LATIS

Landscape Architecture Technical Information Series

Suburban Street Stormwater Retrofitting:

An Introduction to Improving Residential Rights-of-Way

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Suburban Street Stormwater Retrofitting: An Introduction for Improving Residential Rights-of-Way

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Cover

Illustration representing a suburban street that has undergone a stormwater curb extension retrofit. In addition to water quality benefits, street stormwater retrofit devices narrow and calm overly wide streets, and provide habitat, shade, and visual interest. When combined with other traffic calming measures such as bike lanes and crosswalk bulb-outs, traditionally auto-dominated suburban streets are better able to safely support multiple modes of transportation and recreational use. Image credit: Jim Cooper (c) 2012

Following page (right)

A birds-eye perspective highlighting the overall streetscape improvement that street stormwater retrofitting creates within the context of traditional suburban neighborhoods. Image credit: Derek Blaylock (c) 2012

Publisher's Note

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image credit: Derek Blaylock

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Introduction

The purpose of this document is to provide an overview of design and implementation strategies for stormwater retrofitting within suburban street rights-of-way. Street stormwater retrofitting is a Green Street design approach that embraces low impact development (LID) principles in order to treat stormwater runoff within the street right-of-way limits.

The design and implementation strategies presented herein build upon those developed as part of the City of Portland's Green Street Program, Seattle Public Utilities' Street Edge Alternative (SEA) Project, the San Mateo County Water Pollution Prevention Program (SMCWPPP), and North Carolina State University's Biological and Agricultural Engineering Department (BAE) Stormwater Engineering Group. While publications produced by these entities are comprehensive, this resource is intended to serve as an easily understandable, general set of design strategies for street stormwater retrofitting without delving too deeply into technical specifications and construction details. Although it briefly addresses various methodologies for implementing retrofits, it primarily focuses on stormwater curb extensions. This particular stormwater retrofitting solution lends itself well to suburban street applications because it has the potential to treat a relatively large volume of stormwater runoff while both minimizing project costs and impacting the least amount of existing street infrastructure practicable. Like other stormwater retrofitting design strategies, it has the potential to enhance the streetscape environment by providing pedestrian amenities such as curbside plantings, street shade trees, clear spatial definition of the pedestrian corridor, higher visibility pedestrian crossings, and the traffic calming effects of these design features. In these ways, street stormwater retrofits help create beautiful, safe, and comfortable streetscapes capable of enticing people to walk and/or bike when they might otherwise drive.

This document is geared toward city, town, and county planning offices, land developers, homeowners' associations, and the local design community, including landscape architects, civil and water resources engineers, and planners. It is also intended to appeal to smaller groups of interested citizens seeking positive environmental change in their neighborhoods. Even small, localized design interventions can go a long way toward promoting responsible and healthy street stormwater management practices.

The specific details and specifications of roadway designs are not included in this resource because these factors are uniquely guided by each regulating jurisdiction (state, local and, sometimes, private), the specific conditions encountered within any given suburban residential community, and the expertise of respective professional service providers. The overall goal of this document is to illustrate possible outcomes and guide readers through preliminary design assessments. Therefore, this booklet is not intended to be a road design manual, but rather a (sub)urban/neighborhood design primer that uses green infrastructure retrofitting as the principal organizing element to catalyze neighborhood-level watershed and pedestrian improvements.

What is Green Infrastructure?

Stormwater runoff occurs when rainwater or snowmelt flows over impervious surfaces, such as roads, driveways, parking lots, and compacted soil, rather than soaking into the ground. As it flows over these hard surfaces, the runoff collects pollutants, such as sediment, nutrients, pathogens, and heavy metals, and quickly conveys the polluted mixture into nearby streams, lakes, and rivers. Traditional methods of managing stormwater, often referred to as "gray infrastructure," provide limited capture and treatment options because the systems are comprised of gutters, catch basins, and pipes that rapidly transport the runoff to downstream areas. The consequence of these stormwater practices is frequent flooding and nonpoint source pollution that degrades watersheds.

Green infrastructure is a stormwater management approach that addresses these issues by closely mimicking naturalized processes that rely on living materials such as plants and soils "to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water" (USEPA 2015c). More specific to the focus of this document, which is "at the scale of a neighborhood [...], green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water" (USEPA 2015c). Using this approach to stormwater management not only reduces stormwater runoff, but enables communities to achieve "co-benefits that can include improved public health, better quality of life, and economic development," thus providing "the greatest possible benefit out of every investment" (Kramer 2014).

Green infrastructure is quickly gaining momentum around the United States. Highlighting the significance of this move toward a naturalized, multi-benefit approach to stormwater treatment, more than 20 federal agencies, private-sector groups, academic institutions, and non-governmental organizations recently joined together to launch the Green Infrastructure Collaborative, whose aim is to "build capacity for green infrastructure implementation by providing a platform for national stakeholders" (USEPA 2015b).

What are Green Streets?

As a component of green infrastructure, Green Streets are roadways that are designed to minimize impacts to the natural environment, particularly in regard to stormwater runoff management. In essence, Green Streets mimic natural hydrologic processes to mitigate the potentially harmful effects to water and air quality that streets can present. Examples of environmentally deleterious impacts of streets and roadways include, but are not limited to:

- water pollution via increases in sedimentation, total suspended solids (TSS), heavy metals and other toxins, velocity and turbidity, and temperature
- atmospheric pollution via vehicular emissions and heat island effect.

Depending upon their extent within the built environment, Green Streets can mitigate these adverse impacts across a variety of scales and have the potential to greatly affect positive environmental change when implemented across large areas. As described by the Low Impact Development (LID) Center (2015), "Green Streets are designed to:

- Mimic local hydrology prior to development
- Provide multiple benefits along the street right-of-way including:
    - Integrated system of stormwater management within the right-of-way
    - Volume reductions in stormwater which reduce the volume of water discharged via pipe into receiving streams, rivers, and larger water bodies
    - Key linking component in community efforts to develop local green infrastructure networks
    - Aesthetic enhancement of the transit right-of-way
    - Improves local air quality by providing interception of airborne particulates and shade for cooling
    - Enhanced economic development along the transit corridor
    - Improved pedestrian experience along the street right-of-way."

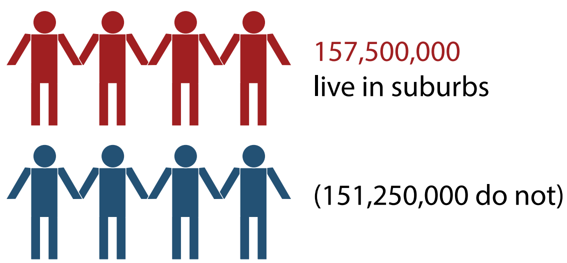
Why Focus on Suburbs?

While other green streets publications have primarily focused on urban settings, this document is specifically geared toward streets in suburban developments. Suburbanization is arguably the predominant land development paradigm in the United States today. The rapid population growth experienced by the U.S. during the past several decades, coupled with automobile-friendly transportation policies, have accelerated the expansion of the built environment into previously undeveloped areas. Approximately 25 percent of the United States' entire land surface area has been developed in the past 15 years, equivalent to a mass greater than the sizes of Alaska and Texas combined (Frumkin, Frank, and Jackson 2004). The majority of new development within this timeframe has been low-density and land-intensive, mainly occurring on the edges of city limits and other places beyond city cores, such as unincorporated areas in adjacent counties and within extraterritorial jurisdiction areas (ETJs).

For example, in the Southeastern United States (one of the fastest growing regions in the country) the metropolitan population grew by 5.3 percent inside central cities and 18.4 percent, or nearly four times as much, in areas outside of central cities (Frumkin et al. 2002). In some cases even cities that have been losing population have actually grown in terms of total land area, as has been the case in Cleveland (Gardner 2006). Historically, these trends demonstrate that many U.S. cities have been decentralizing throughout the last 50-60 years. The lowered population densities and associated morphological changes have resulted in expanded transportation infrastructure networks to accommodate the swelling regional boundaries created by these trends in outward expansion. Recent data suggests that these patterns may be slowing or, in some cases, reversing (U.S. Census 2010). Although this current movement back toward city centers is promising, solutions to the human and environmental health issues created by the sprawling patterns of our past are still required (Figure 1).

Conventional suburban development, which is also referred to as suburban sprawl, has the following key characteristics (Frumkin, Frank, and Jackson 2004):
- low density
- low land use mix (separate land uses are isolated from one another)
- low connectivity (poorly integrated land uses within and among one another)
- automobile dependence.

U.S. Population (in 2010):



By 2010, 51% of the U.S. population lived in suburbs (Population Reference Bureau 2011).

Figure 1: Suburbanization of the United States

These trends began in earnest in 1956 as a result of the Interstate and Defense Highways Act. As the U.S. interstate system developed and expanded, so too did the physical scale and influence of metropolitan regions. Over time, the massive road and highway network grew to interconnect the large swaths of single use, low-density development characteristic of contemporary suburbs (Soule 2006). The current street and roadway system is estimated to occupy upwards of one-third of the total land area within the built environment (Metro 2002). As such, the American roadway right-of-way network represents a very large, continuous, interconnected expanse of public land.

The vast majority of our roadway infrastructure is composed of paved surfaces, including asphalt and concrete vehicular travelways and shoulders, sidewalks, and curbs and gutters. Pavement and other impervious surfaces, including the drainage infrastructure (e.g. concrete gutters and pipes), have traditionally been designed to convey stormwater runoff off the streets and into receiving waterbodies as quickly and efficiently as possible. While other elements of suburban development have the potential to adversely affect the environment, it is the large expanse of impervious surfaces specifically associated with road and street construction that have the greatest consequences for water quality.

In addition to the adverse consequences it presents to the environment, conventional suburban development has negative ramifications for public health and safety. Its characteristically isolated, low-density, and poorly connected development patterns induce reliance on the automobile and foster a sedentary lifestyle (Frumkin, Frank, and Jackson 2004, Ewing, Pendall, and Chen 2002, Fox 2003, Gardner 2006). In fact, residents in communities characterized by conventional suburban development weigh 6.3 pounds more on average than those in more compact, walkable communities (Ewing et al. 2003). This physical inactivity is reinforced by a general lack of quality pedestrian infrastructure that is more common in urban environments. Without streetscape elements that encourage walking, such as an interconnected sidewalk system and street trees and other plantings to provide shade and enhance aesthetics, people are less inclined to walk for leisure or to access nearby destinations. The lower levels of physical activity characteristic of conventional suburbs (here associated with suburban sprawl) have been linked to higher rates of obesity, cardiovascular disease, stroke, and Type-II diabetes, as well as connected to other afflictions such as asthma, chronic lung disease, and hypertension.

Street design that is biased toward vehicular traffic efficiency at the expense of walking and biking also poses consequences to personal safety (Jackson and Kotchtitzky 2001, Transportation Research Board 2001, Transportation for America 2011). Regions characterized by conventional suburban development (suburban sprawl) suffer significantly higher traffic-related injury and fatality rates (Frumkin, Frank, and Jackson 2004, Ewing, Pendall, and Chen 2002, Jackson and Kotchtitzky 2001). These patterns characterize many growing regions. For example, a recent study conducted by Transportation for America

(2011) found that 7 of the top 34 most dangerous large metropolitan areas for walking in the United States were located in the Southern Piedmont, including Atlanta (11th), Raleigh (13th), Birmingham (16th), Charlotte (17th), Richmond (20th), Washington, DC (32nd), and Baltimore (34th). Design interventions such as stormwater curb extensions that narrow travelway lane widths and provide other traffic calming measures, such as creating spatial enclosure of the streetscape with trees and other features, have been demonstrated to enhance pedestrian safety (Transportation for America 2011, Swift, Painter, and Goldstein 1997). When the impacts of street stormwater retrofitting are considered within each metropolitan area and, more importantly, calculated in aggregate across local and regional watersheds, the potential benefits are considerable.

Effects of Conventional Suburban Development on Hydrology

In order to characterize the effects of stormwater on water quality, it is useful to compare the hydrologic function of a healthy, forested ecosystem (the predominate natural cover type within much of the United States) with that of a conventional suburban landscape. In forested ecosystems, trees and soils work together to absorb, filter, evaporate, transpire, cool, and slowly transfer water from precipitation into streams gently across the landscape. Extensive vegetation foliage (trees, shrubs, and herbaceous plants) intercepts rain and evaporates it back into the atmosphere from leaves in a process called canopy interception. As they perform photosynthesis, trees and other plants evapotranspire water vapor back into the atmosphere while shading the land surface, resulting in a cooling effect. Healthy, undisturbed soils percolate rain into the groundwater, replenishing local aquifers, while the remaining runoff gradually enters stream channels and other receiving water bodies. While some sediment is naturally generated and collected by runoff, surface water quality remains high as the various landscape elements described above slow, cool, and filter runoff flow (Figure 2).

It is important to note that a forested ecosystem's hydrologic function also has important ramifications for water quantity. A forest's dense vegetation and healthy soil systems function as a network of checks that delay how rapidly stormwater is sheeted over the landscape into streams. As illustrated in Figure 2, runoff gradually increases to a relatively low level of peak runoff, and then falls slowly after the rainfall event. This hydrographic signature describes how stream channels are able to retain healthy base flow levels in forested ecosystems, benefiting aquatic and terrestrial life.

When forested areas are cleared and graded to accommodate development, the landscape's hydrologic processes are dramatically altered (Figure 3). The hydrograph in Figure 3 illustrates how conventional development practices alter natural hydrologic processes. Rather than a gradual increase in runoff to a sustained, low-level peak volume (as would be the case in forested ecosystems), high proportions of impervious surface coverage directs runoff very rapidly into streams. Runoff from watersheds with high proportions of impervious surfaces exaggerates runoff volume, since the natural series of checks is no longer in place to gradually release it across the land over time (as in Figure 2). Thus, streams in areas with high proportions of impervious surfaces can flood more frequently than those in forested landscapes since their ability to buffer against peak flows is greatly reduced (Center for Neighborhood Technology 2013).

Removal of trees and other vegetation greatly reduces canopy interception and evapotranspiration, thereby increasing the amount of surface runoff after precipitation. Roadway, building, and other structure construction introduce a much greater proportion of impervious areas to the land's surface. As linear conveyances of water, streets (and their accompanying drainage infrastructure) function as stream channels (Figure 4). However, unlike natural streams, streets convey stormwater runoff much more rapidly due to their straightness, typically more continuous slopes, and imperviousness. This high imperviousness is problematic because it impedes percolation of rainfall into underlying soils and, therefore, creates an artificial condition that essentially acts as a waterproof cap covering the ground.

Thus, not only is rainfall runoff unable to replenish groundwater levels and preserve stream channel base flow, it is also accelerated toward receiving water bodies due to removal of vegetative cover and natural microtopographic variation. It is also important to note that during the site preparation phases of land development, much of the underlying soils are reworked and regraded by heavy equipment, resulting in compaction of soil surfaces. Although areas

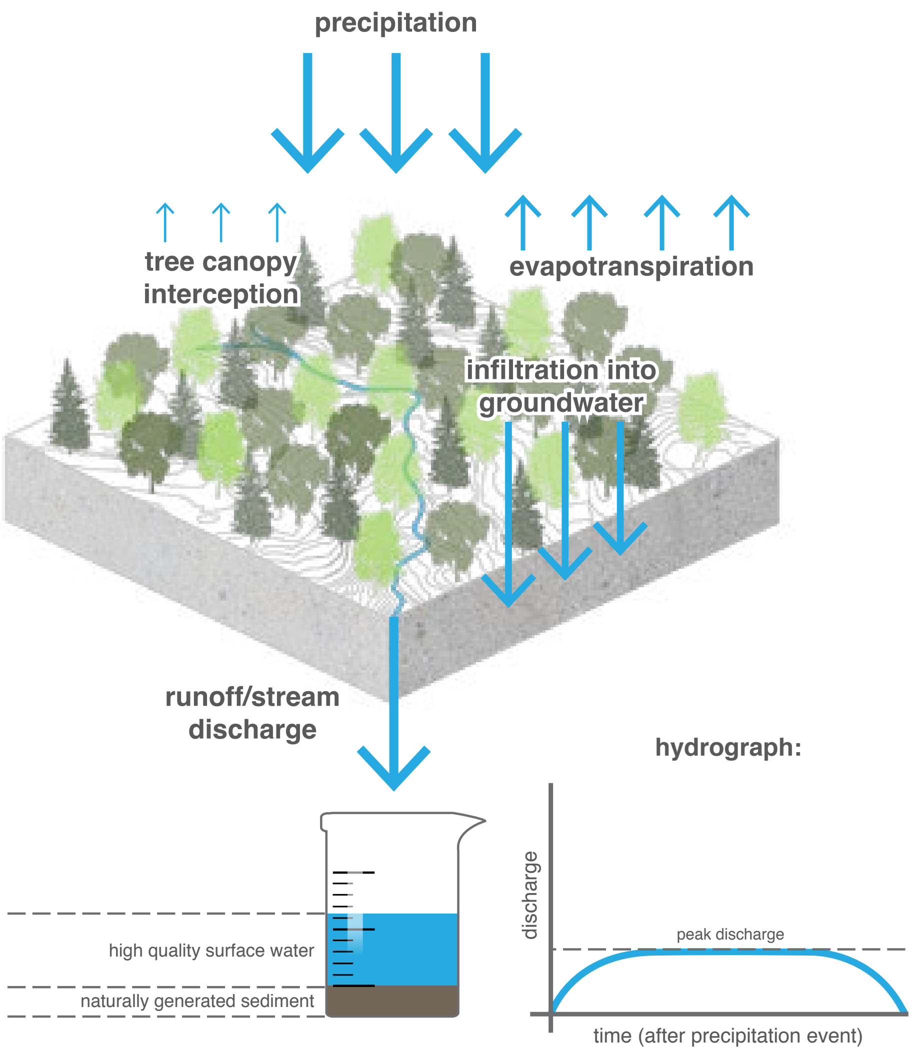


Figure 2: Forested Ecosystem Hydrologic Dynamics

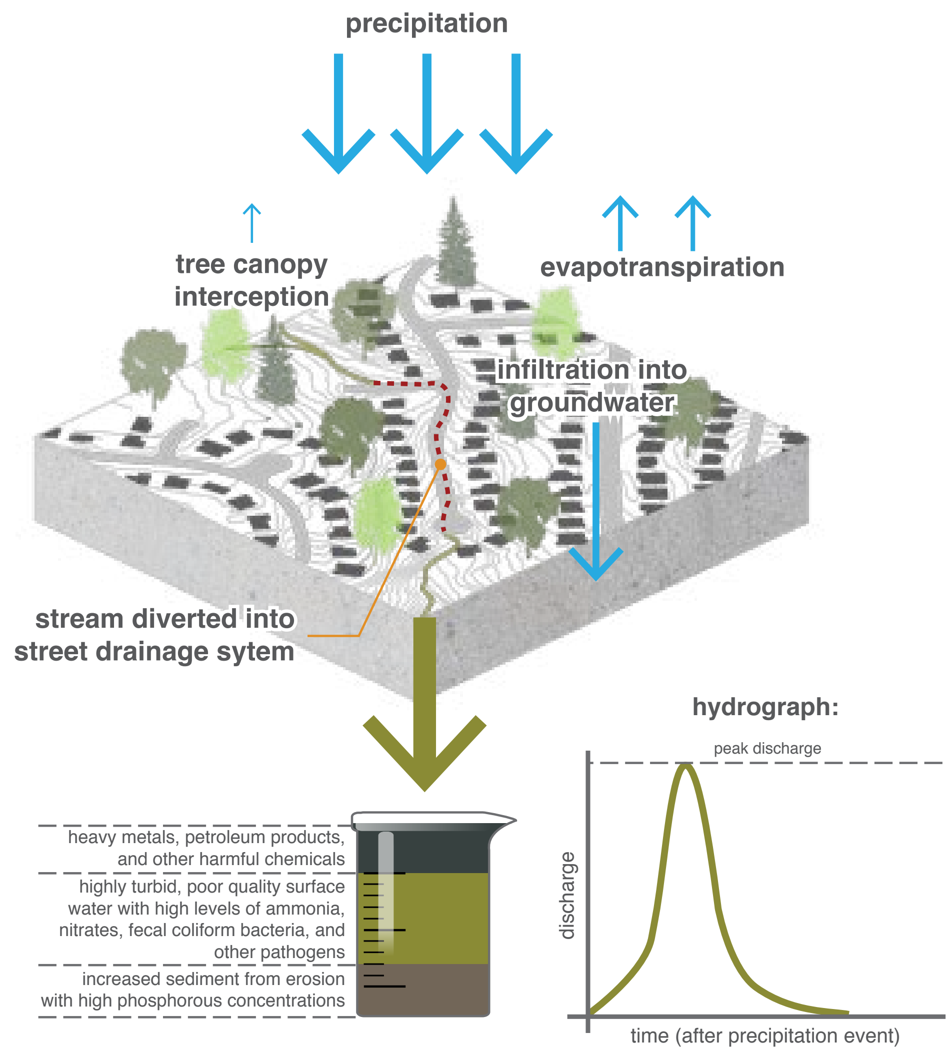


Figure 3: Effects of Suburbanization on Hydrologic Dynamics

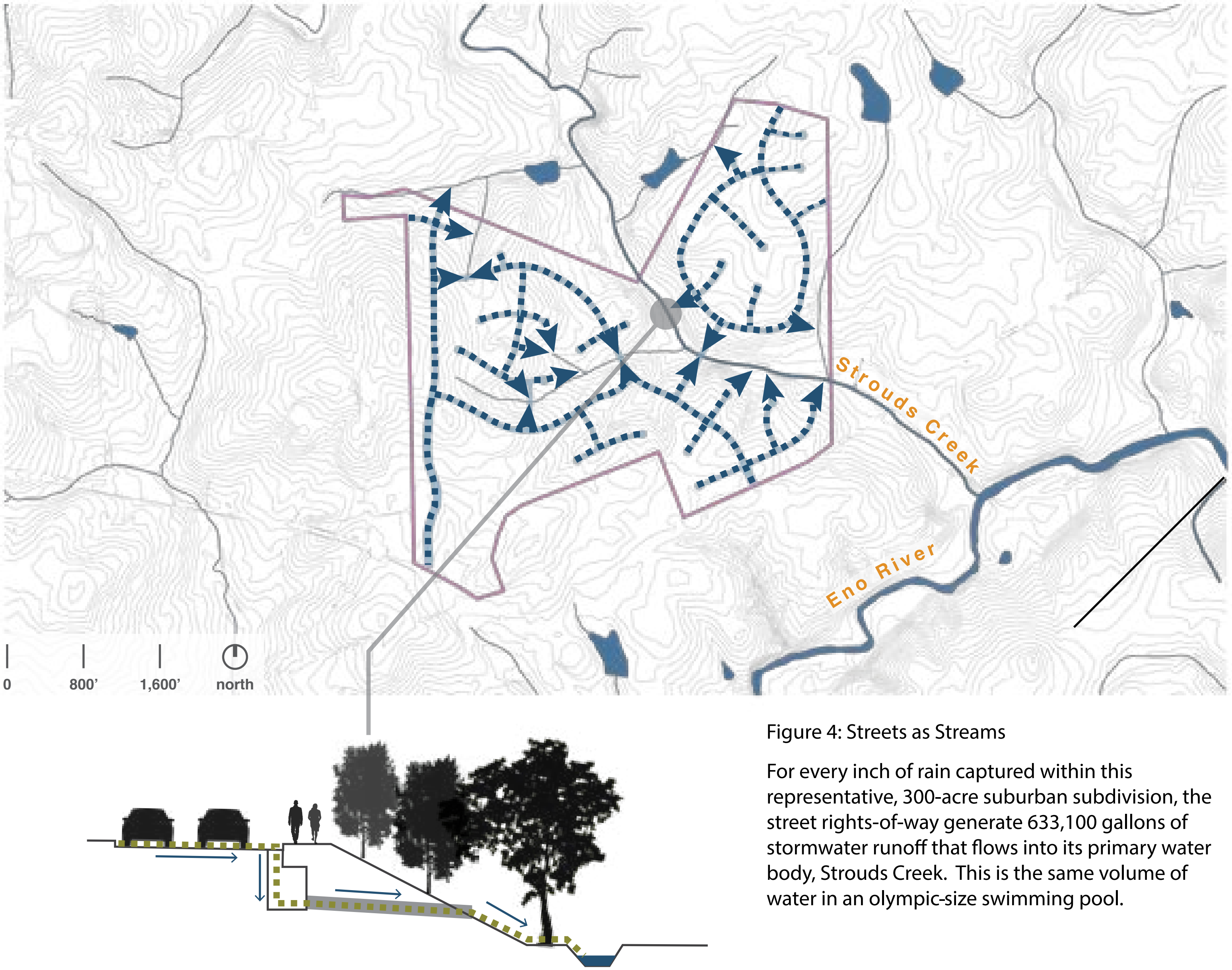


Figure 4: Streets as Streams

For every inch of rain captured within this representative, 300-acre suburban subdivision, the street rights-of-way generate 633,100 gallons of stormwater runoff that flows into its primary water body, Strouds Creek. This is the same volume of water in an olympic-size swimming pool.

compacted during construction may appear to be "natural" after landscaping, they often remain nearly as impervious as concrete, thus restricting percolation and rapidly conveying runoff in a similar way.

Effects on Water Quality

According to the 2000 National Water Quality Inventory, 40 percent of surveyed U.S. waterbodies do not meet water quality standards (USEPA 2000). Stormwater runoff is a leading cause of water quality degradation within these waters. Approximately 13 percent of rivers, 18 percent of lakes, and 32 percent of estuaries suffer water quality problems as a direct result of urban/suburban stormwater runoff (USEPA 2000). Stormwater is host to a suite of pollutants and contaminants that pose substantial threats to water quality. The stormwater runoff that is generated from developed areas is characterized by a variety of polluting constituents that are derived from multiple, diffuse sources. In contrast, other point sources of pollution come from more isolated, identifiable sources, such as discharge from a manufacturing facility. Therefore, creating effective water quality solutions for stormwater runoff presents a complex challenge involving a number of social, environmental, and economic factors.

Whenever it rains, stormwater gradually collects and flows over the landscape. As it concentrates, stormwater gathers increasing amounts of excess nutrients from fertilizers and animal waste, bacteria, viruses, and other pathogens such as fecal coliform, oil, grease and other petroleum products, heavy metals from brake pad wear, pesticides, herbicides, and sediments which are exacerbated by the erosive velocities characteristic of runoff in developed land. Since stormwater runoff collects heat from large expanses of impervious surfaces in developed areas, it causes the ambient temperatures in receiving waters to rise since streams in these areas also receive proportionally less inputs from cooler groundwater.

In high enough concentrations, these pollutants can have dire consequences for aquatic life. Excess nutrient levels (predominately nitrogen and phosphorous) in surface waters result in algal blooms. When the algae die off, they are aerobically decomposed by bacteria in a process that greatly diminishes oxygen available to other aquatic life within the water column, such as fish and mollusks. Bacteria, viruses, and other pathogens contaminate surface drinking water sources, restricting recreational use (typically in summer months). Oil, grease, petroleum products, pesticides and herbicides, and heavy metals pose direct physiological hazards to aquatic organisms and the terrestrial animals that depend upon them, including humans. Increased water temperatures threaten particularly sensitive species, such as trout.

Sediment poses a threat to both water quality and quantity. Phosphorous and other compounds naturally absorbed by soil particles. As high velocity flow runs over the landscape, soil is eroded and entrained by the quickly moving water. As it enters receiving stream channels, the phosphorous and other compounds attached to soil particles contribute to nutrient enrichment. Sediment also increases the turbidity (i.e., lowers the clarity) of receiving streams and other waters, and spreads over the stream substrate, interfering with aquatic life and impeding reproduction. As sediment is transported by stormwater runoff into streams and lakes, it displaces the water, diminishing capacity within these resources. This effect can have severe ramifications for reservoirs and other impoundments, which many cities across the country rely on as sources of domestic water. The costs of cleaning pollutants and removing sediment can be tremendous. For example, the estimated sediment clean up cost for Falls Lake, the primary water supply reservoir for the City of Raleigh, North Carolina, is $1.5 billion (Ovaska 2010).

How Conventional Suburban Development Affects Neighborhood Walkability

In addition to negatively impacting the environment, conventional suburban roadway networks have adverse consequences on neighborhood walkability, and pedestrian and driver safety. City streets in urban contexts typically provide an array of pedestrian-scale amenities, including sidewalks (usually on both sides of the street), street trees, tree lawns and other plantings, clearly marked crosswalks and traffic signals, and other elements that physically buffer pedestrians from vehicular traffic. These amenities, working in concert with denser, integrated land uses, help to create a safe, comfortable, walkable streetscape environment that incentivizes both recreational and utilitarian pedestrian activity (Figure 5).

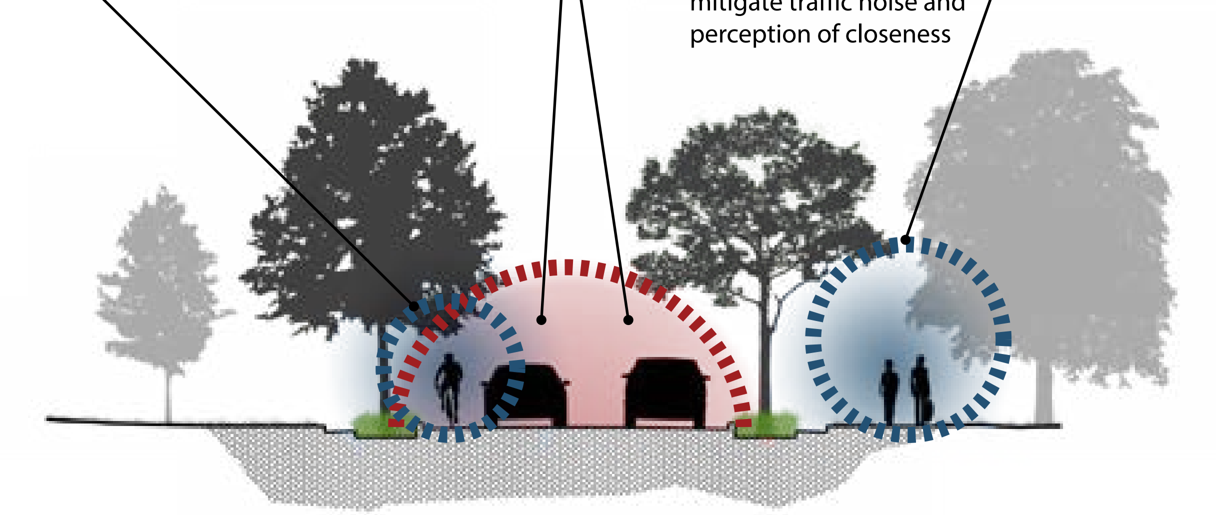


Figure 5: Clear Spatial Definition of Walkable Streets

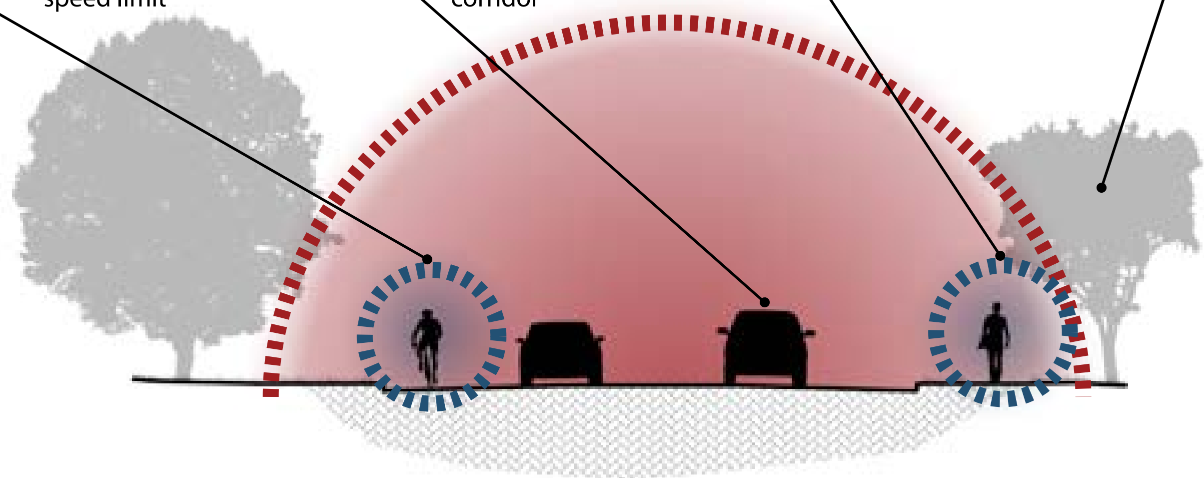


Figure 6: Poor Spatial Definition within Suburban Streets

In contrast, conventional suburban roadway design places a premium on vehicular traffic efficiency, often at the expense of the pedestrian environment. Many of the pedestrian amenities typically found on city streets are absent or significantly scaled back on conventional suburban streets, since the streets are primarily designed for cars. Lane widths, turning radii, and "clear zones" (i.e., the distance between vertical streetscape elements such as trees from the vehicular travelway) are specified to maximize vehicular traffic efficiency, resulting in streetscapes scaled for fast-moving cars. The resulting pedestrian environment suffers, and does not present a comfortable place to walk (Figure 6).

What is Street Stormwater Retrofitting?

By definition, retrofitting involves modifying previously built works in ways that improve their effectiveness and/or increase their functionality. Stormwater retrofitting, as defined by the Chesapeake Stormwater Network (2015), is "providing stormwater treatment on existing development that is currently untreated by any BMP [best management practice] or is inadequately treated by an existing BMP." In the case of street stormwater retrofitting, changes are made to existing street infrastructure (e.g. curb and gutter, drainage network, paved surfaces) that provide for stormwater treatment before runoff is conveyed into receiving water bodies. Another goal of street stormwater retrofitting is to minimize construction costs. Therefore, the impacts of retrofit devices to existing street infrastructure are minimized to the greatest extent practicable.

Figure 7 displays stormwater curb extensions on Siskiyou Street in Portland, Oregon. In this example, asphalt paving adjacent to the existing curb and gutter was removed, and replaced with planted stormwater treatment areas. New curbs were constructed along the perimeter of the stormwater treatment area with lateral curb cuts to convey runoff from the street into treatment areas. Aside from paving and soil removal and construction of new curbs, impacts to existing infrastructure were minimal.

Street Stormwater Retrofitting as LID Application

As a Green Street design strategy, street stormwater retrofitting embraces low impact development (LID) principles. Initially described by Prince George's County, Maryland in its 1999 publication entitled *Low-Impact Development Design Strategies: An Integrated Design Approach*, LID design principles mark a progressive departure from conventional "end-of-pipe" solutions that take a "one size fits all" approach to stormwater management. These traditional practices do little to consider the health, safety, and well-being of both the public and natural environment. Rather, LID stormwater management principles seek to integrate treatment areas with the landscape in a way that minimizes impacts to existing natural assets such as streams, wetlands, topography, and other drainage features. In fact, LID design has great potential to enhance these features as site amenities rather than regarding them as impediments to construction. LID addresses stormwater treatment design at the watershed scale as opposed to the poorly integrated, site-by-site approach favored by conventional stormwater management. From the *North Carolina LID Guidebook*, LID is an "innovative approach to site development and stormwater management that aims to minimize impacts to the land, water, and air while reducing infrastructure and maintenance costs and increasing marketability."

LID design techniques embody the following five strategies (from North Carolina State University 2009):

- **Conserve resources**: site design should protect existing natural assets (streams and wetlands, forested areas, healthy soil bodies, etc.) across multiple scales (watershed to individual site level) to the maximum extent practicable;
- **Minimize impacts**: where impacts to natural assets are unavoidable, every attempt should be made to limit impact extents and effects of site manipulations on natural processes;
- **Optimize water infiltration**: provide as many opportunities as possible with site design to slow, cool, treat, and infiltrate stormwater runoff to mimic the natural hydrologic cycle;
- **Create smaller, localized areas for stormwater treatment**: rather than designing large, centralized stormwater treatment facilities such as wet pond and retention basins, construct multiple, smaller

Project Information:
- Designed and built for $15,000 — $20,000
- Reduces stormwater runoff from street by 88%, retaining and treating runoff within planted areas
- Functions as a traffic calming measure while enhancing the pedestrian experience

Figure 7: A LID Street Stormwater Retrofit - Siskiyou Street, Portland, Oregon

treatment areas that coincide with natural drainage patterns across the landscape;
- **Prioritize maintenance**: establish simple, reliable long-term maintenance programs with clearly enforceable guidelines. Educate residents, management companies, and local governmental agencies on maintenance protocols while placing focus on water quality improvement.

In the United States, LID has steadily gained momentum throughout the past decade as many cities, counties, and states have adopted LID design guidelines and offered incentives for their implementation in development projects. While promising enhancements to environmental sustainability in new site design, many metropolitan areas are host to a legacy of decades worth of conventional, unsustainable suburban developments. Thus, LID retrofitting offers a strategic approach to addressing preexisting stormwater issues because it engages already built works, seeking to modify them to better manage environmental resources (primarily stormwater management) without significantly altering existing infrastructure. Street stormwater retrofits are designed to be constructed within existing roadway rights-of-way. Their primary function is to treat stormwater runoff generated by the large impervious surface areas occupied by paved roadways. In order to protect our precious freshwater resources and enhance livability, street stormwater retrofitting (as well as other LID retrofitting design) merits serious consideration in these older residential developments.

Benefits of Street Stormwater Retrofitting

As with LID, the benefits of street stormwater retrofitting are manifold, and include environmental, social, and economic benefits. Collectively, the following sections provide a brief overview of street stormwater retrofitting's value-added characteristics:

Environmental

Street stormwater treatment areas capture runoff close to its source within the roadway right-of-way extents, thereby functioning as a series of sponges that absorb and treat runoff via plant uptake, filtration through planting media, and in many applications infiltration through the soil profile below. This mimics the natural hydrologic cycle characteristics of forested ecosystems, and in doing so:

- **Assists in recharging groundwater**: treatment areas with permeable subsoils conducive to groundwater infiltration can be designed to infiltrate treated stormwater through the soil profile, helping to recharge depleted groundwater.
- **Lessens downstream flooding**: treatment areas can mitigate localized flooding at the site scale because they provide runoff capacity. At the watershed scale, widespread implementation of street stormwater retrofitting diminishes the severity of flash flooding in streams and rivers through reducing peak flow events.
- **Removes sediment and litter**: treatment areas reduce sediment and trash by slowing and collecting debris, thereby preventing this foreign matter from entering receiving streams and other waterbodies.

Additional environmental benefits of street stormwater treatment devices are temperature regulation and air quality improvement. These functions are maximized in situations where there is adequate space to accommodate tree plantings. In these conditions, treatment areas can provide a continuous tree canopy that can filter out particulates and provide shade, thereby mitigating the urban heat island effect and reducing local temperatures. Additionally, trees and other woody vegetation planted within treatment areas assimilate carbon as part of their biomass, incrementally reducing atmospheric carbon dioxide (a major greenhouse gas) as much as 48 pounds per year for a mature canopy tree (McAliney 1993).

Social

Street stormwater treatment areas can significantly improve pedestrian, bike, and vehicular traffic safety. When professionally designed, street stormwater devices are able to lower effective speeds and calm motorized traffic through the careful manipulation of specific, technical roadway requirements, such as travel widths, roadway geometries, and type and arrangement of features. For example, a treatment area can be strategically placed to provide a pedestrian refuge zone or reduce the crossing distance at crosswalks, thus enhancing crossing safety.

In addition to improving the configuration of rights-of-way, street stormwater retrofits enhance street legibility, character, and walkability through the inclusion of shrubs, herbaceous plantings, and street trees. These pedestrian-scale elements help to spatially define the pedestrian zone, thereby enhancing pedestrian safety. Additionally, the tree canopy shading and vegetation provided by the treatment areas have the potential to greatly enliven conventional suburban streetscapes that were primarily designed for vehicular traffic. An aesthetically appealing, comfortable streetscape provides incentive for people within the community to walk for recreation or to travel to nearby destinations.

Treatment areas also have the potential to serve as learning landscapes, educating people about the importance of sustainable stormwater management practices as well as providing physical continuity with natural waterbodies (Echols and Pennypacker 2008). By highlighting natural processes, stormwater retrofitting extends ecological processes into the built environment. Ultimately, this visible linkage between what is perceived as natural and manmade may foster a greater sense of community identity (Hunter and Brown 2012).

Economic

The large-scale economic benefits of improved residential roadways are of societal importance. Americans spend $50 billion annually on weight loss products (not including surgery) and $17 billion annually on gym memberships and home exercise equipment (Wapner 2003). By improving the streetscape environment and making it a more comfortable and safer place to walk, bike, and jog, members of the community can realize substantial cost savings. Likewise, the preservation of water supply resources is of critical importance across the United States. Water quality degradation decreases the lifespan of reservoirs and other surface water supply resources, and can require the establishment of additional sources. Remediation costs of impaired waters can be tremendous. Street stormwater retrofitting, if undertaken on a large enough scale, can help to reduce cleanup costs, potentially saving millions.

The community- and neighborhood-scale benefits are as equally compelling. For instance, landscaped neighborhoods enhance aesthetics, thereby potentially increasing property values. Consumers value a landscaped home up to 11.3 percent higher than its base price (San Mateo County 2009, Troy and Grove 2008). Furthermore, landscaping may reduce local crime rates (Kuo and Sullivan 2001, Troy and Grove 2008). The presence of large canopy trees (made possible by street stormwater retrofitting) has also been linked with lower crime rates (Donovan and Prestemon 2012).

Street stormwater retrofits are also capable of reducing infrastructure wear, maintenance, and repair costs because treatment areas reduce the volume of stormwater runoff conveyed into existing drainage infrastructure and combined sewer overflows. Combined sewer overflows, or CSOs, are pipes that simultaneously carry stormwater and sewage to wastewater treatment plants. When treatment plants reach capacity during heavy rain events, the CSOs transport both untreated stormwater and raw sewage directly into streams and rivers, thereby threatening the health, safety, and welfare of human, animal, and plant communities alike. This function is critical because much of the country's existing stormwater infrastructure system is either rapidly becoming outdated or, in many cases, has already fallen into a critical state of disrepair. In the most recent *Report Card for America's Infrastructure*, a performance assessment conducted every four years by the American Society of Civil Engineers, the nation's wastewater infrastructure system recieved a 'D' grade (ASCE 2013). The projected capital investment needed to repair these wastewater and stormwater systems is $298 billion over the next twenty years, including required investments totalling "more than $15 billion in new pipes, plants, and equipment to eliminate combined sewer overflows" (ACSE 2013).

Lastly, the life-cycle benefits of street stormwater retrofits extend onto the roadway itself—tree canopy shading alone has been estimated to reduce costs to drainage infrastructure by over $15 per tree per year (Idaho Department of Lands 2002). Canopy shading may also reduce ultraviolet (UV) exposure and premature wear on asphalt and other pavements, further reducing infrastructural upkeep costs.

Approaching Design: Site Analysis

Identifying Candidate Subdivisions for Retrofitting

Candidate subdivisions for street stormwater retrofitting are virtually limitless. However, for improving water quality and enhancing community walkability, more favorable results are often achieved in sites that exhibit the following characteristics:

- Unnecessarily wide streets that promote overly fast vehicular traffic
- Localized flooding (undersized drainage infrastructure)
- Lack of street trees and other pedestrian amenities
- Few clearly marked, safe areas to cross the street
- Relatively low slopes (less than 8 percent)
- Moderately permeable to permeable subsoils.

In order to select optimal treatment area locations within the right-of-way, it is helpful to think of the subdivision in its watershed context.

Mapping

Once a candidate subdivision has been identified, site analysis should begin with obtaining available physical and environmental feature mapping. Where available, mapping should include:

- United States Geologic Service (USGS) 7.5 minute topographic quadrangles
- Culturally and ecologically significant areas—most states have conservation agencies that catalogue known occurences of endangered and/or rare plant and animal species as well as keeping

records of ecologically significant natural plant communities or other significant landscape features (Figure 8).
- Natural Resources Conservation Service (NRCS) county soil survey mapping (Figure 9). An understanding of soil performance (i.e., texture and porosity) is essential for system design and function (Figure 10), therefore consultation with a licensed soil scientist, geotechnical engineer, or other highly trained soil specialist is strongly recommended.
- Federal Emergency Management Act (FEMA) mapping (Figure 11)
- Aerial photography (preferably a sequence of photos over time that characterize trends in land use)
- Street, roadway, and transit network mapping showing roadway maintenance designations (public versus privately maintained) as well as traffic volume approximations (thoroughfares, arterials, local streets)
- Schools, commercial centers, parks, and other recreational amenities
- Site construction documents showing dimensioned street sections.

After mapping is acquired, site visits should be conducted to obtain photography and videography, and to verify mapped features. Visits should be conducted at various times of the day and night to observe problematic traffic areas and pedestrian circulation preferences, and after rainfall events to evaluate potential drainage areas. Unique site features such as large trees, planting assemblages, and greenway trailhead locations should be noted and located for possible design integration.

Measuring Street Dimensions

In order to approximate the room available for retrofit treatment areas, sections of street right-of-way dimensions should be measured to include the following features, where applicable:
- right-of-way width
- vehicular travelway and lane widths
- curb and gutter
- utility structures (manholes, waterline access points, underground power and gas lines, and cable vaults, etc.)
- sidewalks
- tree lawns and turf strips
- medians and other landscaped areas
- drainage inlets (dimensions and spacing along the profile of the street)
- street crowning (in section, streets are sloped to shed stormwater runoff to the curb and gutter. Streets with a central crown sheet runoff to both sides. Streets with a cross-slope shed runoff to one side of the street. It is important to observe how stormwater runoff behaves when designing treatment area locations).

With map and survey information, a street system hierarchy can be developed for a given subdivision corresponding to street type and right-of-way width. For instance, most conventional subdivisions exhibit a dendritic street system, with small residential streets that carry traffic to larger collector streets, which intersect arterial roadways. The total lengths of streets within each type and the areas of the various streetscape elements above should be determined for each type. These lengths and area calculations will be used to estimate stormwater runoff volume.

In many conventional subdivision streets, there is often an excess of paved area within the right-of-way devoted to vehicular traffic. In the examples provided in Figure 12, each street (with a 25 miles per hour speed limit) has a paved surface width of at least 40 feet from face of curb to face of curb. Parallel parking, which is often rarely used (and sometimes not permitted overnight due to homeowners' association guidelines), accounts for 16 feet of the paved surface width (two 8-foot lanes), leaving at least 24 feet for two travelway lanes. Twelve-foot lanes are excessively wide for a 25 mile per hour speed limit; in fact, 12-foot lanes demonstrate no discernible traffic safety benefits when compared to 10-foot lanes (Traffic for America 2011). Lastly, these streets lack pedestrian-scale amenities (including street trees). Therefore, these streets make ideal candidates for stormwater retrofitting because there is adequate room for stormwater treatment areas on either side of the streets and the associated curb extensions will constrict the travelway widths, thereby calming traffic and enhancing the pedestrian experience.

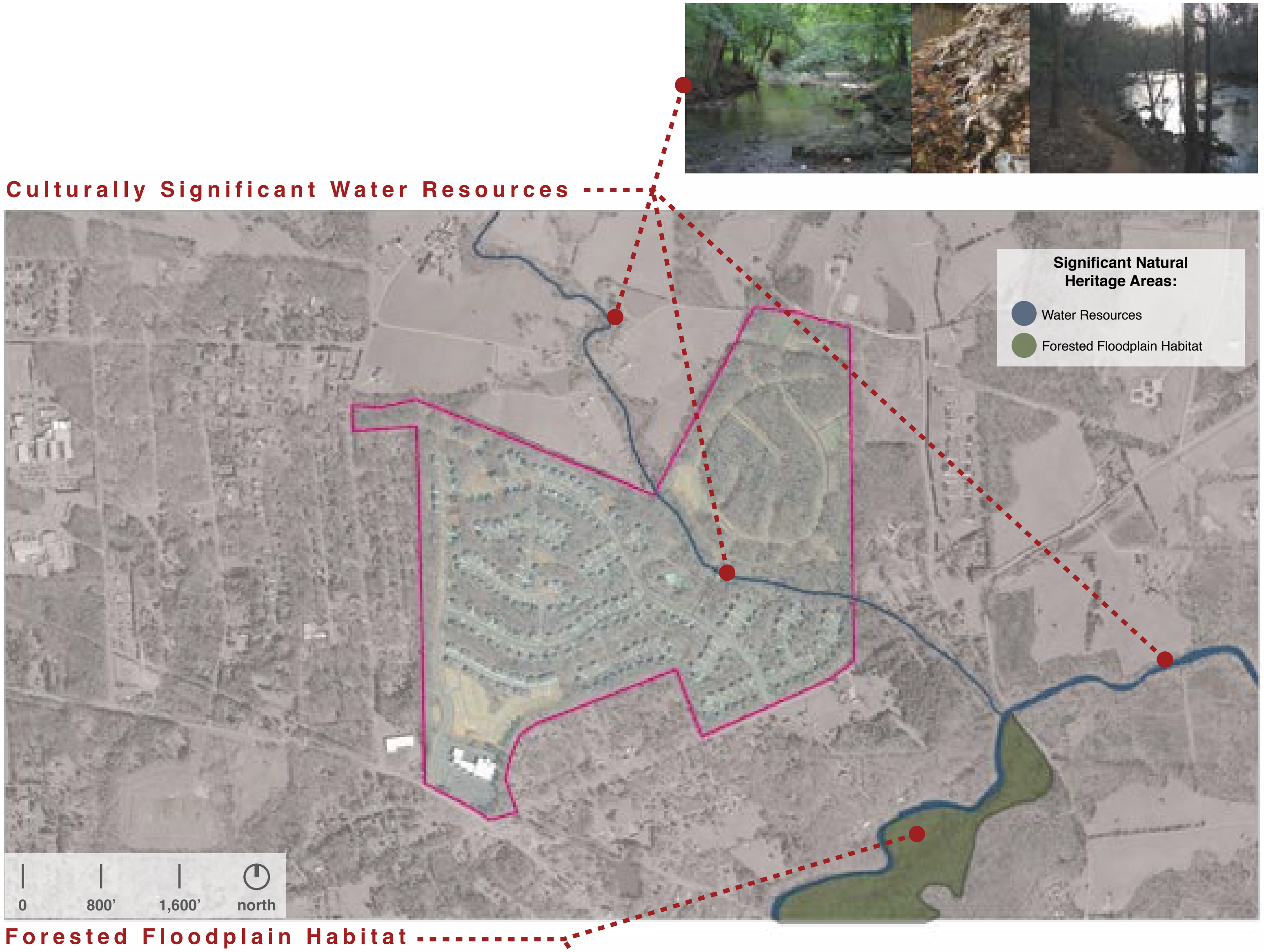


Figure 8: Site Assessment within the Larger Watershed

This representative residential subdivision straddles culturally significant water resources, and a large, contiguous forested floodplain is just to the southeast of the site. Protecting these unique resources helps to build the case for considering street stormwater retrofitting.

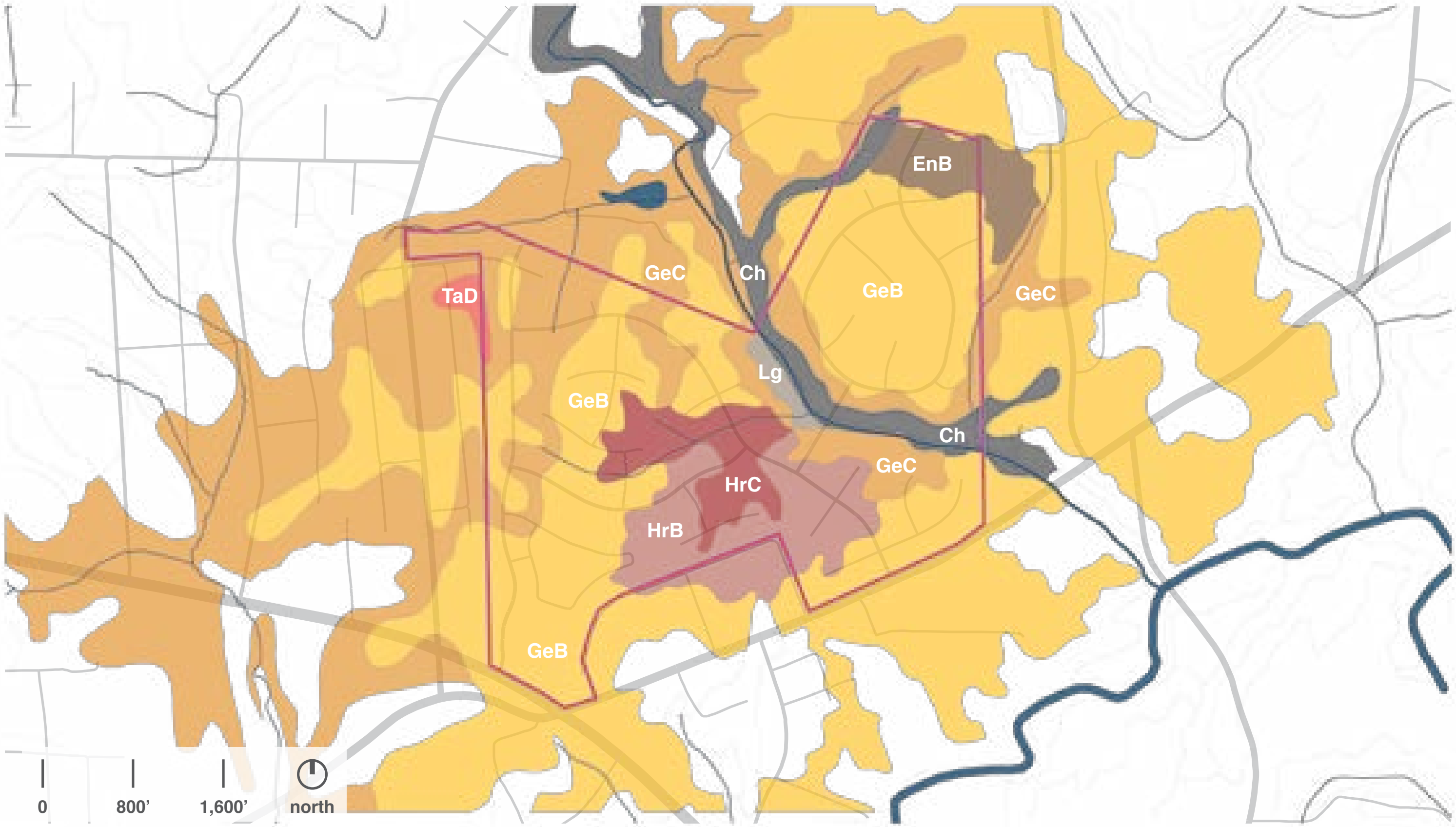


Figure 9: NRCS Soil Mapping

The subdivision is underlain by soils that formed in material weathered from fine-grained metavolcanic rocks in the Carolina Slate Belt. Most on-site soils are deep and well drained, with moderately rapid permeability. While most series within the site have clay subsoils, the clay minerology structure is conducive to good drainage. The Chewacla Series is the only hydric soil (i.e., found in wetlands) on-site.

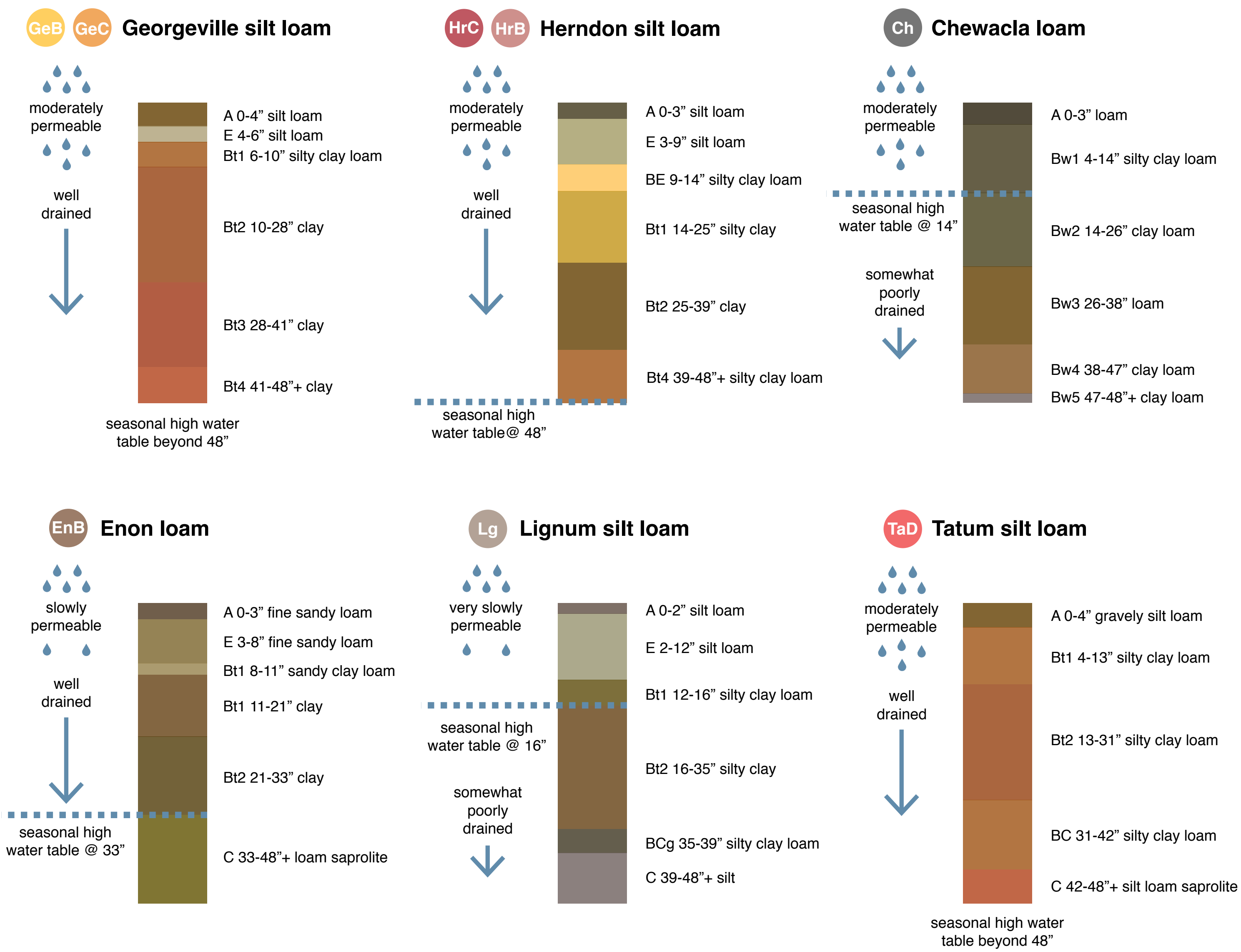
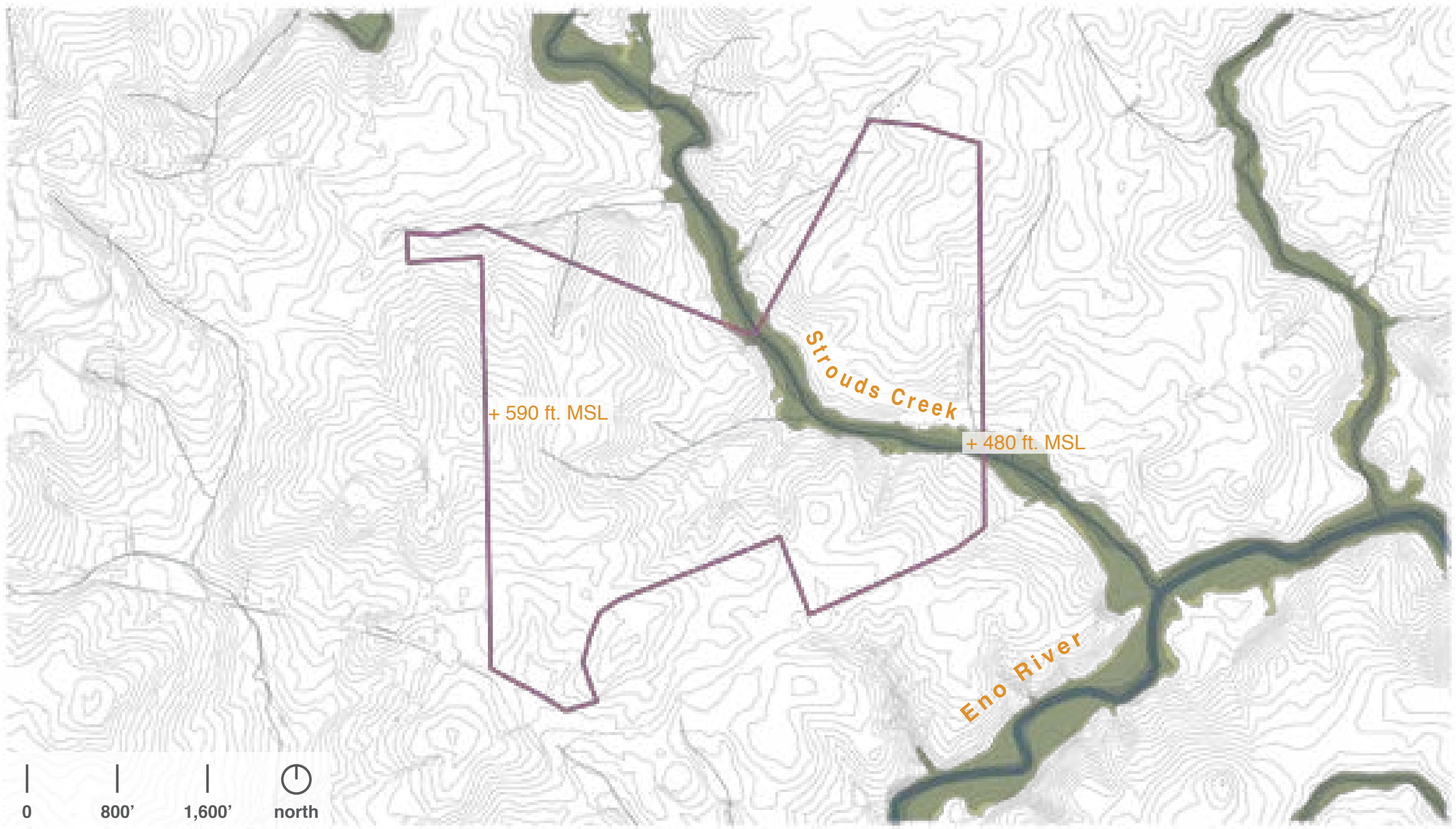


Figure 10: Soil Profiles and Performance Related to NRCS Soil Maps

The Georgeville, Herndon, and Tatum Series belong to NRCS hydrologic soil group B; Chewacla, Enon, and Lignum belong to group C (NRCS).



FEMA zones (100-year floodplain):

- Floodway
- Zone AE
- Zone X
- Rivers and Streams
- Topographic Contour (4-ft. contour interval)

Figure 11: Topography, Surface Hydrography, and FEMA mapping

Strouds Creek is the predominate surface hydrology feature within this subdivision. A third-order stream per United States Geologic Service (USGS) mapping, its confluence with the Eno River is approximately 0.4 mile southeast of the site.

Figure 12: Residential Suburban Streets in Need of Retrofitting

Treatment Options

Although this document uses street stormwater curb extensions to illustrate the design implications of stormwater devices located within paved rights-of-way, there are many other bioretention-based retrofitting solutions that facilitate healthy hydrologic function. Additional biorentention design options have been described by San Mateo County (2009) and are outlined below (Figure 13).

Permeable paving

Unlike conventional asphalt and concrete, permeable paving (also known as pervious or porous paving) permits runoff infiltration into underlying native soils under the right drainage conditions. Permeable pavements are available in a variety of materials and assemblies, including permeable concrete, asphalt, and unit paving (brick or interlocking concrete pavements). Permeable paving systems require either well-drained native soils or the installation of free-draining structural gravels (i.e., washed #57) and underdrainage, frequent maintenance (vacuuming and brushing), and can be costly to install on a widespread basis. Although permeable paving doesn't provide the associated vegetation benefits that planted facilities do, it does reduce and slow the amount of runoff entering the existing drainage infrastructure. However, it is a viable retrofitting option in areas with limited space and/or in areas requiring specialty pavement, such as crosswalks, parking lanes, and alleys.

Vegetated swales

Vegetated swales are analogous to grassed ditches alongside rural roads. However, they feature enhanced soil media and a more intricate planting scheme to provide roughness to slow stormwater flow and enhance treatment. Vegetated swales feature a V- or U-shaped section and are typically not partitioned with concrete sides. Thus, they can require considerable space and may be difficult to fit in street rights-of-ways with limited room. Their primary benefit is low maintenance and installation costs.

Rain gardens

Rain gardens are shallow, vegetated depressions designed with an amended soil substrate that can promote infiltration into underlying subsoils under the right conditions. They provide the dual benefit of stormwater retention and treatment. Rain gardens can be integrated into a variety of irregularly shaped "leftover" spaces within street rights-of-way. They are relatively inexpensive to construct and maintain, although maintenance is typically more extensive than with vegetated swales. Also, to maximize stormwater treatment effectiveness, rain gardens can be relatively space-intensive.

Stormwater curb extensions

Stormwater curb extensions are bioretention devices that are enclosed on the sides by cast-in-place concrete curbs that tie into existing curb and gutter. Unlike bioretention devices that use earth berms or graded slopes, they allow for additional stormwater capture capacity within confined spaces because the hardscape elements enclosing them render side slopes that taper into existing grade unnecessary. Although more costly than vegetated swales and rain gardens, stormwater curb extensions provide relatively high levels of treatment and capacity, and in many respects are ideally suited for implementation in conventional subdivisions with curb and gutter drainage infrastructure.

Sample System Design

Where to Begin? Estimating Runoff

When designing stormwater treatment area extents, a balance must be struck between the volume of runoff targeted for treatment and the optimal post-construction right-of-way proportions. At minimum, the targeted runoff volume should attempt to capture the water quality volume of stormwater off the right-of-way surface whenever possible. The water quality volume is the amount of runoff that requires treatment in order to remove an adequate amount of annual pollutant load from a site. This water quality amount is often referred to as the "first flush"— the runoff that initially collects in the drainage infrastructure as it begins to rain. The first flush collects and conveys concentrations of pollutants, such as sediment, heavy metals, and chemical and biological compounds, that have accumulated during dry weather periods, which could be a day, weeks, or several months depending on local precipitation patterns. Because various materials have had time to collect on streetscape surfaces, the first flush commonly carries the highest concentration of pollutants

permeable paving

vegetated swale

rain garden

Figure 13: Sample Street Stormwater Retrofitting Treatment Options

of pollutants (80-90 percent). Capturing first flush runoff events is desired because they generate a large proportion of the annual runoff volume, often representing the 85th to 95th percentile storm events. First flush volumes are variable based on project location and are defined by individual jurisdictions. For instance, the first flush rain event in North Carolina's coastal counties is a 1.5-inch storm, while the first flush for inland counties is generated by a 1-inch storm (Hunt et al. 2006).

For the purposes of this document, a 1-inch rainfall event represents the first flush volume. There are many methods available to estimate the volume of stormwater runoff that a 1-inch rainfall event generates, including the Rational Method, the Simple Method, and the Natural Resource Conservation Service (NRCS) Curve Number Method.

Rational Method

The Rational Method is used to estimate peak stormwater discharge from small drainage areas, typically under 200 acres. This method is often used to size traditional stormwater infrastructure, such as storm sewers, structures, and channels. However, the Rational Method is not recommended for routing stormwater through basins or developing runoff hydrographs. This method assumes that the surfaces of a watershed are fairly homogeneous; therefore, other methods are recommended if a watershed study area includes a variety of surfaces, such as pavements, turf lawn, and forest.

$$Q = C * i * A$$

Where: Q = quantity of runoff in inches; C = coefficient of runoff (based on generic land cover types), i = intensity of precipitation event, A = land area being assessed

Figure 14: Rational Method

Simple Method

The Simple Method is useful for calculating runoff volumes because it is capable of estimating stormwater runoff and pollutant export from urban sites. To calculate annual runoff, this method requires the designer to know the subwatershed drainage area, amount of impervious cover, and annual precipitation. The Simple Method is also used to calculate chemical and bacterial pollutant loads when the designer has access to runoff pollutant concentration data. Using this method, a general land use category, such as residential, commercial, industrial, or roadway, is selected to calculate annual pollutant loads. While the Simple Method works well to generate general planning estimates of runoff pollutant export from areas at the scale of a development site, catchment, or subwatershed, it does not allow for detailed assessment of the runoff generated from smaller, variable land cover types, such as turf lawn, forested, or impervious (i.e., roofs and traditional pavements).

$$R = P * P_j * R_v$$

Where: R = annual runoff in inches; P = annual precipitation in inches, P_j = correction factor (fraction of precipitation events that produce runoff), R_v = runoff coefficient

Figure 15: Simple Method

NRCS Curve Number Method

This document uses the NRCS curve number method (Figure 16). Unlike the Rational or Simple methods, which do not distinguish between different land cover types, the curve number method takes into consideration the detailed runoff properties of different land uses. For instance, forested land is able to absorb rainfall much better than impervious surfaces because of abundant vegetation and healthy native soils. Thus, forests produce considerably less stormwater runoff than asphalt and concrete, which sheet nearly all of the precipitation that falls during a given rain event since there is no way for the rainfall to enter the soil underneath.

$$R = (P - 0.2S)2/(P + 0.8S)$$

Where: R = runoff depth in inches; P = precipitation depth in inches, S = (1000/Curve Number) – 10

Figure 16: NRCS (formerly SCS) Curve Number Method

The curve number method assigns curve numbers to different land cover types. For example, impervious streetscape elements are assigned a curve number of 98, which means that nearly 100 percent of rainfall sheets off. Higher curve numbers correspond to a greater amount of stormwater runoff volume, while lower numbers are assigned to forests and other land cover types that have a higher permeability. Generally, land cover types within suburban street rights-of-way tend to have high curve numbers, since most of the land surface area within the right-of-way is either hardscape or turf and other landscaped areas. Curve numbers are also dependent upon NRCS hydrologic soil group designations. Soil groups range from A (very well drained and highly permeable) to D (poorly drained with very slow permeability). Hydrologic soil group designations can easily be obtained from NRCS resources for soil series mapped on-site (consult county soil survey mapping).

The calculation table provided in Figure 17 demonstrates how to estimate the runoff volume corresponding to the 1-inch storm event captured in 300 linear feet of a 50-foot right-of-way small residential street. It is important to note that runoff estimates are calculated for the right-of-way area only. As described above, the street section was measured on-site, and the areas corresponding to different cover types were calculated. The asphalt travelway, concrete curb and gutter, and sidewalk areas (totaling 11,477.5 ft^2) were assigned a curve number of 98, and the turf strip adjacent to the sidewalk and the remaining landscaped elements within the right-of-way (totaling 1,990.1 ft^2) were assigned a curve number of 84.

Volumes such as those just illustrated are calculated using the following process:

1. Using available resources (GIS data, construction documents, etc.) and on-site measurements, determine the existing streetscape element dimensions for each street typology within the right-of-way.
2. Using street right-of-way extents as the area required for treatment (per 2009 San Mateo County Design Guidelines), determine land cover types and assign Curve Number values to cover types based on mapped soils and corresponding hydrologic soil group designations:
    - Impervious surfaces (asphalt paving, sidewalk, driveway aprons, curb and gutter): Curve Number = 98
    - Lawn and landscaped areas (lawns, turft strip adjacent to curb): Curve Number = 84 (Roehr and Kong 2010)
3. Determine the surface areas of each land cover type within each street typology right-of-way.
4. Select precipitation event to use for modeling.
5. Using the following NRCS Curve Number equation, determine the runoff depth generated by each cover type within each street right-of-way typology.
6. Multiply the runoff depth (converted to feet) determined for each cover type in Step 5 by the area (in square feet) occupied by each cover type to generate runoff volume in cubic feet.
7. Add runoff volumes for each cover type together to determine total right-of-way runoff volume in cubic feet.
8. To estimate the minimum stormwater retrofit area required to treat the runoff calculated in Step 7 (assuming a ponding depth of 6 inches), divide the total runoff by 0.5 foot (method based on that described in Hunt and White 2001). Additional calculations based on the specific subsurface design standards of individual projects can be run to fine tune the estimated total system storage. For example, total volume of a device may include a number of factors in addition to ponding depth, such as depth/width of excavation and the biomedia backfill material used (and its corresponding void ratio).
9. In an iterative process, manipulate the treatment area sizes (width, length, orientation) to capture the most runoff generated by the 1-inch storm as practicable. Due to right-of-way constraints (travelway widths, etc.), it may not be possible to treat the entire runoff volume generated by the 1-inch storm.

Using the curve number equation, runoff volumes for each cover type are added to estimate the total runoff volume (in cubic feet) for this 300-foot reach of street for the 1-inch storm. Figure 18 shows runoff summary calculations and right-of-way survey information for an existing collector street typical of many subdivisions.

Additional tools exist to assist with this process. For instance, the US Environmental Protection Agency (EPA) offers their National Stormwater Calculator to assist designers, planners, contractors, and homeowners with calculating stormwater runoff totals given the various localized contextual considerations previously described. Likewise, the Center for Neighborhood Technology offers their National Green Values™ Calculator to compare the costs, performance, and benefits of green infrastructure to conventional stormwater practices.

cover type:	impervious	forested	permeable concrete	landscaped area
curve number:	98	55	69	84
area:	**11477.5**	**0.0**	**0.0**	**1990.1**
runoff depth (in):	0.79	0.05	0.00	0.15
runoff volume (cf):	756.47	0.00	0.00	25.18

total runoff (cf):	781.7
total runoff (gal):	5846.7
treatment area required for 1-inch rain (sf): (assumes **6"** ponding depth)	1563.3
proposed treatment area (sf):	1532.4
precipitation event captured by proposed treatment area (in):	**0.98**
percent of 24-hr precipitation totals captured by treatment area (%)	**85.9**

per linear foot of right-of-way:	
impervious surface (sf):	38.3
total runoff (cf):	2.6
total runoff (gal):	19.5
proposed treatment area (sf):	5.1
stormwater treated (gal):	19.1
ratio of treatment area to impervious:	0.13
total treatment area in site (sf):	27705.8
total stormwater treated (gal):	103,619.7

Based on 25 years of precipitation data at the nearest weather station, the proposed treament area for this street typology captures 85.9% of all 24-hour precipitation totals.

Figure 17: Sample Runoff Calculation Summary

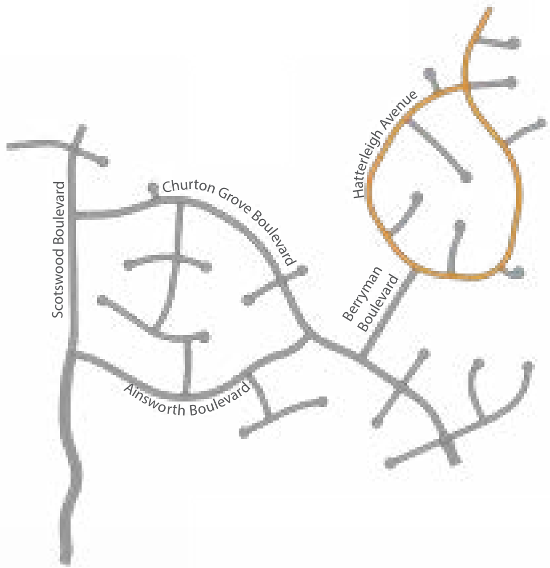
Next Steps: Sizing Treatment Areas

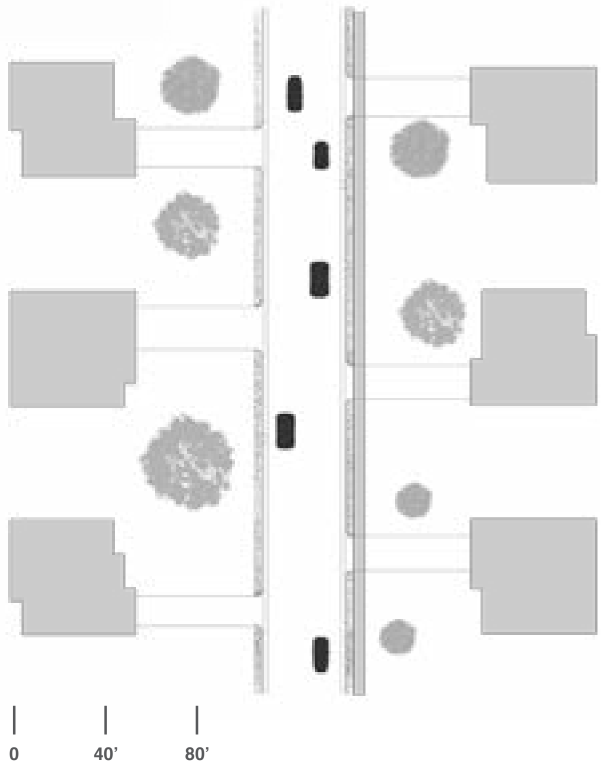
With the runoff volume estimate complete, it is easy to determine the size of the stormwater treatment area required to accommodate the 1-inch storm. Assuming a 6-inch ponding depth, the runoff volume estimate (in cubic feet) is multiplied by 2 to determine the required treatment area in square feet. In the example calculation, the 1-inch storm runoff estimate is 781.7 ft^3. Therefore, the size of the required 6-inch deep treatment area is 1,563.3 ft^2.

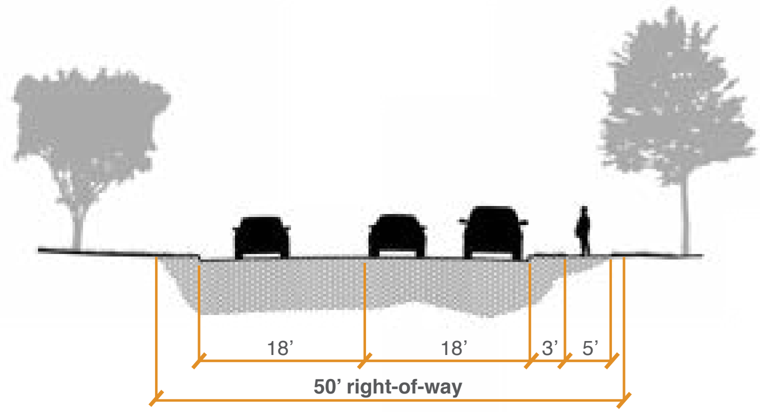
In some cases, it may not be possible to dedicate adequate right-of-way room to stormwater treatment areas due to space and other constraints. In the calculation example, the proposed treatment area (the room available for treatment) is slightly less than that required to capture the full 1-inch storm. However, this should not discourage stormwater retrofitting, because precipitation events less than the 1-inch storm account for the vast majority of storms. In the example calculation, the 0.98 inches of rain captured by the proposed treatment area is greater than 85.4 percent of all rainfall events over the past 25 years according to this site's local historic rainfall data. Figure 19 displays the streetscape changes made possible by sizing treatment areas to capture the runoff generated by less than the full first inch rain.

Design Example: Using Stormwater Curb Extensions

Figures 20 and 21 conceptually demonstrate how stormwater curb extensions work. Asphalt paving and compacted subgrade is scraped away and removed adjacent to the existing gutter pan. The extent of pavement removal depends upon numerous considerations, primarily cost allowances, required treatment area, and right-of-way space allocation for elements such as parking and travel lanes. The illustrated examples have been designed to maintain the existing curb and gutter pan. This strategy minimizes impacts to existing infrastructure and reduces construction costs. Other conditions and/or strategies may require the removal of curb and gutter to allow for greater treatment areas. This alternate approach is equally viable, but will increase project costs via both demolition time and materials.

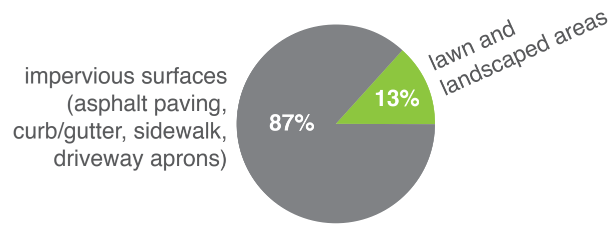






50' right-of-way collector streets:
- Hatterleigh Avenue only street within typology
- 1.0 mile total length
- 25 miles per hour speed limit
- No trees planted within right-of-way

land cover distribution in ROW:



runoff generated by 1" storm:

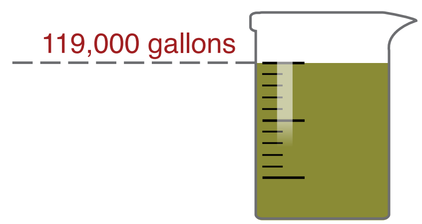
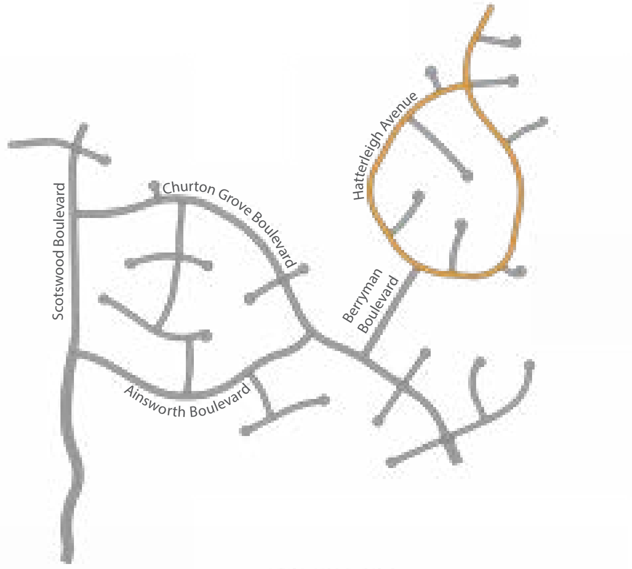
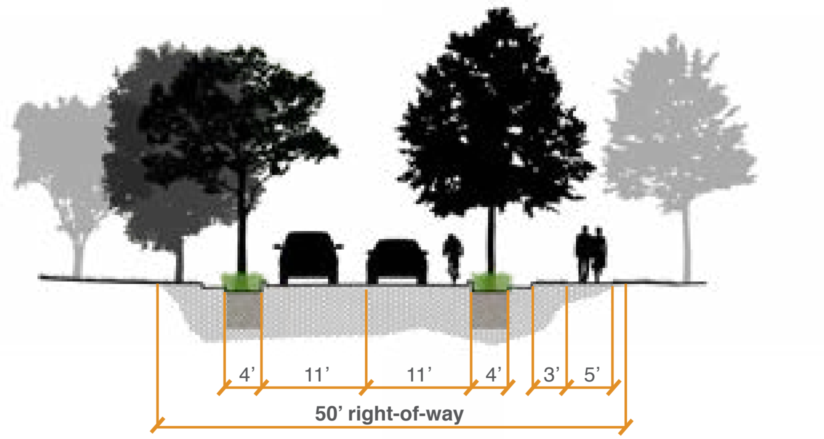
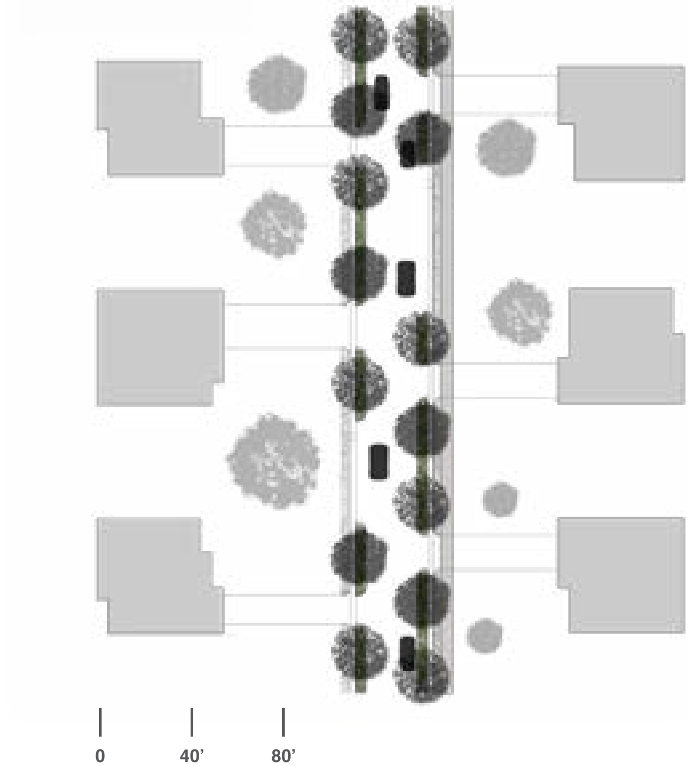


Figure 18: Existing Street Runoff Summary



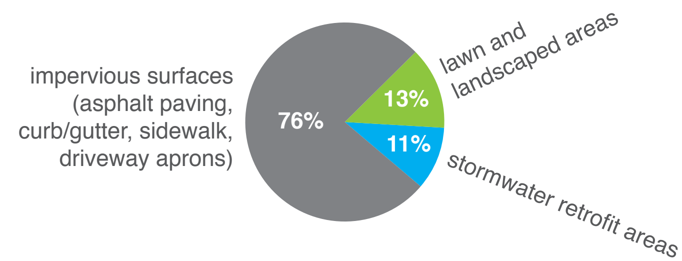




50’ right-of-way collector streets:

- 11% reduction in impervious surface area
- Proposed retrofit areas treat all runoff generated by right-of-way from 0.98” storm (85.9% of all 24-hour precipitation events)
- Capacity for 500+ trees within right-of-way, including BMPs and sidewalk verge

land cover distribution in ROW:



runoff treated by stormwater retrofits:

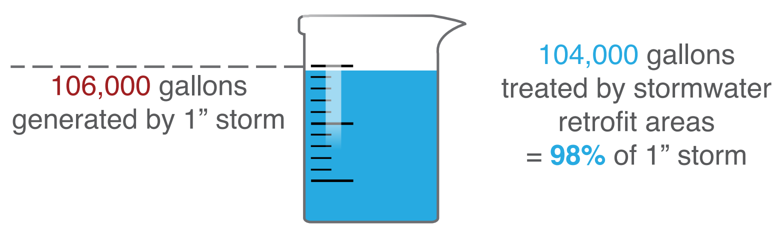


Figure 19: Retrofit Street Runoff Summary

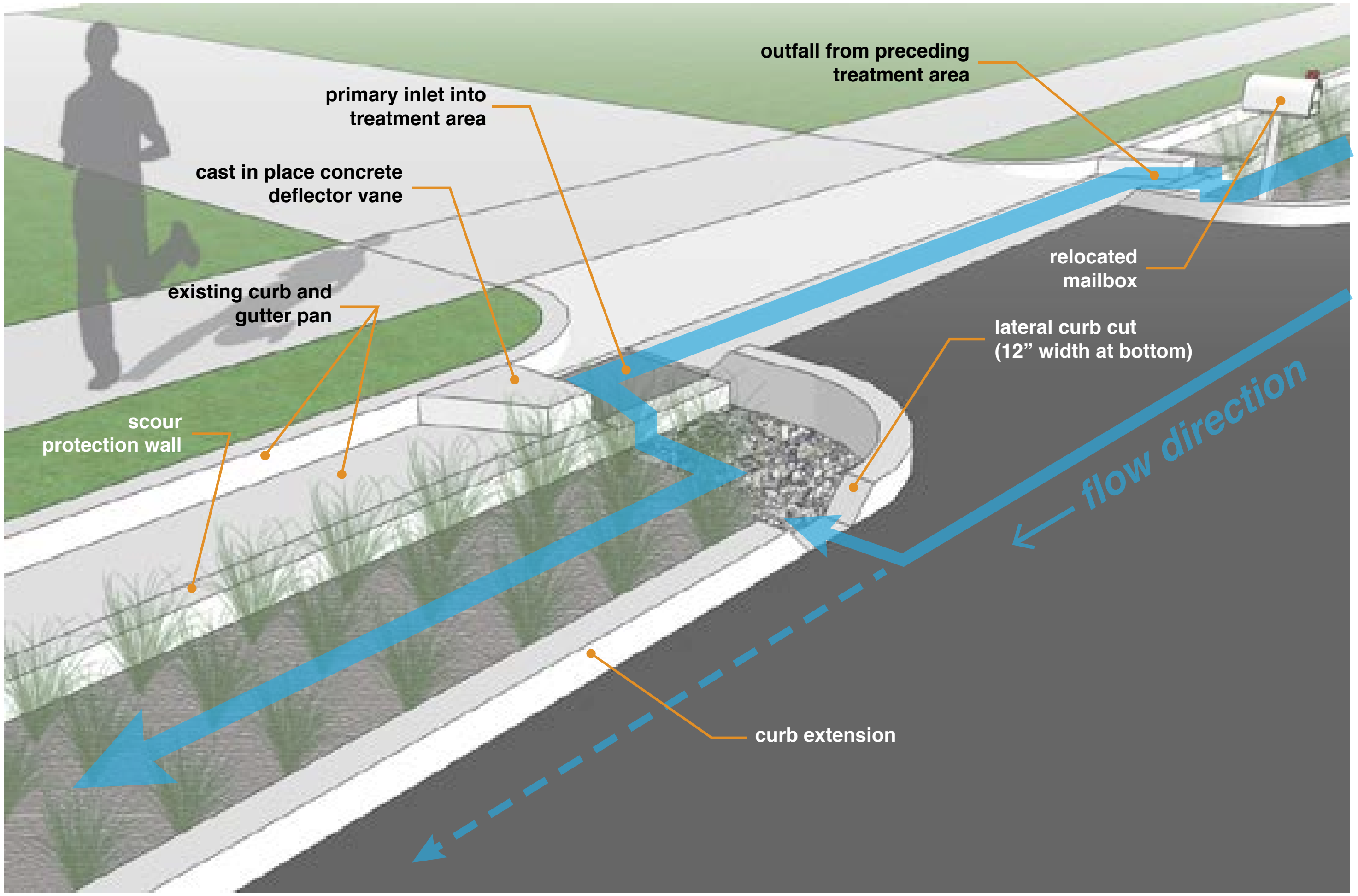


Figure 20: Stormwater Curb Extension Inlet

flow vectors
(width proportional to volume)

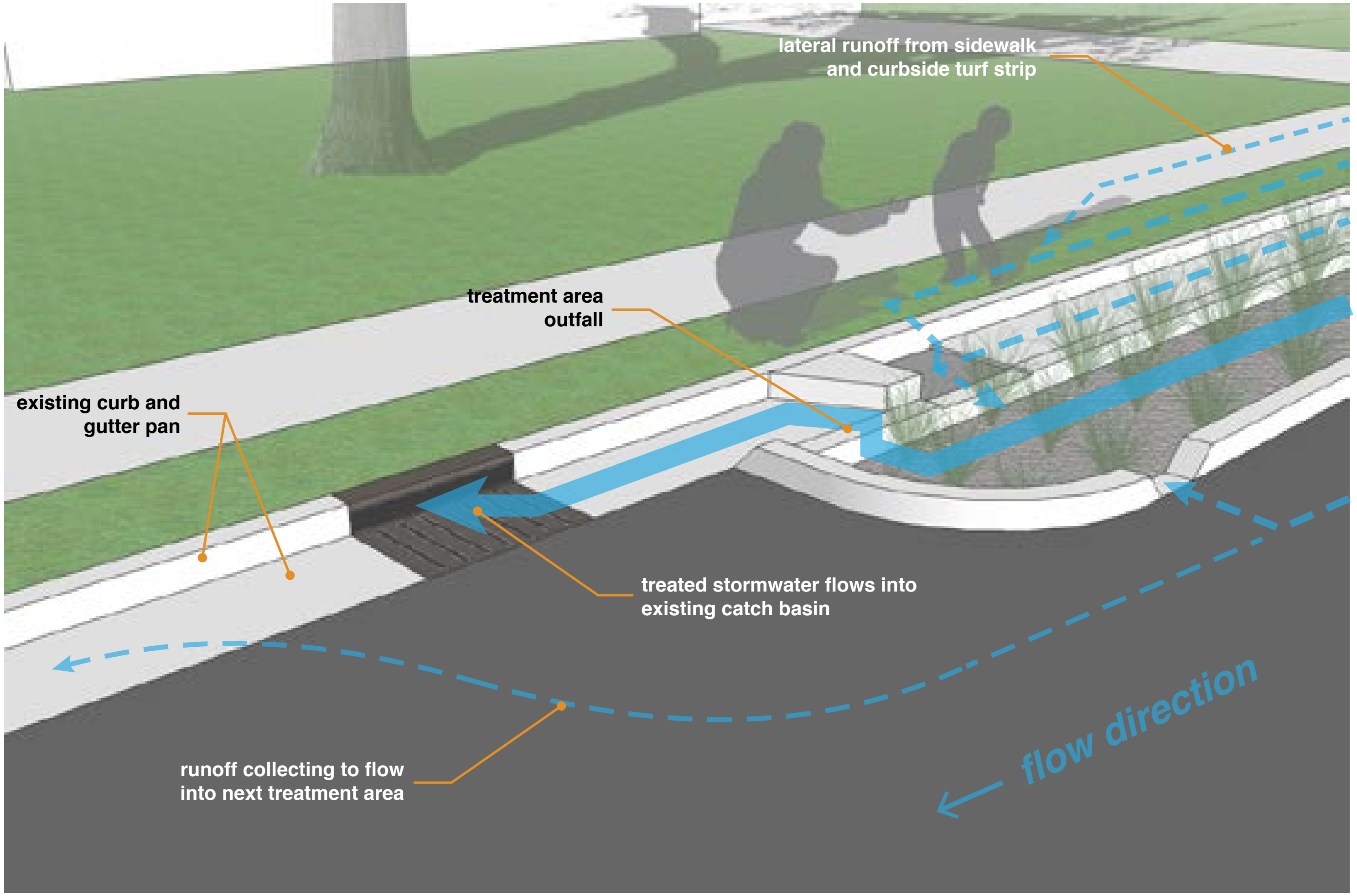


Figure 21: Stormwater Curb Extension Outlet

flow vectors
(width proportional to volume)

Once the new concrete work is completed, the treatment areas are cleaned, prepared, and backfilled with an amended planting media and planted with trees, shrubs, and other herbaceous plantings. In sites with poorly drained native soils (those with NRCS hydrologic soil group C and D designations), treatment areas can be designed with an underdrain that connects with existing drainage infrastructure.

Due to street crowning and cross slopes, most of the stormwater runoff conveyed into curb extension retrofits will move along the existing gutter pan. On the upslope end (inlet) of this example, runoff will be slowed and redirected into treatment areas by a cast-in-place concrete deflector vane (built flush with the height of the existing curb) and stone inlet protection (to prevent scour). Runoff flowing in the gutter pan, which accounts for the greatest flow pathway in most streets, is diverted into treatment areas by constructing a cast-in-place concrete deflector vane within the existing gutter pan that ties into the existing curb. Stormwater flowing off the street adjacent to treatment areas is conveyed into treatment areas via lateral curb cuts.

Once it enters the stormwater curb extension planters, stormwater is slowed, cooled, and infiltrated into planting media. Plants uptake the water and its abundant nutrients, especially nitrogen. Bacteria and other pathogens are absorbed into the planting media. Treatment areas retain oils and other petroleum products. Sediment and other debris are also captured, since the higher velocity flows that entrain them are slowed within treatment areas. Depending on how much rain has fallen and the design volume of the stormwater device(s), treatment areas gradually begin to fill with runoff until capacity is reached. At this point, excess stormwater flows up and over the downslope lip of the gutter pan, where it re-enters the existing drainage network.

Locating Stormwater Curb Extensions

Locating and designing stormwater curb extensions within the suburban streetscape is a relatively straight forward process. Where feasible (both in terms of available room within the street right-of-way and budget), it is advisable to implement them on the widest scale practicable to achieve the greatest benefits, including maximizing stormwater treatment, walkability, and aesthetics.

Stormwater curb extension planters should be carefully designed to fit between home driveway aprons as to not interfere with property access. Treatment areas should be designed to stop short of intersections so that the appropriate sight triangle distances are preserved.

Where full implementation is not feasible, stormwater curb extensions should be strategically located within the site to maximize stormwater treatment efficiency and walkability, as well as enhancing pedestrian safety. These locations include:

- problematic drainage areas (areas observed to pond water within the street after storms)
- streets with flat to low slopes (lengthens stormwater retention time within treatment areas)
- long, straight street reaches with excessive vehicular traffic speeds (streets that would benefit from traffic calming)
- streetscape areas that lack tree canopy shading
- the vicinity of playgrounds, greenway trailheads, and other recreational features or community amenities.

Constraints

Streets are complex networks of activity that may render the establishment of stormwater treatment areas infeasible. Street rights-of-way must conform to a wide array of safety requirements, including allowable site distances, roadway geometries, and accessibility. Therefore, retrofitting design activities should carefully consider the body of knowledge from organizations such as the American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and Transportation Research Board of the National Academies (TRB). These organizations research, document, and regulate a wide range of roadway design issues related to this document. For example, AASHTO has published *A Guide for Transportation Landscape and Environmental Design* (1991) and the TRB offers a series of roadway guides including, but not limited to, *A Guide for Reducing Collisions Involving Bicycles* (2008), *A Guide for Reducing Collisions Involving Pedestrians* (2004), and *A Guide* *for Addressing Collisions with Trees in Hazardous Locations* (2003). The Center for Environmental Excellence by AASHTO also administers a number of programs that address innovative and emerging street and roadway design strategies, including the Transportation and Environmental Research Ideas (TERI) program. Similarly, the ITE manages the Context Sensitive Solutions (CSS) program, which includes useful resources related to walkable thoroughfares, design factors to control speed, and creating livable community streets.

Streets are also very complicated technological and structural systems, comprised of decades' worth of utility and other infrastructural layers that have evolved over time in response to repair or innovation. Streets are constantly reworked for repaving and to upgrade aging infrastructure. However, unlike their heavily urbanized counterparts, suburban streets typically present far fewer obstacles to stormwater retrofitting implementation. The subgrade and pavement depths characteristic of suburban streets are typically not as thick as those of urban streets. This presents opportunities to achieve infiltration of stormwater into native soils underlying suburban streetscapes where soil drainage allows.

The following constraints must be considered before stormwater retrofitting is implemented:

- **Emergency vehicular access**: fire trucks and ambulances often require large turning radii. Stormwater treatment area design must take these radii into consideration with respect to sizing and extents, especially within or near culs-de-sac.
- **Underground and aboveground utilities**: water, gas, electric, fiber optic, telephone, cable, and other utilities are often located within the street right-of-way. These utility lines (and accompanying service access vaults) require adequate soil cover depths that can be accomplished by design in most instances. Required cover depths should be verified prior to design. Aboveground power lines and other vertical impediments must also be taken into consideration with design, especially with specified planting material.
- **Required vehicular and bicycle lane widths**: depending on whether or not the street right-of-way is publicly or privately maintained, many cities and counties have minimum travelway lane widths that must be preserved with any modifications to the streetscape.
- **Steep topography**: stormwater treatment area design can mitigate steeper slopes to an extent by incorporating grade control structures. However, stormwater retrofitting is not recommended along street lengths with slopes exceeding 8 percent.
- **Low permeability native soils**: while the presence of poorly drained soils (namely those with NCRC hydrologic soil group C and D designations) doesn't necessarily preclude stormwater retrofitting, it does require design modifications to stormwater treatment areas. Underdrains that connect with existing drainage infrastructure should be installed within treatment area substrate. Infiltration into poorly drained subsoils (without the use of underdrains) is not advised.

Regulatory Considerations

Regulatory criteria vary widely depending on where street stormwater retrofitting is being considered, from federal and state regulations to local code and jurisdictional guidelines. Local social and environmental conditions also greatly influence which regulatory agencies and other groups represent key stakeholders for potential projects. For example, prospective sites located within water supply watersheds and/or ecologically sensitive river basins present both incentives and additional regulatory concerns for project implementation.

With the exception of cities like Portland, Oregon and Seattle, Washington (both of which have developed standard drawings and specifications for design and construction as part of the Green Streets Project and SEA Project programs, respectively), most cities have not yet had the need to develop permitting guidelines and other regulatory criteria. Therefore, the following regulatory agencies (with parenthesized roles) should be consulted prior to initiating stormwater retrofitting planning and design activities. This is by no means an exhaustive list, and other agencies may warrant consideration:

Federal

- National Pollutant Discharge Elimination System (NPDES), Municipal Separate Storm Sewer System (MS4), or Combined Sewer Overflow (CSO) permits
- United States Army Corps of Engineers (if applicable, Section 404 [1972 Clean Water Act] permitting for potential temporary construction impacts to streams, wetlands, and other waters within and adjacent to the street right-of-way)
- United States Fish and Wildlife Service (threatened and endangered species, habitat, and other wildlife concerns)
- Environmental Protection Agency (EPA) (particularly for publicly owned right-of-ways, National Environmental Policy Act [NEPA] considerations, where applicable)

State

- Department of Transportation (state-maintained right-of-way encroachment permitting, adherence to roadway design standards [lateral and vertical clear zones, planting standards, etc.])
- Division of Water Quality (if applicable, Section 401 [1972 Clean Water Act] permitting as with the United States Army Corps of Engineers)
- Department of Ecology or Department of Natural Resources (State Environmental Policy Act [SEPA])
- Division of Land Quality (sediment and erosion control plan permitting)
- Historic Preservation Office (identification of culturally and historically significant resources potentially impacted by project implementation)

Local (County/City/Town)

- Office of Transportation Planning (locally maintained right-of-way encroachment permitting, adherence to local design standards)
- Department of Public Works (stormwater permitting, obtaining approval for drainage and other infrastructure modifications, if applicable, local sediment and erosion control plan permitting)

Private

- Homeowners Associations (obtaining approval for streetscape modifications and privately maintained right-of-way encroachments)

Design and Construction Details

The accompanying set of drawings provide schematic level detail design and construction conditions related to a sample suburban street retrofitting project designed for a subdivision within the southeastern U.S. The intent of these drawings is to illustrate how the previously discussed criteria can be synthesized into a functional stormwater curb extension. Project conditions are always unique, and any design should consult and conform to all governing regulations and industry best practices, and carefully consider local municipal, agency, and community needs. Additionally, a professional landscape architect (PLA) and/or professional engineer (PE) with experience in road and streetscape design, and LID project design and construction must be consulted for project design, documentation, and implementation.

Site preparation consists of the establishment of sediment and erosion control measures, mainly to protect existing stormwater inlet structures (which are not impacted by design), followed by pavement removal and excavation of subgrade to the treatment area design depth. For this project, excavation to a depth 54 inches below the existing pavement surface was required to accommodate a 6-inch ponding depth and adequate planting media (Figure 22). After subgrade removal, formwork is established for the concrete deflector vane, curb extensions, and scour protection wall, which is essentially a sunken curb poured flush with the existing gutter pan to protect the subgrade from erosion by stormwater flow within treatment areas. It is recommended that the gutter pan adjacent to the deflector vane be ground down to slope away from the curb toward treatment areas to prevent water from ponding within the gutter. In plan (Figure 23), 12-inch wide, chamfered lateral curb cuts should be established along curb extensions every 15 feet to convey runoff into treatment areas from adjacent pavement. The main upslope inlet and lateral curb cut outflows should be stabilized with class A rip rap (or equivalent stone).

Following the construction of concrete deflector vanes, curb extensions, and scour protection walls, formwork is removed. In areas with well drained subsoils (NRCS hydrologic soil groups A and B), an underdrain is usually not required. If this is the case, a backhoe bucket’s teeth can be used to scarify the existing

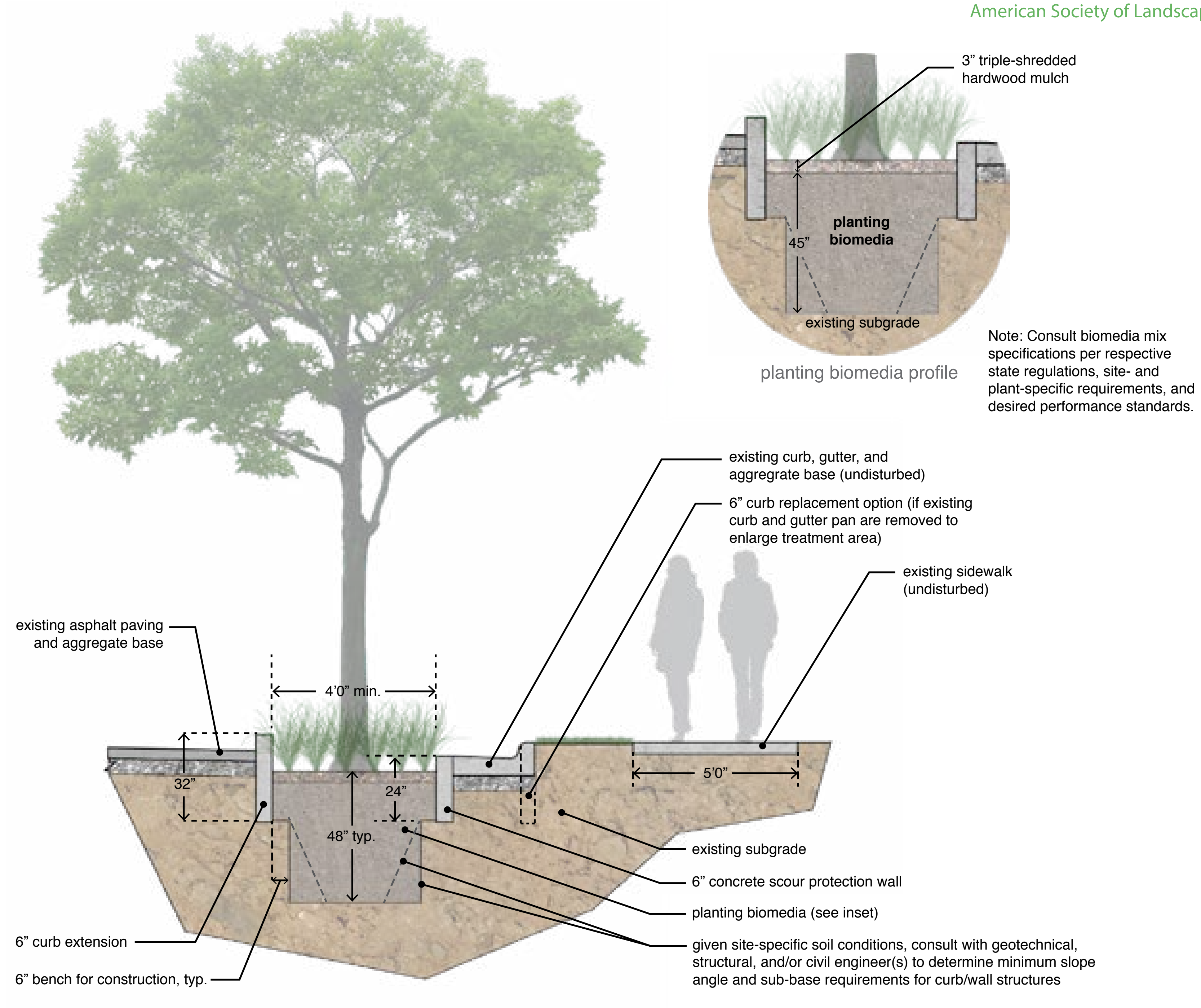


Figure 22: Stormwater Curb Extension Cross-Section

subgrade surface to promote infiltration into the subsoil. In areas with poor subsoil drainage (NRCS hydrologic soil groups C and D), the bottom foot of treatment areas should be fitted with a 6-inch slotted corrugated pipe and backfilled with gravel to connect to the nearest existing catch basin. To promote slow infiltration in C and D soils, the design can also specify a slightly elevated underdrain in the profile, rather than placing it at the bottom of the bioretention section.

Planting media typically consists of an engineered soil mix that consists of sand, silt/clay, and organic material. The proportions of these constituents may vary somewhat depending on site-specific climate, soil conditions, and/or agency regulations. Because soils are complex and essential to the function and longevity of any stormwater treatment device, contacting local soil science professionals to determine the ideal planting media mix is highly recommended. The upper 3 inches of finished grade within treatment areas should consist of triple-shredded hardwood mulch.

Along streets where longitudinal slopes exceed 4 percent, stormwater flow within treatment areas may become erosive and damage plantings and substrate, rendering treatment areas ineffective. Therefore, in street scenarios with slopes ranging between 4 and 8 percent, grade control devices should be constructed within treatment areas. Although there are a variety of grade control options, including "naturalized" structures such as stone check dams and boulder drop structures, cast-in-place concrete grade control sills are recommended for durability. Naturalized solutions are prone to failure over time, due to irregularities in materials and construction, as well as vulnerability

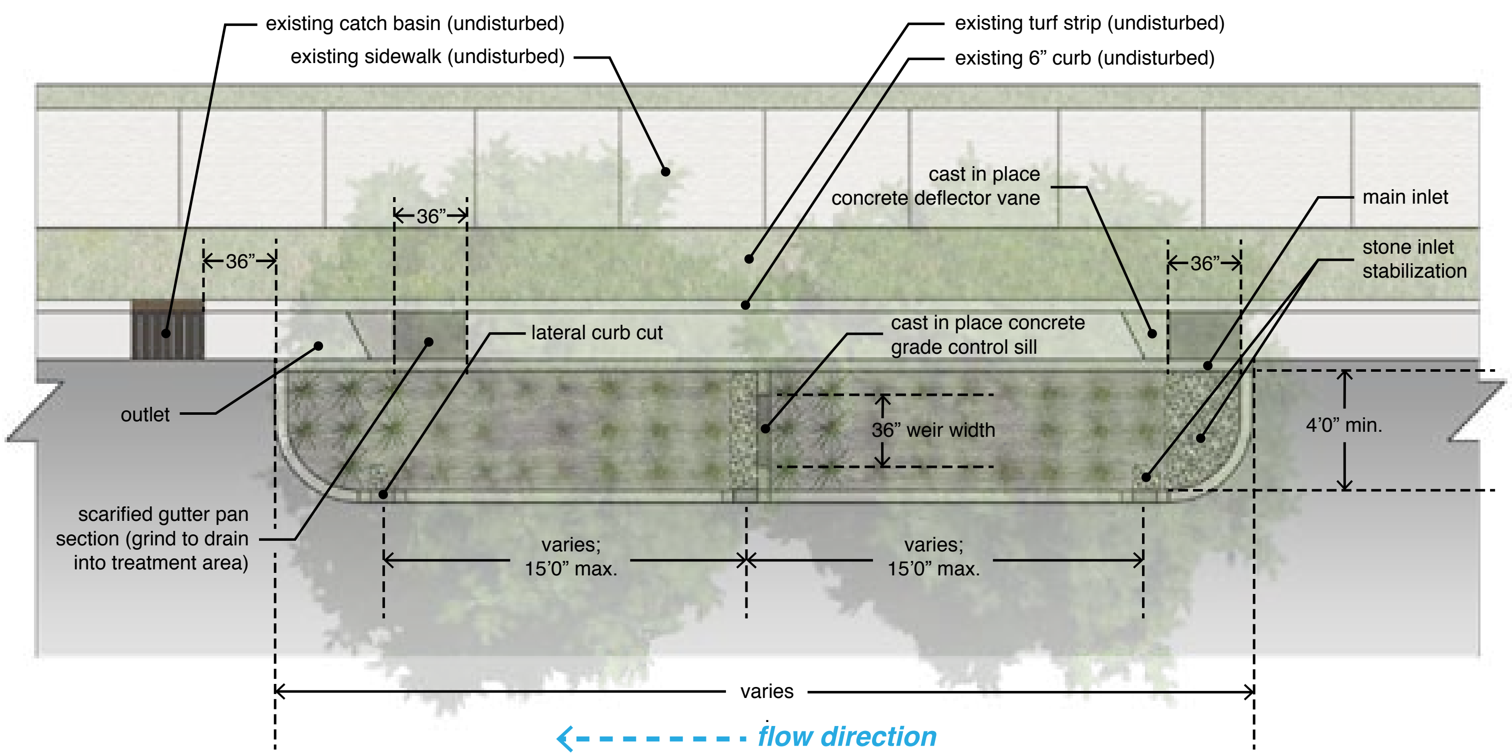


Figure 23: Stormwater Curb Extension Plan

Notes:

1. Grade control sills to be installed where existing street slopes exceed 4%.
2. Maximum slope for curb extension treatment areas not to exceed 8%.

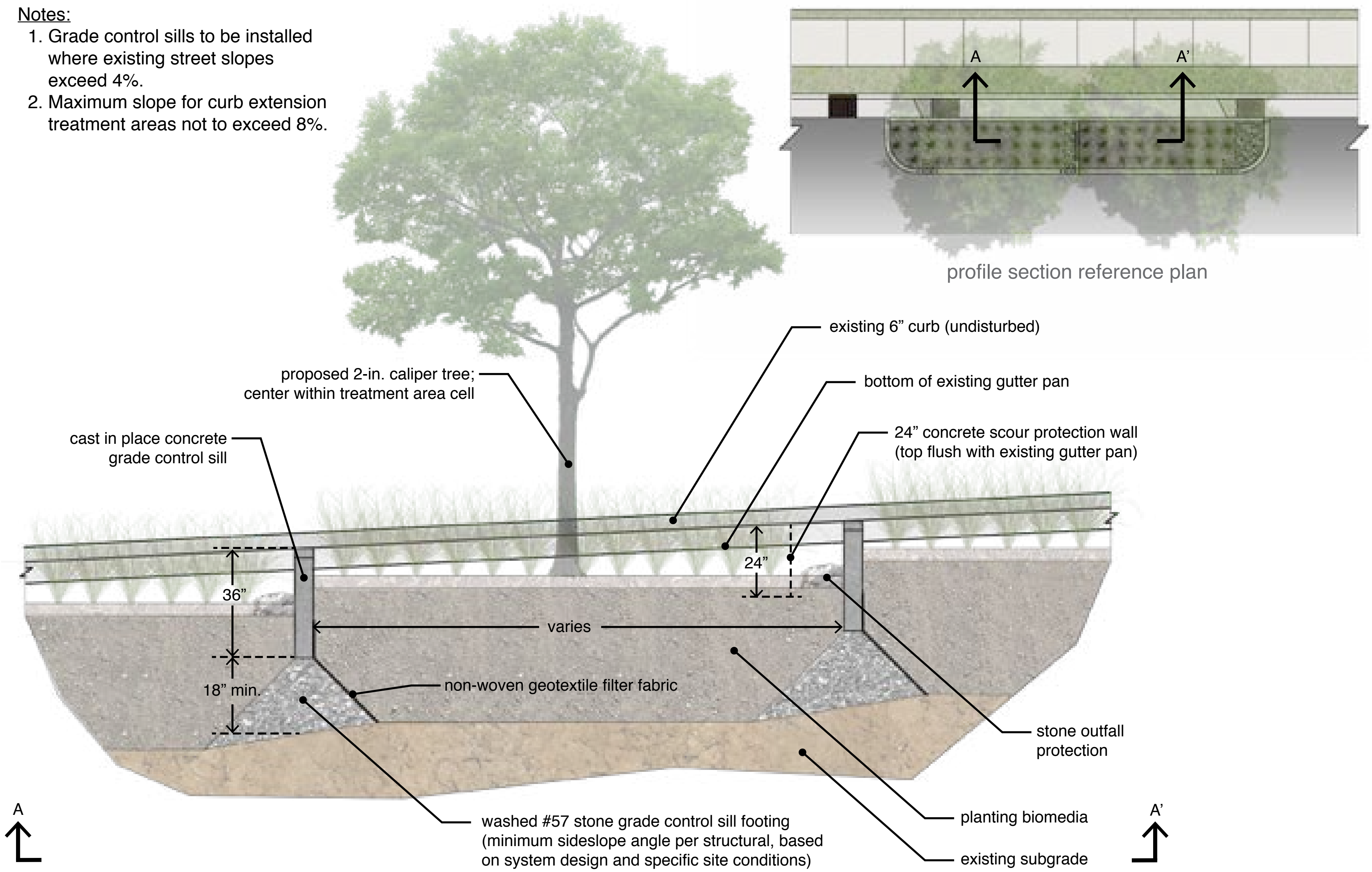


Figure 24: Stormwater Curb Extension Profile

to erosive stormwater velocities produced by high-intensity storms that characterize many areas of the United States. Grade control sill design and spacing is shown in Figure 24. Spacing between weirs varies depending on slope and length of flow pathway, but should not be greater than 10 feet when slopes approach 8 percent.

Planting

Integrating a diverse planting palette into stormwater curb extension treatment areas can greatly enliven drab conventional suburban streetscapes. Planting schemes can incorporate a variety of herbaceous and woody species that reflect seasonality, exhibiting different characteristics throughout the course of the year. Creative planting design within treatment areas also has the potential to entice people to be more active in their surrounding environments. When street trees are added to stormwater retrofit areas, the resultant canopy shading further enhances the streetscape. A shaded, aesthetically appealing streetscape can be a fun, comfortable place to be.

Stormwater treatment areas experience a wide range of moisture conditions within the planting media, and thus, selected plant material needs to be able to tolerate dry and wet conditions alike. Several cities and states have published LID guidebooks that feature both recommended biomedia mixes and lists of species well suited for stormwater treatment areas. Many of the plants, trees, and shrubs that thrive in rain gardens are ideal for inclusion in stormwater curb extensions planting plans.

Wherever possible, street trees should be included within treatment areas to provide the maximum level of benefits that stormwater retrofitting offers. Figure 25 illustrates a typical tree planting detail with several species that tolerate a wide range of soil moisture conditions. Trees should be centered horizontally within treatment areas, which should have a minimum width of 4 feet for trees to healthily grow. It is recommended that trees and plants come from local nurseries with a planting stock that is produced and grown under similar climatic conditions.

Successful herbaceous planting design will account for the moisture gradient within treatment areas (Figure 26). The planting zone closest to the treatment area inlet (the upslope side) will likely be drier than the zone closest to the outlet. Thus, select species that tolerate drier conditions for the "upstream" end of treatment areas and those that tolerate wetter conditions on the "downstream" end. Figure 24 provides an example herbaceous planting scheme that accounts for varying moisture conditions within planting media.

Cost Estimating

The table provided in Figure 27 provides a material cost estimate for an approximate 40 linear feet, 200 ft^2 stormwater curb extension treatment area in the Research Triangle Region of North Carolina. In this example, the cost estimate was based on North Carolina Department of Transportation (NCDOT) bid tab cost data, averaged over a three year period (2008 through 2010). Where applicable, NCDOT specification numbers are provided for reference. Special provision (SP) item costs reflect estimates obtained from area contractors and stormwater management design professionals. The average material cost for this retrofitting project is approximately $14 per square foot. However, costs can be highly variable depending on region, project scale, and associated roadway volumes, mobilization, and traffic planning requirements. It is also important to note that this estimate of probable cost is for materials only and does not include items such as design, engineering, and permitting fees, contractor overhead and profit costs, or contingencies.

Maintenance

As with all stormwater best management practice (BMP) areas, maintenance is an important long-term design consideration. Treatment areas need to be regularly maintained to preserve stormwater treatment efficiency and aesthetic appeal. If stormwater retrofit areas are improperly maintained, they run the risk of failing and becoming eyesores, thereby negatively affecting public perception. In many areas of the country street retrofitting is a new stormwater management approach, therefore there is concern about the intensity of maintenance for treatment areas. In most cases, maintenance activities are not that different or more extensive than those required for planted medians, tree

Sample street tree species for a project in USDA Hardiness Zones 6-9:

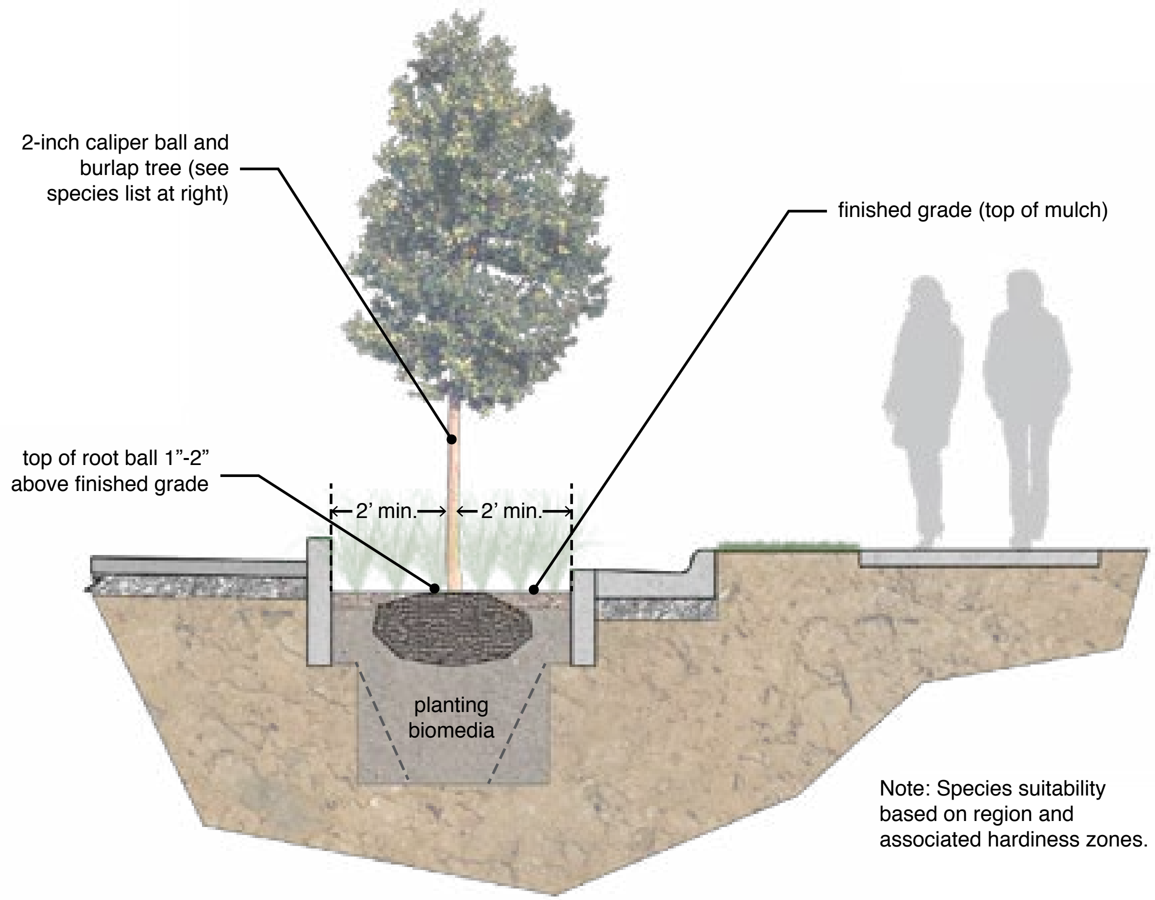


Figure 25: Tree Planting within Treatment Areas

Red Maple
(*Acer rubrum*)

Willow Oak
(*Quercus phellos*)

Green Ash
(*Fraxinus pennsylvanica*)

Shumard Oak
(*Quercus shumardii*)

Bald Cypress
(*Taxodium distichuum*)

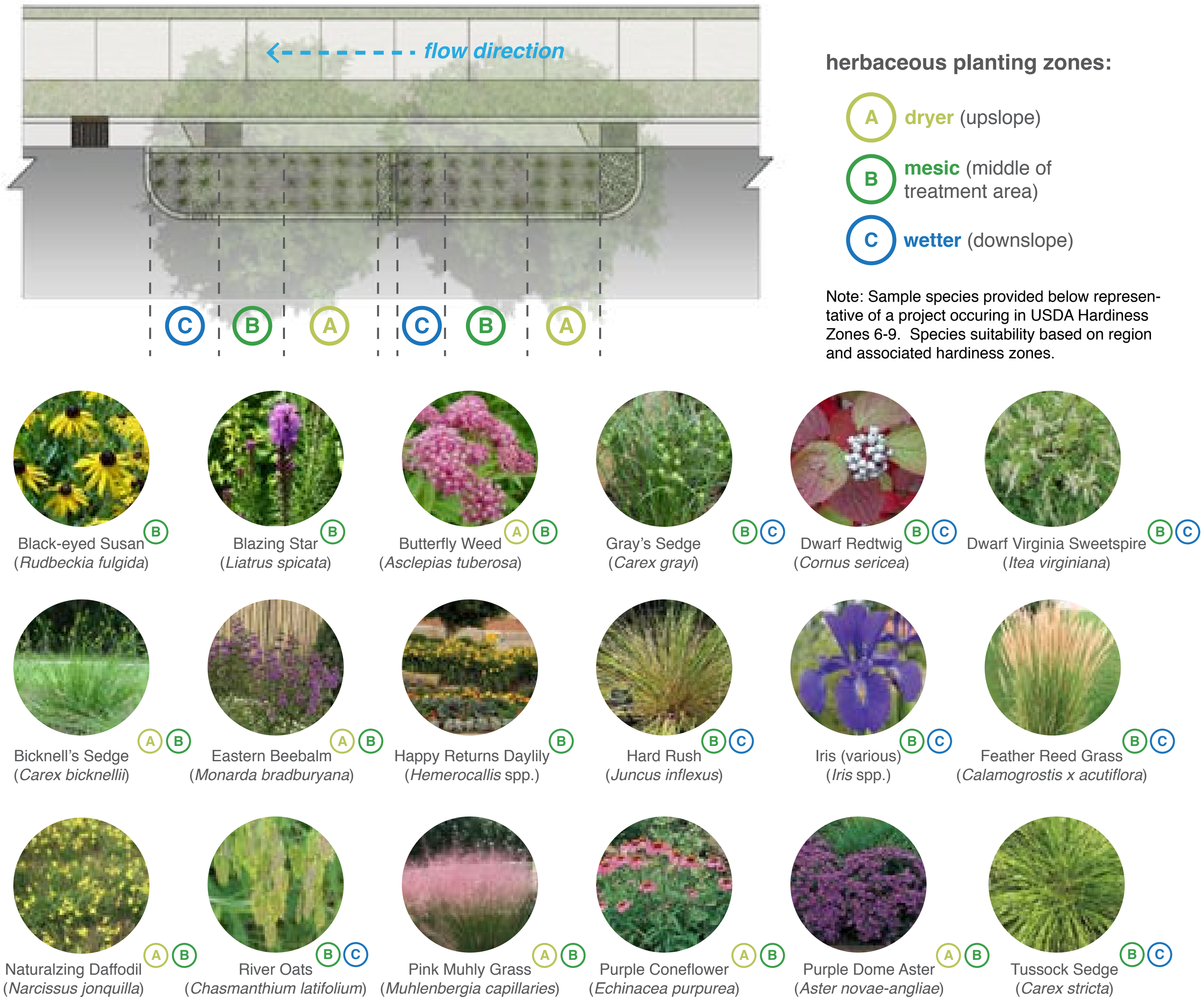


Figure 26: Sample Herbaceous Plantings within Treatment Areas

Material Cost Estimate for 40 linear foot (200 sq. ft. treatment area) stormwater curb extension:

Item No.	Item	Item No.	Quantity	Unit	Cost/Unit	Total Cost
1	asphalt pavement removal	0156000000-E	33	SY	$4.20	$138.60
2	unclassified excavation	0022000000-E	43	CY	$6.26	$269.18
3	curb extension	SP1	50	LF	$9.21	$460.50
4	scour protection wall	SP2	40	LF	$9.21	$368.40
5	concrete check dam	SP3	5	LF	$9.21	$46.05
6	concrete deflector vane	SP4	2	EA	$150.00	$300.00
7	concrete grinding	SP5	2	SY	$2.20	$4.40
8	triple shredded hardwood mulch	SP6	2	CY	$29.00	$58.00
9	planting biomedia	SP7	23	CY	$27.50	$632.50
10	#57 stone	1077000000-E	1.3	TON	$46.54	$60.50
11	class A rip rap	6006000000-E	1.2	TON	$28.30	$33.96
12	geotextile filter fabric	3656000000-E	0.8	SY	$1.51	$1.21
13	coir fiber wattle inlet protection	6071012000-E	6	LF	$6.09	$36.54
14	2-in. caliper tree	SP8	2	EA	$80.00	$160.00
15	2-gal. containerized plant	SP9	72	EA	$3.00	$216.00

total material cost: $2,785.84

material cost per square foot: $13.93/ft²

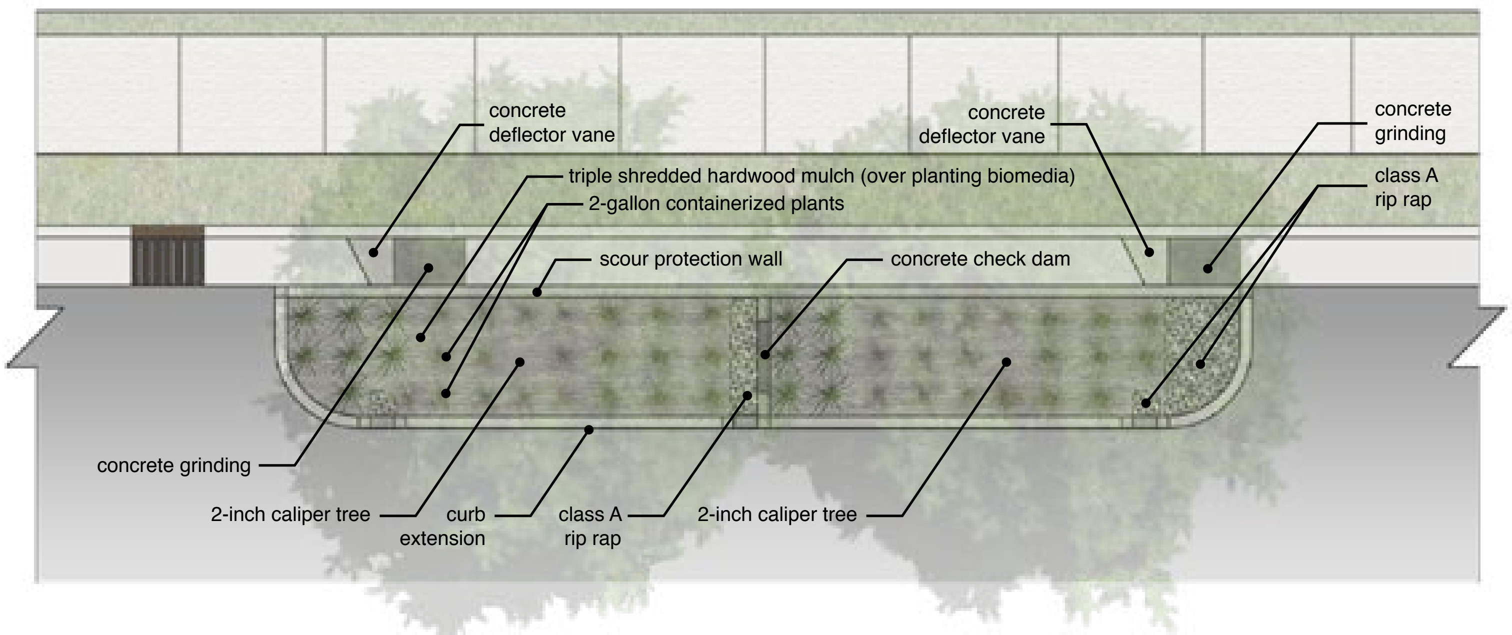


Figure 27: Sample Material Estimates of Probable Costs

Annual Schedule of Maintenance Activities by Month:

Maintenance Activity:	January	February	March	April	May	June	July	August	September	October	November	December
Prune Trees			Once									
Mow and groom herbaceous plants			Once plus as needed	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Once plus as needed	
Weed treatment areas				Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	
Remove plant debris and trash	Once	Once	Once	Weekly	Weekly	Once	Once	Once	Once	Weekly	Weekly	Once
Remove sediment at inlets and curb cuts	Once	Once	Once	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once plus as needed	Once	Once	Once
Inspect for structural damage and scour	Once	Once	Once	Once	Once	Once	Once	Once	Once	Once	Once	Once

Legend:

- Once
- Once plus as needed
- Weekly

Note: This sample schedule was developed for a street stormwater device containing plant materials adapted to USDA Hardiness Zones 6-9. The schedule may require modification based on monthly inspection results.

Figure 28: Annual Maintenance Schedule

yards, and other traditionally landscaped streetscape areas. However, some states have clearly defined BMP maintenance and inspection protocols. With this in mind, and also understanding that rules and regulations can sometimes change during a project's lifecycle, design professionals should always consult their state and local stormwater BMP manuals and regulatory staff throughout the design, permitting, and construction processes.

The schedule shown in Figure 28 summarizes annual maintenance activities and frequency by month. As with other landscaped areas, trees and other plantings within stormwater curb extensions need to be weeded, mowed, and pruned on a regular basis, especially during the growing season. Sediment, trash, and other debris should be regularly removed; however, the regularity of removal will depend on site-specific conditions and regulatory requirements.

Regular inspection is an essential maintenance activity for project success. Treatment areas should be regularly inspected for scour from stormwater runoff flow and structural damage. Many states have stormwater BMP inspection certification programs to educate maintenance staff, design professionals, and other interested stakeholders how to evaluate stormwater treatment effectiveness within treatment areas. Additionally, state university, NRCS, and other extension offices may be able to provide inspections free of charge.

In many cities, street maintenance can be a complicated process, requiring the coordination of different local government agencies to clarify which department is responsible for maintaining treatment areas. In subdivisions with privately maintained rights-of-way, typically the same company that performs streetscape maintenance can be hired to maintain treatment areas (HOAs should be consulted to verify). Regardless of public or private right-of-way designation, a proactive approach should be taken to address maintenance early in the design process to avoid potential conflicts in either project implementation or ongoing system management.

If agency or community budgetary and/or staff resources are not sufficient to guarantee adequate maintenance, designers can assist clients in developing creative solutions to system maintenance. At a programmatic level, municipalities may develop programs that engage residents in ongoing upkeep activities. The City of Portland has one such model; it has developed a Green Street Steward Program that enables residents to "partner with the city and lend assistance with simple activities that include picking up trash, removing leaves and debris, and occasional weeding and watering" (Portland 2015). Likewise, many other organizational resources related to street, waterway, and vegetative maintenance exist across nearly every community. Examples include, but are not limited to, Master Gardener programs, local school and university student groups and clubs, extracurricular programs (i.e., Boy/Girl Scout troops), and adopt-a-street and adopt-a-stream programs. The benefits of engaging stakeholders in these activities extends beyond maintenance— this hands-on interaction also has the potential to engage and educate residents.

Making Street Stormwater Retrofitting Happen: Next Steps

The environmental, economic, and community benefits of stormwater retrofitting alone make a compelling case for project design and implementation in conventional suburban communities. However, as a result of many years' worth of unsustainable development practices that adversely affect water quality, many cities find themselves in the position of having to mandate stormwater retrofitting and other management programs to satisfy EPA regulatory requirements. The question then becomes, "What can be done to advocate for street stormwater retrofits in my community or neighborhood?" In the *Using Rainwater to Grow Livable Communities* (2015) segment of their website, the Water Environment Research Foundation (WERF) recommends four initial steps:

- Learn how you can leverage political, organizational, technical, educational, and other resources to move forward with implementation.
- Arm yourself with effective tools for teaching others about the benefits of stormwater BMPs, strategies for successful implementation, and how to incorporate BMPs into development projects.

- Discover communities that have successfully integrated sustainable stormwater practices into their "toolboxes."
- Explore additional resources to broaden your knowledge and learn more about stormwater management and related topics.

More specifically, design consultants should familiarize themselves with the regulatory landscape – local, state, and federal – to better advocate for street stormwater retrofits as viable solutions. Professional designers then need to become educators, helping communities and clients understand these regulatory drivers, and their associated funding opportunities.

Indentifying Program Drivers

In accordance with Section 303 of the 1972 Clean Water Act, states are required to develop a list (called the 303[d] list) of rivers, streams, lakes, estuaries, and other waters with compromised water quality. For 303(d) listed water bodies, states are required to develop a Total Maximum Daily Load (TMDL) for pollutants to establish an acceptable threshold of pollutant loading in order to remediate water quality. In many cases, these pollutants consist of heavy metals, fecal coliform bacteria, and other nonpoint pollutant sources associated with conventional subdivision development. The TMDL serves as a tool to identify pollutant sources and develop a management plan to mitigate them.

Consequently, the management and mitigation of impaired waters and TMDLs is germane to all of the stormwater issues and opportunities previously discussed. Therefore, professional designers need to familiarize themselves with their respective state-wide and watershed TMDL compliance standards. A thorough understanding of these programs enables practitioners, and all concerned citizens, to build a strong case for the development of any stormwater BMP(s). In addition to providing justification for proposed improvements, familiarity with the regulations and programs will also guide designers toward possible funding sources. Many TMDL programs exist, particularly at the regional watershed scale. The most notable of these is the Chesapeake Bay TMDL, which is a comprehensive and historic "pollution diet" established by the EPA in partnership with the States of Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia (USEPA 2015a).

No matter their scale, designers should be involved with street stormwater retrofitting. The need for quality design is underscored by rapid increases in the density of both human populations and their resultant built environments. In many cities across the country, the available land required to implement large, "end of pipe" treatment systems is scarce. Since the roadway and street right-of-way network occupies such a large, contiguous network of publicly owned land, street stormwater retrofitting is a logical option to address stormwater management. Obstacles to widespread implementation of street stormwater retrofitting include a perception of insufficient funding resources and a lack of design standards and specifications. These are both areas where designers can have significant, positive impacts.

Funding Assistance

Many cities have instituted cost share programs for stormwater management projects that can be used to considerably reduce project design and construction costs. These programs incentivize local stormwater improvements using various utility rebate, tax credit, grant, and/or technical assistance tools. Notable programs exist across the country, and vary based on the scope, scale, and regulatory climate of stormwater-related issues facing a community, city, and/or region. The following examples highlight interesting and effective incentives currently offered by four municipalities:

Raleigh, North Carolina

Raleigh's Stormwater Utility Division offers a Water Quality Cost Share Program to help fund LID stormwater improvement projects. The program offsets construction costs in exchange for long-term maintenance commitments from property owners. For example, the City will reimburse 50 percent of the cost of a stormwater device if the owner agrees to maintain it for 5 years, or 75 percent for 10 years.

Minneapolis, Minnesota

The Minneapolis Department of Public Works has a Stormwater Credit Program that offers utility credits for stormwater management practices that address both stormwater quantity and quality. Through the program, residents can earn up to a 50 percent rate reduction for implementing stormwater quality measures, and a 50 percent or 100 percent reduction for implementing stormwater quantity measures.

Portland, Oregon
Through their Clean Rivers Rewards Program, the Portland Bureau of Environmental Services offers utility discounts to ratepayers for implementing on-site stormwater management tools and techniques. Depending on the level of stormwater management achieved on a property, the rebates can be significant, including discounts up to 100 percent.

Philadelphia, Pennsylvania
Similar to the examples listed above, Philadelphia offers a number of financial incentive programs. The Philadelphia Water Department (PWD) also provides technical assistance using tools like the *Green Guide for Property Management* (a componant of the Green City, Clean Waters Green Businesses Program) and the Fairmount Water Works Interpretive Center (an interactive demonstration site supported by a mutli-agency partnership). Additionally, the PWD and Philadelphia Industrial Development Corporation (PIDC) sponsor two stormwater grants, the Stormwater Management Incentives Program (SMIP) and the Greened Acre Retrofit Program (GARP). The SMIP "provides grants directly to non-residential property owners who want to construct stormwater retrofit projects," whereas the GARP "provides grants to contractors, companies or project aggregators who can build large-scale stormwater retrofit projects across multiple properties" (City of Philadelphia, 2015).

In addition to local funding sources, there are various federal and state monies available to assist with project funding. The EPA's Section 319 grant program, administered by states, provides funding for nonpoint source water quality improvement, which street stormwater retrofitting specifically addresses. For subdivisions and neighborhoods located within urbanized communities where stormwater is legally a point source, 319 funding may not be an option. In this circumstance, the EPA funding option is the Clean Water State Revolving Fund (CWSRF). In addition to state and federal funding sources, there are many privately administered grants that can be obtained for water quality improvement projects.

Local Standardization

Designers can also advance the practice of street stormwater retrofitting through the development of high-performing and long-lasting details suited to specific regions. While cities such as Portland and Seattle, with long established Green Street programs, have developed standard design drawings, specifications, and maintenance regimes, most cities have not, since green infrastructure retrofitting is a relatively new innovation. Working closely with regulators and scientists, designers can actively participate in the creation of standardized design elements and maintenance practices. In turn, these standards will greatly simplify the design, construction, and maintenance processes because designers will be able to draw upon a set of previously approved drawings and details, resulting in substantial time and cost savings. Perhaps more importantly, standardization serves to reduce construction costs because experienced contractors have a higher comfort level when bidding on projects that use familiar drawings and specifications.

Conclusion

As discussed throughout this document, there are significant reasons for improving the streets and roadways that organize and connect the built environments in which we live, work, and play. Street stormwater retrofitting has the transformative power to change potentially hazardous, uncomfortable, bland, and polluting streetscapes into cherished community amenities. With its ability to capture and treat stormwater, calm vehicular traffic, provide affordances for pedestrians and cyclists, and integrate vegetation that creates habitat, beauty, and added environmental function, street stormwater retrofitting is a strategy capable of addressing these challenges.

As demonstrated by the following illustrations (Figures 29-31), this multi-faceted design strategy can transform stark, conventional suburban streetscapes into community assets - places where children and adults alike can safely play and exercise. In sum, street stormwater retrofits, as a progressive stormwater management approach, generate environmental, community, and economic benefits at multiple scales, and make our neighborhoods better places to live.

Existing Conditions

- 50-foot right-of-way
- 25 mph posted speed limit
- All stormwater runoff flows untreated into the existing drainage network
- No street trees
- Lack of pedestrian amenities makes for an inhospitable streetscape and discourages physical activity

Proposed Retrofit

- 5-foot wide stormwater curb extensions added to street in an alternating pattern to preserve traffic flow
- New treatment areas reduce impervious surface by 6%
- Treatment areas are capable of capturing a .73″ rainfall event, or 65% of a 1″ (first flush) storm
- Street trees added to turf areas within right-of-way and treatment areas, providing shading and spatial definition to make the streetscape more comfortable

Figure 29: 50-foot Arterial Street Before (top) and After (bottom) Retrofitting

Existing Conditions

- 60-foot right-of-way
- 42-foot wide paved thoroughfare
- 25 mph posted speed limit
- Straight, overly wide street encourages fast speeds and distracted driving
- All stormwater runoff flows untreated into the existing drainage network
- No street trees
- Lack of pedestrian amenities makes for an inhospitable streetscape and discourages physical activity

Figure 30: 60-foot Collector Street Before (top) and After (bottom) Retrofitting

Proposed Retrofit

- 5-foot wide stormwater curb extensions added to street on both sides, constricting the travelway and calming traffic
- 32-foot wide paved thoroughfare
- New treatment areas reduce impervious surface by 11%
- Treatment areas are capable of capturing a 1.06" rainfall event, or 109% of a 1" (first flush) storm
- Crosswalk striping and sharrows added to street to enhance pedestrian and cyclist visibility
- Street trees within treatment areas provide shading and spatial definition, making physical activity more comfortable

Existing Conditions

- 90-foot right-of-way
- 9′ median
- Four 13.5′ vehicular travel lanes (unstriped)
- No bike lane striping or sharrows
- 25 mph posted speed limit
- Straight, overly wide street encourages fast speeds and distracted driving
- All stormwater runoff flows untreated into the existing drainage network
- Sparse ornamental plantings within median and no street trees make for an unattractive and inhospitable streetscape at the entry to the subdivision

Proposed Retrofit

- 6-foot wide stormwater curb extensions added to street on both sides, constricting the travelway and calming traffic
- Two 5-foot bike lanes added
- Vehicular travel lanes reduced to two, at 14.5″ each
- Crosswalk striping added
- New treatment areas reduce impervious surface by 8%
- Treatment areas are capable of capturing a .88″ rainfall event, or 84% of a 1″ (first flush) storm
- Street trees added to median and perimeter turf areas as well as treatment areas to provide shading and spatial definition, making physical activity more comfortable
- New street trees create a scale and character that is appropriate for the main entrances to the development

Figure 31: 90-foot Boulevard Before (top) and After (bottom) Retrofitting

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Additional Resources

American Association of State HIghway and Transportation Officials (AASHTO)
http://www.transportation.org

American Society of Civil Engineers (ASCE)
http://www.asce.org/

American Society of Landscape Architects (ASLA): Sustainable Stormwater Case Studies
http://www.asla.org/ContentDetail.aspx?id=31301

Center for Environmental Excellence by AASHTO
http://environment.transportation.org/

Center for Neighborhood Technology
http://www.cnt.org/

City of Philadelphia (PA) Water Department: Green City, Clean Waters Program
http://www.phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan

City of Portland (OR) Bureau of Environmental Services: Sustainable Stormwater Management Program
http://www.portlandonline.com/BES/index.cfm?c=34598

City of Seattle (WA) Public Utilities: Street Edge Alternative (SEA) Program
http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_ System/GreenStormwaterInfrastructure/NaturalDrainageProjects/StreetEdgeAlternatives/

Institute of Transportation Engineers (ITE)
http://www.ite.org/

Low Impact Development (LID) Center, Inc.
http://www.lowimpactdevelopment.org/

New York City (NY) Green Infrastructure Plan
http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml

North Carolina Division of Water Quality: Stormwater Best Management Practices (BMP) Manual
http://portal.ncdenr.org/web/wq/ws/su/bmp-manual

North Carolina Low Impact Development Group
http://www.bae.ncsu.edu/topic/lid/index.html

North Carolina Low Impact Development Guidebook
http://www.ces.ncsu.edu/depts/agecon/WECO/lidguidebook/

North Carolina State University Biological and Agricultural Engineering Department: Stormwater Engineering Group
http://www.bae.ncsu.edu/stormwater/

North Carolina State University Watershed Education for Communities and Local Officials Program
http://www.ces.ncsu.edu/depts/agecon/WECO/index.html

North Carolina Watershed Education Network
http://www.wen.ncsu.edu/

North Carolina Wildlife Resource Commission Green Growth Toolbox
http://www.ncwildlife.org/Conserving/Programs/GreenGrowthToolbox.aspx

San Mateo County (CA) Water Pollution Prevention Program: Sustainable Streets
http://www.flowstobay.org/ms_sustainable_streets.php

Transportation Research Board of the National Academies (TRB)
http://www.trb.org/NCHRP/NCHRP.aspx

United States Environmental Protection Agency (US EPA): Chesapeake Bay TMDL
http://www.epa.gov/chesapeakebaytmdl/

US EPA: Green Communities
http://www.epa.gov/greenkit/index.htmUnited States

US EPA: Low Impact Development/Green Infrastructure
http://water.epa.gov/polwaste/green/

US EPA: National Stormwater Calculator
http://www.epa.gov/nrmrl/wswrd/wq/models/swc/

Water Environment Research Foundation (WERF)
http://www.werf.org/

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Jim is a landscape design professional, professional wetland scientist (PWS), and restoration ecologist working at Biohabitats, Inc. in Baltimore, Maryland. He has more than 10 years of experience in water resource restoration, including streams, wetlands, and stormwater management. He is particularly interested in the interface between the natural and built environments, and design that serves to enhance our understanding of the interplay between the two from both functional and aesthetic standpoints. Jim holds a Bachelor of Science in Natural Resources from North Carolina State University, a Master of Environmental Management in Wetland Ecology from Duke University, and a Master of Landscape Architecture from North Carolina State University.

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Andrew is an associate professor of landscape architecture at North Carolina State University, where he is also a University Faculty Scholar, a Community Engaged Faculty Fellow, and co-director of the Coastal Dynamics Design Lab. As a registered landscape architect with more than 15 years of experience in the landscape design and construction industries, Andrew specializes in the areas of applied landscape architecture, urban design, and site construction with a focus on Low Impact Development (LID) and participatory design. He is most interested in public landscapes with a concentration on community involvement and high-performance landscape systems. During his career, Andrew has led numerous award-winning projects, including those receiving honors from ASLA, the North Carolina Chapter of ASLA, AIA, Chesapeake Stormwater Network, Hardscapes North America, and City of Raleigh. Andrew holds a Bachelor of General Studies from the University of Michigan and a Master of Landscape Architecture from Louisiana State University.

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