Tree Canopy Stormwater Implementation & Outreach Program

MassDEP Project 14-07/319
June 2017

Comprehensive Environmental Inc.

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Acronyms Used in this Report

BMP	Best Management Practice
CUFR	Center for Urban Forest Research
CWRP	Center for Watershed Protection
DEM	Digital Elevation Model
DHCD	Department of Housing and Community Development
EIC	Effective Impervious Cover
EMC	Estimated Mean Concentration
EPA	Environmental Protection Agency
ESHGW	Estimated Seasonal High Groundwater
GIS	Geographic Information Systems
HSG	Hydrologic Soils Group
LAI	Leaf Area Index
LID	Low Impact Development
MAPC	Metropolitan Area Planning Council
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer System
NACTO	National Association of City Transportation Officials
NCHRP	National Cooperative Highway Research Program
NOAA	National Oceanic and Atmospheric
NPDES	National Pollutant Discharge Elimination System
NURP	National Urban Runoff Program
RCN	Runoff Curve Number
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VOC	Volatile Organic Compound

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1. Introduction

Mature trees, both as individual landscape features and as undisturbed areas of woodland cover, provide significant benefits in the interception of rainfall and the consequent reduction of stormwater runoff. However, current design practices and regulatory programs for stormwater management in the Commonwealth of Massachusetts do not specifically recognize this ecological service provided by canopy trees. Ironically, development practice often involves clearing large areas of woodland cover in order to provide space for installing stormwater management facilities to meet regulatory standards, with a permanent loss of the stormwater reduction function, not to mention other ecological benefits offered by mature tree canopy.

This study explores the potential stormwater reduction benefits of trees, as a foundation for a program to preserve, replace, and enhance mature tree canopy as an integrated component of stormwater management permitting, design, and implementation in Massachusetts. The study characterizes the potential role of canopy trees in achieving significant reductions in stormwater runoff, offers model regulatory language for use at both the municipal and state level for fostering the employment of tree canopy as a Best Management Practice, and identifies guidelines for the use of trees for stormwater management in the urban landscape.

Background

Trees distributed throughout our community landscapes provide many benefits beyond the inherent beauty they bring to streets and properties. Through a number of research and tree census projects, the USDA Forest Service's Center for Urban Forest Research (CUFR) has explored and documented the ecological services provided by trees in the urban landscape. The CUFR has investigated these ecological benefits both for specific case studies in individual communities (e.g., P.J. Peper, et. al., 2007, *New York City, New York Municipal Forest Resource Analysis*) and through the general development of data to support its suite of "i-Tree Tools" (http://itreetools.org/). The ecological benefits of mature canopy trees include substantial energy savings, carbon sequestration, air pollutants removal, rainfall interception (and the consequent reduction in stormwater runoff), and property value increases.

One of the most overlooked and under-appreciated benefits of mature trees, is their ability to reduce the volume of water generated in the urban landscape during and following a storm event. To illustrate this potential stormwater benefit of a canopy tree, using the *National Tree Benefit Calculator,*[1] a 12-inch red maple in the northeastern United States will intercept about 1353 gallons of water per year. With an estimated tree crown spread of about 27 feet in diameter,[2] this results in an annual reduction in runoff depth of 3.8 inches over the area of the tree's canopy. Based on the rainfall record underlying this estimate (41 inches), this amount exceeds a 9% reduction in annual rainfall reaching the ground beneath the tree. Where such a tree is proximate to a paved surface, this represents a significant reduction in runoff from that surface.

Current federal and state stormwater management regulations require collection and treatment of runoff from paved surfaces; therefore, a program to preserve, replace, and augment mature trees in the urban landscape could not only retain other environmental benefits, but could also reduce the volume of runoff requiring treatment. This would contribute to substantial savings if accounted for in the sizing and operation of stormwater treatment facilities to comply with these programs.

This project characterizes how the preservation and planting of canopy trees would enhance the management of stormwater within existing urban landscapes and in new-development/redevelopment projects, and explores ways to integrate tree canopy maximization into stormwater management permitting, design, and implementation.

Organization of this Report

The study includes four major components summarized in Chapters 2 through 5 of this report as follows:

Chapter 2. Stormwater Reduction by Tree Canopy

The study uses "i-Tree Tools" software developed by CUFR to evaluate selected prototype street tree and parking area landscaping strategies, to characterize the range of stormwater reduction benefits associated with the provision of tree canopy as an integral component of site design.

Chapter 3. Tree Canopy Implementation Tools

The study offers prototypical measures to enable municipalities to implement preservation/planting of trees as a stormwater management objective. The project's primary focus comprises the development of model language for local

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[1] This tool was developed by Davey Tree Expert Co and Casey Trees, based on the CUFR's i-Tree Tools, accessed at the Arbor Day Foundation's web-site: https://www.arborday.org/calculator/index.cfm. This particular calculator uses modeling based on weather data from JFK International Airport, New York City, NY to represent data for the Northeastern U.S. It is also based on a one-year rainfall record (2000) of 41 inches. An evaluation of tree cover using an alternative modeling tool is discussed later in this chapter, which uses more site specific rainfall data and better characterizes annual stormwater benefits.

[2] Estimated from data included in L.E. Frelich, 1992, Predicting Dimensional Relationships for Twin Cities Shade Trees

regulations and bylaws to promote tree canopy enhancement as an integral component of the site development process. In addition, the study identifies selected tools and resources available to communities desiring to implement local programs to enhance tree canopy on public properties. The study team has also developed brochures to support a local outreach program to encourage planting and maintenance of canopy trees on private properties.

A summary of these measures is provided in Chapter 3 and the brochures are included in Appendices C.

Chapter 4. Tree Selection, Planting, and Maintenance

The study describes selected technical recommendations for selection, installation, and maintenance of canopy trees, for achieving successful long term success of tree planting/preservation to meet stormwater reduction objectives. Chapter 4 presents a summary of these recommendations.

Chapter 5. Internet Tree Canopy Stormwater Tool Box

The resources developed under project components 1-3, together with links to other on-line resource material, are compiled to provide a user-friendly Internet "tool box" for implementing tree canopy preservation and enhancement as an integral component of stormwater management in Massachusetts. Chapter 5 offers an overview of the web-site. The web-site can be accessed at: http://treecanopybmp.org/

References

References cited in this study are listed at the end of the report.

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2. Stormwater Reduction by Tree Canopy

The purpose of this component of the tree canopy study project is to characterize the runoff reduction associated with preserving or augmenting tree canopy in proximity to impervious surfaces. This Chapter summarizes the results of this analysis.

Trees offer a number of stormwater management benefits, including the potential to prevent or mitigate impacts related to runoff volume and rate, water quality, erosion, and thermal effects. A general description of these benefits is provided in Section 2.1, as background to the current study.

This component of the study focuses on runoff-reduction associated with tree canopy that extends over impervious surfaces. To characterize this runoff reduction, the study team has modeled the effect of tree canopy on runoff from impervious areas. The analysis evaluates runoff from developed areas for a variety of roadway and parking lot development scenarios, comparing runoff for sites without trees to conditions at those same sites under varying densities of tree cover. Section 2.2 provides an overview of the runoff analysis methodology used for this study, which uses "i-Tree Tools" software developed by the Center for Urban Forest Research (CUFR).

The study has based the runoff analysis on a range of roadway and parking area development scenarios selected to illustrate potential tree landscaping approaches that might typically be applied in Massachusetts communities. The study uses a prototypical suburban subdivision road, urban street, and parking area layout. For each of these prototypes, the study has applied a variety of tree planting densities to characterize a range of "leaf cover" conditions. Section 2.3 describes the development/tree canopy scenarios used to derive the land-use cover parameters needed to populate the model described in Section 2.2.

For each prototypical layout, the study team conducted a quantitative assessment of potential stormwater volume reduction associated with tree canopy. The analysis also includes estimates of phosphorus reduction associated with each scenario. Section 2.4 presents the results of the modeling analysis, and discusses the potential general application of these results to stormwater management design, permitting, and implementation in Massachusetts.

2.1 Stormwater Benefits of Trees - General

Preserving natural tree canopy and the prudent use of tree plantings in urban landscapes contributes to the control of runoff through a number of mechanisms (see Figure 2.1):

- trees intercept and store runoff and transfer water back to the atmosphere through evapotranspiration, reducing the volume of runoff;

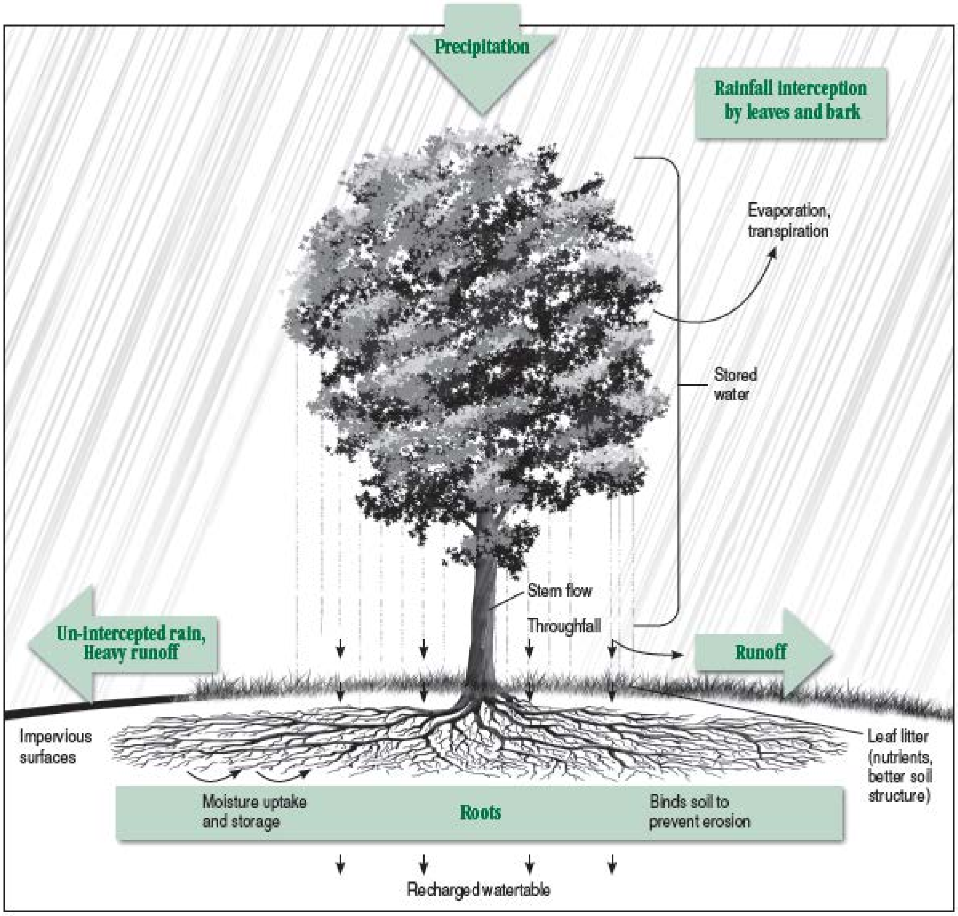


Figure 2.1. The role of a tree in controlling runoff.
(Courtesy of the Arbor Day Foundation, arborday.org)

- the shade and tree litter beneath the canopy help promote infiltration of precipitation that reaches the ground beneath the tree, providing moisture to the tree roots (ultimately to become transpiration) and reducing the volume of runoff.;

- roots, tree litter, and vegetative groundcover beneath the trees can slow the travel of runoff, resulting in lower times of concentration than associated with bare earth or impervious surfaces, and thus lowering peak runoff rates;

- tree roots, leaf litter, and vegetative cover stabilize the soil surface, preventing erosion and associated impacts; and

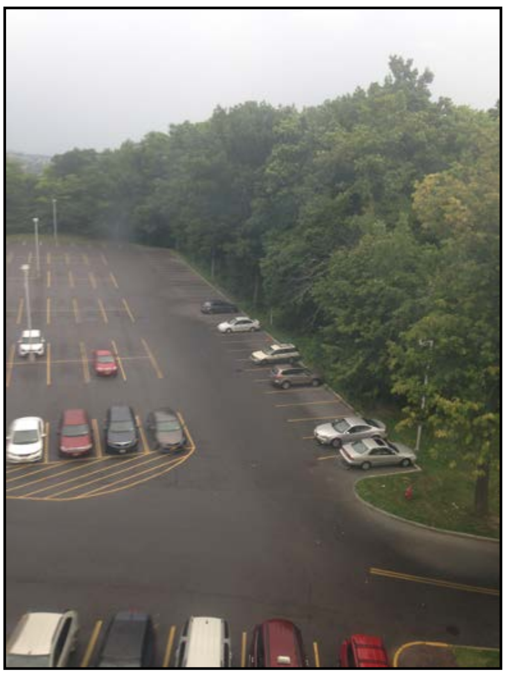
- trees, associated ground litter, and groundcover provide filtration and vegetative uptake of contaminants, enhancing water quality.

These functions for control of runoff and its impacts are further discussed below.

Interception and Evapotranspiration

Through the processes of interception, evaporation, and transpiration, trees and other vegetation capture and store a portion of rainfall and release water to the atmosphere, reducing the net amount of rainfall that becomes runoff. Rain is captured (intercepted) on a plant's leaves and stems (for trees, the leaf and stem complex is referred to as "canopy"). A portion of this captured water evaporates back into the atmosphere before reaching the ground. Larger canopies intercept greater amounts of precipitation because there is more surface area available for water molecules to adhere to.

Some water flows down the plant stem to the ground as "stemflow", and some rainfall infiltrates the ground around the plant, entering the root zone where the plant withdraws moisture to sustain itself. In this process, water taken up through its roots is then released through the plant's vegetative structures as water vapor, a process known as transpiration. The combination of these two mechanisms - evaporation and transpiration - whereby a plant transfers moisture to the atmosphere is referred to as evapotranspiration. In both processes the water is diverted before ever becoming runoff.



Mature tree canopies are of particular value in the interception of rainfall. For example, in a New Hampshire hardwood forest at the Hubbard Brook LTER site, deciduous trees were observed to intercept 13% of the total rainfall during the leaf period and 12% of the total rainfall during the leafless period (Leonard, 1961). In the photo to the left, note how the pavement beneath the trees remains dryer than other pavement early in a storm event, because the tree canopy intercepts the initial rainfall, contributing to an overall reduction in annual runoff.

Individual mature trees also provide significant rainfall interception. An illustration of this potential stormwater benefit using the *National Tree Benefit Calculator* was cited in Chapter 1 of this report (*i.e.*, greater than 9% annual rainfall capture over the "footprint" of the tree). The significant volumes of interception shown in that example and in the Hubbard Brook study cited above are consistent with findings of other studies throughout the United States (see Table 2-1).

Table 2-1. Literature Review of Canopy Vegetation Interception

Literature Reference	Study Location	Interception rate	Remarks
Klingaman, Nicholas P. et al. 2007. A comparison of Three Canopy Interception Models for a Leafless Mixed Deciduous Forest Stand in the Eastern United States. American Meteorological Society DOI: 10.1175/JHM564.1	Fair Hill, MD	Measured throughfall and stemflow over 11 storms canopy intercepted 5.8% of total rainfall. Total of 103.3 mm of rain and 19 mm was intercepted by forest.	American beech, yellow poplar, black oak, silver maple summed totals for the entire canopy
Link, Timothy E., et al. 2004 The dynamics of rainfall interception by a seasonal temperate rainforest Agricultural and Forest Meteorology 124: 171-191.	Gifford Pinchot National Forest, WA	Net canopy interception was 22.8% of 450.9 mm of rain and 25% of 618.7 mm of rain.	Douglas-fir western hemlock ecosystem
Xiao, Qingfu and E. Gregory McPherson 2002 Rainfall interception by Santa Monica's municipal urban forest. Urban Ecosystems 6: 291-302.	Santa Monica, CA	Annual rainfall interception 6.6 m^3/tree or 1.6% of total precipitation.	Model simulated rainfall interception and runoff reduction from street and park trees in urban forest
Xiao, Qingfu et al. 2000 Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrological Processes 14: 763-784.	Davis, CA	Interception accounted for 15% of gross precipitation for pear tree and 27% for oak tree. Oak tree canopy interception varied from 100% at the beginning of the rain event to about 3% at the maximum rain intensity.	9-year-old broadleaf deciduous pear tree and 8-year-old broadleaf evergreen cork oak tree

Literature Reference	Study Location	Interception rate	Remarks
Xiao, Qingfu et al. 1998. Rainfall Interception by Sacramento's Urban Forest Journal of Arboriculture 24: 235-244	Sacramento County, CA	Annual interception 1.1% for entire county and 11.1% interception over urban forest canopy. Summer interception 36% for urban forest stand (large coniferous) and 18% interception for stand (medium coniferous).	Model simulated rainfall interception in Sacramento County, CA
Sanders, Ralph 1986 Urban Vegetation Impacts on the Hydrology of Dayton, Ohio Urban Ecology 9: 361-376.	Dayton, Ohio	Model calculated existing runoff total as 1394.4 million L, 1489 million L with trees removed, and 1321.5 million L by increasing vegetation and herbaceous cover in exposed soil by 50% each. If all trees were removed, but herbaceous cover left, runoff was estimated to increase from 26%-28%.	Model simulated 1 yr 46 mm 6-h storm, no specific tree type
Leonard, Raymond E. 1961 Interception of Precipitation by Northern Hardwoods. Northeastern Forest Experiment Station, Forest Service U.S. Department of Agriculture, Upper Darby, PA Ralph W. Marquis, Director.	Hubbard Brook Experimental Forest, NH	Throughfall for leaf and leafless period was 82% and 88% of gross rainfall. Interception of rainfall by trees averaged 13% during leaf period and 12% during leafless period.	Two year study of interception of precipitation in northern hardwoods (species beech, sugar maple, yellow birch, miscellaneous), where average annual precipitation is 50 inches
Zon, Raphael 1927 Forests and water in the light of scientific investigation. Forest Service Department of Agriculture, United States Government Printing Office Washington, D.C.	Not specific	Proportion intercepted by tree crowns for different aged stands. 20 yr. 2%, 50 yr. 27%, 60 yr. 23%, 90 yr. 17%. Under average conditions spruce forest will intercept 39% and a broadleaf forest will intercept about 13% of annual precipitation.	Beech stands and comparison of broadleaf and spruce forests

The amount of rainfall intercepted by vegetation varies depending on the type of species, time of year, and intensity and duration of the rainfall event. Species characteristics like leaf surface area and specific tree architecture contribute to the variation in total water intercepted. Also, trees typically intercept more rain during a storm of longer duration than a short storm with equal total rainfall accumulation (CUFR, 2002). In areas where rainfall is highest in the fall, winter, and spring, broadleaf evergreens and conifers intercept more rainfall than deciduous species (Xiao and McPherson 2002).

Promotion of Infiltration

Another crucial role plants have in reducing landscape runoff is facilitating ground water infiltration. Plants provide suitable conditions for water to infiltrate through several mechanisms. Decomposing plant material on the ground captures and temporarily stores runoff. Root systems create large pores in the soil called macropores that facilitate infiltration. Tree roots provide pathways for stormwater infiltration to enter soils compacted by development activity (e.g., see Bartens, et.al., 2008). The uptake of water from the soil by plants between rainfall events frees pore space that then becomes available for storage during a subsequent storm.

Note, however, that in the case of trees, much of the infiltrated water will ultimately be taken up by the trees themselves, so that in areas with extensive tree cover, deep groundwater recharge may actually be less than in areas with little or no tree cover.

Vegetative Retardance of Runoff

Vegetation not only reduces the volume of runoff, but can also reduce runoff velocity compared to flow over an un-vegetated surface (an effect referred to as vegetative retardance). This results in longer times of concentration. Natural surface roughness associated with vegetation contributes to lower peak rates of discharge than would occur on an un-vegetated landscape. Maintaining and restoring vegetated landscapes thus can contribute to the control of the rate runoff is transported through a drainage basin.

Surface Stabilization

Trees and other vegetation throughout the landscape stabilize slopes and channels and prevent soil erosion. Trees protect soil from direct exposure to falling rain by intercepting rain, absorbing the impact of rainfall that does drip from the leaf surface to the ground, and providing leaf litter that absorbs the impact of rainfall as it hits the ground. Each of these mechanisms helps prevent dislodgement of soil particles by rainfall. Additionally, the tree's root system keeps soils intact, stabilizing slopes against displacement by runoff flowing over and through the surface soils. Reduced erosion rates from vegetated landscapes protect the quality of receiving waters by minimizing transport of sediments and associated pollutants.

Water Quality Enhancement

Not only can trees reduce the total amount and rate of stormwater runoff, they can also improve the water quality of runoff. The forest litter associated with woody plants (as well as groundcovers that may thrive beneath trees) can filter runoff as it passes over the ground. Woody plants in particular can uptake nutrients, contaminants, and metals from water or soil. A study showed that within one growing season a maple removed 60 mg of cadmium, 140 mg of chromium, 820 mg of nickel, and 5200 mg of lead (Coder, 1996). Vegetative pollutant uptake improves the surrounding soil and water quality, resulting in less contamination in runoff reaching the stormwater system from tree covered landscapes and from stormwater treatment practices that include tree plantings.

An additional water quality benefit provided by tree canopy comprises moderation of the thermal impacts of stormwater runoff. For discharges to temperature-sensitive water resources such as coldwater fisheries, prudent preservation or enhancement of tree cover to shade impervious surfaces (where runoff originates), outlet channels (where runoff discharges), and stream banks can moderate temperatures of stormwater discharges.

2.2 Tree Canopy Runoff Reduction Modeling Methodology

The analysis described in this chapter focuses on quantifying the annual volume of runoff reduction and associated phosphorus reduction that can be theoretically achieved by various densities of tree canopy. The study team selected a modeling approach that could compare the runoff generated by a completely impervious site with the runoff generated by the same site under a range of densities of overhanging tree canopy.

To accomplish this, the study uses selected modeling software from the "i-Tree," a set of peer-reviewed modeling tools developed by the USDA Forest Service for estimating environmental benefits of trees. The software includes utilities for evaluating tree canopy's ability to reduce runoff through the process of interception and evapotranspiration. For this project, the stormwater benefits of trees are illustrated using a hypothetical site located in central Massachusetts. The analysis uses several land cover scenarios including suburban subdivision roads, urban downtown streets, and commercial/residential parking areas, and explores a range of densities of tree canopy for each of these scenarios.

The study uses the software package "i-Tree Hydro" to estimate the runoff reduction for each scenario. The modeling compares runoff volumes for conditions corresponding to zero tree-canopy up to about 80% canopy cover over the paved surface. The modeling software chosen also provides estimates of phosphorus loading for each scenario. Other modeling tools in the "i-Tree Hydro" suite of tools have been used to obtain additional supporting information useful for selecting tree types for the purpose of stormwater management.

The modeling tools are described briefly below. Subsequent sections of this Chapter describe the development of the land-use scenarios, and the results of the modeling analysis.

i-Tree Modeling Software

USDA Forest Service, in partnership with Davey Tree Expert Company, the Arbor Day Foundation, Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees, have developed "i-Tree," a state-of-the-art, peer-reviewed suite of software products for urban and community forestry analysis and benefits assessment. The i-Tree software tools are designed to help communities enhance their urban forest management efforts by quantifying the environmental services provided by trees and assessing the structure of the urban forest.

i-Tree is in the public domain and available by request through the i-Tree website (www.itreetools.org). i-Tree software products have been used by communities, non-profit organizations, consultants, volunteers, and students to report on the urban forest at all scales from individual trees to parcels, neighborhoods, cities, and entire states. The software suite includes a number of products covering a range of applications, including assessing benefits of individual trees at the parcel scale, evaluating street tree conditions and benefits, estimating watershed impacts, and assessing environmental benefits through GIS analysis at the regional scale. For detailed information about the i-Tree suite of software, the reader should refer to the i-Tree website.

For the current study, several of the i-Tree products have been employed to guide and develop the evaluation of runoff reduction anticipated from tree canopy in Massachusetts. These products include the following:

- **<u>i-Tree Design.</u>** This simple on-line tool can be used to assess individual trees at the parcel level. The tool allows the user to locate a site on Google Maps and evaluate how a tree specimen's species, size, and placement relative to a specific building affect a number of environmental benefits.

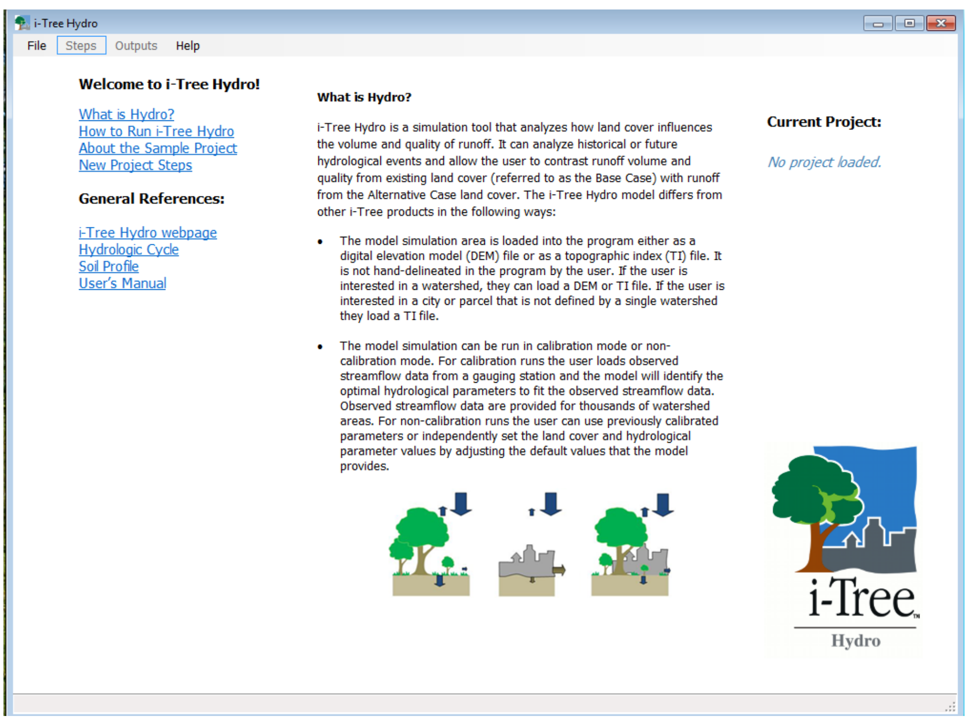
  

  Relevant to the current study, the tool allows for estimating rainfall interception for a tree of a specific age, or for a tree over a projected number of years. The tool is therefore useful for selecting among tree types to optimize stormwater benefits, as well as to compare benefits of a particular tree species at various stages of maturity.

  However, the tool has two limitations of concern to the current study. The tool estimates interception only, and does not directly estimate the resulting runoff reduction at the ground surface. Also, the tool estimates benefits by essentially using a few locations as indices for broad regions of the United States. For example, for sites located throughout the Northeast, the calculator is based on rainfall data for a single year (2000) at the JFK International Airport in New York City (a total annual accumulation of 41 inches). Fortunately, the i-Tree Hydro product discussed below offers a more robust analytical tool for overcoming these limitations.

- **i-Tree Hydro.** The i-Tree suite includes a downloadable hydrologic software package that its developers describe as the first vegetation-specific urban hydrology model. i-Tree Hydro can be used to model how changes in urban tree cover and impervious surfaces affect surface runoff and water quality at the watershed level.

  The i-Tree Hydro simulation tool can analyze historic or hypothetical hydrologic events, allowing the user to compare runoff volume and quality from existing land cover under a Base Case scenario to the corresponding parameters from an Alternative Case land cover scenario. The model simulation can be based on a GIS-derived Digital Elevation Model (DEM) file developed by the user based on a selected watershed. Alternatively, the user may model either a watershed or a sub-watershed parcel, using a regional-based Topographic Index (TI) file from a database archived within the model. If the DEM-file approach is used, the model offers the option to calibrate the simulation to observed streamflow data. Under either approach, the model uses rainfall data from geographically local weather station information accessed through the model software.



For the current study, this modeling tool offers the opportunity to use the TI option and run i-Tree Hydro in non-calibration mode with suggested hydrological default parameters and the weather station information accessed through the model. The simulation method provides for a simple approach to developing runoff estimates from a generic "typical site" under various land cover conditions, without requiring a detailed delineation of a specific watershed. Where this study's objective is to examine prototype landscapes to obtain a general understanding of the role of trees in controlling runoff, this generic approach is warranted.

Furthermore, the modeling tool provides an output that is particularly useful for examining the effect of tree canopy on flows from paved surfaces, as the model output separately identifies pervious surface flow and impervious surface flow (see the sample output table in Figure 2.2). That is, where tree canopy overhangs paved or roofed areas, the model can be used to directly estimate the reduction in runoff from impervious fraction of the area of analysis as a result of tree canopy function.

i-Tree Hydro provides for modeling the cover beneath tree canopy as either pervious or impervious surface. In addition, the model can be set up with pervious areas outside of the tree canopy with a selection of surface cover-type (earth, herbaceous cover, shrub cover). This allows for modeling of landscapes that are a mixture of pavement, roof, tree canopy, and earthen or vegetated surfaces. For example, this feature enables the user to model a parking area with grassed islands as a base case, and tree planted islands as an alternative case, to assess the impact of adding trees on the generation of runoff from the paved surface.

The model also provides estimates of loading of selected pollutants, based on National Pooled estimated mean concentration (EMC) and National Urban Runoff Program (NURP) EMC data. For this study, reductions of total phosphorus (TP) have been estimated for each scenario. An example of the pollutant-loading output from the model is provided in Figure 2.3, which shows a typical comparison of total annual load for base case versus alternative case land-cover inputs.

While this study uses the TI option for the simplified analysis, watershed planners should be aware of the versatility of this model for use with specific watershed data (DEM option) to obtain valuable information about the hydrologic role of trees and to examine watershed-scale effects of changes in tree canopy cover. This information could prove extremely useful in planning a community-wide or watershed-wide approach to conservation or restoration of woodland cover to manage stormwater runoff and stream flows within a specific locale. Where USGS stream gage data are available, improved estimates can be attained with a watershed DEM simulated in calibration mode.

- **i-Tree Species.** This product is a free-standing utility designed to assist the user with selection of the most appropriate tree species based on geographic location and environmental function. The utility provides an input menu for selecting project location and designating applicable height constraints. The menu then allows selection from a number of tree function performance criteria, including VOC reduction, carbon storage, wind reduction, air temperature reduction, UV radiation reduction, building energy reduction, streamflow reduction, and low allergicity. The utility's output comprises a list of trees from its database suitable for the specified locality, sorted by priority for meeting the selected functions.

  This study has employed the i-Tree Species Selector to using the utility to screen a selected list of tree species based on their streamflow reduction function (their capacity for reducing overall surface and base-flow through interception and evapotranspiration). This information is integrated with other information on tree selection considerations discussed in Chapter 4.

2.3 Tree Canopy Development Scenarios

The study team developed an array of land-use/tree canopy prototypes for assessment, including a typical subdivision roadway, an urban street, and a parking lot. For each of these prototypes, variants were developed to represent a range of tree planting strategies that would be generally practicable in Massachusetts communities. While many other variations could be used, the range of impervious-area/tree-cover scenarios used in this study should provide a reasonable assessment of the potential runoff benefits associated with tree canopy. The design scenarios are summarized below.

Subdivision Roadway

This prototype includes a standard two-lane local residential street, with no formal on-street parking, and with a sidewalk on one side. The cross section used for this analysis is adapted from the "Medium Road Cross Section" presented in the publication, *Sustainable Neighborhood Road Design, A Guidebook for Massachusetts Cities and Towns* (APA-MA, 2011). The underlying roadway design is representative of sustainable development practice for subdivisions in Massachusetts.

Three different planting strategies have been modeled:

1. Provision of small trees (25-foot crown spread) on both sides of the street spaced at 25 feet on center. This small-tree planting strategy represents a condition where height constraints are of concern (*e.g.*, presence of overhead wires).

2. Provision of large trees (40-foot crown spread) on one side of the street spaced at 40 feet on-center. This scenario contemplates the existence of either right-of-way limits or some other constraint (*e.g.*, underground or overhead utilities) that limits the placement of trees along one side of the roadway.

i-Tree Hydro Executive Summary

Project Location: Marlborough, Massachusetts
Project Time Span: 01/01/2011 - 12/31/2012

Model Parameters

Watershed Area	Rainfall	Total Runoff
square kilometers	*millimeters*	*cubic meters*
1.00	2,574.29	1,757,435.78

Land Cover	*Base*	*Alternative*
Tree Cover %	1.0	81.2
Shrub Cover %	0.0	0.0
Herbaceous Cover %	27.2	0.4
Water Cover %	0.0	0.0
Impervious Cover %	71.8	18.4
Soil Cover %	0.0	0.0

Streamflow Predictions

	Total Runoff		**Baseflow**		**Pervious Flow**		**Impervious Flow**	
	Base	*Alternative*	*Base*	*Alternative*	*Base*	*Alternative*	*Base*	*Alternative*
Total Flow (cubic meters)	1,757,435.8	1,529,121.9	65,604.7	54,514.7	83,632.7	63,122.4	1,608,198.6	1,411,484.6
Highest Flow (cubic meters / hour)	27,913.8	27,643.3	5.0	5.0	5,293.3	5,256.6	22,617.5	22,384.2
Lowest Flow (cubic meters / hour)	1.3	0.9	1.3	0.9	0.0	0.0	0.0	0.0
Highest Flow Date	07/28/12	07/28/12	10/31/11	11/09/12	07/28/12	07/28/12	07/28/12	07/28/12
Lowest Flow Date	06/11/11	08/15/11	06/12/11	08/15/11	01/01/11	01/01/11	01/01/11	01/01/11
Average Flow (cubic meters/h)	100.3	87.3	3.7	3.1	4.8	3.6	91.8	80.6
Number of flow events ABOVE average flow	258.0	219.0	9.0	6.0	11.0	9.0	260.0	220.0
Average length of flow events ABOVE average (hours)	5.8	6.1	1,244.1	1,382.8	9.8	8.6	5.8	6.1
High Flow: Number of flow events ABOVE 1 standard deviation	165.0	149.0	45.0	14.0	11.0	10.0	171.0	153.0
Average length of flowevents ABOVE 1 standard deviation (hours)	3.6	3.5	46.3	314.4	6.6	4.6	3.8	3.6
Number of flow events BELOW average flow	259.0	220.0	8.0	5.0	12.0	10.0	261.0	221.0
Average length of events BELOW average (hours)	62.0	73.5	877.9	1,755.8	1,358.6	1,664.0	61.5	73.2

Figure 2.2. Example Executive Summary output of the i-Tree Hydro model.

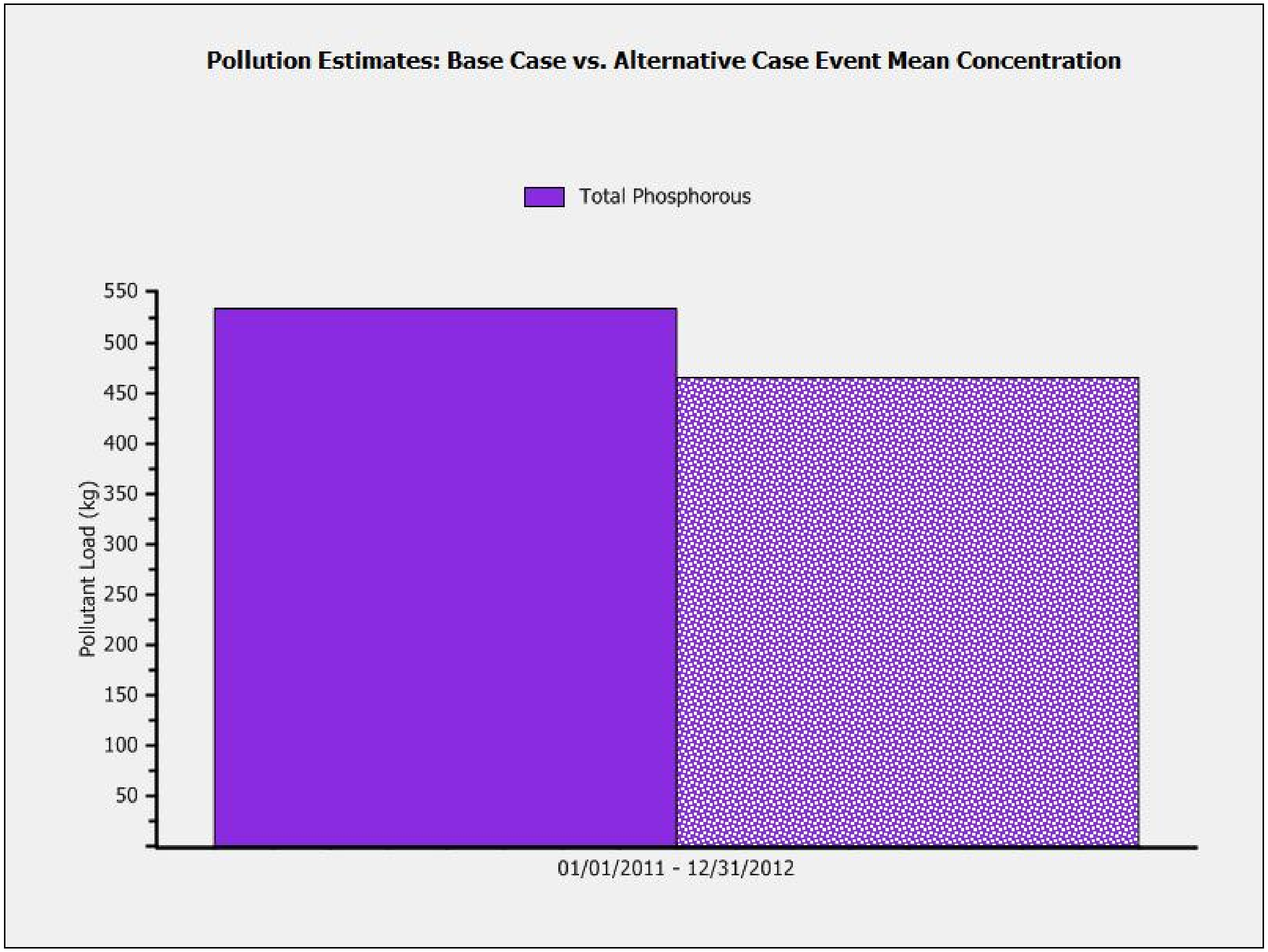


Figure 2.3. Example pollutant load calculation output from the i-Tree Hydro model, corresponding to the analysis scenario represented in Figure 2.2.

3. Provisions of large trees (40-foot crown spread) on both sides of the street spaced at 40 feet on-center. This scenario represents a fairly robust planting strategy, but is consistent with the tree spacing requirements found in a sampling of Massachusetts community subdivision regulations.

These planting strategies are depicted in Figures 2.4 through 2.6, which show the typical placement of trees relative to the edge of pavement in each scenario. The resulting land use coverage of trees, herbaceous ground cover (outside of tree canopy), and impervious surface within the subdivision road right-of-way for each scenario is summarized in Table 2.2. The coverage tabulation only accounts for the portion of tree canopy within the right-of-way; any canopy extending outside of the right-of-way is not included in the model input for purposes of this analysis.

Urban Downtown Street

This prototype comprises a town street with a total width of 90 feet. This roadway example includes two 12-foot wide travel lanes, two parallel parking lanes (each 9 feet wide), and 12-foot wide sidewalks on both sides. The three planting scenarios chosen for this prototype include the following:

1. Provision of large trees (40-foot crown) on both sides of the street spaced at approximately 40 feet (12 trees on each side of a 500-foot long block).

2. Provision of small trees (25-foot crown) on both sides of the street spaced at 25 feet (similar to the length of a parallel parking space).

3. Provision of 1 large tree (40-foot crown) on both sides of each intersection at the ends of a 500-foot long block (4 trees total for the block).

These planting strategies are shown in Figures 2.7 through 2.9. The resulting land coverage for each strategy is summarized in Table 2.2. The portions of tree canopy falling outside of the 90-foot overall width of pavement/right-of-way are not included in the model input.

Parking Area

This prototype consists of a parking lot, typical of one which could serve a commercial, industrial, or multi-family residential land use. The lot consists of "double loaded" parking aisles with planting islands. The analysis considers variations of the placement of the islands and the provision of trees, to cover a range of potential planting densities as described below:

1. Provision of a parking configuration comprising four double-loaded parking bays (8 rows of parking and four access aisles) uninterrupted by planting islands (approximately one acre of pavement). The layout is landscaped with small trees (25-foot crown spread) placed at the outer perimeter of the parking area. Tree spacing within longer planting islands was set at 27 feet on center.

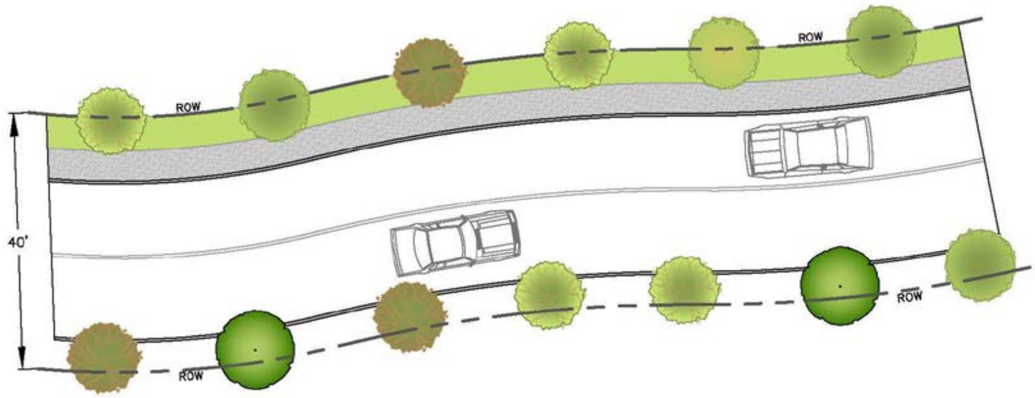
2. Provision of a parking configuration consisting of two double-loaded parking bays, separated by a planting island from an additional two double-loaded parking bays. The same total number of parking spaces is provided as in the first scenario, but additional planting space is included. For this alternative, large trees (40-foot crown) were included at 45-foot spacing.

3. Provision of a parking configuration of four double-loaded parking bays, with each bay separated by a landscaped island. Large trees with a 45-foot spacing were included for this scenario.

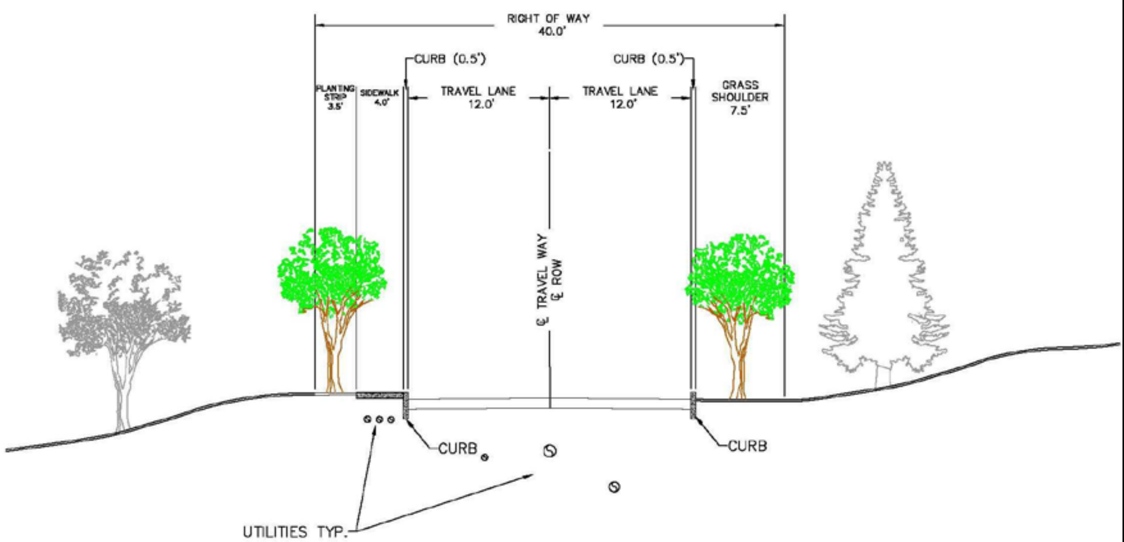
These planting strategies are shown in Figures 2.10 through 2.12. The resulting land coverage for each strategy is summarized in Table 2.2. Note that in each case, the model inputs were developed based on a boundary defined by the centerline of the perimeter landscape islands. The portions of tree canopy falling outside of this boundary are not included in the model input. This allows for the analysis to represent one prototypical "cell" of a much larger parking field.

Table 2-2. Summary of Land Use Scenarios

Scenario Description		Total Analysis Area	Total Impervious Area		Total Canopy Within Analysis Area		Total Impervious Area Beneath Canopy		
		sq. ft.	sq. ft.	% of total area	sq. ft.	% of total area	sq. ft.	% of total area	% of imp area
Subdivision Road									
Scenario 1	Small trees, two sides	40,000	29,000	72.50%	22,618	56.55%	11,801	29.50%	40.69%
Scenario 2	Large trees, one side	40,000	29,000	72.50%	16,208	40.52%	8,854	22.14%	30.53%
Scenario 3	Large trees, two sides	40,000	29,000	72.50%	32,415	81.04%	21,573	53.93%	74.39%
Urban Downtown Street									
Scenario 1	Large trees, two sides	45,000	45,000	100.00%	23,844	52.99%	23,844	52.99%	52.99%
Scenario 2	Small trees, two sides	45,000	45,000	100.00%	18,300	40.67%	18,300	40.67%	40.67%
Scenario 3	Large trees at corners	45,000	45,000	100.00%	4,812	10.69%	4,812	10.69%	10.69%
Parking Area									
Scenario 1	Perimeter landscape	47,880	44,892	93.76%	5,400	11.28%	2,925	6.11%	6.52%
Scenario 2	One intermediate island	49,680	45,072	90.72%	12,566	25.29%	8,318	16.74%	18.45%
Scenario 3	Three intermediate islands	53,280	43,812	82.23%	20,106	37.74%	11,358	21.32%	25.92%

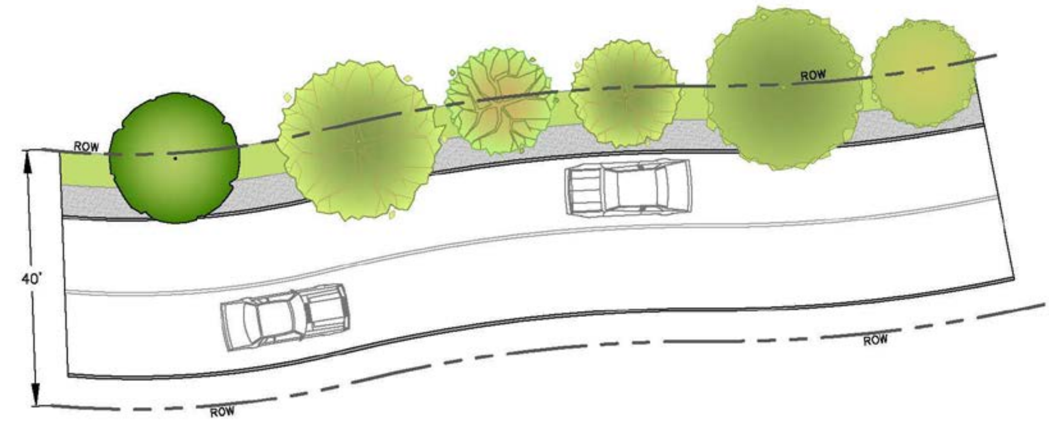


Typical Plan

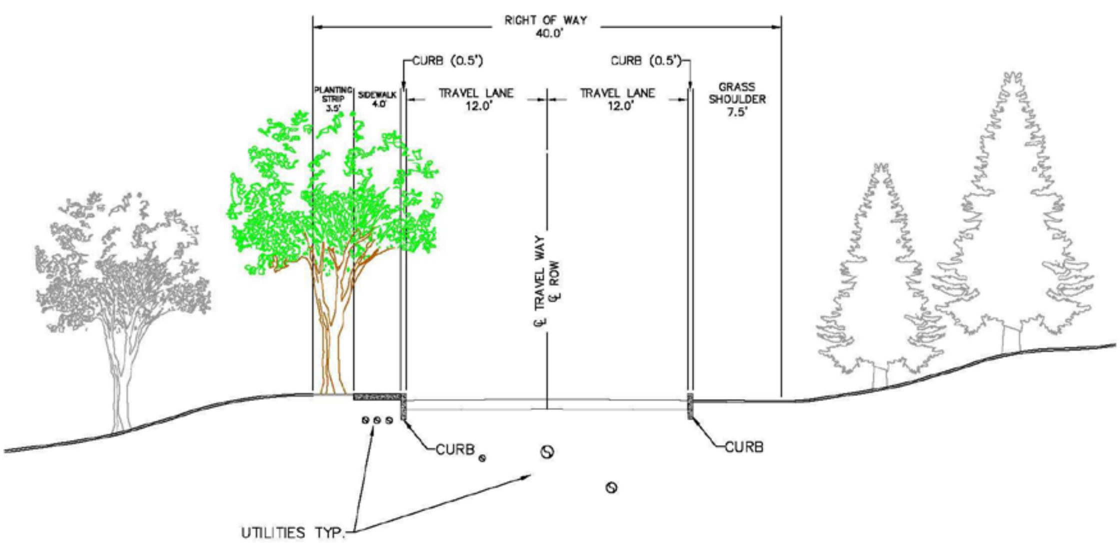


Typical Cross Section

Figure 2.4. Subdivision Road Scenario 1: Small Trees on Both Sides of Road

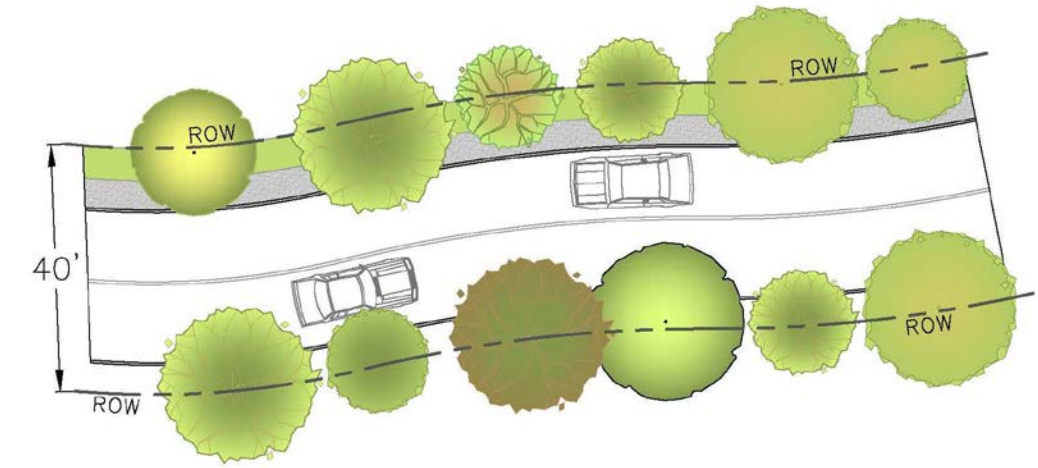


Typical Plan

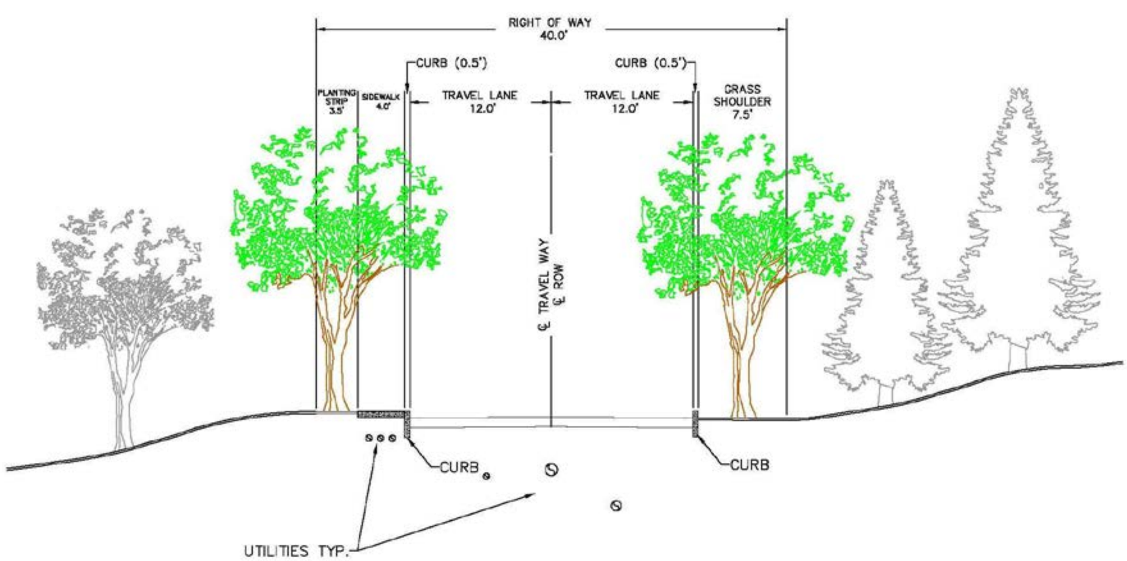


Typical Cross Section

Figure 2.5. Subdivision Road Scenario 2:
Large Trees on One Side of Road



Typical Plan



Typical Cross Section

Figure 2.6. Subdivision Road Scenario 3:
Large Trees on Both Sides of Road

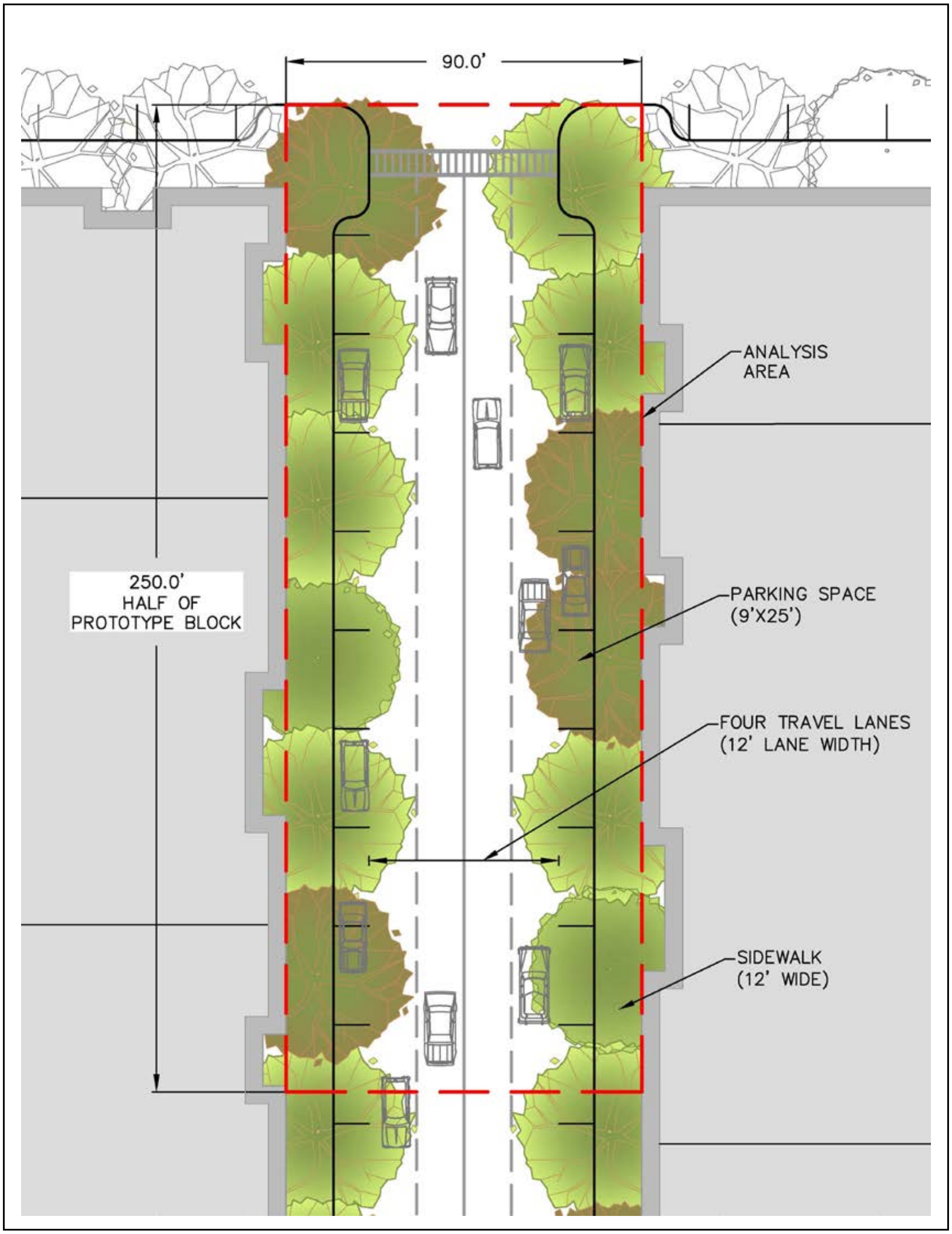


Figure 2.7. Urban Downtown Street Scenario 1:
Large Trees on Both Sides of Street

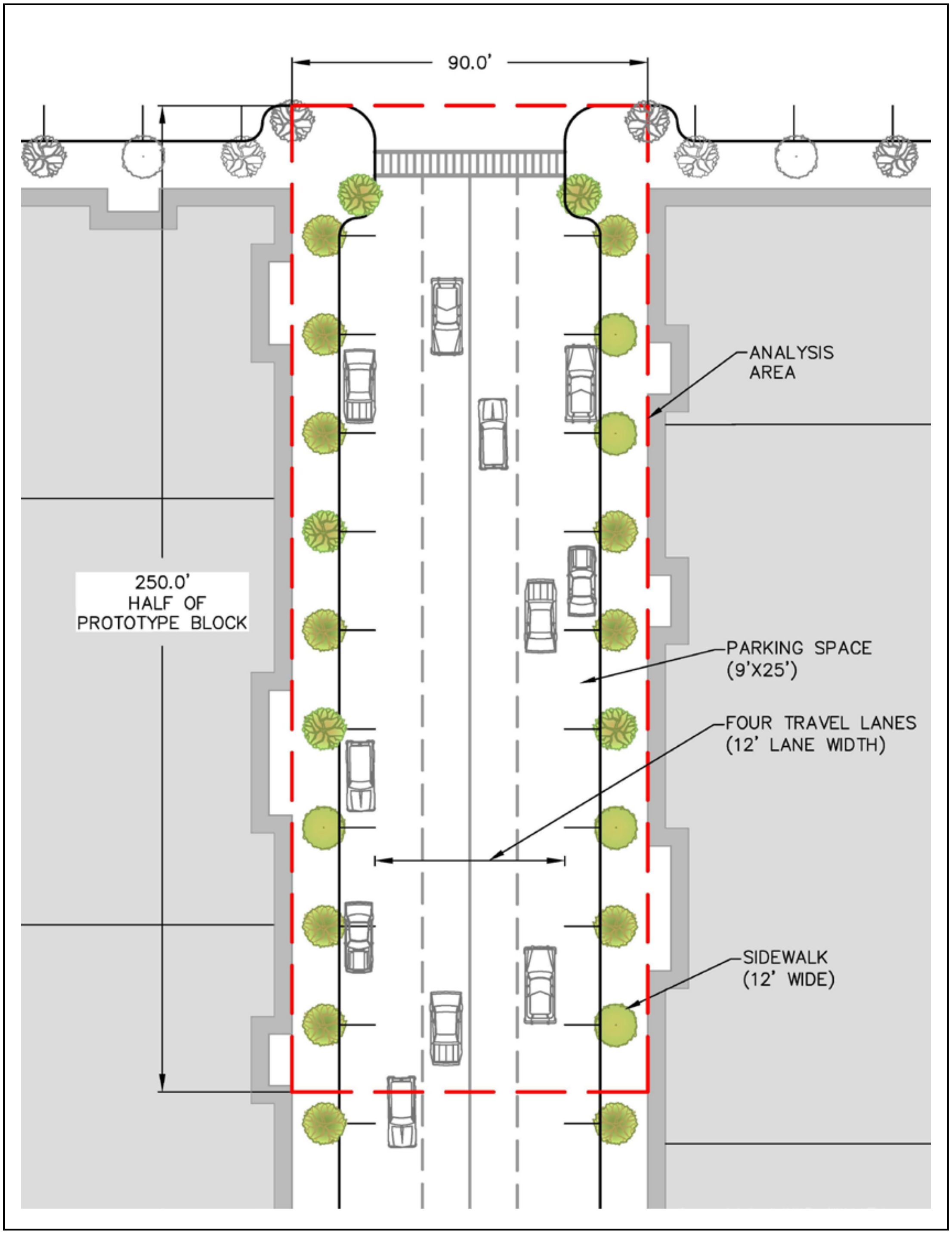


Figure 2.8. Urban Downtown Street Scenario 2: Small Trees on Both Sides of Street

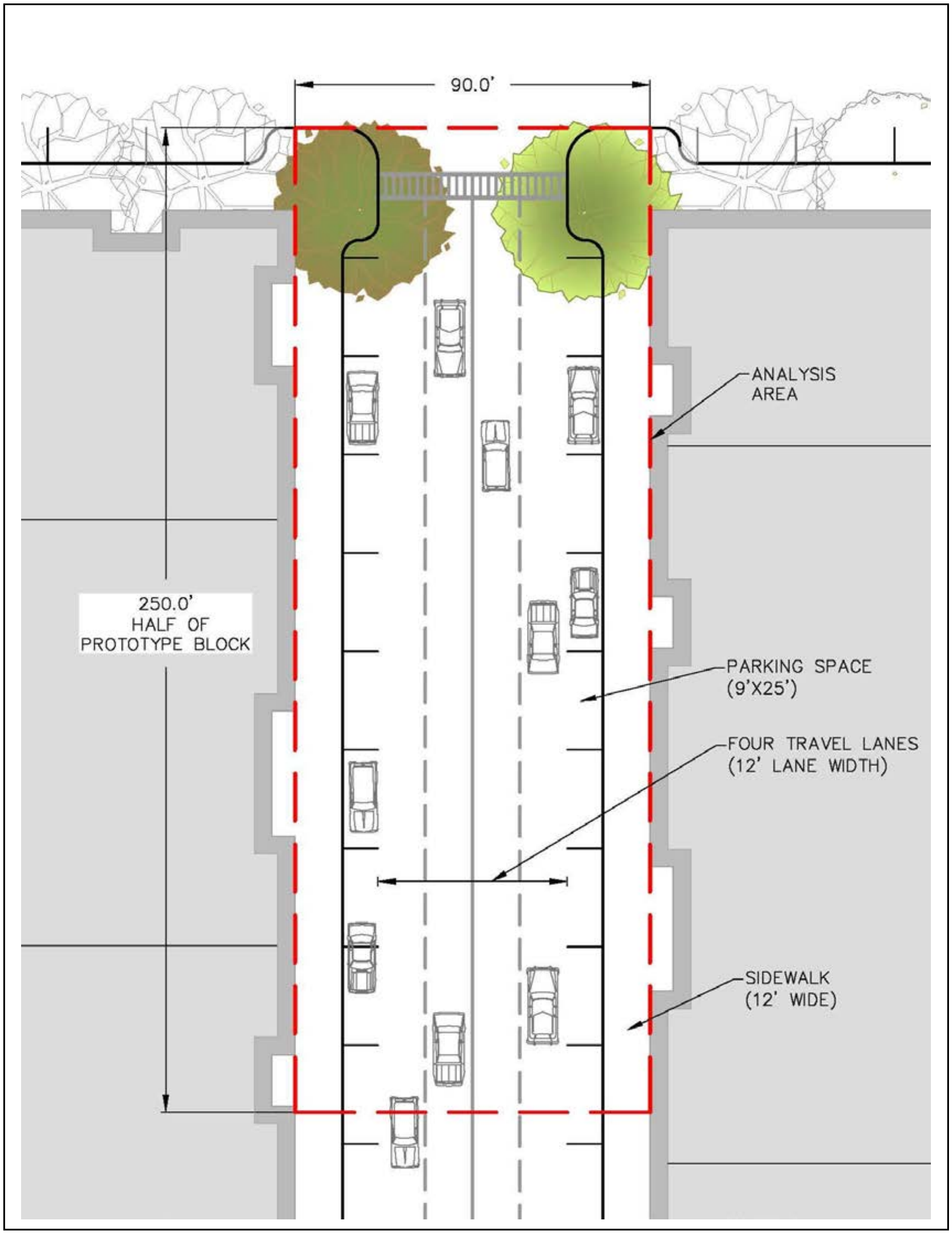


Figure 2.9. Urban Downtown Street Scenario 3:
Large Trees at Street Corners

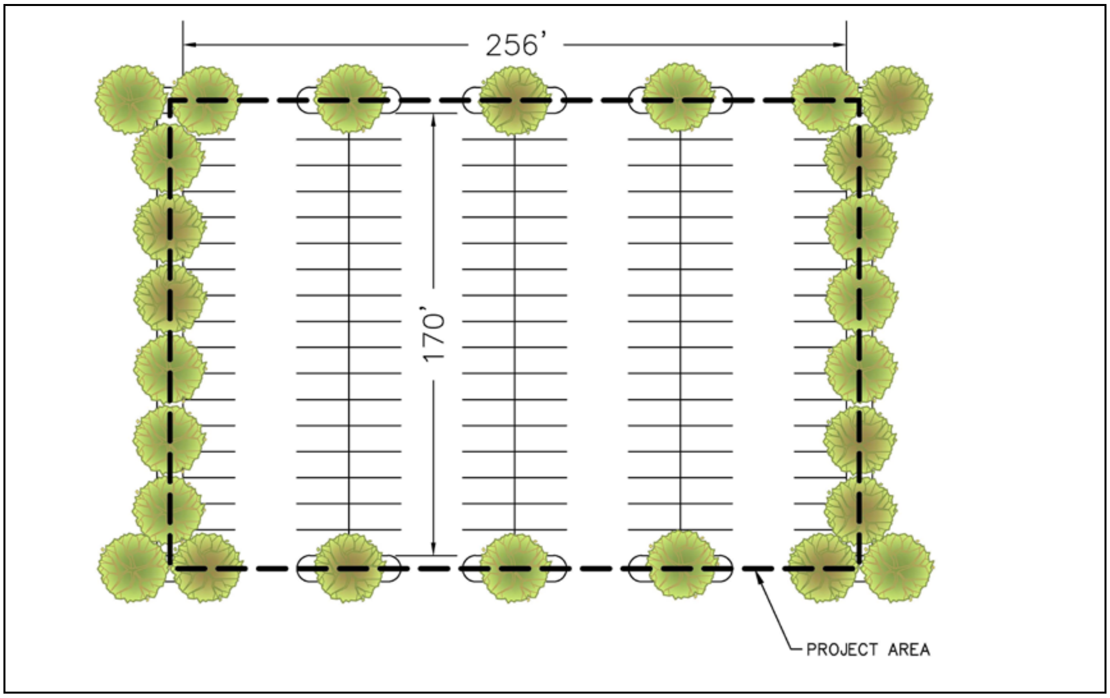


Figure 2.10. Parking Lot Scenario 1: Perimeter Island

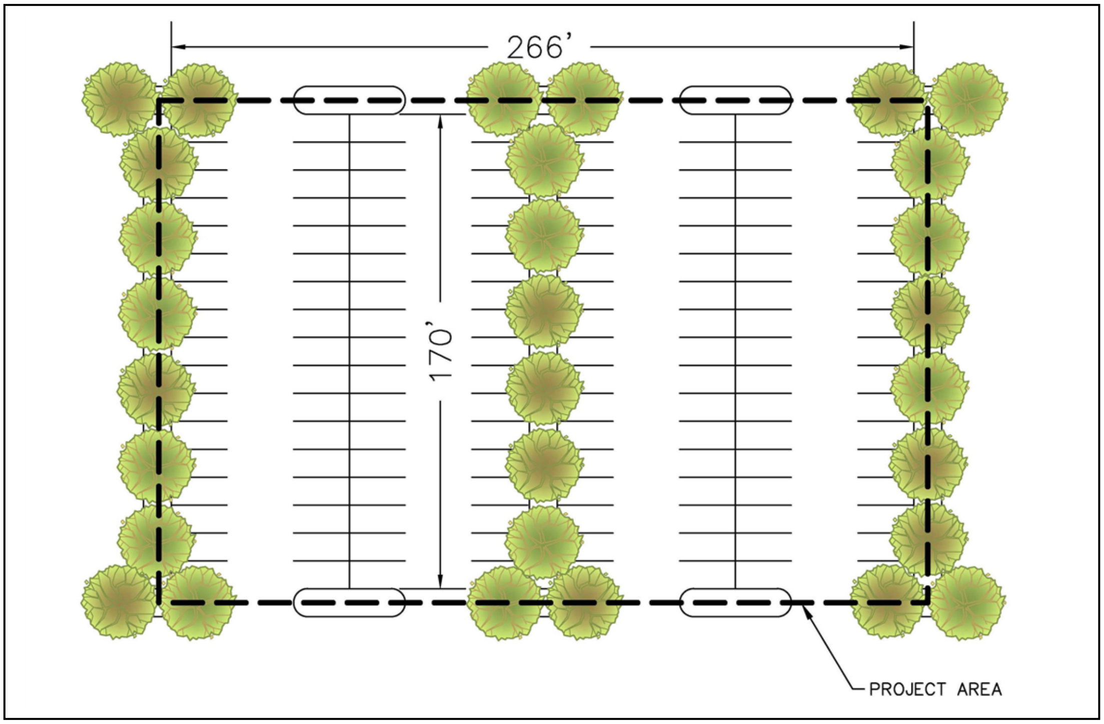


Figure 2.11. Parking Lot Scenario 2: One Intermediate Landscaped Island

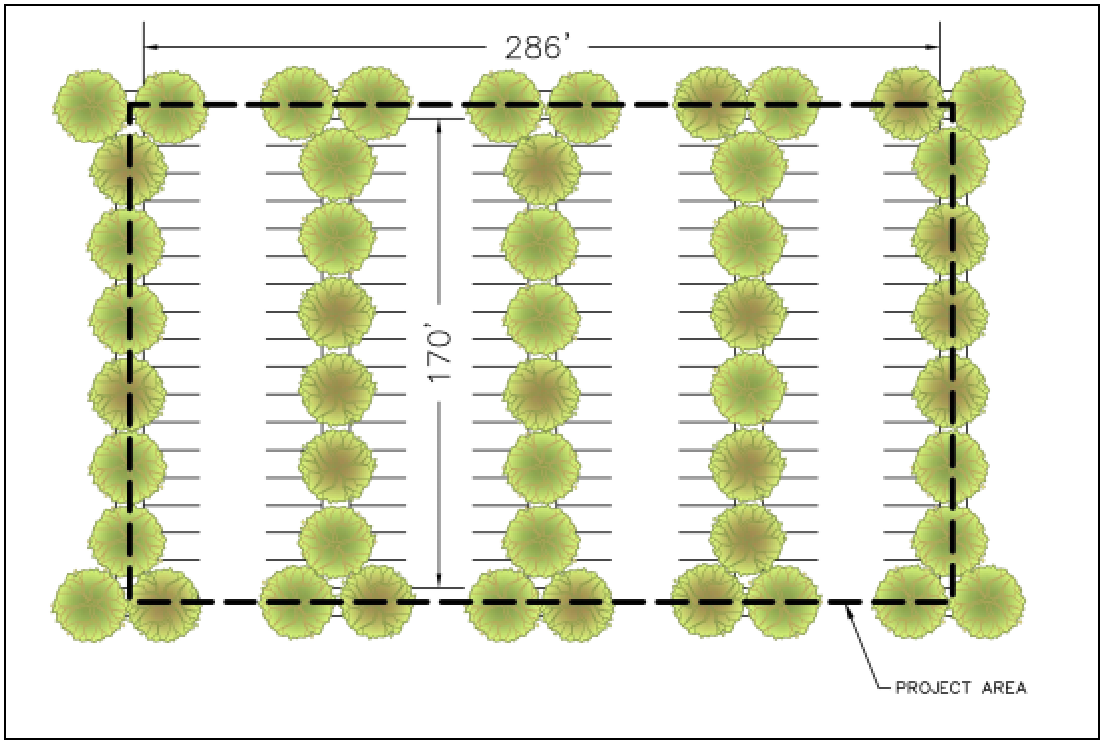


Figure 2.12. Parking Lot Scenario 3: Three Intermediate Landscaped Islands

2.4 Modeling Analysis and Results

The study has developed runoff and phosphorus reduction estimates for each of the land use scenarios described in Section 2.3. A brief discussion of how the model has been developed is provided below, followed by a presentation of the results.

Model Development

For each scenario, the model assesses a Base Case and an Alternative Case. The Base Case comprises the scenario under a condition with no tree canopy. The Alternative Case comprises the condition with tree canopy. In both cases, the analysis considers runoff over an extended period (one or more years of rainfall data), and the tree canopy cover condition remains unchanged over the period of analysis.

The following notes apply to the modeling inputs employed by this study:

- Each simulation was conducted as a non-watershed area using a Topographic Index (TI) drawn from the software database. The modeled scenarios were assumed to be located in Marlborough, Massachusetts. Selected alternative locations were also modeled (see discussion below) to analyze the sensitivity of results to location.

- i-Tree Hydro requires a minimum modeling area of one square kilometer. Therefore, each land use scenario was normalized to this minimum model area (1.0 sq.km.) using land cover percentages.

- i-Tree Hydro requires a minimum tree cover of one percent. To account for this, each Base Case model analytical area was adjusted to provide additional area with tree canopy to achieve the minimum 1% cover. For example, to model the impact on 1.0 acre of 100% pavement, the modeling run would use an analysis area of 1.01 acres, consisting of one acre of pavement (99%) and 0.01 acre of tree canopy (1%). The Alternative Case also included the equivalent additional area of tree cover. Because both Base and Alternative cases contain the same additional "tare" allowance of tree cover, modeled runoff volume reductions represent the reduction over original analysis area.

- The i-Tree Hydro modeling inputs used the following values for parameters for initial analysis. Subsequent model runs varied selected parameters to test the sensitivity of results to these values, as discussed later in this section:

  - Leaf Area Index equal to 5.0 (i-Tree Hydro default value);
  - Evergreen and shrub cover equal to zero;
  - Hydrologic data inputs used 0.5 meter root zone;

   - Hydrologic data inputs used "blended soil" type; otherwise, model default parameters for hydrologic data were used.

- All impervious surfaces were considered 100% directly connected to the drainage system.

- Precipitation records were used as discussed below.

The i-Tree Hydro model accesses precipitation data records through an interactive menu integrated with the input screens. The choice of precipitation records is limited, and the records for each weather station are not necessarily continuous. For example, one-year data files may be obtained for the Worcester Airport weather station for the years 2005, 2006, 2007, 2011, and 2012. The model documentation does not explain why the data for 2008-2010 are not available; however, as the model uses individual rainfall events for the runoff and pollutant reduction calculations, one possible reason for the lack of data for these years is that there are gaps in the daily records during those periods.

Based on other data available directly from NOAA for the Worcester Airport weather station, the study team estimated the average annual precipitation for the ten-year period January 2004 to December 2013 as 51.6 inches. Analysis of the two-year record for 2011-2012 accessed through i-Tree Hydro shows that the average over this period was 50.7 inches and thus comparable to the 10-year average. The study therefore used the 2011-2012 data for initial modeling.

Subsequently, modeling was also conducted for Subdivision Road Scenario 3 for each of the available one-year records in the i-Tree Hydro data base, to assess how results may vary based annual rainfall record.

Model Results for Runoff Reduction

The results for modeling of the nine land-use coverage scenarios (Table 2-2) are presented in Table 2-3 for the 2011-2012 precipitation data period. Table 2-4 presents the results for modeling five separate annual rainfall periods for Subdivision Road Scenario 3.

For the 2011-2012 rainfall record, the basic analysis of the range of land use coverage shows the following:

- The modeling shows a linear relationship between the annual runoff reduction (in percent, distributed over the total paved area) and the percentage of pavement shaded by canopy. This is illustrated in Figure 2.13, which plots data from the two shaded columns in Table 2-3. Assuming that the modeled parameters and rainfall records are representative for locations in Marlborough, MA, one should be able to use this graph to predict anticipated runoff reduction, in percent, if one knows the percentage of pavement lying directly beneath canopy.

- The data in the final column of Table 2-3 fairly consistently show the reduction in runoff for pavement lying directly beneath canopy is consistently in the range of 16.5% to 17.6% (approximately 16.7% on average). Thus, assuming modeled parameters and rainfall records are representative of locations in Marlborough, the analysis shows tree canopy at these locations will reduce runoff from directly shaded pavement by about 16.7%.

However, the modeling indicates that the runoff reduction as a percentage of total runoff is sensitive to the rainfall record used for analysis. The runoff results are likely a function not only of the total annual rainfall, but also of the size and number of precipitation events. As these can vary considerably from year to year, the rainfall interception by trees can also be expected to vary. The results presented in Table 2-4 show how the runoff reduction for a single scenario (subdivision roads with large trees on both sides) vary with rainfall record, holding all other parameters equal. In this case, where the 2-year record resulted in annual runoff reduction over "shaded pavement" of 16.7%, the range for five different annual rainfall records is from 9.8% to 20.5%, with an average for the years of record equal to 15.4%. Assuming a linear relationship between runoff reduction and percent pavement under canopy similar to that for the results plotted in Figure 2.13, the graph in Figure 2.14 summarizes the range of results shown in Table 2-4.

It should be noted that the mean annual rainfall for the five years of record is less than the mean annual rainfall used in the initial modeling (Table 2-3), and several inches less than the long-term average for the selected weather station. This could well explain the lower average value (15.4 versus 16.7%) for the expanded years of record: an additional number of small rainfall events associated with a greater annual rainfall total could result in a proportionately greater volume of interception by tree canopy.

Sensitivity Analysis (Runoff Reduction)

The findings of the initial modeling may also be sensitive to variations in other parameters than the rainfall record. To explore this sensitivity, after conducting the basic modeling of the land use coverage scenarios using parameters noted above, the study team conducted further modeling with variants of several parameters.

- For Subdivision Road Scenario 3 and Urban Downtown Street Scenario 1, model runs were conducted with the following variations to assess sensitivity to selected default parameters and to Topographical Index:
    - Leaf area index (LAI) was set to 3.0 (instead of the default value of 5.0). Leaf area index is a measure of the density of leaf surface in the tree canopy. For example, LAI = 3.0 means that for each square foot of ground area beneath the tree, there are 3.0 square feet of leaf surface in the overlying canopy. Leaf index would therefore reflect the available surface area contributing to leaf interception;

- Root zone was set to 0.05 meters (model default value) instead of 0.5 meters. This represents the effective depth of root penetration, which in turn could affect the modeled amount of transpiration through tree canopy;
- An alternative topographical index (TI) was selected (Rutland, MA), to assess sensitivity to regional variations surface topography and its relationship to groundwater, while using the same Worcester Airport rainfall data.

- For the Subdivision Road Scenario 3, model runs were conducted with the following variations to assess sensitivity to combined rainfall record and location/TI:
  - Alternate location data (TI) and weather station corresponding to Plymouth, MA, for the precipitation record period 2011-2012;
  - Alternate location data (TI) and weather station corresponding to Pittsfield, MA, for the precipitation record period 2011-2012.

The modeling results for these sensitivity analyses are presented in Table 2-5. The findings of this analysis include the following:

- The reduction in leaf area index results in somewhat poorer canopy performance for runoff reduction, as illustrated by Subdivision Road Scenario 3A and Urban Downtown Street Scenario 1A. Setting LAI at 3.0 results in 15.8% runoff reduction from the directly shaded pavement, compared to 16.7% with LAI equal to 5.0. However, this is only a 5% change in performance (compared to 40% decrease in leaf density).

- The modeling of tree canopy overhanging pavement does not appear sensitive to the depth of root zone (Subdivision Road Scenario 3B, Urban Downtown Street Scenario 1B). Note, however, that the analysis focuses on the runoff from paved areas, and has not explored variations in depth of root zone relative to overall runoff reduction for the unpaved portions of the watershed. This latter analysis could prove complex, and is not within the scope of this study.

- The modeling of tree canopy overhanging pavement is not particularly sensitive to location, while holding the weather station and precipitation record constant. (Subdivision Road Scenario 3C, Urban Downtown Street Scenario 1A.)

- The modeling of tree canopy overhanging pavement is sensitive to variation of both location and weather record, as illustrated by Subdivision Road Scenarios 4 and 5. Based on the earlier discussion of modeling Subdivision Scenario 3 with varying rainfall records, this sensitivity would be expected, particularly given the substantial differences in annual rainfall associated with Scenarios 4 and 5.

Table 2-3. Runoff Reduction for Study Scenarios: 2011 to 2012 Precipitation Record

Scenario Description		Total Impervious Area	Total Canopy Within Analysis Area	Total Pavement Beneath Canopy		Annual Precip	Annual Runoff from Impervious	Avg. No. of Impervious Flow Events	Annual Runoff Reduction Distributed Over Total Paved Area		Annual Runoff Reduction over Paved Area Beneath Canopy	
		% of total area	% of total area	% of total area	% of imp area	inches	inches	(base case: no trees)	inches	% annual runoff	inches	% annual runoff
Subdivision Road												
Scenario 1	Small trees, two sides	73%	57%	30%	41%	50.7	43.5	71.5	3.0	6.8%	7.3	16.7%
Scenario 2	Large trees, one side	73%	41%	22%	31%	50.7	43.5	71.5	2.2	5.1%	7.3	16.8%
Scenario 3	Large trees, two sides	73%	81%	54%	74%	50.7	43.5	71.5	5.4	12.4%	7.3	16.7%
Urban Downtown Street												
Scenario 1	Large trees, two sides	100%	53%	53%	53%	50.7	43.5	70.0	3.8	8.8%	7.3	16.7%
Scenario 2	Small trees, two sides	100%	41%	41%	41%	50.7	43.5	70.0	3.0	6.8%	7.3	16.8%
Scenario 3	Large trees at corners	100%	11%	11%	11%	50.7	43.5	70.0	0.8	1.8%	7.4	16.9%
Parking Area												
Scenario 1	Perimeter landscape	94%	11%	6%	7%	50.7	43.5	71.0	0.5	1.1%	7.7	17.6%
Scenario 2	One intermediate island	91%	25%	17%	18%	50.7	43.5	71.0	1.3	3.0%	7.2	16.5%
Scenario 3	Three intermediate islands	82%	38%	21%	26%	50.7	43.5	71.5	1.9	4.3%	7.3	16.7%

Table 2-4. Runoff Reduction for Maximum Canopy Scenario: Available Annual Precipitation Records

Scenario Description		Precip Record Year	Total Impervious Area	Total Canopy Within Analysis Area	Total Pavement Beneath Canopy		Annual Precip	Annual Runoff from Impervious	No. of Impervious Flow Events	Annual Runoff Reduction Distributed Over Total Paved Area		Annual Runoff Reduction over Paved Area Beneath Canopy	
		Year	% of total area	% of total area	% of total area	% of imp area	inches	inches	(base case: no trees)	inches	% annual runoff	inches	% annual runoff
Subdivision road													
Scenario 3	Large trees, two sides	2005	73%	81%	54%	74%	53.8	47.0	77.0	4.8	10.2%	6.4	13.7%
		2006	73%	81%	54%	74%	46.9	41.1	66.0	3.0	7.3%	4.0	9.8%
		2007	73%	81%	54%	74%	40.1	32.7	74.0	5.0	15.3%	6.7	20.5%
		2011	73%	81%	54%	74%	60.8	53.7	77.0	6.8	12.6%	9.1	16.9%
		2012	73%	81%	54%	74%	40.6	33.3	64.0	4.0	12.1%	5.4	16.2%
Average over years of record			**73%**	**81%**	**54%**	**74%**	**48.4**	**41.5**	**71.6**	**4.7**	**11.5%**	**6.3**	**15.4%**

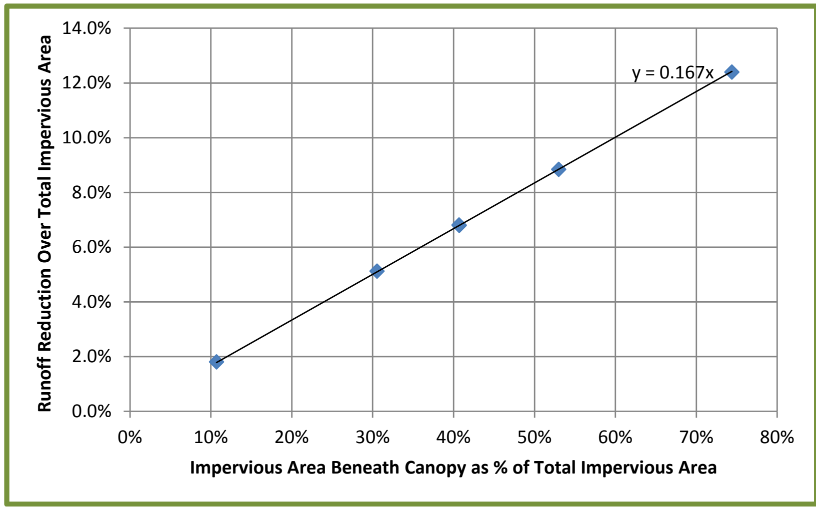


Figure 2.13. Runoff reduction as a function of the portion of paving located beneath tree canopy (2011-2012 precipitation record).

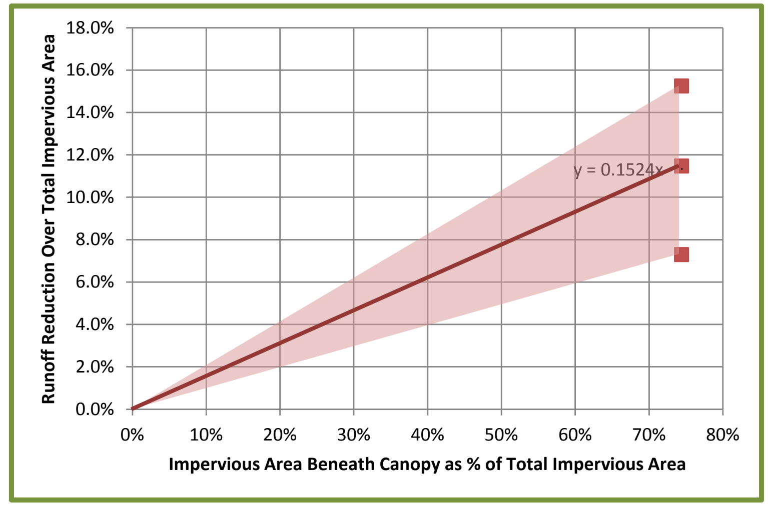


Figure 2.14. Runoff reduction as a function of the portion of paving located beneath tree canopy (individual years of precipitation record)

Table 2-5. Sensitivity of Runoff Reduction to Variation in Selected Model Parameters

Scenario Description	Total Impervious Area	Total Canopy within Analysis Area	Total Pavement Beneath Canopy		Annual Precip	Annual Runoff from Impervious Surface	Avg. No. of Impervious Flow Events	Annual Runoff Reduction over Total Impervious Area		Annual Runoff Reduction over Imperviouos Area Beneath Canopy		
	% of total area	% of total area	% of total area	% of imp area	inches	inches	(base case: no trees)	inches	% annual runoff	inches	% annual runoff	% change from base
Subdivision Road - base for comparison (see not												
Scenario 3 Large trees, two sides	73%	81%	54%	74%	50.7	43.5	71.5	5.4	12.4%	7.3	16.7%	
Alternative parameter for sensitivity analysis												
Scenario 3 A Leaf Area Index (LAI) = 3	73%	81%	54%	74%	50.7	43.5	71.5	5.1	11.7%	6.9	15.8%	5.3%
Scenario 3 B Root zone = 0.05 m	73%	81%	54%	74%	50.7	43.5	71.5	5.4	12.4%	7.3	16.7%	0.0%
Scenario 3 C Alternative TI (Rutland, MA)	73%	81%	54%	74%	50.7	43.5	71.5	5.3	12.2%	7.1	16.3%	2.0%
Scenario 4 Plymouth TI and Rainfall	73%	81%	54%	74%	37.0	32.3	61.0	2.1	6.4%	2.8	8.6%	48.4%
Scenario 5 Pittsfield TI and Rainfall	73%	81%	54%	74%	42.4	36.0	70.0	4.1	11.4%	5.5	15.3%	7.9%
Urban Downtown Street - base for comparison (see note)												
Scenario 1 Large trees, two sides	100%	53%	53%	53%	50.7	43.5	70.0	3.8	8.8%	7.3	16.7%	
Alternative parameter for sensitivity analysis												
Scenario 1A Leaf Area Index (LAI) = 3	100%	53%	53%	53%	50.7	43.5	70.0	3.6	8.4%	6.9	15.8%	5.3%
Scenario 1B Root zone = 0.05 m	100%	53%	53%	53%	50.7	43.5	70.0	3.8	8.8%	7.3	16.7%	0.0%
Scenario 1C Alternative TI (Rutland, MA)	100%	53%	53%	53%	50.7	43.5	70.0	3.8	8.7%	7.1	16.4%	2.0%

Note: Each base used for comparison used a Leaf Area Index = 5, root zone = 0.5, Marlborough TI, and Worcester Airport weather data.

Based on this sensitivity analysis, it appears that the potential stormwater reduction benefit of tree canopy may vary considerably with location/rainfall record. A potential topic for future research would be to further investigate whether the variation in rainfall by location results in a significant difference in the estimated interception performance of tree canopy. A detailed analysis of variation across the state is beyond the scope of the current study. We note that the rainfall data record for Plymouth contained in the i-Tree Hydro model database shows a value of 37 inches for annual rainfall, compared to long-term average annual value of over 48 inches.[3] It may be that the period of record used for our modeling is not representative of average conditions and would thus result in a differing tree-canopy performance outcome.[4]

It appears that tree canopy runoff reduction benefits may also vary with leaf density (although the cases examined by this study showed less sensitivity to this parameter). Therefore, the development of design and regulatory approaches to accounting for this benefit will need to account for potential variations in rainfall record by location, and to some degree for the leaf habit of trees selected for planting schemes intended to achieve rainfall reduction.

Model Results and Sensitivity Analysis for Reduction in Total Phosphorus

i-Tree Hydro also provides estimates of pollutant loading for the modeled land coverage scenarios. For this study, the reduction in phosphorus loading was assessed. Results for the reduction in total phosphorus (TP) are presented for each of the nine land use coverage scenarios in Table 2-6.

Figure 2.15 plots the relationship between estimated phosphorus (TP) reduction and the percentage of impervious area shaded by canopy. As with runoff reduction, the relationship is linear. Figure 2.16 plots the relationship between TP reduction and runoff reduction distributed over the total paved area. This latter figure shows an essentially one to one relationship between percent TP reduction and percent runoff reduction, and suggests that if one estimates the % reduction in runoff resulting from tree canopy, then there is a corresponding reduction of TP. This relationship suggests that the removal of TP over the unpaved portions of the modeled watershed is not significant, for the scenarios analyzed.

As with the analysis of runoff reduction, modeling was also conducted to assess sensitivity of the TP reduction results to various parameters, rainfall record, and location.

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[3] Derived by MassDEP from PRISM grid, personal communication from T. Maguire, MassDEP, April 6, 2016.

[4] We also noted in consultation with MassDEP that some rainfall data-sets used by i-Tree Hydro may be incomplete. This was the case for the data available for the Marshfield precipitation data set, which we considered but did not use in this analysis. This suggests that users of the model should verify that the data records are complete when using the rainfall records accessed through i-Tree Hydro. In some cases, users may need to compile data directly from available rainfall station records for use in the model.

The results of this sensitivity analysis are also presented in Table 2-6, and directly parallel the results found for the analysis of runoff reduction.

TP reduction does not appear particularly sensitive to leaf area index, root zone depth, or location/TI with equivalent rainfall record. TP reduction is sensitive to variation in rainfall record and in combination location/rainfall record. Thus, if tree canopy benefits for phosphorus reduction are under consideration, decision makers will need to account for the sensitivity to location and corresponding rainfall record.

Table 2-6. Reduction in Total Phosphorus for Study Scenarios

Scenario Description		Total Impervious Area	Total Canopy Within Analysis Area	Total Pavement Beneath Canopy		TP Load for Base Case	TP Load Reduction	
		% of total area	% of total area	% of total area	% of imp area	pounds	pounds	%
Subdivision Road								
Scenario 1	Small trees, two sides	73%	57%	30%	41%	531	41	8%
Scenario 2	Large trees, one side	73%	41%	22%	31%	531	31	6%
Scenario 3	Large trees, two sides	73%	81%	54%	74%	531	62	12%
Urban Downtown Street								
Scenario 1	Large trees, two sides	100%	53%	53%	53%	696	60	9%
Scenario 2	Small trees, two sides	100%	41%	41%	41%	696	48	7%
Scenario 3	Large trees at corners	100%	11%	11%	11%	696	12	2%
Parking Area								
Scenario 1	Perimeter landscape	94%	11%	6%	7%	656	8	1%
Scenario 2	One intermediate island	91%	25%	17%	18%	643	22	3%
Scenario 3	Three intermediate islands	82%	38%	21%	26%	590	27	5%
Sensitivity Analysis:								
Subdivsion Road Scenario 3								
Available Annual Precipitation Records								
	Precip record year 2005	73%	81%	54%	74%	547	56	10%
	Precip record year 2006	73%	81%	54%	74%	513	37	7%
	Precip record year 2007	73%	81%	54%	74%	544	84	16%
	Precip record year 2011	73%	81%	54%	74%	538	72	13%
	Precip record year 2012	73%	81%	54%	74%	500	56	11%
Subdivision Road Scenario 3								
Scenario 3A	Leaf Area Index = 3	73%	81%	54%	74%	531	62	12%
Scenario 3B	Root zone = 0.05 m	73%	81%	54%	74%	531	62	12%
Scenario 3C	Alternative TI Rutland	73%	81%	54%	74%	531	62	12%
Scenario 4	Plymouth TI and Rainfall	73%	81%	54%	74%	429	47	11%
Scenario 5	Pittsfield TI and Rainfall	73%	81%	54%	74%	430	49	11%
Urban Downtown Street Scenario 1								
Scenario 1A	Leaf Area Index = 3	100%	53%	53%	53%	696	60	9%
Scenario 1B	Root zone = 0.05 m	100%	53%	53%	53%	696	60	9%
Scenario 1C	Alternative TI Rutland	100%	53%	53%	53%	696	60	9%

Notes:

1. All scenarios based on precipitation record 2011 to 2012, except as noted in table.
2. TP loads are approximate, estimated by scaling from graphical output provided by the i-Tree Hydro model.

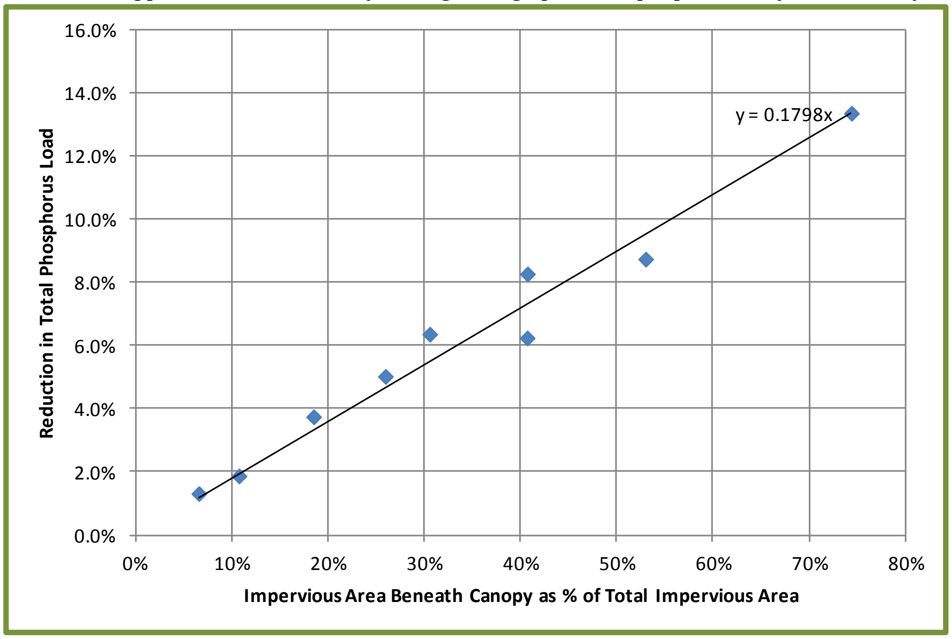

Figure 2.15. Phosphorus reduction as a function percent of impervious area beneath canopy.

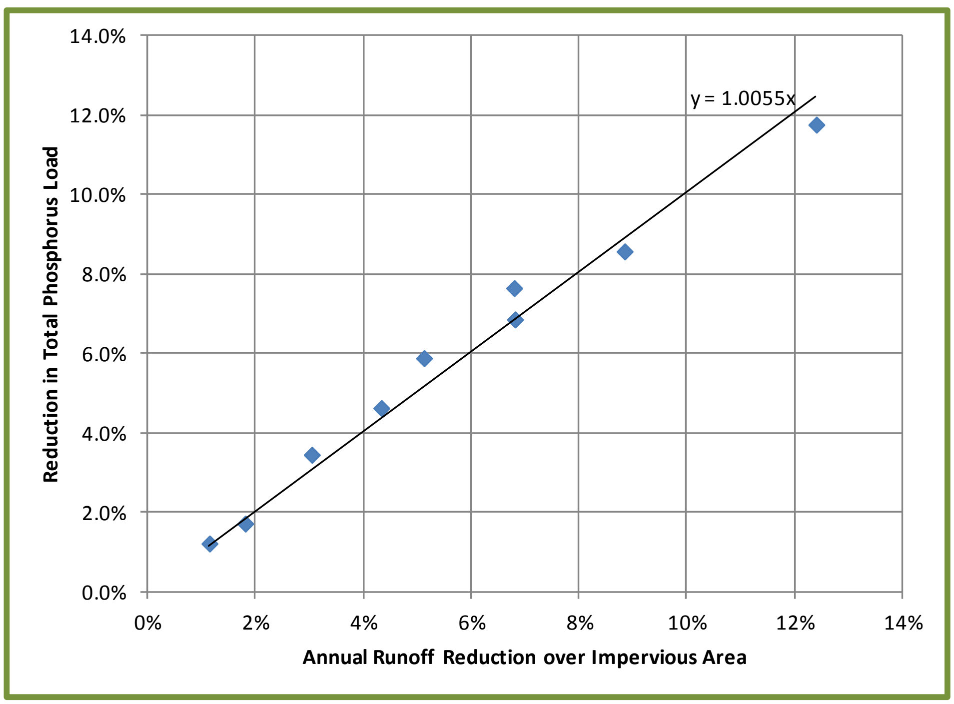

Figure 2.16. Phosphorus reduction as a function of annual runoff reduction distributed over total impervious area

Variation of Rainfall Reduction with the Age of Tree

The i-Tree Hydro modeling utility is essentially based on the area of tree cover and leaf area index, but is otherwise not specific to the individual size, species, or age of tree. However, for evaluating the impacts of tree planting activities on runoff reduction for new development projects or for tree planting programs, it would be helpful to have information on how tree canopy varies with age of tree.

To assess this characteristic, the study has used the i-Tree Design utility, which enables the analyst to choose a particular tree species, and characterize its interception performance at different stages of the tree maturity. This particular utility uses prototypical calculations for trees located, in this case, in the northeastern United States.

The study team selected a variety of trees to compare over a 40-year life span, based on a 2-inch caliper tree at the time of planting. The i-Tree utility was used to estimate the annual interception of the tree at the 40th design year and the average annual interception over the 40-year span. Table 2-7 summarizes the results of this analysis. For the range of tree sizes and species analyzed, if the initial planting diameter of the tree is 2-inches, over a 40 year period the annual average interception will equal about 54% of the interception that the tree achieves at the 40th year of maturity.

In addition, three trees of different mature sizes were selected and characterized for their interception rates at multiple intermediate ages between initial planting and the 40th design year. Figure 2.17 plots the interception rates for these selected trees as a function of age. The shape of the trend lines for the data points for each tree indicates that interception rate increases more rapidly as each tree type matures. This implies that if trees are to be credited for interception benefits over a selected life-cycle, it is important that trees be cared for to ensure health growth and survival over that entire life cycle, in order to achieve projected long term benefits. The incremental yearly increase in interception rate is larger in the latter part of the cycle than in the early years, and this growth in interception rate would be needed to sustain the long-term projected average.

Table 2-7. Annual Tree Interception: Average Year vs. Mature Year

Scientific Name	Common Name	Mature Spread[3] Lower Range	Mature Spread[3] Upper Range	2" Diameter Interception	40 year Interception	Total Interception during 40 year period	Average Annual Interception 40 year period	40-yr Avg. Annual vs 40th year
				Gal.	Gal.	Gal.	Gal.	%
Large Trees								
Acer rubrum	Red maple	25	35	84	2,216	49,653	1,241	56%
Celtis occidentalis	Northern hackberry	40	50	103	2,460	53,719	1,343	55%
Fraxinus pennsylvanica	Green ash	45	50	77	2,944	55,379	1,384	47%
Ginkgo biloba	Ginkgo	50	60	33	642	11,157	279	43%
Gleditsia triacanthos	Honeylocust	35	50	83	3,545	63,626	1,591	45%
*Platanus hybrida**	London planetree	50	70	78	2,890	52,153	1,304	45%
Quercus palustris	Pin oak	35	40	153	3,023	52,786	1,320	44%
Quercus robur	English oak	40	60	102	2,458	54,316	1,358	55%
Quercus rubra	Northern red oak	50	60	102	2,186	41,983	1,050	48%
Tilia cordata	Littleleaf linden	35	50	49	1,412	26,199	655	46%
Ulmus americana	American elm	50	70	134	3,231	56,635	1,416	44%
Ulmus parvifolia	Chinese elm	35	50	134	2,563	52,362	1,309	51%
Ulmus sp.	Elm hybrids	Data not available - assumed comparable to Chinese Elm						
Zelkova serrata	Japanese zelkova	50	75	103	1,237	23,845	596	48%
Medium Trees								
Acer campestre	Hedge maple	30	35	58	331	9,012	225	68%
Koelreuteria paniculata	Goldenraintree	30	40	Data not available				
Pyrus calleryana	Callery pear	30	40	68	2,464	39,067	977	40%
Small Trees								
Acer ginnala	Amur maple	20	25	Data not available				
Amelanchier sp.	Common serviceberry	15	20	71	206	7,256	181	88%
Crataegus phaenopyrum	Washington hawthorn	20	25	71	707	16,096	402	57%
Cornus kousa	Kousa dogwood	15	20	71	225	7,305	183	81%
Malus sp.	Crabapple	10	25	59	1,097	21,110	528	48%
Ostrya virginiana	Eastern hophornbeam	25	30	84	862	21,243	531	62%
Overall Average Interception: Annual average over 40 Year life versus interception during 40th year								54%

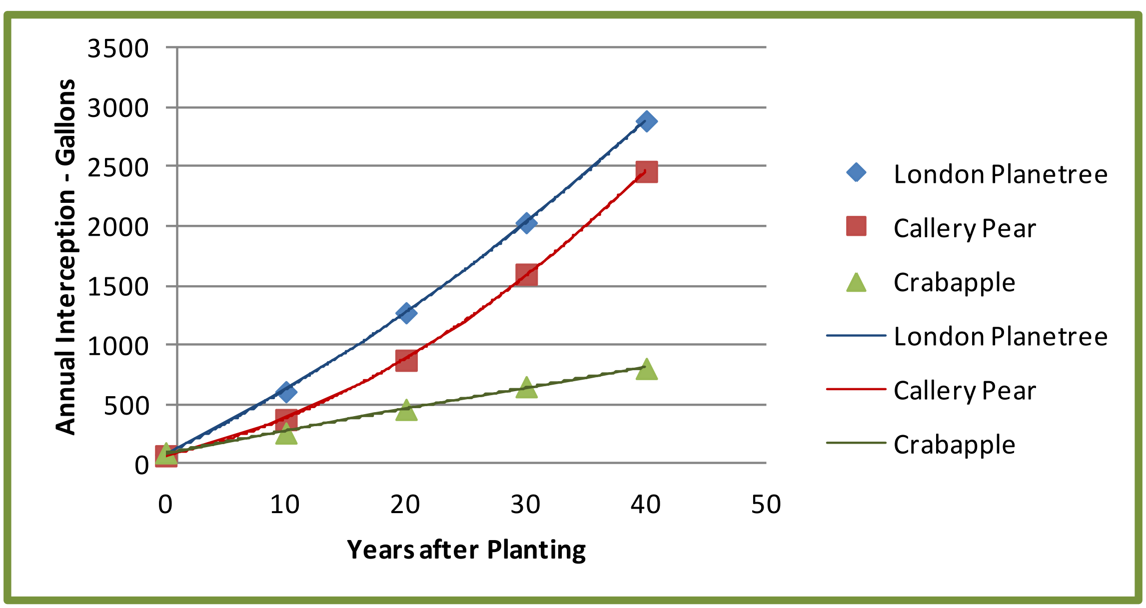

Figure 2.17. Increase in annual interception by selected trees with age.

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3. Tree Canopy Implementation Tools

This Chapter offers prototypical measures to enable municipalities to implement preservation/planting of trees as an integral component of their stormwater management programs. Section 3.1 discusses and presents model language for local regulations to promote tree canopy preservation and enhancement through a low-impact development credit for runoff reduction. In addition, Section 3.2 identifies selected tools and resources available to communities desiring to implement local programs to enhance tree canopy on public properties, and introduces a brochure to support a local outreach program to encourage planting and maintenance of canopy trees on private properties.

3.1 Regulatory Provisions for Tree Canopy Runoff Credits

As discussed in Chapter 2, the interception of rainfall by tree canopy results in a reduction of runoff from impervious surfaces lying beneath the canopy. For development and redevelopment projects, this benefit could be recognized through the application of an appropriate Low Impact Development (LID) credit. This section of Chapter 3 offers recommended regulatory language for municipalities that seek to provide a quantitative credit for stormwater management designs that include preserving or planting canopy trees that overhang impervious surfaces.

Rationale for Recommended Tree Canopy Runoff Credits

The proposed credit system is based on the results of the modeling and analysis discussed in Section 2.4 and shown in Table 2-4. Based on the conclusions of that analysis, we offer the following rationale for developing LID credits for tree canopy:

- The runoff from impervious surface located beneath tree canopy is reduced by greater than 15% for a site located in central Massachusetts, based on the precipitation record in the i-Tree Hydro modeling tool. Therefore, for mature trees, this implies that for sizing of BMPs to infiltrate or treat runoff, the "effective impervious area" to be treated can be reduced by 15% of the area located beneath tree canopy.

- For new tree plantings, the full benefit of runoff reduction does not accrue until the trees reach maturity. As shown in Table 2-7, the average benefit over a 40-year period resulting from installing a 2-inch caliper tree is somewhat greater than 50% for a range of trees recommended for street plantings in Massachusetts. Therefore, for new trees, this implies that for sizing BMPs to infiltrate or treat runoff, the "effective impervious area" to be treated can be reduced by 50% x 15%, or 7.5%.

- New trees also need to be planted with sufficient soil volume to allow for root penetration and healthy growth (discussed further in Chapter 4) so they reach their full potential crown spread. Provision of adequate space for root growth is therefore a prerequisite for full runoff reduction credit for new trees.

- The runoff reduction provided by trees occurs through interception of a fraction of an inch of rainfall over each of many rainfall events. However, the intercepted runoff during any single event does not significantly affect the peak rates of discharge except for the very smallest events. Therefore, no runoff reduction credit is warranted for sizing of BMPs designed to control peak discharges and flooding.

- This rationale for tree credits only accounts for rainfall falling on impervious surfaces that are within the drip line of tree canopy. While tree canopy can also reduce runoff and associated pollutants from lawn areas, the federal and state regulations under which the credits will apply explicitly deal with runoff from impervious surfaces. Therefore, the credit system envisioned in this report is based on direct impacts of tree interception on the volume of runoff from ground-level impervious surfaces.

- As deciduous trees in New England lose their leaves each fall, the accumulation of leaf litter on the paved surface could become a source of nutrients in stormwater runoff. If credits are provided for runoff reduction as a result of tree canopy, the potential for leaf-drop to result in further pollutant generation should be addressed. Therefore, the credit system envisioned in this report includes a provision for pavement sweeping each fall, subsequent to leaf-drop, as a necessary condition for any project to qualify for runoff reduction credit.

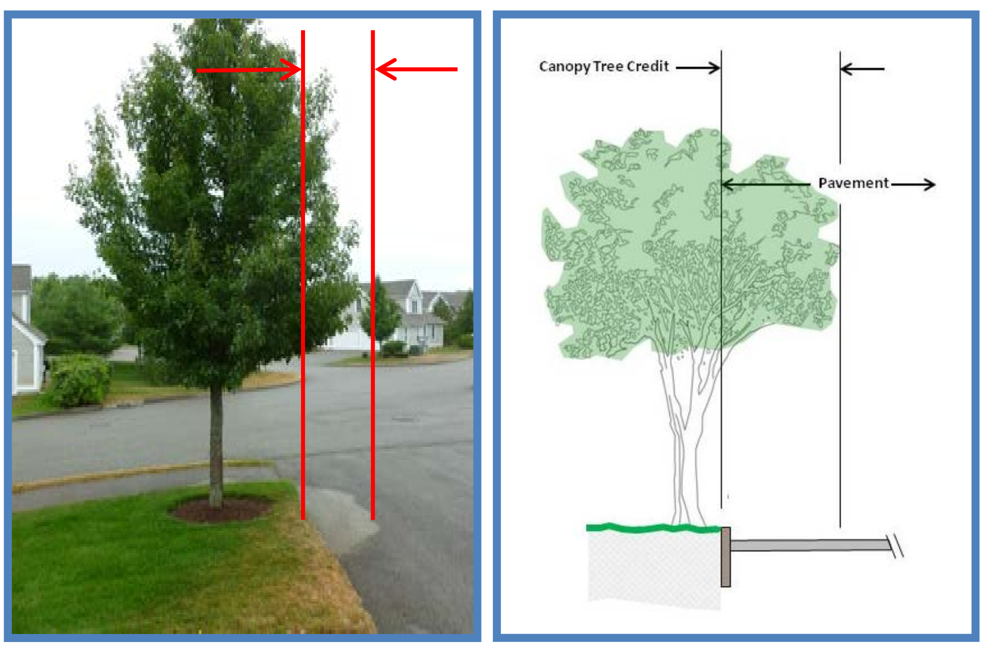

Figure 3.1 Runoff Reduction Credit based on area of pavement beneath tree canopy.

Note that a tree credit system based on the above rationale will generally only consider deciduous trees for new plantings, as the vertical geometry of coniferous trees (wide at the base, narrow at the top) makes these trees impractical for shading actively-used impervious surfaces. In some cases, an existing mature conifer that has been pruned over its lifetime to provide a clear understory may be eligible for credit.

Recognizing that only a portion of the paved area within a typical development site will lie within the extent of canopy cover, the overall credit for reduction in runoff will likely be small. If 100% of the pavement on a site was located within the extent of tree canopy, the reduction in runoff (at tree maturity) would be a maximum of 15% under this suggested methodology. However, combining this credit with other LID credits will help reduce the volume of runoff ultimately requiring treatment in structural BMPs, and has the further benefit of encouraging the use of trees, which offer a number of other environmental services (as discussed in Chapter 2). Also, in an ultra-urban setting (such as a downtown area or dense residential neighborhood), the preservation or provision of street trees may be one of the few options for offsetting the environmental impacts of runoff, and the ability to account for this benefit can help support decision makers in their efforts to promote tree planting and maintenance programs.

Federal and State Regulatory Context for Providing Tree Canopy Credits

The US Environmental Protection Agency, Region 1 issued the Massachusetts MS4 General Permit in April 2016. The permit requires permittees to develop, implement, and enforce a program to address post-construction stormwater runoff from new development and redevelopment sites. The post-development controls must include provisions to require the retention and/or treatment of runoff for both new and redevelopment projects.[5]

For new development, stormwater management systems need to be designed to retain the volume of runoff equivalent to or greater than one (1.0) inch multiplied by the total post-construction impervious surface area of the development site and/or meet specific pollutant removal requirements. Redevelopment stormwater management systems must be designed to retain at least 0.80 inch of runoff and/or meet specific pollutant removal requirements.

The use of existing or new tree canopy to intercept a portion of rainfall that would otherwise become runoff would help reduce the volume of runoff that must be retained and/or treated under the MS4 Permit conditions. In this report, we recommend a credit system that a regulatory authority could use for quantifying this reduction to meet EPA requirements.

[5] Please see the current MA MS4 General Permit for all requirements applicable to stormwater management for new and redevelopment projects:
https://www3.epa.gov/region1/npdes/stormwater/MS4_MA.html

Under State regulations, MassDEP does not currently provide for a quantitative credit for runoff reduction by tree canopy. This report recommends that the MassDEP consider providing a runoff reduction credit for tree canopy as a Low Impact Development credit based on the rationale described above, and supplement or amend Volume 3, Chapter 1 of the *Massachusetts Stormwater Handbook* to reflect such a credit. If MassDEP adopts an LID credit, then a municipal regulation could simply reference the MassDEP provisions, instead of adopting and codifying a local credit methodology.

If MassDEP does not provide an approach for crediting the runoff reduction afforded by tree canopy, then the local municipality may wish to adopt a local standard to enable projects within its jurisdiction to address MS4 General Permit retention requirements, to the extent these requirements are more stringent than the provisions of the Massachusetts Stormwater Management Standards. For example, for development of impervious surfaces on Hydrologic Soils Group (HSG) B soils, Massachusetts requires retention and infiltration of 0.35 inch of runoff (Stormwater Management Standard 3), while the MS4 General Permit requires retention of 1.0 inch for a new development project, and if such retention cannot be achieved, a specified level of treatment. A project in the municipality could propose to provide infiltration BMPs sized to recharge 0.35 inches of runoff, and apply tree canopy credits (and other LID credits) to help further reduce all or part the remaining 0.65 inches of runoff, with treatment of the remaining runoff to the level required under the MS4.

Given this state and federal regulatory context, this section of Chapter 3 offers example regulatory language for a municipality to include in its Stormwater Management Regulations to provide for runoff reduction credits under certain conditions where the development design provides for the preservation or establishment of tree canopy in proximity to ground-level impervious surfaces.

Stormwater Bylaw and Regulations Language:

The authors of this document assume that a community interested in adopting a system of credits for the preservation or establishment of tree canopy has already adopted or intends to adopt a Stormwater Management Bylaw and Stormwater Management Regulations that comply with the MS4 General Permit requirement. The typical Stormwater Bylaw and Regulations cover a wide range of topics outside of the scope of this report. Guidance for developing or modifying local stormwater bylaws and regulations may be found elsewhere. This report focuses on specific provisions to account for the benefits of tree canopy adjacent to impervious surface.

Typically, municipal regulatory authority will be codified in two parts: (1) a Stormwater Management Bylaw and (2) the supporting Stormwater Management Regulations. Typically, the Bylaw component does not need to include specific language pertaining to runoff reduction credits for tree canopy. On the other hand, the supporting Regulations would typically require modification to include provisions for tree canopy credits. Recommended language is offered below.

Municipalities that elect to adopt the regulatory language recommended below should note the following:

- The suggested language may need to be modified to be consistent with the format of the municipality's particular bylaw and regulations.
- The municipality should consult with its legal counsel to review proposed new or modified Bylaws and Regulations, as well as the procedural requirements for adopting these instruments, for consistency with applicable laws and regulations of the Commonwealth of Massachusetts.

Stormwater Management Regulations Language

Under the appropriate section(s) addressing administrative review procedures and standards:

1. [*List required performance standards for Land Disturbance Review, including provisions required to comply with the MS4 General Permit, including its requirements pertaining to the retention and treatment of runoff for new development and redevelopment sites. Modify or amend to include the following provisions relative to runoff reduction credits for tree canopy.*]

2. To meet or partially meet the runoff retention requirements described above, stormwater management systems on new and redeveloped sites may use low impact development (LID) techniques to achieve reduction in stormwater runoff where soil, groundwater and topographic conditions allow. These may include but not be limited to reduction in impervious surfaces, disconnection of impervious surfaces, infiltration systems, [*list other LID techniques allowed*[6]] and preservation or provision of tree canopy in compliance with the [*name of municipality*] Stormwater Management Bylaw and these Stormwater Management Regulations.

Under the appropriate sections prescribing the development of a Stormwater Management Plan required for permit applications

The Stormwater Management Plan shall fully describe the project in narrative, drawings, and calculations. It shall at a minimum include:

1. [*List requirements for the Stormwater Management Plan and include the following*

[6] LID techniques covered by this provision should be addressed under the accompanying stormwater regulations. Also, the techniques should have a runoff reduction volume (or an equivalent reduction of area of impervious cover) that be quantified. Other sections of the Regulations which list acceptable LID practices should include tree canopy preservation and enhancement.

Stormwater Management Regulations Language

provisions for describing tree canopy for which runoff credits will be claimed.]

2. Narrative describing:

   a. [*List required contents of stormwater management narrative and include the following provision regarding tree canopy protection and enhancement.*]

   b. Where and how the project will provide for preservation of existing trees or the installation of new trees for which runoff reduction credits will be claimed under the provisions of these regulations. The narrative shall describe completely how existing trees will be preserved, how new trees will be installed, who will be responsible for maintenance and replanting, and how the tree canopy will be permanently maintained for the life of the project (40 years) or until redevelopment occurs. The maintenance plan shall also provide for sweeping of paved areas each fall following leaf-drop.

3. Plans

   a. [*List required contents of stormwater management plans and include the following provision regarding tree canopy protection and enhancement.*]

   b. Indicate existing trees to be preserved and for which runoff reduction credits are claimed under the application.

      i. Indicate size, species, and dimensions of existing tree crown for each tree qualifying for runoff reduction credit.

      ii. Provide a tabulation of the total area of ground-level impervious surface that will be located beneath existing tree canopy.

   c. Indicate proposed trees to be installed for which runoff reduction credits are claimed under the application.

      i. Indicate size, species, and projected dimensions of mature tree crown (use an age of 40 years for estimating mature crown diameter).

      ii. Provide a tabulation of the total area of ground level impervious surface that will be located beneath proposed canopy at maturity.

4. Calculations

   a. [*List required stormwater management calculations and include the following provision regarding tree canopy protection and enhancement.*]

   b. Provide calculations showing the computed runoff reduction credit for preservation of existing trees or provision of new trees, as stipulated in the

Stormwater Management Regulations Language

methodology included in these Regulations.

Under the appropriate section(s) prescribing the provision of an Operation and Maintenance Plan for permit applications:

A stand-alone Operation and Maintenance Plan (O&M Plan) shall be provided at the time of application and shall include:

1. [*List requirements for the Stormwater Operation and Management Plan, and include the following provision for maintaining tree canopy for which runoff credits will be claimed.*]

2. For projects that claim runoff reduction credits for existing or new tree canopy, the O&M Plan shall include:

    a. A map showing locations of all trees designated for tree canopy reduction credits. The map shall be annotated to advise the party responsible for maintenance of the obligation to maintain and replace the designated trees for the life of the project (40 years).

    b. Instructions for the routine care of the trees for the life of the project. The instructions shall be prepared by a qualified professional (Registered Landscape Architect, Massachusetts Certified Arborist, or other professional approved by the municipality).

    c. Provisions for the replacement of trees that die or are damaged beyond salvage, for the life of the project. Dead or severely damaged trees shall be replaced within 6 months with new trees meeting the requirements of these regulations.

    d. Provisions for sweeping of paved areas to remove and dispose of leaves accumulated on the paved surface following leaf-drop each fall.

Under the appropriate section(s) prescribing Performance and Design Standards for permit applicants

[*List performance and design standards applicable to the Stormwater Management System required under the regulations and include the following provision for tree canopy for which runoff credits will be claimed.*]

Tree Canopy Runoff Credits and Requirements[7]

1. A "Tree Canopy Runoff Credit" shall be allowed when new or existing tree canopy from a

[7] If MassDEP adopts a Low Impact Development Credit for Tree Canopy, then this regulation could reference the MassDEP provision instead of adopting the following tree credit allowance provisions.

Stormwater Management Regulations Language

list of approved species extends over ground level impervious cover:

a. The credit shall consist of a reduction in effective impervious area, and shall be calculated as stipulated in these Regulations.

b. Ground level impervious cover includes paved streets and parking areas, sidewalks, and other impervious surfaces at grade. Ground level impervious cover does not include the roofs of structures.

c. The credit (in terms of square feet of impervious cover) may be deducted from the total area of impervious surface that must be managed under the runoff retention and treatment requirement of the USEPA MS4 Massachusetts General Permit (see Paragraph 7 below.[8]

d. The tree canopy credit shall not be used to reduce the area of impervious surface for the analysis of peak runoff rates or volumes.

e. To qualify for tree canopy runoff reduction credits, existing trees to be preserved and proposed tree plantings shall meet the requirements specified in these regulations.

f. To qualify for tree canopy runoff reduction credits, the project must have a maintenance program that provides for long term tree care and replacement, as well as pavement sweeping each fall following leaf-drop.

2. To qualify for tree canopy runoff reduction credit, the tree species must be non-invasive species suitable for use in an urban environment. Trees shall be species found on the municipality's approved tree list, unless otherwise authorized by the (*stormwater review authority*).

3. Drawings and supporting documents shall indicate how existing and new trees will be protected and maintained during construction.

   a. To qualify for tree canopy runoff reduction credits, existing and proposed trees shall be protected during construction according to written instructions prepared by a qualified professional (Registered Landscape Architect, Massachusetts Certified Arborist, or other professional approved by the municipality).

   b. Generally, disturbance within the essential root zone, defined as the area located on the ground between the tree trunk and 10 feet beyond the drip line of an existing

[8] If MassDEP amends the Massachusetts Stormwater Handbook to include runoff reduction credits for tree canopy, then the qualifying area could also be used to reduce the area requiring management under Stormwater Management Standards 3 (Recharge) and 4 (TSS Removal).

Stormwater Management Regulations Language

tree, shall not be permitted, except where conducted in strict accordance with such instructions.

4. Existing trees proposed for preservation and new trees proposed for installation to qualify for runoff reduction credits shall be considered an integral component of the stormwater management system, and shall be subject to the review, inspection, completion, surety, and other procedural requirements applicable to other stormwater management system components under these regulations.

5. Tree Canopy Credits for new trees

   a. New trees shall be deciduous trees at least 2-inch diameter at breast height (dbh) to qualify for the credit. (Coniferous trees are not typically installed to overhang impervious surfaces, and are not included as qualifying trees for the purposes of this regulation.)

   b. The Effective Impervious Cover Reduction (EIC_R) shall be calculated for new trees as follows:

      i. Tabulate the qualifying Canopy Area (CA) consisting of the area of ground level impervious surface beneath the canopy projection area (i.e., within the drip line) of new trees for which credit is claimed. The area shall assume the tree canopy projection at maturity (40 years). Pervious surfaces beneath the canopy shall not be included in this tabulation.

      ii. Credit for EIC_R shall be computed as follows:

      Maximum $EIC_R = (0.075) \times (CA)$[9] where EIC_R and CA are measured in square feet.

   c. The reduction credit shall be dependent on the provision of sufficient soil volume to sustain a mature tree, as follows:

      i. For full credit, each new tree shall be installed in a planting bed or trench with a soil volume available for rooting (S_v) equal to two (2) times the total canopy projection area (CP) of the tree at maturity (use 40 years as the age at maturity):[10]

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[9] This formula accounts for the average interception benefit of a tree from the time it is installed (2-inch caliper) until the time it reaches its mature size.

[10] For example, a tree with a mature crown diameter of 30 feet has an area at the drip line equal to 707 square feet. The required soil volume for this tree would be 2 X 707 = 1414 cubic feet. At four feet of soil depth, the required planting area for this tree would be 354 square feet of suitable planting material.

Stormwater Management Regulations Language

$S_v = 2 \times (CP)$, where is CP is measured in square feet and S_v in cubic feet.

ii. If the actual provided soil volume does not equal 2 times the mature canopy area, the tree may receive partial credit, prorated based on soil volume according to the formulas:

Adjustment factor = (actual S_v) / (2 x CP)

Credited EIC_R = (Adjustment Factor) x (Maximum EIC_R) [11]

iii. The soil shall consist of native natural soil materials or installed planting media meeting standard horticultural practices, designed to promote normal, healthy root penetration and tree growth. The required soil volume shall not extend under pavement or other compacted surfaces, unless the applicant provides for specialized structural soils systems specifically designed for tree plantings.[12]

iv. The soil shall have a depth of at least 3 feet.

6. Tree Canopy Credits for existing trees.

   a. Existing trees shall be at least 4-inch diameter at breast height (dbh) to be eligible for the reduction.

   b. A qualified professional (Massachusetts Registered Landscape Architect, Massachusetts Certified Arborist, or other professional approved by the municipality[13]) shall document the following:

      i. The location of each existing tree proposed for credit is suitable for continued growth and health of the tree (including but not limited to consideration of such factors as proximity to power lines, overshadowing by larger trees, and proximity to buildings and pavements);

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[11] For example, in the above case, if the designed planting bed has only 400 cubic feet of soil volume (e.g., 10 ft. x 10 ft. x 4 ft. depth), then the tree credit shall be multiplied by the factor: 400/1414 = 0.28. That is, only 28% of the maximum allowable credit shall be allowed for that tree. Note that tree boxes are typically much smaller than the reduced area used for this example; their size confines the roots of the installed trees and inhibits the natural growth and crown development of the trees, reducing the long term potential runoff reduction benefits. One purpose of this report and the recommended regulatory language is to encourage the provision of a growing environment that fosters the long-term viability of canopy trees.

[12] See discussion of structural soils systems in Chapter 4.

[13] If the community employs a tree warden or community arborist, this provision may include that person in the list of approved professionals.

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ii. The tree is in healthy condition, based on visual examination of factors including but not necessarily limited to evidence of disease, pest infestation, foliage die-back, and structural deficiencies.

c. The reduction credit shall be calculated for existing trees as follows:

i. Tabulate the qualifying Canopy Area (CA) consisting of the area of ground level impervious surface beneath the canopy projection area (i.e., within the drip line) of the existing trees for which credit is claimed. Pervious surfaces beneath the canopy shall not be included in this tabulation. Project plans should documentation the extent of the existing canopy.

ii. Credit for Effective Impervious Cover Reduction (EIC_R) shall be computed as follows:

Credited EIC_R = (0.15) x (CA)[14]

d. The project design shall ensure the existing tree will be viable following completion of the project.

i. Except as may be otherwise provided by a qualified professional as described below, the tree shall be protected during construction according to the practices outlined in the publication *Protecting Trees from Construction Damage* (Nancy Miller, David Rathke, and Gary Johnson, 1993, rev. 1999, Saint Paul, MN: Minnesota Extension Service).[15]

ii. Any new earth disturbance within the essential root zone, defined as the area located on the ground between the tree trunk and 10 feet beyond the drip line of an existing tree, shall be prohibited unless the following provisions are followed.

iii. Such disturbance shall only be conducted in strict accordance with written tree preservation/protection instructions prepared by a qualified professional (Massachusetts Registered Landscape Architect, Massachusetts Certified Arborist, or other professional approved by the municipality);

iv. Finished grade shall be no higher than the trunk flare of each tree to be retained. If a grade change of 6 inches or more at the base of a tree is

[14] This formula accounts for the interception benefit of the tree at the time of permit issuance, and assumes no increase in benefit over time.

[15] Accessed at http://www.extension.umn.edu/garden/yard-garden/trees-shrubs/protecting-trees-from-construction-damage/

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proposed, a retaining wall or tree well shall be required, unless alternative measure is specified by a qualified professional;

v. The applicant shall provide performance surety approved by the municipality, providing for the replacement with a qualifying new tree in the case that the existing tree dies within 5 years of the date of issuance of a certificate of compliance under these regulations.

7. Remaining impervious surface requiring retention and/or treatment under the provisions of the MS4 General Permit.

   a. Tabulate the total area of impervious cover (IC) subject to runoff retention and treatment under these regulations.

   b. Tabulate the total Credited EIC_R for existing and new tree canopy as provided in these regulations.

   c. Compute the Effective Impervious Cover (EIC) for which runoff must be retained and infiltrated and/or treated under these regulations, using the following formula:

      $EIC = (IC) - (EIC_R)$ where EIC, IC, and EICR are measured in square feet.

   d. The remaining EIC shall be retained and treated as provided by these regulations using a combination of other LID techniques and Best Management Practices.

Example Tree Credit Calculation

A project subject to issuance of a stormwater permit under the regulations will result in the development of 60,000 square feet of impervious surface. The site plans document the preservation of existing trees in compliance with the terms of the regulations, to provide 6,000 square feet of canopy extending over parking areas, walks, and drives.

The proposal also provides for 36 new trees whose estimated crown diameter at maturity will be 40 feet (20-foot radius), if the trees are planted with sufficient space for root growth.

- 12 of the new trees will each be planted in a 10-foot by 20-foot landscaped island located in a parking area, with suitable soils extending to at least 4 feet of depth.
- The remaining 24 trees are planted in lawn areas and spaced so that available soil for root penetration exceeds 2600 cubic feet for each tree. The drawings document that the canopy overhanging pavement at full maturity would be 8,000 square feet.

The allowable reduction in effective impervious cover under the recommended regulations is computed as follows:

Credit for existing trees:

EIC_R existing trees = 0.15 x 6,000 square feet = 900 square feet

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Credit for new trees in planted islands:

Crown project each tree: CP = (π) x (20 ft.)^2 = 1257 sq. ft.

Area of each planter: A = 10 ft. x 20 ft. = 200 sq. ft.

Impervious area beneath crown: CA_{each} = 1257 - 200 = 1057 sq. ft.

Total area of impervious under canopy: CA = 12 x 1057 = 12,684 sq. ft.

Maximum credit: EIC_R max. = 0.075 x CA = 0.075 x 12,684 = 951 sq. ft.

Required soil volume each tree: S_v = 2 x CP = 2 x 1257 = 2514 cu. ft.

Soil volume provided each tree: S_v actual = 10 x 20 x 4 = 800 cu. ft.

Adjustment soil volume: Adj. Factor = 800/2514 = 0.32

Final credit for trees in planters:

EIC_R trees in islands = 0.32 x EIC_R max = 0.32 x 951 = 304 sq. ft.

Credit for new trees in lawn areas, with tree canopy overhanging pavement:

EIC_R trees in lawns = 0.075 x 8,000 sq. ft. = 600 square feet.

Total credit for all qualifying trees:

EIC_R = 900 + 304 + 600 = 1804 sq. ft.

This area can be deducted from total impervious area used to compute the volume of runoff that must be retained and/or treated under these standards.

Alternative Methods for Providing Tree Canopy Runoff Reduction Credit

Chapter 2 presented the results of an analysis of runoff reduction benefits of tree canopy, using i-Tree Hydro modeling of a variety of prototypical planting scenarios. The regulatory language presented above applies the results of that analysis, allowing stormwater designs based on a reduction of "effective impervious cover" for development and redevelopment projects that provide for preservation or enhancement of tree canopy. The proposed credit system reduces directly connected impervious surface in proportion to tree canopy area overhanging the pavement.

In developing this methodology, the project team noted that a number of communities across the country provide stormwater management credits for trees. While it is beyond the scope of the current project to extensively investigate the various tree credit programs in use, municipalities or the MassDEP may wish to explore credit systems currently in place in other jurisdictions. The following publication provides a useful overview of some of the regulations currently in application:

Stone Environmental, Inc. 2014. *Tree Credit Systems and Incentives at The Site Scale: Final Report.* Prepared for Urban and Community Forestry, Vermont

Dept. of Forests, Parks & Recreation, Montpelier, VT. Accessed at: http://www.vtcommunityforestry.org/sites/default/files/pictures/site_scale_tree_credits_2014_02_28_final.pdf

The project team's brief review of a selection of the credit systems currently in place indicates that many of them provide credits on a per individual tree basis, without reference to ultimate canopy spread, or whether this canopy overhangs pavement. The findings of our analysis indicate that essentially, reduction of runoff in numerous small storm events only occurs where impervious surface lies beneath tree canopy, as most vegetated ground surfaces (whether or not beneath canopy) generate little if any runoff during these rainfall events.

Further, the credit systems based on individual trees typically do not directly relate the size of area reduction to the portion of rainfall intercepted by trees. Our analysis found that runoff reduction was on the order of 15% of canopy cover. A number of the credit systems provide a standardized area credit (e.g, 100 square feet per qualifying tree) that does not necessarily bear a relationship to the actual expected runoff reduction resulting from interception.

A more promising alternative for accounting for the stormwater management benefits of trees is included in the Minnesota Stormwater Manual developed by the Minnesota Pollution Control Agency (MPCA). That agency has developed a method to account on a "per event" basis the stormwater benefits of trees used in "tree trenches" and "tree boxes" (these are essentially "bioretention" BMPs). The runoff reduction credits account for interception, evapotranspiration, and infiltration (where soils are suitable) for these BMPs. A major advantage of the MPCA methodology is that it allows for draining paved areas into the tree trench or tree box. A tree has an evapotranspiration capacity that generally exceeds the amount of rainfall falling directly on the ground within the tree's drip line. Therefore, a tree is capable of processing water from areas well beyond its footprint. The MPCA credit calculation accounts for this capacity. A copy of the credit method has been downloaded from the MPCA web-site and included in Appendix B. The credit system description can be accessed at the following web page, which also provides links to BMP design standards, methodology documentation, and related supporting information:

http://stormwater.pca.state.mn.us/index.php/Calculating_credits_for_tree_trenches_and_tree_boxes

We recommend that the MPCA credit methodology should be considered for both State and local stormwater credit systems. However, prior to adoption of the practice, further analysis of the method is required, to refine the hydrologic components to correspond to Massachusetts climate conditions (the method currently uses Minnesota hydrologic parameters). We recommend MassDEP consider further research to adapt this methodology for Massachusetts.

3.2 Local Programs for Enhancing Tree Canopy for Stormwater Benefits

In addition to the stormwater benefits of tree canopy, the ecological benefits of mature trees include substantial energy savings (through moderation of local temperatures), carbon sequestration, air pollutant removal, aesthetic value, and increased property values. Through a number of research and tree census projects, the USDA Forest Service's Center for Urban Forest Research (CUFR) has explored and documented the ecological services provided by trees in the urban landscape. For example, one of the CUFR studies, the *New York City, New York Municipal Forest Resource Analysis* (P.J. Peper, et. al., 2007), showed that at the time of the study, New York City street trees returned $5.60 of ecological benefits to the community for every $1 spent on management, with about 29% of these benefits derived from savings in stormwater management costs.

Given the multiple ecological services provided by trees, communities may want to explore the establishment of well-planned urban forestry programs (or the improvement of existing programs) designed to ensure the accrual of these benefits for their residents and businesses. There are numerous resources available to a community interested in developing a municipal forestry program that includes measures to promote the management of tree canopy for stormwater benefits. The following offers suggestions to assist the community to initiate development of a local public program for promoting effective tree canopy.

Internal Program: Municipal Urban/Community Forestry

A community may be interested in maintaining, enhancing, and increasing its population of trees located on public property, including public roadways and publicly owned facilities (municipal offices, public works facilities, schools, and other governmental properties). Guidance for the development of an effective program for tree management may be found in a number of resources, including the following:

- The Massachusetts Department of Conservation and Recreation (DCR) offers a wide range of support materials describing urban and community forestry programs and the management of community trees. The following links connect to general information about the DCR program and to detailed lists of publications available from that program:
    - http://www.mass.gov/eea/agencies/dcr/conservation/forestry-and-fire-control/urban-and-community-forestry.html
    - http://www.mass.gov/eea/agencies/dcr/conservation/forestry-and-fire-control/picks-and-shovels-urban-and-community-forestry-faqs-resources-fact-sheets.html
- The USDA Forest Service, in partnership with the Center for Watershed Protection (CWRP) has prepared the *Urban Watershed Forestry Manual*, a three

volume guide to assist communities, developers, and individual residents in establishment and maintenance of forest resources within the built environment:

- Part 1: Methods for Increasing Forest Cover in a Watershed
- Part 2: Conserving and Planting Trees at Development Sites
- Part 3: Urban Tree Planting Guide

- The USDA Forest Service, in partnership with Davey Tree Expert Company, the Arbor Day Foundation, Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees, has developed a suite of software tools and associated resources referred to as "i-Tree Tools." *i-Tree* comprises a state-of-the-art, peer-reviewed software suite designed to support urban and rural forestry analysis and benefits assessment. Municipalities of all sizes can employ i-Tree Tools to quantify the structure and condition of community trees and forests and document the environmental services that trees provide. A community that is considering developing an well-founded urban forestry program may want to investigate these tools to support this effort. The resources include tools for such activities as landscape level assessments, street tree inventories, quantification of benefits, and tree selection.

  The software tools, underlying research documentation, and supporting materials can be accessed at the following links:

  - https://www.itreetools.org/
  - https://www.itreetools.org/applications.php

External Program: Community Outreach

In addition to considering a public program for installing and maintaining trees for stormwater and other benefits, a community should also consider promoting and supporting tree canopy establishment by individual homeowners, business owners, and property developers. Potential outreach activities that communities could undertake to promote the use of tree canopy for stormwater management include:

- Homeowners:
  - Develop a page on the community's stormwater web site to provide resources on tree selection, installation, and care on individual home and apartment sites;
  - Develop and distribute one or more fact sheets to homeowners describing the benefits of trees for stormwater management and providing guidance on where the homeowner can find information to assist in the selection, installation, and care of trees for this purpose. Such a fact sheet could be a

component of a community's public education program for complying with its US EPA NPDES MS4 Permit.

The fact sheet could link to interactive tree benefit calculation tools such as those maintained on the internet by the Arbor Day Foundation and by i-Tree Tools:

- Simple benefit calculator (allows selecting a tree and a size to compute ecological benefits):

  http://www.treebenefits.com/calculator/

- Interactive map calculator (more complex on-line tool allowing use of an interactive map to locate a property, select and locate trees on the site, and compute the resulting benefits):

  http://design.itreetools.org/

- If the community has a fee structure for stormwater management (through an enterprise fund or other mechanism), the community could offer a discount for installing and/or preserving a tree meeting qualifying conditions established by the municipality. For example, the city of Roanoke Virginia includes a fee credit for a variety of Low Impact Development and other treatment measures, including tree canopy meeting certain conditions.[16]

- Commercial/Industrial Property Owners:
  - Provide community web-site information for commercial properties similar to that discussed for homeowners above.
  - Provide outreach brochures to businesses, comparable to the measure described for homeowners above.
  - If there is a fee structure for stormwater, consider a credit/discount for tree canopy as discussed for homeowners above.
  - Promote tree canopy coverage in local regulations governing the development of parking lots.

    Many communities have Zoning Bylaws or Ordinances that require the provision of landscaped buffers, landscaped perimeters around parking islands, and landscaped islands within parking areas. We recommend that

[16] See: City of Roanoke, VA. 2014. Stormwater Utility Fee Credit Manual, Single Family Residential Properties. https://www.roanokeva.gov/DocumentCenter/View/354

communities consider reviewing the regulatory provisions for these landscaped areas to accomplish the following:

- Promote the maximum practicable tree canopy coverage. A number of Massachusetts communities have established coverage requirements up to 30% of the area of parking lots.

- Ensure that the dimensions of the planting areas are sufficient to provide the soil volumes necessary to support the healthy growth of trees so that they achieve mature canopy. Refer to the discussion in Chapter 4 of this report for information on the required volume of soil. Note that the typical 4 foot square tree pit is far too small to support the long term viability of a full size tree.

- Subdivision and Site Developers:

  - Promote tree canopy development under the stormwater management regulations, using language such as the prototype provided in Section 3.1 of this report.

    Zoning and Subdivision Regulations should cross reference to the Stormwater Management Regulations, or contain comparable requirements for the provision of canopy trees.

    Communities should ensure that qualifications for runoff reduction credits for canopy trees include an operations and maintenance plan that provides for care of the trees, sweeping of pavements in the fall after leaf drop, and adequate budgeting for the tree maintenance and replacement program.

  - Promote the development of stormwater reducing tree canopy in local Zoning and Subdivision Regulations.

    We recommend that communities should review local regulations to ensure that the provisions are consistent with developing healthy, mature tree canopy. In addition to the provisions discussed above for commercial/industrial sites, communities consider the following:

    - Regulations should clearly permit the use of open space areas, landscaped islands, and landscaped portions of new roadways for the installation of Low Impact Development drainage practices, including the installation or preservation of canopy trees (with provisions, as necessary, for protecting pavements against root damage – see discussion in Chapter 4).

    - Regulations should not require the full clearing of rights-of-way within new subdivisions, but allow the retention of existing trees where feasible, given consideration for the installation of utilities, provision of adequate vehicular sight-lines, and limits on root disturbance of existing trees.

Appendix C includes brochures designed to assist communities with implementing an outreach program to encourage the use of trees for stormwater management and other ecological benefits, in line with the above suggestions for a local urban/community forestry program.

4. Stormwater Management with Trees

Previous chapters have discussed the role of trees in reducing runoff through direct interception of rainfall and through evapotranspiration. In addition, trees provide other stormwater management benefits, through the uptake of nutrients, moderation of local temperature conditions, and control of erosion and the attendant generation of pollutants. Recognizing the value of trees in offsetting the impacts of runoff, new development and redevelopment projects should integrate trees into the overall design of stormwater management features included in those projects.

This integrated approach includes:


MassDOT

- Canopy trees as BMPs.

  Trees should be considered as a Best Management Practice (BMP), to be used with other stormwater practices to achieve effective control of stormwater impacts.

- Canopy trees in BMPs.

  Trees should be incorporated into the design of a broad array of vegetated BMPs applied to the management of stormwater. The use of vegetation includes the prudent use of trees to enhance the function and performance of these practices.

This Chapter considers the use of trees for their stormwater benefits and offers guidance on tree selection, installation, and maintenance to integrate tree canopy into stormwater management design.

4.1 Canopy Trees as BMPs.

As considered in Chapter 2, tree canopy that overhangs impervious surface provides a direct reduction in annual volume of runoff through interception. Where feasible, runoff directed from nearby impervious areas into the tree's rooting media can also be reduced in volume as a result of evapotranspiration. Either of these approaches employs the tree as a BMP for the management of runoff.

Chapter 3 includes suggested regulatory language for integrating the preservation and enhancement of tree canopy into the overall stormwater treatment train, through a Low Impact Development credit that essentially accounts for interception. Chapter 3 also cites the potential design practice for crediting tree trench and tree box BMPs for quantitative reductions in stormwater runoff associated with interception, evapotranspiration, and infiltration associated with these measures.

In this Section, we discuss selecting and installing canopy trees for stormwater management. While the discussion below offers some general guidance on the selection and installation of trees, its purpose is not to provide a comprehensive guide for tree planting and care. Instead, this report focuses on factors to consider when selecting and installing trees for stormwater management function. Landscape design and tree installation practices are addressed extensively in other literature and training. For example, see the following:

- *Tree Owner's Manual for the Northeastern and Midwestern United States* (Johnson, J.R., et. al. 2008), and

- *Guidelines for Planting Trees and Shrubs* provided by the UMassAmherst Center for Agriculture, Food, and the Environment, accessed at:

  https://ag.umass.edu/landscape/fact-sheets/guidelines-for-planting-trees-shrubs

A project designer should consult with appropriate professionals (e.g., landscape architects, urban forestry professionals, and arborists) in the preparation of a tree planting plan for a new development or redevelopment site. Similarly, municipalities are encouraged to consult with trained professionals in the development of community tree planting programs, including the compilation of plant lists that support regulatory requirements relevant to tree planting.

Selecting Trees for Runoff Reduction Benefits

The selection of tree species for street plantings and the landscaping of development projects should be based on site-specific assessment of environmental conditions and on the desired tree functions. Preferably, trees selected for urban plantings should comprise native species because they are adapted to local conditions and likely to require less maintenance. However, given the space constraints and the severe environmental conditions associated with urban environment, selection of appropriate trees may require considering hardy, non-invasive, non-native species, consistent with regional horticultural practices.

Table 4-1 presents an overview of environmental conditions affecting the selection of tree species for planting in the urban environment. The designer or municipal tree program personnel can use this general guide to assist in the screening and selecting tree species for a particular project setting. *The Urban Forestry Manual: Part 3. Urban Tree Planting Guide* offers an "Urban Tree Selection Guide" that includes fields that correspond to a number of these factors, to facilitate selection of tree and shrub species for a site. This selection guide is available on the internet as an interactive data-base and may be accessed at: http://forestsforwatersheds.org/planting-and-maintaining-trees/

Table 4-1 Environmental Conditions Affecting Tree Selection[17]

Environmental Condition	Species Selection Guidance
USDA plant hardiness zone	Select species appropriate to hardiness zone (see Figure 4.1). However, consider tolerance of species to potential shift in temperature regime associated with climate change.
Sunlight exposure	Select species tolerant of sun exposure at site.
Microclimate features	Select drought tolerant species for areas subject to high wind exposure or high heat reflection.
Topography	Consider landscape position in assessing tree exposure to excessive drainage or flooding.
Regional forest association	Where feasible, select native species from regional forest association in preference to other species.
Soil texture	Select species based on tolerance to conditions on-site. In urban settings and redevelopment sites, design of tree plantings may need to address modifying or replacing existing soils to provide conditions supportive of healthy tree growth.
Soil drainage	
Soil compaction	
Soil pH	Select species tolerant of existing pH conditions. If trees will be planted where concrete pavement surfaces or prepared soil mixtures (e.g., "structural soils") may alter soil pH, select species with a tolerance to alkaline soil conditions.
Soil chemistry	Consider salt content of existing soils, and select salt tolerant species as warranted.
Stormwater runoff to planting site	Assess whether the planting site will likely receive runoff from adjacent areas, in determining whether species should be flood tolerant and drought tolerant. See Tables 4-2 and 4-3 for additional considerations relevant to using trees for stormwater management.
Floodplain connection	Consider position relative to floodplain in assessing whether species should be flood tolerant.
Space limitations	Consider location of surface features (buildings, pavements), subsurface features (pipe and other underground utilities), and above surface features (overhead wires) in selecting species and mature tree size.
Other limiting factors	Consider other limiting factors that may be specific to the site or its local context, including disease and pest resistance, cultural factors, potential exposure to animal and human impacts, and other factors.

[17] Adapted from Capiella, et. al., 2006.

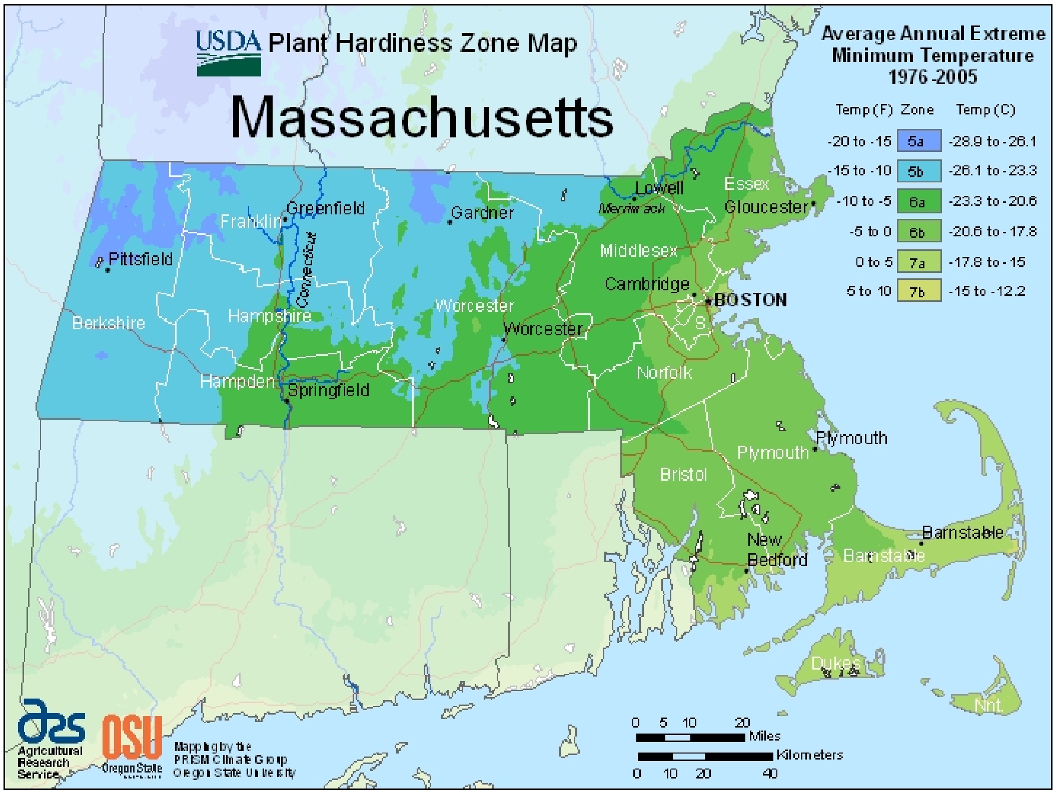

Figure 4.1 Plant Hardiness Zones of Massachusetts
(accessed at: http://planthardiness.ars.usda.gov/PHZMWeb/Default.aspx#)

In addition to the general environmental considerations outlined in Table 4-1, the tree-selection process should also consider factors pertinent to the stormwater management function of the trees. Municipalities and project designers can draw upon many tree species to develop site landscaping and street-planting plans. To illustrate the evaluation of trees for stormwater runoff management benefits, this report uses a limited selection of street trees recommended by MassDOT and posted on the agency's website.[18] It would be difficult to compile an exhaustive list of species for use on projects in Massachusetts. Therefore, street tree program planners and project designers should not feel constrained by this list, but instead use it as a guide for evaluating trees for stormwater management canopy.

Based on the core list adapted from MassDOT, Tables 4-2 and 4-3 offer information for screening trees for providing canopy in the urban setting. Table 4-2 provides a comparative rating of the trees for stormwater reduction benefits. Table 4-3 provides a

[18] The MassDOT tree list was accessed at: https://www.massdot.state.ma.us/highway/Departments/LandscapeDesign/PlantInformation/SuggestedUrbanStreetTrees.aspx

summary of other characteristics that may need to be considered when selecting trees for installation close to pavements in the urban setting. Both tables list the trees by general size category, followed by the pertinent information.

Table 4-2 provides basic information on the mature height and spread of each tree. The remainder of the table (except for the final column) presents results from a comparative analysis of each tree using i-Tree Design (see the description of this model in Chapter 2). The final column in the table presents a rating of the tree based on the i-Tree Species utility (also described in Chapter 2).

Using the i-Tree Design analysis, the table provides an estimate of the total interception of rainfall (in cubic feet) over a 40 year period for each tree, assuming that each tree has a 2-inch diameter at the time of initial planting. By dividing the annual average interception by the area of the tree crown at maturity, the table provides an estimate of the runoff reduction per square foot of canopy. This allows a comparison among the various tree species to evaluate relative effectiveness for rainfall interception.[19] For example, a red maple intercepts an annual average 2.8 inches of rainfall over the canopy area of the tree, out of a total of 41 inches of rainfall for the period of record covered by the model, a reduction of 6.9%. The American elm intercepts about 3.6% of annual rainfall over the canopy of the tree for the same rainfall record. Differences in leaf density and crown area result in the maple tree being more efficient per square foot of canopy at intercepting rainfall than the elm tree.

The final column in Table 4-2 presents an alternative indicator of each tree's relative effectiveness for reducing runoff that accounts for combined interception and evapotranspiration. The "i-Tree Species" utility allows screening a list of trees for their relative effectiveness for "streamflow reduction" (essentially a measure of evapo-transpiration plus interception), grouping trees in ten-percentile groups ranging from the "Top 10%" meeting this function, to the 90-100 percentile group (lowest 10% relative to this function). Thus, if a tree has a higher "percentile group" rating in Table 4-2, the more effective the tree will be for the combined interception/evapotranspiration function.

If a municipality or designer wishes to evaluate a tree that is not listed in Table 4-2, they may use the i-Tree design tool to develop an overall average interception rating for that particular tree, and then compare it to the values in Table 4-2. The i-Tree Design tool can be used on-line and is accessed at: http://www.itreetools.org/design.php

The i-Tree Design model should be used with the following parameters to obtain results for the selected tree, for comparison with Table 4-2:

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[19] Note that the runoff reduction is based on a single year of rainfall record (41 inches) and a representative location for the Northeast US (Queens, NY). Thus, the magnitude of interception in this table is not necessarily consistent with the modeling results presented in Chapter 2. Table 4-2 uses the "i-Tree Design" tool to develop comparative results for the various tree types to illustrate the variability of interception characteristics within this list of trees. Thus, in Table 4-2, the <u>relative</u> amount of interception is of importance (not the <u>total</u> amount).

- A location in central Massachusetts (use Postal Zip Code 01752)
- Exposure setting: Full Sun
- Tree condition setting: Good
- Caliper size at time of planting: 2-inch
- Period of analysis: 40-years
- Crown diameter at maturity can be obtained from US Forest Service information or tree nursery information for the particular tree species.
- Annual precipitation: 41 inches (used for comparison purposes only, does not represent the annual average for central Massachusetts).

For trees not listed in Table 4-2, the designer will need to use the i-Tree Species utility to obtain the "streamflow reduction" percentile category of the selected species. To do this, the designer will need to register and download the suite of i-Tree modeling tools from the following website: http://www.itreetools.org/tools.php

The software contains instructions that will enable access to the listing of trees by functional benefit. This utility can also be used to further screen for trees that have other benefits as well as runoff reduction, if the designer desires to do so. The i-Tree suite program "i-Tree Species" screens a list of about 1600 tree species for trees that provide specific functions. i-Tree Species rates the following tree functions:

- Air pollution removal
- Air temperature reduction
- Ultraviolet radiation reduction
- Carbon storage
- Pollen allergenicity
- Building energy conservation
- Wind reduction
- Stream flow reduction

The user enters location data and selects a ranking of the project-specific importance of each tree function (based on a scale of 0 to 10). The utility returns a ranked list of appropriate species suitable for the hardiness zone associated with the location. The resulting list would need to be further screened to select trees appropriate for the planting conditions at the user's site (e.g., drainage conditions, sun exposure, pest susceptibility, soil pH limitations, aesthetic requirements, etc.).

Table 4-3 presents additional tree selection factors pertaining to stormwater management, including:

- salt tolerance for street/roadside trees;
- drought tolerance for ultra-urban planting;
- alkaline soil tolerance for tree planting (a factor to be considered along with drought tolerance if the designer is considering using a specially designed structural soil, such as CU-Structural Soil - see discussion under installing trees for canopy enhancement - or if the tree will be located in a planting bed exposed to runoff from concrete or aggregates that can result in elevated pH levels in the soil); and
- sensitivity to pollutants (ozone, nitrogen dioxide, sulfur dioxide).

For trees not listed in Table 4-3, the designer may obtain pertinent information from other sources, such as individual Tree Fact Sheets published by the USDA Forest Service, (accessed at: http://hort.ifas.ufl.edu/database/trees/trees_scientific.shtml) or the "Urban Tree Selection Guide" (found on the web page: http://forestsforwatersheds.org/planting-and-maintaining-trees/).

Installing Trees for Tree Canopy Enhancement

Trees require an appropriate balance of sunlight, rooting space, soil nutrients, and water to grow. Installing a tree so that it will thrive within the urban environment is a challenge, because site conditions may adversely affect light penetration, root space, nutrients, and water availability. Often, the initial installation conditions will severely limit the potential for a tree to live more than a few years, let alone attain its full mature size. Thus, in addition to selecting the correct tree species for the environmental conditions on a site, provisions for its initial planting and care are essential to the long-term viability of the tree.

As with the discussion of tree species selection, this report defers to the extensive literature and established professional practices for installing and caring for street trees and other trees in the developed landscape.[20] However, a particularly critical component of tree installation practice merits attention in this document: the provision of adequate soil volume to support the long-term healthy growth of the tree.

As a general rule, for optimal growth, the volume of useable soil for a tree should be approximately 2 cubic of soil for each square foot of crown projection, the area of the tree within the "drip line" of the overhanging leaf canopy (Capiella, et. al., 2006). Thus, a small to medium size tree with a mature crown spread of about 25 feet should have an available soil volume of about 980 cubic feet for healthy growth. Frequently, trees are installed near pavements without providing for sufficient soil volume to support development of healthy, mature canopy.

[20] For example, see the *Tree Owner's Manual for the Northeastern and Midwestern United States* (Johnson, J.R., et. al., 2008).

Table 4-2. Runoff Reduction Characteristics of Selected Canopy Trees

Scientific Name	Common Name	Tree Height[a]	Mature Spread[b]	Area of Average Mature Spread	Intercep-tion During 1st Year[c]	Intercep-tion during 40th year[c]	Interception during 40 year period[c]		Average Annual Intercep-tion	Interception as % of Annual Precip	Streamflow Reduction Rank[d]
		ft	ft	sq ft	cu ft	cu ft	cu ft	inches	inches	%	Percentile
Large Trees											
Acer rubrum	Red Maple	40-75'	25-35	707	11	296	6,638	113	2.8	6.9%	Top 10%
Celtis occidentalis	Northern Hackberry	40-60'	40-50	1,590	14	329	7,182	54	1.4	3.3%	Top 10%
Fraxinus pennsylvanica	Green Ash	50-60'	45-50	1,771	10	394	7,404	50	1.3	3.1%	Top 10%
Ginkgo biloba	Ginkgo	50-80'	50-60	2,375	4	86	1,492	8	0.2	0.5%	Top 10%
Gleditsia triacanthos	Honeylocust	30-70'	35-50	1,418	11	474	8,506	72	1.8	4.4%	80-90
*Platanus hybrida**	London Planetree	70-100'	50-70	2,826	10	386	6,972	30	0.7	1.8%	Top 10%
Quercus palustris	Pin Oak	60-70'	35-40	1,104	20	404	7,057	77	1.9	4.7%	10-20
Quercus robur	English Oak	40-50'	40-60	1,963	14	329	7,261	44	1.1	2.7%	30-40
Quercus rubra	Northern Red Oak	60-80'	50-60	2,375	14	292	5,613	28	0.7	1.7%	30-40
Tilia cordata	Littleleaf Linden	60-70'	35-50	1,418	7	189	3,503	30	0.7	1.8%	Top 10%
Ulmus americana	American Elm	60-80'	50-70	2,826	18	432	7,572	32	0.8	2.0%	Top 10%
Ulmus parvifolia	Chinese Elm	40-50'	35-50	1,418	18	343	7,000	59	1.5	3.6%	20-Oct
Zelkova serrata	Japanese Zelkova	50-80'	50-75	3,066	14	165	3,188	12	0.3	0.8%	Top 10%

Table continues on next page.

Table 4-2. Runoff Reduction Characteristics of Selected Canopy Trees

Scientific Name	Common Name	Tree Height[a]	Mature Spread[b]	Area of Average Mature Spread	Intercep-tion During 1st Year[c]	Intercep-tion during 40th year[c]	Interception during 40 year period[c]		Average Annual Intercep-tion	Interception as % of Annual Precip	Streamflow Reduction Rank[d]
		ft	ft	sq ft	cu ft	cu ft	cu ft	inches	inches	%	Percentile
Continued from Table on previous page.											
Medium Trees											
Acer campestre	Hedge Maple	25-35'	30-35	829	8	44	1,205	17	0.4	1.1%	20-30
Koelreuteria paniculata	Goldenraintree	30-40'	30-40	962	0	Data Not Available					
Pyrus calleryana	Callery Pear	30-35'	30-40	962	9	329	5,223	65	1.6	4.0%	40-50
Small Trees											
Amelanchier sp.	Common Serviceberry	15-25'	15-20	240	9	28	970	48	1.2	3.0%	90-100
Crataegus phaenopyrum	Washington Hawthorn	25-30'	20-25	397	9	95	2,152	65	1.6	4.0%	80-90
Cornus kousa	Kousa Dogwood	30	15-20	240	9	30	977	49	1.2	3.0%	80-90
Malus sp.	Crabapple (Indian Summer)	15-30	10-25	240	0	64	1,644	82	2.1	5.0%	60-70
Malus sp.	Crabapple (Harvest Gold)	15-30	10-25	240	0	107	2,360	118	2.9	7.2%	60-70
Ostrya virginiana	Eastern Hophornbeam	30'	25-30	594	11	115	2,840	57	1.4	3.5%	Top 10%

Sources of Information:

a. MassDOT Short List of Suggested Street Trees, accessed at: https://www.massdot.state.ma.us/highway/Departments/LandscapeDesign/PlantInformation/SuggestedUrbanStreetTrees.aspx

b. USDA Forestry Service Tree Fact Sheets, accessed at: http://hort.ifas.ufl.edu/database/trees/trees_scientific.shtml

c. i-Tree Design (on-line design tool)

d: i-Tree Species (i-Tree Tools utility)

Table 4-3. Characteristics of Selected Canopy Trees for Stormwater Management in the Urban Setting

Scientific Name	Common Name	Tree Height[a]	Mature Spread[b]	Growth Rate[b]	Crown Density[b]	Pollutant Sensitivity[c]			Alkaline Tolerant[b]	Drought Tolerant[b]	Aerosol Salt Tolerant[b]	Soil Salt Tolerant[b]
		ft	ft			O_3	NO_2	SO_2				
Large Trees												
Acer rubrum	Red Maple	40-75'	25-35	Fast	Moderate	I	I		No	Moderate	Low	Poor
Celtis occidentalis	Northern Hackberry	40-60'	40-50	Fast	Moderate				Yes	High	Moderate	Good
Fraxinus pennsylvanica	Green Ash	50-60'	45-50	Fast	Moderate	S	S		Yes	High	Moderate	Moderate
Ginkgo biloba	Ginkgo	50-80'	50-60	Slow	Open				Yes	High	Moderate	
Gleditsia triacanthos	Honeylocust	30-70'	35-50	Fast	Open	S			Yes	High	High	Good
*Platanus hybrida**	London Planetree	70-100'	50-70	Fast	Dense				Yes	High	Moderate	Moderate
Quercus palustris	Pin Oak	60-70'	35-40	Medium	Moderate	S/I			No	Moderate	Low	Poor
Quercus robur	English Oak	40-50'	40-60	Medium	Moderate				Yes	High	High	Moderate
Quercus rubra	Northern Red Oak	60-80'	50-60	Fast	Dense				Yes	High	High	Good
Tilia cordata	Littleleaf Linden	60-70'	35-50	Medium	Dense				Yes	Moderate	None	Poor
Ulmus americana	American Elm	60-80'	50-70	Fast	Moderate		S/I		Yes	High	Moderate	Good
Ulmus parvifolia	Chinese Elm	40-50'	35-50	Medium	Moderate	I	S		Yes	High	Moderate	
Zelkova serrata	Japanese Zelkova	50-80'	50-75	Medium	Moderate	S			Yes	High	Moderate	

Table continues on next page.

Table 4-3. Characteristics of Selected Canopy Trees for Stormwater Management in the Urban Setting

Scientific Name	Common Name	Tree Height[a]	Mature Spread[b]	Growth Rate[b]	Crown Density[b]	Pollutant Sensitivity[c]			Alkaline Tolerant[b]	Drought Tolerant[b]	Aerosol Salt Tolerant[b]	Soil Salt Tolerant[b]
		ft	ft			O_3	NO_2	SO_2				
Continued from Table on previous page.												
Medium Trees												
Acer campestre	Hedge Maple	25-35'	30-35	Slow	Dense				Yes	High	Moderate	
Koelreuteria paniculata	Goldenraintree	30-40'	30-40	Medium	Open				Yes	High	Moderate	
Pyrus calleryana	Callery Pear	30-35'	30-40	Fast	Dense				Yes	High	Moderate	Moderate
Small Trees												
Amelanchier sp.	Common Serviceberry	15-25'	15-20	Medium	Open		S		No	Moderate	Moderate	Moderate
Crataegus phaenopyrum	Washington Hawthorn	25-30'	20-25	Medium	Moderate				Yes	High	Moderate	Poor
Cornus kousa	Kousa Dogwood	30	15-20	Slow	Dense				No	Moderate	Moderate	Moderate
Malus sp.	Crabapple	15-30'	10-25	Medium	Moderate	S			Yes	Moderate	Low	Moderate
Ostrya virginiana	Eastern Hophornbeam	30'	25-30	Slow	Moderate				Yes	High	None	Poor

Sources of Information:
a. MassDOT Short List of Suggested Street Trees, accessed at: https://www.massdot.state.ma.us/highway/Departments/LandscapeDesign/PlantInformation/SuggestedUrbanStreetTrees.aspx
b. USDA Forestry Service Tree Fact Sheets, accessed at: http://hort.ifas.ufl.edu/database/trees/trees_scientific.shtml
c. i-Tree Species (i-Tree Tools utility)

A typical tree pit (4 feet square and 3 feet deep) has less than 50 cubic feet of volume.[21] A 4-foot wide "tree lawn" (the landscape strip between a roadway and adjacent sidewalk) with trees of this size spaced at 25-foot intervals would have about 300 cubic feet of available soil volume, assuming a 3-foot depth and assuming limited root growth beneath the adjacent paved surfaces. These limited soil volumes confine roots and restrict their growth, reducing anchorage and also limiting the supply of water and nutrients. These constraints, combined with soils compaction, low soil fertility, heat from adjacent pavements, and other environmental stresses where trees are in close proximity to pavement severely hamper the long-term viability of trees. As a result, most urban trees have an average life expectancy in the range of 7-10 years (Appleton, et.al., 2009).

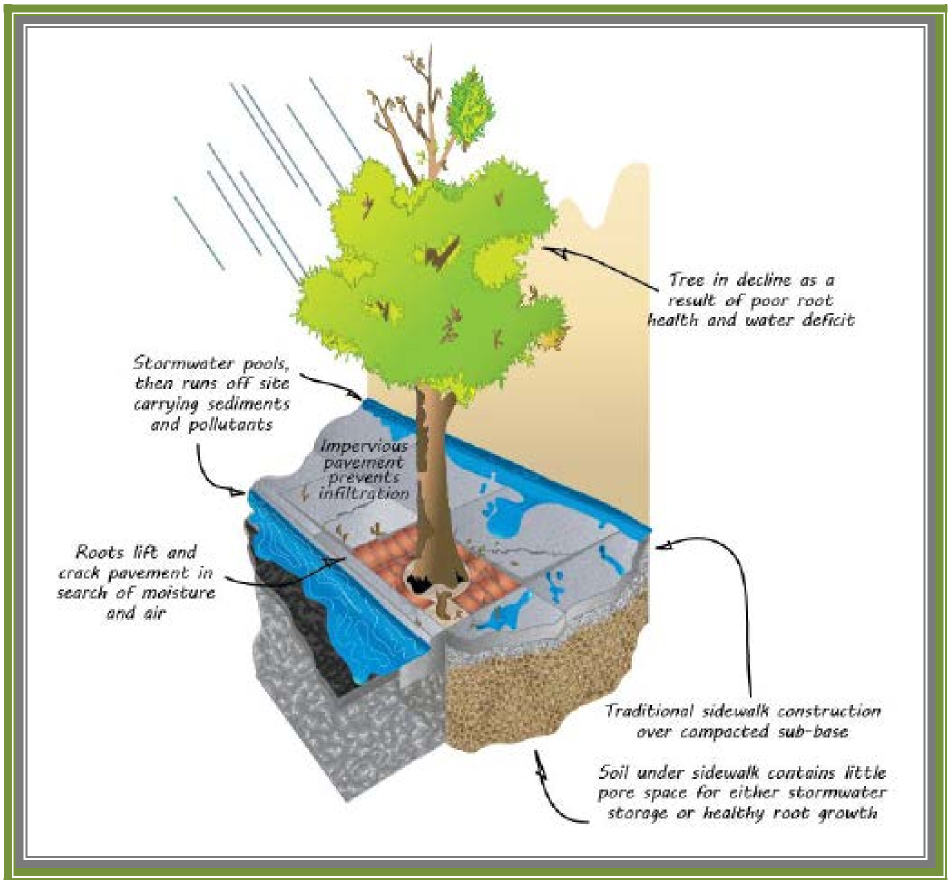


Figure 4.2. Illustration of Stresses on Trees Resulting from Paved Surfaces and Compacted Pavement Base Materials. (Source: US EPA, 2013)

[21] A typical "tree box filter" would contain a comparable volume. Many tree box products would likely prevent the contained tree from reaching full canopy development, and would also likely limit tree life to only a few years. If designers are using tree-box filters to meet stormwater management requirements, we recommend considering designs that allow unrestricted root growth into the surrounding soil. Otherwise, benefits from infiltration and evapotranspiration will be minimal.

If trees are to be planted to achieve stormwater and other environmental benefits, then the provision of adequate soil volume comprises a critical element of planting design. The designer should provide either for adequate landscape islands or tree lawns to support required soil volume, or explore the use of structural measures to provide for root growth beneath adjacent impervious surfaces. Some of these structural measures are discussed further below.

Not only do adjacent pavements inhibit tree growth, but tree growth can result in structural damage to pavements as roots penetrate beneath these surfaces. Therefore, to sustain healthy growth of trees while ensuring the structural integrity of road and sidewalk surfaces, design needs to account for root penetration. Providing adequate soil volume for root growth, moisture storage, and nutrient supply can address this concern.

MassDOT

Tree installation design can provide for adequate soil volume simply by furnishing adequate space within a landscaped planting island. In the example of a 25-foot tree crown requiring 980 cubic feet of space, a landscaped island or planting strip 12 feet in width and 3 feet in depth would provide suitable growing space, with trees planted about 27 feet on center. If trees at the same spacing are planted in lawn areas behind a sidewalk, and buildings are at least 12 feet from the walk, a similar soil volume would be available.

Alternatively, designers may consider measures to allow for root penetration, moisture storage, and nutrient storage designed into the support structure beneath sidewalks and parking areas. In conventional pavement designs, these paved surfaces are supported on densely compacted, well-graded aggregates. This compacted material obstructs root penetration and reduces the moisture and nutrient storage available compared to natural, uncompacted soil. In addition, the overlying pavement prevents infiltration of water and water-borne nutrients into the material. There are two general approaches to providing for a "rootable" growing media beneath these paved areas: (1) the use of suspended pavement and (2) the use of specially designed structural soils. These approaches are described briefly below.

1. Suspended Pavement

   A suspended pavement consists of a paved surface supported on a network of structural elements, rather than founded on compacted soil materials. A suspension system comprising pillars, piles, or structural cells supports the weight of the pavement and live loads, allowing placement of soil material within the structural grid to be designed to support tree growth (see Figure 4.3). The soil material remains un-compacted, and can be designed to provide for soil moisture and nutrient conditions supportive of healthy tree development.

Depending on design, the structural elements and paving can support varying surface load conditions, including vehicular traffic. Examples of proprietary systems include:

- DeepRoot Green Infrastructure, LLC, *Silva Cell* and *Silva Cell 2*: http://www.deeproot.com/index.php/products/silva-cell/landing-page/sc

- CityGreen Landscape Solutions, *Strata Cell*, *RootCell*, and *Strata Vault*: http://www.citygreen.com/products/structural-cells/

Stratavault by Citygreen.com   Western Pennsylvania Conservancy

Figure 4.3. Examples of Suspended Pavement Systems

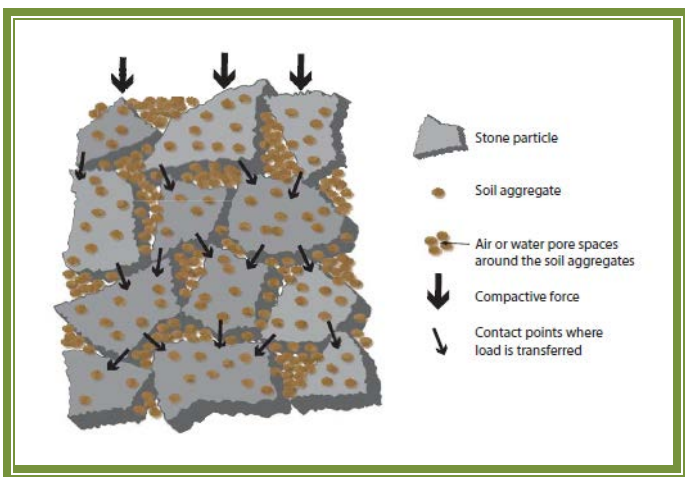
2. Structural Soils.

A "structural soil" consists of a specially prepared aggregate or soil mix designed to support the overlying pavement, while providing sufficient void space and soil structure to allow root penetration and storage of moisture and nutrients essential to plant viability (Figure 4.4). Structural soil is generally available as a proprietary product. Examples of proprietary structural soils used in the eastern US (available through licensed distributors) include the following:

- "CU-Structural Soil™" - this is a mixture of crushed gravel and soil with a hydrogel additive (to prevent the stone and soil from separating during mixing and installation). The gravel consists of uniform (poorly graded) particle sizes with no fine particles and forms the structural matrix to support the pavement, while also providing large void spaces that contain the soil. The soil comprises a loam or clay loam with at least 20% clay and an organic content of 2%-5% to maximize water and nutrient storage, encourage beneficial microbial activity, and provide adequate cation exchange capacity (Bassuk, 2005). The proportion of stone to soil is approximately 80:20 to create a rigid lattice so that when compacted, the load is borne from stone to stone, with the soil between stones remaining un-compacted (http:/thefield.asla.org/2014/01/30/structural-soil-part-1/). Further information about this product can be found at the following link: http://www.hort.cornell.edu/uhi/outreach/index.htm#soil

- "Carolina Stalite Structural Soil" - this is a mixture of "Stalite" expanded slate aggregate and sandy clay loam (80:20 ratio of aggregate to loam). The rough texture of the processed slate is such that a tackifier is not needed to prevent segregation of the soil and aggregate during mixing and placement (Day and Dickinson, Eds., 2008). "Stalite" is a proprietary product of the Carolina Stalite Company. Additional information about this product can be found at the following link: http://www.stalite.com/index.php

Further information on the use of trees and structural soils may be found in Day and Dickinson, Eds. (2008) and US EPA (2013).



Sarah Dickinson Gugercin as adapted from Nina Bassuk reprinted with permission from Managing stormwater for urban sustainability using trees and structural soils. Susan Day and Sarah Dickinson, Eds. (2008)

Figure 4.4. Illustration of structural soil showing stone-to-stone load bearing and void spaces with soil particles.

4.2 Canopy Trees in BMPs.

The MassDEP's *Massachusetts Stormwater Handbook* presents a broad array of Stormwater Best Management Practices (BMPs) that integrate the use of vegetation into their design. The use of such vegetation should include the prudent use of trees to enhance pollutant removal, mitigate for thermal impacts, protect against erosion, and provide aesthetic interest and appeal.

Specific recommendations relative to the integration of vegetation into BMP design include the following:

- To the extent feasible, avoid converting upland forests to open stormwater systems. Consider siting BMPs to preserve existing woodland to the extent practicable. Where woodland is disturbed, consider restoring tree canopy in the design of the BMPs that take its place.

- For Bioretention Areas, the bioretention media should be planted with herbaceous and shrub species such as those listed in the *Massachusetts Stormwater Handbook*. Trees should be integrated into the area at the immediate perimeter of the bioretention cell.

- Constructed wetlands and wet ponds with wetland features should mimic natural wetlands and ponds found in the project area. Plant species - including trees - should be chosen that are compatible with desirable native species in the nearby wetland resource areas.

- For conventional drainage channels, grassed swales, and water quality swales, designers should consider adding alternate side slope tree plantings to enhance stormwater treatment in these BMPs.[22] Providing this additional plant cover is particularly important in areas draining to cold water fisheries, where the shade provided by this vegetation can cool runoff conveyed in these channels.

- The side slopes of basin-type BMPs (with the exception of embankments that serve as "dams" as discussed in the next paragraph), and the dry bottom surfaces of infiltration basins, dry extended-detention basins and conventional detention basins, may be landscaped with shrubs and trees, in addition to herbaceous plantings. The selection of landscaping should consider the full range of vegetation types, as long as such plantings do not interfere with sediment removal and other maintenance activities. The design storage capacity of these basins should be conservatively sized, so that the volume occupied by tree and shrub stems is not of concern in the hydraulic operation of the basins.

- Designers should not introduce trees or other woody vegetation on earthen embankments (or "dikes" or "berms") that serve as dams. Root growth from woody vegetation can compromise the structural integrity of the embankment.

[22] The designer should refer to *The Urban Watershed Forestry Manual - Part 1: Methods for Increasing Forest Cover in a Watershed* for additional guidance in incorporating tree plantings into stormwater management BMPs.

Such embankments must be mowed at least once a year to prevent the establishment and growth of new woody vegetation, so the landscape design must also consider access to allow this maintenance activity. In addition, designers should exercise care in selecting species for planting on nearby cut slopes and basin floors, to avoid introducing trees or other woody species that could rapidly colonize impoundment structures.

- The use of trees in forebays should be avoided, to allow for frequent access for the removal of accumulated sediment. An effective forebay will minimize the need to remove sediment from the next BMP in the treatment train, allowing for more flexibility in the landscape design of that downstream BMP.

- In the roadway setting, the provision of trees must consider roadway design criteria for the provision of driver recovery areas, clear sight lines, and other safety considerations, as well as maintenance activities (and access for such maintenance). Preservation and restoration of landscape features must be balanced with these considerations.

Note that certain tree-based BMPs can be designed to receive runoff from adjacent impervious surfaces. The discussion of regulatory approaches in Chapter 3 cites the practice adopted by the Minnesota Pollution Control Agency (MPCA) that provides for a runoff reduction credit for tree trenches and tree boxes that accounts for direct interception by the trees, as well as evapotranspiration and infiltration of water from the soil media surrounding the tree within the limits of the BMP. The water captured by this media includes both direct rainfall on the surface of the BMP as well as runoff directed into the BMP from adjacent paved surfaces. In New England, trees have the capacity to evapo-transpire a greater volume of water than available by direct precipitation over the area of the tree crown. Design can take advantage of this capacity by introducing runoff into the soil media used in these types of BMPs. This report therefore recommends MassDEP consider adapting the MPCA practice to the Massachusetts setting. See previous discussion in Chapter 3, and the excerpt of the MPCA methodology attached in Appendix B.

4.3 Maintaining Trees for Runoff Reduction Benefits

As noted earlier in this Chapter, there is extensive literature describing the selection, installation, and care of street trees. For example, the *Tree Owner's Manual for the Northeastern and Midwestern United States* (Johnson, J.R., et. al. 2008) provides basic information on long term care of trees. Therefore, this report does not include information on routine care of individual trees or other urban forestry practices. However, communities that elect to include the use of canopy trees for stormwater management should assure that local maintenance programs – both public and private – include measures to assure the long term development of healthy, mature tree canopy.

If a community adopts a public program to preserve and install trees along roads and on other public properties, it should include measures in the municipal stormwater management plan and supporting budget for the maintenance of the tree canopy. Similarly, if a community adopts a system of runoff reduction credits for new development and redevelopment projects as discussed in Chapter 3, then the community should monitor and enforce the Operation & Maintenance (O&M) Plan provisions recommended in the model regulatory language. Whether trees are located within public property or within approved projects, recommended practices include:

- Routine care to maintain healthy, vigorous trees;
- Timely care for damaged and diseased trees and for replacement of dead or severely damaged trees;
- Annual sweeping following leaf-drop in the fall to remove leaf litter that can contribute nutrients to stormwater runoff;
- Enforcement of the provisions for maintenance included in the model regulatory language presented in Chapter 3, as applicable to new development and redevelopment projects approved under the municipality's stormwater regulations.

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5. Internet Tree Canopy Stormwater Tool Box

The information described in Chapters 1 through 4 of this report, together with links to other resource materials, have been compiled in a user-friendly Internet "tool box" to assist municipalities and other agencies, and also project designers, in using tree canopy preservation/enhancement for stormwater management in Massachusetts. This Chapter introduces the website.

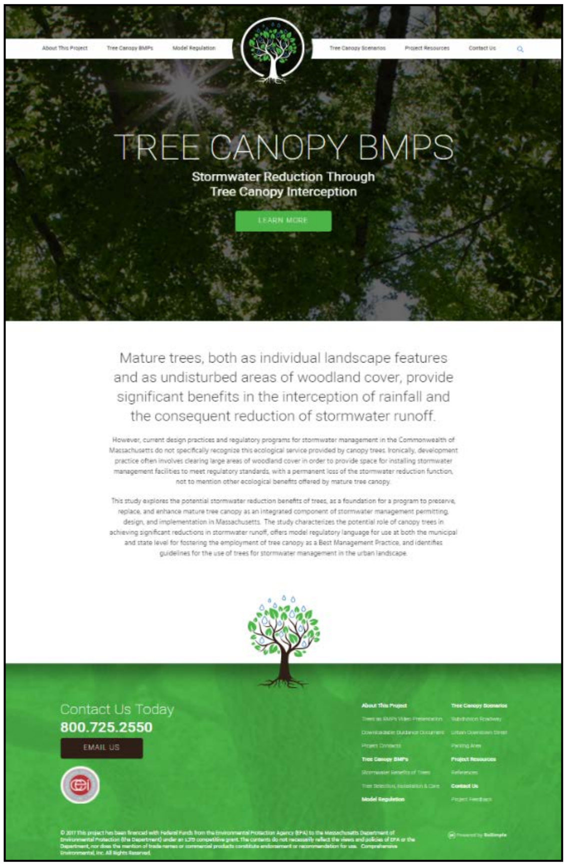
The website www.treecanopybmp.org provides information and outreach to federal, state, and municipal agencies interested in learning more about the benefits tree canopies can provide to stormwater management programs. The intent of this website is to provide an easily accessible avenue for decision-makers looking for information specific to tree canopy use in the interception and reduction in stormwater runoff volume. This website is divided into several simple sections where information from this report is presented.

As of the date of this report, www.treecanopybmp.org contains the following resources:

- Model regulation (in both Word and .PDF)
- Downloadable copy of this document
- Tree canopy scenarios used in the analysis presented in this report
- Tree selection, planting and care references
- Project resources
- ‘Trees as BMPs” Video and PowerPoint presentation
- Customizable brochure encouraging tree planting for homeowners
- Project contacts for more information
- Project feedback survey

The project website will be reviewed and updated as needed on a monthly basis with new information added as it becomes available.

Below are example pages from the project website.


TREE CANOPY BMPS
Stormwater Reduction Through
Tree Canopy Interception
LEARN MORE
Mature trees, both as individual landscape features and as undisturbed areas of woodland cover, provide significant benefits in the interception of rainfall and the consequent reduction of stormwater runoff.
Contact Us Today
800.725.2550
EMAIL US


Subdivision Road Scenario #3
Large Trees on Both Sides of Road - Typical Plan and Cross Section
Contact Us Today
800.725.2550
EMAIL US

References

APA- MA. 2011. Sustainable Neighborhood Road Design: A Guidebook for Massachusetts Cities and Towns. American Planning Association - Massachusetts Chapter and Homebuilders Association of Massachusetts. Accessed at http://www.apa-ma.org/

Appleton, B., J. Horsley, V. Harris, G. Eaton, L. Fox, J. Orband, C. Hoysa. 2009. Trees for Parking Lots and Paved Areas. College of Agrriculture and Life Sciences, Virginia Polytechnic Institute and State University.

Bartens, Julia et.al. 2008. Can Urban Tree Roots Improve Infi ltration through Compacted Subsoils for Stormwater Management? J. Environ. Qual. 37:2048–2057 (2008).

Cahill Associates Inc. 2005. Pennsylvania (Draft) Stormwater Best Management Practices Manual: 2nd Draft – January 2005. Retrieved from the Pennsylvania Department of Environmental Protection website: http://www.elibrary.dep.state.pa.us/dsweb/Get/Version-48477/07_Chapter_6.pdf

Center for Watershed Protection. 2009. 2000 Maryland Stormwater Design Manual Volumes I & II. Retrieved from Maryland Department of the Environment website: http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/programs/waterprograms/sedimentandstormwater/stormwater_design/index.aspx

City of Mountlake Terrrace. 2011. Urban Tree Guide. Retreived from the City of Mountlake Terrace website: http://www.cityofmlt.com/DocumentCenter/Home/View/675

City of Roanoke, VA. 2014. Stormwater Utility Fee Credit Manual, Single Family Residential Properties. Department of Planning, Building, and Development. Roanoke, VA

Coder, R. 1996. Identified Benefits of Community Trees and Forests. University of Georgia Cooperative Extension Service Forest Resources Unit Publication FOR96-39; October 1996.

CUFR. 2002. Fact Sheet #4: Control Stormwater Runoff with Trees. Center for Urban Forest Research, Pacific Southwest Research Station, USDA Forest Service, Davis, California, July 2002.

Day, S. D. and S.B. Dickinson, Eds. 2008. Managing Stormwater for Urban Sustainability Using Trees and Structural Soils. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Frelich, Lee E. 1992. Predicting Dimensional Relationships For Twin Cities Shade Trees. Department of Forest Resources, University of Minnesota – Twin Cities.

Johnson, J.R., et. al. 2008. Tree Owner's Manual for the Northeastern and Midwestern United States. USDA Forest Service, Northeastern Area State and Private Forestry, Newton Square, PA. NA-FR-04-07

Klingaman, Nicholas P. et al. 2007. A comparison of Three Canopy Interception Models for a Leafless Mixed Deciduous Forest Stand in the Eastern United States. American Meteorological Society. DOI: 10.1175/JHM564.1

Lamson, Neil I. 1987. D.b.h./Crown Diameter Relationships in Mixed Appalachian Hardwood Stands. Northeastern Forest Experiment Station. United States Department of Agriculture. Research Paper NE-610.

Leonard, Raymond E. 1961. Interception of Precipitation by Northern Hardwoods. Northeastern Forest Experiment Station, Forest Service. U.S. Department of Agriculture, Upper Darby, PA Ralph W. Marquis, Director.

Link, Timothy E., et al. 2004. The dynamics of rainfall interception by a seasonal temperate rainforest. Agricultural and Forest Meteorology 124: 171-191.

MDE. 2010. Environmental Site Design (ESD) Process & Computations. Maryland Department of the Environment. Baltimore, MD.

NACTO. 2012. NACTO Urban Street Design Guide. National Association of City Transportation Officials, New York, NY 10041. www.nacto.org

Peper, P.J., et. al. 2007. New York City, New York Municipal Forest Resource Analysis. Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

Sanders, Ralph. 1986. Urban Vegetation Impacts on the Hydrology of Dayton, Ohio. Urban Ecology 9: 361-376.

Storey, B.J., M. Li, J. A. McFalls and Y. Yi. 2009. Stormwater Treatment with Vegetated Buffers (NCHRP Project 25-25 Task 53). Retrieved from Transportation Research Board website at: http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25%2853%29_FR.pdf

U.S. Environmental Protection Agency (US EPA). 2013. Stormwater to Trees: Engineering Urban Forests for Stormwater Management. US EPA Office of Wetlands, Oceans and Watersheds, Nonpoint Source Control Branch (4503T), Washington, DC. EPA 841-B-13-001.

Xiao, Qingfu et al. 1998. Rainfall Interception by Sacramento's Urban Forest. Journal of Arboriculture 24: 235-244.

Xiao, Qingfu et al. 2000. Winter rainfall interception by two mature open-grown trees in Davis, California. Hydrological Processes 14: 763-784.

Xiao, Qingfu and E. Gregory McPherson. 2002. Rainfall interception by Santa Monica's municipal urban forest. Urban Ecosystems 6: 291-302.

Xiao, Qingfu et al. 2007. Northeast Community Tree Guide: Benefits, Costs, and Strategic Planting. Forest Service Department of Agriculture. Pacific Southwest Research Station Albany, CA.

Zon, Raphael. 1927. Forests and water in the light of scientific investigation. Forest Service Department of Agriculture. United States Government Printing Office Washington, D.C.

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