Puget Sound Urban Tree Canopy and Stormwater Management HANDBOOK

AN INTERDISCIPLINARY RESOURCE FOR PRACTITIONERS

The Companion Handbook

This Handbook is a companion to the Technical Report from the *Puget Sound Urban Tree Canopy and Stormwater Management Project*. That Project brought together urban forestry and stormwater professionals in a collaboration to investigate urban forestry and stormwater management modeling tools. As a companion to the Technical Report, the Handbook is intended to support ongoing collaboration across these professional disciplines. While primarily framed and addressed to urban forestry and stormwater professionals, the Handbook is useful to all audiences and users. The Handbook and Technical report are features of the Puget Sound Trees and Stormwater Toolkit.

- Section 1 of the Handbook includes descriptions of the multiple benefits of urban tree canopy and especially as they relate to stormwater management.
- Section 2 of the Handbook provides an overview of the tree canopy and stormwater analysis performed using i-Tree Hydro and WWHM as a part of the *Puget Sound Urban Tree Canopy and Stormwater Management Project* and highlights programs, incentives, tools, and other resources and research related to the stormwater volume reduction benefits of tree canopy. Additionally, the Handbook makes a case for using urban trees and tree canopy in LID, GSI, and GI applications.
- Section 3 of the Handbook promotes engagement with policy makers and implementers, builders and developers, and property owners on the role of urban tree canopy in regional stormwater and water quality management, including policy, program development and practice implementation.
- This publication is available as a PDF with live links to the cited references and included resources. Visit www.trees-and-stormwater.org to access this PDF and more.

ACKNOWLEDGEMENTS

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Grant funding for this project received from the US Environmental Protection Agency National Estuary Program administered through the Washington Department of Ecology in association with the Puget Sound Partnership, and the USDA Forest Service Urban and Community Forestry Program administered through the State of Washington Department of Natural Resources Urban and Community Forestry Program.
The USDA is an equal opportunity provider and employer.

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Front cover, *Dustin Taylor on Unsplash*/Back cover, *Eric Cook on Unsplash*

Contents

Introduction

Overview and Purpose

In the Puget Sound region, growth and land development have greatly expanded the amount of impervious surface, leading to increased stormwater runoff volumes and associated negative impacts to water quality and wildlife habitat. Urban tree canopy plays a vital role in reducing stormwater runoff, yet this benefit is often undervalued when it comes to stormwater management policies, incentives and implementation practices. The *Puget Sound Urban Tree Canopy and Stormwater Management Handbook - An Interdisciplinary Resource for Practitioners* (Handbook) provides an overview of both the general and stormwater reduction benefits of urban tree canopy. The goal of this Handbook is to promote tree planting and tree retention as a green stormwater infrastructure (GSI) strategy. The intent is to encourage dialogue between urban forestry and stormwater management professionals and support engagement among these groups with policy makers and implementers, builders and developers, and property owners to achieve this goal. The Handbook serves as a companion document to the Technical Report of the *Puget Sound Urban Tree Canopy and Stormwater Management Project*. Key findings and information from the Technical Report are referenced in the Handbook to illustrate the role of urban tree canopy in reducing stormwater runoff volumes. The Handbook and Technical Report are features of the Puget Sound Trees and Stormwater Toolkit, a web-based compendium of useful resources and tools to support collaboration on urban forestry and stormwater priorities.

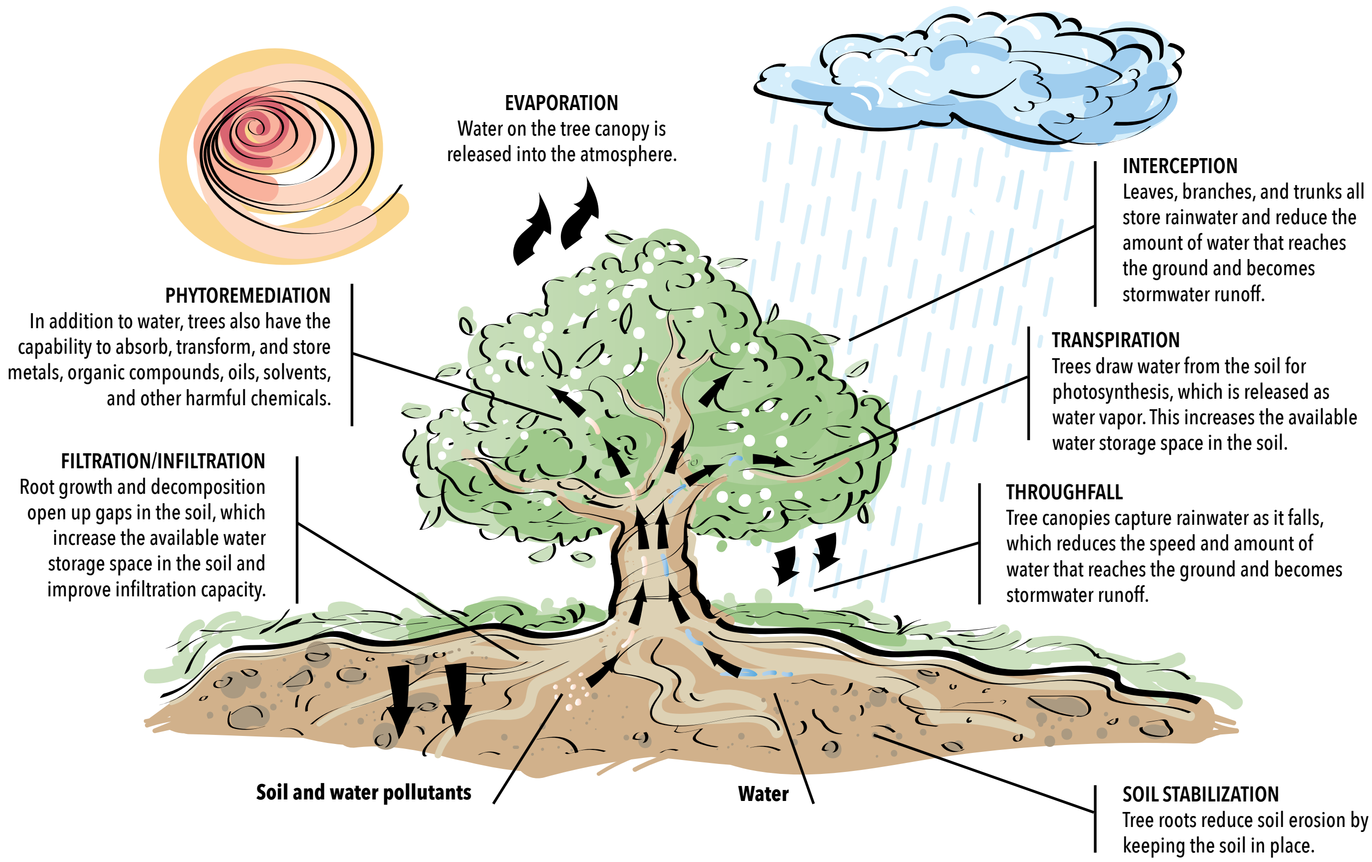
Defining Urban Tree Canopy, Its Roles, and Uses

Urban tree canopy is defined as “the layer of leaves, branches, and stems that provide tree coverage on the ground when viewed from above” (U.S. Department of Agriculture, 2019).

In our communities, urban tree canopy performs important roles and provides many ecosystem, human health, environmental, and economic benefits. A healthy urban tree canopy ensures wildlife habitat structure, improves air quality, and reduces energy use. Other important ecosystem services include mitigating urban heat islands, sequestering carbon, and improving climate resiliency. Urban tree canopy also enriches the quality of life in our cities and towns by promoting physical health and activity, reducing stress, and enhancing aesthetics.

Urban tree canopy provides a range of water quality and stormwater management benefits, which include protecting watershed health, drinking water supplies, surface water systems, and property. The mitigating functions of urban tree canopy are performed through rainfall interception, evaporation, transpiration, infiltration, and phytoremediation. Key outcomes from the Technical Report demonstrate the influence of urban tree canopy in reducing stormwater runoff volumes. For example, retaining trees during new

TREES AND WATER MANAGEMENT



development, redevelopment, or retrofit projects reduces stormwater runoff volumes to a higher degree compared to removing existing trees and planting new trees in the same scenario. Moreover, stormwater runoff volumes increase when trees are replaced with any other land cover type (including shrubs, grass, or pavement).

> **TREES TAME STORMWATER**
>
> https://www.arborday.org/trees/stormwater.cfm
>
> An interactive graphic understanding created by the Arbor Day Foundation, on how trees affect stormwater.

To capture the benefits of urban tree canopy, we need to prioritize tree retention and new tree planting in a variety of settings. Options include planting street trees, adding trees to residential and commercial landscaping, enhancing tree canopy on undeveloped lands, integrating trees into stormwater facilities (such as bioretention areas), and extending tree canopy over impervious surfaces. In some cases, funding sources are available to support and promote these urban tree canopy stewardship activities. Efforts to capitalize on the range of ecosystem, human health, and economic benefits outlined in this handbook require the adoption of urban tree canopy policies at the local and Puget Sound regional levels.

Benefits of Trees

Much of Puget Sound's 1,300 plus miles of coastline are connected to densely populated urban areas. During the winter and spring months, heavy precipitation events in these areas create significant stormwater runoff volumes that flow over impervious surfaces and collect harmful pollutants such as oils, metals and pesticides. These polluted waters—which discharge into surrounding waterways and eventually into Puget Sound—are the number one toxic threat to Puget Sound (Ecology and King County, 2011). This threat grows as impervious area increases. The region's forests and urban tree canopy help mitigate this environmental problem by decreasing the amount of rain that becomes stormwater runoff, thus protecting water quality. This benefit is described in detail in Section 2 of this Handbook.

The Nature Conservancy

TREES AND STORMWATER LINKS

Two Minute Takeaway - What is Tree Canopy?

Urban Trees and Climate Change

Trees Prevent Stormwater Pollution

City Habitats - Why Puget Sound Needs Our Help

Boeing Funds Trees for the Health of Puget Sound

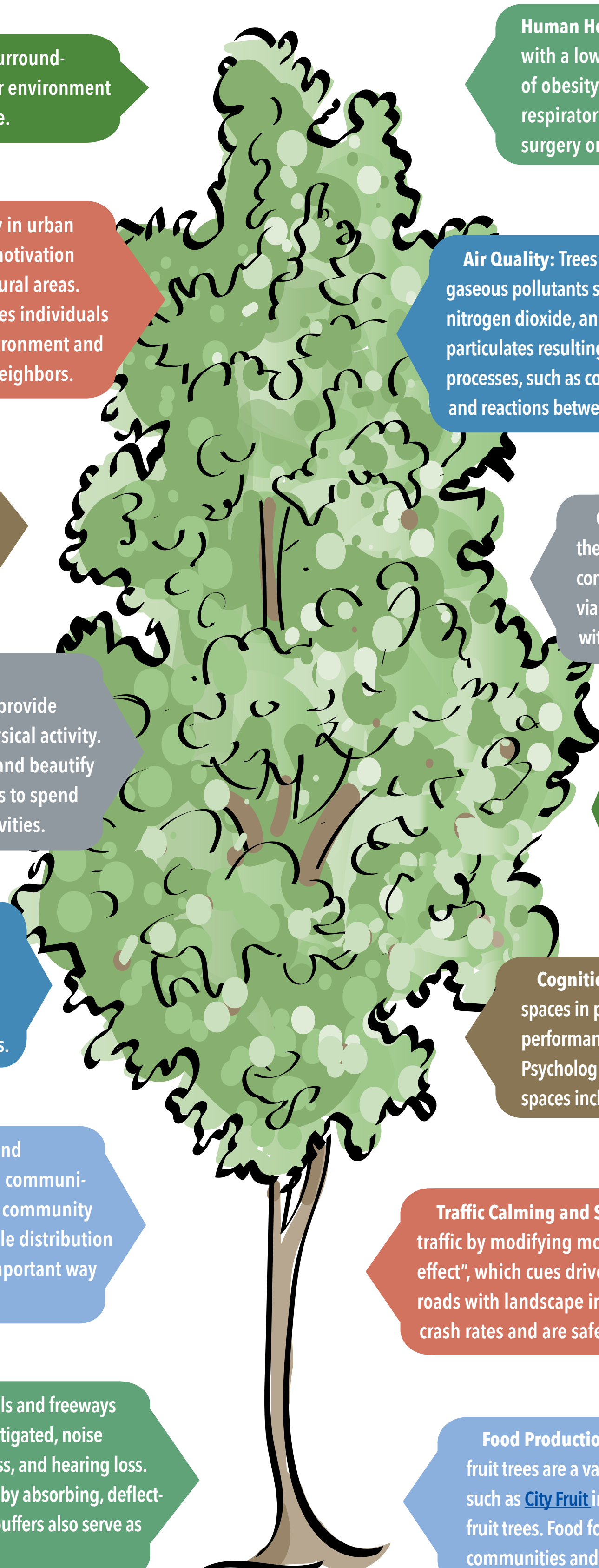
Beyond reducing stormwater runoff volumes, urban tree canopy offers a spectrum of ecosystem services while contributing to the natural beauty of the region. Tree canopy in urban landscapes improves air quality, provides habitat for wildlife, supports greater biodiversity, and helps to save energy by shading and shielding buildings. For residents, tree canopy promotes health and well-being by encouraging physical activity and creating attractive, shared outdoor spaces for people to enjoy. The myriad of benefits that tree canopy provides are described in more detail in the following sections.

Human Health and Quality of Life Benefits

Throughout history, humans have recognized the quality-of-life enrichment that trees provide by beautifying landscapes and contributing to a more pleasant living environment. Exposure to forested environments can instill positive feelings and physiological reactions in people while helping to improve the health and well-being of urban community residents. Green landscapes provide restorative settings that allow people to recover from daily and chronic stressors. Living near green areas, having a view of vegetation, and spending time in urban natural settings can reduce stress, and contribute to enhanced wellness for city dwellers (Wolf

QUALITY OF LIFE BENEFITS

(Diamond Head Consulting, 2017) (Wolf and Krueger, 2010) (Wolf, 2009) (Nowak and Greenfield, 2015)



Aesthetics: Trees add beauty to their surroundings, contributing to the character of their environment and influencing a community's way of life.

Connection to Nature: Tree canopy in urban areas inspires a sense of pride and motivation to care for urban landscapes and natural areas. Availability of green space encourages individuals to engage in stewardship of the environment and promotes social bonding between neighbors.

Livability: Trees and tree canopy enhance communities by increasing walkability, reducing crime and violence, and strengthening community ties.

Physical Activity and Recreation: Community trees and green spaces provide opportunities for recreation and physical activity. Urban trees and forests both shade and beautify communities–encouraging residents to spend more time outdoors engaged in activities.

Cooling from Shade: Shade from tree canopy cools air, decreasing temperature-related illnesses, and encourages residents to spend more time outside, reducing use of air conditioning in homes.

Environmental Justice: Planting and preserving trees in partnership with communities can address environmental and community health disparities. Ensuring equitable distribution of trees across communities is an important way to foster environmental justice.

Noise and Privacy Buffer: Urban arterials and freeways are a source of noise pollution. When unmitigated, noise pollution can induce tension, anxiety, illness, and hearing loss. Trees and vegetated buffers mitigate noise by absorbing, deflecting, or refracting sound waves. Vegetated buffers also serve as visual screens, enhancing privacy.

Human Health: Trees and tree canopy are associated with a lower likelihood of heart attack, lower rates of obesity, reduce incidence of asthma and other respiratory symptoms, and accelerated recovery from surgery or illness.

Air Quality: Trees and green spaces remove harmful gaseous pollutants such as ozone, carbon monoxide, nitrogen dioxide, and sulfur dioxide. They also reduce particulates resulting from fossil fuel combustion, industry processes, such as construction and demolition, soil erosion, and reactions between sunlight and gaseous pollutants.

Oxygen: A healthy urban forest, including the trees in our yards and throughout our community, release oxygen into the atmosphere via photosynthesis. Oxygen production increases with the size and health of a tree.

Reduced Stress: Trees and green spaces reduce stress, lower blood pressure, improve mood, and improves recovery from daily and chronic stressors.

Cognition and Education: Urban trees and green spaces in proximity to schools improve student performance and increase concentration and attention. Psychological benefits from being in and around green spaces include reduced ADD/ADHD symptoms

Traffic Calming and Safety: Trees along streets calm traffic by modifying motorist behavior through "edge effect", which cues drivers to slow speeds. Tree lined urban roads with landscape improvements experience decreased crash rates and are safer for pedestrians and cyclists.

Food Production and Security: Urban orchards and urban fruit trees are a valuable community food resource. Programs such as City Fruit in Seattle help maintain and harvest urban fruit trees. Food forests and forest gardens can provide food to communities and contribute to food sustainability.

and Krueger, 2014). Cultivating nature within these urban areas correlates to improving the quality of life and livability of the community. Extended research has been conducted on these connections (see Urban Tree Canopy and Human Health Studies below). The graphic on page 9 lists some of the human health and quality of life benefits of urban tree canopy.

URBAN TREE CANOPY AND HUMAN HEALTH STUDIES

Exploring Connections Between Trees and Human Health
USDA Forest Service

Planting Healthy Air
The Nature Conservancy

Trees Improve Human Health and Well-Being in Many Ways
USDA Forest Service

Green Cities: Good Health
University of Washington

Portland, OR Air Quality Study
US Forest Service

Ecological and Environmental Benefits

In urban areas, tree canopy serves an important role in improving the environment and mitigating impacts related to climate change. Increasing the amount of tree canopy increases wildlife habitat, improves air and water quality, decreases carbon emissions, and mitigates rising average summer temperatures.

URBAN TREE CANOPY AND ECOLOGICAL IMPACTS

The Sustainable Urban Forest - As Step-by-Step Approach
Davey Institute, US Forest Service

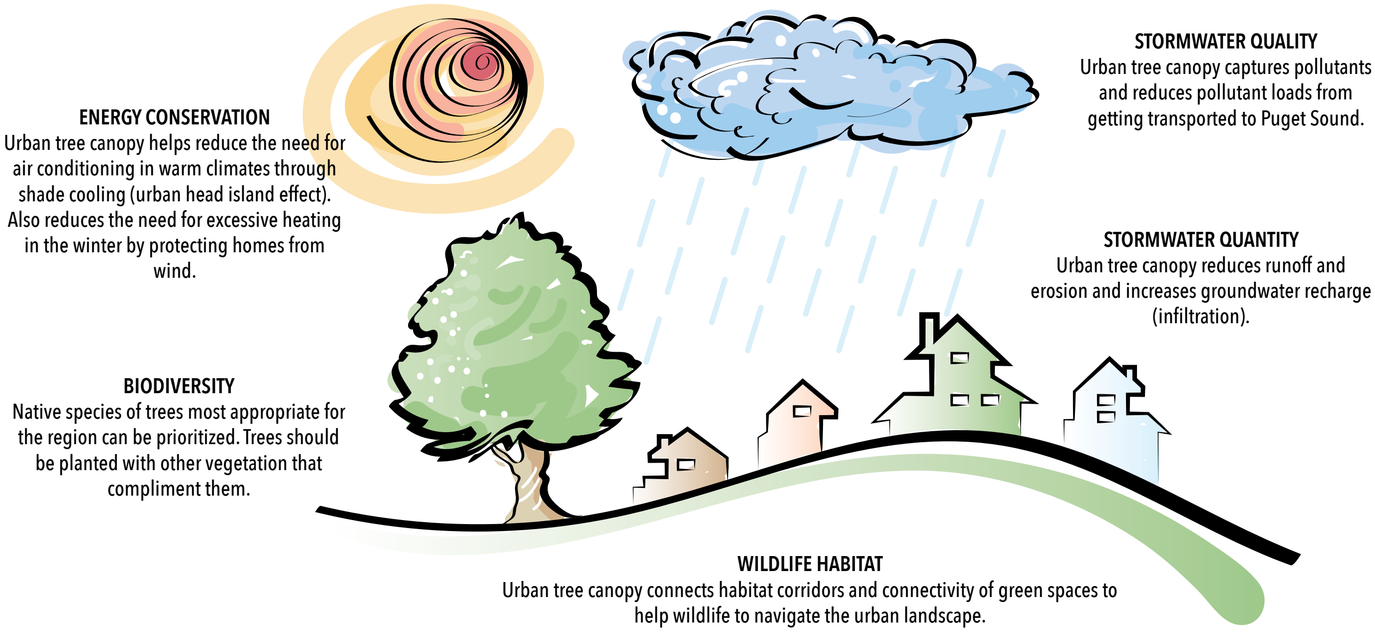
Ecohydrological Consequences of Tree Removal in an Urban Park
Science of The Total Environment

WILDLIFE HABITAT

A decline in the quality and amount of wildlife habitat has created significant challenges for wildlife species occupying urban areas. Some of these challenges include reduced food supplies and competition for space. Healthy urban tree canopy provides a critical element in the habitat equation for many wildlife species. Migration corridors are supported by urban tree canopy networks that facilitate wildlife navigation to and from sources of food, water, and shelter within urban areas and across the larger landscape.

Planting native trees, shrubs, and other perennial and annual species in urban areas

ECOLOGICAL, ENVIRONMENTAL AND ECONOMIC BENEFITS OF TREES



increases vegetation cover and improves biodiversity in plant communities while enhancing carrying capacity for wildlife species. Using native plant species in residential and commercial landscapes and with habitat restoration plantings in parks and open spaces helps to promote wildlife habitat benefits. Some have shown that native urban trees and plants help promote healthy native fauna populations, especially among pollinator insects, birds, fish, amphibians and small mammals (Narango et al, 2017) (Baisden, 2018) (Narango et al, 2018). Web-based tools (such as the Avian Suitability Report in i-Tree Eco) evaluate habitat requirements for a variety of species and identify opportunities to provide necessary habitats through trees and vegetation (see Wildlife Habitat Evaluation and Planning Tools below).

WILDLIFE HABITAT EVALUATION AND PLANNING TOOLS

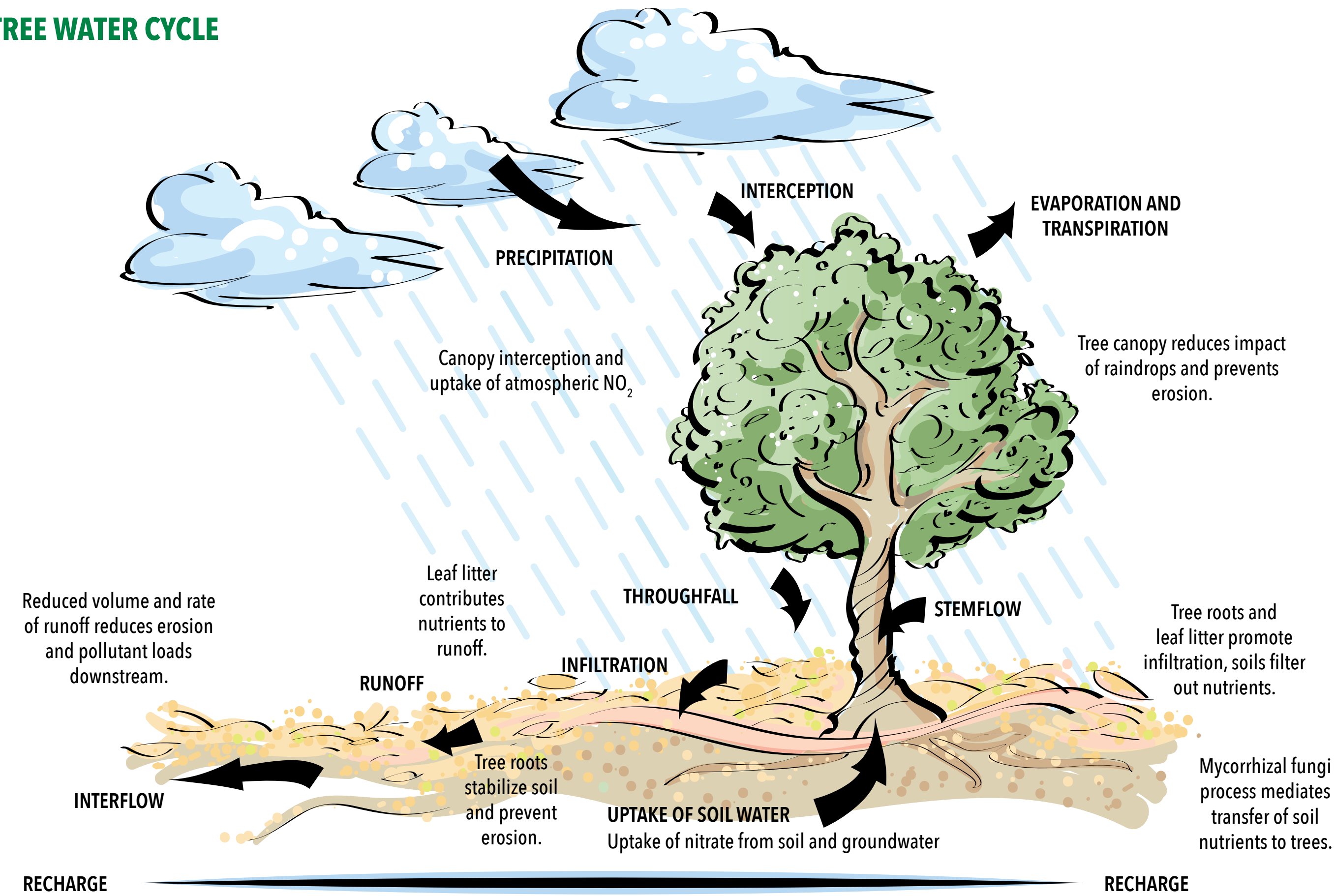
Avian Habitat Suitability Report
    USDA Forest Service i-Tree

Environmental Response Management Application (ERMA)
    NOAA Office for Coastal Management

Priority Habitats and Species
    WA Department of Fish & Wildlife

Trees of different ages and sizes provide food, habitat, and protection for urban wildlife. Keeping or creating dead trees and wildlife snags in areas where public safety is not a concern are important ways to provide key wildlife habitat on a small scale. Preserving

TREE WATER CYCLE



fallen branches, snags, woody debris, leaf litter, and rotten stumps in areas where natural habitat can remain 'ungroomed' are practices that support an urban ecosystem.

WATER QUALITY PROTECTION

Trees and vegetation help protect water quality by decreasing stormwater runoff, reducing soil erosion and pollutant loading, and shading water bodies. Tree canopy reduces stormwater runoff volumes by promoting rainfall interception, evaporation, transpiration, infiltration, and phytoremediation. Soil erosion is reduced when tree canopy breaks or softens the impact of raindrops and when tree roots hold soil in place on slopes and along stream banks. Trees also enhance the quality of rainwater runoff delivered to surface waters or groundwater by absorbing nutrients and promoting the growth of beneficial organisms that take up pollutants. Forests play an important role in protecting the quality of drinking water supplies. In the U.S., forests are the source of safe, clean drinking water for more than 180 million people (greater than 50% percent of the population) (USDA Forest Service, n.d.). In the Puget Sound region, some municipal water systems depend upon clean surface waters from forested basins—such as the City of Seattle's

Phytoremediation
The use of living green plants for in situ removal, degradation, and containment of contaminants in soils,surface waters, and groundwater.

[Phytoremediation in the Encyclopedia of Ecology]

Cedar River Watershed—and some depend on clean overland flow and infiltration to recharge groundwater aquifers, like the City of Renton's Cedar Valley Aquifer. Trees growing adjacent to water bodies help decrease water temperatures through direct shading, and tree planting is a best practice to mitigate temperature Total Maximum Daily Loads (TMDLs) on 303(d) listed impaired water bodies.

STORMWATER RUNOFF REDUCTION

Urban trees reduce stormwater runoff through rainfall interception, evaporation, transpiration, and infiltration. This combination of functions reduces the amount of rainfall reaching the ground and attenuates the timing and movement of rainwater on and offsite, improving onsite retention of water and groundwater recharge. The portion of total precipitation that is not evaporated falls to the ground where it can be taken up by trees and other plants, recharge shallow and deep groundwater, and move through the soil or across vegetated land to eventually recharge surface waters.

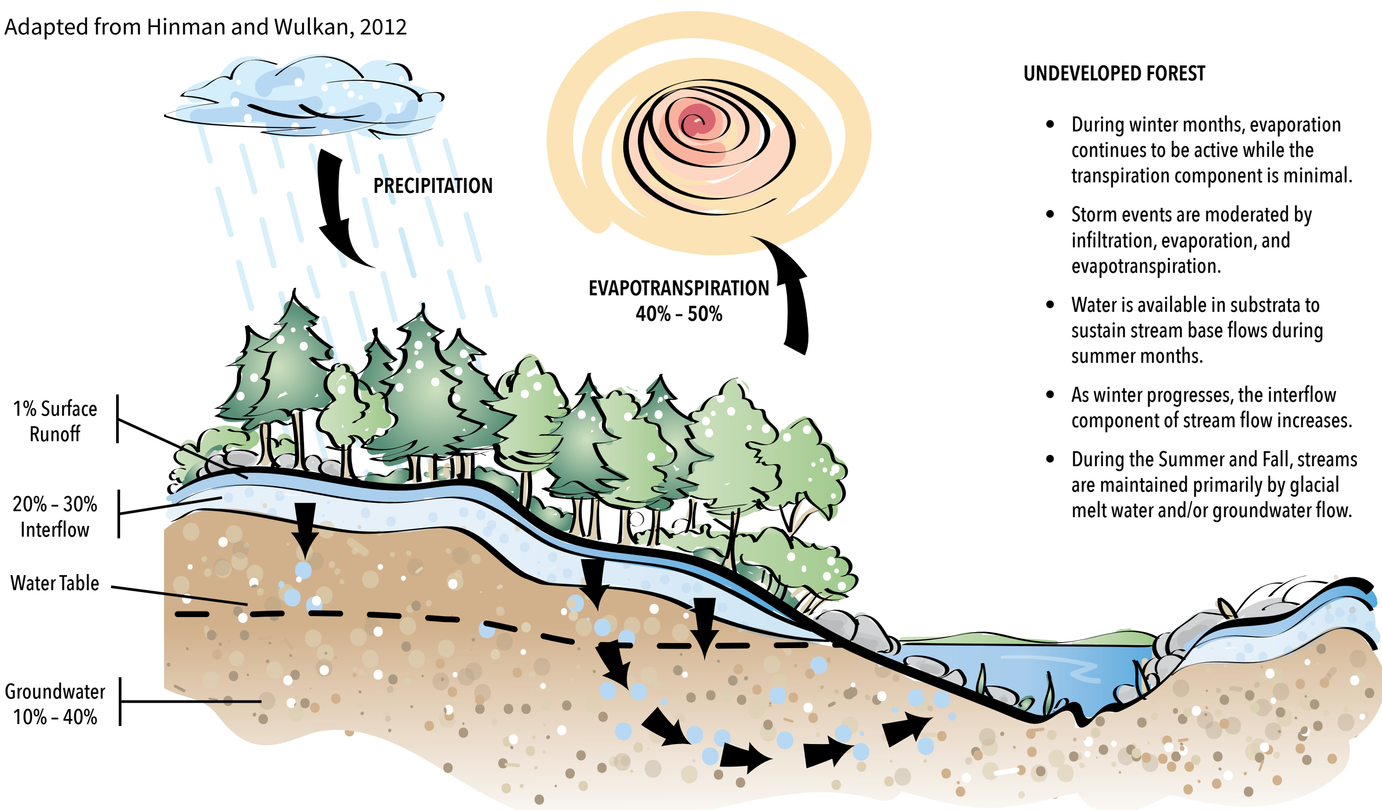
When trees, understory vegetation, soil layers, and duff are present, only a fraction of total precipitation forms runoff. Studies have estimated total runoff from intact forest systems under a variety of regional hydrology patterns.

Duff

Duff, also called litterfall, plant litter, leaf litter, tree litter, and soil litter, is the branches, twigs, bark, leaves, and needles that have fallen to the ground and are dead and partly decayed.

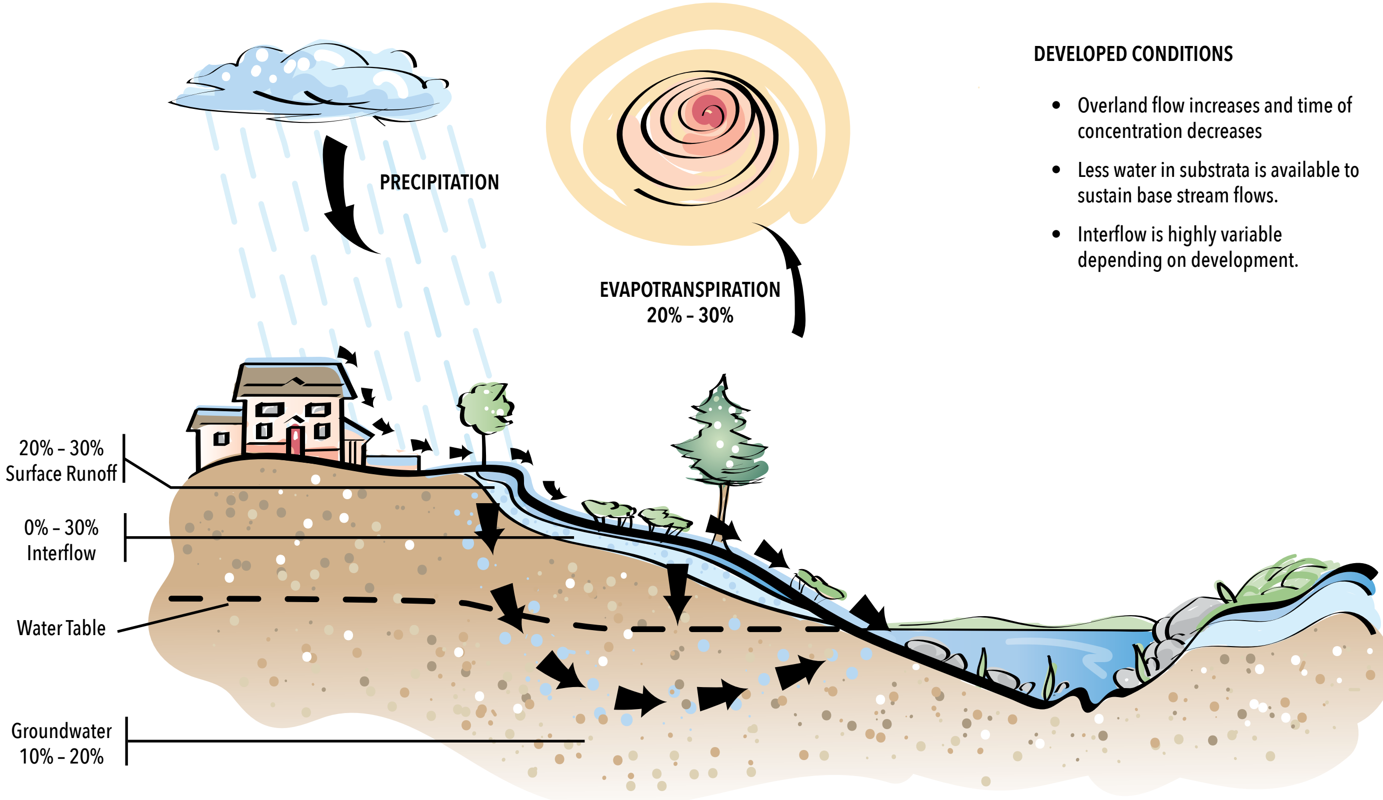
PREDEVELOPMENT WATER CYCLE

Adapted from Hinman and Wulkan, 2012



POST DEVELOPMENT WATER CYCLE

Adapted from Hinman and Wulkan, 2012



One synthesis of existing research found predevelopment forest runoff volumes to be as low as one percent of total precipitation (Hinman and Wulkan, 2012). While urban tree canopy may not function equivalent to an intact forest, efforts to enhance urban tree canopy in combination with understory vegetation and amended soils can help communities reach their reduction goals for stormwater runoff volumes.

> **THE ROLE OF TREES IN STORMWATER MANAGEMENT**
>
> Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management
>
> US EPA

CARBON SEQUESTRATION

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide (USGS, n.d.). Trees harness the sun's energy to grow and, in doing so, collect carbon from the atmosphere and store (sequester) it in the form of woody tissue—also called a "carbon sink." Tree and forest conservation protect these stocks of carbon by retaining woody biomass, preventing the release of the stored carbon into the atmosphere until converted through biological and physical processes. Actively growing trees continue to collect and

"Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide."

CARBON CALCULATORS

[Carbon Online Estimator (COLE)]

USDA Forest Service Climate Change Resource Center

COLEv2.0 enables the user to examine forest carbon characteristics of any area of the continental United States.

[i-Tree Landscape (Tree Benefits)]

USDA Forest Service & Davey Institute

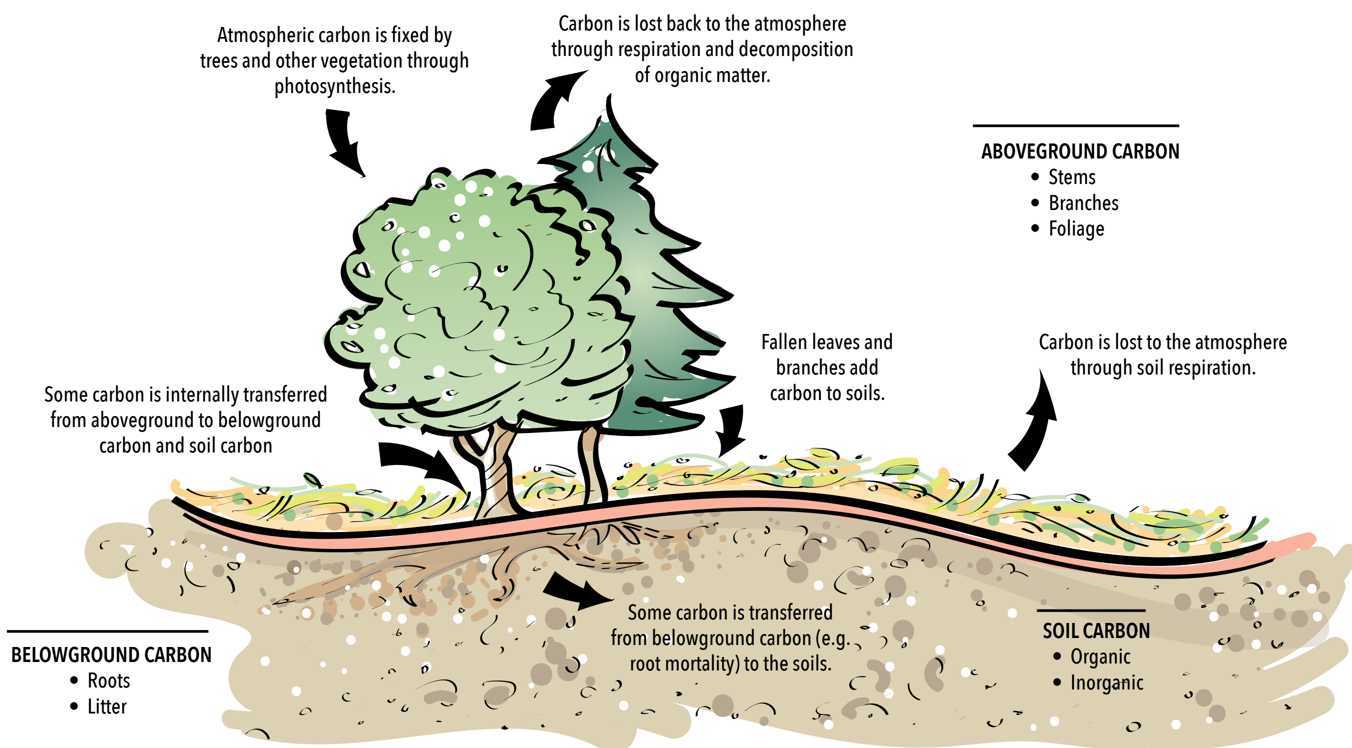
i-Tree Landscape provides carbon sequestration $/yr and ton/year for the selected area using MRLC NLCD 2011 and 2001 data.

[CUFR Tree Carbon Calculator (CTCC)]

USDA Forest Service Climate Change Resource Center

The CUFR Tree Carbon Calculator (CTCC) provides quantitative data on carbon dioxide sequestration and building heating/cooling energy effects provided by individual trees. CTCC outputs can be used to estimate GHG (greenhouse gas) benefits for existing trees or to forecast future benefits.

TREE CARBON CYCLE

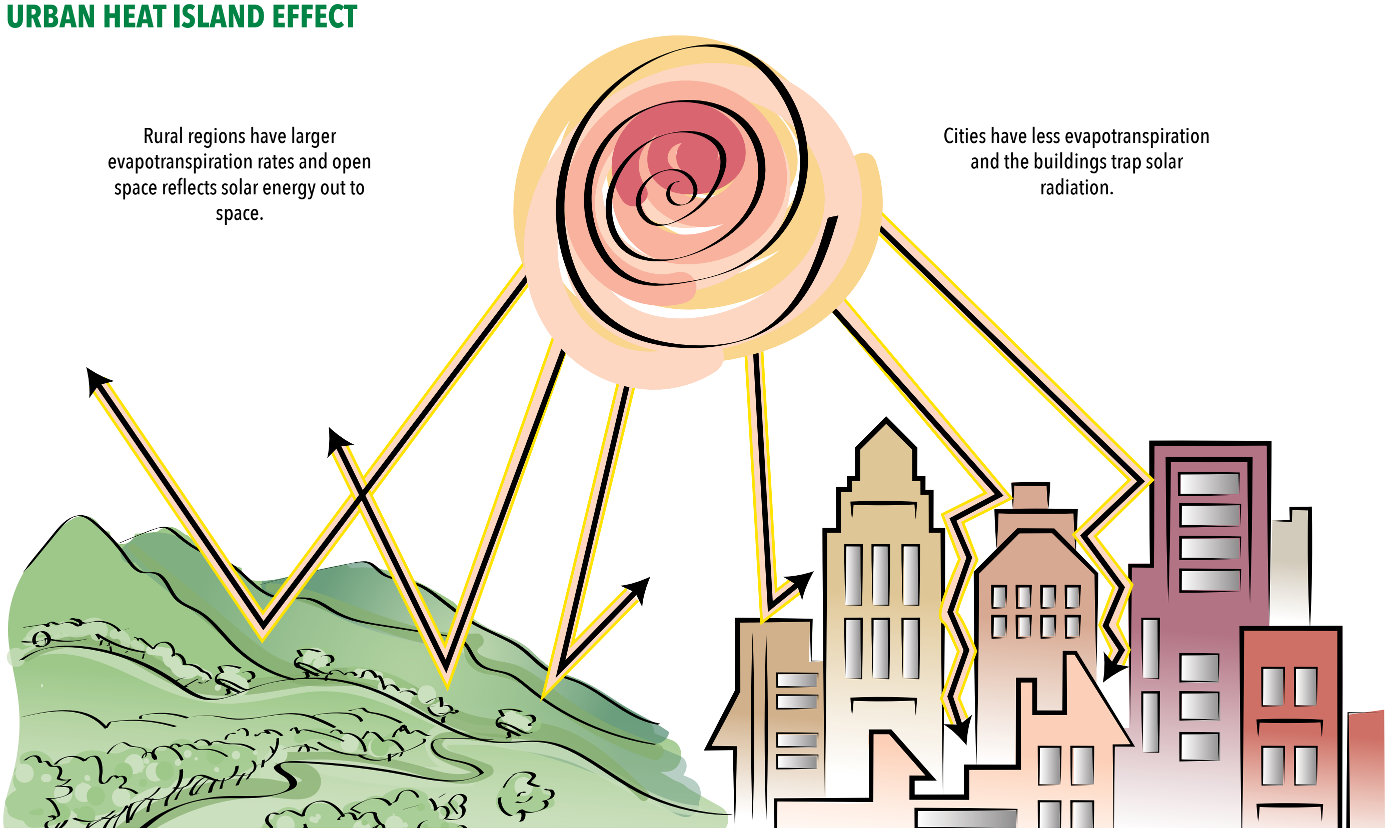


store atmospheric carbon until they reach biophysical equilibrium, at which point the carbon stored in tree biomass becomes a static carbon pool. Climate-focused forest conservation policies and programs focus forest conservation activities on mitigating greenhouse gas emissions through carbon sequestration. This focus includes conservation of forests in ecozones beyond rainforests, including temperate forests in urban communities where many of these systems function as significant carbon sinks. Urban forest carbon studies are contributing to a better understanding of the role of trees in managing our atmospheric carbon challenges. For example, a London-based study used LiDAR to map above ground tree biomass and estimate the amount of carbon contained in the mapped trees. The trees of London's urban forests were found to be carbon storage powerhouses with carbon storage ranging between that of temperate forests and rainforests (Wilkes et al., 2018). Closer to home, carbon sequestration calculations attribute 150 to 700 tons of carbon stored per hectare in Douglas fir forests and 80 to 300 tons of carbon stored per hectare in Alder/Maple forests (Smith et al., 2006).

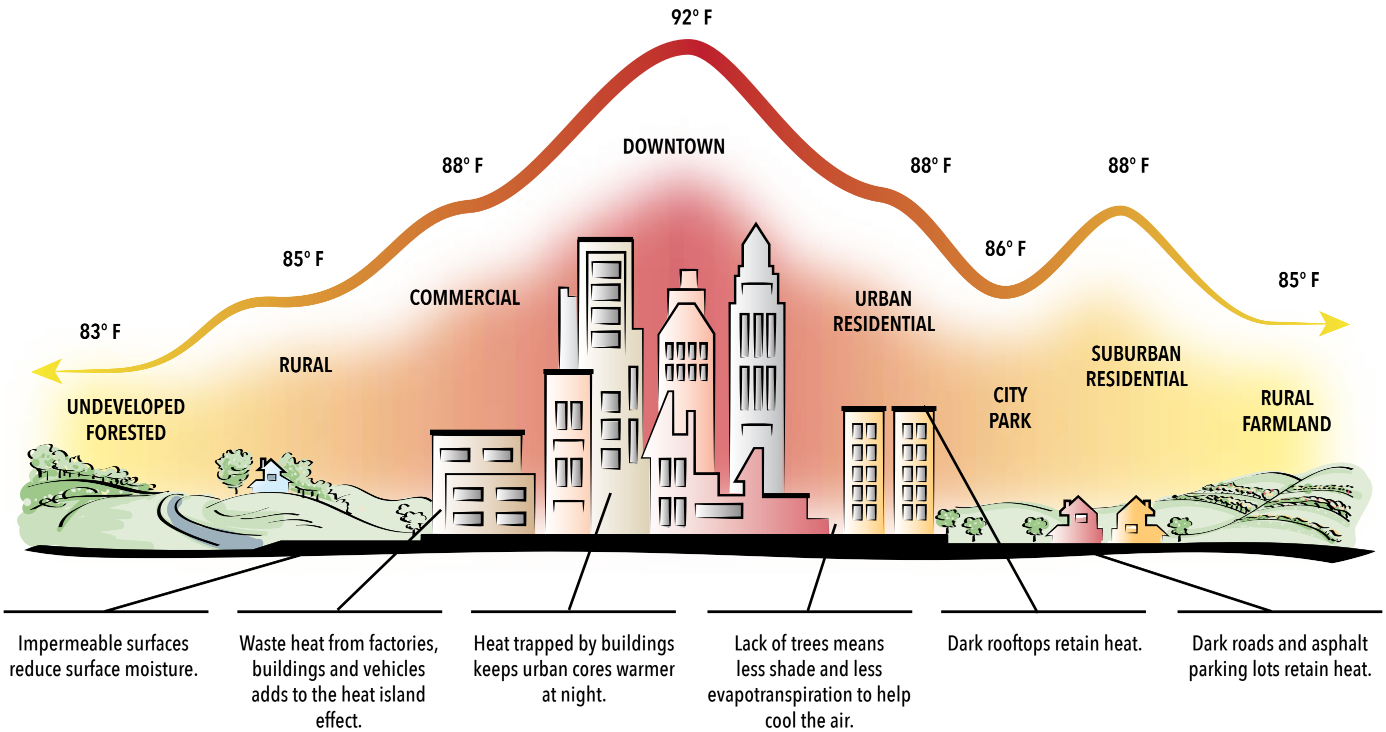
CLIMATE RESILIENCY

Urban tree canopy improves the climate resiliency of communities by reducing summer peak temperatures, moderating winter winds, and improving air quality. Overheating of urban areas, referred to as the urban heat island effect, is a challenge in many urban landscapes and likely to become an increasing concern with rising summer tempera-

URBAN HEAT ISLAND EFFECT



URBAN HEAT ISLAND EFFECT - LATE AFTERNOON TEMPERATURES



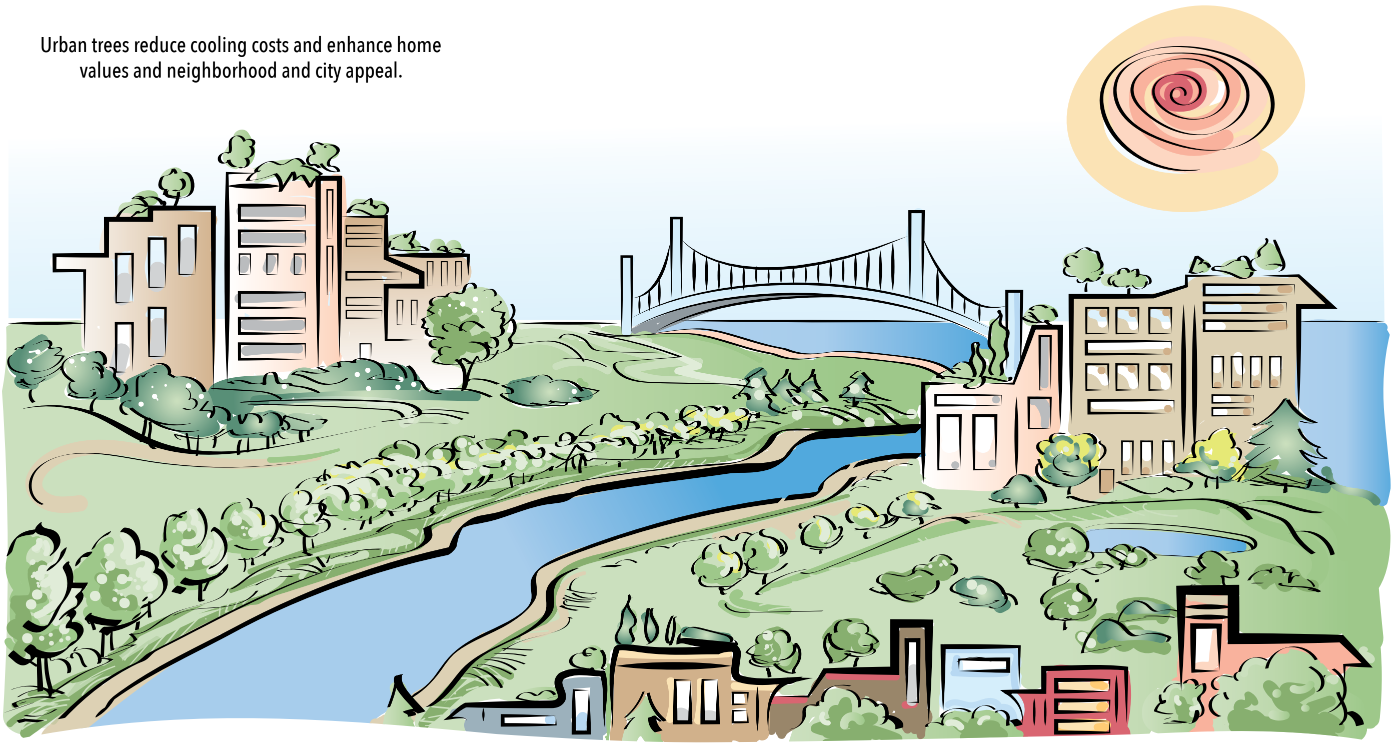
tures in the Puget Sound region. Urban heat islands occur when infrastructure, such as roads and buildings, absorb and re-emit heat from solar radiation. Other factors that contribute to urban heat islands include heat-generating mechanical equipment, emission-derived pollution (which induces heat retention), and a lack of natural vegetated surfaces—especially a lack of trees. Adding trees to the urban landscape helps cool air temperatures through shading and evaporation-transpiration processes that increase water content in the air. Cooling from shade provided by urban tree canopy in the summer lowers residential energy use by reducing air temperatures in the range of one to five degrees Fahrenheit (McDonald et al. 2016). Several programs and tools are available that address urban heat islands through energy conservation actions. For example, the Arbor Day Foundation has partnered with the United States Department of Agriculture Forest Service (USDA FS) and the Davey Institute i-Tree program to offer the *Community Canopy Program and Energy Saving Trees Tool* to help homeowners map tree placement on their property for optimal energy savings. In some locales, this program is combined with free trees for planting.

Economic Benefits

Urban tree canopy provides cost reducing, value increasing, and productivity improving benefits to communities and their residents and businesses. Trees and tree canopy passively mitigate solar radiation-induced temperatures through shading, which can reduce cooling costs for homes and businesses. Trees create desirable community environments—

ECONOMIC BENEFITS OF TREES

Urban trees reduce cooling costs and enhance home values and neighborhood and city appeal.



improving the aesthetic value of individual properties, neighborhoods, and communities. These improvements include physical enhancements such as landscaping on private and public property and reclaiming underutilized areas as community amenities. Mature, well-maintained trees can boost curb appeal for selling homes (The Davey Tree Expert Company, 2018). Curb appeal can also translate into increased property values. The USDA FS Pacific Northwest Research Station reports that a tree in front of a home increases the home's sales price by $7,130 (Wells, 2010). Trees and natural landscaping around office buildings and the proximity of offices to trees, natural areas, parks, and trails can enhance workplace productivity (Gilchrist and Montarzino, 2015).

THE VALUE OF TREES

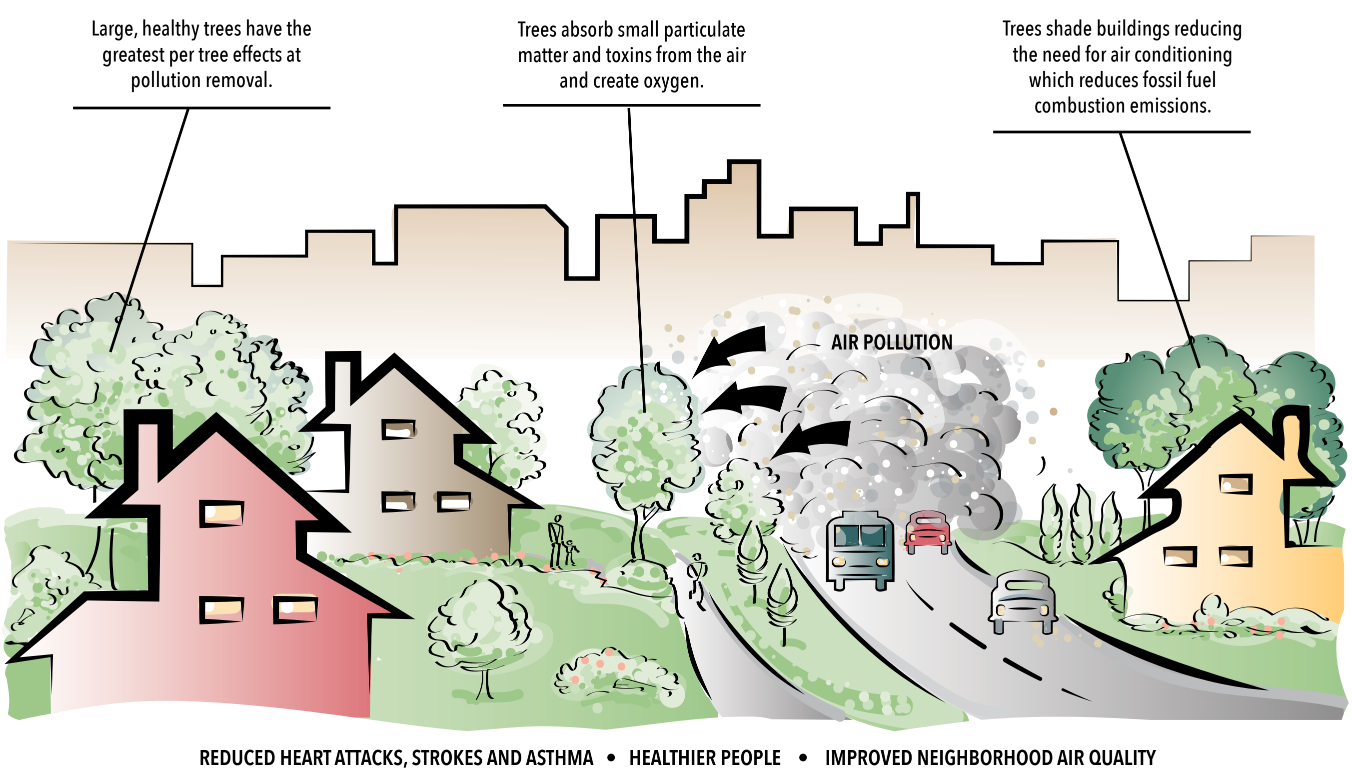
Urban trees in the U.S. are estimated to store 643 tonnes of carbon - a value of $50.5 billion.

Air Quality Improvement

Trees improve air quality through oxygen production and pollution abatement. By producing oxygen, trees give us air to breath. Trees remove particulate matter pollution in their vicinity by intercepting and holding small particles on the surfaces of leaves, stems and trunks. When planted between residences, schools, and other facilities, trees protect human health. Trees also absorb gaseous pollutants, such as nitrogen oxides, ammonia, and sulfur dioxide. Ground-level ozone formation is reduced when trees of sufficient density and canopy cool the air."

Trees remove particulate matter pollution in their vicinity by intercepting and holding small particles on the surfaces of leaves, stems and trunks.

URBAN TREES, BETTER AIR QUALITY



Stormwater Management Benefits and Challenges of Urban Trees in the Puget Sound Region

When rain hits surfaces, such as roads, parking lots, building roofs, or lawns, some of the rainfall becomes stormwater runoff. As stormwater runoff flows over these surfaces, it collects debris, sediment, fertilizers, pesticides, oils, metals, and other pollutants that eventually make their way to streams, rivers, lakes, and other water bodies. In Western Washington, all stormwater runoff eventually discharges into Puget Sound, which is highly valued for its natural beauty and wildlife and its contribution to quality of life in the region.

Puget Sound's many miles of coastline are connected to densely populated urban areas that generate significant volumes of stormwater runoff, much of which is generated during the winter and spring months when precipitation is higher. Urban stormwater pollution is a significant environmental challenge in the Puget Sound region. Urban tree canopy helps address this challenge by reducing stormwater runoff volumes and improving water quality. Individual trees are also an integral component to managing stormwater runoff at the parcel scale—as a stand-alone low impact development (LID) design, trees can be used with stormwater best management practices (BMPs). Trees also can be integrated in other LID designs such as bioretention and some vegetated roof systems, as well as green stormwater infrastructure (GSI) and green infrastructure (GI) designs. Table 1 summarizes several terminologies used to describe practices that manage runoff or mimic natural hydrology.

Quantifying Stormwater Benefits of Urban Trees

The importance of urban tree canopy for reducing the impact of stormwater is widely recognized, but studies that evaluate models and tools for quantifying those benefits in the Puget Sound region are limited. The *Puget Sound Urban Tree Canopy and Stormwater Management Project* (Project) set out to fuel productive conversations between the urban forestry and stormwater management communities about the role of tree canopy in reducing stormwater runoff volume and addressing associated water quality concerns. In doing so, the Project compared analyses from two hydrology models used by these communities: i-Tree Hydro, typically used by urban forestry professionals, and the Western Washington Hydrology Model (WWHM), typically used by stormwater professionals. Both models were applied to a common set of management scenarios, results were compared, and the findings described in a Technical Report.

Table 1. "Green" Stormwater Management Terms Defined

TERMINOLOGY	DEFINITION	WHEN USED IN THIS HANDBOOK
Green Stormwater Infrastructure (GSI)	GSI includes stormwater BMPs designed to reduce runoff from development using infiltration, evapotranspiration, and/or stormwater reuse. To be considered GSI, it must provide a function in addition to stormwater management such as water reuse, providing greenspace, and/or habitat. Examples of GSI include trees, bioretention facilities, rain gardens, permeable pavement, vegetated roofs, and rainwater harvesting. www.seattle.gov/utilities/environment-and-conservation/projects/green-stormwater-infrastructure/stormwater-code	In Western Washington, GSI is often used synonymously with LID. In this Handbook, GSI is the preferred term unless referring to requirements specified in the Stormwater Management Manual for Western Washington (SWMMWW) or the National Pollutant Discharge Elimination System (NPDES) municipal stormwater permit.
Low Impact Development (LID)	LID is a stormwater and land use management strategy that strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation, and transpiration by emphasizing conservation, use of on-site natural features, site planning, and distributed stormwater management practices that are integrated into a project design.	In this Handbook, LID is used when referring to the requirements in the SWMMWW or the NPDES municipal stormwater permit.
Green Infrastructure (GI)	At the city or county scale, GI is a patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the neighborhood or site scale, GI refers to stormwater management systems that mimic nature's ability to soak up and store water. www.epa.gov/green-infrastructure/what-green-infrastructure	In this Handbook, green infrastructure is used when broadly referring to tree canopy and not when referring to trees as a standalone stormwater management BMP.
Nature-based solutions	Nature-based solutions refer to the sustainable management and use of nature for tackling challenges such as climate change, water and food security, biodiversity protection, human health, and disaster risk management. They provide co-benefits for people and nature—notably, capturing and storing CO2 emissions and reducing the impacts of climate change (including droughts, floods, fires, and land erosion). They also preserve plant and animal biodiversity and build more resilient and healthy communities by protecting fisheries and improving farmland. https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions https://www.naturebasedsolutionsinitiative.org/what-are-nature-based-solutions/	Nature-based solutions is not used in this Handbook but is another widely used term that encompasses GSI/LID.

COMPARISON OF HYDROLOGY MODELS

Different hydrology models are available for evaluating stormwater runoff volumes. i-Tree Hydro and WWHM were selected for analysis in the Project because of their widespread use in the industry and applicability for stormwater modeling by urban forestry and stormwater practitioners.

i-Tree Hydro

i-Tree Hydro is a hydrology modeling tool in a suite of i-Tree tools created by researchers from the USDA FS and the Davey Institute. The i-Tree Hydro software tool employs algorithms to account for seasonal and local variability in precipitation for plot-based evaluations of trees. i-Tree Hydro was designed to inform urban forestry professionals about the effects of urban tree canopy and impervious cover on streamflow and is a flexible tool for modeling the effect of different land covers on stormwater runoff volumes. i-Tree Hydro is particularly useful for modeling the nuances and complex variables at play in the Puget Sound region where increases in impervious area generate high stormwater runoff volumes and water quality impacts.

While i-Tree Hydro was the primary i-Tree tool evaluated by the Project, an additional i-Tree tool—i-Tree Eco—was used and evaluated in some of the modeled scenarios (parcel scale). In these cases, tree inventories were conducted to evaluate the stormwater runoff reduction benefits of individual trees on individual parcels. i-Tree Eco also can be used to determine the ecosystem service benefits of an entire urban forest ecosystem through analysis of randomly located plots within a defined geographic scale across all land ownerships (public and private).

i-Tree

I_TREE TOOLS

i-Tree Hydro

USDA Forest Service & Davey Institute

Simulate the effects of land cover changes on water quantity and quality, unique in explicitly modeling vegetation processes

i-Tree Landscape

USDA Forest Service & Davey Institute

Explore tree canopy, land cover, and basic demographic information in a location of your choosing

i-Tree Eco

USDA Forest Service & Davey Institute

Use data collected in the field from single trees, complete inventories, or randomly located plots throughout a study area along with local hourly air pollution and meteorological data to quantify forest structure, environmental effects, and value to communities

Western Washington Hydrology Model

WWHM has been used to evaluate the effects of tree canopy coverage on stormwater runoff in the Puget Sound region since the early 2000s and works by simulating the hydrologic processes of streams, impoundments, and pervious and impervious surfaces. Stormwater professionals use WWHM to design stormwater flow control and water quality treatment facilities to mitigate the impacts of increased impervious surfaces. In addition to sizing stormwater facilities, stormwater flow control credits offered through the Washington State Department of Ecology (Ecology) can also be calculated outside of WWHM for tree planting and tree retention and applied in WWHM to reduce the size of these stormwater facilities.

> **WWHM**
>
> [Western Washington Hydrology Model]
>
> WA Department of Ecology
>
> Users Manual and free model download

PROJECT APPROACH

The Project team applied i-Tree Hydro (and i-Tree Eco) and WWHM at four spatial scales (citywide, drainage basin, neighborhood, and parcel) in four pilot communities (the cities of Kent, Kirkland, Snohomish, and Tacoma) to demonstrate the practical applications of both models. The results from both models were compared to evaluate the effects of tree canopy on stormwater runoff volumes.

Three management scenarios were applied to evaluate increases or decreases (percent change) in stormwater runoff volume over a six-year period. These included 1) loss of tree canopy, 2) changes in tree canopy and impervious area resulting from development, and 3) increases in tree canopy from current tree canopy levels. Each management scenario was further split into two cases representing different levels of scenario implementation. For example, the tree canopy loss scenario includes a case with no canopy (100 percent loss) and a case with a partial canopy decrease (10 percent loss).

Table 2. Modeled Management Scenarios

MANAGEMENT SCENARIO	CASE
Existing Conditions	Base Case
Tree Canopy Loss	1A. Present Tree Canopy Stormwater Benefits 1B. Partial Tree Canopy Loss
Development	2A. Build-out with Tree Preservation 2B. Build-out without Tree Preservation
Tree Canopy Increase	3A. Tree Canopy Increase: Over Pervious Area 3B. Tree Canopy Increase: Over Impervious Area

PROJECT RESULTS

Model Comparison

The modeled results of i-Tree Hydro and WWHM demonstrate a positive relationship between urban tree canopy and stormwater runoff volume reduction. Runoff volume values generated by both models differed, with i-Tree Hydro yielding lower runoff volume outputs than WWHM in all modeled scenarios. These differences are attributed to variances in model parameters and suggest that each model is ideally suited for application at different scales—i-Tree Hydro at the landscape, including smaller geographies such as the neighborhood scale, and WWHM at the parcel scale, including larger geographies such as the neighborhood scale.

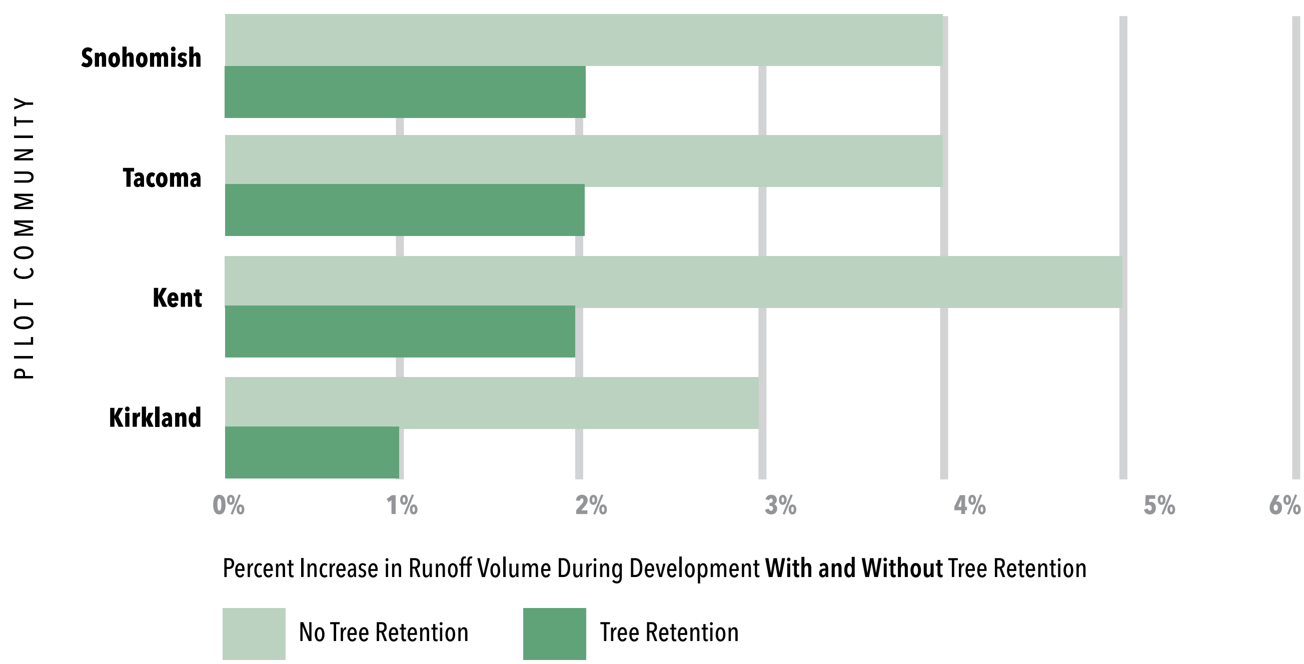
Modeled Results

A comparison of modeled outputs for the three management scenarios at four spatial scales and across four pilot communities demonstrated the important role of urban tree canopy in managing urban stormwater runoff volumes. Key recommendations to be derived from the Project outcomes include:

- Integrate tree canopy cover wherever possible.
- Retain existing tree canopy during development.
- Increase tree canopy over impervious surfaces.

A complete treatment of the modeled results can be found in the [Technical Report](), *beginning on page 25.*

Tree Retention During Development Decreases Stormwater Runoff



Key Findings and Associated Recommendations

The Project analysis yielded several key findings that illustrate a positive correlation between tree canopy and stormwater runoff volume reduction. Additionally, the results show with few exceptions that the two models generated similar outputs in a majority of the modeled scenarios. The key findings and associated management recommendations are summarized below in Table 3.

Table 3. Key Findings and Management Recommendations

KEY FINDING	RECOMMENDATIONS
1. Replacing tree canopy with any other land cover type increases stormwater runoff volume.	Retain and plant trees wherever possible (overhanging impervious areas and over pervious areas) to reduce stormwater runoff volume and pollution loads.
2. Increasing tree cover over impervious surfaces decreases runoff volumes.	Plant trees to overhang impervious surfaces for high stormwater runoff and pollution reduction benefits.
3. Development that includes tree retention results in reduced runoff volume compared with development without tree retention.	Retain existing trees during new development and redevelopment for higher stormwater runoff and pollution reduction benefits.
4. Areas with higher amount of existing tree canopy experience a lower magnitude of increased runoff volume when tree canopy is reduced.	Retain and expand tree and forest canopy cover where possible for maximum stormwater runoff reduction benefits.

Model Comparison Outcomes

Based on the modeled results of i-Tree Hydro and WWHM, the Project team concluded the following summary of key model comparison outcomes:

- The greater the amount of impervious area, the less the two models can demonstrate a benefit from trees (the models cannot demonstrate benefits of individual trees; tree/canopy stormwater benefits are overwhelmed as impervious surface area increases).
- The two models could not effectively account for certain parameters, such as the benefits of tree canopy relating to ephemeral stream flow peaks, erosion control, and wildlife habitat along water bodies.
- In nearly all modeled scenarios, i-Tree Hydro yielded lower runoff volume outputs than WWHM, suggesting the models are better suited for application at different scales.

Retaining and Planting Trees for Stormwater Management

The Puget Sound Urban Tree Canopy and Stormwater Management Project is one of many studies demonstrating the stormwater management benefits of trees and tree canopy. The Project's findings established that:

- Existing trees reduce runoff volumes.
- Clearing trees increases stormwater runoff volumes.
- Tree canopy over roads, sidewalks, and parking lots reduces runoff volumes.

The stormwater benefits of trees and tree canopy are also an asset to development and redevelopment scenarios for meeting various state and federal regulations that require measures to control stormwater runoff.

The following BMPs in the Stormwater Management Manual for Western Washington (SWMMWW) provide additional context to the content in this section:

- BMP T5.16: Tree Retention and Tree Planting
- BMP T5.40: Preserving Native Vegetation
- BMP T5.41: Better Site Design

In Western Washington, trees are considered during development and redevelopment activities as a result of the state's alignment with the Clean Water Act (CWA) and National Environmental Policy Act (NEPA), implemented through Ecology's water quality and stormwater programs and the State Environmental Policy Act (SEPA). Ecology's Stormwater Management Manual for Western Washington (SWMMWW) drives tree considerations during two phases of development and redevelopment—the site design and layout process and when selecting and designing stormwater BMPs for a site. The following provides an overview of Ecology's SWMMWW which guides site design and layout, using trees as a stand-alone LID BMP, and integrating trees into other BMPs.

CONSIDERING TREES DURING SITE DESIGN AND LAYOUT

Preserving native vegetation (including trees) during the site design process is an important tenet of LID in Western Washington. The application of LID principles and practices to a site varies depending on local development codes, rules, and standards. During the preliminary development layout stage (*Step 2* of preparing a *Stormwater Site Plan*), the guidance provided in the SWMMWW is to "preserve areas with natural vegetation (especially forested areas) as much as possible."(Washington State Department of Ecology Water Quality Program, 2019). The Site Design BMPs (*BMP T5.40: Preserving Native Vegetation*, and *BMP T5.41: Better Site Design*) provided in the SWMMWW are optional for integration into local development codes, rules, and standards. *BMP T5.41: Better Site Design* includes defining the development envelope and protected areas such as important existing trees. By minimizing the development envelope, environmental impacts can be minimized, construction costs can be reduced, and attractive landscape features, such as trees, can be retained.

USING TREES AS STAND-ALONE STORMWATER BMPS

In the past, tree retention and tree planting at the parcel scale has largely been driven by tree retention codes and policies established at a local jurisdiction level. Assigning a specific quantitative value to the stormwater benefits of a single tree represents a more recent shift.

Flow Control Credits

Flow control credits allow for reductions in target impervious surface area when calculating mitigation needs to meet flow control requirements. Ecology's SWMMWW currently includes optional flow control credits that can be applied for both retained and newly planted trees. The amount of impervious surface area reduction depends on the tree type (e.g., coniferous or deciduous), canopy area, and proximity of the tree to the impervious surface. Existing and newly planted trees must be within 20 feet of new or replaced ground level impervious surface to receive a flow control credit, thus street trees planted near impervious surfaces (along sidewalks, in medians, and in parking lots) can be one of the most impactful applications of stand-alone tree BMPs for reducing stormwater volumes in areas with significant impervious land cover.

How can a retained tree qualify for a flow control credit?

- 6-inch diameter at breast height (DBH) minimum
- Within 20 feet of new or replaced ground level impervious surface

How can a new tree qualify for a flow control credit?

- 1.5-inch diameter at 6 inches off the ground at time of planting (deciduous trees)
- At least 4 feet tall at the time of planting (coniferous trees)
- Within 20 feet of new or replaced ground level impervious surface
- Listed on a jurisdiction's approved species list

Existing trees are assigned a flow control credit based on their canopy area, with evergreen trees receiving a larger credit than deciduous trees. (Evergreen credit equivalent to 20% of canopy area; minimum of 100 square feet per tree. Deciduous credit equivalent to 10% of canopy area; minimum of 50 square feet per tree.)

New trees are assigned a square-foot-per-tree credit, again with evergreen trees receiving a larger credit (50 square-feet-per tree) than deciduous trees (20 square-feet-per tree). Flow control credits are not allowed for trees in native vegetation areas that are being used for flow dispersion or other flow control credits. Flow control credits are also not applicable to trees in planter boxes.

INTEGRATING TREES INTO STORMWATER BMPS

In addition to using trees as a stand-alone LID BMP for flow control credit, other GSI BMPs can integrate trees as a component of the landscape design, including rain gardens, bioretention facilities, planter boxes, full dispersion, and some vegetated roof designs. These designs reduce stormwater runoff in areas where large amounts of impervious surfaces would otherwise generate high stormwater runoff volumes. Some of these GSI BMPs (e.g., bioretention, full dispersion) are also designed to provide water quality treatment and reduce pollutant loading. Full dispersion preserves a large portion of a site as native vegetation (typically forest) to provide stormwater management functionality for a site. Trees can also be integrated into the design of traditional non-GSI BMPs including detention ponds and stormwater treatment wetlands.

Challenges with Integrating Trees into GSI Designs

Integrating trees with stormwater management solutions can present challenges for urban forestry professionals, stormwater professionals, and builders and developers. These include implementation costs, tree and canopy establishment timeframe, new tree maintenance, and a limited range of incentives to promote tree retention and tree planting during development and redevelopment scenarios.

TREE PLANTING COSTS

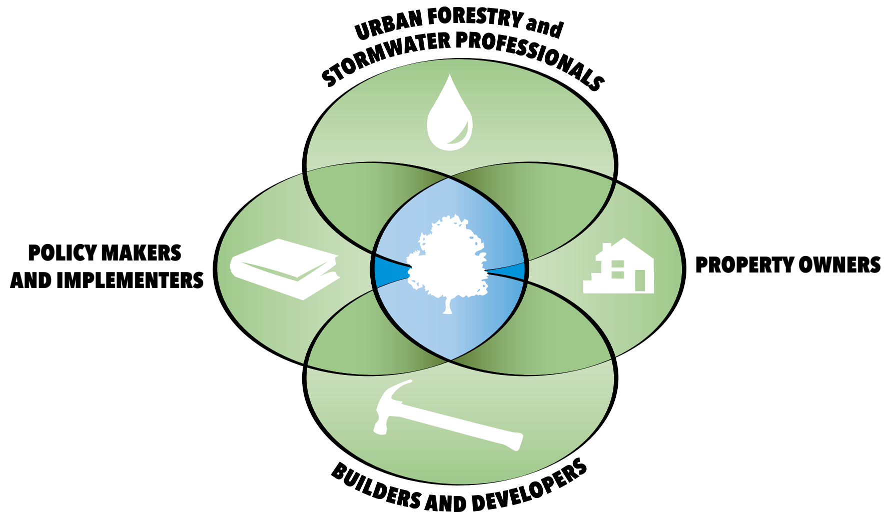
The cost of tree planting relative to the amount of time until a tree will provide stormwater management benefits can be difficult for urban forestry and stormwater professionals to justify—especially when elected officials in charge of approving budgets want to see immediate results. Investments in GSI and GI trees require lifetime costs for cities and property owners, not just one-time installation costs. Such investments often need to consider all the benefits of trees to justify the cost. Understanding how integrated trees can decrease other environmental costs is important for implementers to take into consideration. As a similar context example, stormwater management costs can be decreased when GSI is implemented properly. GSI has a longer lifespan than conventional stormwater infrastructure, and therefore, the overall costs are comparable to conventional stormwater infrastructure (Hjerpe and Adams, 2015).

TREE ESTABLISHMENT AND MAINTENANCE

Establishing new trees and maintaining existing trees requires commitment to best practices. When best practices are absent, expensive investments in trees are undermined by poor tree establishment and even mortality. Poor site selection—such as picking an unsuitable location for a specific tree species—and improper tree planting techniques—such as planting a tree too deep in a planting hole—are common culprits. After a tree is planted—or when stewarding previously established trees—the short- and long-term survival can be compromised by lack of nutrients, soil compaction, mechanical and natural damage, and the introduction of opportunistic and invasive pests. Overly tidy maintenance techniques that remove natural sources of nutrients from areas surrounding trees can contribute to nutrient depauperate growing conditions. Competition with other species for limited nutrient supplies, including water and space, further reduces establishment and short- and long-term survival. Compaction of soils—which result when mechanical pressure is applied while soils are wet or saturated—creates stressful growing conditions generally in the form of restricted root growth, crushed roots, and poor oxygen and water transport in the root zone. Damage to bark, buds, and foliage from herbivory, as well as tools and mechanical equipment impair fitness. Pests that are present at background levels or that pose a more serious threat by way of their arrival into a new environment can infest stressed and unhealthy trees.

These and other issues can be managed or addressed through changes in tree care and site maintenance practices. The supply of available nutrients can be augmented by allowing organic sources such as leaves, twigs, and branches to decompose. Soil health can be maintained by periodically applying compost and aerating. Nutrient rich aerated soils in combination with watering to establish newly planted trees and to support established trees during water-scarce periods help trees overcome environmental stressors and maintain overall health for short- and long-term survival.

From Conversations to Collaboration



Tremendous opportunities exist for collaboration among urban forestry and stormwater professionals, and between these groups and audiences that have a direct influence on urban tree cover. These audiences include community advocates, policy makers and implementers, builders and developers, property owners, and a wide array of local groups that can link the benefits of urban greening to a specific need. Collaboration can be a compelling driver for supporting urban canopy policies and actions. Collaboration also can improve communication between urban forestry and stormwater professionals working with community advocacy groups to achieve shared goals.

Collaboration is especially powerful when it works to facilitate constructive dialogue between opposing parties. Notably, collaboration can bridge conflicts between project developers and local environmental groups, helping to discover common ground and potentially leading to alignment in terms of project outcomes. Additionally, collaboration is beneficial in that it involves the transfer of knowledge and skillsets. And in many cases, collaborative efforts can turn detractors into advocates and make projects more relevant to local needs—and more likely to succeed.

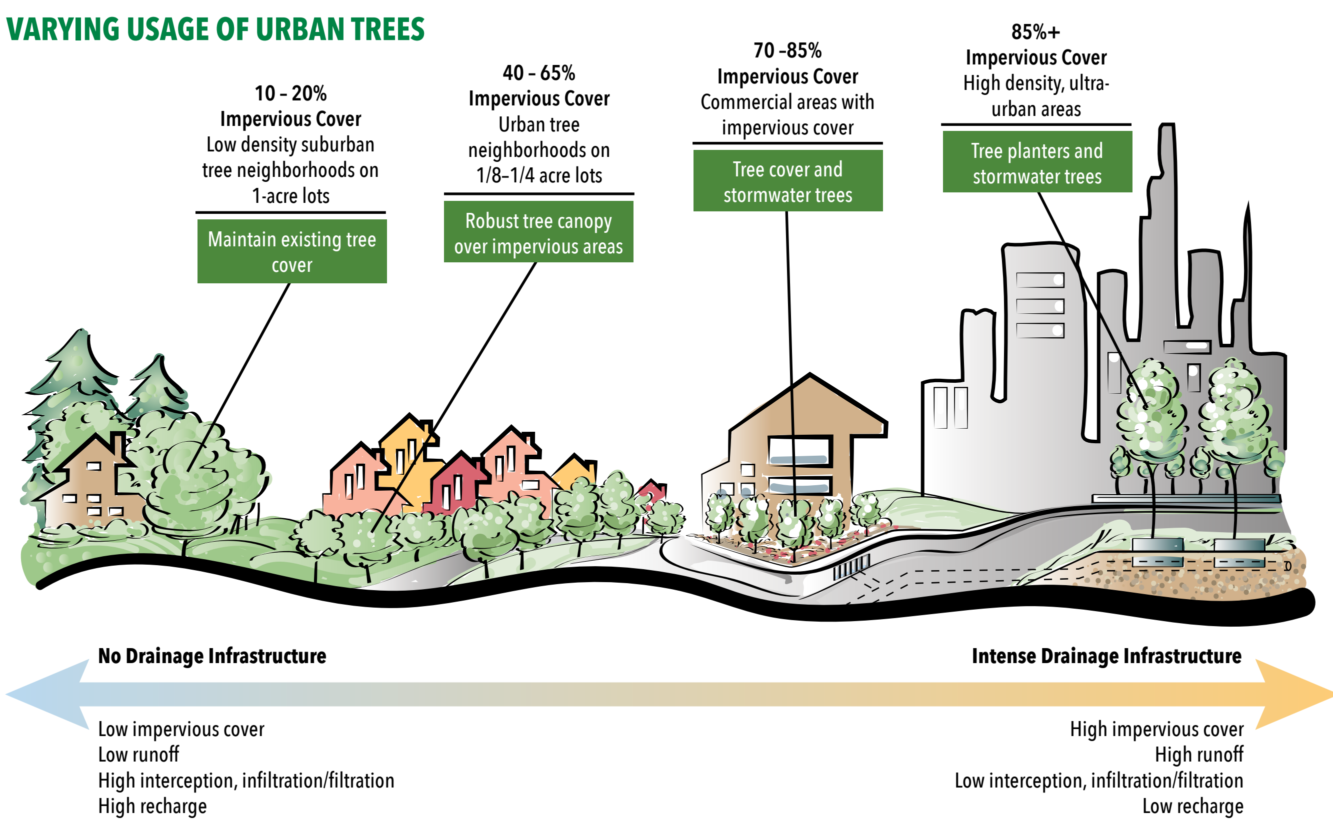
Urban settings provide frequent public-private opportunities to collaborate on the use of urban trees. Examples include engagement programs and development policies that promote or require street tree planting, open space stewardship, tree retention on private lots, the use of tree filters as stormwater mitigation features, and more. Public policy that guides planning can lead to innovative tree canopy and stormwater management approaches. For instance, planners are increasingly familiar with green street designs that offer an alternative to conventional street drainage systems and that more closely mimic the hydrology of a natural landscape by infiltrating rainfall. A green street that features trees, landscaping, and GSI and LID designs helps capture and filter stormwater runoff within the right-of-way. Green streets also provide the added benefits of cooling and enhancing the appearance of streets and neighborhoods.

Importantly, municipalities can increase the likelihood of successful green street designs and larger GI/GSI-based programs by collaborating and seeking participation with the community. Efforts that proactively engage and work in partnership with homeowners and residents can help preserve urban trees and better manage mature trees for longevity. By providing programmatic access to urban forestry, stormwater, and other professionals, municipalities can empower residents to be better tree, backyard habitat, and urban forest stewards.

The following section provides examples and resources to go beyond conversation and fuel productive collaboration between urban forestry and stormwater professionals, community leaders, and other stakeholders about the role of urban trees in mitigating stormwater-related issues and improving the health and well-being of communities. The goal is to illustrate how collaborative efforts can create successful links between a robust urban tree canopy, the built environment, and mitigation of stormwater impacts.

Trees in the Urban Environment

Tree policies in urban environments range from the protection of existing forest cover in low density new development to the use of highly engineered tree planters for stormwater management in urbanized settings. Individual urban trees add the benefit of a "sponge



factor” to the built environment that is lost in the absence of a robust tree canopy. Urban trees intercept and capture rainfall, allowing for retention and infiltration. Stormwater that is retained and infiltrated is filtered by soils and provides groundwater recharge. In addition to removing toxic stormwater contaminants, these processes contribute to temperature moderation and climate resiliency. Stormwater benefits may occur from preserving existing tree cover for new development, or from retaining large mature trees and canopy along sidewalks and roads over urban neighborhoods. Similarly, benefits from trees can result when they are used with highly engineered applications such as stormwater planters in commercial and industrial areas that encourage retention, biofiltration, and infiltration.

Urban Forestry and Stormwater Management Collaboration

CHALLENGES AND OPPORTUNITIES

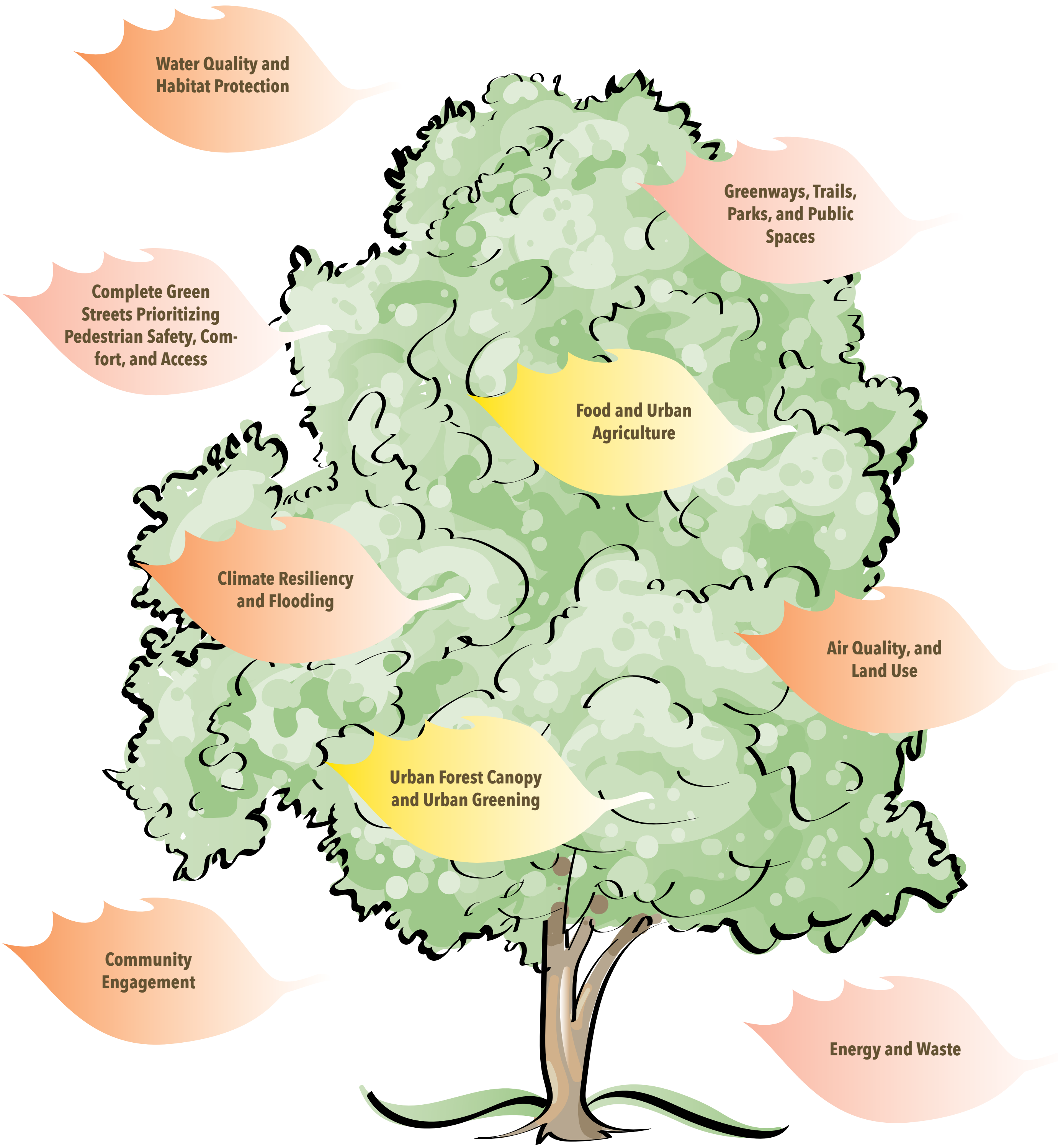
Project development in built environments is increasingly time consuming and complicated. This is due, in part, to permitting challenges, stakeholder concerns, and project opposition that includes “not in my backyard” viewpoints from adjacent property owners. Stakeholder collaboration offers a way to address these issues and turn project challenges into opportunities, and detractors into champions. Project support can be built by partnering with community advocates to address environmental issues and add neighborhood amenities like parks, trails, and other green spaces. Community advocates who support redevelopment plans can be tremendous assets when it comes to project approval.

Collaboration can also help overcome obstacles with permitting, which often represent a significant cost component of private sector development. Frequently, developers are most concerned about the time to obtain a permit, the iterative project review, and the lost opportunity costs from a drawn-out process. Similarly, complex projects often involve lengthy site plan reviews that result in heavy workloads for municipal staff and boards. Preliminary technical reviews can help streamline municipal reviews by ensuring a high degree of regulatory compliance prior to public hearings. In a comparable manner, collaboration at the stakeholder engagement and public input stages can help address both permitting concerns and local property owner opposition, both of which contribute to prolonged reviews. Often, developers are willing to include site development elements that are coaligned with stakeholder interests when there are incentives to be gained that can streamline project approval or increase the financial viability of a project.

STAKEHOLDER GROUPS

Understanding the motivations and concerns of urban forestry and stormwater management professionals and other stakeholders is key to successful collaboration. In 2019, a

COLLABORATION THEMES



survey was distributed to 95 urban forestry and stormwater professionals. This included attendees of the University of Washington Center for Urban Horticulture 2019 Urban Forestry Symposium as well as members of the Technical Committee and Stakeholder Engagement Committee of the *Puget Sound Urban Tree Canopy and Stormwater Management Project* (King Conservation District et al., 2019). Information gathered through the survey provides insight on the motivations and concerns of the respective parties and is reflected in the following sections.

Urban Forestry Professionals

Urban forestry professionals believe that retaining tree canopy is important in urban areas and are aware of the many benefits that trees provide. This group has a firm understanding of the benefits of intercepting rainfall and reducing stormwater runoff. Urban forestry professionals have mixed opinions on the effectiveness of stormwater centric messages in motivating people to change behavior. Therefore, a key concern of this group is how to more effectively promote and impact tree retention and tree planting for the myriad of benefits through the lens of stormwater management.

Stormwater Professionals

Stormwater professionals have mixed opinions regarding the link between urban tree canopy and stormwater management but recognize the importance of retaining tree canopy in urban areas and the multiple benefits that trees provide. This group also has mixed opinions on whether their program budgets have sufficient capacity to support both urban forestry priorities and stormwater priorities like meeting the requirements of municipal stormwater permits. Additionally, some stormwater professionals feel uncertain about regulations that provide stormwater credits for trees, particularly when there is no mechanism to ensure tree retention for long-term mitigation benefits.

Municipal Staff and Policy Makers

Municipal staff, policy makers, and implementers are critical to developing and enforcing local and regional regulatory policies, programs, and goals. They play a key role in prioritizing and funding water quality solutions, protecting urban tree canopy, and retaining trees. Local government staff, and city/county councils and commissioners are aware of larger master planning efforts and civic visions to enhance the urban forest, such as opportunities to link greenways through redevelopment.

Builders and Developers

Builders and developers are critical to ensuring that urban trees are protected and planted during new development and redevelopment. It is necessary to understand the drivers and financial reasons why these groups may prefer to clear a site of mature trees for development only to replant with smaller trees. Addressing these motivations and working closely with these groups towards compromises may serve to protect and preserve mature tree canopies in new and redevelopment projects. More effective communication is needed with builders and developers about the benefits of trees to the community and environment. This can be accomplished through outreach, incentives, consistent and easy to understand information on code requirements, and training in some cases.

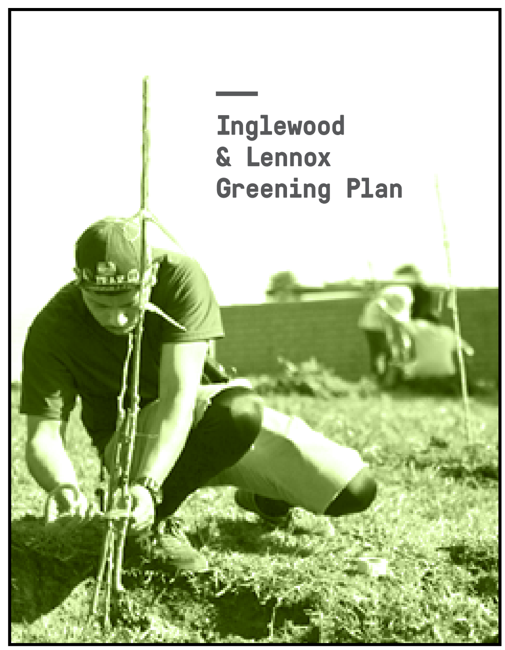
Property Owners

Property owners play a vital role in maintaining and expanding urban tree canopy on private lands and where jurisdictions primarily have indirect control over tree protection and planting. Through education and outreach programs that focus on tree care and tree benefits as a public good, residential and commercial property owners can benefit from the knowledge, expertise, and assistance of urban forestry and stormwater professionals.

Community Advocates

Community advocates and other non-governmental organizations representing various interests can have considerable influence on the success and outcome of projects. Community advocates may include environmental and social justice groups, educational institutions, neighborhood organizations, or non-profit organizations. The issues and areas they may be involved in include urban greening, food and agriculture, water and air quality, transportation, energy, land use, and community engagement. Development and redevelopment projects that address some of these issues/areas will be more relevant to local residents and can therefore benefit from more direct and local project support.

Collaboration Case Studies



CASE STUDY 1. THE INGLEWOOD, CALIFORNIA AND LENNOX COMMUNITY GREENING PLAN

Collaboration among policy makers, stakeholders, and community groups to identify criteria for a range of greening strategies in underserved communities

In the Los Angeles Metro area, the City of Inglewood bears heavy environmental and social burdens while facing increasing redevelopment pressures (Vibrant Cities Lab, 2021). From 2013-2014, TreePeople and the Social Justice Learning Institute worked with the City of Inglewood and the adjacent unincorporated community of Lennox to develop the Inglewood & Lennox Greening Plan (TreePeople et al., 2016). The Greening Plan focuses on creating a more equitable distribution of GI and a range of social benefits throughout these communities. The Plan was made possible with funding from the State of California Strategic Growth Council Urban Greening and Sustainable Communities Planning Grant Program.

As the Greening Plan was initiated, the use of trees was recognized as an effective measure for meeting priority issues. Using iTree Canopy, the project teams determined that the project area contained roughly 18% canopy cover. Using this amount as a starting point, the group set a goal of 25% canopy cover within five years based on increased efforts to coordinate planting and maintenance with the community. The process was designed to minimize "expert" lecturing and instead focus on hearing the participants' goals for their community. The priority themes that were identified in the planning process included:

- **Urban Greening**
- **Food & Urban Agriculture**
- **Water**
- **Transportation, Air Quality, Land Use**
- **Energy & Waste**
- **Community Engagement**

Community Engagement Planning Process

Collaboration and facilitation with NGOs and community members were central to the Plan development. The Social Justice Learning Institute (SJLI) and TreePeople began work in 2009 with the City of Inglewood and the community of Lennox on environmental and community health conditions. The mission of SJLI is to improve the education, health, and well-being of youth and communities of color by empowering them to enact social change through research, training, and community mobilization. The mission of TreePeople is to unite the power of trees, people, and technology to grow a sustainable future for Los Angeles.

SJLI and TreePeople focused their joint efforts on developing the Greening Plan through a non-traditional planning effort with extensive and meaningful stakeholder involvement to develop a common vision. Stakeholders included community members; local, county, and state governments; and NGOs and other community anchors. The plan represents community-led themes, priorities, and implementation strategies.

Plan Elements

Priority actions included increasing tree canopy cover to at least 25% within five years and supporting urban agriculture through community gardens and rainwater harvesting. Plan information was presented to multiple audiences, which included community members, businesses, and local government.

The Greening Plan identifies focus areas, presents a prioritization process, and introduces

BMPs appropriate for the community. The BMPs included GSI stormwater management practices, such as bioswales, porous pavements, vertical gardens, and green walls. BMPs also included edible and urban agriculture, "climate appropriate" plants, a wide array of trees for building an urban forest canopy, and fruit bearing trees to support urban agriculture. Resources provided in the Plan included a tree list and plant palette. Concept site plans and a BMP site matrix were developed to facilitate selection, prioritization, and implementation. The Plan also addresses new mandates for climate resiliency, clean air and water, access to parks, and healthy food.

Urban trees are a central element of the Plan's Urban Greening and Food and Urban Agriculture priority themes. The list of BMPs were prioritized by land use, the Plan's main themes and goals, and input from the community. Climate appropriate plantings are acclimated to thrive in local conditions, are generally low water use, and provide erosion prevention, air quality improvement, and habitat enhancement for local butterflies, bees, and birds. Edible and urban agriculture supports the local food system and economy and includes fruit bearing trees among others. The Plan also contains green streets and complete streets, which feature urban trees and landscaping and combine drainage infrastructure and stormwater planters for water quality treatment. Also included are pocket parks—small public areas with green spaces and places for community residents to relax.

The Greening Plan identifies trees as a standalone BMP rather than a component of another BMP (such as a green street or pocket park). The Plan provides information on deciduous, evergreen, and fruit bearing trees and describes the benefits of trees to the community and the urban water cycle. Community benefits include urban heat-island mitigation, increased shade, improved air quality, soil conservation through erosion prevention, and energy conservation. Urban water cycle benefits include rainwater capture, flood reduction, and water quality improvement.

Fruit trees provide environmental benefits and a resource for fresh local produce. They also offer an educational opportunity for the community and demonstrate an obvious link between an urban forest and community benefits. Detailed information is provided for tree care (including mature trees), tree selection, water needs, and pruning. Information is also included on design references, maintenance expectations, and costing.

CASE STUDY 2. PORTSMOUTH, N.H. MUNICIPAL PROJECTS

Municipal projects embrace collaboration for improving water quality and climate resiliency

■ Example 1. Portsmouth Tree Filter Project

In Portsmouth, N.H., the State Street Redesign was a combined sewer separation that included the use of numerous tree filters and other advanced stormwater management designs. The Portsmouth Tree Filter project, a component of the State Street Redesign, provides a relevant example of collaboration between urban forestry and stormwater professionals, city representatives, project engineers, and environmental advocates. The City committed to building a high-quality project that would satisfy the many stakeholders who were involved. Permitting requirements formed the basis of the State Street Redesign, which received the 2010 Outstanding Civil Engineering Award from the New Hampshire Section of the American Society of Civil Engineers. The project, led by CMA Engineers in partnership with the University of New Hampshire (UNH) Stormwater Center, the Urban Forestry Center, and the City of Portsmouth, addressed a settlement agreement to use nitrogen-reducing LID practices in stormwater capital improvement projects.

Working with the City Urban Forester, the project design team accomplished multiple goals that included increasing the use of urban trees as both standard tree plantings and stormwater tree planters. The stormwater tree planters provide advanced stormwater management and nutrient controls for over 13 acres—including the separated combined sewer areas—to improve stormwater quality.

TREE FILTER PROJECT GOALS ACHIEVED

- Combined sewer separation for 13 acres
- Widespread addition of urban trees as typical urban tree planters
- Addition of stormwater tree filters and other LID components for water quality improvement and nutrient removal
- Increased health and longevity of urban trees
- Improved pedestrian mobility and local business access by enhancing the street appearance with trees, landscaping, and related green infrastructure
- Community and environmental advocate support for a green-community friendly project

Thriving Urban Trees

In many ultra-urban environments, trees have very short lives lasting only five to 10 years. This is due in large part to stress from lack of nutrients and water and frequent damage from collisions. The marriage of drainage and urban trees in a tree filter enables the nutrients to be removed from stormwater runoff while providing necessary food and water for the trees to thrive. This has the dual benefit of reducing the water and feeding demand associated with tree care and enabling more robust and healthy trees capable of thriving in a highly urbanized setting. Twelve years following installation, the stormwater tree planters are functioning as designed and the trees are thriving. In contrast, other street trees planted at the same time have demonstrated mixed outcomes with some tree mortality and others surviving but not thriving.

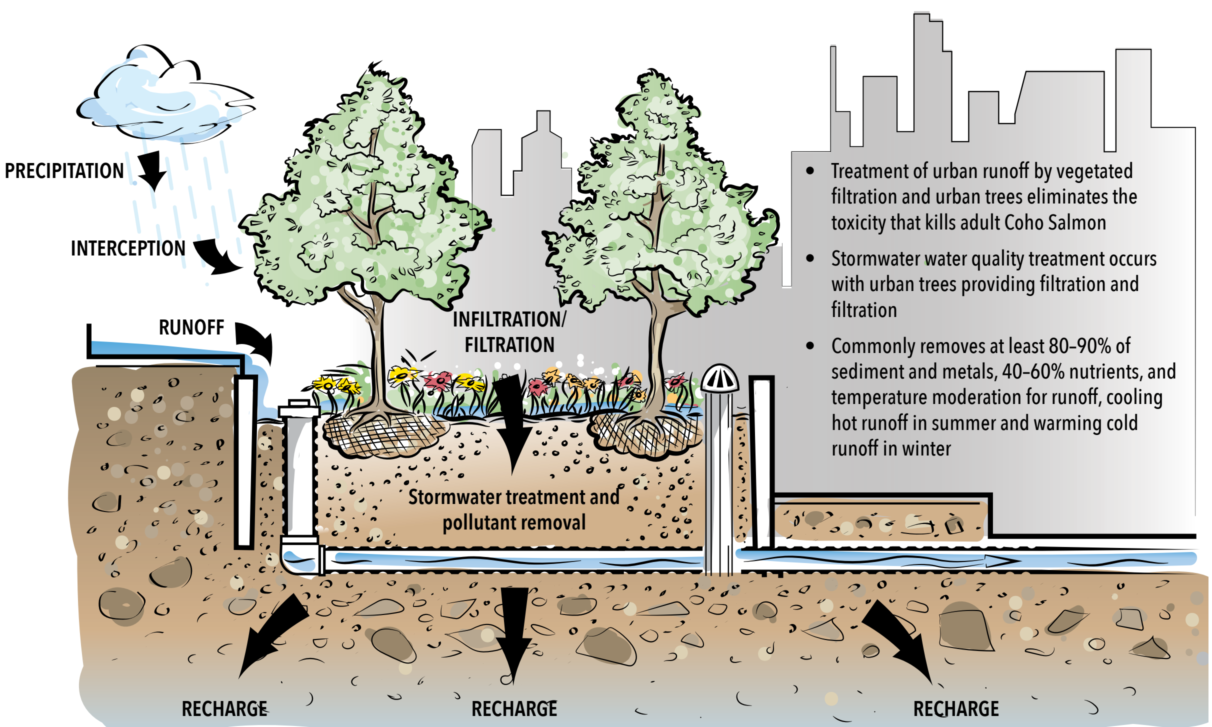
With the project, 12 street trees were installed including three tree box filters that were placed where street trees had previously been located. The tree box filters were fully contained and underdrained to storm drains to eliminate concerns about unwanted infiltration into adjacent basements of old buildings. The tree boxes were installed along State Street, a busy downtown street with curbside parking traveled mainly by passenger vehicles and delivery trucks.

Twelve-year-old stormwater tree filter Portsmouth, NH

Low Maintenance Asset Management

One of the greatest concerns for municipalities with using LID and GSI is the additional maintenance burden for asset management. It is not uncommon for LID and GSI pretreatment to be inadequate, resulting in the need for frequent cleaning. The goal for this project was to use existing staff and equipment for standard catch basin cleaning. This was accomplished through a design that was appropriate for a high intensity land use and a trash and debris load, which enabled maintenance to be separated for aesthetics (i.e., pruning) and functionality (i.e., trash and debris removal). If these elements are not adequately dealt with, trash and debris removal requirements can frequently become a maintenance practice simply for aesthetic needs.

WATER QUALITY TREATMENT PERFORMANCE OF URBAN STORMWATER TREE PLANTERS



Another key design consideration included winter maintenance and cold climate performance. In working with the UNH Stormwater Center and the urban forester, stormwater tree box filters were designed with catch basin drop inlets that could easily be plowed of snow and ice and that contained sufficient subsurface storage capacity to capture trash and debris. The maintenance considerations were an essential component of municipal approval to ensure that the maintenance burden would be manageable.

Tree Filtration Water Quality Performance

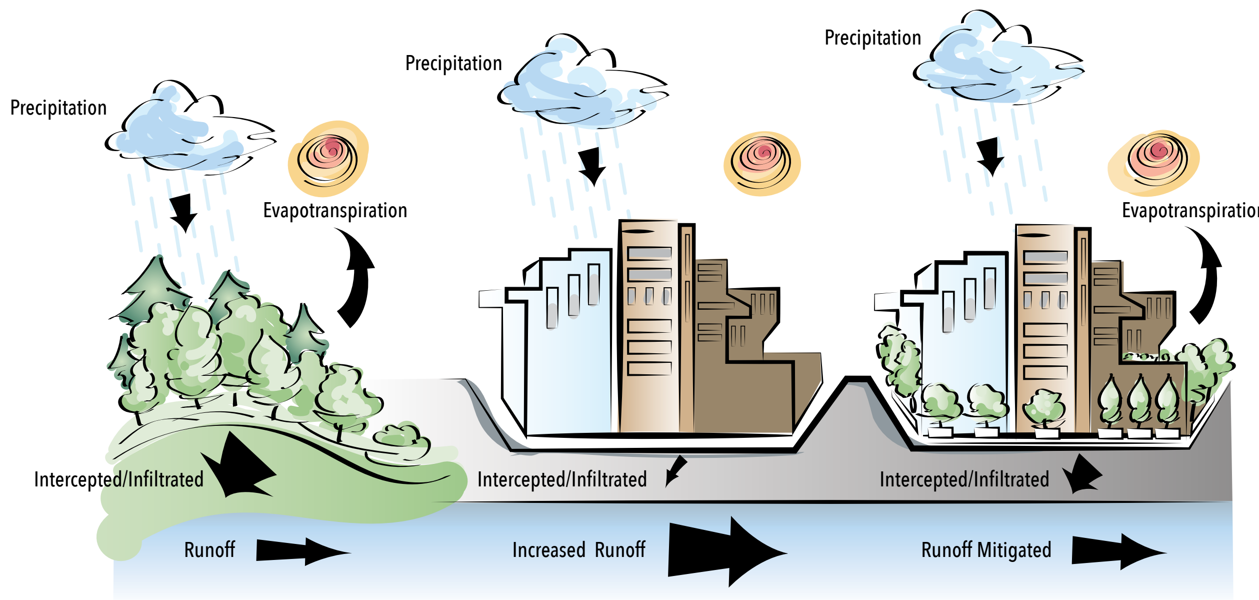
The tree box filters each drained an impervious area of approximately 13,000 square feet (about 1/3 acre). One of the tree box filters was monitored for stormwater treatment performance with funding from the Northeastern Area State and Private Forestry Competitive Grant Initiative (N.H. Division of Forests and Lands, 2010). The study demonstrated that the tree box filter removed most of the pollutants in stormwater runoff, with removal efficiencies ranging from excellent to modest depending on the pollutant. The system performed very well (>85%) in removing sediment and sediment associated pollutants and exceptionally well at removing metals and hydrocarbons. The system also showed promising phosphorus removal (52%) (Peterson et al., 2010) and modest removal of total nitrogen (14%). The poor nitrogen removal was likely due to high-flow-rate media soils that prevented sufficient contact time with soil microbes. Of note, the tree filter performance was based on water quality treatment for a system where no infiltration occurred. In contrast, a tree filter that was designed to infiltrate would be expected to have greater water quality performance through runoff volume reduction.

PROJECT RECOMMENDATIONS

Project recommendations from the State Street project included the following:

- Be prepared to plant some trees more deeply than typical street trees to allow for a stormwater inlet.
- Work with experienced and motivated partners such as community groups, professionals, universities, local experts, contractors, and businesses.
- Include adjacent property owners and affected parties in early planning to help avoid conflicts.
- Select tree varieties that can tolerate both extreme wet and dry conditions and salt used for de-icing.
- Tree box filter trees may suffer less soil compaction than typical street trees with large soil filters and structural soil designs (e.g., grates and Silva Cells).
- Plan your design with appropriate maintenance considerations, such as a “drop inlet debris catcher,” and use maintenance agreements.

CLIMATE RESILIENCY AND FLOOD MITIGATION WITH URBAN TREES



- Urban trees contribute to climate change resiliency and flood reduction by increasing the "sponge factor" of the built environment. This enables the trees and the landscape to absorb runoff, increasing resiliency, and helping mitigate extreme rainfall and urban flooding.
- An increase in 20% tree cover showed a runoff decrease of 4%

■ Example 2. 105 Bartlett Street

Developer and municipal collaboration played a key role with a redevelopment project of an industrial parcel located at 105 Bartlett Street on North Mill Pond in Portsmouth. (City of Portsmouth, 2021). Effective collaboration and project planning, a creative design team, and a developer committed to creating both a high-quality project and a community asset all led to a wealth of positive outcomes.

Bartlett Street Redevelopment, Portsmouth, NH, Iron Horse Properties, LLC, Drawing by Woodburn and Co

Located along 2,000 feet of tidal waterfront and intact shoreline, the site had previously served as a railyard with many challenges common to industrial uses inhibiting redevelopment. Collaboration between the project design team, the developer, and the city's environmental planner enabled the development of a shared vision. The project consists of two multifamily apartment buildings with basement level parking and one mixed-used building with first floor office and amenity space and upper story apartments. The three buildings contain a combined 174 dwelling units. The project includes a private road with cul-de-sac, parking, utilities, stormwater management, tree canopy and landscaping, and lighting. As part of the project, land from North Mill Pond's mean high-water line to the 50ft wetland buffer was designated as community space for the City's North Mill Pond Trail project. In addition, a greenway park was constructed between the buildings and North Mill Pond trail to provide opportunities for marsh restoration and a living shoreline.

This project addresses many municipal, community, and environmental needs and cleaned up a dangerous, historical industrial parcel. GSI provided stormwater quality treatment, and combined with other measures to protect and restore the vegetated tidal shoreline and increase the climate resiliency of the site against coastal storms and sea level rise. In nearby areas, marsh restoration and living shoreline projects were constructed. The project implements a significant portion of the City's vision for the North Mill Pond Trail and Greenway (City of Portsmouth, 2019). The trail, which also includes climate resiliency strategies, creates a new area for recreation while improving multi-modal connections, expanding public access to the water's edge, and restoring coastal habitat.

CASE STUDY 3. LENEXA, KANSAS RAIN TO RECREATION PROGRAM

Multi-stakeholder watershed scale collaboration to reduce flooding, restore habitat, and provide recreation opportunities

Located along the banks of the Kansas River within the Kansas City Metropolitan area, the City of Lenexa, Kansas has taken a decisively green approach to managing their stormwater issues that have caused major flooding and sewer overflows. In response to these challenges, the City developed Rain to Recreation (Vibrant Cities Lab. 2021), a proactive watershed-based stormwater management program that works to reduce flooding, protect water quality, preserve wildlife habitat, and create recreation and education opportunities. Rain to Recreation embraces stormwater as an asset for community development and treats water as an amenity rather than a liability. The program addresses flooding by restricting development in floodplains and utilizing GI and stormwater BMPs to reduce runoff volume and treat pollution.

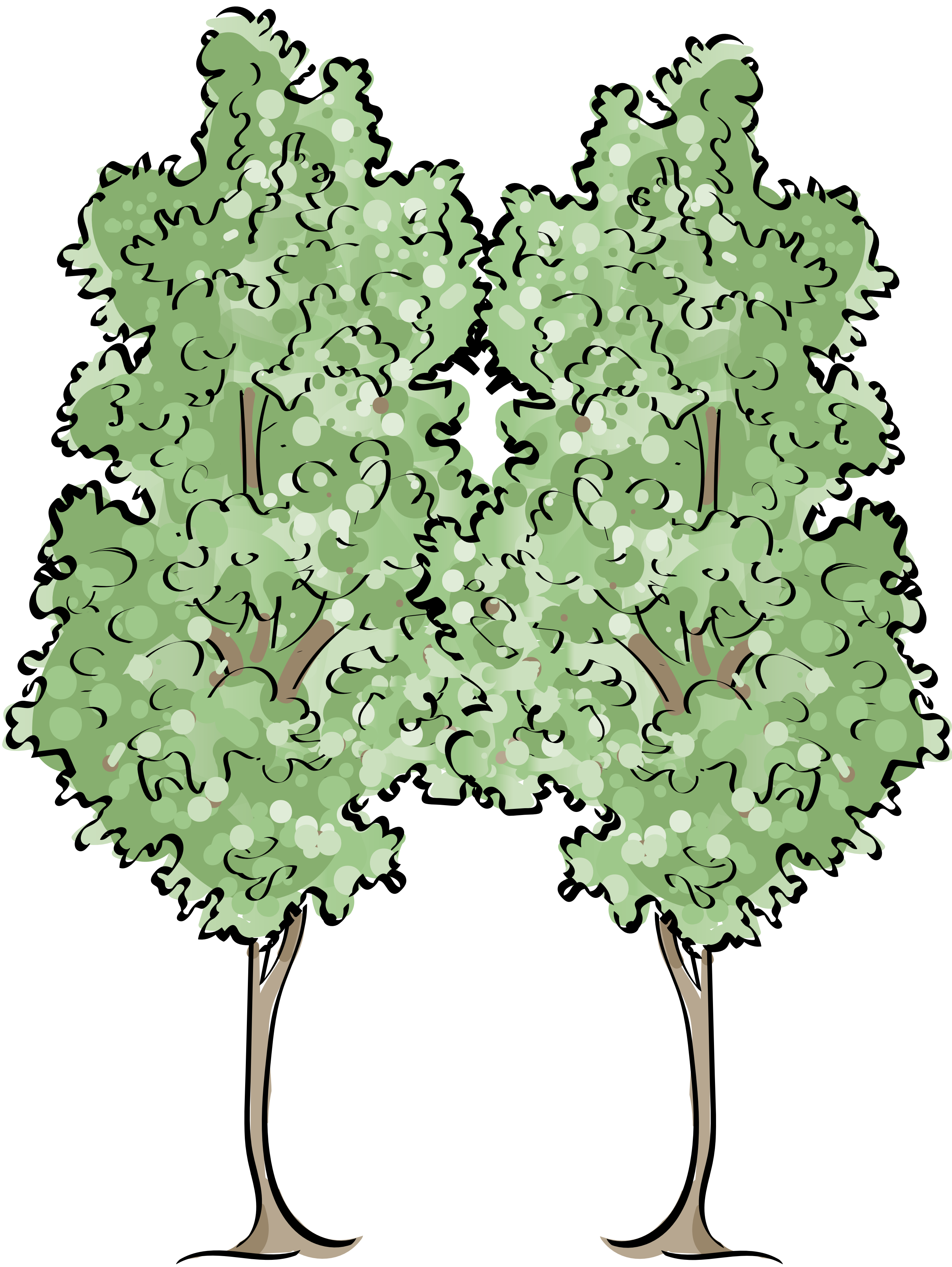
Collaboration with stakeholder groups—including neighboring communities, state and federal regulators, the development community, and residents—formed the basis of the City's approach and continues to be a key aspect of the program. The City works with owners and maintenance contractors to ensure that once BMPs are installed they are kept in working order to provide the intended water protection and flood control benefits (Adaption Clearinghouse. 2021). As part of the program, City staff take a watershed-level approach toward engaging the community on ways to protect stormwater and educating residents on measures to prevent pollution and reduce stormwater runoff (City of Lenexa, Kansas. 2021). Developer collaboration has been an important part of the program's success and includes proactive flood management for upper watershed development to address existing downstream flooding.

The funding strategy for the program began with general funds and small sales tax and progressed to financing via stormwater utility bills. Projects include the development of regional detention facilities with floodplain wetlands, which has both improved existing flooding problems within the lower watershed and provided management for new development. Floodplain wetlands provide an important water quality benefit by filtering pollutants and providing storage and detention. Research has shown that trees with developed root systems reduce nitrogen loading by approximately 50% and phosphorus by 75% (Bratieres, et al. 2008).

Rain to Recreation uses regulatory and non-regulatory approaches, as well as major capital projects and land acquisition to achieve its goals. Trees play a key role within these strategies. Land within floodplains and riparian zones that are purchased outright are restored with native vegetation, including trees to increase infiltration of rainwater and filter out pollutants before they can reach the river. The program restores and maintains 22 miles of streams to ensure adequate capacity for large storms. Importantly, program success involves collaboration at many levels.

RAIN TO RECREATION PROGRAMS AND RESOURCES

- Funding
- Implementation
- Partnerships
- Cost Share Program
- Healthy Lawn & Garden Guide
- Flood Prevention
- Protect Water Quality
- Stormwater Operations
- Raindrop Walk



Conclusion

The Urban Tree Canopy and Stormwater Story

In the coming decades, the population of the Puget Sound region is projected to grow significantly, rising from 4.5 to 7 million people by 2040 (Puget Sound Partnership, 2018). With this growth, urbanization and development will further increase the amount of impervious area, creating greater volumes of stormwater runoff and higher risks to the quality of Puget Sound's waters. As demonstrated in this Handbook, urban tree canopy provides a myriad of environmental, ecological, and human health benefits and is effective at reducing stormwater runoff, removing pollutants, and protecting the region's vast water resources.

Integrating trees in stormwater management systems poses both opportunities and challenges. A focus on trees as a form of GSI will help the Puget Sound region meet stormwater management and land cover goals prioritized in regional recovery strategies such as the Puget Sound Partnership Action Agenda. A growing body of knowledge to support tree canopy as an element in GSI applications is acknowledged and shared by urban foresters and stormwater management professionals. Sharing this knowledge with policy makers and implementers will help them make important decisions in support of urban tree canopy strategies with GSI efforts. Endeavoring to engage other groups and audiences, such as developers, builders, and homeowners in addressing the region's stormwater management challenges will extend the urban tree canopy dialogue to include private and residential spaces.

"...Urban tree canopy provides a myriad of environmental, ecological, and human health benefits and is effective at reducing stormwater runoff, removing pollutants, and protecting the region's vast water resources."

Cited Literature and Additional Resources

This section includes several resource tables. The first table lists references for the literature cited in this Handbook. The second table includes the resources highlighted in lists that feature tree and stormwater literature, resources, and tools to support dialogue and action. The third table lists other resources recommended by the project team and technical and stakeholder engagement committees of the *Puget Sound Urban Tree Canopy and Stormwater Management Project*.

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Tremendous opportunities exist for collaboration among urban forestry and stormwater professionals, and between these groups and audiences that have a direct influence on urban tree cover ... Collaboration can be a compelling driver for supporting urban canopy policies and actions.