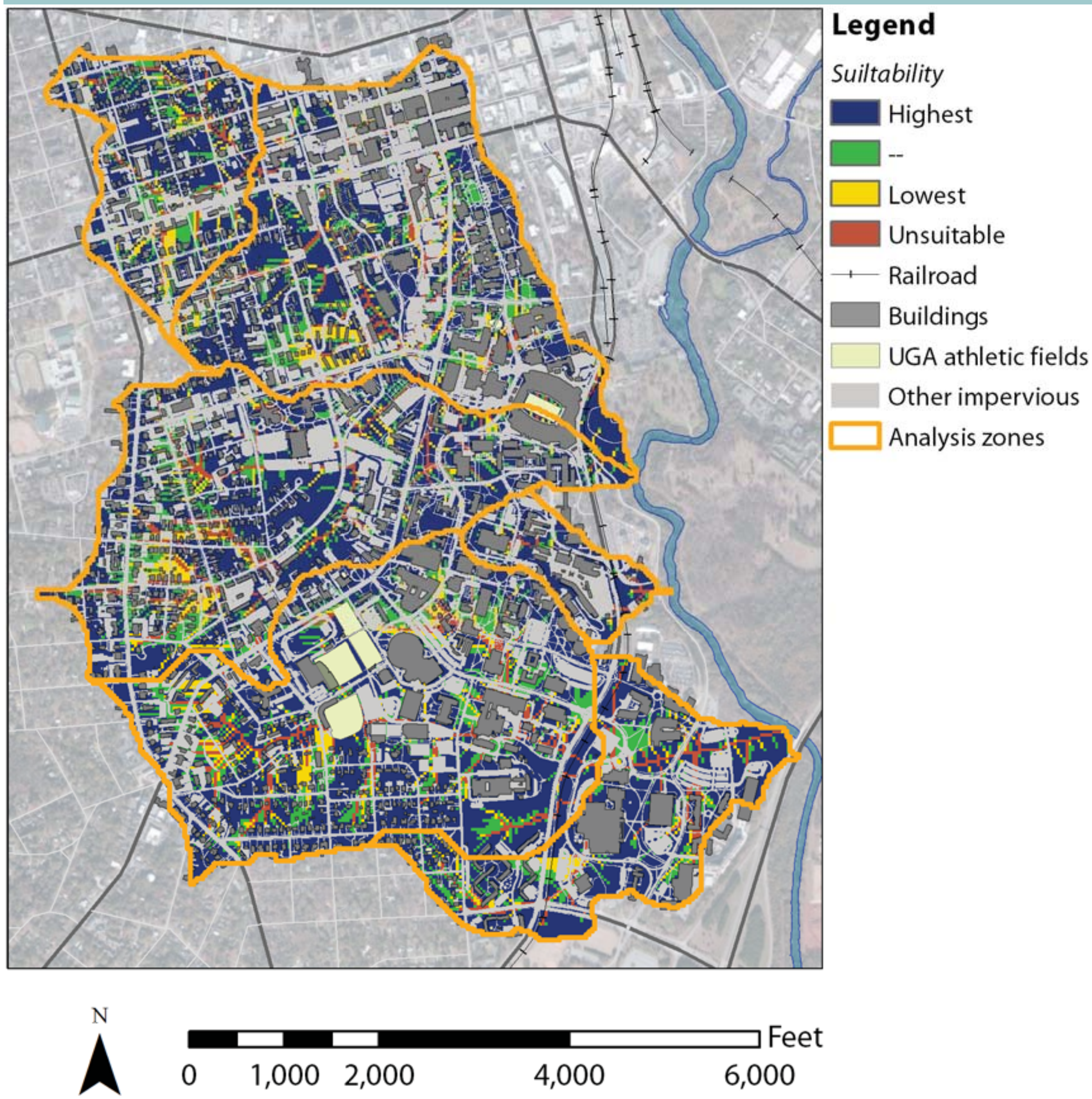

Figure 6-9. Suitability for installing a system for water harvesting other than directly from a rooftop. Water harvesting systems usually capture rainwater that falls on buildings, but it can also be harvested from other surfaces if desired.

Cistern overview: page 71

Condition included in suitability analysis:

- Catchment area

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	Above ground cisterns should drain an area no larger than 1/4 acre, while the recommended maximum for below ground cisterns is 1 acre.
1/4 - 1/2	8	
1/2 - 1	6	
> 1	Restricted	

Considerations omitted from suitability analysis: When considering potential cistern locations, the following additional design considerations should be evaluated at the site level.

- Catchment area/expected water harvest volume
- Nearby opportunities to use harvested water
- Potential rate of harvested water use
- Location relative to existing water pollution problems that may contaminate harvested water or that may clog the water harvesting system.

Priority areas, water harvesting (other)

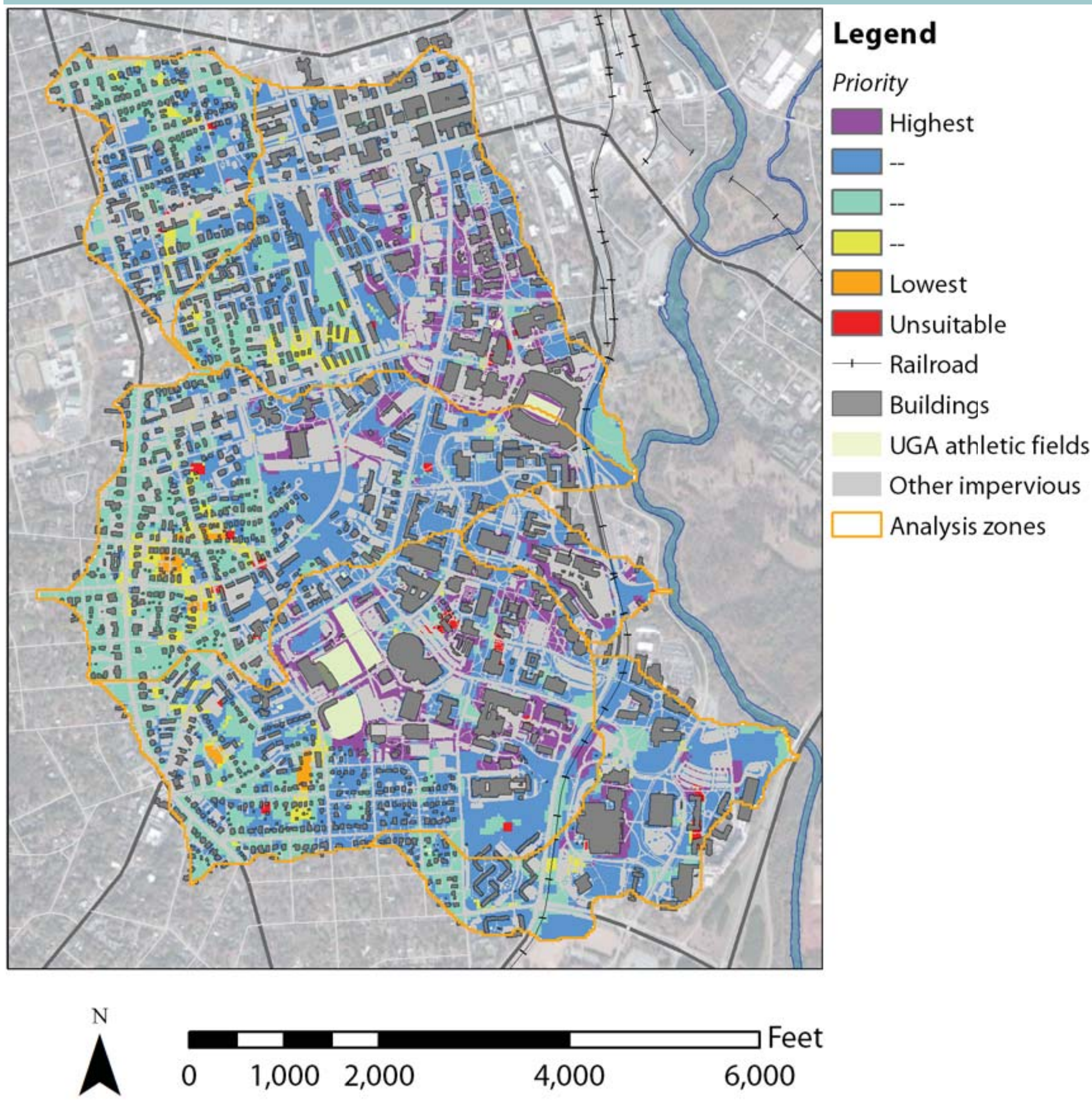

Figure 6-10. Priority areas for water harvesting, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, bioretention

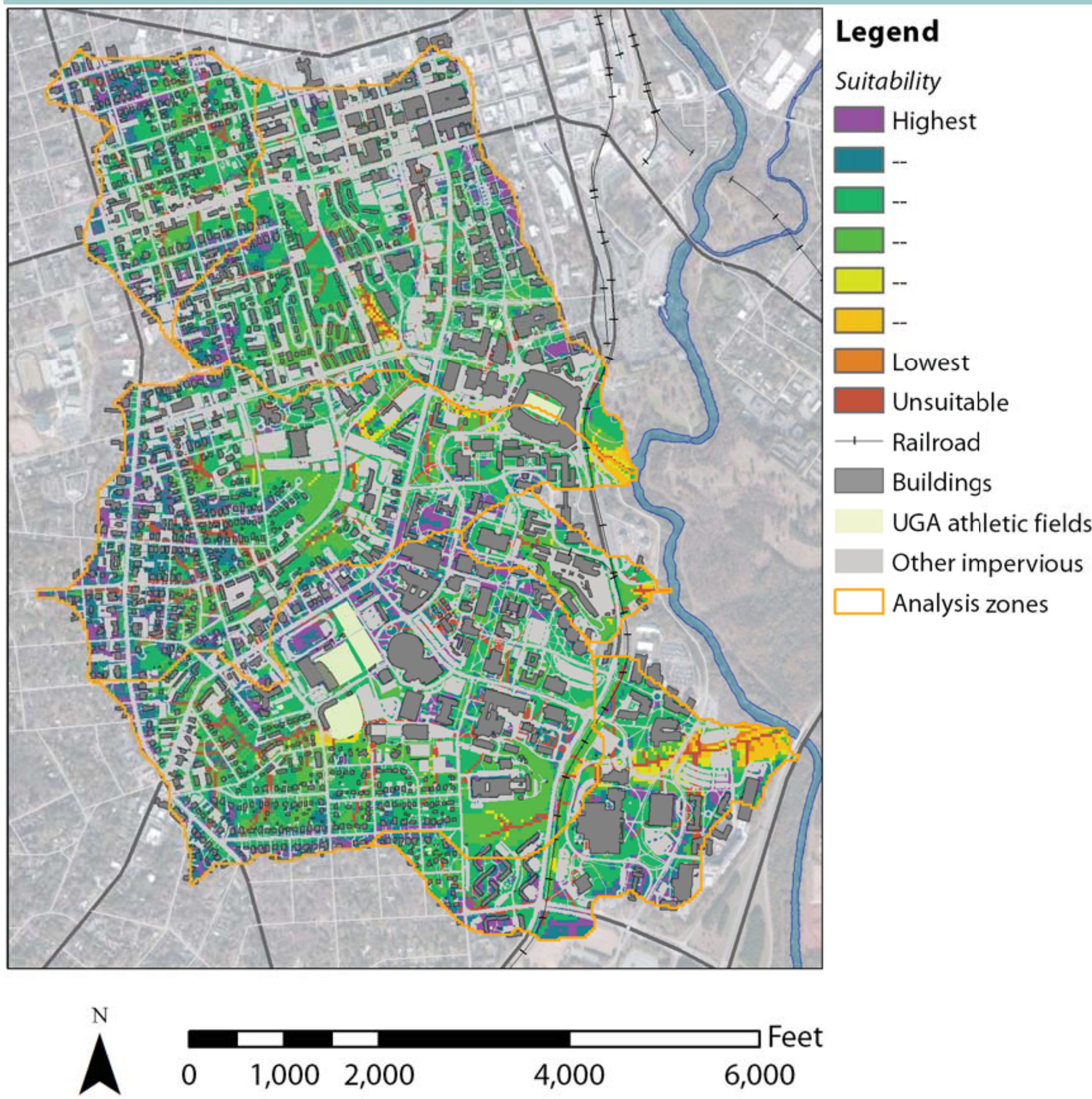

Figure 6-11. Suitability for installation of bioretention areas or rain gardens, based on site conditions.

Bioretention and rain garden overview: page 72

Conditions included in suitability analysis:

- Catchment area
- Hydrologic soil group
- Existing ground cover
- Flood zones
- Slope

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	The recommended maximum catchment area for bioretention is 1 acre, with smaller sizes being more appropriate, especially for small, distributed rain gardens.
1/4 - 1/2	8	
1/2 - 1	6	
> 1	Restricted	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	10	Low-infiltration soils should be avoided, although moderately slow draining soils can be overcome with underdrains. The NRCS label "pit" (included in "other") encompasses both pits and quarries, so low infiltration was assumed.
B (moderate)	6	
B/D (moderate/very slow)	4	
C/D (slow/very slow)	2	
Other	1	

Existing ground cover	Overlay value	Explanation
Turf (UGA)	10	Turf reduction is an objective of LID, due to its elevated irrigation needs, fertilizer inputs, and maintenance requirements over other ground covers. Preservation of natural areas is desirable, but SCMs in or adjacent to natural areas can augment their existing stormwater management function. Undefined areas (including all off campus areas) are likely a mixture of turf, landscaping, and natural areas.
Landscaped (UGA)	7	
Undefined/No Data	7	
Natural	3	

Flood zone	Overlay value	Explanation
100 year flood zone	2	Flood zone data are used as a partial surrogate for water table depth, in that the water table is likely to be high within a flood zone.
500 year flood zone	4	
Outside of flood zone	10	

Slope (percent)	Overlay value	Explanation
0 - 1	6	The recommended slope range for bioretention areas is 1 to 5 percent.
1 - 2	8	
2 - 4	10	
4 - 5	8	
5 - 6	6	
> 6	1	

Considerations omitted from suitability analysis: When considering potential bioretention areas or rain gardens, the following additional design considerations should be evaluated at the site level.

- Soil infiltration rate
- Amount of land needed (should be 5 to 10 percent of catchment size)
- Location of upslope sediment sources, due to clogging risk
- Sunlight availability
- Location relative to pollution sources and areas of poor water quality, especially for pollutants that may be increased (e.g. nitrate) reduced (e.g. total nitrogen, metals, fecal coliform) by bioretention areas

Priority areas, bioretention

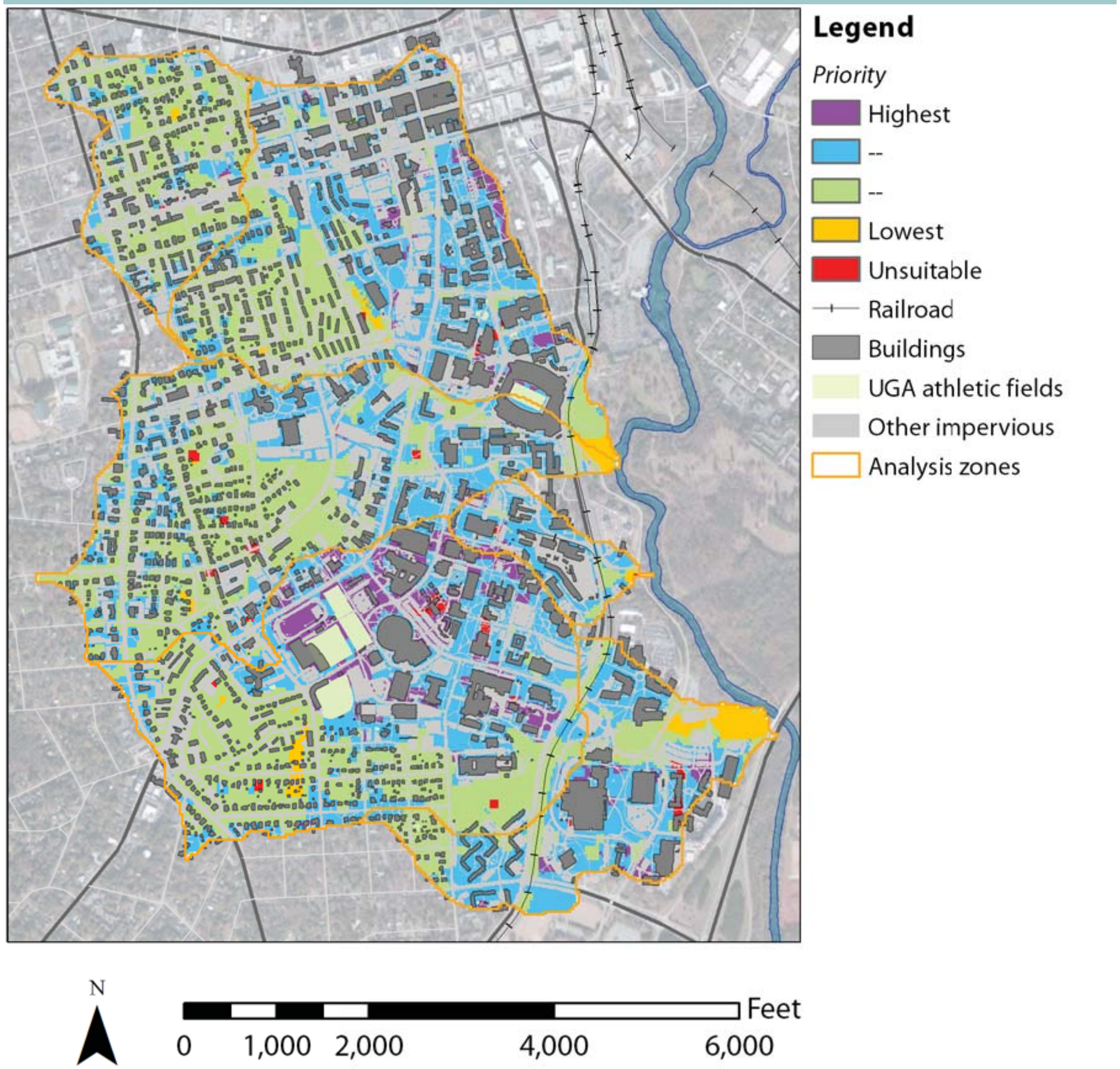

Figure 6-12. Priority areas for bioretention, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, sand filters

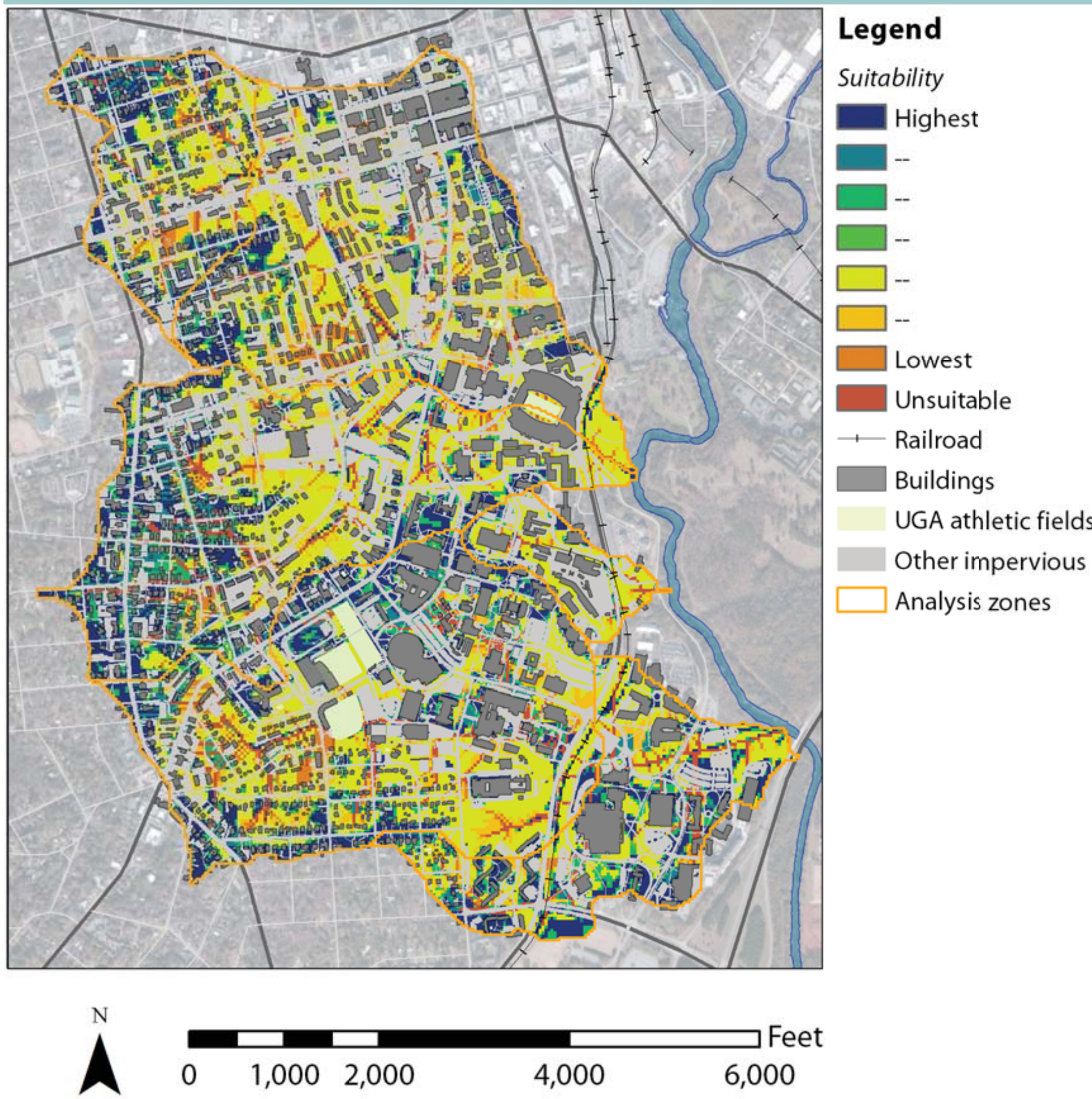

Figure 6-13. Suitability for installation of sand filters, based on site conditions.

Sand filter overview: page 73

Conditions included in suitability analysis:

- Catchment area
- Slope

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	Sand filters should drain an area no larger than 1 acre. As with all SCMs, smaller drainage areas are preferred.
1/4 - 1/2	8	
1/2 - 1	6	
> 1	Restricted	

Slope (percent)	Overlay value	Explanation
0 - 1	6	The recommended maximum slope for the land surrounding sand filters is 6 percent. Completely flat areas are difficult for most types of sand filters.
1 - 6	10	
6 - 7	6	
> 7	1	

Considerations omitted from suitability analysis: When considering potential sand filters, the following additional design considerations should be evaluated at the site level.

- Land availability and land price, to determine cost effectiveness of sand filter installation; feasibility and effectiveness of less expensive alternatives
- Water table depth
- Location of nearby parking lots and similar, low-sediment surfaces
- The presence of upslope sediment sources, due to clogging risk
- Location relative to pollution sources and areas of poor water quality, especially for pollutants that may be increased (e.g. nitrate) or decreased (e.g. phosphorus, metals, fecal coliform) by sand filters

Note: Bear in mind that while sand filters are possible throughout much of the study area, the expense of installing and maintaining them usually relegates them to an alternative option when stormwater management is needed but other SCMs are unsuitable.

Priority zones, sand filters

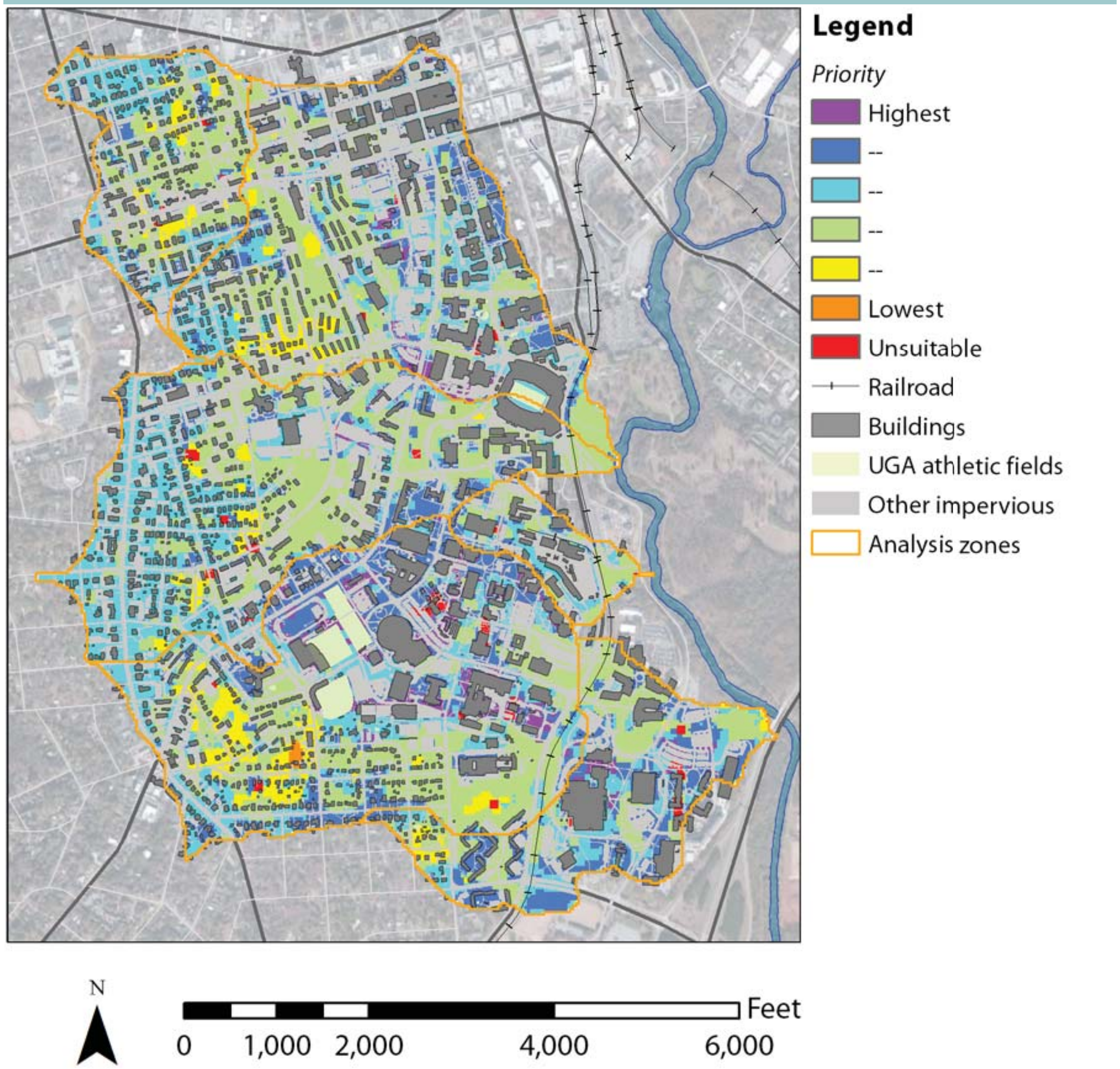

Figure 6-14. Priority areas for sand filters, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

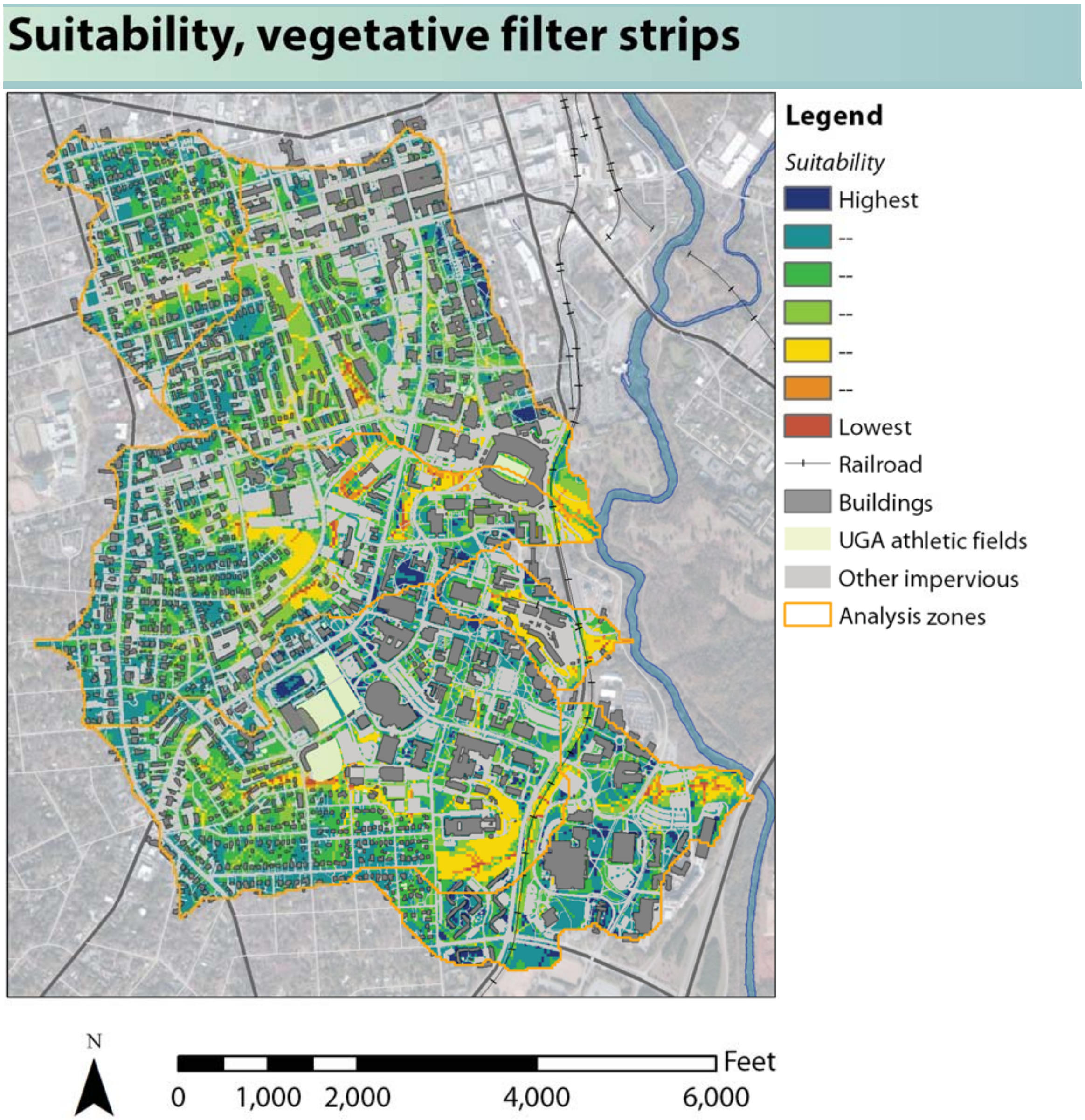

Figure 6-15. Suitability for installation of vegetative filter strips, based on site conditions.

Vegetative filter strip overview: page 73

Conditions included in suitability analysis:

- Catchment area
- Slope
- Ground cover
- Hydrologic soil group

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	As with all SCMs, smaller catchments are preferred over larger ones.
1/4 - 1/2	8	
1/2 - 1	6	
1 - 2	4	
2 -5	2	
> 5	1	

Slope (percent)	Overlay value	Explanation
< 1	6	A minimum slope of 1 percent is recommended. For a vegetative filter strip/level spreader combination, the maximum recommended slope for the area downhill from the level spreader is 15%, with flatter slopes being more effective.
1 - 2	10	
2 - 4	9	
4 - 6	8	
6 - 8	7	
8 - 10	6	
10 - 12	5	
12 - 13	4	
13 - 14	3	
14 - 15	2	
> 15	1	

Existing ground cover	Overlay value	Explanation
Turf (UGA)	10	Turf reduction is an objective of LID, due to its elevated irrigation needs, fertilizer inputs, and maintenance requirements over other ground covers. Preservation of natural areas is desirable, but SCMs in or adjacent to natural areas can augment their existing stormwater management function. Undefined areas (including all off campus areas) are likely a mixture of turf, landscaping, and natural areas.
Landscaped (UGA)	7	
Undefined/No Data	7	
Natural	3	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	10	Vegetative filter strips function best on permeable soils. The NRCS label "pit" (included in "other") encompasses both pits and quarries, so low infiltration was assumed.
B (moderate)	6	
B/D (moderate/very slow)	4	
C/D (slow/very slow)	2	
Other	1	

Considerations omitted from suitability analysis: When considering potential vegetative filter strips, the following additional design considerations should be evaluated at the site level.

- Water table depth, as vegetative filter strips may be the best option available where water tables are high
- Whether dogs are frequently walked in the area
- Location relative to pollution sources and areas of poor water quality, especially for pollutants that may be increased (e.g. fecal coliform) or decreased (e.g. metals) by vegetative filter strips.

Priority areas, vegetative filter strips

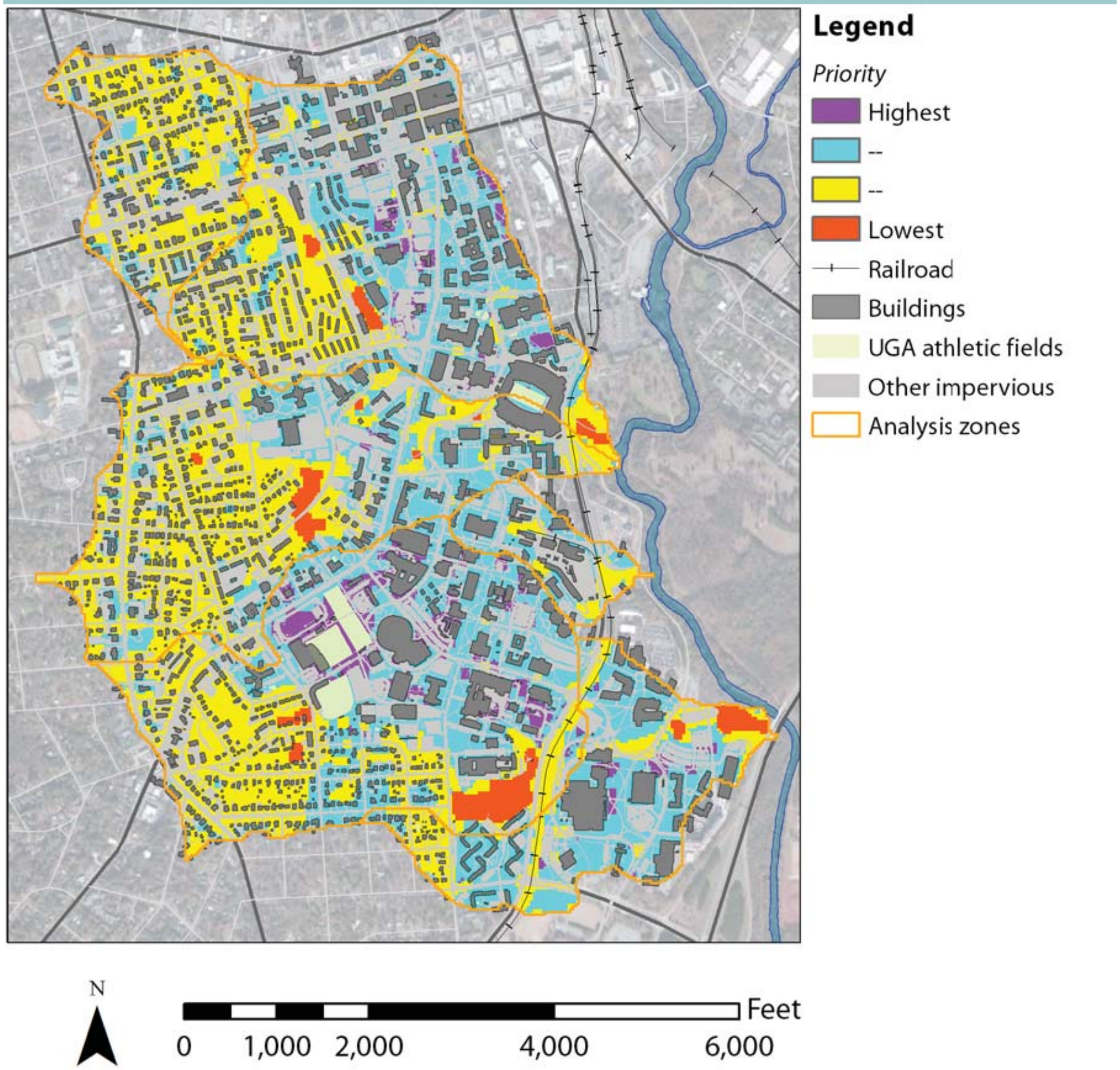

Figure 6-16. Priority areas for vegetative filter strips, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

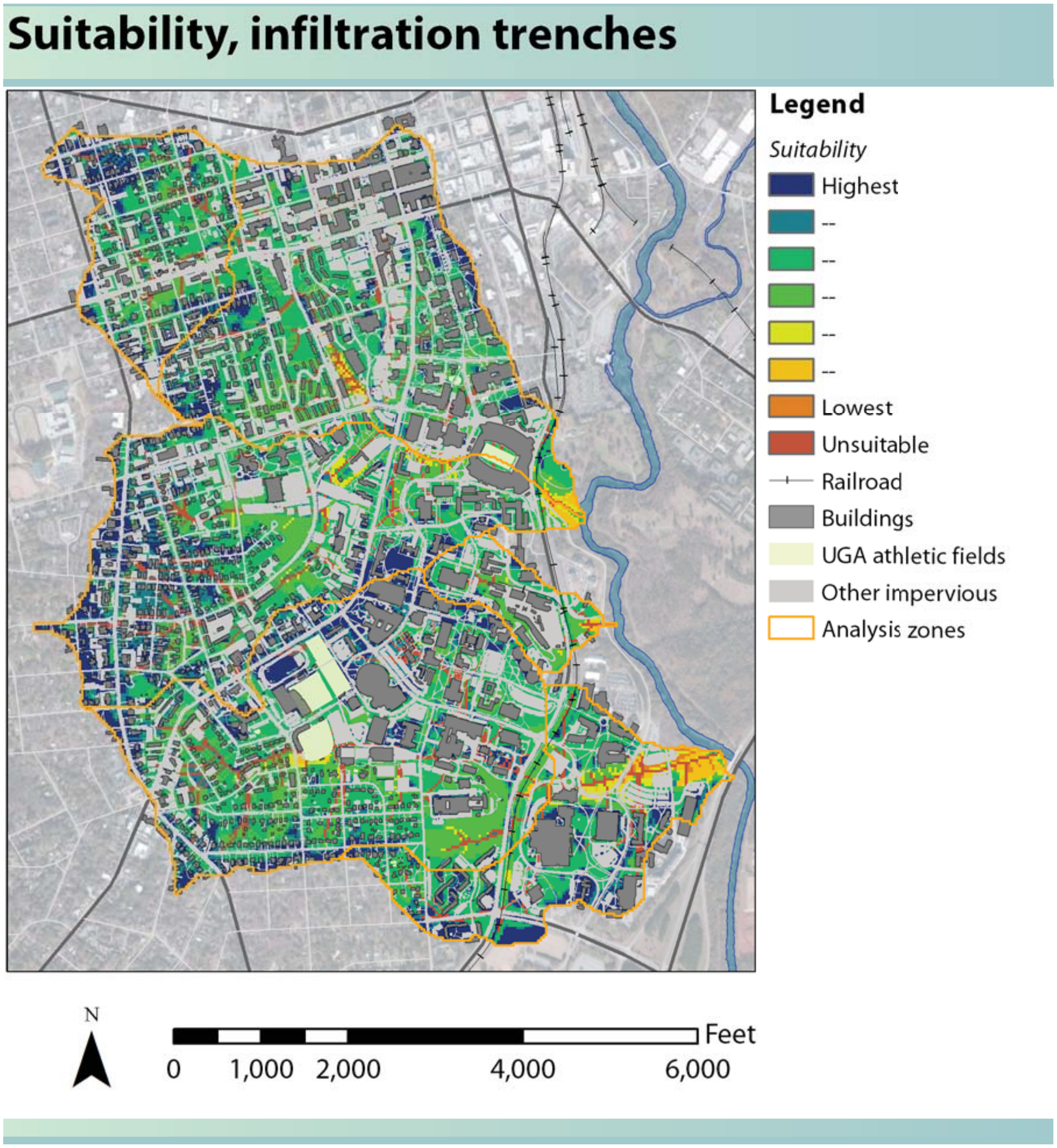

Figure 6-17. Suitability for installation of infiltration trenches, based on site conditions.

Infiltration basin and trench overview: page 74

Conditions included in suitability analysis:

- Catchment area
- Ground cover
- Hydrologic soil group
- Flood zone
- Slope

Note: While most references grouped infiltration trenches and basins together for discussion and made little distinction between them or their relevant design considerations, the Georgia Stormwater Manual does distinguish between them. It recommends against using infiltration basins at all in Georgia, due to the high clay content of soils, but suggests that infiltration trenches may have limited usefulness (Atlanta Regional Commission 2001). Based on these recommendations, this suitability analysis and subsequent prioritization analysis are for infiltration trenches only.

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	The recommended maximum catchment size is 1 acre. As with all SCMs, smaller catchments are preferred over larger ones.
1/4 - 1/2	8	
1/2 - 1	6	
> 1	Restricted	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	10	Slower draining soil is less suitable for infiltration based SCMs.
B (moderate)	6	
B/D (moderate/very slow)	4	The NRCS label "pit" (included in "other") encompasses both pits and quarries, so low infiltration was assumed.
C/D (slow/very slow)	2	
Other	1	

Existing ground cover	Overlay value	Explanation
Turf (UGA)	10	Turf reduction is an objective of LID, due to its elevated irrigation needs, fertilizer inputs, and maintenance requirements over other ground covers. Preservation of natural areas is desirable, but SCMs in or adjacent to natural areas can augment their existing stormwater management function. Undefined areas (including all off campus areas) are likely a mixture of turf, landscaping, and natural areas.
Landscaped (UGA)	7	
Undefined/No Data	7	
Natural	3	

Flood zone	Overlay value	Explanation
100 year flood zone	2	Flood zone data are used as an incomplete surrogate for water table depth, in that the water table is likely to be high within a flood zone.
500 year flood zone	4	
Outside of flood zone	10	

Slope (percent)	Overlay value	Explanation
0 - 5	10	The land upslope of an infiltration trench should be no steeper than 5 percent.
5 - 6	6	
> 6	1	

Considerations omitted from suitability analysis: When considering potential infiltration trenches, the following additional design considerations should be evaluated at the site level.

- Water table depth
- Soil infiltration rate
- The presence of upslope sediment sources, due to clogging risk
- Proximity to buildings with basements or crawl spaces
- Proximity to areas of high pollution

Priority areas, infiltration trenches

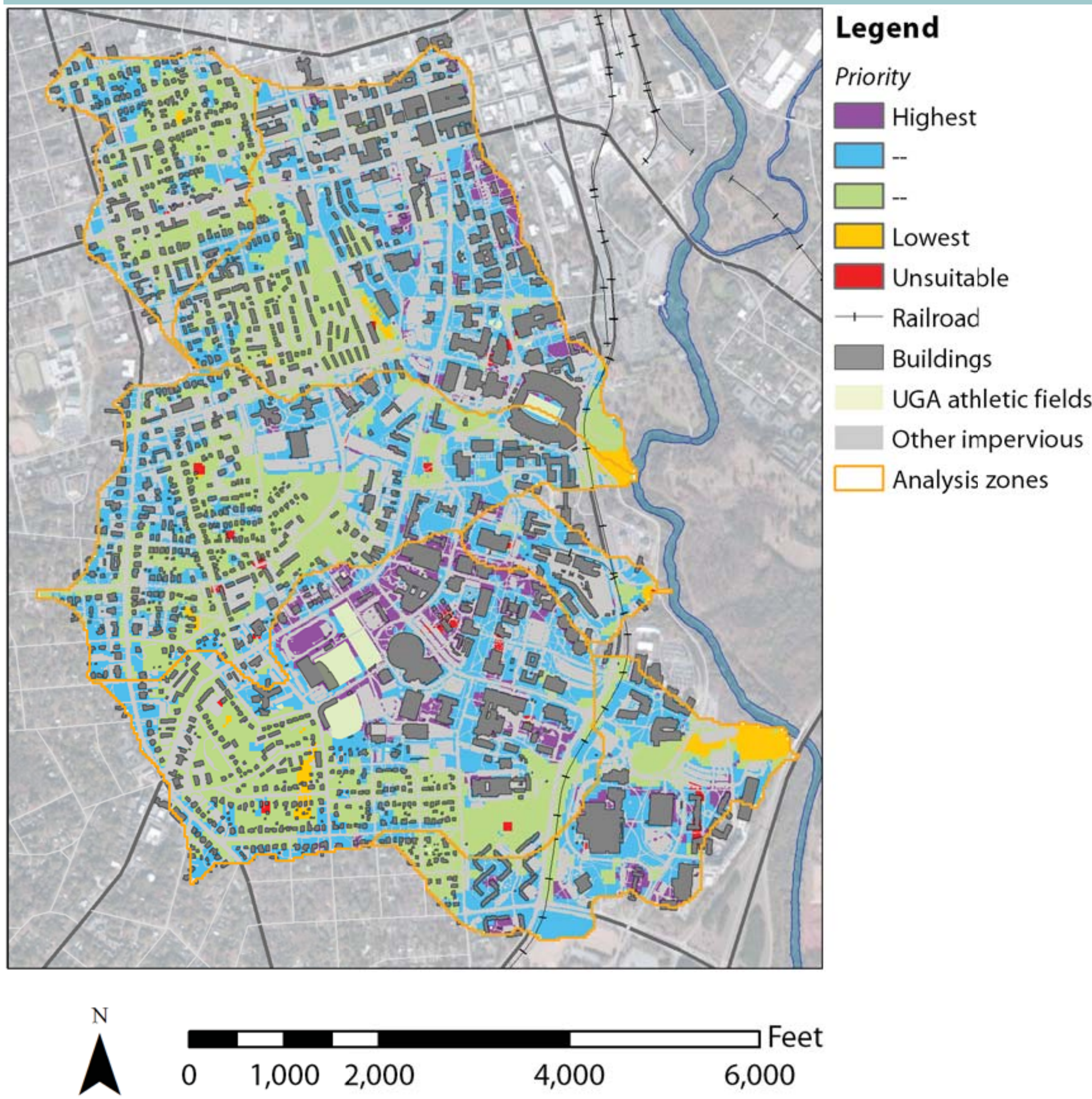

Figure 6-18. Priority areas for infiltration trenches, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, stormwater wetlands

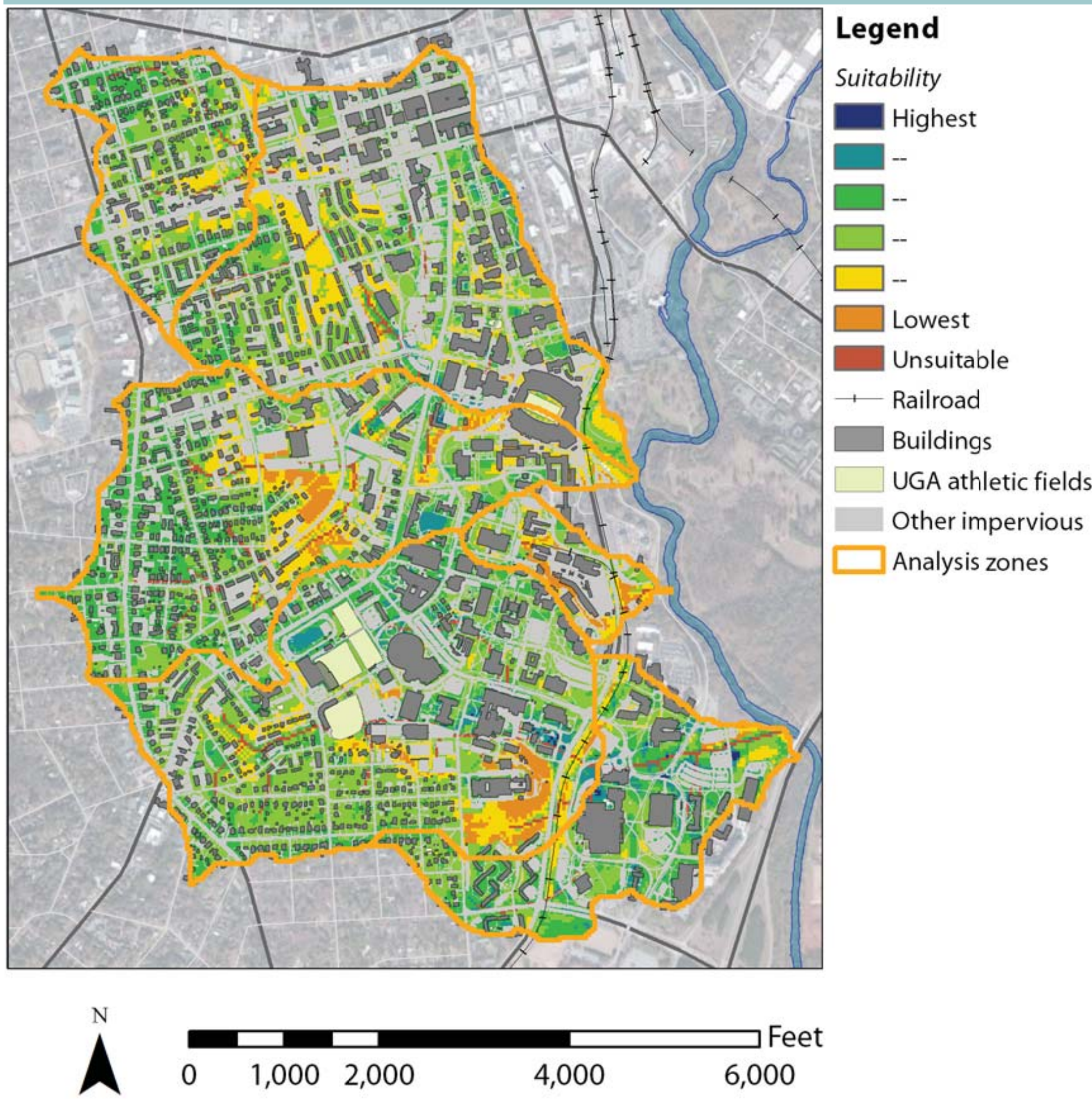

Figure 6-19. Suitability for installation of stormwater wetlands, based on site conditions.

Stormwater wetland overview: page 74

Conditions included in suitability analysis:

- Catchment area
- Ground cover
- Slope
- Hydrologic soil group
- Flood zone

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	6	The recommended maximum catchment size is 5 acres. Stormwater wetlands that are in-line with ephemeral drainages (approximated here as increasing flow accumulation/catchment area) perform better than those that are off line.
1/4 - 1/2	7	
1/2 - 1	8	
1 - 2	10	
2 - 5	10	
> 5	Restricted	

Hydrologic soil group (infiltration)	Overlay value	Explanation
A (high)	2	Fast draining soils would drain a wetland too quickly for it to maintain standing water. The NRCS label "pit" encompasses both pits and quarries, so low infiltration was assumed.
B (moderate)	6	
B/D (moderate/very slow)	8	
C/D (slow/very slow)	10	
Other	1	

Existing ground cover	Overlay value	Explanation
Turf (UGA)	10	Turf reduction is an objective of LID, due to its elevated irrigation needs, fertilizer inputs, and maintenance requirements over other ground covers. Preservation of natural areas is desirable, but SCMs in or adjacent to natural areas can augment their existing stormwater management function. Undefined areas (including all off campus areas) are likely a mixture of turf, landscaping, and natural areas.
Landscaped (UGA)	7	
Undefined/No Data	7	
Natural	3	

Flood zone	Overlay value	Explanation
100 year flood zone	8	The most appropriate location for a stormwater wetland is often in the portion of the flood plain that is farther from a stream.
500 year flood zone	10	
Outside of flood zone	6	

Slope (percent)	Overlay value	Explanation
0 - 2	10	Stormwater wetlands are best suited for relatively flat slopes.
2 - 5	8	
5 - 7	6	
7 - 10	4	
10 - 12	3	
12 - 15	2	
> 15	1	

Considerations omitted from suitability analysis: When considering potential stormwater wetlands, the following additional design considerations should be evaluated at the site level.

- Water table depth/access to a reliable natural water source
- Soil infiltration rate
- Nearby land uses for which the safety risks associated with standing water would be a concern
- Amount of available land relative to catchment area
- Location of upslope sediment sources
- Location relative to pollution sources and areas of poor water quality, especially for pollutants that may be reduced (e.g. metals, nutrients, fecal coliform) by stormwater wetlands

Priority areas, stormwater wetlands

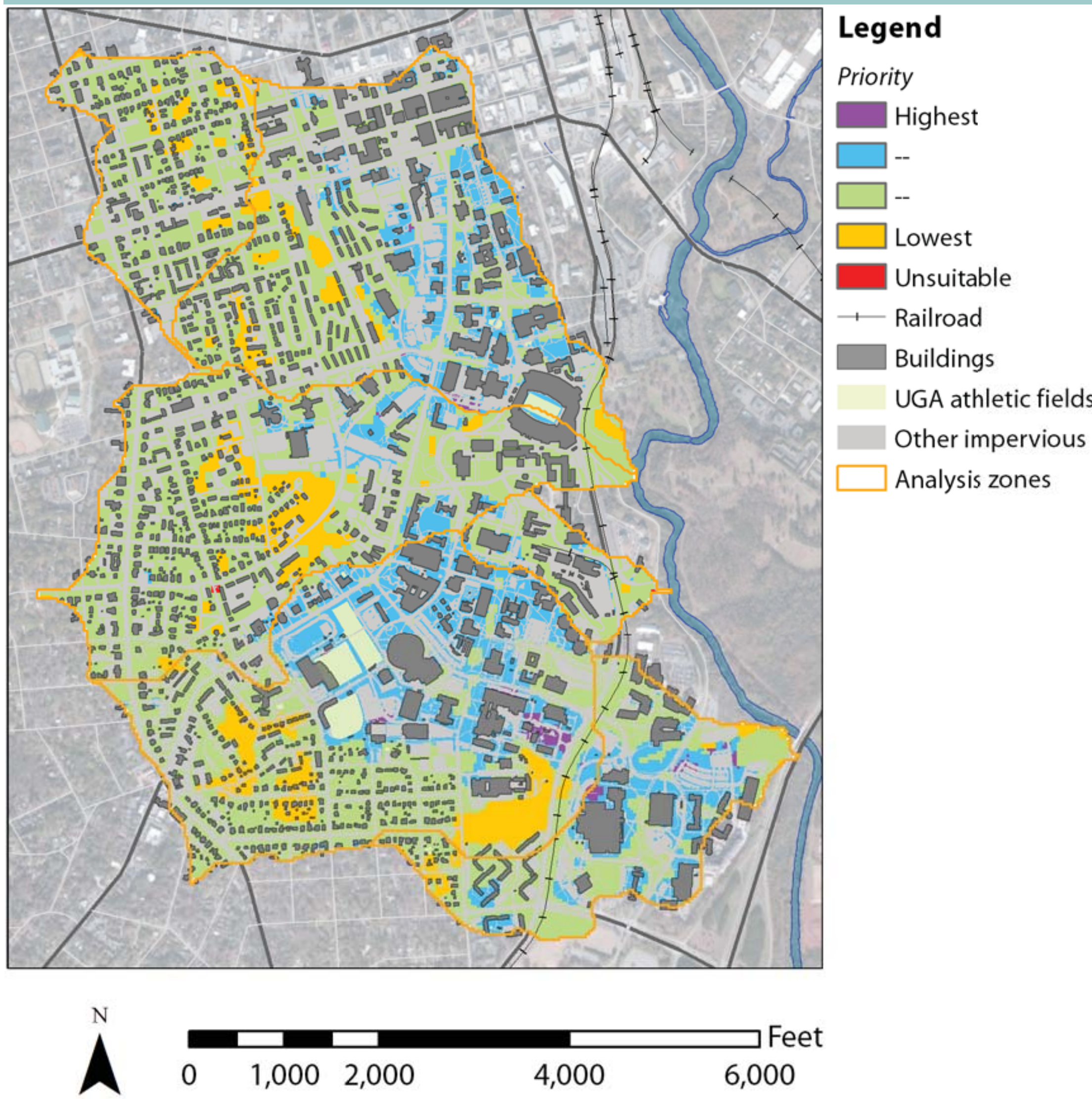

Figure 6-20. Priority areas for stormwater wetlands, based on site suitability, opportunity, and overall potential SCM needs.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

Suitability, swales

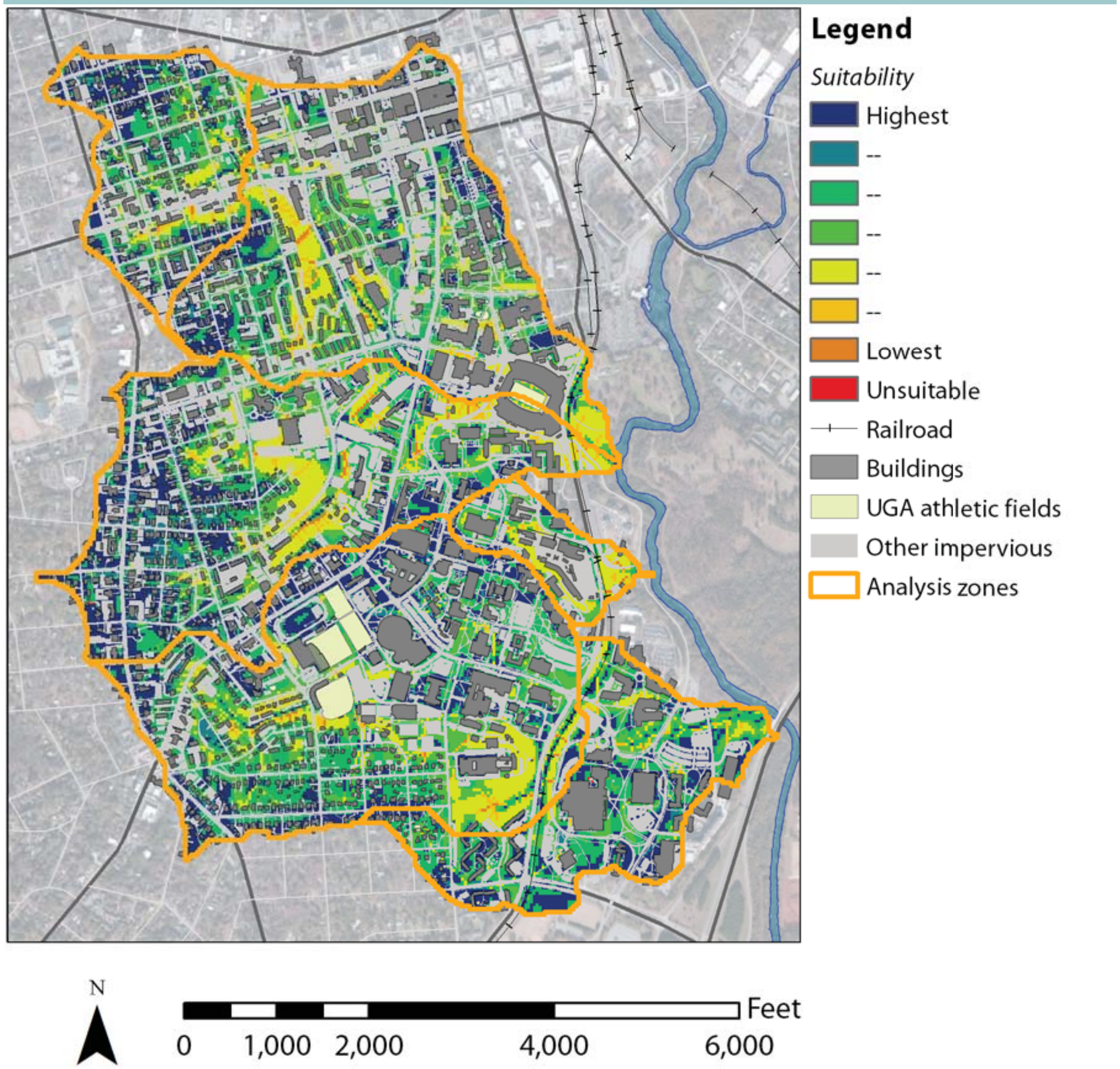

Figure 6-21. Suitability for installation of swales, based on site conditions.

Swale overview: page 76

Conditions included in suitability analysis:

- Catchment area
- Slope

Weighted overlay values:

Catchment size (acres)	Overlay value	Explanation
< 1/4	10	The recommended maximum catchment size is 5 acres. As with all SCMs, smaller catchments are preferred over larger ones.
1/4 - 1/2	9	
1/2 - 1	8	
1 - 2	7	
2 - 5	6	
> 5	Restricted	

Slope (percent)	Overlay value	Explanation
0 - 1	6	A longitudinal slope of 1 to 6 percent is recommended for most swales; however, modifications such as step pools make it possible to construct swales in steeper areas. In addition, due to the linear shape of swales, it is sometimes possible to construct a relatively flat swale in a steep area.
1 - 6	10	
6 - 10	6	
10 - 15	4	
15 - 20	2	
> 20	1	

Considerations omitted from suitability analysis: When considering potential swales, the following additional design considerations should be evaluated at the site level.

- Conveyance needs
- Likely velocity of incoming water
- Soil infiltration rate
- Proximity to other SCMs where overflow systems are needed
- For grass swales, whether dogs are often walked in the area
- Water table depth
- Location relative to pollution sources and areas of poor water quality, especially for pollutants that may be reduced or increased by the type of swale of interest

Note that for swales, many of these conditions determine the type of swale used and possible modifications needed, rather than absolute suitability or unsuitability, as different swale types have different suitability criteria. As certain types of swales share traits with certain other SCMs, it would be beneficial to refer to the analyses for those SCMs. Bioswales are similar to bioretention areas (page 126), and wetland swales are similar to stormwater wetlands (page 144).

Priority areas, swales

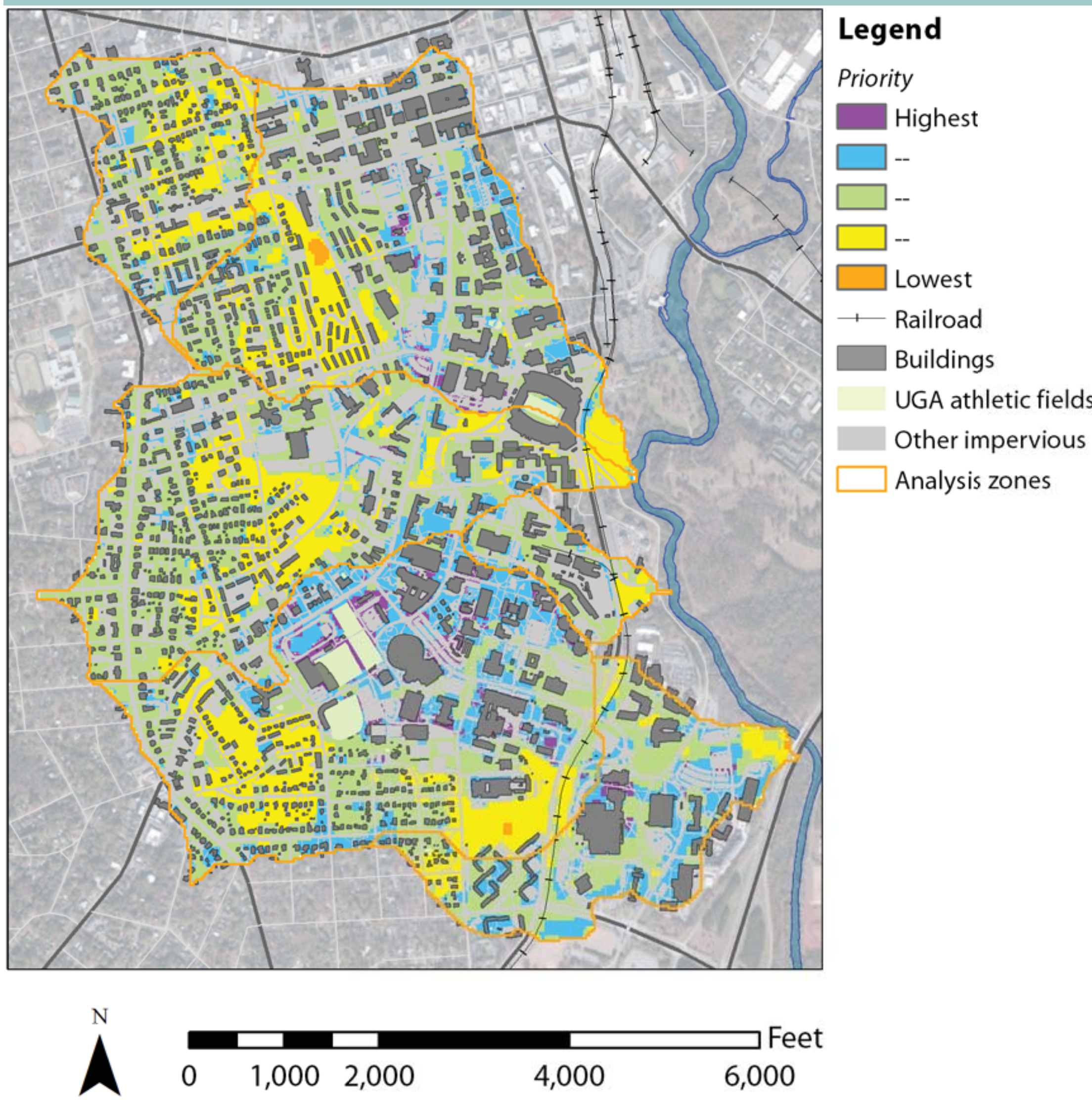

Figure 6-22. Priority areas for swales, based on site suitability, opportunity, and overall potential SCM needs. Please also refer to page 129 for consideration of bioswales, and page 144 for consideration of wetland swales, as these types of swales share many similarities with bioretention areas and stormwater wetlands, respectively.

Areas identified as a high priority are those where this SCM is most likely to be suitable, feasible, and helpful for stormwater management, relative to other locations within the target watersheds.

Please see page 108 for a description of the prioritization analysis procedure.

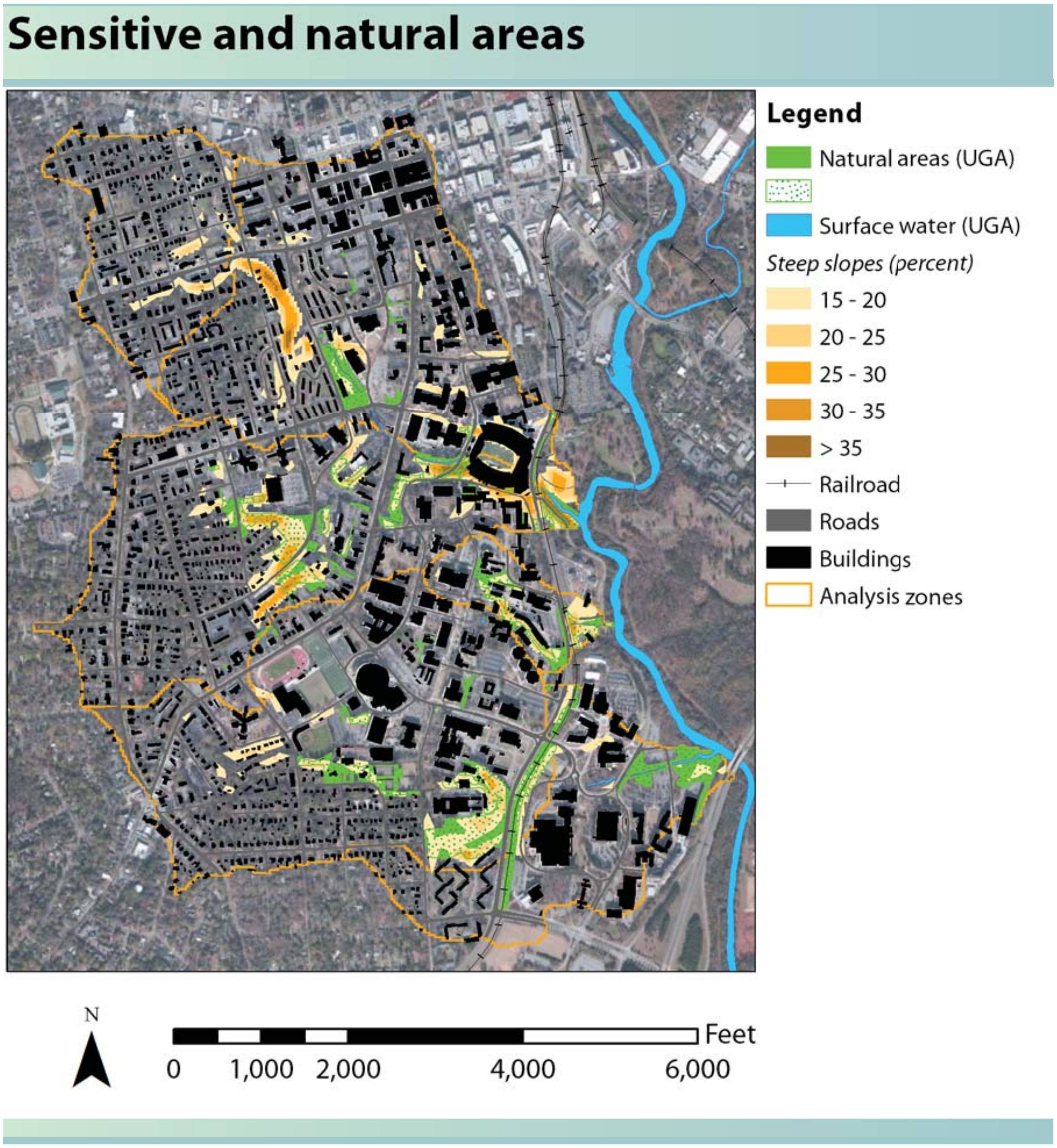

Figure 6-23. Natural and sensitive areas.

Natural and sensitive areas have not been analysed like the other SCMs in this chapter. In already developed watersheds like these, any existing undeveloped areas have likely been left in that state because they are either difficult to build on or protected by law, or because a land owner has already made a decision to preserve or restore them.

This map should be referred to in combination with the suitability and prioritization maps for SCMs. Vegetated areas already serve a stormwater management function. That function may be augmented with SCMs within them or nearby. Steep slopes are unsuitable for most SCMs, but the use of SCMs upslope or downslope of these areas may help control erosion within them or slow runoff as it leaves them. Steep areas without existing vegetation are especially vulnerable.

Chapter 7: Recommendations and Conclusions

This section provides recommendations based on the background information, inventory, and analyses presented in chapters 1 through 6.

Organization

General recommendations

The following recommendations apply to the entire study area as a whole. They include information about interpretation of analysis results, SCM design specifications, limitations of the current study, and suggestions for future, related research. Location-specific recommendations can be found following these general recommendations.

Interpretation of analyses

When reviewing the results of the analyses presented in chapters 5 and 6, please bear the following in mind:

1. *The colored areas of each map are generalizations.* The original analyses were conducted at with a cell resolution of approximately 31 feet (1/3 arcsecond) per side, and then the results of most of the analyses underwent further generalization procedures (as described in chapters 5 and 6). The objective of these analyses was to provide approximate areas where SCMs were most *likely* to be needed, feasible, and suitable, to provide a starting point for decision makers to use when considering potential SCM sites, not to pinpoint exact locations for siting individual SCMs.

2. *Analyses were limited to data that was already available in GIS format, or that could be created in GIS format based on available information.* Some potentially relevant information was excluded due to lack of available information. In addition, many factors influencing SCM availability and constraints can only be determined at the site level. Each SCM suitability analysis in chapter 6 is followed by a list of factors that should be considered at the site level before any SCM-related decisions are made.

3. *Each analysis was weighted based on the author's assumptions and opinions.* All weighting decisions and the reasoning behind them are presented in chapters 5 and 6; however, a different weighting system may be more appropriate or more desired based on different objectives or on additional available information. This topic is discussed in more detal under "limitations of the current study" on page 150.

SCM design specifications

The background information and recommendations presented herein provide an overview of general considerations and design criteria for each SCM type, but this document includes very little of the specific information that would be needed by someone designing an SCM. Examples of such specifications include dimensions, construction and fill materials, and planting lists. Consider the information presented in this report to be an outline of the types of design criteria that should be considered, as well as an overview of how SCM selection performance can be affected by various factors.

More specific design specifications for each SCM are widely available on fact sheets, on websites, and in textbooks and other reference books. For example, North Carolina State University and the US EPA both have SCM fact sheets available as a starting point.

In addition, SCM design can affect pollutant removal ability. The most comprehensive source available for detailed information about SCMs and pollutant removal is the International BMP Database. Many of the BMP Database Team's qualitative findings and recommendations are presented within this report, but the qualitative data and analyses upon which those recommendations are based is available on the BMP Database's website, as well as additional qualitative recommendations that fall beyond the scope of this management plan.

Limitations of the current study; future research

Several stormwater-related factors were either beyond the scope of this managment plan, or could have been incorporated differently. This list provides a description of these limitations, including ideas for future research and planning efforts.

1. *Water quality data:*

   First, the way the water quality data were incorporated into the potential SCM needs analysis (chapter 5) is based on each map cell's distance from each downstream water quality monitoring point. This method puts too much emphasis on the somewhat arbitrary locations of the Brown and Caldwell water quality monitoring locations, rather than on each stream as a whole. In addition, it fails to take into account that pollution sources further from a stream have less of an impact on stream quality than those adjacent to a stream.

   A better way of incorporating water quality data into the analysis might be to begin by interpolating the expected water quality value along each entire stream based on its distance from the nearest upstream and downstream monitoring sites. For example, a point along the stream that is exactly halfway between two monitoring locations would be assigned an expected water quality measurement value that is the average of the values measured at those two monitoring sites. Then, some distance weighting factor could be used to emphasize potential pollution sources near the stream and deemphasize those that are further away.

   Second, all land uses were treated equally in the water quality analysis, when in reality, different land uses produce different types of pollution. For example, most metal pollution comes from automobile traffic, whereas nutrient pollution is more likely to come from fertilized areas and locations with numerous dog walkers. A more precise water quality analysis would be one that takes land use into account, emphasizing the surfaces that are most likely to produce each type of pollution.

Finally, the only water quality data used in this study were those sampled by Brown and Caldwell at least three times from 2010-2012, with one exception as noted on page 42. Other water quality sampling data are available, including other Brown and Caldwell sites, as well as sites monitored by the Upper Oconee Watershed Network, Athens-Clarke County, and UGA's Environmental Law Practicum students. A more complete picture of watershed health could be compiled by using all available data, especially after ongoing sampling results in more repetition at the additional sampling locations.

Despite the above limitations, it should be noted that water quality sampling data had relatively little influence on the resulting potential SCM needs analysis (chapter 5). There are two reasons for this low level of influence. First, most sampling sites were only moderately polluted by most pollutants, resulting in moderate water quality weights throughout the study area. Second, different pollutants exhibited different trends (e.g. increasing or decreasing moving downstream), such that while some catchments were more polluted than others in terms of specific pollutants, no catchments could be identified as being much more or less polluted overall, for all pollutants. These two factors combined to have a moderating influence on water quality weights throughout the study area.

2. *Weighting:*

   For the potential SCM needs analysis, equal weight (20%) was placed on each of the five factors (chapter 5), which included water quality, soil erodibility, slope, and two measures of impervious surface cover. A more nuanced weighting system, such as those used in Guo, Wang, and Zhu (2004) and Al-Awadhi and Hersi (2006), may be desireable.

3. *Soil erodibility index*:

   The potential SCM needs (chapter 5) analysis used one soil erodibility index, Kw. Other methods of estimating soil erodibilty exist that may have been suitable instead of or in addition to Kw. An example is the Revised Universal Soil Loss Equation (RUSLE), an erosion prediction model (USDA Agricultural Research Service 2010).

4. *Impervious surface cover:*

   The two mesures of impervious surface cover included in the potential SCM needs analysis (chapter 5) give equal weight to all types of impervious surface, but actually, different surfaces generate different amounts of runoff. For example, while athletic fields and impermeable pavement are both considered impervious surfaces, more rainwater will infiltrate a ball field than an asphalt parking lot. Curve numbers are an indicator of how much of the water that lands on a surface will become runoff, taking infiltration, evaporation, and evapotranspiration into account . An analysis that incorporates curve numbers may better predict high needs areas than one that treats all impervious surfaces as equivalent.

5. *Potential green roof sites:*

   The green roof suitability analysis (chapter 6) includes only the proposed status of buildings in the UGA Master Plan. It does not take into account details such as the slope of the roof, building age, expected roof replacement schedule, or property ownership. While these and other details are listed after the green roof suitability analysis as information to gather at the site level, they could also be investigated comprehensively throughout the target watersheds, especially for the buildings owned by Athens-Clarke County and UGA. As a starting point, Timothy Carter's dissertation identifies all of the flat roofs in the Tanyard Creek watershed (Carter 2006).

6. *Physical stream quality:*

   While this analysis does take water quality into account, it does not address physical stream quality in any way. If highly eroded sites were identified along all stream reaches, for example, that information could be used to identify areas where SCMs are needed for the specific purpose of reducing water velocity.

   On a related note, stream restoration was beyond the scope of this practicum, but continued efforts to improve and restore the structure and quality of stream reaches are important. A stream restoration master plan (including an invasive species removal plan) for the target watersheds could be an entire thesis or practicum by itself.

7. *On-ground stormwater conditions:*

   The potential SCM needs analysis identifies the areas that are most likely to have or contribute to stormwater problems, but no actual, on-ground storm event conditions were examined. If areas where the existing stormwater infrastructure is working well or poorly were identified, it would help inform future SCM and stormwater management decisions.

8. *Existing SCMs:*

   Numerous SCMs exist within the target watersheds, mostly located on UGA property. Performance monitoring of their effectiveness would provide information about their impact on stormwater conditions. This information could help inform future SCM decisions and help determine whether current maintenance regimes are sufficient.

9. *Hydrologic modeling:*

    All surface flow estimates in these analyses are based on a digital elevation model at a course scale. They only take overall surface shape into account. Additional information, calculated in a hydrologic model, would provide a more complete picture of stormwater accumulation and areas of need. For example, what are the effects of the existing conventional stormwater infrastructure and existing SCMs on surface flow? Where are evaporation and infiltration likely to occur? How is water redirected by curbs and gutters, which are too small to have been taken into account by the digital elevation model used here?

10. *Costs*

    This practicum report does not include cost data, although cost greatly affects SCM decisions. Future efforts can involve compiling cost data for each SCM type, including how costs are affected by site conditions.

Education and training

To receive the most benefit from many of the SCMs described in this report, staff training will be required, both for those designing, purchasing, or installing SCMs, such as staff the University Architects office, as well as for end users like Grounds and Building Maintenance staff.

For example, a water harvesting system that is not regularly emptied between storms is not an effective stormwater management tool, although it can still serve a water conservation function. If stormwater management is an obective for installed water harvesting systems, then employee education efforts may be needed to train grounds and building maintenance staff in the proper use schedule of cistern water to ensure that the water is routinely emptied between storms. In addition, those designing and installing cisterns may not be aware of functional design options available, such as the use of a built in leak to promote cistern emptying.

Another example where staff training may be required is in proper routine maintenance of SCMs. Many SCMs are prone to clogging, and must undergo regular maintenance to remove built-up sediment to remain effective.

For certain SCMs, public signage or other education efforts may help increase effectiveness. For example, signage can be used near vegetative filter strips to alert dog walkers to avoid the area.

Future efforts related to stormwater planning should include an inventory of SCM-related educational and training needs, as well as the development of educational protocols or materials.

Specific recommendations, by analysis zone

Location-specific stormwater management recommendations are given on pages 157 through 181, broken down by analysis zone (Figure 5-2). The recommendations for each zone include:

- Location
- Stormwater management needs overview
- Water quality monitoring
- Property ownership and significant structures
- Existing stormwater infrastructure
- Sensitive and natural areas
- Existing stormwater-related plans
- A map to accompany the information presented in the text

Recommendations Legend

Analysis zone border

Property ownership

University of Georgia

Athens-Clark County

Transportation

Road

Railroad

Buildings

Existing

Proposed (UGA master plan)

Demoed (UGA master plan)

Other surfaces/structures

UGA athletic field

Swimming pool

Other impervious

NHD stream flow path

Pipe

Culvert

Channel

Perennial stream (surface)

Intermittent stream (surface)

Intermittent stream (unknown)

Contour intervals

10 foot

Flood zones

100 year

500 year

Existing stormwater infrastructure (UGA)

Cistern (approximate location)

Green roof

Other SCM (e.g. rain garden, permeable pavement)

Catch basin

Drop inlet

Water quality monitoring

Monitoring site

Potential SCM needs (see chapter 5)

Very high

High

Moderate

Low

Other areas referenced in recommendations text

Approximate boundary, existing stormwater plan

Approximate boundary, other

1 See text for description of numbered areas

Figure 7-1. Legend for analysis zone recommendation maps (Figures 7-2 through 7-7).

West Broad analysis zone

Location

This zone is located in the headwaters of the Tanyard Creek main stem (Figure 7-2).

Stormwater management needs overview

Overall, the West Broad analysis zone is among those with the lowest potential SCM needs, relative to other zones within the three target watersheds. Impervious surface coverage here is moderate relative to other zones, with higher impervious surface coverage in the southern portion than in the north.

The area with the most potential stormwater problems falls in the center of this zone, along W. Broad Street. To address potential problems here, SCMs can be located upslope, within, and downslope of this area. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities in this area. In addition, because the West Broad zone is part of the Tanyard Creek headwaters, small, distributed SCMs throughout this zone can treat small amounts of runoff here before they collect and become larger problems downstream.

Water quality monitoring

Site MP-1 falls within this analysis zone. For the 2010-2012 sampling period, recorded values for metals (lead and copper), pH, and fecal coliform bacteria (dry sampling only) were poorer in the Tanyard Creek headwaters than downstream. Conductivity and total nitrogen were higher in the Tanyard Creek main stem than in its tributary, Cloverhurst Branch. Fecal coliform (wet sampling) and total phosphorus were elevated at most monitoring sites throughout the study area, including MP-1 (page 64).

Specific stormwater-related sources for the above pollutants within the West Broad zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

Property ownership within this area is mostly private, with commercial properties lining W. Broad street and mostly residential properties elsewhere. Some churches and nonprofit organizations are located in the center and northern portions, while some Greek System properties are located near the southern tip. Piedmont college owns land to the northwest. Encouraging any desired SCM installation within these private and semiprivate areas will require some combination of collaboration, education, and incentives.

Athens -Clarke County does own some property within this zone, including the Clarke County Health Department (the largest building within the West Broad zone), some vacant lots immediately east of the Health Department, and a small neighborhood park on the southeast corner of the intersection of Pope and Reese Sts. These locations provide easier opportunities for SCM installation, but they are located in low to moderate need areas. In addition, Athens-Clarke County property includes a small daylit stream. While this location is indicated as having moderate stormwater management needs, it is located immediately downslope of a high needs area near W. Broad Street; therefore, improvements on the south side of this stream could be used to treat runoff from the direction of W. Broad Street before it reaches the stream.

Existing stormwater infrastructure

GIS data for existing conventional stormwater infrastructure and SCMs was unavailable for this zone, as it is located outside of the UGA campus. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat runoff before it is carried to streams.

Sensitive and natural areas

There are some areas with steep slopes running along both sides of W. Broad Street, behind the first row of buildings. In general, these steep areas are already tree covered or vegetated, and should remain so if possible (Figure 6-23).

Existing stormwater-related plans

Timothy Carter, PhD dissertation (*Vegetated roofs for stormwater management performance and policy in the Tanyard Branch watershed*). Of particular usefulness for potential green roof siting is Figure 4.2, in which Carter identified all of the flat roofs within the Tanyard Creek watershed (Carter 2006).

Tanyard Creek, Cedar Creek & Shoal Creek management strategy analysis, a report for Athens-Clarke County evaluating potential stormwater detention sites, including site TA-D2 (Tetra Tech 2012).

Pongsakorn Suppakitpaisarn, Environmental Law Practicum memo, Spring 2012 (*Campus stream restoration best management practice design (at S Pope St and Reese St)*).

West Broad

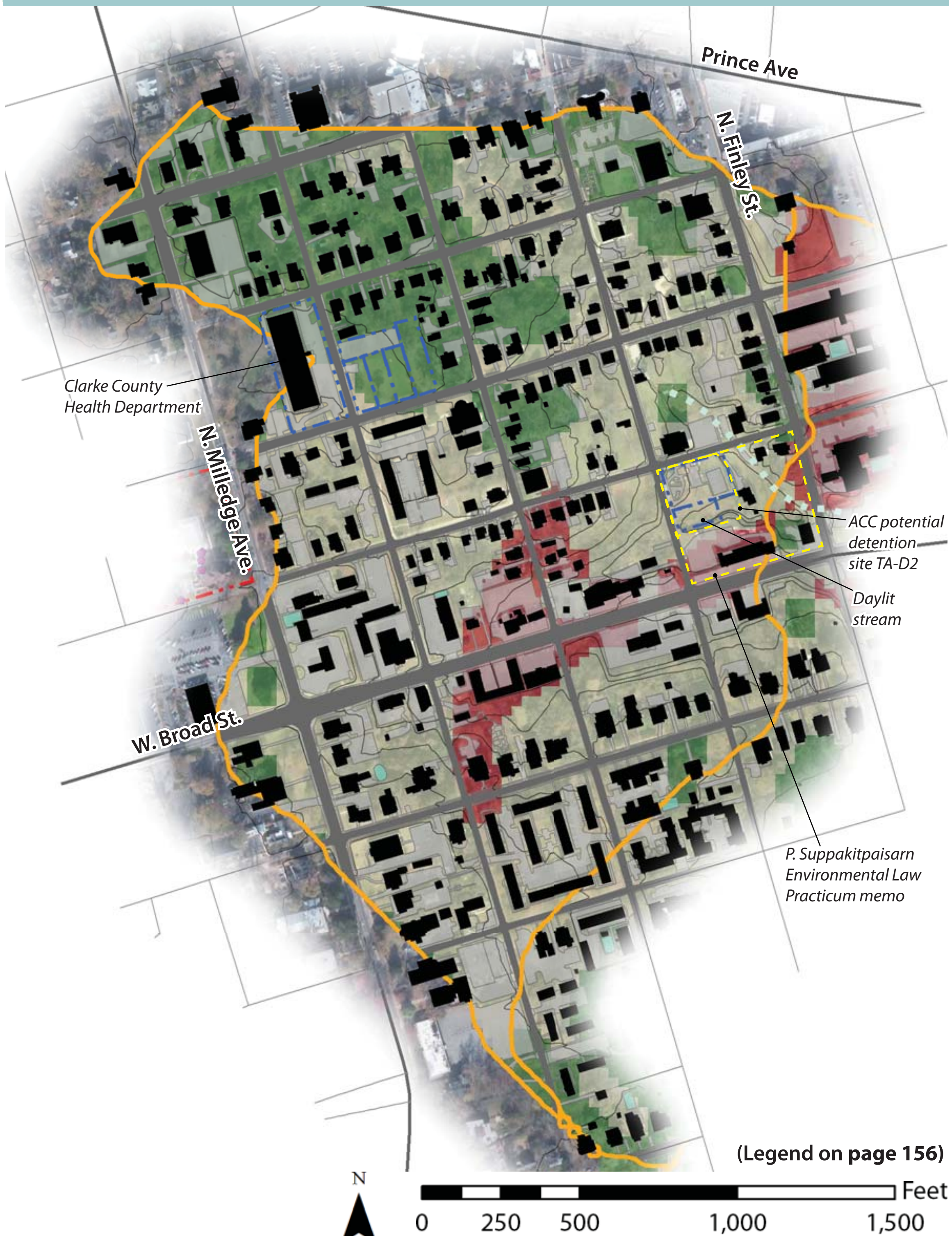

Figure 7-2. West Broad analysis zone, within the headwaters of the Tanyard Creek watershed. Recommendations for this analysis zone are described beginning on page 157.

North Campus/Downtown analysis zone

Location

The North Campus/Downtown zone (NC/D) is within watershed of the Tanyard Creek main stem. Upstream of the confluence of Tanyard Creek with Cloverhurst Branch, the land on both sides of Tanyard Creek falls within this zone. Between the Cloverhurst Branch confluence and the North Oconee River, only the land on the north side of Tanyard Creek is included (Figure 7-3).

Stormwater management needs overview

Overall, the NC/D analysis zone is among those with the highest SCM needs, relative to other zones within the three target watersheds. Tanyard Creek divides this zone into two very different areas in terms of potential stormwater management needs.

Potential SCM needs are high throughout most of the land northeast of Tanyard Creek, with the exception of large open spaces on the UGA campus such as the North Quad and Herty Field. Impervious surface coverage is very high northeast of Tanyard Creek, especially downtown. Downtown, there is very little land that is not already covered by a building or pavement, so the SCMs that are most likely to be feasible there are those that require little to no land beyond the impervious surfaces themselves, such as water harvesting, permeable pavement, sand filters, and green roofs. South of W. Broad Street, there are more open spaces than in downtown, allowing more SCM options. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities in this area.

In contrast, potential SCM needs are relatively low in the portion of the NC/D zone that is southwest of Tanyard Creek. Throughout most of this area, the use of small, distributed SCMs is appropriate, but there are not high needs areas to target. The one exception is an area with a very steep slope (① on map), located behind the Holiday Inn Express and adjacent to the path of Tanyard Creek. It is already well vegetated, so protection of existing vegetation is the recommended SCM for this location. Most other SCMs are unlikely to be suitable there, due to the steep slope. In addition to protecting existing vegetation here, be mindful that there may be high velocity runoff exiting this area, if it is not sufficiently slowed by existing vegetation alone.

Water quality monitoring

Water quality problems that are higher in the Tanyard Creek main stem than elsewhere include conductivity and total nitrogen. While improvements within the NCDT zone may help reduce these problems, it is likely that the primary source of elevated levels of these two pollutants originate upstream, within the Tanyard Creek headwaters. In contrast, total suspended solids and turbidity (under wet sampling conditions) increase moving downstream in Tanyard Creek, indicating that the NCDT zone does increase the sediment load delivered to the stream. Identification and treatment sediment sources within this zone is recommended. Phosphorus is elevated at all sites within the Tanyard Branch watershed; removal of sediment from runoff should also help reduce the load of sediment-bound phosphorus. Fecal coliform is also elevated throughout the Tanyard Creek watershed under wet sampling conditions (page 64).

Specific stormwater-related sources for the above pollutants within the NC/D zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

Most of the eastern portion of the NC/D zone is owned by UGA. The largest buildings within the UGA portion of this zone are UGA's stadium, Miller Learning Center, Tate Center complex, Psychology-Journalism complex, Special Collections Libraries, UGA Main Library, UGA Law Library, and Hull Street Deck, as well as to numerous other large academic buildings. In addition, there are many large parking lots on this portion of the UGA campus.

The land bounded by Lumpkin, Hull, Broad, and Baxter Streets, most of which is owned by UGA, is of particular note (② on map). These two blocks are heavily covered with a row of impervious surfaces that lie directly within a relatively large natural ephemeral drainage. Currently, most of these surfaces are parking lots, but UGA's Master Plan shows five proposed, large buildings to be added there at a future date. Most of the existing parking lots there are too steep for conversion to permeable pavement, but there are opportunities for many other SCMs in the spaces around and between these parking lots. Construction of the five proposed buildings will present additional opportunities. Consider SCMs here that can treat the relatively high runoff volume entering this area from off site, rather than systems sized to treat only the runoff generated by existing and new structures on site.

Athens-Clarke County owns several parcels in the downtown portion of the NC/D zone. Most of these properties are entirely or nearly entirely occupied by buildings. The notable exception is City Hall, which is surrounded by a high amount of open space relative to other buildings downtown. This presents opportunities for small SCMs; however, as the City Hall land is near the watershed boundary and has among the highest elevations within the target watersheds, SCMs there would only be able to treat stormwater generated on the City Hall property itself.

The largest other landholder within the NC/D zone is the Housing Authority. Most of the remaining land is under private ownership, with churches, hotels, and apartment complexes making up the majority of the remaining large buildings. The apparent open space east of the UGA stadium is a cemetery.

Existing stormwater infrastructure

UGA has at least 23 rain gardens, porous pavement projects, or other ground level SCMs within the NC/D zone. There are also at least four cisterns, as well as a small green roof project at the Tate Center. Most of these are associated with recent construction projects, including the Special Collections Libraries, Tate Center phase II, and Reed Plaza (immediately north of the stadium). All are located within or in close proximity to high SCM needs areas.

Existing catch basins and drop inlets are shown for the UGA-owned portion of the NC/D analysis zone. GIS data for existing conventional stormwater infrastructure and SCMs was unavailable for the portions of this zone that are located beyond the UGA campus. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat runoff before it is carried to streams.

Sensitive and natural areas

There are several steep areas within the NC/D analysis zone (Figure 6-23), most of which are on the UGA campus. Few of them have been designated as "natural" by the UGA grounds department, but most have trees and other vegetation. Where vegetation exists, it should be maintained on steep areas to prevent erosion, slow runoff, and encourage infiltration. Where steep slopes are long, runoff velocity may become rapid. The large natural area immediately west of the Hull Street Deck is a narrow riparian corridor for an intermittent section of Tanyard Creek (③ on map). Some of the land within this natural area is part of the flood zone.

Existing stormwater-related plans

Timothy Carter, PhD dissertation (*Vegetated roofs for stormwater management performance and policy in the Tanyard Branch watershed*). Of particular usefulness for potential green roof siting is Figure 4.2, in which Carter identified all of the flat roofs within the Tanyard Creek watershed (Carter 2006).

Tanyard Creek, Cedar Creek & Shoal Creek management strategy analysis, a report for Athens-Clarke County evaluating potential stormwater detention sites, including sites TA-D3 and TA-D4 (Tetra Tech 2012).

Heather Blaikie, Environmental Law Practicum memo, Spring 2012 (*Campus urban streams: best management practices (BMPs) for a segment of Tanyard Creek*).

UGA Green Infrastructure Plan sites 1, 2, 5, and 6 (*http://www.ced.uga.edu/index.php/services_outreach/detail/green_infrastructure/*).

Tanyard Branch restoration and design studio, Summer 2002 (note: plan predates Tate Center phase II construction) (*www.architects.uga.edu/sites/default/files/pdf/TanyardStudy.pdf*)

North Campus/Downtown

Figure 7-3. North Campus /Downtown (NC/D) analysis zone, within the Tanyard Creek watershed. Recommendations for this analysis zone are described beginning on page 160.

Central analysis zone

Location

The Central Analysis zone includes the entire Cloverhurst Branch watershed, as well as the land south of the Tanyard Creek section between Cloverhurst Branch and the North Oconee River (Figure 7-4).

Stormwater management needs overview

Overall, the Central analysis zone is among those with the lowest SCM needs, relative to other zones within the three target watersheds. Impervious surface coverage here is moderate overall, with the highest impervious coverage being located near the confluence of Cloverhurst Branch and Tanyard Creek. Within this zone of otherwise low to moderate needs, two high needs areas are apparent. The first, which is located immediately south of the stadium, was likely classified as high needs due to steep slopes and the relatively high density of the large surrounding buildings. There are existing trees within much of this area, which should be maintained. Installation of most other SCMs may be difficult here, due to the area's steepness and the lack of available land. Green roofs and water harvesting may be good options for the group of science buildings located here, especially the Biological Sciences building, in the absence of other likely suitable options.

The other high SCM needs area in the Central analysis zone is in the vicinity of the West Campus Deck and Legion Pool. In addition to the large West Campus Deck building, there is also high parking lot coverage in this area. One large, relatively flat parking lot (④ on map) there shows up as a high priority for conversion to permeable pavement; however, as UGA's master plan includes three proposed buildings on the site of the current parking lot, it is unlikely to be worth the investment to convert the lot to permeable pavement for the short term. The large number of proposed buildings and demolitions near and within this high needs area present good opportunities for future SCM installation there during construction. In addition to the buildings indicated as demolished, Legion Pool is also planned to be removed. In the prioritization analysis results (chapter 6), this area is shown as a high priority area for most SCM types.

Most of the western half of the Central zone falls within low SCM needs areas; however, due to flat slopes and small drainage areas, this portion of the Central zone is more suitable for many SCMs than most of the eastern half. Small, distributed SCMs are appropriate within these headwaters, as they can be used to treat small amounts of runoff here before they collect and become larger problems downstream. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities throughout the Central zone.

Water quality monitoring

The only water quality condition that was noted as being worse at site MP-3 (Cloverhurst Branch) than downstream during wet sampling conditions was pH. Fecal coliform bacteria were measured at higher levels here than downstream during dry sampling conditions, but dry sampling results are more likely to be from constant inputs like leaking sewage pipes rather than from runoff. Fecal coliform (wet sampling conditions) and total phosphorus were found to be elevated throughout the Tanyard Creek watershed (page 64).

Specific stormwater-related sources for the above pollutants within the Central zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

UGA owns most of the land on the eastern half of the Central analysis zone. The group of large buildings on the far east end of this zone are academic buildings for several science disciplines. Other large UGA buildings within this zone include several residence halls, the Bolton Dinning Commons, and the West Campus Deck. UGA's master plan includes numerous new buildings there, mostly located in the middle part of the Central analysis zone. Construction of these structures, as well as the planned demolition of several existing buildings, parking lots, and Legion pool in this area, will provide many convenient opportunities for SCM installation. The Myers Quad, located near the southern edge of this analysis zone, shows up on the suitability and prioritization maps for most SCM types as being an area of high suitability, high priority, or both (chapter 6). Any SCM projects located here would need to balance stormwater control objectives with the desire to maintain the quad as an open space.

Beyond the UGA campus, the non-residential property ownership pattern follows three significant roads. Most of the properties along this portion of Baxter Street are commercial properties that cater to college students, such as academic bookstores and restaurants that specialize in carryout and delivery. This portion of Milledge Avenue is lined with Greek system houses (fraternities and sororities), as well as professional offices and small commercial operations. This portion of Lumpkin Street is lined with churches. The remaining land is primarily residential, with multifamily residential complexes scatted throughout the area.

Of final note is a relatively large hole park (⑤ on map) in the southwestern portion of the Central analysis zone, which is not really owned by anyone or being used for a particular purpose purpose. There are some trees and shrubs spaced out along the outside edge, but the center portion is turf covered. For the most part, its location does not show up as high needs, high priority, or high suitability relative to its surroundings in the analyses in chapters 5 and 6; however, the installation of SCMs there would offer some benefits. First, it would provide a function to land that currently has little utility. Second, a vegetated, landscaped SCM located there would have lower maintenance needs than the turf that currently covers the center portion of the site, as mowing would no longer be required. Third, it could be a visual amenity to drivers on the three roads surrounding the hole park.

Existing stormwater infrastructure

UGA currently has only a few rain gardens or other ground level SCMs within the Central analysis zone. Four are clustered together (⑥ on map) along the east side of Lumpkin Street; the long, linear SCM in this cluster is a rock lined swale. This cluster is not located in an area identified as high needs relative to the rest of the watershed, but the topography there makes it a logical location for SCMs, especially a swale. The Geography/Geology Building's green roof is also located within the Central analysis zone.

Existing catch basins and drop inlets are shown for the UGA-owned portion of the Central analysis zone. GIS data for existing conventional stormwater infrastructure and SCMs was unavailable for the portions of this zone that are located beyond the UGA campus. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat incoming runoff before it is carried to streams.

Sensitive and natural areas

There are several steep areas within the Central analysis zone (Figure 6-23). Most are located on the UGA campus, and most have existing vegetation. Where steep slopes are long, runoff velocity may become rapid. Where vegetation exists on steep slopes, it should be maintained to prevent erosion, slow runoff, and encourage infiltration. Where steep slopes are covered only by turf, additional vegetation should be planted when possible, and additional SCMs may be needed to manage the rapid runoff passing through and off of these areas.

Some daylit sections of Cloverhurst Branch run through the Central analysis zone. In addition, the flood plain extends onto the eastern tip of this zone; this land is occupied by a cemetery, so it is unlikely that the flood plain there will be further disturbed by construction projects.

Existing stormwater-related plans

Timothy Carter, PhD dissertation (*Vegetated roofs for stormwater management performance and policy in the Tanyard Branch watershed*). Of particular usefulness for potential green roof siting is Figure 4.2, in which Carter identified all of the flat roofs within the Tanyard Creek watershed (Carter 2006).

Tanyard Creek, Cedar Creek & Shoal Creek management strategy analysis, a report for Athens-Clarke County evaluating potential stormwater detention sites, including site TA-D1 (Tetra Tech 2012).

UGA Green Infrastructure Plan sites 7, 8, 9, and 10 (*http://www.ced.uga.edu/index.php/services_outreach/detail/green_infrastructure/*).

Central

Figure 7-4. Central analysis zone, within the headwaters of the Tanyard Creek watershed, including Cloverhurst Branch. Recommendations for this analysis zone are described beginning on page 165.

PPD analysis zone

Location

The PPD analysis zone encompasses the entire PPD watershed (Figure 7-5). It is the smallest analysis zone in this stormwater management plan.

Stormwater management needs overview

Proportionally, the PPD analysis zone has among the highest SCM needs. The central portion of this zone was identified as a high needs area, while most of the surrounding land was identified as having moderate needs. The applicability of most SCMs is limited in the high needs area by high impervious surface coverage and somewhat steep slopes upslope of the existing parking lots. If possible, ground level SCMs to control runoff from the buildings and parking lots in the high needs area would be most appropriate along the western side of E. Campus Road (though space is currently limited there), as the land on the eastern side of the road is quite steep and mostly occupied by the flood plain. One parking lot (⑦ on map) in the high needs area was identified as a relatively high priority for conversion to permeable pavement; however, decisions about such a conversion should take into account UGA's plans for this parking lot when the proposed buildings nearby are built. If the parking lot is expected to be removed, conversion to permeable pavement is likely not worth the investment. Overall, low land use SCMs like green roofs and water harvesting may be most appropriate for this high impervious surface coverage area.

The moderate needs area, in the headwaters of this small watershed, presents many more open space opportunities for SCM installation. In the analyses in chapter 6, these headwaters are identified as a high to moderately high suitability and priority area for most SCM types. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities throughout the PPD watershed.

Water quality monitoring

Total suspended solids, turbidity, and conductivity were recorded as higher in the PPD watershed than within the Tanyard Creek or Lilly Branch watersheds, especially during dry sampling conditions. While these issues may be able to be addressed through SCMs, the fact that these trends were especially pronounced during dry sampling indicates a likely pollution source that is not stormwater related. In addition, some or all of these pollutants may have been introduced by the large coal pile that used to occupy part of this watershed. Fecal coliform bacteria (warm weather, wet sampling conditions) and total phosphorus were consistently high throughout the three target watersheds, including within the PPD watershed (page 64).

Specific stormwater-related sources for the above pollutants within the PPD zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

UGA owns all of the land within the PPD watershed except for a railroad right-of-way. There are several large academic buildings there, the largest being UGA's Science Library. This zone is an area that is likely to undergo a considerable amount of change, based on the high density of proposed buildings there. If built, the construction and soil disturbance associated with these new buildings will offer numerous opportunities for SCM installation.

Existing stormwater infrastructure

The only existing SCMs within the PPD zone are a small experimental green roof on the Science Library, a cistern near the Physical Plant building, and high tree cover on the largest steep slope area.

Existing catch basins and drop inlets are shown for the PPD analysis zone. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat incoming runoff before it is carried to streams.

Sensitive and natural areas

Steep and designated natural areas surround most of the area identified as high needs within the PPD zone, and also in the portion of this zone that is east of the railroad right of way. The latter area is also partly covered by the flood plain (Figure 6-23). Where steep slopes are long, runoff velocity may become rapid. Where vegetation exists on steep slopes, it should be maintained to prevent erosion, slow runoff, and encourage infiltration. Where steep slopes are covered only by turf, additional vegetation should be planted when possible, and additional SCMs may be needed to manage the rapid runoff passing through and off of these areas.

Existing stormwater-related plans

UGA Green Infrastructure Plan site 11 (*http://www.ced.uga.edu/index.php/services_outreach/detail/green_infrastructure/*).

PPD

Figure 7-5. Physical Plant Drainage (PPD) watershed and analysis zone. Recommendations for this analysis zone are described beginning on page 170.

Lilly West analysis zone

Location

The Lilly West analysis zone contains the headwaters and midstream sections of the Lilly Branch watershed. The portion of Lilly Branch that flows through the UGA campus within the Lilly West zone is entirely piped, whereas the off campus section is likely to be daylit based on the fact that it is surrounded by heavy tree cover and other riparian vegetation (Figure 7-6).

Stormwater management needs overview

Overall, the Lilly West analysis zone is among those with the highest SCM needs, relative to other zones within the three target watersheds. Impervious surface coverage is highest in the northern portion of this zone, moderate through the middle and most of the southern section, and relatively low in a small, steeply sloped catchment at the southeastern edge of Lilly West. There is a clear divide within this zone between the relatively low needs headwaters beyond the UGA campus and the midstream section of the watershed, which is mostly occupied by UGA. This division was most likely influenced by water quality data, as the catchment boundary for monitoring point MP-8 correlates with the apparent dividing line, which is most likely because the catchment of monitoring point MP-9 had the highest having the poorest calculated wet weather water quality value in the overall water quality overlay.

Based on prioritization analyses (chapter 6), the high needs portion of the Lilly West Zone that falls on UGA property is highlighted as being among the highest priority areas for many types of SCM. This pattern is due to the combination of high stormwater management needs, high likelihood of finding suitable SCM sites due to the relatively flat topography and other site conditions, and UGA property ownership. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities throughout the Lilly West zone.

One location to take note of is a field that is currently part of UGA's veterinary medicine diagnostic facility (8 on map). As this field is currently in use for veterinary diagnostics, it is currently unsuitable for SCMs; however, UGA is preparing for the construction of a new veterinary hospital away from the main campus. After that transition is complete, this field may be a good location for some future SCMs. It is identified as a likely high priority zone for most SCM types. In particular, it is highlighted as one of the few possible highest priority sites within the study area for a potential stormwater wetland. Of course, a closer examination of site conditions may indicate that a stormwater wetland is inappropriate here after all, but the option should be considered.

Water quality monitoring

Lilly West includes monitoring points MP-8, MP-9, and MP-10. The headwaters of Lilly Branch (sites MP-8 and MP-9) were more acidic (i.e. had a lower pH) than the rest of the sites within the three target watersheds, especially during wet weather sampling. Total nitrogen, total phosphorus, total suspended solids, copper, and lead appeared to increase moving downstream in Lilly Branch, but as sites MP-9 and MP-10 were not sampled for these pollutants, the status of these pollutants is unknown in the middle portion of the Lilly Branch watershed. Under wet weather sampling, turbidity was higher at sites MP-9 and MP-10, in the center of the Lilly Branch watershed than upstream or downstream. Fecal coliform bacteria were high at all sites during wet weather sampling. Fecal coliform bacteria under was higher during dry weather sampling at the upstream sampling site, MP-8, than at the other monitoring points on Lilly Branch, but dry weather results are more likely to indicate an ongoing problem (e.g. leaking sewage pipes) than a stormwater-related source (page 64).

Specific stormwater-related sources for the above pollutants within the Lilly West zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

UGA owns most of the land in this watershed, with residential uses (single and multifamily) making up the majority of the remaining land. Milledge Avenue and Lumpkin Street, which come together at the Five Points intersection, support a higher diversity of uses, such as restaurants, neighborhood scale commercial properties, and professional offices. The US government owned inholding on the UGA campus is a US Forest Service facility. Most of the land on which Barrow Elementary School sits also falls within Lilly West. Caution should be used near the elementary school in regard to potential SCMs that include standing water, due to the elevated drowning risks associated with them.

The portion of Lilly West owned by UGA is unusual when compared with the rest of the study area due to the high concentration of athletic fields and other large athletic facilities. Among them are Stegman Coliseum, the Butts-Mehre athletic complex, Foley Baseball Field, and the indoor tennis stadium and its associated tennis courts. Other large UGA structures within the Lilly West analysis zone include Georgia Center for Continuing Education, two parking garages, and numerous large academic and support buildings. Eleven proposed buildings from UGA's master plan are located within Lilly West, providing future construction-related opportunities for SCM installation.

As mentioned in the stormwater management needs overview section above, the off-campus high needs area south of the stream reach that connects monitoring points MP-8 and MP-9 (9 on map) was likely identified as having higher needs than similar nearby residential areas due to poor water quality in this catchment as a whole; however, note that an examination of land uses suggests that pollution inputs are more likely to have come from the northern side of this reach's catchment (athletic fields, large buildings, and high impervious surface coverage), rather than from this southern, off campus side (small, residential structures with a lower proportion of impervious surface cover).

Existing stormwater infrastructure

The Lilly West zone includes at least 10 permeable pavement projects, rain gardens, or other ground level SCMs. The largest of these is a permeable pavement installation adjacent to the Coliseum. This zone also includes three cisterns. Some existing SCMs, such as the ones that run through the middle of the parking lot across Carlton from the Coliseum, are located on or near the sites of proposed future construction, and so may need to be replaced with other SCMs at the time of construction.

Existing catch basins and drop inlets are shown for the UGA-owned portion of the Lilly West analysis zone. GIS data for existing conventional stormwater infrastructure and SCMs was unavailable for the portions of this zone that are located beyond the UGA campus. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat incoming runoff before it is carried to streams.

Sensitive and natural areas

As described above, the on-campus portions of Lilly Branch within the Lilly West zone are all underground, while the off-campus section is already surrounded by dense riparian vegetation. One large, steep area exists at the southeastern extent of this analysis zone This area, which is owned by UGA, is heavily vegetated and is likely to remain that way. Other steep areas include land south of Foley Baseball Field and Barrow Elementary School (Figure 6-23). Where steep slopes are long, runoff velocity may become rapid. Where vegetation exists on steep slopes, it should be maintained to prevent erosion, slow runoff, and encourage infiltration. Where steep slopes are covered only by turf, additional vegetation should be planted when possible, and additional SCMs may be needed to manage the rapid runoff passing through and off of these areas.

Existing stormwater-related plans

James Eason, Tracy Hambrick, Jennifer Kanine, James Kelly, and Lauren Satterfield. Environmental Law Practicum, Spring 2011. *Lilly Branch Rehabilitation Plan*, a plan for the headwaters of Lilly Branch, upstream of Foley Baseball Field.

UGA Green Infrastructure Plan sites 12, 15, 16, 17, 19, and 20 (*http://www.ced.uga.edu/index.php/services_outreach/detail/green_infrastructure/*).

Lilly West

Figure 7-6. Lilly West analysis zone, including the headwaters and central section of the Lillyl Branch watershed. Recommendations for this analysis zone are described beginning on page 173.

Lilly East analysis zone

Location

The Lilly East analysis zone includes the downstream portion of the Lilly Branch watershed (Figure 7-7).

Stormwater management needs overview

Overall, the Lilly East analysis zone is among those with the lowest SCM needs, relative to other zones within the three target watersheds. Impervious surface coverage is relatively moderate to low relative to the rest of the study area. Most of the land within this zone was classified as having moderate potential SCM needs, but two locations were classified as high needs areas. The first is adjacent to the Ramsey Center, while the second is at the site of a large parking lot north of the East Village residential complex. Caution should be taken when considering the second high needs area, as it is located almost entirely within the flood plain. Please refer to the SCM suitability and prioritization maps in chapter 6 when considering SCM possibilities throughout the Lilly East zone. Note the classification of the open space immediately northwest of the Ramsey Center as an especially high priority area for consideration of a possible stormwater wetland.

Water quality monitoring

Lead, copper, total nitrogen, total suspended solids, turbidity (wet sampling only), and conductivity (dry sampling only) were higher downstream in Lilly Branch than upstream. Fecal coliform bacteria (wet sampling only) and total phosphorus were elevated at most sampling sites throughout the three target watersheds, including Lilly Branch.

Specific stormwater-related sources for the above pollutants within the Lilly East zone should be identified and treated according to the guidelines given in chapter 4. SCMs used for pollution control should be placed as close to the pollution source as possible, even if a source is located in an otherwise low SCM needs area.

Property ownership and significant structures

UGA owns most of the land within the Lilly East zone. This zone also includes a railroad right-of-way, as well as some private single family residential property, located on the western side. The largest building in the Lilly East zone is the Ramsey Center, but there are also several large arts complex buildings, two parking garages, a large academic building that houses the Rhodes Animal Science Center, the East Village (a collection of four residence halls), as well as additional support buildings. West of E. Campus

Road lies a complex of university owned multifamily residences. Most of the proposed construction within this watershed surround the East Campus Parking Deck.

Existing stormwater infrastructure

Most existing SCMs within the Lilly East zone are associated with recent construction projects at the arts complex and the expanded Student Health Center. These include ground level SCMs (e.g. rain gardens, swales), two cisterns, and a green roof that lies on a portion of the Lamar Dodd School of Art. There is also a rain garden between the eastern high needs zone and Lilly Branch.

Existing catch basins and drop inlets are shown for the UGA-owned portion of the Lilly East analysis zone. GIS data for existing conventional stormwater infrastructure and SCMs was unavailable for the portions of this zone that are located beyond the UGA campus. SCM placement decisions should take existing stormwater infrastructure into account, as it can affect runoff accumulation, flow path, and speed. Potential SCM locations upslope of existing inputs to the conventional stormwater system are the last opportunity to treat incoming runoff before it is carried to streams.

Sensitive and natural areas

Most of the portion of Lilly Branch that flows though Lilly East is daylit. The daylit sections are surrounded by trees and other vegetation, with increasing riparian vegetation density approaching the North Oconee River. Vegetation should be maintained on these riparian areas. There are almost no areas classified as having steep slopes; one notable exception is the land separating the art museum from the art school (Figure 6-23).

In this zone, the flood plain covers much of the land surrounding Lilly Branch for a considerable distance on either side of the stream. Several existing buildings and parking lots, as well as some existing SCMs, are built in the flood plain. Caution should be used when selecting stormwater management strategies for this large flood plain area. Most SCMs are less suitable in the flood plain than elsewhere; however, floodplains may indicate good potential stormwater wetland sites.

Existing stormwater-related plans

Lisa Biddle, Environmental Law Practicum memo, Spring 2012 (*BMP Design for Lilly Branch: Retrofitting two parking islands in the E06 lot*).

Peter Hawman, BLA senior design project, Spring 2009 (*East Campus Stream Restoration and Greenway Extension*). This design focuses on stream restoration and circulation, rather than on SCMs, but it is included as a related plan.

UGA Green Infrastructure Plan sites 13, 17, 18, and 20 (*http://www.ced.uga.edu/index.php/services_outreach/detail/green_infrastructure/*).

Lilly East

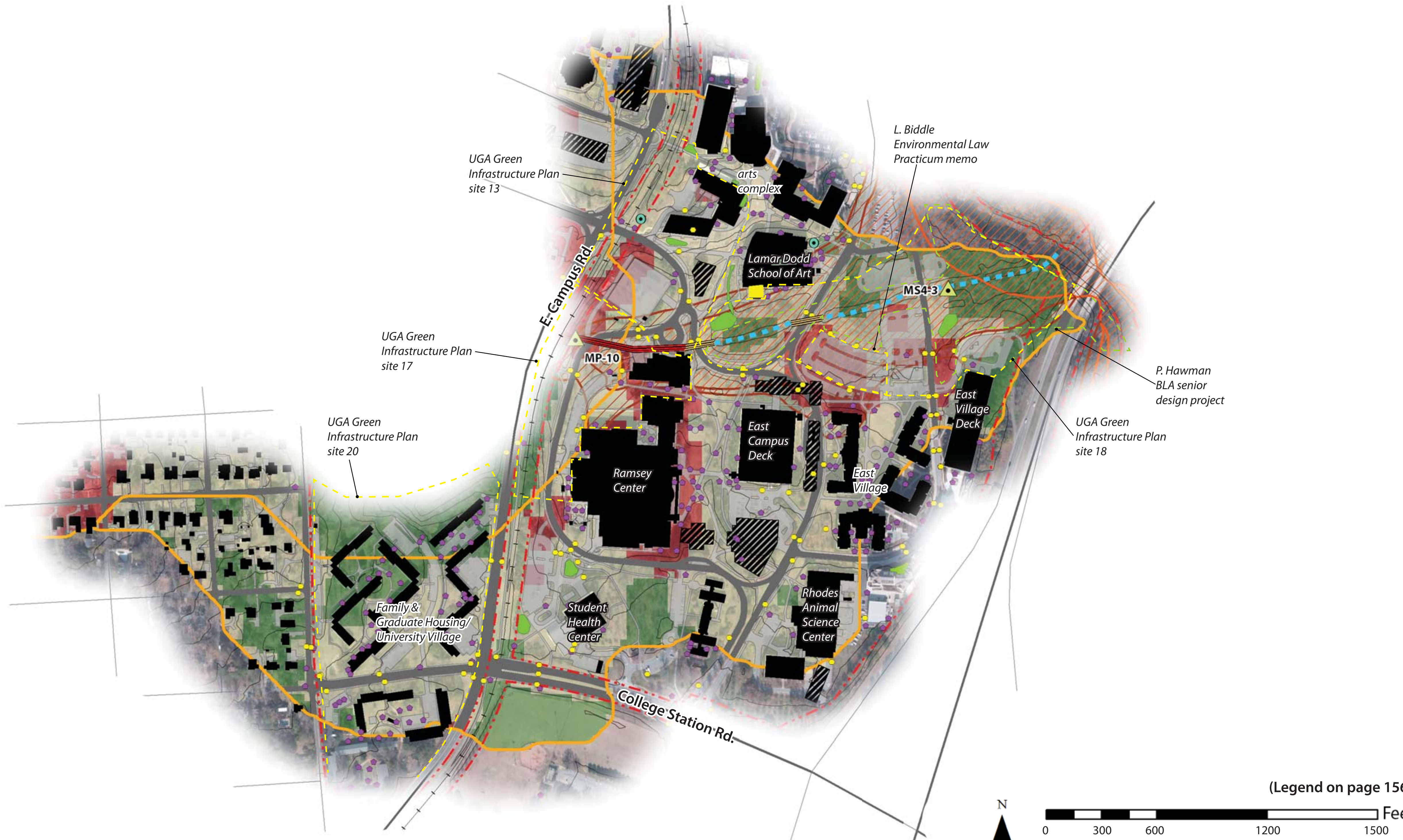

Figure 7-7. Lilly East analysis zone, which includes the downstream portion of the Lilly Branch watershed, including its confluence with the North Oconee River. Recommendations for this analysis zone are described beginning on page 178.

Appendix: GIS methods

The following pages list the ArcMap processes, tools, and settings used.

Organization

All GIS map creation, analyses, and new layer creation was done using ArcMap 10, the Spatial Analyst extension, and the ArcHydro Tools plug-in. The following pages list the ArcMap processes, tools, and settings used. The default options were always selected unless otherwise noted.

Formatting for this appendix:

Tool names are italicized, in brackets: *[Tool]*
GIS layer names (rasters or features) are italicized: *Layer*
Brackets followed by > indicate right click and selection: *{layer}* > *Option*
Settings are underlined: Setting
Field names are capitalized: FIELD

Note that the italicized raster and feature names listed below are descriptive, for clarity. They do not necessarily correspond with the exact file name used for each feature or raster in the GIS.

Universal settings

The following settings were used for all GIS work unless otherwise noted.

Projection

NAD 1983, State Plane, Georgia West, FIPS 1002, feet (referred to below as "State Plane, Georgia West")

Raster cell resolution

1/3 arcsecond (31.06 feet). This resolution is based on the finest resolution digital elevation model (DEM) available from the National Elevation Dataset for the study area.

Stream network and catchment delineation

1. Converted elevation units (meters to feet).

   [Raster Calculator]
   DEM(meters)[1] / 0.3048 = *DEM(feet)*

2. Imposed streams onto digital elevation model.

   [Project]
   input feature class: *NHDflowline*[2]

1 1/3 arcsecond DEM from National Elevation Dataset
2 National Hydrographic Dataset

output projection: State Plane, Georgia West
output feature class: *NHDflowline(projected)*

[ArcHydro Tools > DEM Reconditioning]

raw DEM (input): *DEM(feet)*
agree stream (input): *NHDflowline(projected)*
agreeDEM (output): *AgreeDEM*
vector buffer (cells): 5
smooth drop/raise: 10
sharp drop/raise: 100

3. Filled sinks.

   (Note that filling sinks was necessary for the flow direction and flow accumulation processes to be able to generate a stream network; however, the process resulted in a flattening of the terrain in certain areas (e.g. the entire ravine area near UGA's stadium) that made the resulting DEM unusable for slope calculations.

   [ArcHydro Tools > Fill Sinks]

   DEM (input): *AgreeDEM*
   hydro DEM (output): *FillDEM*

4. Calculated flow direction.

   [ArcHydro Tools > Flow Direction]

   hydro DEM (input): *FillDEM*
   flow direction grid (output): *FlowDirection*

5. Calculated flow accumulation.

   [ArcHydro Tools > Flow Accumulation]

   flow direction grid (input): *FlowDirection*
   flow accumulation grid (output): *FlowAccumulation*

6. Determined the primary drainage network, which includes all cells with a flow accumulation above a given threshold. The threshold used was the flow accumulation value that resulted in the delineation of the PPD watershed as a single catchment.

   [ArcHydro Tools > Stream Definition]

   flow accumulation grid (input): *FlowAccumulation*
   stream grid (output): *Stream*
   number of cells (threshold): 1528

7. Created a network of stream segments, divided by stream junctions, each with a unique identification number.

   [ArcHydro Tools > Stream Segmentation]
   flow direction grid (input): *FlowDirection*
   stream grid (input): *Stream*
   link grid (output): *StreamSegment*

8. Delineated an individual catchment for each stream segment.

   [ArcHydro Tools > Catchment Grid Delineation]
   flow direction grid (input): *FlowDirection*
   link grid (input): *StreamSegment*
   catchment grid (output): *Catchment(raster)*

9. Converted catchments from raster to vector (polygon) format.

   [ArcHydro Tools > Catchment Polygon Processing]
   catchment grid (input): *Catchment(raster)*
   catchment (output): *Catchment(polygon)*

10. Created a primary drainage line feature

    [ArcHydro Tools > Drainage Line Processing]
    link grid (input): *StreamSegment*
    flow direction grid (input): *FlowDirection*
    drainage line (output): *DrainageLine*

11. In cases where a delineated catchment was bisected by the primary drainage line feature, divided the original catchment into two new catchments.

    [Topology Toolbar > Split Polygons]
    selected line feature: *DrainageLine*
    selected polygon to edit: *Catchment(polygon)*
    target (output): *SplitCatchments*

Drainage area in acres

Each 1/3 arcsecond cell is 0.022152 acres. The “+ 1” in the equation below is because each cell’s drainage area includes all of the cells that drain to it, plus itself.

[Map Algebra]
(<u>*FlowAccumulation* + 1) * 0.022152</u> = *DrainageArea(acres)*

Parcels: zoning and property ownership[3]

1. In Microsoft Excel, converted *realprop.dbf* and *owner.dbf* to excel (xls) files to prepare for join.

2. In Microsoft Excel, in *realprop.dbf*, renamed field EXISTS to EXISTS_. EXISTS is a reserved field in ArcGIS. Zoning categories were obtained from *realprop.dbf*.

3. In Microsoft Excel, created OWNERTYPE field in *owner.dbf*. Assign owner type categories as described on page 34.

4. Joined data.

   [{Parcel(clipped) layer*} > Join]*
   field in this layer that join will be based on: REAL_KEY
   table to join: *realprop.xls*
   field in the table to base the join on: REALKEY
   [{Parcel(clipped) layer*} > Join]*
   field in this layer that join will be based on: OWNKEY
   table to join: *owner.dbf*
   field in the table to base the join on: OWNKEY

5. Saved as new layer to preserve joins.

Combined impervious surface layer

1. Created combined impervious surface layer (*impervious_surface(union)*) from Athens-Clarke County and University of Georgia impervious surface data, using a combination of the *[Clip]*, *[Select by Location]*, and *[Union]* tools.

   Athens-Clarke County impervious surface data included all impervious surface categories used in this practicum. UGA data were in separate layers, and included only buildings, sidewalks, and parking areas. UGA data were more up to date regarding recent UGA construction, and so were used where available. Additionally, the UGA sidewalk layer was more detailed than ACC's sidewalk data.

2. The above process left some slivers of features at the boundary between UGA and non-UGA property. These were removed using the *[Editor Toolbar]*.

3 Parcels shapefile (*parcels059*), ownership data (*owner.dbf*), and real estate data (*realprop.dbf*) were obtained was obtained from Blake Conant at the UGA Office of Sustainability.

3. While buildings, parking lots, and sidewalks in the combined layer reflected recent UGA construction, such as the Special Collections Libraries, the roads in the combined layer reflected pre-construction conditions. The *[Editor Toolbar]* was used, in combination with aerial imagery from Bing Maps, to update roads where affected by recent construction. The new parking garage downtown was also added.

Percent impervious surface coverage

1. Created indicator grid, using cells 1/100 the size of the desired final grid size (1/10 the length of each side).

   [Feature to Raster]

   input features: *impervious_surface(union)*
   value field: TYPE (any field with data for all entries would be fine)
   output raster: *impervious_indicator(temp)*
   output cell size: 3.10635036973668 ft (1/10 of 1/3 arcsecond)

   [Reclassify]

   input raster: *impervious_indicator(temp)*
   reclassify all old values to: 1
   reclassify no data to: no data
   output raster: *impervious_indicator*

2. Added the indicator values for each group of 100 indicator cells that corresponds to each 1/3 arcsecond cell in the output raster.

   [Aggregate]

   input raster: *impervious_indicator*
   output raster: *percent_impervious*
   cell factor: 10
   aggregation technique: sum

3. Calculated the estimated percent impervious surface coverage for each catchment by averaging the percent cover of all cells within each catchment.

   [Zonal Statistics]

   input feature zone data: *SplitCatchments*
   zone field: FID
   input value raster: *percent_impervious*
   output raster: *percentImp_byCatchment*
   statistics type: mean

Flow-weighted distance from impervious surfaces

1. Created layer including all impervious surfaces except paths (roads and sidewalks).

   [{impervious_surface(union)} > Select All]
   [Select by Attributes]
   layer: *impervious_surface(union)*
   method: remove from current selection
   "TYPE = uga sidewalk or private concrete sidewalk or public concrete sidewalk or road"
   [{impervious_surface(union)} > Export Data]
   output: *impervious_surface(no_path)*

2. Reclassified flow accumulation for values less than the primary drainage cutoff (1528 cells). Used a geometric interval, rounded to the nearest whole number, for values below cutoff. Everything with a flow accumulation greater than 1528 cells received a 10.

   [Reclassify]
   input raster: *FlowAccumulation*
   reclassify from old values to new values

Old:	New:
0-92	1
93-168	2
169-260	3
261-374	4
375-512	5
513-682	6
683-890	7
891-1144	8
1145-1528	9
>1528	10
no data	no data

   output raster: *FlowAccumulation(reclass)*

3. Assigned flow accumulation classification values to the impervious surfaces (non-path) they intersect.

   [Spatial Join]
   target features (input): *impervious_surface(no_path)*
   join features (input): *FlowAccumulation(reclass)*
   output feature class: *OnDrainage_FlowAccumulation(reclass)*

4. Created a buffer so that the land adjacent to impervious surfaces would be included, rather than just the impervious surfaces themselves, since this is where most SCMs would be located.

   [Buffer]

   input features: *OnDrainage_FlowAccumulation(reclass)*
   output feature class: *OnDrainage_FlowAccumulation_Buffer*
   linear unit: <u>100 ft.</u>
   dissolve type: <u>list</u>

   [Polygon to Raster]

   input features: *OnDrainage_FlowAccumulation_Buffer*
   value field: <u>MAX_GRID_C</u> (the maximum flow accumulation classification value (from *OnDrainage_FlowAccumulation(reclass)*) intersecting each non-path impervious surface)
   output raster dataset: *OnDrainage_FlowAccumulation_Buffer(raster)*
   priority field: <u>MAX_GRID_C</u> (this step tells it to select the highest flow accumulation value for each cell, when overlapping buffers are present)

5. Calculated the distance from each impervious surface.

   [Euclidean Distance]

   input feature class: *impervious_surface(union)*
   output distance raster: *EucDist_impervious*

   [Reclassify]

   input raster: *EucDist_impervious*
   reclassify from old values to new values

Old:	New:
<u>0-10 (ft)</u>	<u>10</u>
<u>10-20</u>	<u>9</u>
<u>20-30</u>	<u>8</u>
<u>30-40</u>	<u>7</u>
<u>40-50</u>	<u>6</u>
<u>50-60</u>	<u>5</u>
<u>60-70</u>	<u>4</u>
<u>70-80</u>	<u>3</u>
<u>80-90</u>	<u>2</u>
<u>>90</u>	<u>1</u>

   output raster: *EucDist_impervious(reclass)*

6. Combined above into one layer.

   [Weighted overlay]

   input rasters: *EucDist_impervious(reclass)* and *OnDrainage_FlowAccumulation_Buffer(raster)*
   values: given above

evaluation scale: 1 to 10 by 1
set equal influence
output raster: *OnDrainage_Weighted*

Slope

1. Calculated slope from 2 ft contour intervals.

   [Topo to Raster]
   input feature data: *2ftContour*
   output surface raster: *topoToRaster_2ftContour*
   [Slope]
   input raster: *topoToRaster_2ftContour*
   output raster: *slope_2ftContour*
   output measurement: percent rise
   [Reclassify]
   input raster: *slope_2ftContour*
   reclassify as described on page 97
   output raster: *slope_2ft(reclass)*

2. Calculated average slope for each catchment.

   [Zonal Statistics]
   input feature zone data: *SplitCatchments*
   zone field: FID
   input value raster: *slope_2ftContour*
   output raster: *slope_byCatchment*
   statistics type: mean
   [Reclassify]
   input raster: *slope_byCatchment*
   reclassify as described on page 97
   output raster: *slope_byCatchment(reclass)*

3. Combined above into one layer.

   [Weighted overlay]
   input rasters: *slope_byCatchment(reclass)* and *slope_2ft(reclass)*
   values: given above
   evaluation scale: 1 to 10 by 1
   set equal influence
   output raster: *SlopeWeighted_2ftContour*

Water quality

1. Found the catchment of each water quality monitoring site.

   [{monitoring_locations} > Select]
   (selected the 8 monitoring points that met the criteria described on page 41, which were used for fecal coliform, pH, conductivity, and turbidity data)
   [{monitoring_locations} > Export Data]
   output: *fecal8*
   [Snap Pour Point]
   input feature pour point data: *fecal8*
   input accumulation raster: *FlowAccumulation*
   output raster: *snapFecal8*
   [Watershed]
   input flow direction raster: *FlowDirection*
   input raster pour point data: *snapFecal8*
   output raster: *watershed_Fecal8*
   [Raster to Polygon]
   input raster: *watershed_Fecal8*
   output polygon: *watershed_Fecal8(polygon)*
   [{watershed_Fecal8(polygon)} > Select > Export Data]
   (selected all catchments that make up the entire watershed of each monitoring point (including upstream catchments); exported as individual shapefiles for use as clipping boundaries in subsequent steps)
   output format: *catch-ptX*[4]

2. Calculated the euclidean distance from each monitoring point individually.

   [Raster to Polygon]
   input raster: *snapFecal8*
   output shapefile: *snap_Fecal8(point)*
   [{snap_fecal8(polygon)} > Select > Export data]
   (selected each monitoring point individually, then exported each to its own shapefile)
   output format: *snap_fecal8-X*
   [Euclidean distance]
   input feature data source: *snap_fecal8-X*

4 X represents the monitoring site number. In this and all subsequent steps, numbers 1, 3, 6, 8, 9, 10, 42, and 43 were used for sites MP-1, MP-3, MP-6, MP-8, MP-9, MP-10, MS4-2, and MS4-3, respectively. A total of 8 shapefiles were created here, one for each site.

output distance raster: *dist-ptX*

[Extract by Mask]

input raster: *dist-ptX*
input feature mask data: *catch-ptX*
output raster: *ClipDist-ptX*

3. Calculated the weight to be given to each site's water quality monitoring data for each cell in the grid (calculated as the ratio of the cell's distance to each downstream sampling point).

   (a) For catchments falling upstream of only one sampling point (MP-6, MS4-2, MS4-3), the value used for all cells within the catchment was the value of that catchment's monitoring point (e.g. all cells in the catchment for site MS4-2 received the average water quality value calculated for site MS4-2).

   output rasters: *ratio-pt6-, ratio-pt42-, ratio-pt43-*[5]

   (b) For catchments falling upstream of at least one other monitoring point, calculated the ratio of each cell's distance from its catchment's monitoring point to its distance from the next further downstream monitoring point e.g. for cells in the catchment of monitoring point MP-1, the ratio was: *ClipDist-pt1/ ClipDist-pt6*

   output rasters: *ratio-pt1_6, ratio-pt3_6, ratio-pt10_43, ratio-pt9_10, ratio-pt8_9*

4. Calculated the water quality value for each cell, one catchment at a time (repeat for each water quality parameter.

   [Raster Calculator]

   (a) For furthest downstream catchments (MP-6, MS4-2, MS4-3):
   e.g. <u>*(ratio-pt6-)* * (WQ value for point 6)</u> = *WQ_pt6*[6]

   (b) For all other sites[7]:
   e.g. <u>[*(ratio-pt1_6)* * *(WQ_pt6)*] - [(1 - *(ratio-pt1_6)*) * (WQ value for point 1)]</u> = *WQ_pt1*

5. Combined the eight individual WQ rasters into one (repeat for each water quality parameter).

   [Model Builder]

---

5 All cells in these three rasters = 1; for use in equations in subsequent steps

6 WQ is a placeholder for each water quality parameter (e.g. fecal coliform-dry/warm or lead-wet). For most pollutants, the mean value was used. For fecal coliform, the water quality parameter used was $\log_{10}$(geometric mean). For pH, the parameter used was hydrogen ion concentration.

7 Note that the weighted WQ values for Lilly Branch must be calculated in the order MS4-3, MP-10, MP-9, MP-8.

(copied and modified model for each water quality parameter)

[Raster Calculator]

(a) Lilly Branch:

Con(IsNull(“*WQ_pt8*”)),[Con(IsNull(“*WQ_pt9*”)), [Con(IsNull(“*WQ_pt10*)), “*WQ_pt43*”, “*WQ_pt10*”], “*WQ_pt9*”], “*WQ_pt8*” = *WQ_Lilly*

(b) Tanyard Creek:

Con(IsNull(“*WQ_pt1*”)),[Con(IsNull(“*WQ_pt3*”)), “*WQ_pt6*”, “*WQ_pt3*”], “*WQ_pt1*” = *WQ_Tanyard*

(c) Combine all three watersheds (PPD is *WQ_pt42* from previous step):

Con(IsNull(“*WQ_Tanyard*”)),[Con(IsNull(“*WQ_Lilly*”)), “*WQ_pt42*”, “*WQ_Lilly*”],“*WQ_Tanyard* = *WQ_all*

(d) Only for fecal coliform (because calculations up to this point were based on logarithmic data, due to use of geometric mean):

Exp10(“*WQ_all*”) = *WQ_all10*

(e) Only for pH (to convert back to pH from hydrogen ion concentration):

$-\log_{10}$(“*WQ(H)_all*”) = *WQ(pH)_all*

6. Pollutants not listed under step1 above were only sampled at 6 water quality monitoring sites, omitting sites MP-9 and MP-10 on Lilly Branch. For these pollutants, steps 1-6 were repeated, but modified to exclude sites MP-9 and MP-10.

7. For each water quality parameter, reclassified data according to pollution levels.

   [Reclassify]

   input raster: *WQ_all* or *WQ_all10*
   old and new values as given in chapter 5
   output raster: *WQ_reclass*

8. Combined into one layer.

   [Weighted Overlay]

   input rasters: *pH_W_reclass, fecal_WC_reclass, Copper_reclass, Lead_reclass,* and *TSS_W_reclass*
   values: given in chapter 5.
   evaluation scale: 1 to 10 by 1
   set equal influence
   output raster: *WQ_wet5*

Weighted overlay/analysis example (potential SCM needs)

This example demonstrates how weighted overlays and generalization tools were used in the needs, suitability, and prioritization analyses. For analyses where individual structures were identified, rather than general areas (e.g. green roofs, porous pavement), *[Majority Filter]* and *[Boundary Clean]* processes were omitted. For more information on specific procedures, see chapters 5 and 6.

This example shows the potential SCM needs analysis.

[Weighted Overlay]
    input rasters: *WQ_wet5*, *SlopeWeighted_2ftContour*, *OnDrainage_Weighted*, *percentImp_byCatchment*, and *SoilErod_PolygonToRaster*
    values: given in chapter 5
    evaluation scale: <u>1 to 10 by 1</u>
    <u>set equal influence</u>
    output raster: SCM*Needs*
[Majority Filter]
    input raster: SCM*Needs*
    output raster: SCM*Needs_MF*
    number of neighbors to use: <u>eight</u>
    replacement threshold: <u>half</u>
[Boundary Clean]
    input raster: SCM*Needs_MF*
    output raster: SCM*Needs_BC*

Suitability and prioritization analysis preparation

Analyses were carried out using a weighted overlay as shown in the potential SCM needs example above, with the overlay values and percentages given in chapter 6. Generalization procedures (Majority Filter and Boundary Clean) were used for prioritization analyses, as demonstrated above, except where it was desirable to identify individual structures such as parking lots or buildings.

As these weighted overlay and generalization weights and processes have been documented elsewhere, they are not included here. This section only includes steps that were used to prepare data for analysis.

1. For water harvesting analysis, joined potential SCM needs analysis results with current and proposed buildings layers and to buildings from impervious surface layer.

[Raster to Polygon]
[Spatial Join]
    Field Map GRIDCODE merge rule: <u>maximum</u>

2. For permeable pavement (existing parking), calculated average slope for existing parking lots.

   [Zonal Statistics]
   zone (input): *parking(shapefile)*
   raster (input): *slope_2ftContours*
   method: <u>mean</u>

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