Page Content

Overview for trees

Green Infrastructure: Trees can be an important tool for retention and detention of stormwater runoff. Trees provide additional benefits, including cleaner air, reduction of heat island effects, carbon sequestration, reduced noise pollution, reduced pavement maintenance needs, and cooler cars in shaded parking lots.

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Practices incorporating trees into the design are often a specific type of **bioretention practice**. This page provides an overview of tree-based practices. Also see Overview for bioretention.

This page provides general information

Contents

Function within stormwater treatment train

Use of trees to manage stormwater runoff encompasses several practices. Tree trenches and tree boxes (collectively called tree **best management practice** (BMPs)), the most commonly implemented tree BMPs, can be incorporated anywhere in the **treatment train** (https://stormwater.pca.state.mn.us/index.php?title=Using_the_treatment_train_approach_to_BMP_selection) but are most often located in upland areas of the treatment train. The strategic distribution of tree BMPs help control runoff close to the source where it is generated. Tree BMPs can mimic certain physical, chemical, and biological processes that occur in the natural environment. Depending upon the design of a facility, different processes can be maximized or minimized depending on the type of pollutant loading expected (Prince George's County, 2002). As with any **filtration** (https://stormwater.pca.state.mn.us/index.php?title=Filtration) and **infiltration** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices) BMPs, **pretreatment** (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment) is recommended to prevent clogging of the media, particularly when **permeable pavement (https://stormwater.pca.state.mn.us/index.php?title=Permeable_pavement)** is used in conjunction with the tree BMP.

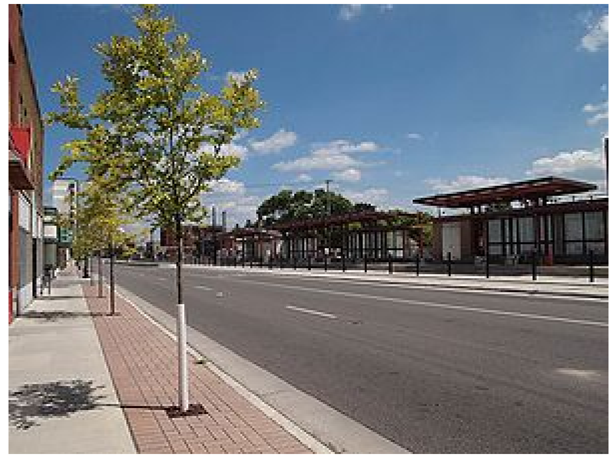
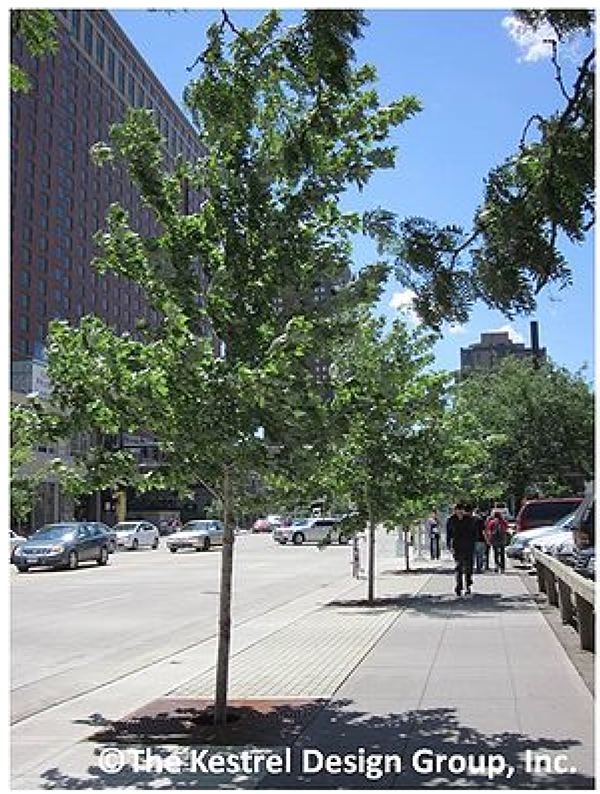


Photo showing trees BMPs along the Central Corridor, St. Paul, MN, using Cornell University structural soil. Photo courtesy of Capital Region Watershed District (http://www.capitolregionwd.org/).

Tree BMPs are one component of urban forestry. Urban forestry is a broad term that applies to all publicly and privately owned trees within an urban area, including individual trees along streets and in backyards, as well as stands of remnant forest (Nowak et al., 2001). Urban forests are an integral part of community ecosystems, whose numerous elements (such as people, animals, buildings, infrastructure, water, and air) interact to significantly affect the quality of urban life. (Nowak et al., 2010 Sustaining America's Urban Trees and Forests). Trees are already part of virtually all development and can be integrated anywhere in the treatment train, even into the densest urban areas. Many cities already have tree requirement ordinances. However, the potential of these trees to provide significant stormwater benefits is largely untapped to date.



Tree BMPs on Marquette Avenue, Minneapolis Minnesota, using Silva cell technology. Photo courtesy of the Kestrel Design Group, Inc.

For more information on urban forestry, we suggest visiting the following websites.

- Urban and Community Forestry (http://www.fs.fed.us/ucf/) - USDA Forest Service
- Urban Forestry & Ecosystem Management (http://www.mayorsfundphila.org/initiatives/urban-forest/) - City of Philadelphia
- Watershed Forestry Resource Guide (https://allaboutwatersheds.org/library/watershed-forestry-resource-guide) - Center for Watershed Protection and US Forest Service - Northeastern Area State & Private Forestry
- American Forests (https://www.americanforests.org/)
- Urban Forestry (https://uf.frec.vt.edu/) - Virginia Tech University

- Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management (https://www.epa.gov/sites/default/files/2015-11/documents/stormwater2streettrees.pdf) - U.S. EPA


Tree BMPs, Pace University, New York, using Stratacell technology. Photo courtesy of Citygreen.

MPCA permit applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP) (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program), which includes design and performance standards for permanent stormwater management systems. Standards for various categories of stormwater management practices must be applied in all projects in which at least one acre of new impervious area is being created.

For regulatory purposes, tree BMPs with no **underdrain** are **infiltration** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices) systems as described in the CGP. Tree BMPs with an underdrain are **filtration** (https://stormwater.pca.state.mn.us/index.php?title=Filtration) systems as defined in the permit. If used in combination with other practices, credit for combined stormwater treatment can be given. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases tree BMPs will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

There are situations, particularly retrofit projects, in which a tree BMP is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that additional and potentially more stringent design requirements may apply for a particular tree BMP, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Retrofit suitability

Tree BMPs are an ideal and potentially important BMP in urban retrofit situations where existing stormwater treatment is absent or limited. Tree BMPs can be utilized in **highly urban and ultra-urban environments**.

Special receiving waters suitability

The following table provides guidance regarding the use of tree BMPs in areas upstream of **special receiving waters** (https://stormwater.pca.state.mn.us/index.php?title=Special_Waters_and_Impaired_Waters).

Infiltration and filtration bmp[1] design restrictions for special waters and watersheds. See also Special waters and other sensitive receiving waters.
Link to this table

BMP Group	receiving water

BMP Group	**A Lakes**	**B Trout Waters**	**C Drinking Water[2] receiving water**	**D Wetlands**	**E Impaired Waters**
	A Lakes	**B Trout Waters**	**C Drinking Water[2]**	**D Wetlands**	**E Impaired Waters**
Infiltration	RECOMMENDED	RECOMMENDED	NOT RECOMMENDED if potential stormwater pollution sources evident	RECOMMENDED	RECOMMENDED unless target TMDL pollutant is a soluble nutrient or chloride
Filtration	Some variations NOT RECOMMENDED due to poor phosphorus removal, combined with other treatments	RECOMMENDED	RECOMMENDED	ACCEPTABLE	RECOMMENDED for non-nutrient impairments

[1]Filtration practices include green roofs, bmps with an underdrain, or other practices that do not infiltrate water and rely primarily on filtration for treatment.

[2] Applies to groundwater drinking water source areas only; use the lakes category to define BMP design restrictions for surface water drinking supplies

Water quantity treatment

Trees with underdrains are not typically suitable for providing water quantity control. In limited cases, a tree filtration practice may provide some (albeit limited) storage volume. Tree BMPs can help reduce detention requirements for a site by providing elongated flow paths, longer times of concentration, and volumetric losses from infiltration and **evapotranspiration**. Experience and modeling analysis have shown that tree BMPs can be used to reduce runoff and maintain the pre-existing time of concentration. This effort can be incorporated into the site hydrologic analysis. Generally, however, it is Highly Recommended that in order to meet site water quantity or peak discharge criteria, another structural control (e.g. detention) be used in conjunction with tree BMPs.

Depending on sizing and design, tree infiltration practices can retain significant volumes of water.

Water quality treatment

Tree BMPs that utilize **engineered media** (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_bioretention#Materials_specifications_-_filter_media) provide water quality benefits through the same mechanisms as standard bioretention systems. The soil, trees, and microbes in a bioretention system with trees work together as a system to improve water quality of stormwater that falls on the tree and/or is filtered through the soil volume. Some pollutants are adsorbed or filtered by soil, others are taken up or transformed by plants or microbes, and still others are first held by soil and then taken up by vegetation or degraded by bacteria, “recharging” the soil’s sorption capacity in between rain events.

Summary of bioretention water quality cleansing mechanisms for common stormwater pollutants.
Link to this table

Pollutant	**Bioretention cleansing mechanism**

Pollutant	Bioretention cleansing mechanism
Total suspended solids	Sedimentation and filtration (e.g. Davis et al., 2009)
Metals	Filtration of particulate metals, sorption of dissolved metals into mulch layer (e.g. Davis et al, 2009), plant uptake (e.g. Toronto and Region Conservation, 2009)
Nitrogen	Sorption; uptake by microbes and plant material, uptake into recalcitrant soil organic matter (e.g. Henderson, 2008)
Phosphorus	Sorption, precipitation, plant uptake, uptake into recalcitrant soil organic matter (e.g. Henderson, 2008)
Pathogens	Filtration, UV light, competition for limited nutrients, predation by protozoa and bacterial predators (e.g. Zhang et al., 2010)
Hydrocarbons	Filtration and sorption to organic matter and humic acids, then degraded by soil microbes (e.g. Hong et al., 2006)

Several recent literature reviews of lab and field studies concluded that tree BMPs have the potential to be one of the most effective BMPs for pollutant removal. High load reductions are consistently found for suspended solids, metals, **polycyclic aromatic hydrocarbons** (PAHs), and other organic compounds. Nutrient (dissolved nitrogen and phosphorus) removal has been more variable. Healthy vegetation has been found to be especially crucial for removal of dissolved nitrogen and phosphorus, hence the importance of large trees. Several studies that have compared vegetated media to unvegetated media have found that the presence of vegetation substantially improves total phosphorus (TP) and total nitrogen (TN) retention, as vegetated media is much more effective than unvegetated media at removing phosphate (PO_4) from solution and preventing nitrate (NO_3) leaching from media (e.g. Henderson, 2008, Lucas and Greenway, 2007a, 2007b, 2008, May et al., 2006). Not only has vegetation been shown to significantly improve nutrient removal, trees also benefit from the nutrients in stormwater (May et al., 2006), with greater growth in height and greater root density compared with those irrigated with tap water, turning stormwater nutrients into an asset.

For a summary of these literature reviews see File:Trees Tasks 2 and 13 Water quality benefits.docx.

Information on pollutant removal is provided in the following table.

Median pollutant removal percentages for several stormwater BMPs. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References). More detailed information and ranges of values can be found in other locations in this manual, as indicated in the table.
Link to this table

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Infiltration (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices)[2]	3	3	3	3	3	3	3	3

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Biofiltration and Tree trench/tree box with underdrain	80	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	50	35	95	80
Sand filter	85	50	85	0	35	50	80	80
Iron enhanced sand filter (http://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_%28Minnesota_Filter%29)	85	74	85	60[6]	35	50	80	80
Dry swale	68	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	35	0	80	80
Wet swale	35	0	0	0			0	
Constructed wet ponds[4, 5]	84	46	84	0	30	70	60	80
Constructed wetlands	73	38	69	0	30	70	60	80
Permeable pavement	74	41	82	0				
Green roofs	85	0	0	0				

TSS=Total suspended solids, TP=Total phosphorus, PP=Particulate phosphorus, DP=Dissolved phosphorus, TN=Total nitrogen

[1]Data for metals is based on the average of data for zinc and copper

[2]BMPs designed to infiltrate stormwater runoff, such as infiltration basin/trench, bioinfiltration, permeable pavement with no underdrain, tree trenches with no underdrain, and BMPs with raised underdrains.

[3]Pollutant removal is 100 percent for the volume infiltrated, 0 for water bypassing the BMP. For filtered water, see values for other BMPs in the table.

[4]Dry ponds do not receive credit for volume or pollutant removal

[5]Removal is for Design Level 2 (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_stormwater_pond_as_a_BMP_in_the_MIDS_calculator#Pollutant_Reduction)

[6]Removal is for Tier 2 iron enhanced sand filter. Tier 1 removal is 40 percent, resulting in a TP removal of 65%

Non-stormwater benefits of trees

In addition to stormwater management, trees provide a host of other benefits including other environmental benefits, energy savings, social and health benefits, wildlife benefits, and economic benefits. For more detailed information on these, see File:Trees Task 2 Overview.docx

Environmental benefits include

- cleaner air;
- reduction of heat island effect;
- carbon sequestration;
- reduced noise pollution;
- reduced pavement maintenance needs; and
- cooler cars in shaded parking lots.

Strategically placed trees can reduce building and heating energy use. Examples include the following.

- Trees properly placed around buildings as windbreaks can reduce winter heating costs.
- Shade from two large trees on the west side of a house and one on the east side can save on annual air conditioning costs.

Trees have a wide range of social benefits, including

- reduced stress of both body and mind in urban areas (Parsons et al., 1998; USDA Forest Service, 2004);
- improved outdoor leisure and recreation experiences (Dwyer et al., 1989; USDA Forest Service 2004) ;
- reduced crime (Kuo and Sullivan, 2001; USDA Forest Service 2004);
- improved recovery from surgery (Ulrich 1984 and Ulrich, 1985; USDA Forest Service, 2004);
- improved ability of automobile drivers to cope with driving stresses (Wolf, 2000; USDA Forest Service, 2004); and
- improved safety on streets (Wolf, 2010)

Monetary benefits as ecosystem services significantly outweighs the cost of utilizing trees in an urban setting. McPherson et al. (2005) observed Minneapolis's municipal tree resource provides approximately 79 dollars per tree in total net annual benefits to the community. Examples of other economic benefits include the following.

- Shoppers in well-landscaped business districts are willing to pay more for parking and up to 12 percent more for goods and services (Wolf, 1999; USDA Forest Service, 2004).
- Landscaping, especially with trees, can significantly increase property values (Neely 1988 in USDA Forest Service 2004).
- Desk workers with and without views of nature were surveyed. Those without views of nature, when asked about 11 different ailments, claimed 23 percent more incidence of illness in the prior 6 months (Kaplan and Kaplan 1989 in USDA Forest Service 2004).
- Amenity and comfort ratings were about 80 percent higher for a tree-lined sidewalk compared with those for a nonshaded street (Wolf, 1998; USDA Forest Service, 2004).
- Quality of products ratings were 30% higher in districts having trees over those with barren sidewalks (Wolf, 1998; USDA Forest Service, 2004).

Trees also benefit wildlife. For example Talamy and Darke (2007) observed that the Oaks genus supports 534 species of Lepidoptera (a large order of insects that includes moths and butterflies) as well as many bird species.

The following table summarizes some additional benefits for select tree species.

Non-stormwater benefits of several trees that can be used in tree trenches/tree boxes. NOTE: this list is not exhaustive and could include dozens of additional species.
Link to this table

Scientific name[1,2,3]	Common name [1,2,3]	Additional benefit (F=human food, W=wildlife habitat/browse, L=lumber)[3]
Acer saccharinum [1,2]	Silver maple	FWL
Amelanchier spp. [2]	Juneberry/serviceberry	FW
Betula populifolia [2]	Gray birch	W
Carya ovata [2]	Shagbark hickory	FWL
Catalpa speciosa [2]	Northern catalpa	WL
Celtis occidentalis [2]	Common hackberry	W
Cercis canadensis [2]	Eastern redbud	W
Cladrastis kentukea [2]	Yellowood, Kentucky yellowood	L
Crataegus crus-galli var. inermis [2]	Thornless cockspur hawthorn	W
Fraxinus americana [2]	White ash	WL
Fraxinus mandschurica	Manchurian ash	WL
Fraxinus nigra [1]	Black ash	WL
Fraxinus pennsylvanica [1,2]	Green ash	WL
Gleditsia tricanthos var. inermis [2]	Thornless common honeylocust	WL
Gymnocladus dioicus [2]	Kentucky coffeetree	WL
Larix decidua [3]	European larch	L
Larix laricina [1]	Tamarack	L
Malus spp. [2]	Crabapple spp.	FW
Ostrya virginiana [2]	American hophornbeam, ironwood	W
Populus grandidentata Michx.	Bigtooth aspen	WL
Populus deltoides [1,2]	Eastern cottonwood	L
Populus tremuloides [1,1]	Quaking aspen	L
Prunus virginiana [2]	Chokecherry	FW
Quercus bicolor [2]	Swamp white oak	WL
Quercus macrocarpa [2]	Bur oak	WL
Quercus rubra [2]	Red oak	WL

Scientific name[1,2,3]	Common name [1,2,3]	Additional benefit (F=human food, W=wildlife habitat/browse, L=lumber)[3]
Robinia pseudoacacia [2]	Black locust, false acacia, robinia	L
Salix babylonica	Weeping or Babylon willow	L
Taxodium distichum [2]	Common baldcypress	L
Tilia americana [2]	Basswood	WL

[1] Shaw, D. and R. Schmidt. 2003. *Plants for Stormwater Design (https://stormwater.pca.state.mn.us/index.php?title=Minnesota_plant_lists): Species Selection for the Upper Midwest*. Minnesota Pollution Control Agency (MPCA)

[2] Bassuk, N. et al. 2009. *Recommended Urban Trees: Site Assessment and Tree Selection for Stress Tolerance (http://www.hort.cornell.edu/uhi/outreach/recurbtree/)*. Urban Horticulture Institute, Dept of Horticulture, Cornell University, Ithaca, NY

[3] USDA NRCS Plants Database (https://plants.usda.gov/home).

Constraints on the use of trees

Potential constraints on the use of urban trees for stormwater management include:

- above ground space limitations such as utilities, lighting, signs, structures;
- below ground space limitations such as structures, pavement, existing trees, and utilities;
- regulations regarding types and locations of trees planted along public streets and right of ways, such as, for example, minimum sight distances and setbacks from street corners; and
- the need to locate trees outside of snow plow paths and snow storage areas.

While engineers often worry that tree roots will affect underdrains, inspections of underdrains in hundreds of bioretention practices by North Carolina State Engineers did not find roots clogging underdrains (Winston, 2013).

Tree performance can be adversely affected by a variety of factors, including

- salt (soil salt and salt spray exposure);
- high temperatures, particularly in urban areas due to heat island effects or reflected heat from adjacent buildings;
- vehicle exhaust;
- drought tolerance;
- exposure to frequent inundation;
- atmospheric pollution;
- physical damage from vandalism, mowers, and other maintenance;
- droughty conditions in between rain events, particularly if sandy soils are used; and
- tree bioretention areas that are used for snow storage due to compaction from the snow as well as salt from the snow.

According to Coder (2007), by far the most important factor to grow healthy trees is to provide an adequate volume of rootable soil (i.e. not compacted to a level that affects root growth). The top three factors causing the greatest growth limitations for tree growth are soil water availability, soil aeration, and soil drainage. Each of these can be related to site compaction.

Research has shown that trees need 2 cubic feet of rootable soil volume per square foot of tree canopy to thrive (e.g. Lindsey and Bassuk, 1991). Most urban trees, confined to a 4 foot by 4 foot (i.e. 64 cubic feet if assumed to be 4 feet deep) tree pit hole, have less than 1/10th the rooting volume they need to thrive. To provide 2 cubic feet of rootable soil to allow a tree with a 30 foot canopy to thrive would require 1413 cubic feet of rootable soil. Not surprisingly, studies have found that trees surrounded by pavement in urban downtown centers only live for an average of 13 years (Skiera and Moll, 1992), a very small fraction of their much longer lifespan under natural conditions.

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This list contains many references not cited on this page. A review of many of these articles can be found in File:Trees Task 2 Overview.docx.

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Related pages

- Overview for trees
- Types of tree BMPs
- Plant lists for trees
- Street sweeping for trees
- References for trees
- Supporting material for trees

The following pages address incorporation of trees into stormwater management under paved surfaces

- Design guidelines for tree quality and planting - tree trenches and tree boxes
- Design guidelines for soil characteristics - tree trenches and tree boxes
- Construction guidelines for tree trenches and tree boxes
- Protection of existing trees on construction sites
- Operation and maintenance of tree trenches and tree boxes
- Assessing the performance of tree trenches and tree boxes
- Calculating credits for tree trenches and tree boxes
- Case studies for tree trenches and tree boxes
- Soil amendments to enhance phosphorus sorption
- Fact sheet for tree trenches and tree boxes
- Requirements, recommendations and information for using trees as a BMP in the MIDS calculator
- Requirements, recommendations and information for using trees with an underdrain as a BMP in the MIDS calculator