Stormwater, Trees, and the Urban Environment

A Comparative Analysis of Conventional Street Tree Pits and Stormwater Tree Pits for Stormwater Management in Ultra Urban Environments
March 2009

Forward

Many U.S. cities face water-related disasters. Clean water supplies are becoming scarce; flood damage is widespread; water tables are unstable; rivers, lakes, and ponds are polluted; crumbling sewer and drain infrastructure demands repair. Fortunately, a convergence of new technologies and a growing interest in urban revitalization makes it possible to rethink urban water management and apply solutions to make our cities more sustainable.

Charles River Watershed Association (CRWA) has developed a suite of tools and an approach to the urban environment that will help create a new kind of place: a Blue City. Bringing together techniques such as Low Impact Development (LID), Green Building, Green Infrastructure, Green Corridors, and stormwater management, the Blue Cities approach provides a way to solve problems and build a sustainable urban future. Using water as a foundation for planning and design leads to a whole host of benefits: more pleasant streets; integrated public open space; a cleaner, more accessible river; and infrastructure that is flexible and resilient.

An importance piece of Blue Cities design is LID stormwater management. LID stormwater best management practices (BMPs) are systems designed to capture, collect, treat and/or infiltrate stormwater into the ground, prior to, or instead of, discharging it to surface waterways. This is a significant departure from the traditional “grey” stormwater infrastructure, such as drains and pipes which quickly funnel polluted runoff to the nearest surface waterway. By restoring natural hydrologic function to the urban environment, the Blue Cities approach results in cities designed to capture and cleanse water and convey it to rivers, lakes, and harbors gradually, improving human and aquatic ecosystems.

As part of our Blue Cities Initiative, CRWA is actively promoting the use of LID BMPs in our watershed and beyond. The following paper offers a comparison of one stormwater BMP, the stormwater tree pit, with a traditional Boston street tree. CRWA hopes this document will be useful to municipal stormwater officials as well as urban foresters, developers, planners, engineers and conservation agents working in urban and ultra-urban environments. Through our experience working on environmentally sensitive design projects, CRWA has learned that while stormwater control is often the responsibility of a single municipal agency, the use of certain LID stormwater treatment practices can accomplish many goals, reaching well beyond stormwater management; therefore inter-agency coordination can maximize the benefits and possibly help fund installation and maintenance of stormwater BMPs. This analysis is intended as a general reference article, and provides broad conceptual level information. It is ***not*** a design document or how-to manual. Site specific information is critical to the success of stormwater tree planters and officials looking to design and install stormwater tree pits will need to consult other sources for design and installation details.

CRWA considers this to be a working document, which will be revised and updated as new information becomes available. CRWA is open to questions, comments and suggestions on this analysis from anyone with experience in stormwater management and/or urban forestry. CRWA is extremely grateful to the individuals who provided invaluable information and feedback on this document during the initial publication phase, Tom Brady, Paul Iorrio, Bob Pine, John Swallow, and Leif Fixen. Updated versions of this paper and other publications about stormwater best management practices will be made available on our website www.charlesriver.org. Please send questions and/or comments to jwood@crwa.org.

Objective

Restricted availability of public space in urban or ultra-urban environments poses a challenge to alternative stormwater management. Many low impact development (LID) best management practices (BMPs) that are available to slow down, store, treat, and infiltrate stormwater runoff require a footprint larger than what is available on a highly developed site or in an urban public right-of-way. While working to incorporate LID BMPs into the ultra-urban areas of our watershed, CRWA began looking at existing urban "green space" and sought ways to retain its aesthetic and public health amenities while also using it to treat stormwater runoff. In many of the dense neighborhoods of Boston, the only existing green space is street trees. CRWA investigated stormwater tree pits (a.k.a. tree box filters, tree boxes), a small scale bioretetion BMP, which do not take up any more space than an ordinary street tree pit common to most urban environments. This document presents a general comparison of typical street trees and stormwater tree pits based on:

- water quality improvement
- stormwater runoff reduction
- pit design
- tree species
- soils and mulch,
- cost, and maintenance

The systems are discussed in relation to their ability to meet stormwater management goals established by CRWA. This is ***not*** a design document or installation manual. Anyone looking to design and install stormwater tree pits will need to consult other sources to do so.

Conventionally planted urban street trees provide numerous valuable environmental benefits, including lower energy costs, reduced urban heat island effect, improved air quality, wildlife habitat, and beautification of a community which often leads to increased property values. Traditional street trees also have many stormwater benefits; they reduce stormwater runoff and soil erosion through canopy interception, absorption of rainwater, evapotranspiration and increased soil infiltration. It is estimated that Boston's existing tree cover reduces stormwater runoff by 342 million gallons/year.[1] Street trees can also filter out some common stormwater pollutants such as sediment and nutrients. These benefits are unsurprising as trees and other vegetation are nature's filters. Even greater stormwater benefits are possible, however, by using designs that are specially targeted to maximize stormwater absorption and treatment within the tree planting footprint.

Unfortunately, urban environments can often prove hostile to a tree's growth and longevity. In a traditional tree pit, urban street tree growth can be limited by the soils in which they are planted; flooding or poor stormwater drainage; local air quality; surrounding structures such as buildings, utilities lines and sidewalks; and improper or lack of maintenance. Stormwater tree pits need to be designed to help the tree withstand these pressures.

Stormwater tree pits are small scale stormwater treatment systems which are designed to maximize the stormwater benefits of a tree planting and enhance stormwater management overall through the use of design techniques, engineered soils and proper maintenance. Furthermore, certain stormwater tree pits designs are appropriate for locations where a typical street tree may not be incorporated, such as adjacent to a catch basin, resulting in an overall increase in tree cover. The result is greener neighborhoods and healthier waterways.

CRWA's goal is that trees planted in Boston will begin to properly incorporate elements of stormwater tree pit design to effectively improve their stormwater control functions. These designs may result in increased costs over the price of a typical street tree; however, it is important to realize that they are much more than just a typical street tree. Stormwater tree pits improve water quality of local waterways, reduce peak runoff flows, increase groundwater infiltration (if site appropriate), and improve the health of urban trees. These systems meet the dual need of greenery in the urban realm while also being a vital part of a community's stormwater management system. Therefore, stormwater tree pits should *not* be thought of as a direct replacement for traditional street trees; while the above ground aesthetic may be similar, all the work stormwater tree pits are accomplishing below the pavement will lead to a cleaner environment overall!

Stormwater Reduction and Water Quality Improvements

Across the Commonwealth, municipal officials, private property owners, and members of the general public share the responsibility of protecting and enhancing the environment. Improving stormwater management is a critical piece of this effort. In general, common stormwater management goals include:

1. Improve the quality of local surface waterways
2. Minimize flooding and erosion caused by stormwater runoff
3. Reduce volume of stormwater runoff
4. Slow the velocity of stormwater runoff
5. Cool the temperature of stormwater runoff
6. Filter pollutants from stormwater runoff

[1] Lord, Charlie. COMMONWEALTH, Seeing the forest and the trees, Urban greenery can bring better health, more attractive neighborhoods, and even safer streets. Summer 2008.

7. Recharge groundwater
8. Fulfill stormwater management requirements of town/city's NPDES permit/Massachusetts stormwater policy

Traditional street trees provide water quality improvement through filtration and attenuation of stormwater runoff; stormwater tree pits are designed to enhance these capabilities. Certain stormwater tree pit designs can also infiltrate runoff to provide groundwater recharge. Furthermore, some types of stormwater tree pits can be employed as a substitute for traditional stormwater control infrastructure such as catch basins or hydrodynamic separators which can lead to a reduction in overall project costs.[2]

Runoff Reduction

Many studies have attempted to quantify the runoff reduction capabilities of urban street trees. Estimates for the amount of water a typical street tree can intercept in its crown range from 760 gallons/tree/year to 4,000 gallons/tree/year. Interception is rainfall that lands on tree leaves and is stored or evaporated back into the atmosphere and therefore never reaches the ground where it would become stormwater runoff. Interception is affected by intensity and duration of yearly rain events, tree species, tree structure, and local climate.[3]

Stormwater tree pits also reduce runoff through crown interception, but provide increased runoff reduction because they are designed specifically to absorb and treat runoff from surrounding paved areas, not just rainwater that falls directly on the system. Absorption and treatment of runoff is maximized through the use of engineered soils which store water for uptake by the tree and, if possible, drain treated runoff into the ground to recharge groundwater supplies.

Water Quality Improvements

Traditional street trees may collect some stormwater runoff which can be filtered in the soil and taken up and filtered by the tree. Stormwater tree pits are designed to funnel a certain quantity of stormwater runoff to the tree pit system which can be filtered and temporarily stored in the soil and vegetation. Studies indicate stormwater tree pits have high pollution removal rates and have proven to be effective at reducing some of the pollutants of most concern in the Charles River watershed:

Total suspended solids: 85%
Total phosphorus: 74%
Total nitrogen: 68%
Metals: 82%[4]

[2] Cooke, I. (13 January 2009). Neponset River Watershed Association. Personal Communication.
[3] Center for Urban Forest Research. (July 2002). Urban Forest Research.
[4] Low Impact Development Center (LIDC). (2005, November). Tree Box Filters. Low Impact Development for Big Box Retailers. Available at: http://www.lowimpactdevelopment.org/bigbox/lid%20articles/bigbox_final_doc.pdf.

Design

Stormwater management goals as well as public realm improvement goals can be address through design:

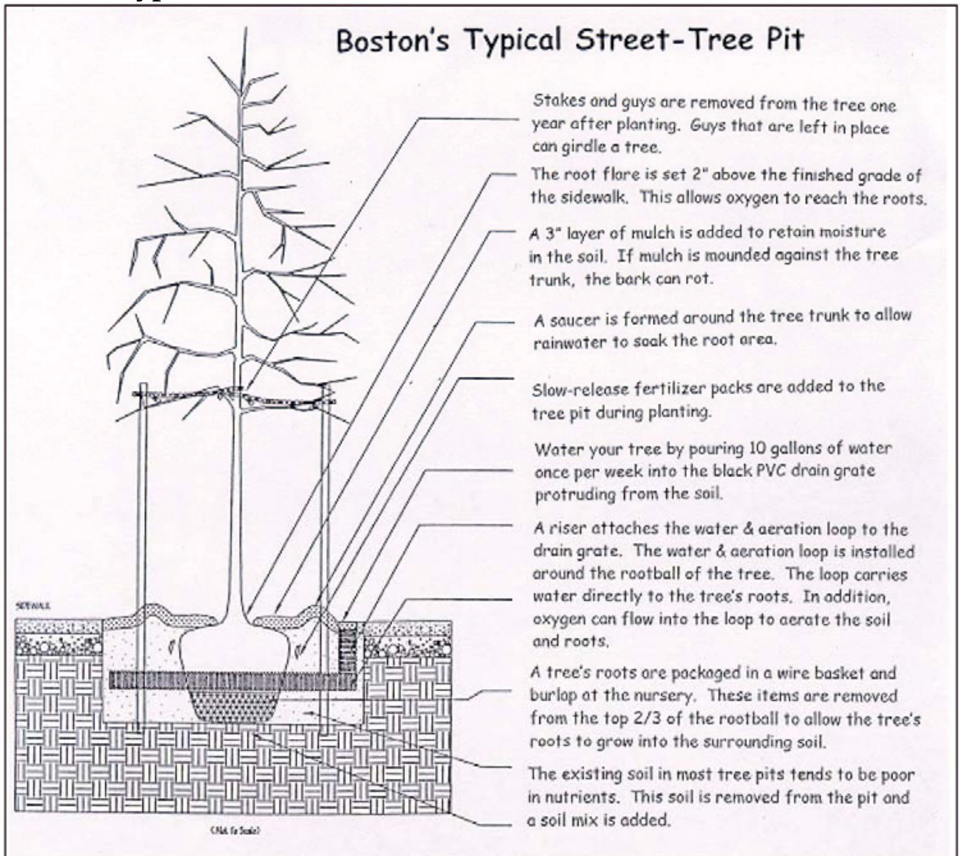
1. Collect stormwater runoff to undergo filtration by the tree and soil media
2. Provide cost-effective stormwater treatment in a public right-of-way or area with limited space
3. Maximize health and life expectancy of street trees
4. Minimize the possibility of sidewalk heaving by tree roots
5. Improve the aesthetic and environmental conditions of the public realm

Presently, trees planted in the public realm in Boston follow the City's tree planting design requirements (Figure 1).

As discussed above, traditional street trees reduce stormwater runoff and soil erosion through canopy interception, absorption of rainwater, evapotranspiration, and increased soil infiltration. Additionally, street trees may also filter out some common stormwater pollutants such as sediment and nutrients. Aspects of traditional tree pit designs can often unintentionally prove hostile to a tree's health. Urban soils are often severely compacted by the traffic loads they withstand. When soils become compacted, pore space is eliminated, leaning no space for water and oxygen to percolate into the soil and making root penetration and expansion difficult or impossible. [5] If compacted soils prevent water from reaching a tree's roots or from properly draining, the consequences for a tree can be fatal. Furthermore, urban soils often have elevated pH levels which are unsuitable for tree growth.[6] Unhealthy trees will ultimately do little to manage stormwater and can be a drain on municipal resources.

[5] Kirwan, J., Kane, B. (July 2005). Urban Forestry Issues. Publication Number 420-180. Virginia Cooperative Extension. Available at: http://www.ext.vt.edu/pubs/forestry/420-180/420-180.html.
[6] Day, S.D. and S.B. Dickinson (eds.) (2008). Managing Stormwater for Urban Sustainability Using Trees and Structural Soils.

Figure 1: Boston's Typical Street-Tree Pit



City of Boston, Boston, MA
http://www.cityofboston.gov/parks/streettrees/pdfs/streettree_pit.pdf Accessed: June 16, 2008

Stormwater tree pits are specially designed to improve upon both the runoff reduction and pollutant removal capabilities of regular tree pits, while not requiring any more space. Many designs also provide solutions for common urban tree health issues, leading to healthier, longer living trees. Additionally certain stormwater tree pit designs allow trees to be planted in places traditional tree pits may not be appropriate, resulting in an overall increase in tree cover.[7]

Stormwater tree systems are designed to collect, filter, and, if appropriate, store and/or infiltrate stormwater runoff. The major design variations between traditional tree pits and stormwater tree pits include:

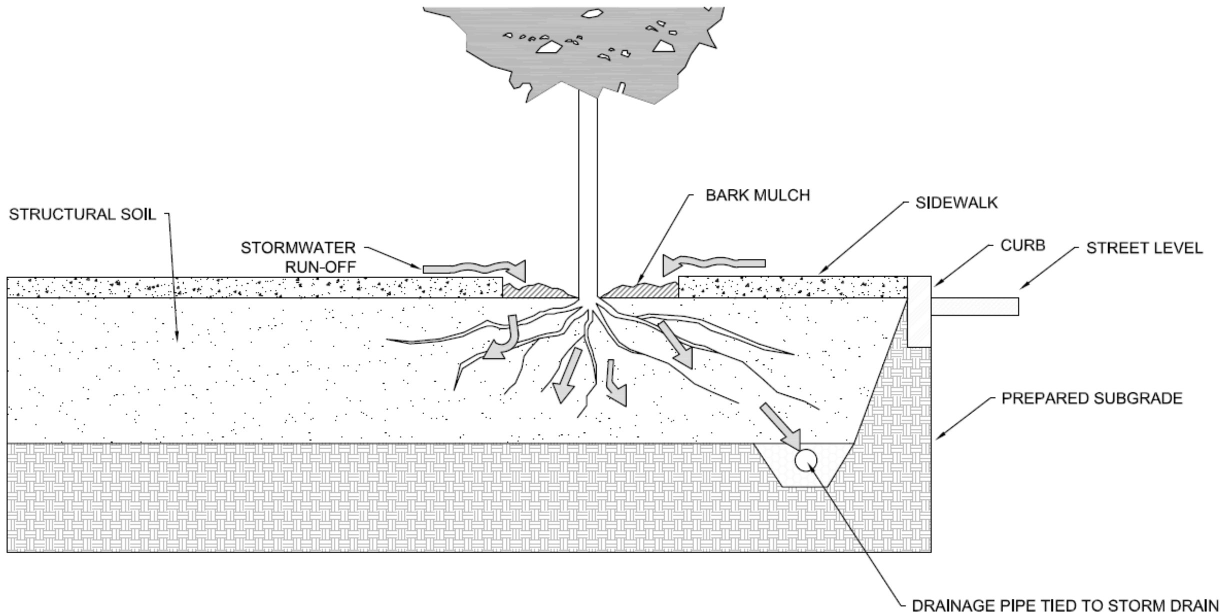
- specially designed soils that can accommodate inflow of runoff and tree root expansion;
- mechanism for funneling stormwater runoff to the tree; and
- design for storage and treatment of a specific volume of water, with overflow (through a drainage system) for excess volume.

Stormwater tree pits are available in a variety of designs. Figures 2 through 5 display some common designs which are in use today. Table 1 summarizes the elements in each design which

[7] Tree Box Filters. Low Impact Development (LID) (2007). Urban Design Tools Website. http://www.lid-stormwater.net/treeboxfilter_home.htm.

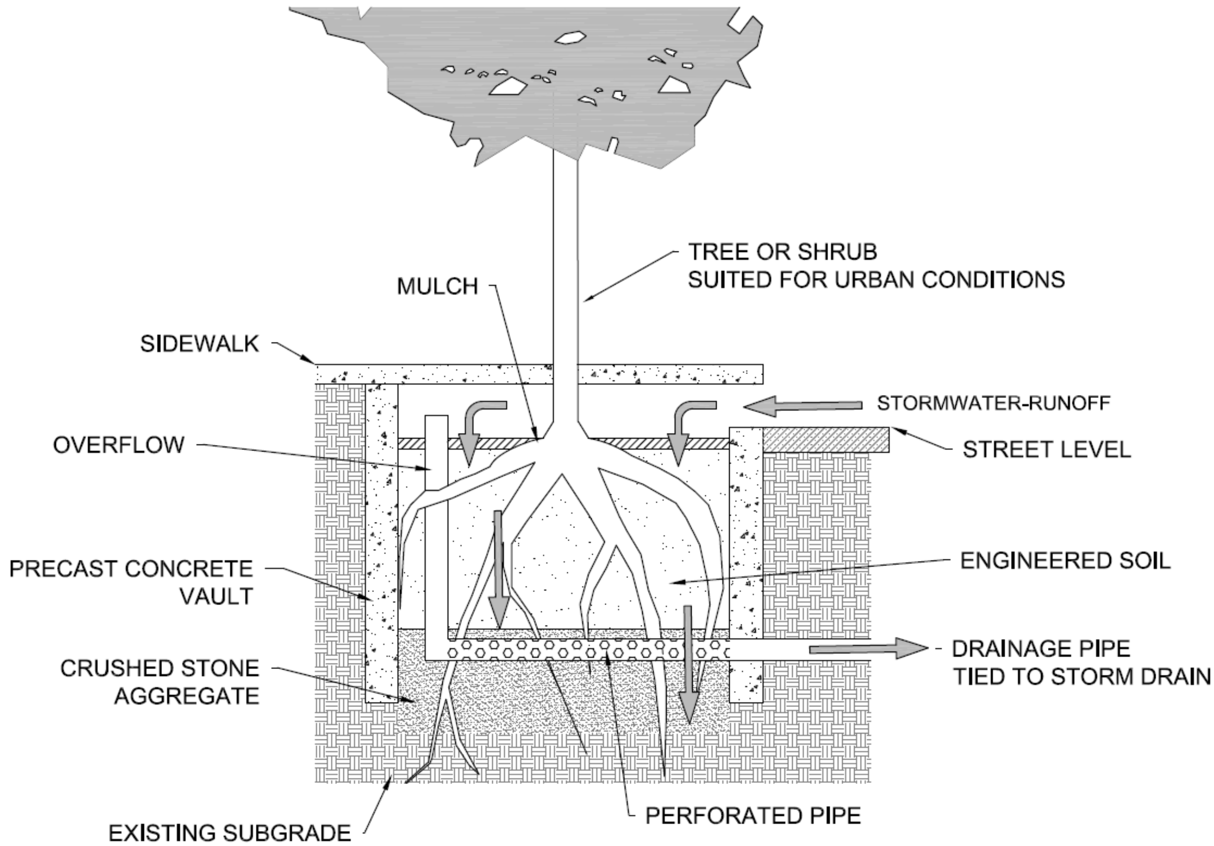
are intended to enhance a street tree's ability to perform its natural runoff reduction and filtration functions as well as some of the drawbacks to of each design's stormwater function.

Figure 2: Open Design with Extended Use of Structural Soils



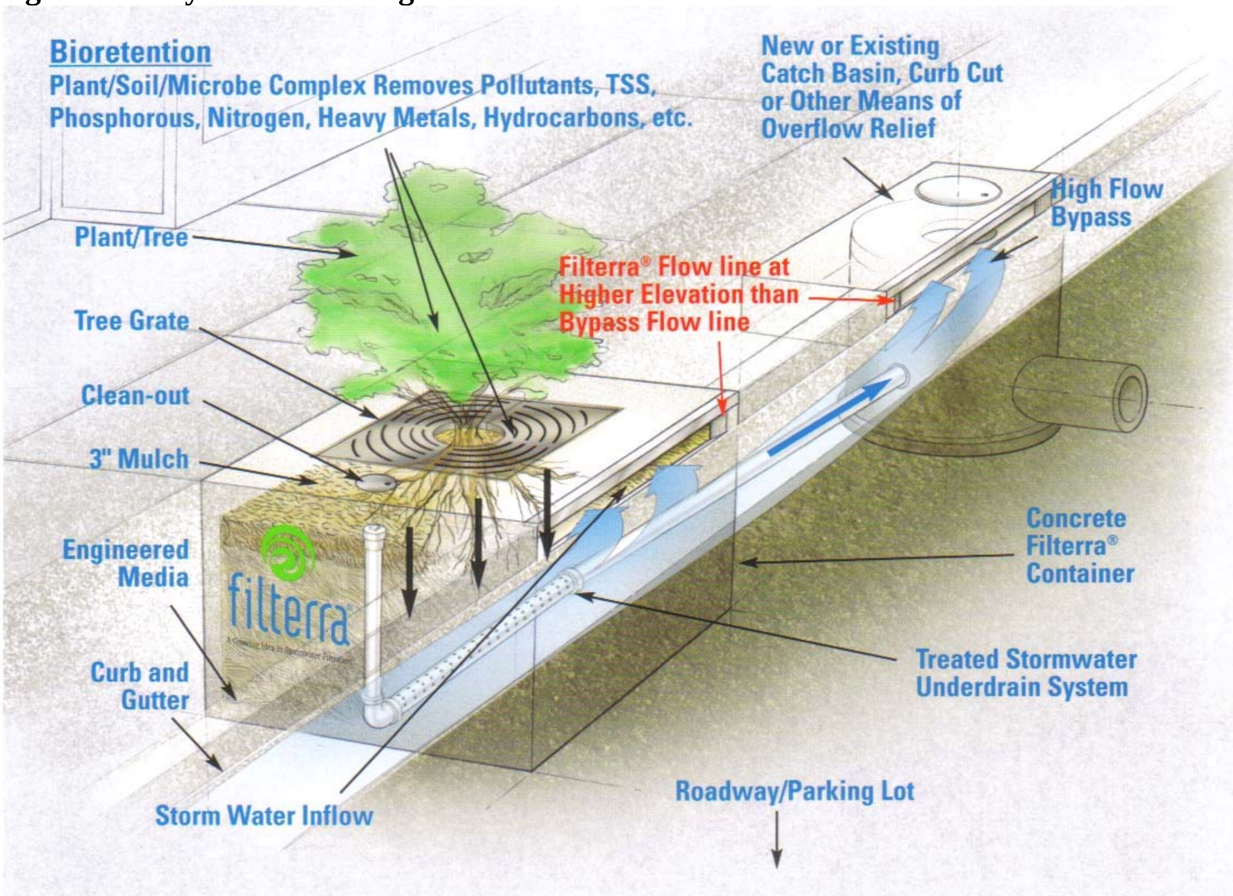
Source: Modified from information and images found in Bassuk, N., Grabosky, J., and Trowbridge, P. Urban Horticulture Institute. (2005). Using CU-Structural Soil™ in the Urban Environment. http://www.hort.cornell.edu/UHI/outreach/pdfs/custructuralsoilwebpdf.pdf

Figure 3: Partially Contained Open Bottom Design



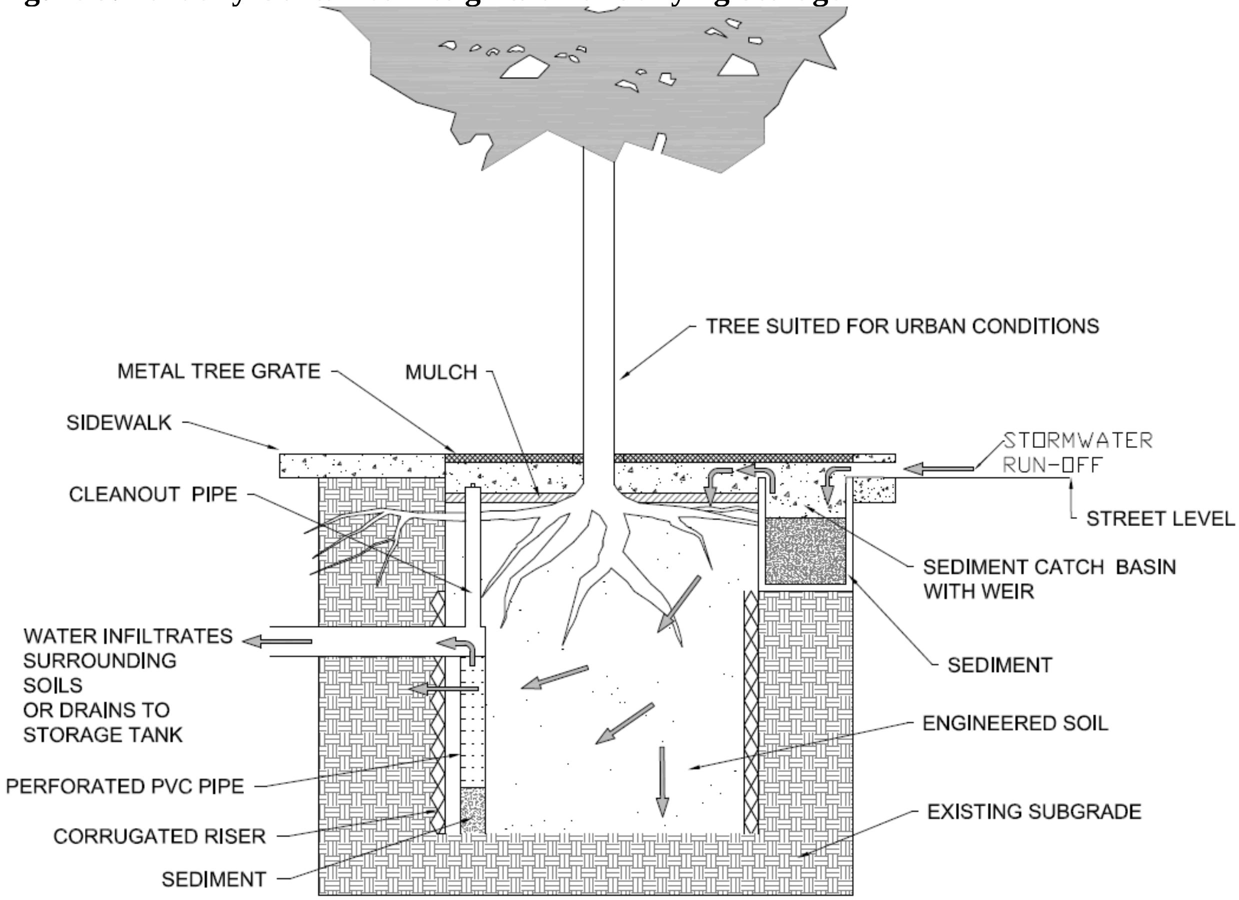
Adapted from:
Low Impact Development Technologies for Stormwater Management/UNH Stormwater Center
http://www.unh.edu/erg/cstev/Presentations/index.htm

Figure 4: Fully Enclosed Design



Source: Filterra© Stormwater Bioretention Filtration System Brochure

Figure 5: Partially Contained Design with Underlying Storage



Source: Modified from information and images proved by Paul Iorrio

Table 1: Design Elements of Four Stormwater Tree Pits Intended to Promote a Tree's Natural Filtration Functions and Potential Drawbacks/Limitations to the Design's Stormwater Function

Design	Benefits	Drawbacks
Open Design with Extended Use of Structural Soils (Figure 2)	• Structural soils are designed to meet all street-level load-bearing requirements *without* compacting soil, therefore tree root expansion is not prohibited as it can be in typical soils[8] • Allows roots to penetrate and extend throughout the subsurface layer, reducing pavement damage by tree roots[9] • Allows for adequate aeration and drainage, and provides necessary soil content to promote tree growth and health[10] • Improves tree life expectancy from 7-10 years on average to as much as 50 years[11] • Healthier, longer living trees provide increased stormwater benefits due to larger canopies and increased evaporation • Engineered soil mix and trees provide biological, physical and chemical water treatment through pollutant uptake by vegetation and soil microorganisms, sedimentation and sorption with organic matter • Structural soil has high porosity allowing for increased infiltration into the soil subgrade compared to conventional, loamy, compacted soils[12] • Some current systems successfully incorporate the use of porous pavement, increasing overall runoff volume reduction and treatment • Currently being used in Boston and Cambridge, therefore likely to have a high level of public acceptability[13]	• Engineered structural soils, both proprietary and non-proprietary, can be very variable and require extensive oversight to ensure that they are to spec and installed correctly[14] • Stormwater infiltration will not be appropriate at all sites • System can fail without proper maintenance

[8] Bassuk, N., Grabosky, J., Trowbridge, P. and Urban, J. Urban Horticulture Institute. Structural Soil: An Innovative Medium Under Pavement that Improves Street Tree Vigor.
[9]Bassuk, N., Grabosky, J., and Trowbridge, P. Using CU-Structural Soil™ in the Urban Environment. Available at: http://www.hort.cornell.edu/uhi/outreach/pdfs/custructuralsoilwebpdf.pdf
[10]Bassuk, N., Grabosky, J., and Trowbridge, P. Using CU-Structural Soil™ in the Urban Environment. Available at: http://www.hort.cornell.edu/uhi/outreach/pdfs/custructuralsoilwebpdf.pdf

Design	Benefits	Drawbacks
Partially Contained Open Bottom Design (Figure 3)	• Incorporates mechanisms which direct a design amount of stormwater runoff to the system for treatment and infiltration[15] • Engineered bioretention soil mix maximizes permeability for increased water infiltration while providing required organic material to support tree growth • Engineered bioretention mix and tree provide biological, physical and chemical water treatment through pollutant uptake by vegetation and soil microorganisms, sedimentation and sorption with organic matter[16] • Reduces peak runoff flows[17] • Open bottom allows for increased infiltration into the ground, providing some recharge benefits[18] • May be incorporated as a direct replacement for a stormwater catch basin[19]	• Planting vault limits root expansion, precluding the use of large trees which provide the most effective canopy interception • Trees species selection will be limited by: o Width of tree pit vault which limits horizontal tree root expansion o Salt-tolerance (in communities where salt is used for snow and ice removal) o Aggressive root growth (plants with very aggressive root growth could clog drainage structures)[20] • Stormwater infiltration will not be appropriate at all sites • System can fail without proper maintenance
Fully Enclosed Design (Figure 4)	• Incorporates mechanisms which direct a design amount of stormwater runoff to the system for treatment • Engineered bioretention soil mix and tree provide biological, physical and chemical water treatment through	• Planting vault limits root expansion, precluding the use of large trees which provide the most effective canopy interception

[11] Bassuk, N., Grabosky, J., Trowbridge, P. and Urban, J. Urban Horticulture Institute. Structural Soil: An Innovative Medium Under Pavement that Improves Street Tree Vigor
[12] Bassuk, N. CU-Structural Soil: An Updated after More than a Decade of Use in the Urban Environment.
[13] Brian Kalter. (November 20, 2008). Personal Communication.
[14] Pine, B. (2008). Pine and Swallow Environmental. Personal Communication.
[15] University of New Hampshire Stormwater Center. (UNHSC) (2007). Annual Report. Available at: http://www.unh.edu/erg/cstev/pubs_specs_info.htm#pubs.
[16] UNHSC 2007 Annual report
[17] UNHSC 2007 Annual report
[18] UNHSC 2007 Annual report
[19] UNHSC 2007 Annual report
[20] UNHSC 2007 Annual report

Design	Benefits	Drawbacks
	pollutant uptake by vegetation and soil microorganisms, sedimentation and sorption with organic matter[21] • Enclosed casing allows system to be installed in places where typical street trees are not appropriate, however system depicted above must be sited in conjunction with a catch basin (Figure 3) • Design has been tested and proven effective in a variety of settings[22]	• Trees species selection will be limited by: o Depth and width of tree pit vault which limits vertical and horizontal tree root expansion o Salt-tolerance (in communities where salt is used for snow and ice removal) o Aggressive root growth (plants with very aggressive root growth could clog drainage structures)[23] • System can fail without proper maintenance • Does not allow for groundwater infiltration • Must be situated near an existing catch basin
Partially Contained Design with Underlying Storage (Figure 5)	• Incorporates mechanisms which direct a design amount of stormwater runoff to the system for treatment and infiltration • Incorporate small pre-treatment sediment catch basin to filter particulate pollution • Engineered bioretention soil mix, tree and mulch provide biological, physical and chemical water treatment through pollutant uptake by vegetation and soil microorganisms, sedimentation and sorption with organic matter[24] • Storage area surrounding and below tree planting vault holds water as it infiltrates into the ground	• Trees species selection will be limited by: o Planting vault (vault allows for considerable vertical and horizontal expansion but certain species may not be appropriate) o Salt-tolerance (in communities where salt is used for snow and ice removal) o Aggressive root growth (plants with very aggressive root growth could clog drainage structures)[25] • System can fail without proper maintenance • Stormwater infiltration will not be appropriate at all sites

[21] Coffman, L. and Siviter, T. White Paper. Filterra® by Americast. An Advanced Sustainable Stormwater Treatment System. http://www.filterra.com//pdf/FilterraWhitePaper-07.pdf.
[22] Coffman, L. and Siviter, T. White Paper. Filterra® by Americast. An Advanced Sustainable Stormwater Treatment System. http://www.filterra.com//pdf/FilterraWhitePaper-07.pdf.
[23] UNHSC 2007 Annual report
[24] Iorrio. P. (2008). Personal Communication.
[25] UNHSC 2007 Annual report

Tree Selection

Tree species selection is an import element of urban forestry and a critical element for stormwater tree pits. Trees intended to perform stormwater control functions should be selected with these goals in mind:

1. Utilize tree species that have desirable stormwater control characteristics
2. For trees receiving runoff, utilize species that have a high tolerance for common urban pollutants (in cold climates salt tolerance will be particularly important)

Certain characteristics make particular tree species more effective at reducing stormwater runoff and filtering pollutants. Trees that are well suited for stormwater management typically have many of the following characteristics:

- Foliage patterns (deciduous or evergreen) that match local precipitation patterns[26]
- Wide-spreading and dense canopies
- Long-life expectancies
- Fast growing rates
- High tolerance to summer drought
- Tolerant of saturated soils
- Resistant to air and water pollutants common in urban environments
- Extensive root systems
- Rough bark
- Tomentose or dull foliage surface
- Vertical branching structure[27]

The Boston Parks Department has a list of forty-nine tree species which are approved for use as street trees; of these forty-nine species, ten are also recommended for their stormwater benefits in Metro Portland's "Trees for Green Streets: An Illustrated Guide". These matches are summarized in Table 2.[28] .

Table 2: Tree Species Approved by Boston Parks Department and Recommended for Use on "Green Streets"[29]

Latin Name	**Common Name**
Native Species	
Acer rubrum 'autumn spire'	Red maple
Quercus rubra	Red oak
Quercus bicolor	Swamp white oak
Celtis occidentalis	Hackberry
Non-Native Species	
Koelreuteria paniculata	Goldenraintree (non-native)
Liquidamber styraciflua	Sweetgum (native to North America, non-

[26] Center for Urban Forest Research. (July 2002). Urban Forest Research.
[27] Trees for Green Streets. (June 2002). Metro. Portland.
[28] Trees for Green Streets. (June 2002). Metro. Portland.
[29] The complete list of forty-nine trees was not evaluated independently based on the criteria listed above, however, so additional tree species from the approved planting list may also have some stormwater-friendly characteristics

	native to Massachusetts)
Platanus x. acerifolia 'Bloodgood'	London plan (non-native)
Quercus macrocarpa	Bur oak (native to North America, non-native to Massachusetts)
Gingko biloba (male)	Gingko (non-native)
Ulmus var. 'Accolade'	Accolade elm (hybrid species)

Soils and Mulch

Soils and mulch play a significant role in pollutant removal and tree health. Selection of soils and mulch intended to improve stormwater controls should be selected with these goals in mind:

1. Employ soils which allow water to infiltrate into the soil, be stored temporarily for use by vegetation, be filtered by soil microbes, and ultimately drain well
2. Employ soils with content that meets the needs of a healthy tree
3. Employ a soil volume that meets the needs of a health tree
4. Use mulch as an added filtration mechanism

Many factors influence a soil's ability to promote stormwater runoff filtration and reduction and promote healthy tree growth. Soils well suited for bioretention have many of the following characteristics:

- Soil make-up: appropriate to support tree species or vegetation at site, adequate organic content
- Soil compaction: minimum to none
- Soil porosity: Adequate for storage of water and oxygen to support healthy tree growth
- Soil permeability: Allow for water infiltration and proper drainage to underlying substrate or drainage system
- Soil volume: adequate to support tree species or vegetation at site

Typical urban soils can have negative impacts on stormwater management when they become compacted and/or have a low organic content. Soils under well traveled roads and sidewalk can easily become compacted. Compacted soils have minimal capacity to infiltrate stormwater and recharge groundwater and often act similar to impervious surfaces. As rainwater runs off these impermeable soils it erodes sediment and picks up pollutants which are carried to local waterways. Additionally, soils with minimal capacity to store water and with reduced organic matter do not have the necessary elements to support healthy vegetation, requiring increased maintenance of existing vegetation, such as supplemental watering and fertilization. Increasing soil porosity and organic content and controlling soil acidity can improve the stormwater management capabilities of a vegetated area.[30]

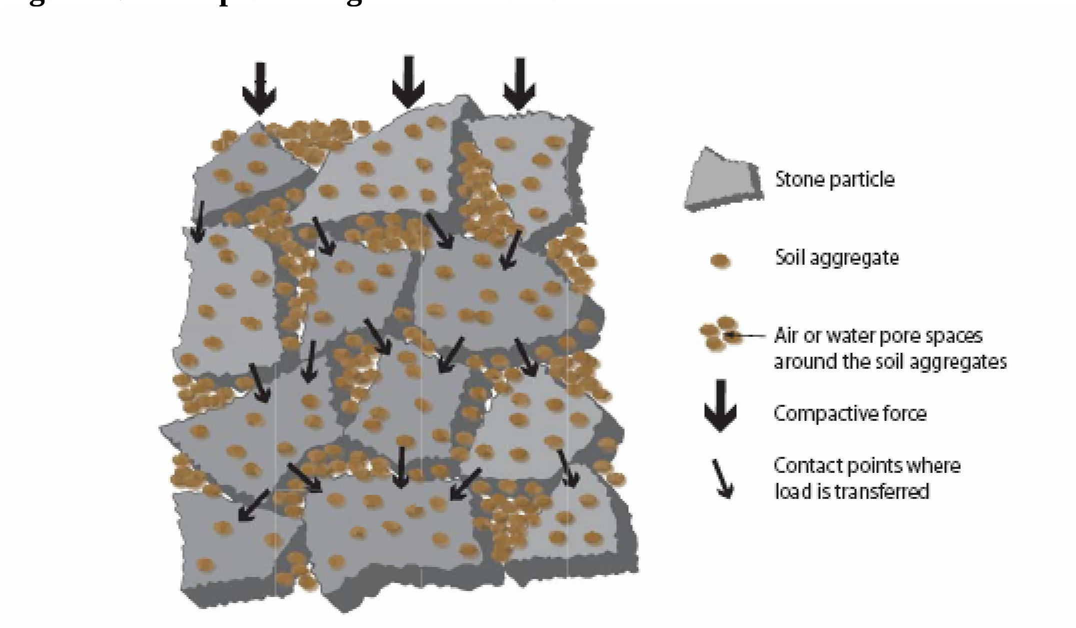
Bioretention facilities, such as stormwater tree pits, employ specially engineered soils and mulch as key elements of their stormwater control function. The New Jersey Stormwater Best Management Practices Manual describes some of the roles soil plays in stormwater reduction and filtration: "The planting soil bed provides the environments for water and nutrients to be

[30] Soil Amendments. Low Impact Development (LID) (2007). Urban Design Tools Website. http://www.lid-stormwater.net/soilamend_home.htm.

made available to the vegetation. The soil particles can adsorb some additional pollutants through cation exchange, and voids within the soil particles can store a portion of the stormwater quality design storm runoff volume."[31]

Structural soils (Figure 2) are a type of engineered soil which are designed to meet the load bearing requirements of most urban streets and properties while maintaining adequate porosity to allow for tree root expansion, water and oxygen storage (porosity), and proper soil drainage (permeability). By allowing for adequate root expansion, structural soils can also reduce root penetration and subsequent heaving of sidewalks and other paved areas. Structural soils employ uniform grade stone or other "structural" particles to meet load bearing requirements and maintain pore space. Pore spaces are filled with uncompacted, high quality soil which roots are able to penetrate easily (Figure 6).

Figure 6: Conceptual Diagram of Structural Soils



Source: Sarah Dickinson, adapted from Nina Bassuk. Day, S.D. and S.B. Dickinson (eds.) (2008). Managing Stormwater for Urban Sustainability Using Trees and Structural Soils.

A note of caution: a mix of stone particles and soil does not make a structural soil. Structural soils and all specially engineered soils require extensive testing prior to their use to ensure that drainage, water storage, and load bearing capacities are adequate for a particular site.[32] A soil mix that functions well at one site may fail miserable at another as many factors contribute to the success of tree plantings, therefore a thorough analysis of existing site conditions is essential.[33]

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[31] NJDEP. Chapter 9.1: Standards for Bioretention Systems. (February 2004). New Jersey Stormwater Best Management Practices Manual. Available at: http://rwqp.rutgers.edu/univ/nj/Stormwater%20Management%20Education%20Program/feb2004chap9_1.pdf.
[32] Day, S.D. and S.B. Dickinson (eds.) (2008). Managing Stormwater for Urban Sustainability Using Trees and Structural Soils.
[33] Pine, B. (2009) Pine and Swallow Environmental. Personal Communication.

While acknowledging the need for thorough site analysis, many stormwater manuals attempt to provide some guidance on the make up on engineered soils.

In addition to soil type or make-up, the volume of soil available for the tree to expand into is a very important factor affecting tree growth. Necessary soil volumes will need to be determined on a site by site basis, when inequity volume is supplied trees can suffer severely.[34]

Incorporating mulch can provide additional treatment. In Boston's current tree pit design a 3" layer of mulch is employed to retain moisture in the underlying soil. Mulch is applied in a ring around the trunk of the tree leaving a gap to prevent the trunk from rotting. Mulch is currently used in bioretention systems to control erosion and maintain the infiltration capacity of the underlying soils.

Cost and Maintenance

Conventional and stormwater tree pits both require some maintenance, maintenance is essential for stormwater tree pits systems as they function as both a street tree and a stormwater best management practice. The following stormwater management goals can help guide stormwater tree pit use:

1. Provide truly cost-effective stormwater management by evaluating all secondary costs and benefits
2. Select stormwater management practices that can be effectively maintained using existing resources or with realistic capacity enhancements
3. Provide adequate maintenance to maintain functionality and effectiveness of all stormwater treatment practices employed

Cost

Currently, purchase and installation costs for stormwater tree pits exceed those for typical street trees by nearly an order of magnitude.[35,36] However, direct comparison of purchase and installation costs of these systems with installation costs of traditional street trees undervalues the vast increase in benefits achieved through the use of stormwater tree pits. Stormwater tree pits serve a dual function as stormwater management practices and landscaping features, additionally these systems can result in the direct reduction of stormwater infrastructure costs, reducing overall project costs. Finally, direct cost comparisons do not take into consideration the improvements in downstream water quality likely to be achieved through the use of stormwater tree pits or secondary benefits such as decreased pressure and wear on existing stormwater infrastructure.

Maintenance

Stormwater tree pits and traditional street trees both require regular maintenance. Table 4 summarizes maintenance requirements/suggestions for stormwater tree pits with current maintenance practices in the City of Boston. Some proprietary stormwater tree pit systems include upkeep and maintenance agreements for the first few years the system is operational. As with installation costs, maintenance costs may not look comparable at first sight, however, when

[34] Swallow, J. (2009). Pine and Swallow Environmental. Personal Communication.
[35] Cooke, I. (2007). Neponset River Watershed Association. Personal Communication.
[36] Fixen, L. (2008). Boston Parks and Recreation. Personal Communication

secondary benefits such as potential decrease in maintenance of traditional stormwater infrastructure, the true cost becomes more evident.

Table 4: Comparison of Maintenance for Stormwater Tree Pits and Traditional Street Trees

Task	Traditional Boston Street Tree	Stormwater Tree Pit
Watering	15 gallons (30 gallons during dry spells) weekly for the first two years of the tree's life[37]	Only requires watering during periods of extreme drought
Mulch	Added as needed during the first two years of the tree's life; additional mulching after the first two years is done by local residents on an ad hoc basis.[38]	Replace once or twice annually
Removal of trash and debris	Currently done by neighborhood residents periodically and on a voluntary basis, otherwise trash is not removed	Remove as needed, preferably at least seasonally and after severe storm events
Inlet/outlet pipes and/or aeration loops	No current maintenance, weekly watering keeps the loops functional for the first two years of the tree's life, beyond that loops are not maintained.[39]	Inspect regularly and clean out to prevent clogging
Tree	Replace as needed	Inspect regularly and replace as needed

[37] Fixen, L. (2008). Boston Parks and Recreation. Personal Communication
[38] Fixen, L. (2008). Boston Parks and Recreation. Personal Communication
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Limitations and Considerations
Certain site or agency capacity constraints may cause additional concerns and constraints in efforts to transition existing tree pits into stormwater management facilities:

- It is not appropriate to direct stormwater runoff to a traditional tree pit and expect to obtain the benefits of a stormwater tree pit. On the contrary this could be fatal to the existing street tree. Stormwater tree pits are specially designed systems which provide for adequate drainage to prevent soil saturation through the use of overflow and drainage structures and employ specially engineered soil mixes which allow for water filtration and runoff reduction.

- Engineered structural soils, both proprietary and non-proprietary, can be very variable and require extensive oversight to ensure that they are to spec and installed correctly.[40] Additionally, proprietary soils can be somewhat expensive, therefore non-proprietary designs may be a preferred alternative.

- Inlet and outlet pipes can get destroyed or clogged after a year or two of use, therefore proper maintenance is essential to maintaining the functionality of the system.

- The location of pits with underground structures may cause problems with utilities under sidewalks. With natural trees, they can often grow around utilities as the roots at depth are not typically the support roots and therefore are smaller.

- For pit designs with the soil grade below the sidewalk level, trash and other debris will collect in the "headspace" between the surrounding sidewalk and the soil. While this will require additional maintenance, it is a good thing! Trash that would otherwise flow into catch basins and ultimately end up in our surface waterways is now captured by the stormwater tree pit where it can be removed and disposed of properly.

- Certain stormwater tree pit designs may be limited by the placement of existing catch basins. Some designs are intended to work in conjunction with a catch basin and therefore will need to be sited accordingly; however, this may be a location where a traditional street tree would not be appropriate and lead to an overall increase in tree cover. Additionally, many designs may require a certain volume of runoff feed into the system and existing grading and placement of catch basins will dictate available drainage areas.[41]

Conclusion

Incorporating elements of stormwater tree pit design into existing street trees is not as simple as directing stormwater runoff into a tree pit. Nevertheless, many features of stormwater tree pits can help improve the health and longevity of street trees and provide stormwater management functions. One relatively simple change available to communities is to include stormwater

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function and characteristics of various tree species in the criteria for selecting the types of trees approved for planting in the community. Opting for more stormwater friendly tree species may be a very inexpensive way to begin to see stormwater improvements.

Making the switch from traditional tree plantings to a stormwater tree pit design will require additional time and funds, but it will likely generate additional benefits. Stormwater tree pits are not a direct replacement for traditional street trees; they are a stormwater management facility that incorporates the added amenity and all the benefit therein of a street tree, without requiring additional space. Cross agency cooperation to install and maintain these facilities as well as assessment of their true costs may make incorporation more realistic.

Future Work

CRWA hopes to continue our research into stormwater tree pit designs and using existing street tree pits as potential stormwater treatment facilities. CRWA is actively seeking examples of communities who have successfully incorporated these systems into their stormwater management infrastructure to learn more about how installation and maintenance costs and responsibilities are born across agencies or between public and private entities. Finally, CRWA believes simple modeling efforts at subwatershed or municipal levels could help further inform the water quality and stormwater runoff reduction improvements possible through the replacement of traditional tree pits with stormwater tree pits.

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