TREES IN BIORETENTION

Prepared for Arlington County, Virginia

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Section 1. Introduction

Over the past several years, interest in the use of trees for stormwater management has increased as more communities adopt a “green infrastructure” approach. Green infrastructure includes the preservation of large, continuous networks of forests and wetlands to store floodwaters and protect downstream conditions, as well as the use of numerous, small vegetated stormwater management practices to capture runoff and promote infiltration. Trees have well-documented environmental and community benefits, and therefore the idea of incorporating them directly into stormwater management practices is an appealing one. However, there is little data to document their influence on the effectiveness of stormwater management practices, and, in fact, concerns have been raised by the design community and maintenance practitioners about potential conflicts with trees in these facilities.

This memorandum summarizes the available knowledge on the benefits and potential conflicts with trees in one specific type of stormwater management practice: bioretention. This study was conducted by the Center for Watershed Protection, Inc. for the Department of Environmental Services in Arlington County, Virginia to address concerns about the impact of trees in bioretention, especially as it pertains to the effect of long-term maintenance activities on the trees.

The research questions identified for this effort included the following:

1. What are the benefits of trees in bioretention?
2. What are potential problems with trees in bioretention?
3. How have communities addressed these concerns?

Sources of information for this research included interviews with watershed and stormwater managers and researchers, as well as literature reviews of relevant research and other reported results. A summary of research findings is provided and is followed by alternatives and recommendations for Arlington County.

Section 2. Summary of Findings

Section 2a. Benefits of Trees in Bioretention

> *“There is untapped potential in utilizing trees to address stormwater runoff in urban areas. Traditional approaches used by most municipalities to manage urban trees have focused on short-term aesthetic goals often to the detriment of tree health and full realization of ecosystem services provided by trees. Many municipalities are reluctant to expand tree programs due to budget, staffing, and liability issues. However trees are useful and valuable components of city*

> *stormwater infrastructure and provide measurable reductions in runoff volume and pollutant loads. Municipalities should explore opportunities to expand tree planting programs and incorporate trees into engineered stormwater systems. Trees are not just landscaping placed on top of city infrastructure, they are city infrastructure"*
>
> – Shirley Trier, Davey Resource Group

Little to no research has been published that addresses the runoff reduction or water quality impacts of trees in bioretention compared to similar facilities without trees. As indicated in Section 2c, this may be because so few communities are actually incorporating trees into bioretention, let alone studying their impacts. One study did document the delayed and reduced peak flows and decreased runoff volume from six bioretentions containing trees in North Carolina and Maryland; however, the study did not measure these same factors in similar bioretention facilities without trees (Li et al., 2009). Another study in North Carolina found that bioretention cells vegetated with sod provided similar fecal coliform, N, and P removal as bioretention vegetated with mulch, shrubs, and trees (Passeport et al., 2009), while two studies reported that the vegetated biofiltration mesocosm systems reduced more P and N than mesocosms without vegetation (Lucas and Greenway, 2008; Henderson et al., 2007). The US Forest Service's Urban Forests Effects – Hydrology (UFORE-Hydro) model, which simulates tree effects on urban hydrology and runoff, will soon be used to model the impacts of trees in bioretention basins in the Chesapeake Bay (Wang et al. 2008). This upcoming modeling effort will help to address this important data gap.

The best currently available example for trees in bioretention research comes from Virginia Tech. Studies to maximize the use of urban trees to better manage stormwater are being conducted by Dr. Susan Day of Virginia Tech in partnership with Cornell University and the University of California at Davis. A series of small scale experiments and larger demonstration sites aim to determine how to integrate trees into urban landscapes. These studies incorporate structural soils, which are engineered mixes designed to both support pavement loads and simultaneously provide rooting space for trees. Two container experiments were used to establish that urban tree roots have the potential to penetrate compacted subsoils and increase infiltration rates in reservoirs being used to store stormwater. One study found infiltration rates were increased on average 153% by both black oak and red maple trees, which penetrated clay loam soil that was compacted to 1.6 g/cm^3. In another experiment, researchers created a small-scale version of a stormwater best management practice (BMP) that includes a below-pavement stormwater detention reservoir constructed of structural soil. In this study, green ash trees increased the average infiltration rate by 27 times to that of unplanted controls. In the experiment, the structural soil reservoir (CUSoil, Amereq Corp., New York) was separated from compacted clay loam subsoil (1.6 g/cm^3) by a woven geotextile in 102-liter containers. After two years, the roots penetrated both the geotextile and the subsoil in the structural soil reservoir (CUSoil, Amereq Corporation, NY). Interestingly, the roots proliferated where geotextile tears existed (American Society of Agronomy, 2008). See Day and Dickinson (2008) for more information.

Although the research is lacking on this specific topic, there is a vast quantity of literature on the environmental, social and economic benefits of trees. In urban areas, where green space is limited, stormwater management practices can be a logical option for increasing the tree canopy to help provide some of these benefits, such as cooling and shade, removal of air pollutants, reduced stormwater runoff, traffic calming, increased property values and recreational, health and aesthetic benefits. A collection of research papers on the social and economic benefits of urban trees is provided at http://www.naturewithin.info/urban.html.

In addition to the potential for trees in bioretention practices to provide these community benefits, planting trees in stormwater treatment practices may also increase nutrient uptake, reduce stormwater runoff through rainfall interception and evapotranspiration (ET), enhance soil infiltration, provide soil stabilization, increase aesthetic appeal, provide wildlife habitat, provide shading, and reduce mowing costs (Shaw and Schmidt, 2003). While few studies exist that directly quantify these benefits, research is available on rainfall interception and ET rates, as well as pollutant removal for individual trees. This data suggests that incorporating trees into stormwater management practices may increase their pollutant removal and runoff reduction effectiveness, but it is challenging to quantify these benefits for application to stormwater management because the extent to which forests and trees intercept rainfall, evapotranspire water, promote storage of water in the soil, and remove pollutants varies widely with factors such as the species and size of trees, forest condition, climate, rainfall characteristics, soil characteristics, tree health and management practices.

In short, since most of the water entering bioretention is from the drainage area versus directly falling on the bioretention surface, the rainfall interception and ET benefits provided by trees within a bioretention facility are likely to be negligible in terms of annual runoff reduction. Therefore, as an overall runoff reduction strategy, reforesting larger acreages adjacent to the bioretention or elsewhere in the watershed will provide more significant annual runoff reduction. The limited data available on the runoff reduction and water quality benefits of trees versus other vegetation suggests that trees can potentially remove significantly greater volumes of water through transpiration and enhance pollutant removal, but no studies are available to directly measure these effects in bioretention with trees versus bioretention without trees. These potential benefits of trees in bioretention and the many social and economic benefits of trees are very important considerations in a community’s decision to encourage or even require the incorporation of trees in stormwater facilities such as bioretention.

A summary and discussion of the impacts of urban trees on hydrology and water quality is provided here.

Stormwater Benefits of Trees

Impacts of Urban Trees on Hydrology

The specific processes by which trees impact hydrology can best be described as part of a cycle of inter-related components (Figure 1). When rain occurs, forests capture rainfall in their canopies (**rainfall interception**). Intercepted rainwater is either evaporated directly into the atmosphere (**evaporation**), absorbed by the canopy surfaces, or transmitted to the ground via stems, branches, and other tree surfaces (**stemflow**). The water delivered to the base of trees penetrates the soil rapidly (**infiltration**) by following interconnected pathways in the soil formed by large roots. In a forested environment, leaf litter and other organic matter, soil macropores, and small depressions in the forest floor all work to slow runoff, hold water and further promote infiltration. Trees uptake water from the soil through tree roots and release moisture in the form of water vapor from leaves (**transpiration**). This increases soil water storage potential, effectively lengthening the amount of time before rainfall becomes runoff. Increased infiltration helps to replenish groundwater supplies (**recharge**).

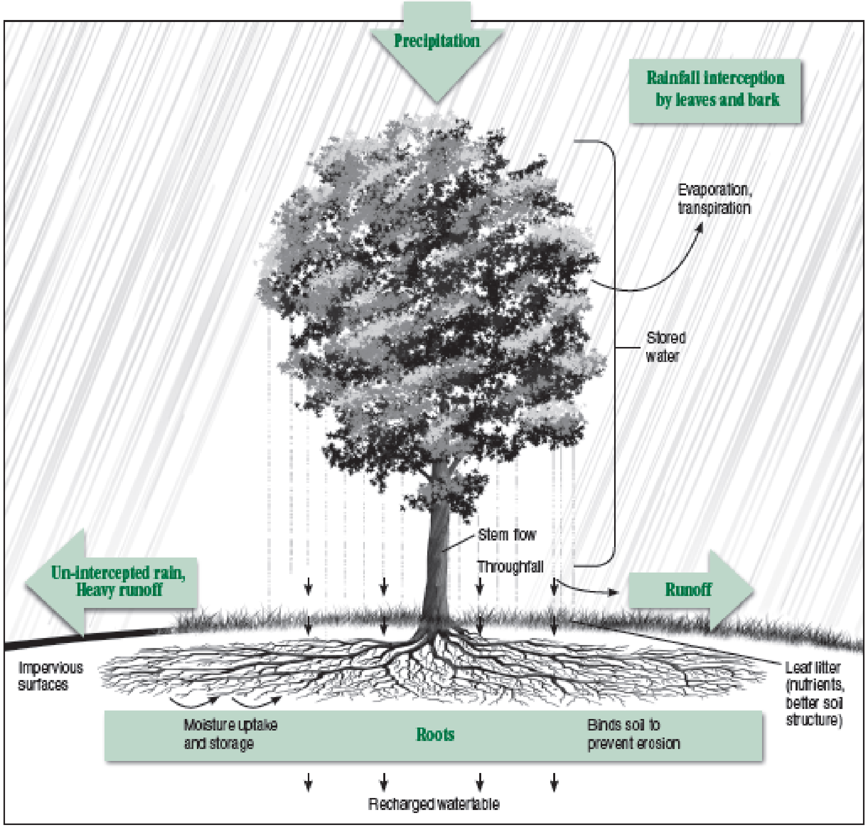

Figure 1. Urban trees impact the hydrologic cycle by intercepting and storing rainfall, releasing water through ET, promoting soil infiltration and recharging groundwater. Combined, these processes reduce the proportion of rainfall that becomes stormwater runoff. (Figure credit: Tree City USA, 2010).

There are several methods to estimate the runoff reduction provided by trees. First, monitoring studies can be conducted to measure the proportion of rainfall that is removed through individual processes such as interception, transpiration and infiltration. The sum of these processes equals the total runoff reduction. Or, monitoring studies can focus on actually measuring the runoff from a forested catchment. Runoff reduction provided by trees can also be modeled. Each method is briefly described below.

Interception. Most interception studies use similar methods where the rainfall beneath the canopy plus the water running down the trunk are measured and subtracted from the measured rainfall outside the dripline. Three studies of canopy interception by deciduous trees report a reduction in rainfall of 13%, 8% and 11% respectively (Dunne and Leopold, 1978; Reynolds et al., 1988; Xiao et al., 1998). Interception by conifers is greater than interception by deciduous trees and can also be affected by seasonality and rainfall conditions. In general, mature trees with a wide crown will intercept the most rainfall and, in urban areas, stormwater runoff reduction benefits will be maximized when trees are located so they overhang impervious surfaces.

Urban forests have been shown to be most effective at intercepting rainfall from small, short duration storms often responsible for the “first flush” of runoff, during which most annual pollutant runoff occurs (Xiao et al., 1998). A sampling of interception studies for individual trees is provided here:

- A single mature tree with a 30-foot crown can intercept up to 4,600 gallons of water per year (Portland BES, 2000).
- A mature deciduous tree intercepted 760 gallons of rainfall per year in its crown in one California study, while an evergreen tree was estimated to intercept 4,000 gallons annually (CUFR, 2001).
- A study in California found that a mature Bradford Pear intercepted 15% of gross precipitation in winter, while a Cork Oak, which is evergreen, intercepted 27% of gross precipitation (Xiao et al., 2000).

Transpiration. Tree transpiration is usually measured using micro-metrological stations positioned above the canopy, sap-flow monitors and soil lysimeters. One study of transpiration by deciduous trees reported a 25% reduction in rainfall (Schlesinger, 1997). Transpiration depends on the plant type, leaf area, nutrients, soil moisture, temperature, wind conditions, and relative humidity. In general, trees and shrubs have greater capacity to transpire water than emergent vegetation. Certain tree species (called phreatophytes), such as willows, cottonwood and poplars, can transpire large amounts of water because they are deep-rooted, water loving species. Table 1 provides transpiration rates for these types of trees.

Table 1. Transpiration Rates of Various Tree Species (ITRC, 2001).

Plant Name	Plant Type	Transpiration Rate*
Cottonwood	Tree (2 years old)	2.00-3.75 gpd/tree
Hybrid poplar	Tree (5 years old)	20-40 gpd/tree
Cottonwood	Full mature tree	50-350 gpd/tree
Weeping willow	Full mature tree	200-800 gpd/tree

* gpd = gallons per day

Although no studies have measured ET in bioretention with trees, two studies of ET in bioretention basins with herbaceous vegetation point to the importance of ET in general for bioretention function. One North Carolina bioretention study estimated ET at 18% (Li et al., 2009), while Hickman (2011) found that ET was a major runoff reduction factor in a laboratory experiment that used a weighted lysimeter for a bioretention and for a bioinfiltration practice. Hickman (2011) reported the ratio of water lost from ET to infiltration for the lysimeter bioretention was 1:2 and for the lysimeter bioinfiltration was 1:6. The ET had significant water loss for the bioretention and bioinfiltration basins. Extrapolating data for the 358 mm attributed to ET for the lysimeter bioinfiltration area to the bioinfiltration basin area at the Villanova Campus, resulted in potential ET water loss of 145 m^3 (145,000 L) over nine months. Furthermore, the internal water storage (IWS) or saturated zone in the bioretention cell increases ET. The IWS dries in between storm events and then IWS fills with water during storm events. This IWS is infiltrated, taken up by plants, and evapotranspired (Hickman, 2011). There is likely an upper limit to bioretention ET water loss for storm event runoff. Currently, this upper ET limit is unknown. Additional research is needed to estimate bioretention ET and determine how trees in the bioretention impact ET.

Additional findings from ET and transpiration studies of individual trees include:

- A single tree can transpire up to 100 gallons of water a day on a sunny summer day (Metro, 2002; US EPA, 1992).
- Poplar trees can transpire between 50 and 300 gallons of water out of the ground in one day (US EPA, 1998).
- An open grown hardwood tree will consume from 1.2 to 1650 gallons of water per day, depending on the size of the tree and the ET rate (Perry, 1994).
- A mature, properly watered shade tree with a 30 foot crown can evapotranspire up to 40 gallons of water a day (Heat Island Group, 1996).
- A mature bald cypress can absorb 880 gallons per day, depending on the soil type and saturation (Keating, 2002).

Infiltration. Infiltration rates are dependent on land cover, soil type, antecedent soil moisture, seasonality, and rainfall conditions. Studies that measure soil infiltration rates in forest conditions compared to other land use conditions generally show significant increased infiltration capacity by forest soils (Wondzell and King, 2003; Lal, 1996; Kays, 1980). However, the values from these studies are not likely to be applicable to this research because they were derived from existing forested areas whereas planting trees in bioretention involves creation of a forested condition in an artificial soil media. It is well known that tree roots can improve soil infiltration capacity and therefore would likely add complexity and structure to the bioretention over time.

Runoff. Two primary methods have been used to measure in-stream runoff from forested catchments. The first is to conduct monitoring of a forested catchment before and after deforestation. The second is to measure rainfall and runoff from a forested basin. Two before/after studies of deciduous forest catchments reported a 23% and 32% increase in runoff after deforestation, and one study measuring rainfall and runoff from a deciduous forest catchment reported that 39% of the rainfall was reduced (Post and Jones, 2001; Martin and Hornbeck, 2000; Hornbeck et al., 1997).

Modeling. Most modeling studies of runoff reduction by trees are based on simple land use models that use curve numbers (CNs) and predict runoff based on land use type. In many cases, the "value" of urban trees has also been estimated based on the avoided cost of having to construct retention facilities to manage an equivalent volume of runoff. One of the most commonly used models of this type is American Forests' CityGreen model, a GIS application that can be used to digitize tree canopy and calculate the stormwater runoff reduction and associated benefits. CityGreen can be calibrated for local condition by adapting the CNs and soil types. CityGreen is based on the NRCS' technical Release 55 (TR-55) which is best applied at the catchment scale.

The U.S. Forest Service has developed a more sophisticated model called Urban FORests Effects (UFORE). UFORE is based on hydrodynamic canopy models and the Hydro portion of the model estimates streamflow and water quality changes based on tree cover and impervious cover in a watershed. UFORE is calibrated against actual streamflow data and required inputs include rainfall, elevation, land cover, watershed boundary, and gaging station data. The current resolutions available are 10 m and 30 m but 1 m is available within a <5 km^2 area.
A major limitation of the modeling approach is that is does not accurately account for tree interception and canopy storage (Xiao et al., 1998).

Examples of results from modeling studies are provided here:

- In Tucson, Arizona, an increase in tree cover from 21% to 35% resulted in a decrease in the mean annual runoff by 50% (Lormand, 1988 in Herrera, 2008).
- New York City Department of Parks and Recreation estimates that 500,000 street trees can reduce 6.5 billion gallons of stormwater runoff per year. This amounts to investing $1,000 per tree to receive 13,740 gallons of stormwater runoff reduction each year (Plumb, 2008).
- Another model in Ohio reported that 22% tree cover reduced small event runoff by 7% in an urban basin (Sanders, 1986 in Herrera, 2008).
- Tree cover models in Garland, Texas, found that a site with 8% tree canopy coverage reduces stormwater runoff by 1,315 ft^3 which equates to a 3% runoff reduction. Estimated runoff volume ranged from 2.54 to 3.67 inches based on an average 24-hour, 2 year storm event. Using CITYgreen ® to model 35% and 45% tree canopy at the site would provide 13% and 16% more runoff reduction at the site (which is about 5,941 ft^3 and 7,635 ft^3, respectively) (American Forests, 2000).
- In Milwaukee, Wisconsin, where urban trees cover about 16% of the city, trees reduce stormwater flows by 22%. The city saves an estimated $15.4 million by avoiding the construction of additional combined sewer retention capacity.

- In Austin, Texas, heavy rains make stormwater management a priority issue. Austin's tree canopy is approximately 30%, and reduces stormwater flow by 28%, providing the city with an estimated $122 million in savings (MacDonald, 1996).
- Wang et al. (2008) used the UFORE-Hydro model to estimate that increasing the tree cover over pervious areas from 12% to 40% in a catchment reduced runoff by 2.6%. However, the study reported 3.4% runoff reduction when trees were replaced over the catchment's impervious cover from 5% to 40% (12% of the catchment area).
  The Virginia Assessment Scenario Tool (VAST) is a nutrient and sediment load estimator tool consistent with the Chesapeake Bay Program's Watershed Model. VAST credits planting 100 trees as equivalent to one acre of "pervious urban" to forest (MDE, 2011), and, on average across the watershed, this equates to a nitrogen loading reduction from an estimated 13 lbs/acre to 4 lbs/acre.

<u>Application of Studies to Arlington County</u>

A review of field studies of interception, transpiration, and infiltration associated with trees found that these combined processes can be expected to significantly reduce annual rainfall by an estimated 30% (based on data for conifers in the Pacific Northwest) (Herrera Environmental Consultants, 2008). To develop an estimate of runoff reduction by trees in bioretention for Arlington County, Virginia, we used the data from monitoring studies of deciduous trees (versus studies of conifers) presented in Herrera Environmental Consultants (2008). The average proportion of precipitation intercepted by deciduous trees is around 10%. Only one study was available for transpiration by deciduous trees and this value was 25% of precipitation. Taken together, we can assume that 35% of rain falling on a deciduous forest would be intercepted or transpired by the trees. However, this does not account for water losses through infiltration, so this is likely an underestimate. The values derived from infiltration studies are difficult to apply to a reforestation situation because it is unknown how long it takes for soils in a newly planted reforestation site to achieve the infiltration rates associated with undisturbed mature forests, on which these studies were conducted. In addition, the bioretention retrofits planned for Arlington County are primarily on sites that have already been grade for roadways, so infiltration benefits at these sites may be marginal.

For comparison, the average runoff reduction estimated through catchment-scale studies of forest runoff was around 31%. These values are from studies conducted at the catchment scale, so they may not be entirely applicable to a bioretention situation. However, it is reasonable to assume that the runoff reduction provided by trees is at least 30% given these values and the measured values for interception and transpiration.

To illustrate how these values might be used in a bioretention application, we assume that the ground cover underneath the trees in the bioretention facility is turf or other herbaceous vegetation with B soils. The runoff coefficient for the turf cover is 0.20. Therefore, if 10% of rainfall is lost to canopy interception, approximately 90% of the rainfall would reach the surface. Of this 90%, 25% is lost to transpiration by trees and another 80% is lost to evaporation and infiltration by the turf. In this scenario, the proportion of rainfall that becomes runoff is -4.5%. The water transpired by the tree may be the same water falling through the canopy, or it may be water that originates from adjacent areas, or groundwater. Therefore, the negative value illustrates that it may be possible for trees to remove more water than what actually falls on the ground. Compare this scenario to a bioretention facility with no trees and similar soil and ground cover conditions that would result in 20% of rainfall falling on the bioretention area being converted to runoff. This amounts to a 24.5% improvement in runoff reduction for the bioretention surface area with trees compared to bioretention without trees.

It is important to note that this analysis only considers the surface area of the bioretention area itself, which is a very small percentage of a bioretention drainage area. The benefit of trees in bioretention is harder to illustrate when the additional runoff from the drainage area is considered, but the analysis does indicate at least some potential for trees to aid in runoff reduction of bioretention areas.

One caveat to this approach is that the studies for which the values were derived may have been conducted under varying seasonal and site conditions. Herrera Environmental Consultants (2008) provides more information on the effects of trees on stormwater runoff. It is also important to note that these values would apply to areas planted to achieve a “forest-like” condition within the facility since the values are taken from studies of forests rather than individually planted trees.

Impacts of Trees on Water Quality

Trees improve soil and water quality through uptake of soil nutrients by plants and soil microbes, and filtering of sediment and associated pollutants from runoff. In addition, tree roots stabilize the soil and tree canopies reduce the impact of raindrops, both of which reduce soil erosion. Very little of the nutrients in forests are delivered to water bodies because they are cycled through these various processes and locked up in live and dead biomass (e.g., leaves), as well as soils. However, in urban watersheds, trees, especially street trees, can actually contribute phosphorus to the environment because there is no forest floor or intact riparian ecosystem to process and recycle the nutrients resulting from degradation of leaves (Dorney, 1985; Cowen and Lee, 1973).

Trees also show enormous potential to remove other pollutants, such as metals, pesticides, and organic compounds. The process of using plants to remove contamination from soil and water is called **phytoremediation.** Phytoremediation has mainly been applied to soil and groundwater but could easily be applied to stormwater runoff. Plants can be used to clean up certain metals (e.g., cadmium and zinc), pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates (US EPA, 1998). Tree species typically used for phytoremediation include willow, poplar (cottonwood hybrids), and mulberry, because they have deep root systems, fast growth, a high tolerance to moisture, and are able to control migration of pollutants by consuming large amounts of water (Metro, 2002; IRTC, 2001; Puckette, 2001).

The major processes at work with phytoremediation include plant uptake, adsorption and microbial activity. Once pollutants are taken up by plants, one or more activities may occur. Pollutants can be moved into the above-ground portions of the plants, accumulate in the root zone, be broken down through natural processes of plant growth, or be transformed into inert material and discharged through plant leaves or shoots. Biological uptake is seen as only a temporary removal process because the pollutants may be returned to the system when the plant dies, unless it is harvested.

While the influence of different types of vegetation on pollutant removal processes in stormwater treatment practices is still not fully understood, dense emergent wetland vegetation appears to be important for nitrogen removal (through denitrification and adsorption), while woody vegetation is more beneficial as a sink for phosphorus (and carbon) though uptake (Mitsch and Gosselink, 2000). Biological uptake most often occurs through plant roots and is increased in plants having high transpiration rates and fast growth, such as willows and poplars (Shaw and Schmidt, 2007). Trees and shrubs also promote infiltration near their root systems, which can filter out additional pollutants. As a result, stormwater treatment practices designed with both emergent and woody vegetation may be most effective from a pollutant removal standpoint because they incorporate a variety of removal processes.

Section 2b. Potential Problems of Trees in Bioretention

As described in Section 2a, there are clearly many potential benefits of using trees in bioretention. However, regulators and designers may wonder if the potential problems could outweigh these benefits. This section summarizes: 1) the potential negative impact of trees on bioretention function and maintenance and 2) bioretention conditions that may impact trees.

Potential Negative Impacts of Trees on Bioretention Function and Maintenance

In 2004, the Center for Watershed Protection and USDA Forest Service facilitated a design symposium attended by foresters, stormwater engineers, arborists, landscape architects, and practitioners to discuss the topic of integrating trees into stormwater management practices. As a result of this discussion a set of potential (real or perceived) engineering conflicts were identified, along with proposed resolutions, summarized in Table 2. While not all of these concerns will apply to bioretention in an urban setting such as Arlington County, the table provides a starting point to summarize the knowledge on this topic.

Table 2. Potential Engineering Conflicts and Resolutions for Planting Trees in Stormwater Treatment Practices (Cappiella et al., 2006).

Potential Engineering Conflict	Resolutions
Tree litter may clog outlets and drainage pipes, increasing maintenance, and potentially drowning trees if not unclogged.	• Select species that do not produce excessive litter.
Trees may shade out grass and contribute to erosion in practices with higher flows	• General consensus was that this should not be a concern. As a precaution, plant shade-tolerant ground covers where possible.
Tree roots may puncture filter fabric or underdrains	• Increasingly, designers are moving away from the use of filter fabric between the filter media

Table 2. Potential Engineering Conflicts and Resolutions for Planting Trees in Stormwater Treatment Practices (Cappiella et al., 2006).

Potential Engineering Conflict	Resolutions
	and site soil, as it may create an undesirable soil-water interface. To replace the function of the filter fabric where needed, a sand or pea gravel layer may be used. • Tree roots clogging or puncturing underdrains should not be a major concern. As a precaution, do not plant trees directly over underdrains.
Presence of trees in practice may reduce storage or conveyance capacity	• Modify practice design to account for trees (e.g., make the practice slightly larger).
Mowing around trees, where required, may be more difficult	• Cluster trees where possible to allow easier mowing. • Cease mowing where it is not necessary and allow regeneration. • Use meadow grasses that do not require frequent mowing (if appropriate for the region).
Overgrowth of trees in maintenance areas may limit access	• Limit trees in maintenance access areas and within 15 feet of these areas.
Trees with excessive fruits, nuts and other litter may be nuisances, particularly adjacent to impervious surfaces	• Select species that do not produce excessive litter, particularly when planting near impervious surfaces.

The main concerns related to tree impacts on bioretention function revolve around the tree's roots and the organic debris produced by the tree. One of the most potentially detrimental impacts of tree roots is damage to or clogging of the perforated underdrain. Perforated underdrains located only a few feet from the surface could potentially be invaded and eventually clogged by tree roots. Tree roots tend to grow in the first 18 inches of soil but will naturally seek water and this is true especially in urban environments. The perforations in the underdrain can allow tree roots to enter and subsequently expand within the pipe. Puncture of filter fabric by tree roots is another potential concern where filter fabric is used between the filter media and the gravel jacket around the underdrain or along the sides of the excavated area.

Some deciduous trees shed leaves that persist on the ground. While in a forest condition, this leaf matter eventually breaks down and forms an organic soil layer, in bioretention practices where water inundation/ponding can be frequent, these newly fallen leaves can form a thick mat that can reduce drainage rates and result in water ponding for longer than desired or designed and permitted. The added organic debris can not only contribute to clogging of the soil media, it can also clog inlets and outlets.

Routine maintenance for bioretention typically includes ensuring the inlet and outlet structures are clear of debris, removing trash, maintaining and replacing vegetation, replacing mulch, repairing eroded areas, removing invasive plants, maintaining access, and performing inspections of the facility as well as its contributing drainage area to identify problems (e.g., harmful substances that could contaminate the facility soil media). Of these maintenance efforts, trees in bioretention have the potential to increase maintenance burden by clogging inlet/outlet structures and contributing to clogged soil media if not properly placed/selected.

Other potential infrastructure impacts to consider for bioretention facilities located near roadways include damage to nearby sidewalks and utilities. For example, trees planted near sidewalks can damage pavement when root growth causes cracking or heaving. In California alone, it is estimated that $70 million is spent annually to repair street tree damage to sidewalks, curbs and gutters (McPherson and Peper, 2000). In Europe, 20% to over 50% of street trees surveyed were found to cause some damage to hardscape (Reichwein, 2002; Wong et al., 1988). Since bioretention soil media typically has a high sand content, drought conditions within the facility could cause tree roots to spread beyond the soil media in search of water, increasing the potential for damage to nearby infrastructure. However, there is a lack of data on stormwater facilities with mature trees to fully assess this concern (Scott, pers. comm., 6/11/11). Trees can also cause conflicts with both above ground and underground utilities if not located properly.

Conditions that May Impact Trees

The potential benefits of trees in bioretention described in Section 2a can only be provided if the trees survive and thrive. However, conditions in urban areas and (more specifically) within stormwater management practices, are not always ideal for tree health. Cappiella et al. (2006) identifies the following conditions of bioretention facilities that may limit tree growth:

- Exposure to frequent (10 to 50 times per year or more) inundation to a depth of 6 inches to 12 inches lasting a few to several hours
- High chloride levels
- Exposure to drought during dry periods
- May be used for snow storage
- Exposure to moderate to high levels of urban stormwater pollutants (e.g., metals)
- High sand content of soils

Additionally, trees can be impacted by routine maintenance practices such as invasive plant removal or by repairs to adjacent utilities and sidewalks. The most common non-routine bioretention maintenance problem involves standing water. Depending on the cause of the standing water, required repairs could range from snaking a clogged underdrain to remove accumulated sediment to complete replacement of the soil media. Some of these practices have the potential to damage existing trees or require their removal; however, regular inspections, routine maintenance and proper design and construction of the facility should reduce the occurrence of these problems.

Ultimately, replacement of bioretention facility components (such as the soil media or underdrain) that have reached the end of their lifespan may require removal of trees placed in the facility. However, since bioretention is a relatively new practice, limited data exists to determine the lifespan of the soil media. Estimated bioretention lifespans range from 10 to 40 years

(Biosystems Engineering, 2007). Fairfax's LID Fact Sheet estimates bioretention lifespans at 25 years (Fairfax County, 2005). Davis (2003) estimates bioretention lifespan to be approximately 20 years, which is when the metal accumulation exceeds the bioretention adsorption capability. Stormwater maintenance professionals indicate that the number one issue seen with bioretention facility failures is related to the amount of fines in the soil mix, as the greater fines content that is allowed, the more likely the performance will diminish over time (Scott, pers. comm., 6/11/11). This is in part due to the commonly specified "topsoil," for which there is no gradation specification regarding clay and fines content. These experts believe that the life cycle of filter media can be indefinite if the proper soil mixture specifications are used and regular inspections are performed to control unusual pollutant loads into the facility.

Section 2c. Case Studies from Communities

While the research to document the potential benefits and conflicts caused by trees in bioretention is limited, there is much to be learned from communities that have first-hand experience integrating trees into their facilities. Our research found a handful of communities across the country that are using or are planning to use trees in bioretention and the results are summarized below.

Loudoun County, Virginia

Loudoun County has successfully used trees in bioretention for the last ten years. Currently, they have about 15 bioretentions with trees including at the Loudoun Wastewater Treatment Plant (WWTP), an elementary school, a subdivision, and a church. During this time they learned: 1) that maintenance is a key aspect and mulching about every 2 years was needed; 2) trees are not always acceptable to the landowner, for example one BMP owner was concerned about the potential for tree roots to conflict with pipes and used grass instead of trees; 3) more communication is needed during construction of the bioretention facility construction when trees are included. Loudoun County used many different types of trees and shrubs that work well and specifically like red maples because they are adaptable to the site conditions. Also, the community's reaction has been generally positive, although often the bioretention is viewed simply as a landscape feature.

See Figure 2, Figure 3, and Figure 4 for examples from Loudoun County, Virginia for bioretention areas with trees on the edges and in the middle of the practice. The designs are approved by the Loudoun County Department of Building and Development in accordance with the Facility Standards manual and the Virginia Blue Book.

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Figure 2. Trees planted along the bioretention edge. This site is the Reserve at Belle Terra. Courtesy of Boyd Church in Loudoun County, Virginia.

Figure 3. Trees (River Birch) planted within a bioretention facility. Switchgrass vegetation is also present. Courtesy of Boyd Church in Loudoun County, Virginia.

Figure 4. Trees planted within a bioretention facility. Courtesy of Boyd Church in Loudoun County, Virginia.

- Contact: Boyd M. Church, Senior Public Works Engineer for Loudoun County, VA

Richmond, Virginia: Greening of Virginia's Capital

Many sustainable site design elements will soon be constructed on and around the grounds of the State Capital in Richmond, Virginia. This project aims to implement several innovative LID stormwater management practices in an urban environment that is also highly visible to the public. Several BMPs are proposed and in various stages of design and construction, such as rainwater harvesting, permeable pavement, and bioretention, and once installed, the team will monitor their performance.

Numerous bioretention planters will be installed along Capitol Street, 9th Street and 10th Street and some will include an infiltration gallery under the planter to maximize rainwater capture. Trees will be incorporated into some of the planters. The project team notes a few design modifications for the planters with trees:

- VA DCR's current bioretention specification calls for 48 inches of bioretention soil depth for planters with trees. However, there are concerns about tree stability when placed on a deep bed of loose, highly organic soil. The team addresses this issue by using structural soils under the trees.
- The team incorporated openings in the planter walls (12 inches by 24 inches) where new or existing trees are located beside planter walls. Therefore, tree roots can access soils and moisture in the planters.
- The team incorporated small pipe features to convey stormwater from the planter to the root zone of adjacent trees.
- Future 10th street designs will convey stormwater to existing trees using permeable pavement that directs stormwater runoff to trees via underdrains that convey to RootWell units.

An example is included in Figure 5. More about the street bioretention including photos and videos is available online at: http://sustainable-sites.com/capitolgreenproject.html.

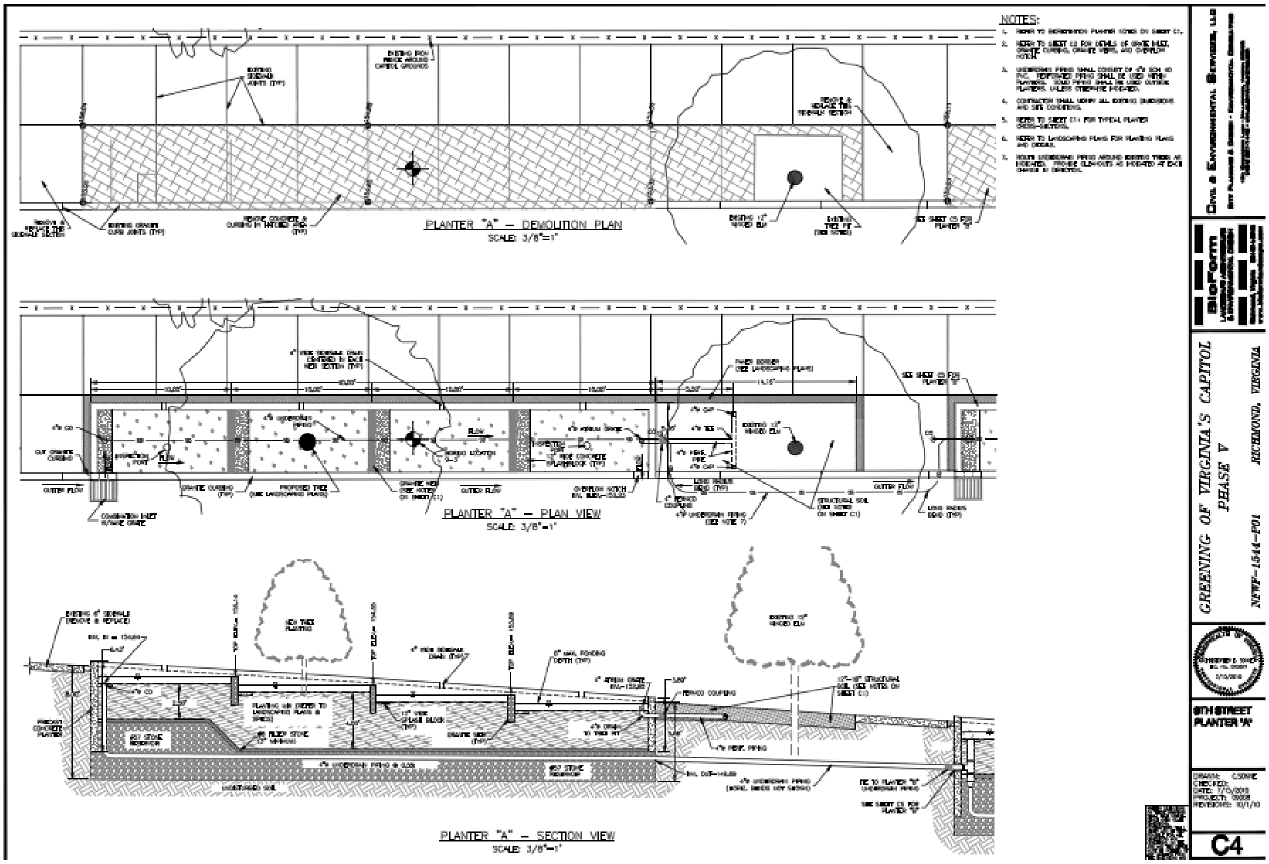

Figure 5. Bioretention proposed on 9th Street that incorporates existing trees adjacent to the practice and proposed trees within the practice.

- Contact: Christopher E. Sonne, PE, LEED AP, Civil & Environmental Services and Chris Hale, Bioform Landscaping

Montgomery County, Maryland

Trees are allowed in bioretention in Montgomery County, Maryland, and the County has about 100 bioretention facilities. Bioretention planting plans are approved by a landscape architect and trees are generally placed around the edges of the bioretention instead of in the middle to keep the underdrain protected. During maintenance visits, volunteer trees have been detected in the middle of the facility and these are generally removed. To date there has been no need to disturb or remove trees planted along the edges of these facilities in order to conduct maintenance.

The County is currently working with the Department of Transportation (DOT) and the Department of Environmental Protection (DEP) to develop a list of trees that will be successful in bioretention. Key tips from Montgomery County's experience are the following: 1) plant trees that are salt tolerant; 2) plant trees that are drought tolerant and water inundation tolerant; 3) use a mix of vegetation types to increase function and survivability; 4) consult a landscape architect to ensure trees are planted as designed; and 5) keep leaf litter from obstructing the inflow and outflow.

- Contact: Christy Ciarametaro, Stormwater Planning Specialist for Montgomery County, MD

Baltimore City, Maryland

Baltimore City incorporates trees into their street bioretention facilities using tree pits or cells that are interconnected to the bioretention hydrology. Each cell is connected to a 7 foot by 7 foot tree planter box that has 3 inches of mulch on top of 18 inches of soil mix on top of 12 inches of #57 stone. The three planter boxes are interconnected by 4 inch perforated PVC underdrain which connects to a downstream stormwater junction box. An example from Watershed 263 for this design is provided in Figure 6 and Figure 7. See Figure 8 for a plan view and cross section of this practice.

Figure 6. Example using trees and bioretention in Baltimore, MD. Source: City of Baltimore.

Figure 7. Curb "bump-out" bioretention with tree pit. Source: City of Baltimore.

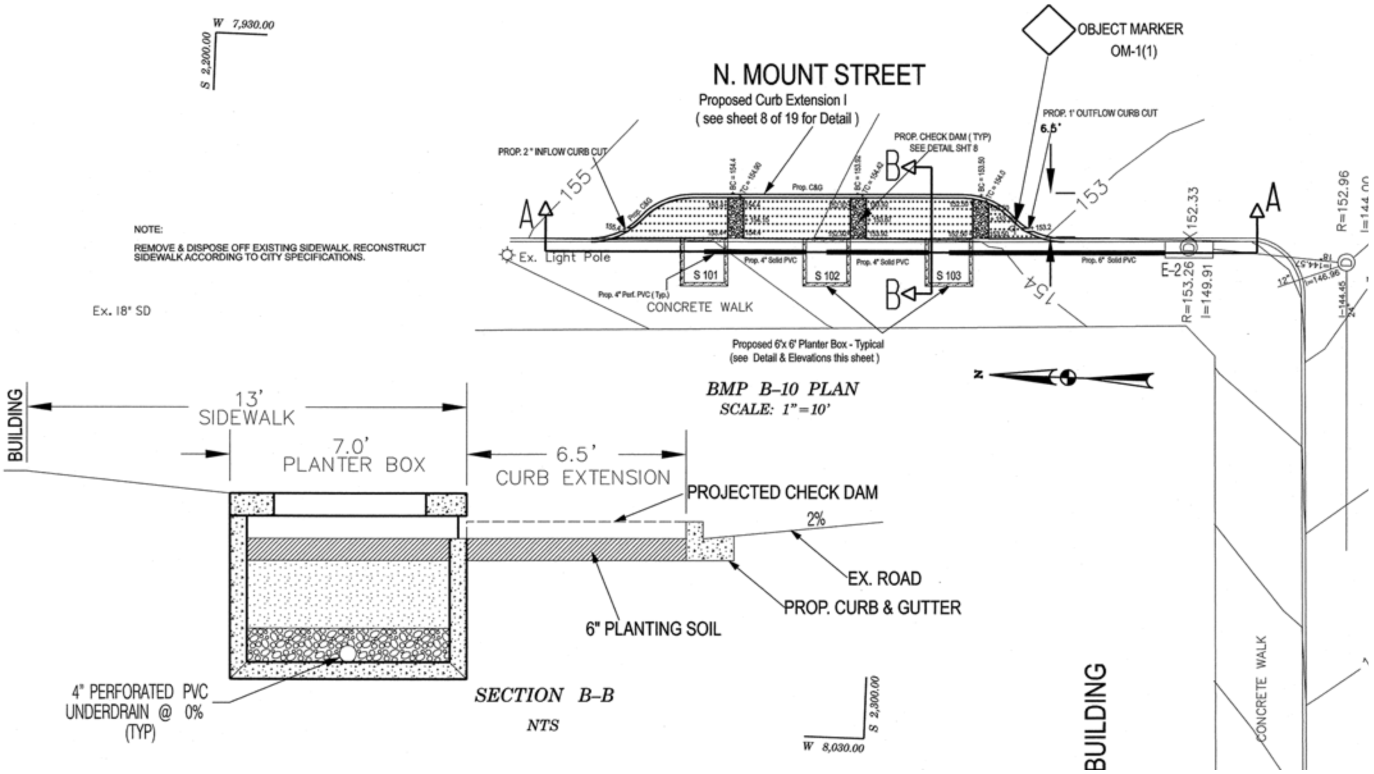

Figure 8. Plan example for curb "bump-out" bioretention with tree pit. City of Baltimore, MD.

- Contact: Kim Burgess, the Chief of Surface Water Management, Baltimore City Department of Public works. More information about this project is available online at: http://www.d2edesign.com/ws263_test2/ws26306.html

Saint Louis, Missouri

Metropolitan St. Louis encourages the local street departments to use bioretention when doing street and sidewalk widening projects. To address the street department's concerns about maintaining these systems, the City is taking a trees and mulch approach. The City will be installing several street and sidewalk bioretentions following the general plan in Figure 9. This design uses an upturned elbow and locates the underdrain at a lower elevation to reduce the chances of tree roots damaging the underdrain system.

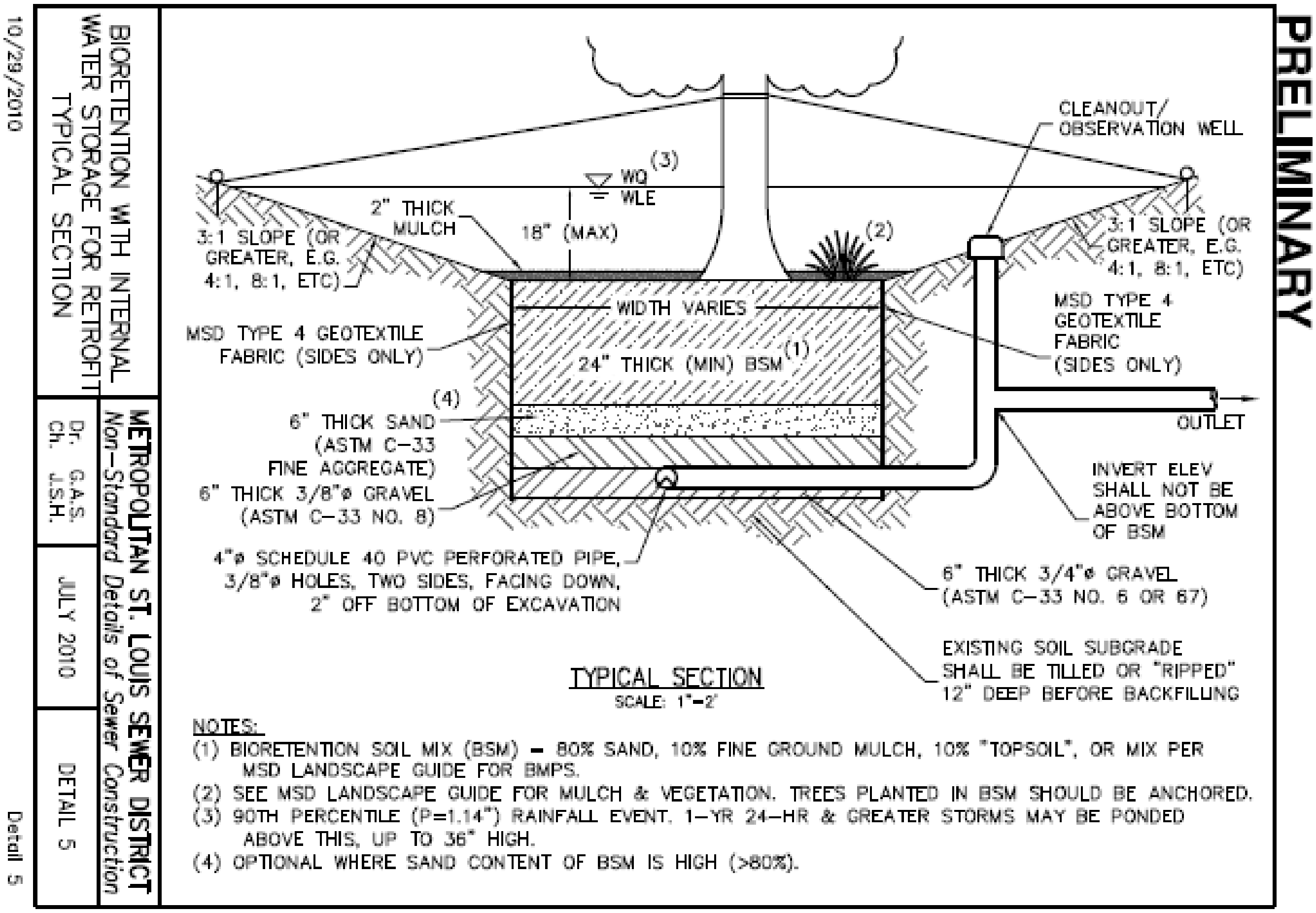

Figure 9. Typical bioretention with internal water storage for retrofit (preliminary). This design uses an upturned elbow to increase the saturated zone and is indicated in the figure at the 90 degree turn from the underdrain to the outlet. Source: St. Louis Sewer District.

- Contact: Jay Hoskins, Metropolitan St. Louis Sewer District

Section 2d. Research Needs

Bioretention practices are a relatively new stormwater BMP and therefore not much research information is available on their longevity and function over longer time periods. In addition, because few communities are incorporating trees in bioretention, there are still many unanswered research questions related to this topic:

- What is the pollutant removal benefit associated with trees in bioretention?
- Which tree species provide the most benefit?
- What is the runoff reduction benefit of trees in bioretention?
- How does the storm event size (i.e., rainfall amount) impact the pollutant removal effectiveness of trees in the bioretention?
- What are transpiration rates for urban trees that overhang impervious cover? These rates will differ greatly from the "in the field" rates that are likely surmised in forested or turf areas (Peters, 2010).
- What are the impacts of climate change on evapotranspiration for urban trees and which tree species should be selected to minimize these impacts (Peters, 2010)?
- Which plant functional types (e.g., high leaf area index, long growing season, canopy, etc.) are exhibited by native plants that can maximize the ecosystem services provided for stormwater management and urban environments (Peters, 2010)?
- What is the lifespan of bioretention filter media?
- Do trees negatively impact the function of the bioretention?

Section 3. Trees in Bioretention Recommendations

Based on the research gathered, case studies, and our professional judgment it is recommended that Arlington County incorporate trees into bioretention facilities where possible, subject to a few specific limitations. Trees are likely to enhance the water quality and water quantity treatment and reduction for urban stormwater runoff when used in bioretention practices. While there are known potential conflicts for using trees in bioretention, one or more resolutions to these concerns have been identified. For additional information see the Urban Tree Resources in Appendix A and the Expert Contacts in Appendix B.

Two design options that address the key concerns with trees in bioretention are presented here in addition to the trees recommended for trees in bioretention. The recommendations presented serve as a guide for Arlington County, Virginia.

Section 3a. Design Options

The following two design options are presented for the highly urban area in Arlington County where the majority of bioretention practices will be in the street right of way. In addition, tree species are recommended for use in bioretention practices and each recommended tree species' attributes are included to better guide tree selection. It is important to incorporate each site's unique characteristics and limitations into the trees in bioretention design, implementation, and maintenance. In addition to these two design options for the bioretention facility itself, trees can be added within the drainage area to the facility or the larger watershed wherever possible.

Option 1: Bioretention with Trees

The first bioretention with trees alternative presented is a bioretention facility that directly incorporates trees. An initial "concept" for this practice was developed by the Center for Watershed Protection and USDA Forest Service during a 2004 design symposium on trees and stormwater management and has been revised to include the research summarized in this memo. Table 3 presents design guidance for planting trees in bioretention that addresses these potential concerns.

Table 3. Design Guidance for Planting Trees in Bioretention.

Potential Conflict	Design Adaptations
Tree roots may puncture underdrains	• Locate the underdrain 4 ft below the bioretention surface (use an upturned elbow if necessary) • Select trees with shallow, fibrous roots (see Table 4)
Tree roots may damage adjacent utilities or sidewalks	• If overhead wires are present, provide a 10 to 15 ft clearance between top of mature tree and overhead wires • <u>Do not</u> use trees in bioretention if the practice is above a sanitary sewer or water main line • Provide sufficient good quality soil for trees to grow (e.g., 2 ft^3 useable soil per 1 ft^2 mature canopy (Urban, 1999)) • Select trees with shallow, fibrous roots (see Table 4) • Consider the use of structural soils underneath adjacent pavement or alternative designs where trees can share rooting space, if installation is done in conjunction with sidewalk replacement • Consider alternative sidewalk materials if installation is done in conjunction with sidewalk replacement • Use root guidance systems to direct roots away from utilities and sidewalks
Tree litter may clog outlets, drainage pipes, or soils	• Increase frequency of routine maintenance to ensure outlets and pipe do not clog o Monthly maintenance recommended • Select trees with smaller leaves or leaves that tend to decompose quickly (e.g., willow oak or river birch) to reduce the potential of clogging from the leaf mat

Table 3. Design Guidance for Planting Trees in Bioretention.

Potential Conflict	Design Adaptations
Trees with excessive fruits, nuts, and other litter may be nuisances, particularly adjacent to impervious surfaces	• Select species that do not produce excessive litter, particularly when planting near impervious surfaces (see Table 4)
Soil and water conditions within the facility are not ideal for tree health	• Select species that are tolerant of bioretention conditions (see Table 4 and list of conditions in Section 2b) • Provide sufficient soil volume for trees (e.g., 2 ft^3 useable soil per 1 ft^2 mature canopy (Urban, 1999)) • Each 1 inch of diameter at breast height (DBH) for a mature tree should have 20 to 25 ft^2 of planting surface area provided in the bioretention area • Tree planting holes in the filter bed should be ≥ 4 ft deep and the holes soil used in the planting hole should be amended with organic matter: 50% sand, 30% topsoil, and 20% acceptable leaf compost (VA DCR, 2010)
Eventual replacement of soil media will require removal of mature trees	• Perform regular inspections of the facility and its drainage area to reduce the potential that replacement is needed due to contamination or unusual pollutant loads • Replace mulch annually • Plant trees only along the bioretention edge when space is available (e.g., schools or parks)
Soil media may not support large trees due to instability	• Where possible, plant large trees on side slopes only • Use structural soils in adjacent areas (e.g., underneath sidewalks) to allow tree roots to expand beyond the bioretention cell and increase stabilization (applicable only if installation is done in conjunction with sidewalk replacement)

Option 2. Bioretention with Adjacent Tree Pits

In sites where proximity to utilities is a concern and space is available, a bioretention practice located in the street right of way can be hydrologically connected to adjacent tree “boxes.” In this design, trees are planted in concrete planter boxes that are physically separated from the bioretention cell but are hydraulically connected using underdrains that run laterally from the bioretention to the trees. The bioretention contains an underdrain that extends the length of the practice and discharges to the existing stormwater infrastructure (e.g., storm drain catch basin). This design option would provide additional surface area for treatment and provide a secondary area for tree roots to grow. This design reduces the potential for impacts to the underdrain and in the event of a complete bioretention rehab the tree could be preserved. The bioretention with adjacent tree pits should be considered when sufficient sidewalk width is available and sidewalk improvements adjacent to the bioretention in the street right of way are possible. Similar designs are currently in use or proposed in Baltimore City, Maryland, and in Richmond, Virginia.

A cross-section and plan view of this design option is shown in Figure 10, from Baltimore, Maryland. Note that in this particular design, a single underdrain runs through the tree boxes. Modifications to this design that are recommended for Arlington County include: 1) including a bioretention soil mix layer and underdrain in the bioretention cell itself below the 6 inch planting soil indicated; 2) connecting the perforated polyvinyl chloride (PVC) underdrain laterally from the street bioretention to the tree pits located in the sidewalk area; and 3) increasing the depth of the underdrain to at least four feet below the bioretention surface (via an upturned elbow if necessary).

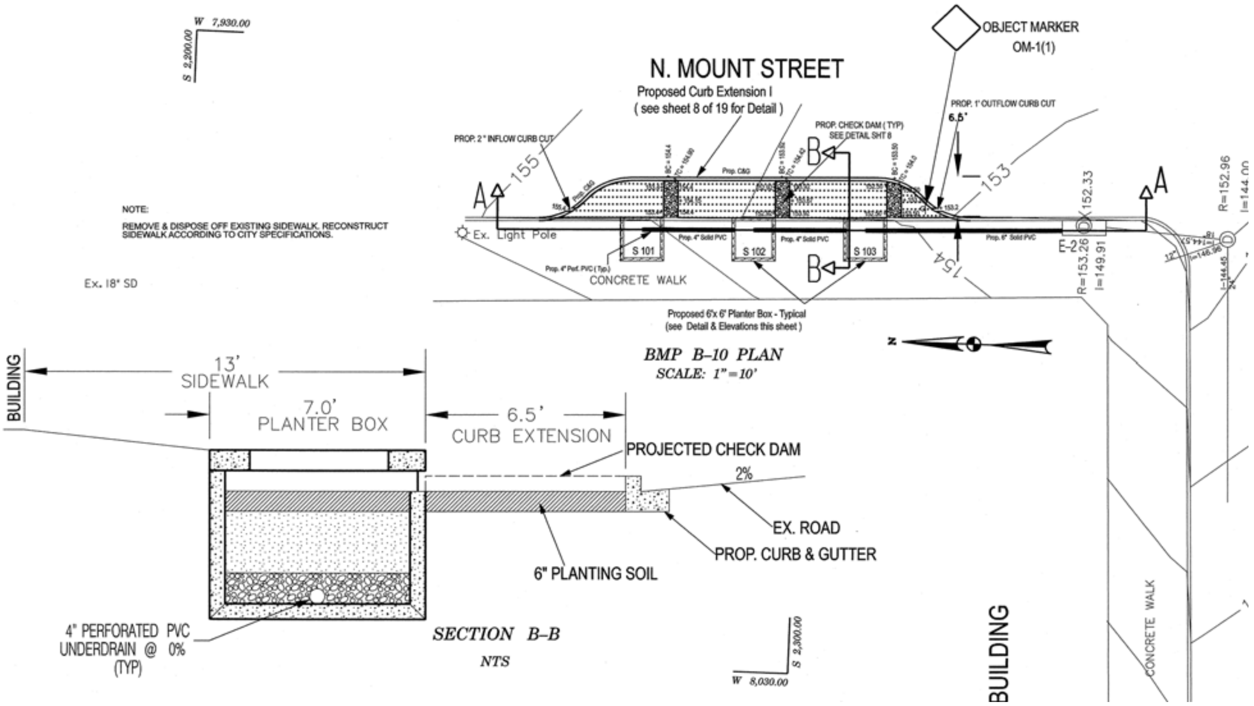

Figure 10. Baltimore, Maryland bioretention “bump-out” in the street right of way with hydrologically connected tree pits. Arlington County’s design should consider an underdrain in the bioretention and lateral underdrains connecting each tree pit to the bioretention. Source: Baltimore City.

Section 3b. Recommended Trees

Table 4 presents a list of species that are recommended for use in the two bioretention design options presented above for Arlington County. This list is not intended to be a substitute for consultation with a landscape architect, field evaluations of specific sites, or employing the best professional judgment to ensure project success. This table was developed in response to the potential conflicts described earlier. The trees in this table include characteristics such as shallow root systems, inundation tolerance, salt tolerance, and quick decomposition of leaves, to increase tree survivability and reduce potential conflicts in the bioretention. The Urban Tree Selection Guide can be used to select additional species based on their tolerance for urban conditions and tree characteristics: http://www.forestsforwatersheds.org/storage/Urban%20Tree%20Selection%20Guide%20with%20instructions.xls

While the species included in Table 4 were selected in part for their low potential to create conflicts with nearby utilities, the actual placement of the tree in relation to the utilities, and the type and character of utilities (e.g., height of overhead wires) are just as important in predicting conflicts at a particular site. Of the species in Table 4, willow oak, bald cypress and eastern white pine have the highest potential for utility conflicts due to susceptibility to ice and snow damage, leaf litter and rooting structure. Selection of appropriate species is only one part of a planting strategy to reduce tree/utility conflicts. Costello and Jones (2003) provides a review of additional methods.

Table 4. Recommended Tree Species for Bioretention in Arlington County, Virginia.

Common Name	Species	Size	Spread	Spacing	Light Conditions	Soil Volume ft^3*	Urban Pollution **	Water Tolerance	Other Benefits	Notes
Red Maple	*Acer rubrum*	L	35 ft	30 ft	Full/Part Sun	800	Very Tolerant	Tolerates periodic flooding; drought	Great fall color	Lots of cultivars
Japanese Zelkova	*Zelkova serrata*	L	30 ft	25 ft	Full Sun	800	Very Tolerant	Drought tolerant	Resembles Elm	Not native
Redbud	*Cercis canadensis*	S	20 ft	15 ft	Full Sun	200	Not Tolerant	Low flooding tolerance	Attractive flowers and foliage	Fast grower, popular landscape tree
Service-berry	*Amelanchier canadensis*	S	10 ft	15 ft	Full/Part Sun	200	Not Tolerant	Low flooding tolerance	Attractive flowers	Ranges from shrub to small tree
Swamp White Oak	*Quercus bicolor*	L	50 ft	35 ft	Full Sun	1000	Very Tolerant	Tolerates prolonged flooding; drought	Transplants well	In wet areas this plant will develop a dual-layered root system, using the upper layer during wet conditions and switching to the lower roots during dried periods.
Pin Oak	*Quercus palustris*	L	30 ft	25 ft	Full Sun	800	Very Tolerant	Tolerates periodic flooding	Fast growing	Very distinct branching angles
Willow Oak	*Quercus phellos*	L	35 ft	30 ft	Full Sun	800	Tolerant	Tolerates prolonged flooding; drought	Small leaves	Important acorn source
Black Gum	*Nyssa sylvatica*	M	25 ft	25 ft	Part Sun	450	Tolerant	Tolerates consistent flooding	Exceptional Fall Color	May be difficult to transplant
River Birch	*Betula nigra*	M	30 ft	20 ft	Full/Part Sun	450	Very Tolerant	Tolerates periodic flooding	Fast growing	Attractive in the winter, multi or single stem

Table 4. Recommended Tree Species for Bioretention in Arlington County, Virginia.

Common Name	Species	Size	Spread	Spacing	Light Conditions	Soil Volume ft^3*	Urban Pollution **	Water Tolerance	Other Benefits	Notes
Bald Cypress	*Taxodium disticum*	L	30 ft	25 ft	Full Sun	1000	Very Tolerant	Tolerates prolonged flooding	Fast growing	Where conditions are constantly wet Cypress with thrive but might produce "knees" that impact sidewalks
Eastern White Pine	*Pinus strobus*	L	40 ft	25 ft	Full/Part Sun	800	Tolerant	Tolerates periodic flooding	No leaf litter	Tolerates a variety of soil conditions
American Holly	*Illex opaca*	M	35 ft	25 ft	Part Sun/Full Shade	800	Tolerant	Drought tolerant	Winter foliage	Wildlife value, slow growing

**Soil volume Requirements based on Urban (1992) where a small tree = 4 inches in diameter at breast height (DBH); medium tree = 8 inch DBH; large tree = ≥ 12 inch DBH.*

***Urban pollution takes into account salt, air quality, soil compaction, and transplant ability.*

Note: There is no clear cut difference between a tree and a shrub; a small sapling could easily be characterized as a shrub despite the fact that ultimately it will become a tree. The most commonly accepted definition of a shrub is a woody plant that consists of several stems growing up from the base and reach an average maximum height of 15 feet; a tree has one main stem with branches growing outward some distance above the base. Trees can be further broken down to small trees (average maximum height of 35 feet) or large trees (average maximum height > 50 feet). The key difference between trees and shrubs is multi-stems versus single stem, yet there can be some exceptions, river birch is clearly a tree but can have multiple stems, serviceberry generally is considered a shrub but can have a single leader and resemble a small tree. For this project, a tree is considered a single stem (generally) woody plant that achieves an average maximum height of 35 feet or greater at maturity.

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Appendix A. Urban Tree Resources

CITYgreen model

American Forest's software conducts GIS based analyses for local ecosystem services based on land cover data. The model outputs tree and green space economic benefit.
http://www.americanforests.org/productsandpubs/citygreen/

City of Portland Standard Plans and Specifications (2010)

Portland has a new 2010 City of Portland Standard Construction Specifications manual which is a revision to the 2007 edition
http://www.portlandonline.com/transportation/index.cfm?c=40032

City of Portland Urban Forestry website

http://www.portlandonline.com/parks/index.cfm?c=38294

Cornell University Department of Horticulture Urban Horticulture Institute

Recommended Urban Trees
http://www.hort.cornell.edu/uhi/outreach/recurbtree/index.html

Trees and Stormwater Symposium, hosted by Bonestroo

Leading practitioners and researchers took part in this day long event that focused on integrating trees with stormwater management. Presentations are posted online.
http://www.bonestroo.com/trees_and_stormwater_symposium/

Urban Tree Growth Symposium Sept 12-13 at Morton Arboretum in Chicago:

http://www.masslaboratory.org/urbantreegrowth.htm

Using Trees to Reduce Stormwater Runoff. This Powerpoint slideshow covers many of the topics presented on this webpage. Click on the link above to view the slideshow or download the Powerpoint file from Slideshare so you can give the presentation yourself.
http://www.slideshare.net/watershedprotection/using-trees-to-reduce-stormwater-runoff-formatted-presentation?type=powerpoint

Virginia Cooperative Extension

Trees for Parking Lots and Paved Areas
http://pubs.ext.vt.edu/430/430-028/430-028.html

Virginia DCR Stormwater

Virginia bioretention stormwater guidance includes tips and good standards of practice
http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_9_BIORETENTION_FinalDraft_v1-8_04132010.htm

Virginia Urban Street Tree Selector

The street tree selector is designed to serve as a resource and forum for street trees. http://dendro.cnre.vt.edu/treeselector/index.cfm

Watershed Forestry Resource Guide

This website is a central clearinghouse for all things related to forests and watersheds. There have been many recent efforts towards managing urban forests for watershed health that have resulted in a variety of highly useful tools and training materials. This site compiles these resources into a format that can be easily accessed and downloaded. http://www.forestsforwatersheds.org/

Appendix B. Expert Contacts

Several of these experts were contacted for this report. Their expertise contributed to the report content and they are resources for trees and bioretention.

Last Name & Suffix	First Name	Organization	Expertise Area	Email	Phone
Cahil	Maria	Green Girl Land Development Solutions	Sustainable Site Specialist	greengirl@greengirlpdx.com	503-334-8634
Church	Boyd M.	Senior Public Works Engineer for Loudoun County, VA	Stormwater Engineer	boyd.church@loudoun.gov	571-258-3204
Ciarametaro	Christy	Stormwater Planning Specialist for Montgomery County, MD	Stormwater Science/Management	christy.ciarametaro@montgomerycountymd.gov	240-777-7720
Day, PhD.	Susan	Assistant Professor Department of Forest Resources and Environmental Conservation and Department of Horticulture for Virginia Tech	Research	sdd@vt.edu	540-231-7264
Foraste, PE	Alex	US EPA	Water Resources Engineer EPA - Nonpoint Source Control Branch	Alex.Foraste@usepa.gov	
Greer, PE	Randy	Engineer VI Sediment & Stormwater Program Div. of Watershed Stewardship	Engineer/Management	Randell.Greer@state.de.us	302-739-9921
Hair, PE	Lisa	US EPA	Engineer	Hair.Lisa@epamail.epa.gov	
Hitchcock, PhD., PE	Daniel	Assistant Professor Belle W. Baruch Institute of Coastal Ecology and Forest Science	Engineer/Researcher	DHITCHC@clemson.edu	843-546-1013 ext 236
MacDonagh	Peter	Kestrel Design Group, Minneapolis, MN	Tree Specialist & Scientist	pmacdonagh@tkdg.net	952-928-9600
McPherson, PhD.	Greg	Urban Ecosystems and Social Dynamics Pacific Southwest Research Station USDA Forest Service	Researcher	gmcpherson@fs.fed.us	530-759-1723
Neprash	Randy	Bonestroo in MN	Engineer (Civil)/Stormwater Regulatory specialist	randy.neprash@bonestroo.com	651-636-4600

Last Name & Suffix	First Name	Organization	Expertise Area	Email	Phone
Peters	Emily	University of Minnesota	Research	pete1679@umn.edu	
Robert Perry	Kevin	Nevue Ngan Association	Landscape Architect	kevin@nevuengan.com	503-239-0600
Rossman	Lew	US EPA	Research	Rossman.Lewis@epamail.epa.gov	
Schueler	Tom	Chesapeake Stormwater Network	Research & Policy	watershedguy@hotmail.com	410-608-7117
Scott, PE (MD), CPESC, MSP, LEED AP	Theodore	Stormwater Maintenance, LLC., Stormwater Consulting, Inc.	Maintenance and Practice	tes@MdSWM.com	410-458-2651
Sonne, PE, LEED AP	Christopher	Civil & Environmental Services, LLC	Engineer	chris@sustainable-sites.com	434-361-1443
Seiler, PhD. (aka Dr. Dendro)	John R.	Department of Forest Resources and Environmental Conservation VA Tech	Researcher	drdendro@vt.edu	540-231-5461
Smiley, PhD.	Tom	Bartlett Tree	Bartlett Tree Research Laboratory, Adjunct. Professor	tsmiley@bartlettlab.com	704-588-1150 ext 123
Snyder	Mark	City of Eugene – Public Works	Urban Forester	Mark.r.snyder@ci.eugene.or.us	541-682-4819
Sonne, PE, LEED AP	Chris	Civil & Environmental Services, LLC	Engineer, LEED, Stormwater	chris@sustainable-sites.com	434-361-1443
Staeheli, ASLA, LEED AP	Peg	SvR Design Company	Landscape Architect	pegs@svrdesign.com	206-223-0326 ext1012