TREES IN RESIDENTIAL RAINWATER MANAGEMENT

opportunities for trees as natural assets for private realm rainwater management in low density residential zoning

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Executive Summary

This report examines and summarizes the opportunities and constraints for implementing green rainwater infrastructure in private-realm low-density residential zones in Vancouver, British Columbia (currently RS and RT), focusing on trees as natural assets. This work coincides with recent Council directives for staff to examine providing additional housing options in lower density neighbourhoods through the Making HOME motion, as well as additional community and city-wide sustainability policies. Given typical existing lot geometries and current desires to preserve street character, front yards are examined to determine how much on-site rainwater management can be obtained from additional tree planting as landscaped stormwater management systems.

In compiling this report, a review of research was done on the effectiveness of trees in intercepting rainfall and attenuating runoff. This research was further investigated to consider how trees would fit into the context of typical lot geometry, with competition for yard space, and offset requirements from structures and utility services. Implementation strategies and successes from other relevant municipalities and cities were also examined and used to support findings.

This report aims to summarize and characterize the emerging redevelopment footprints of low-density (RS and RT) land use with the objective of assessing potential front-yard space for trees, assesses the rainwater retention/detention potential of trees in Vancouver's local climate and into the climate future, and identifies potential challenges to residential front yard planting such as offsets from structures, streets, sidewalks, and utilities. Literature review was done to fill in information gaps, estimate hydrologic values of trees are given, and recommendation of tree species have been suggested to provide a starting point from which an urban forest canopy can help successfully mitigate rainfall runoff on properties as low-density residential areas continue to densify throughout the city.

1 Introduction

1.1 Context

This report looks at trees ability to intercept rainfall and improve storm water management on low-density, residential lots located within Vancouver, British Columbia. With negative impacts of climate change resulting in shorter duration but higher intensity storms throughout the summer, and more continuous rainfall events in the winter, trees and large shrubs may be beneficial natural assets in mitigating some of the increased demand on Vancouvers storm water system.

1.2 Purpose

With climate change being a major global issue, by 2050, Vancouver will have hotter, drier summers, and warmer, wetter winters (City of Vancouver, 2019a). This means that the summer season will bring more frequent heat waves, twice as many days reaching temperatures above 25°C, increased health risks, and 20% less rainfall. In the winter, the minimum temperature is expected to rise by 4.8°C, there will be a 58% decrease in snowpack leading to increased risk of summer droughts, and increased risk of coastal flooding due to higher king tides and stormy weather (City of Vancouver, 2019a, pp. 8,10,12). This all leads to fewer but more intense summer storms which may overwhelm Vancouver's current stormwater infrastructure, and more consistent winter rainfall leading to potentially hazardous saturated conditions. In both scenarios, trees may help to mitigate some of the demand on

Vancouver's storm water system by intercepting rainfall, taking up rainwater that reaches the ground, and slowing infiltration rates.

Another factor that plays into rainwater management is the availability, or lack thereof, of pervious area in the urban environment. With densification, there is a constant increase in paved streets and sidewalks, and new housing and commercial spaces in the urban realm leading to more impermeability and less green spaces. When considering low-density, single-family housing, much of the available, once green, space is taken up by building footprints, garages, laneway houses, backyard patios, and amenities. This generally leaves virtually no green space in the backyard for rainwater infiltration or tree planting. Instead, all that is left is a small fraction of the front yard that could potentially be conducive to tree planting and natural rainfall mitigation strategies. With increased rainfall and higher demand on Vancouver's existing stormwater system, it is paramount to decrease impermeability where able and increase green space and canopy cover to help alleviate the ever-growing demand on the City's stormwater infrastructure. Unmitigated, increased rainfall and runoff will further burden the existing drainage infrastructure and reduce its level of service.

Planting trees in the private realm may be an effective step to using natural assets that will offer city-wide benefits. Trees can improve water quality, effectively sequester carbon, offer shade with increased canopy cover, decrease the urban heat island effect, and beautify the city, all while intercepting rainfall and alleviating demand on stormwater infrastructure in residential areas.

1.3 Scope

This report was created and written in phases. The first phase included research on the contextual setting of Vancouver, conducting background literature reviews, identifying key stakeholders as professional engineers, landscape architects, and community and urban planners, and identifying and looking into reference studies. The second phase focused on doing a comparative analysis of the available literature and reference studies. Specifically, previous work within the Metro Vancouver region, as well as related research from other jurisdictions, quantifying rainfall interception and uptake by different tree species, developing characterizations of low density lots, and identifying constraints to associated tree planting was done. This information is summarized in the appendices. The third and final phase of the project was to compile key findings and draft this report. Upon the completion of this report, recommendations were made as to which tree species would thrive in Vancouver's climate within the limited spaces of residential front yards, while also being effective at intercepting rainfall and decreasing stormwater runoff amid the changing climate.

1.4 Methodology

This report was completed by *reviewing* relevant sustainability policies, *researching* various tree species around British Columbia and globally, and *recommending* trees that can successfully be used as a natural rainwater management strategy across Vancouver's low-density residential zones.

Review

This project began by reviewing the City of Vancouver's existing policies and plans in primary regards to sustainability, green infrastructure and natural assets, and rainwater management. Secondary plans and guidelines regarding sustainable transportation plans, biodiversity goals, and zoning policies were also reviewed to ensure this project would help the city's sustainability goals.

Next, assessment of Vancouver's typical RS (residential, single-family lots) and RT (residential, two-family lots) zoned lots was done to ensure availability of green space, and policies and regulations around setbacks and planting limitations were done.

Research

The following portion of the report revolved around researching different case studies and strategies for successful planting of trees in residential and urban areas. The case studies ranged from British Columbia and other areas of the Pacific Northwest to different urban centers and cities in Europe. These studies were selected as a focus due to their similar climates, economic state, and seasonal weather patterns. Additional case studies were researched to ensure proper design and implementation of trees as natural assets, and used to summarize costs spent and saved, how to support tree growth, and incentives for the public to utilize trees for stormwater management in their residential front yards.

Research was done on various tree species characteristics, how trees could perform as rainwater assets, and the benefits that they could provide to the well-being of people, economic and social values, and hydrologic value that trees would hold as a stormwater asset. These benefits and co-benefits are laid out in a table.

Recommendations

Finally, the researched data and strategies were used to inform recommendations made for the urban context of Vancouver. Tree species recommendations for rainwater management were separated into categories of the marginal recommendations for residents with limited space, recommended species that have a greater stormwater impact but still fit into residential lots of limited space, and ideal species that have the highest hydrologic benefits given the changing climate if available space for planting was of no concern. Any of the recommended trees would have a positive impact on stormwater management and help to alleviate some of the demand on current stormwater infrastructure. These recommended species are also suitable to be planted in a hardiness zone of 7 (Vancouver's hardiness zone) at a minimum.

2 Background

British Columbia is one of the fastest growing provinces in Canada. Between 2016 to 2021, the provinces population increased by 7.6% (Statistics Canada, 2022) and a significant contribution to that increase was due to the number of people moving to Vancouver. During this time, the population of Vancouver grew at a rate of 4.9%. With large amounts of internal migration, and both interprovincial and international immigration, the city continues to grow and expand. This growth impacts many aspects of life around the city, in particular housing availability and demand on current infrastructure. With the increasing population, many single-family homes are being rezoned as multi-family, densified dwellings. Although this may help alleviate some of the inflation to the housing market, bigger developments lead to bigger building footprints and therefore less permeable area in residential lots.

Vancouver boasts a temperate climate, but receives nearly 1400mm of rain annually, primarily in the fall and winter months between October and March (Current Results, 2022). This high annual rainfall, mixed with the fact that Vancouver is becoming more impermeable with each new development, has started to overwhelm an already loaded, and perhaps outdated, drainage collection system. Designed and built in the 20th century, Vancouver's drainage infrastructure was not designed to accommodate the dense and highly impervious neighbourhoods we continue to see today. Without proper infrastructure that can accommodate ongoing redevelopment and densification, runoff is starting to become a serious challenge within the city's urban setting.

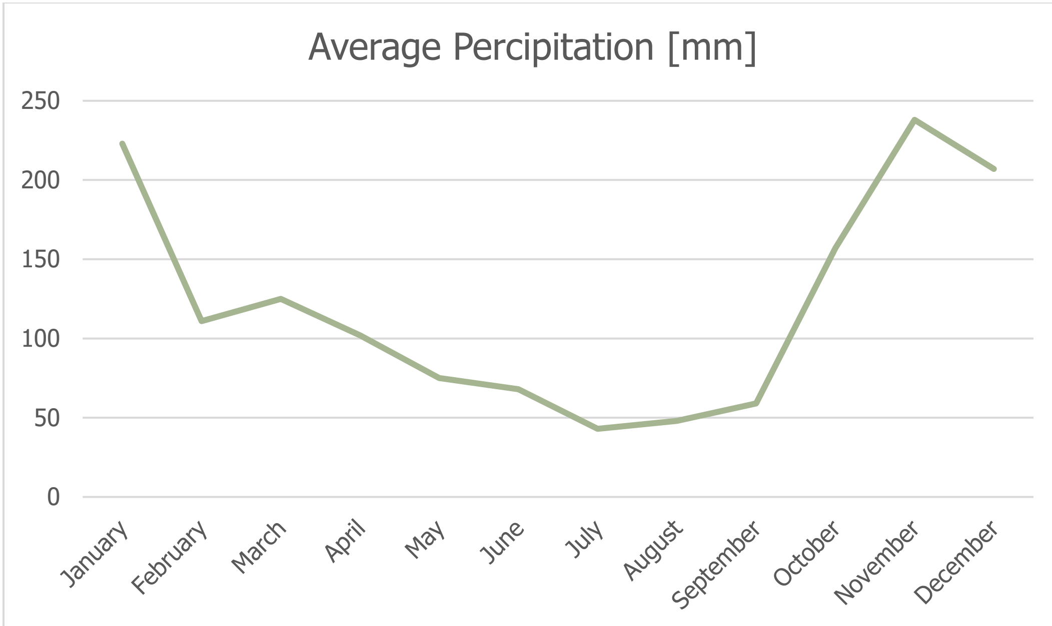

Figure 1: Vancouver's monthly average precipitation. Monthly rainfall numbers are averages of weather data collected during 1981 to 2010 (Current Results, 2022)

Vancouver's Urban Forest Strategy (City of Vancouver and Vancouver Park Board, 2018) outlines strategic actions that align with five different goals that will help steward and grow the urban forest. These goals are to protect, plant, manage, engage, and monitor trees in the city. This strategy states that canopy cover averages just 12% on private land. However, because private land accounts for 57% of the land base, it encompasses a large portion of the urban forest (City of Vancouver and Vancouver Park Board, 2018, p. 18), which is why tree canopy on private land is vital to rainwater management within the city.

Tree canopy cover on private land has been declining. "Between 1996 and 2013, almost 50,000 trees were removed under permits from the City of Vancouver," (City of Vancouver and Vancouver Park Board, 2018, p. 19) made possible in part due to a former tree by-law allowing the removal of one tree per year by property owners. This by-law was repealed in 2014. Now, when trees are removed from private lots due to poor health or development, tree replacement is highly encouraged and required when possible. Another reason why so many trees were removed involves redevelopment. With the conversion of many single-family and low-density lots into multi-family, high density developments, building footprints increase and garages and laneway houses are added to maximize development potential and profits, all leading to reduced pervious areas available for trees.

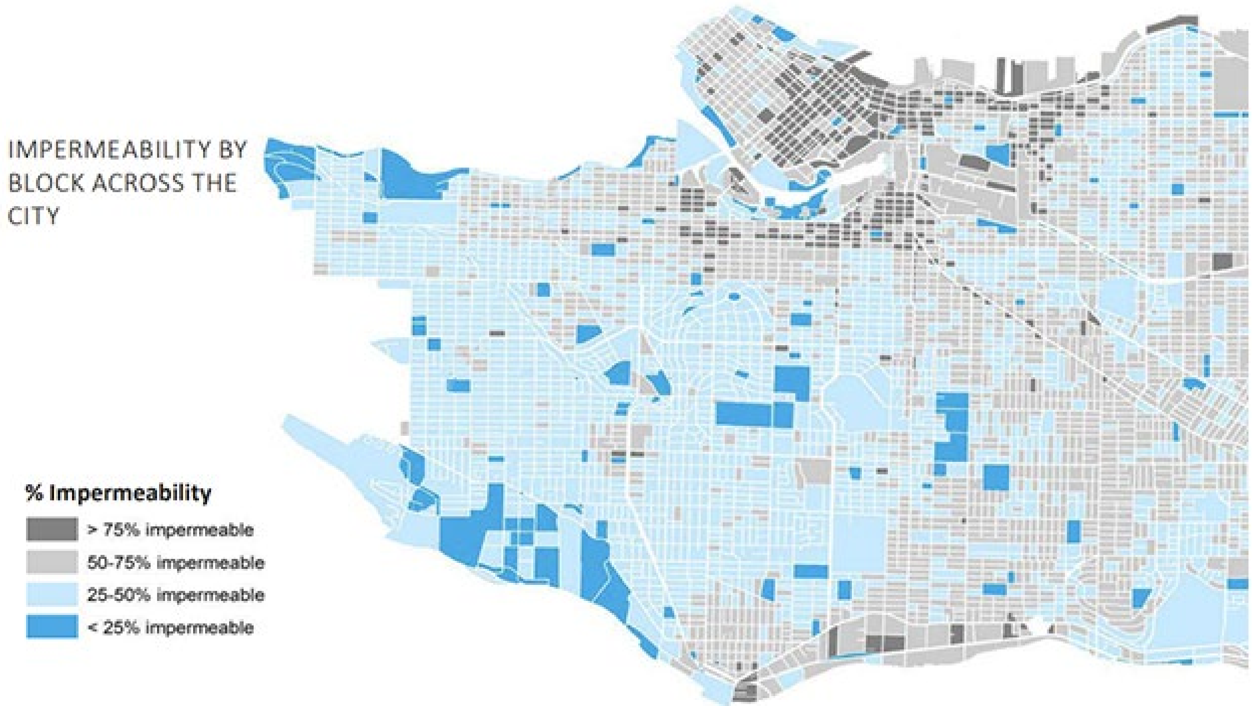

Figure 2: Impermeability by block, retrieved from: Urban Forest Strategy (City of Vancouver and Vancouver Park Board, 2018, p. 27)

High percentages of impermeability and required offsets in residential areas limits the available planting area for new and replacement trees and decreases soil volume for rainwater to infiltrate and be stored in the soil. Impermeability affects tree planting so much so, that within the city, when impermeability was measured at exceeding 50%, then the average tree canopy cover was recorded at less than 10% (City of Vancouver and Vancouver Park Board, 2018, p. 27).

Despite the significant reduction in trees in the early 2000s, property owners are becoming more aware of the ecosystem services and sustainability benefits that trees provide. As such, "private land planting has averaged around 9,000 trees per year since 2015" (City of Vancouver and Vancouver Park Board, 2018, p. 22). Although this does not make up for the loss of tree canopy in the past, it will help to improve upon the existing canopy, and enhance tree canopy for the future.

Private realm tree planting is encouraged through tree and nursery sales offered by the Vancouver Park Board to incentivize homeowners (accounting for approximately half – 5,000 – of new trees planted annually), as well as coordination between City of Vancouver Planning staff, landowners, and consultants to protect existing trees and increase canopy cover (accounting for approximately 3,800 trees annually) (City of Vancouver and Vancouver Park Board, 2018, p. 22). Additionally, it is estimated that approximately 500 trees are planted annually on private land that are unaccounted for in the City of Vancouver Park Board tracking process. Today, "trees on private property account for almost 40% of the city's urban forest" (City of Vancouver and Vancouver Park Board, 2018, p. 26). More and more, these private realm trees are one of a variety of species; these are usually smaller, deciduous trees such as maples, snowbell, katsura, magnolia and various fruit trees. It should be noted that the urban forest is also suffering from a lack of planting of coniferous trees, which are approximately 2.3 times more effective at intercepting and slowing down rainfall (About Here, 2021). Specific recommendations for tree species will be discussed in section 5.2.1.

3 Policy Context

There is a variety of frameworks that has been put into action at both the city-wide and local scale that help to justify the use of trees as natural assets throughout urban areas in a growing and developing city. Vancouver has seen meteorological changes from global warming, as well as economic changes with the demand on housing and stormwater infrastructure as people continue to move into the city. The following policies outlined illustrate some actions, goals, and strategies that can benefit from planting trees in residential areas throughout the city of Vancouver.

Figure 3: Vancouver city-wide action plans and strategies

3.1 City Wide

There are many plans and policies that have been published by the City of Vancouver that align with the necessity of trees in rainwater management across the city. These policies and plans and how they connect to planting residential trees as natural assets are briefly outlined below.

3.1.1 Primary Policies

Climate Change Adaption Strategy

The Climate Change Adaption Strategy (CCAS) (City of Vancouver, 2019a) relies on a diversity of existing City and community strategies and efforts that aim to improve the overall resilience of Vancouver. The strategy focuses on climate robust infrastructure, climate resilient buildings, healthy and vigorous natural areas and green spaces, connected and prepared communities, and coastal preparedness. This report aligns with the third core action highlighting *natural areas and green space*, which looks at supporting the implementation of the Urban Forest Strategy, shifting urban forest maintenance from reactive to proactive, increasing soil preservation, and improving water quality. Specific objectives that may see benefits from additional residential tree planting include:

- Enhance the long-term health and vigor of blue spaces, green spaces, **trees,** and biodiversity.
- Increase **canopy cover** in the city
- Improve **water quality** of local water bodies

Greenest City Action Plan

The Greenest City Action Plan (GCAP) (City of Vancouver, 2020a) outlines 10 sustainability goals for the City of Vancouver that will ensure Vancouver stays on the leading edge of city sustainability. To do this, the city aims for zero carbon, zero waste, and healthy ecosystems. Many goals have been set, but this report will mainly contribute to:

- *Access to Nature*:
    - **Goal 5.4** Strategically expand private property, street, and park tree planting

Additional goals such as, climate and renewables, clean water, clean air, and lighter footprint will all see benefits from additional private realm tree planting.

Rain City Strategy

Endorsed by Council in 2019, the Rain City Strategy (RCS) (City of Vancouver, 2019b) outlines Vancouver's vision to see rainwater as a valued resource for its communities and natural ecosystems. Its aim is to improve and protect water quality in Vancouver, increase resilience through sustainable practices, and enhance livability in the city by improving both natural and urban ecosystems.

Specifically, the use of trees as natural rainwater management assets supports the following *Building & Sites Action Plan*:

- Implementation Program
    - **B&S-03** Single Family Dwellings, Laneway Homes, and Townhouses – Assessing New & Existing Building Opportunities
- Enabling Program
    - **B&S-08** Public Engagement and Activation – Empowering Positive Community Action

The above goals aim to engage key stakeholders, evaluate development opportunities, implement green rainwater infrastructure, rain awareness of rainwater management, and assess infiltration opportunities and constrains, among others.

Urban Forest Strategy

The Urban Forest Strategy (UFS) (City of Vancouver and Vancouver Park Board, 2018) was updated by the city in 2018. In it, the city has outlined 12 principles that drive the goals of protecting the urban forest during development, planting more trees and managing their health and safety, engaging citizens, and monitoring the condition of the growing urban forest. Some of the principles that this project aligns with include creating beautiful urban landscapes, enhancing habitat and supporting biodiversity, selecting the right tree for the right place, helping mitigate and adapting to climate change, using sound science, and contributing to a healthy city.

Measurable targets have been set out to ensure the city of Vancouver is achieving its sustainability goals. The city was able to plant 150,000 trees and aimed to restore 25 hectares of natural area between 2010 and 2020. Now, Vancouver is working towards increasing the urban forest canopy to 22% by 2050, a target in which tree planting in low-density residential lots will help to achieve.

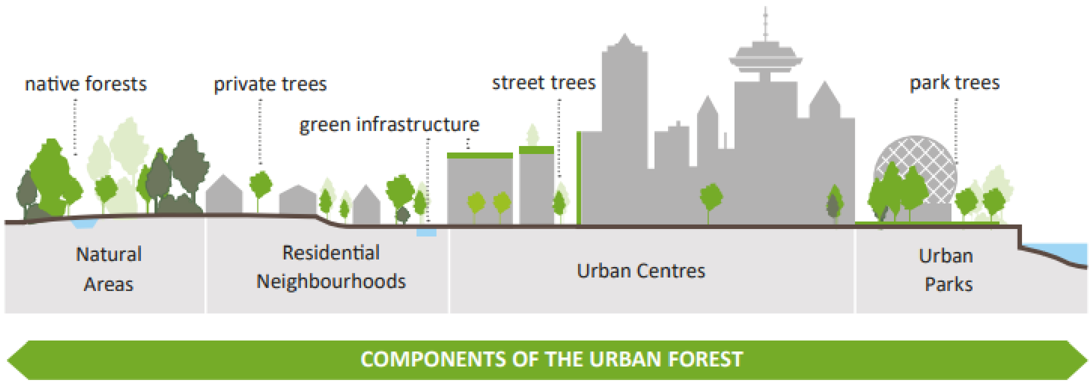

Figure 4: Components of the urban forest, retrieved from: Urban Forest Strategy (City of Vancouver and Vancouver Park Board, 2018, p. 1)

As noted earlier, tree species diversity is somewhat lacking around the city. The UFS aims to maintain and increase tree diversity while still selecting trees that will thrive in the future climate. "A diverse and well-adapted tree population will be less vulnerable to insect and disease attack, more resilient to climate change, and provide a stable supply of ecosystem services." (City of Vancouver and Vancouver Park Board, 2018, p. 33). This report will help outline some of the suitable tree species that will help with rainwater management and be both attainable and realistic.

Specifically, the use of trees as natural rainwater management assets supports the following strategies and actions:

- *Protect*: Retain and protect more trees during development;
  - **Action 1** Update policies and standards to enable proactive design for retaining healthy, mature trees.
  - **Action 2** Develop policy for retaining soil and growing space for trees on private property in coordination with other Planning policy updates and sustainable site design goals.
  - **Action 3** Develop forest canopy targets by land use type or neighbourhood.
- *Plant*: Increase tree planting in neighbourhoods with low urban forest cover;
  - **Action 9** Expand tree planting in residential neighbourhoods using subsidized tree sales and nursery rebate programs.
  - **Action 10** Partner with First Nations, the Vancouver School Board, and other groups to support tree planting on private and institutional lands.
- *Plant*: plant trees to support green infrastructure and reduce climate change impacts;

- **Action 17** Identify tree species, varieties, cultivars, or geographic seed sources that are suited for Vancouver's future climate.
- **Action 19** Increase canopy cover in conjunction with green infrastructure initiatives to improve rainfall interception and infiltration.

- *Monitor*: support research on urban forests;
  - **Action 48** Support the Greenest City Scholar program, City Studio, and other academic partnerships with urban forest-focused collaborations.

3.1.2 Secondary Policies

Biodiversity Strategy

The goal of the Biodiversity Strategy (Vancouver Board of Parks and Recreation, 2016) is to increase the amount and ecological quality of Vancouver's natural areas to support biodiversity and enhance access to nature. One of the set objectives to help reach this goal is to *support biodiversity within parks, streets, and other city-owned lands*, as well as *protect and enhance biodiversity during development*. These are important objectives to note as Vancouver continues to grow and develop. The Biodiversity Strategy hopes to assist landowners in increasing biodiversity values on their private property through education and stewardship.

With the increase of trees in available space on private residential lots, biodiversity in the city will increase with the added ecosystem services offered by the trees.

Climate Emergency Action Plan

The Climate Emergency Action Plan (City of Vancouver, 2020b) was approved by council at the end of 2020 with the main goal of reducing Vancouver's carbon pollution by 50% by 2030. To do this, the city will look at how they move (transportation), how they build and renovate (infrastructure), and how they capture carbon (natural assets and ecosystems).

This report aligns with the city's hope of increasing natural assets, with the aim of lowering urban temperatures, decreasing health risks for the public, and increasing carbon sequestration. Although the aim of using trees as natural assets in rainwater management is not the focus of the Climate Emergency Action Plan, additional tree planting in low-density residential lots will nevertheless work towards achieving their goals. When trees are planted as natural stormwater assets, they continue to also work as environmental assets, helping to remove carbon pollution form the atmosphere and limiting the effects of global warming by increasing canopy cover and lowering urban temperatures. In 2019, Vancouver's carbon emissions and pollution were due to natural gas use in buildings (~54%), gas and diesel in vehicles (~39%), electricity (~2%) and waste production (~4%) (City of Vancouver, 2020b). Capturing carbon through urban forests and by restoring natural shorelines will play a big role in reaching the United Nations goal, adopted by the City of Vancouver, of limiting global warming to 1.5°C.

Healthy City Strategy

Vancouver's Healthy City Strategy (City of Vancouver, 2015) lays out framework to create and continually improve on city living conditions that enable everyone to enjoy a high level of health and well-being. The healthy city strategy focused on creating healthy people, healthy communities, and healthy environments. It is this last sector that will be positively impacted by the execution of private realm tree planting through an increase in tree canopy cover.

Rewilding Action Plan

The Rewilding Action Plan (Vancouver Board of Parks and Recreation, 2014) seeks to improve and enhance experiences of nature for all Vancouverites, while also increasing understanding and awareness of nature within the city. This plan aims to create great experiences for all ages and abilities, provide relevant programs and services, preserve, restore and expand green spaces, advocate for healthy ecosystems, foster effective partnerships, and build community.

Vancouver Bird Strategy

The Vancouver Bird Strategy (City of Vancouver, 2020c) aims to create suitable conditions for native and migratory birds to thrive in Vancouver and surrounding region. The objectives of the strategy are to support bird habitat, reduce threats in the urban environment, improve access to nature, enhance awareness of the importance and benefits of birds in the city, and grow bird related tourism opportunities. Due to increasing urbanization and development of the city, bird habitat has decreased. By planting residential trees, bird habitat in urban areas will increase and help provide additional ecosystem services in those low-density residential zones.

All of these policies will see benefits both directly and tacitly, from the prioritization of tree planting in low-density residential zones of Vancouver. In turn, as steps are taken to further these policies, additional city strategies will see benefits.

Figure 5: Interplay of Vancouver's city-wide strategies. Graphic modified by J. Neudorf from the City of Vancouver's Urban Forest Strategy (City of Vancouver and Vancouver Park Board, 2018, p. 3)

3.2 Site Specific Guidelines

When looking at the private realm, there are a few guidelines and requirements when it comes to planting trees. Some of these policies are outlined below.

Protection of Tree By-Law – 9958

In the city of Vancouver's tree protection by-law (City of Vancouver, 2022a), there are a few requirements with respect to trees distances to primary and accessory buildings, protection barriers required during development, and number of trees allowed and required on site. When a tree is measured at a 20cm diameter or more, steps must be taken to ensure the health and safety of the tree. During development, 20cm diameter trees require at least 1.2m space around their base while larger trees can require up to 6m. See Schedule A in Section 1.2 of by-law 9958 for further details.

Another important consideration in development is tree distance from buildings. Trees need adequate space to grow and thrive as so a by-law was developed to clearly lay out spacing requirements. Trees of a 20-30cm diameter must be at least 2m from principal buildings, and at least 1.2-1.3m from secondary accessory buildings. Larger trees can require up to 4m spacing from structures. Further information can be found in Schedule B in Section 5.2(e) and (f) of by-law 9958.

In addition, Vancouver has done well to require a certain number of trees to be present on sites of different areas in the hopes of reaching canopy cover goals throughout the city. Schedule C in Section 5.2 outlines this information. For small sites up to 365m^2 in size, two (2) trees are required, while for large sites of 2901-3250m^2, 30 trees are required. As this report is looking at residential RS and RT zoned lots, typical lot sizes fall into the 350-500m^2 rage, requiring 2-4 trees to be planted on each lot. These trees can be planted anywhere on the lot where there is adequate permeable space and soil provided.

Tree Regulations Toolkit

In 2021, Metro Vancouver published a publicly accessible tree regulations toolkit as a resource for municipal staff, decision makers and other practitioners, including planners, arborists, biologists, engineers, and landscape architects. This guide is in place to help ensure the preservation and growth of trees and tree canopy through a framework for selecting regulatory tools to help achieve municipal tree preservation or canopy growth objectives (Metro Vancouver, 2021, p. 1). This toolkit is helpful in understanding different approaches BC has taken in better regulating trees throughout the province, as well as how to select trees that will thrive in different communities.

In order to help promote the health and safety of urban trees, the tree regulations toolkit lays out plans and policies for private yard trees. In *official community and neighbourhood plans* there are policies supporting the treed character of new landscaping in land uses and neighbourhoods. *Zoning bylaws* require lot sizes, trees per lot, impermeable/permeable cover, off-street parking, screening and landscaping that is favourable to yard trees. *Subdivision servicing bylaws* have set standards for access and utilities placement favourable to yard trees. *Development permit areas* promote energy conservation, water conservation and reduction of greenhouse gas emissions using trees. *Tree bylaws* regulate certain trees and require a minimum number of trees or canopy area per lot as well as specify assessment and replacement standards. This information is summarized in a table on page 7 of the Tree Regulations Toolkit (Metro Vancouver, 2021).

Making HOME

The Making HOME (Housing Options for Middle-income Earners) program, proposed by Vancouver's Mayor, Kennedy Stewart, was passed in January 2022 and designed to encourage more available and attainable housing options for a wider range of Vancouver's population. This program allows for one standard sized residential lot to hold up to six sellable market homes on them, as long as two or more of the homes are set aside as affordable to middle-income working households. Looking at the average price of a detached house in Vancouver today, these homes are only affordable to the top 2.5% of incomes within the city. With the Making HOME policy, housing ownership availability would increase to 50% of the population (Chan, 2020).

"There will be a relaxation of parking requirements, design, floor space ratio density, and various other city regulations to allow for smaller homes on a single-family lot" (Chan, 2020). This is important to consider as it allows the possibility for regulations around trees and new planting to be slackened or prioritized. With new developments, comes new opportunities to promote tree planting and the benefits they provide, not only for stormwater management and environmental advantages, but for social, economic, and health benefits as well. The Making HOME program already aligns with the City of Vancouver's Climate Emergency Action Plan through helping fund actions to meet emissions reduction targets (Making HOME, n.d.), and with the proper policies and steps taken towards creating a more sustainable, green city with more urban trees, this housing program could align with other goals set in many city-wide policies.

4 Tree Characteristics and Benefits

Trees are considered to be a natural asset beneficial to cities all over the world. Natural assets are "the stock of natural resources and ecosystems that yield a flow of benefits to people" (Municipal Natural Assets Initiative, 2017, p. 3). This is to say that trees, when considered as natural assets, can provide value and benefits to municipalities worldwide. In a study conducted by the district of West Vancouver (West Vancouver, 2022), their forests were estimated to hold a value of $653 million to $1.8 billion for the district. This value came from a trees' ability to absorb rainwater and release it more slowly to the environment helping in heavy rain events, help with climate regulation (as trees grow they capture carbon dioxide from the air and store it in their tissues in a process of carbon sequestration), their role in animal habitat as food and protection, the makeup of hiking and biking trails in recreational opportunities for locals and tourists, and added aesthetic and cultural value to residents (West Vancouver, 2022, p. 4).

Although there are many characteristics to consider when looking at trees as natural assets – the ecosystem services they offer to both humans and non-humans such as lowering temperatures, providing habitat, and sequestering carbon – how do they benefit rainwater management? When it rains in a city, the water hits the ground and runs into catch basins and drainage swales. Before this, running water picks up sediments and pollutants including gas and oil, heavy metals, pesticides, fertilizers, and other chemicals that harm the natural environment, as it moves over paved surfaces. The now polluted rainwater runs over impervious surfaces and into the city's stormwater system instead of being allowed to infiltrate into the ground. However, planting more trees in the city can help mitigate some of these effects through natural processes of infiltration, evaporation, evapotranspiration, and phytoremediation.

In a basic sense, tree canopies act as large umbrellas that intercept, and slow rain fall while also allowing for water to evaporate from its leaves in a process of evapotranspiration. This helps to reduce flooding and run off as rainwater doesn't fall to the ground directly, but drops onto tree leaves, branches, and trunk before reaching the ground below. In turn, this will allow more time for rainwater to infiltrate into the soil rather than running off into storm water systems and local water supplies. Both deciduous and coniferous trees will slow and capture rain in their canopy, however, coniferous trees are 2.3 times as effective as deciduous trees and therefore are statistically more beneficial to rainwater management when considered year-round (Asadian, Rainfall Interception in an Urban Environment, 2010).

Another way in which trees benefit rainwater management is with their roots. Not only do tree roots drink up water from the soil, but the presence of the roots help disturb the soil and allow more opportunity for infiltration. It has been measured that a permeable area without the presence of trees allows approximately 4" (100mm) of water to infiltrate into the soil per hour, whereas pervious areas that contain trees allow for 10" (250mm) of water to infiltrate the soil per hour (Penn State Extension, 2022). Similarly, when looking at a natural, undeveloped forest, only 10% of rainfall will reach the ground as annual runoff while the rest makes its way back into the atmosphere through evaporation or is absorbed by roots and used to sustain life. However, if the trees are cut down to make way for urban development, canopy cover decreases leading to an annual runoff of 25% or greater for the area's rainfall volume (Waterbucket, 2021). When there is limited, or less tree roots and leaf litter helping to create soil conditions that promote infiltration, there will be higher amounts of runoff, and groundwater supplies are in turn replenished much slower (The Center for Watershed Protection, 2022). This may lead to drought conditions and low streamflow during dry periods, and higher chances of flooding and erosion during wet seasons.

As rainfall is absorbed into tree leaves and bark, the water is cleaned of pollutants. Trees and forested areas reduce pollutants by taking up nutrients and other impurities from soils and water through their roots, and by transforming pollutants into less harmful substances (The Center for Watershed Protection, 2022). This process is called phytoremediation. Similar to looking at how tree leaves are able to sequester carbon from the atmosphere (helping to improve air quality), phytoremediation will help to reduce the number of contaminants that enters stormwater systems and eventually Vancouver's creeks, rivers, and ocean. Generally, trees are most effective at reducing runoff and pollutants from frequent, smaller storm events.

Outside of rainwater management and water flow benefits, trees provide a plethora of co-benefits when planted in developing urban areas. Along with their mental and aesthetic values in beautifying neighbourhoods, trees also help to lower surface temperatures in metropolitan areas. Stephan Sheppard, a forestry professor at the University of British Columbia, found there to be an 8°C difference in neighbourhood temperatures of those with higher green canopy and those dominated by asphalt. This was due to the added shade and moisture that trees release into the air through evapotranspiration. It is estimated that in Vancouver 23% of the city is covered by green canopy. The aim is to increase this percentage to a minimum of 30% by 2050 (Ghoussoub, 2022). Ultimately, whether or not this goal is reached, planting more trees will lead to larger areas of canopy cover and more social and environmental benefits within the city. A full table of direct and accessory benefits of urban trees is laid out in Appendix A.

5 Findings

Table 1 provides definitions of important terminology as it relates to the research and findings of this report:

Table 1: Noted terminology

Noted Terminology

Rainfall Interception	The process of precipitation falling on a tree surface (branches, leaves, trunk) where it is temporally stored. It can then either be absorbed by the tree, evapotranspirate to the atmosphere, or flow down to the ground. This can delay the onset and reduce peak flow of runoff.
Interception Loss	The difference between gross precipitation and the sum of throughfall and stemflow.
Throughfall	The rainfall that passes through the tree canopy and becomes stemflow and/or reaches the ground surface. Reducing the throughfall reduces soil erosion as it diminishes rainfall velocity and volume.
Storage Capacity	The water that never reaches the ground and it stored on the leaves and branches of the tree.

Noted Terminology

Canopy Cover	The percentage of ground covered by the vertical projection of the tree crown.
Stemflow	The rainfall that reaches the tree branches and truck and runs down along the bark to the ground.
Net Precipitation	The water that reaches the ground surface.
Runoff	The portion of water that reaches the ground surface but does not infiltrate.
Infiltration	Water that reaches the ground and is absorbed into the ground surface. Tree root growth and leaf litter decomposition can increase soil infiltration rate and capacity.
Canopy Interception	The difference between gross rainfall and the amount of rain that passes through the canopy.
Evapotranspiration (Transpiration)	A process where a tree releases water from its canopy as a vapor to the atmosphere.
Phytoremediation	The process of absorbing harmful chemicals and pollutants and transforming them into less harmful matter. Trees can take up trace amounts of organic compounds, fuels, metals, and solvents from the soil, which can then be used as nutrients or stored in the tree stems/roots/leaves.

5.1 Limitations

The follow sections look into some of the constraints that may be encountered when looking to use trees as natural rainwater management assets in residential areas of Vancouver, BC.

5.1.1 Vancouver Zoning

To date, 12,559 Hectares (ha) of land have been zoned within the bounds of metro Vancouver (City of Vancouver, 2022b). Of this zoned land 71% (8935ha) is classified as residential area, with the majority being classified single-family (RS, 7300ha) zones and some two-family (RT, 791ha) zones. This report and further analysis will focus on the RS and RT portion of Vancouver zoning.

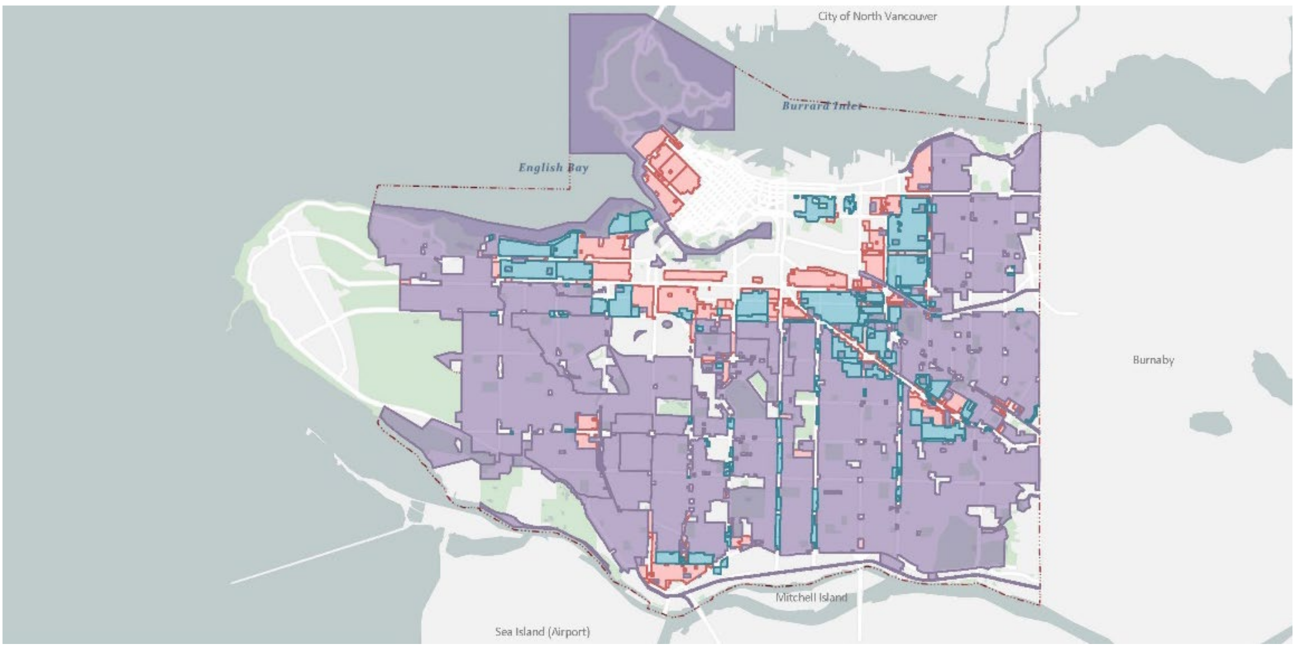

Figure 6: Residential zoning across Vancouver, single-family zones in purple, two-family zones in blue, and multifamily zones in red. Retrieved from VanMap (City of Vancouver, 2022)

Many RS and RT zones neighbourhoods around Vancouver are composed of a typical 33′ x 120-122′ lot geometries. Looking at an average block in the Kitsilano and Mount Pleasant neighbourhoods, these RT lots fall into the typical long and narrow geometry of 33′ x 120′ (Kitsilano) to 122′ (Mount Pleasant). In the Dunbar-Southlands and Marpole neighbourhoods, typical RS lots range a bit more in shape. Dunbar-Southlands average RS lot geometry is 33′ x 130′ while the Marpole typical RS lots average at 44′ x 115′. This information is summarized in Table 2:

Table 2: Typical lot geometries

Lot Zoning	Neighbourhood	Average Typical Dimension	Average Area [m²]	Front Yard Area [m²]
RT	Kitsilano	33′ x 120′	370	74
RT	Mount Pleasant	33′ x 122′	375	75
RS	Dunbar-Southlands	33′ x 130′	400	80
RS	Marpole	44′ x 115′	470	94

Although lot geometries somewhat differ, with a dominance of single-family and two-family homes making up the majority of urban Vancouver, outside of urban parks and street boulevards, these lots provide the greatest source of space for tree planting. However, this function is challenged by trends in greater lot utilization through additional buildings and structures and increasing lot densification bringing increasing imperviousness and less space for trees.

Looking at the RS and RT low-density lots, these lots can be split into areas of building footprint and back and front yards. Typically, the building footprint of a family home will take up 35% of the residential lot, backyards (which are increasingly impervious with built sheds, storage, separate suites, and patios and pools) account for 45% of the lot, leaving only 20% for the front yard. This means average RS and RT lots only have **74-94 m^2** of available space for trees in their front yards, without considering required property line or right-of-way setbacks.

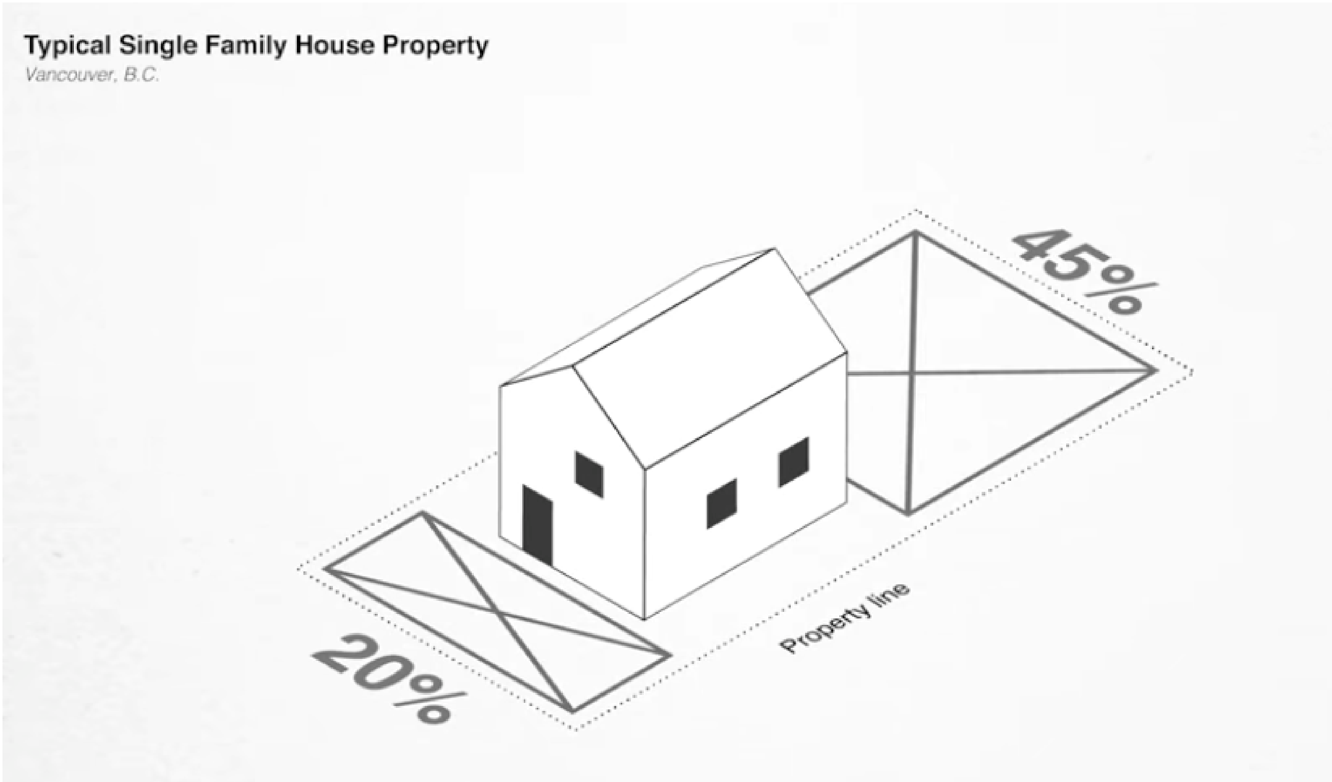

Figure 7: Typical single-family house property. Retrieved from https://www.youtube.com/watch?v=wzBL85kTwwo&t=54s (About Here, 2021)

Natural assets like trees are often forgotten about and left to be fit into the dwindling pervious areas of front yards. However, despite this lack of prioritization, tree planting in residential front yards still holds the capacity to help mitigate effects of development and urban runoff.

5.1.2 Setbacks

"Trees require space from buildings and paved surfaces to grow to maturity without conflict with adjacent infrastructure" (Metro Vancouver, 2021, p. 18). This is why municipalities require setbacks – an offset of one thing from another existing feature – in developments, both public and privately zoned. When looking at tree planting, a setback is required to ensure tree roots that are spreading underground do not interfere with existing underground structures and utilities. Additionally, setbacks better allow enough space for the tree to grow and thrive. When looking at private developments, the City of Vancouver requires all structures to be setback a minimum of 5m from other buildings, utilities, and property lines (Metro Vancouver, 2021, p. 18) . All trees are required to have a 3m setback from structures and utilities. This may impact where a tree is able to be planted with enough space available to grow. Caution and consideration will need to be executed to ensure that trees planted on low-density residential lots are able to grow to maturity in order to play a better role in rainwater management.

Table 3 highlights some important setback requirements that need to be considered when planting trees in privately zoned lots:

Table 3: Setback requirements

Setback From	Distance Required	Notes
Trees from above ground structures	3m +	Required by City of Vancouver
Trees from sewer laterals and underground water lines	3m +	Recommended by plumbing professionals
Trees with spreading roots from underground utilities	6m +	Recommended by plumbing professionals
≤5m tall trees from above ground utility pole	0-5m	Required by BC Hydro
≤12m tall trees from above ground utility pole	5-10m	Required by BC Hydro
>12m tall trees from above ground utility pole	10m +	Required by BC Hydro
Low-growing trees or small shrubs from gas transmission line	2.5-10m	Required by Fortis BC

Setback From	Distance Required	Notes
Trees or large shrubs from gas transmission line	10m +	Required by Fortis BC
Trees or large shrubs from service lines	Distance equivalent to the height of the mature tree	Recommended by Davey Tree Expert Company
≤5m tall trees or shrubs from overhead power lines	5-10m	Required by Fortis BC
>5m tall trees or shrubs from overhead power lines	10m +	Required by Fortis BC. Note trees planted here should not grow tall enough that they would fall on top of the power line if blown over or uprooted
Trees from street or roadway	0.6m	Required by City of Vancouver
Broad or spreading trees from outside edge of awning or balcony	1.8m	Required by City of Vancouver
Upright or columnar trees from outside edge of awning or balcony	1.2m	Required by City of Vancouver

Assuming a smallest typical residential lot geometry of 33' x 120', or approximately 10m x 37m, with a setback minimum of 3m from other structures, we can assume that **1-4** trees could safely be planted in an area approximately 10m x 30m. This considers a 3m setback from the house or residential building in the lot, and a 3m setback from the sidewalk assuming there are some underground utilities there. If the 3m setback cannot be achieved, it is important to use a root barrier fabric or liner so growing tree roots don't conflict with nearby underground utilities (Ministry of Health, Government of British Columbia, 2014, p. 100). Further information regarding setback requirements can be found in Appendix B.

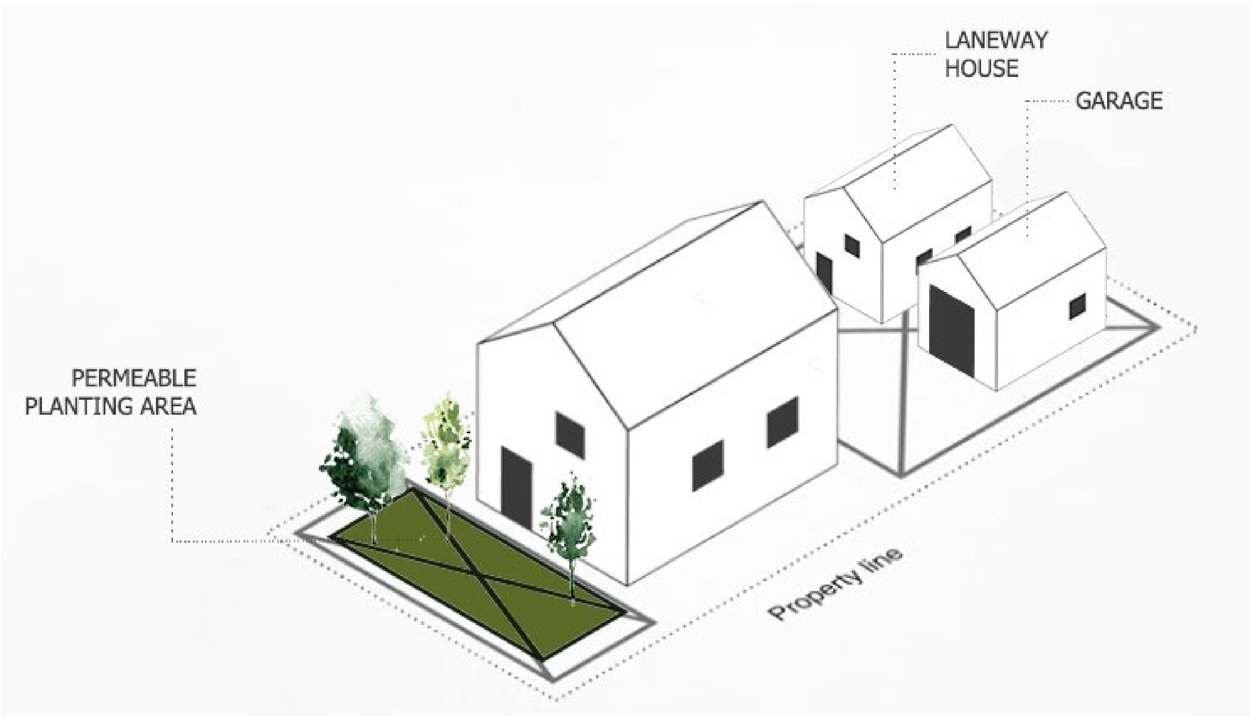

Figure 8: Illustrated single-family house property with planting zone. Base graphic (About Here, 2021) adapted by J. Neudorf

If space allows and adequate soil volume is provided, additional trees are encouraged to be planted in the back yard or along the side of the house. Residential lots in Vancouver are not all laid out identically and consideration should be taken when selecting the appropriate area for trees to be planted so they can thrive. Table 4 summarizes trees that can be planted given typical lot geometries and setbacks.

Table 4: Planting space available given lot geometries and setbacks

Lot Zoning	Neighbourhood	Typical Lot Dimension [ft]	Average Area [m^2]	Front Yard Area [m^2]	Assumed Setback [m]	Available Area [m^2]	Number of Trees Planted on Lot (with preferred soil volume)			Available Front Yard Area [m^2]	Number of Trees Planted in Front Yard (with preferred soil volume)		
							Small	Medium	Large		Small	Medium	Large
RT	Kitsilano	33' x 120'	368 m2	74 m2	3	338	10	5	3	44	1	1	0
					5	318	9	5	3	24	1	0	0
					10	268	8	4	2	-	-	-	-
RT	Mount Pleasant	33' x 122'	374 m2	75 m2	3	344	10	5	3	45	1	1	0
					5	324	9	5	3	25	1	0	0
					10	274	8	4	2	-	-	-	-
RS	Dunbar-Southlands	33' x 130'	399 m2	80 m2	3	369	11	5	3	50	1	1	0
					5	349	10	5	3	30	1	0	0
					10	299	9	4	3	-	-	-	-
RS	Marpole	44' x 115'	470 m2	94 m2	3	431	12	6	4	64	2	1	1
					5	405	12	6	4	44	1	1	0
					10	340	10	5	3	-	-	-	-

Note that it is assumed that small trees prefer 35m³ soil volume, medium trees prefer 70m³ soil volume, and large trees prefer 110m³ soil volume. The above calculation assumes a soil depth of 1m.

Lot Zoning	Neighbourhood	Typical Lot Dimension [ft]	Average Area [m^2]	Front Yard Area [m^2]	Assumed Setback [m]	Available Area [m^2]	Number of Trees Planted on Lot (with minimum soil volume)			Available Front Yard Area [m^2]	Number of Trees Planted in Front Yard (with minimum soil volume)		
							Small	Medium	Large		Small	Medium	Large
RT	Kitsilano	33' x 120'	368 m2	74 m2	3	338	17	10	6	44	2	1	1
					5	318	16	9	6	24	1	1	-
					10	268	13	8	5	-	-	-	-
RT	Mount Pleasant	33' x 122'	374 m2	75 m2	3	344	17	10	6	45	2	1	1
					5	324	16	9	6	25	1	1	1
					10	274	14	8	5	-	-	-	-
RS	Dunbar-Southlands	33' x 130'	399 m2	80 m2	3	369	18	11	7	50	3	1	1
					5	349	17	10	6	30	2	1	1
					10	299	15	9	5	-	-	-	-
RS	Marpole	44' x 115'	470 m2	94 m2	3	431	22	12	8	64	3	2	1
					5	405	20	12	7	44	2	1	1
					10	340	17	10	6	-	-	-	-

Note that it is assumed that small trees require 20m³ soil volume, medium trees require 35m³ soil volume, and large trees require 55m³ soil volume. The above calculation assumes a soil depth of 1m.

5.1.3 Soil Requirements

The Tree Regulations Toolkit does well at laying out some of the requirements for surface area, minimum pervious cover required to sustain some trees (Metro Vancouver, 2021, p. 17), and minimum soil volume required for trees in relation to their canopy size (Metro Vancouver, 2021, p. 20). To meet minimum soil volume requirements, it is recommended that at least 0.3m^3 of soil and preferably 0.6m^3 of soil per m^2 of mature canopy area is recommended (Metro Vancouver, 2021). The following tables (Table 5 and Table 6) are adapted from the Tree Regulations Toolkit:

Table 5: Area requirements

Tree Size	**Approximate Surface Area [m^2] of Soil Required Per Tree (assuming 1m soil depth)**		
	On Ground	Under Hardscape Soil Cells (92% Soil)	Under Hardscape Structural Soil (20% Soil)
Small Tree Canopy (0-6m Spread)	8	X1.1	X5
Medium Tree Canopy (6-10m Spread)	20	X1.1	X5
Large Tree Canopy (10m+ Spread)	35	X1.1	X5

Where trees are installed in hardscaped areas, soil cells or structural soil can be used. This will allow trees and shrubs to grow in soil under paved areas, but soil requirements will be higher in order to provide adequate and equivalent volumes of soil (Metro Vancouver, 2021, p. 17).

Table 6: Soil requirements

Tree Size	Minimum Soil Volume [m^3]	Shared or Irrigated Soil Volume [m^3]
Small Tree Canopy (0-6m Spread)	8	6
Medium Tree Canopy (6-10m Spread)	20	15
Large Tree Canopy (10m+ Spread)	35	30

Soil volume shall be calculated as:

- Soil: Surface area (Length x Width) of connected pervious x 1
- Soil under hardscape:
  - Soil: Volume of soil (Length x Width x Depth)
  - Soil cells: Volume of soil cell installation (Length x Width x Depth) x .92

Design Guidebook: Maximizing Climate Adaption Benefits with Trees

In 2016, Metro Vancouver commissioned a design guidebook to lay out some principals that would help maximize climate adaption benefits through the use of trees in communities around Vancouver. This guidebook (Metro Vancouver, 2017) is intended to offer regionally specific information on trees and urban forest management in order to see the most climate adaption benefits through the use of these natural assets. The direct benefits we see from trees within the city are summer shading, cooling from evapotranspiration, stormwater management, air pollution reduction, water quality, erosion control and slope stabilization, carbon sequestration, and wind buffer (Metro Vancouver, 2017, p. 7). Accessory benefits that trees add to the quality of life in cities include aesthetics and beautification, cultural and spiritual benefits, connection to nature, human health and well-being, social strengthening, recreation, productivity, noise and privacy buffer, crime reduction, road safety, food production, and an added biodiversity and habitat value (Metro Vancouver, 2017, p. 8).

This guidebook is useful in that it presents tips and tricks for a variety of different sites around the city, including private realm planting. With private planting there is usually additional space available adjacent to curb-side or public street plantings, which is important to consider when looking at front yard space available for planting (Metro Vancouver, 2017, p. 17). Additionally, there are advantages to private realm planting that include the increase in canopy cover (over the sidewalk and in private front yards). When front yard planting is staggered with public sidewalk planting a continuous canopy can be created which would maximize canopy spread and better cool hot neighbourhoods and manage rainwater. However, there are also some constraints that need to be considered. Trees are required to have a 3m setback from buildings and structures on residential lots, which, when considering geometries and sizes of front yards, may not leave much space available for front yard tree planting. Trees should be strategically placed and planted where they will have adequate space to grow and thrive. Table 7 is adapted from the design guidebook (Metro Vancouver, 2017, p. 18) to illustrate some of the recommended targets for private realm planting of trees of various sizes where there is expected to be a low volume of street traffic:

Table 7: Tree planting targets

40-80% Canopy Cover Targets	**Shading, Cooling, and Stormwater Management Benefits**		
Tree Size	Large (>15m tall, 10-20m spread)	Medium (10-15m tall, 7-12m spread)	Small (<10m tall, <8m spread)
~ number of trees per 1,000m² to achieve 80% canopy cover	5 (~150m² canopy per large tree)	11 (~70m² canopy per medium tree)	26 (~30m² canopy per small tree)
Soil Volume⁺	45-150m³ per tree	20-70m³ per tree	15-30m³ per tree
Tree Spacing	12-15m	10-14m	6-9m
Permeable Area around each Tree	Minimum ~150m² per tree	Minimum ~70m² per tree	Minimum ~30m² per tree

+Target 0.6m³ of soil for every 1m² of crown projection (~1000 mm depth). Connect soil volume between trees to reduce the soil volume target to 0.4m³ per 1m² of crown projection. Smaller volumes can be provided but will reduce the ultimate size of the tree and increase root damage potential.

5.2 Opportunities

The follow sections look into some of the recommended tree species for their ability to effectively manage rainwater in residential areas of Vancouver, BC, given the limitations outlined above.

5.2.1 Recommended Species

Through rainfall interception and evapotranspiration trees can help to slow stormwater runoff and effectively manage rainwater during low intensity rainfall events. Table 8 below identifies tree species that are suitable to Vancouver's climate and are ranked among the top 10% of species for their potential to reduce runoff and stream flow by the USDA (USDA Forest Service, 2006a) (for the extensive species list see Appendix C). They are also found on the *Urban Tree List for Metro Vancouver in a Changing Climate* (Metro Vancouver, 2019a) (see Appendix C) which corresponds to the database (Metro Vancouver, 2019b), and ranked as 'Very Suitable', 'Suitable', and 'Marginal'. All trees listed should fit into an area of $75m^2$ – $100m^2$ as this is the typical front yard space available on RS and RT lots in Vancouver, BC. Further consideration was given as to the potential for root damage when planting near underground utilities or structures.

Table 8: Recommended tree species for stormwater management given a changing climate in Vancouver, British Columbia

Common Name (Scientific Name)	Deciduous or Evergreen	Size Class / Canopy Spread [m]	Minimum Soil Volume per Tree [m³]	Prefered Soil Volume per Tree [m³]	Root Damage Potential
Trees can help slow stormwater runoff and the flow of water into streams and rivers by intercepting rainfall and through evapotranspiration. The following species are suitable to Vancouver's climate, and ranked among the top 10% for their potential to reduce runoff and stream flow. They are also found on the Urban Tree List for Metro Vancouver in a Changing Climate and ranked as Very Suitable, Suitable, and Marginal. All trees listed should fit into an area of 75-100m² as this is the typical front yard space available on RS and RT lots.					
Very Suitable					
Chinese Flame Tree (Koelreuteria bipinnata)	Deciduous	Medium / 8m	20	35	L
Golden Rain Tree (Koelreuteria paniculate)	Deciduous	Medium / 8m	20	35	L
Chinese Pistacio (Pistacia chinensis)	Deciduous	Medium / 12m	35	70	L
Osage Orange (Maclura pomifera)	Deciduous	Medium / 8m	20	35	M
Ginkgo (Ginkgo biloba)	Deciduous	Large / 8m	20	35	M
Amur Corktree (Phellodendron amuren)	Deciduous	Medium / 12m	35	70	M
Arizona Walnut (Juglans major)	Deciduous	Large / 12m	35	70	M
Monterey Cypress (Cupressus macrocarpa)	Evergreen	Large / 12m	35	70	M
Shumard Oak (Quercus shumardii)	Deciduous	Large / 12m	35	70	M
Common Hackberry (Celtis occidentalis)	Deciduous	Large / 12m	35	70	M
Deodar Cedar (Cedrus deodara)	Evergreen	Large / 15m	55	110	M
Cork Oak (Quercus suber)	Evergreen	Large / 12m	55	110	M
Suitable					
American Hop Hornbeam (Ostrya virginiana)	Deciduous	Medium / 8m	20	35	L
Field Maple (Acer campestre)	Deciduous	Medium / 10m	25	50	L
Bald Cypress (Taxodium distichum)	Deciduous	Medium / 8m	20	35	M
Giant Sequoia (Sequoiadendron giganteum)	Evergreen	Large / 10m	25	50	M
Boxelder (Acer negundo)	Deciduous	Medium / 12m	35	70	M
Persian Ironwood (Parriotia persica)	Deciduous	Medium / 12m	35	70	M
European Ash (Fraxinus excelsior)	Deciduous	Medium / 12m	35	70	M
Freeman Maple (Acer x Freemanii)	Deciduous	Large / 12m	35	70	M
Black Maple (Acer nigrum)	Deciduous	Large / 15m	55	110	M

Common Name (Scientific Name)	Deciduous or Evergreen	Size Class / Canopy Spread [m]	Minimum Soil Volume per Tree [m³]	Prefered Soil Volume per Tree [m³]	Root Damage Potential
European Hop Hornbeam (Ostrya carpinifolia)	Deciduous	Large / 15m	55	110	M
Sugar Maple (Acer saccharum)	Deciduous	Large / 15m	55	110	M
Red Maple (Acer rubrum)	Deciduous	Large / 15m	55	110	M
Japanese Zelkova (Zelkova serrata)	Deciduous	Large / 15m	55	110	M
Black Poplar (Populus nigra)	Deciduous	Large / 5m	10	15	H
White Mulberry (Morus alba)	Deciduous	Medium / 10m	25	50	H
Velvet Ash (Fraxinus velutina)	Deciduous	Medium / 12m	35	70	H
Fremont Cottonwood (Populus fremontii)	Deciduous	Large / 12m	35	70	H
Sweetgum (Liqiudambar styraciflua)	Deciduous	Large / 15m	55	110	H
White Poplar (Populus alba)	Deciduous	Large / 15m	55	110	H
Marginal					
Lily Tree / Yulan Magnolia (Magnolia denudata)	Deciduous	Medium / 9m	20	40	L
Shantung (Acer truncatum)	Deciduous	Medium / 10m	25	50	L
Chinese Tulip Tree (Liriodendron Chinense)	Deciduous	Large / 8m	20	35	M
Dawn Redwood (Metasequoia glyptostroboides)	Deciduous	Large / 10m	25	50	M
River Birch (Betula nigra)	Deciduous	Large / 15m	55	110	M
White Ash (Fraxinus americana)	Deciduous	Large / 15m	55	110	M
American Sycamore (Platanus occidentalis)	Deciduous	Large / 18m	80	155	M
Cottonwood* (Populus balsamifera)	Deciduous	Large / 12m	35	70	H
Black Walnut (Juglans nigra)	Deciduous	Large / 12m	35	70	H
Bigleaf Maple* (Acer macrophyllum)	Deciduous	Large / 15m	55	110	H
White Alder (Alnus rhombifolia)	Deciduous	Large / 17m	70	140	H

Legend			
	Native Species	*	
	Size Class (Tree Height)	Small	<10m
		Medium	10-15m
		Large	>15m
	Root Damage Potential	L	Low
		M	Moderate
		H	High

5.2.2 Hydrologic Values

Another factor to consider when selecting the appropriate tree is its hydrologic value. Using the United States Department of Agriculture (USDA) Forest Service i-Tree Selector online tool (USDA Forest Service, 2006b), we can estimate an overall monetary value for different tree species, as well as the specific stormwater value saved, runoff avoided, and rainfall intercepted per tree at planting, and in 20 years' time when the tree has grown to be more mature. Table 9 illustrates some of the estimated runoff avoided for a typical small, medium, and large deciduous and evergreen tree found throughout Vancouver's residential front yards (USDA Forest Service, 2006b). This table shows trees in 'excellent' condition at a more mature size, as well as younger trees that are smaller in size and said to be in 'fair' condition to encompass both ends of the growth/health spectrum.

Table 9: Avoided annual runoff

Annual Avoided Runoff [L]				
Tree Species	**Excellent Condition, Mature Size**		**Fair Condition, Young Size**	
	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)
Snowbell (Small Deciduous)	2,473.87	53,633.35	482.27	11,782.85
Japanese Cherry (Medium Deciduous)	3,794.06	76,750.05	530.91	13,252.03
Katsura (Large Deciduous)	5,735.54	121,225.21	1,558.93	34,674.65
Baby Blue Spruce (Small Evergreen)	1,268.14	28,309.46	244.73	5,808.71
Southern Magnolia (Medium Evergreen)	2,837.76	59,798.84	2,326.97	48,579.30
Black Pine (Large Evergreen)	4,346.20	92,884.40	3,563.89	75,329.11
Average				
Total	3,409.26	72,105.05	1,451.95	31,571.11
Vancouver				
There are 79,368 RS and RT zoned lots in Vancouver. The below values assume that each residential lot would plant one (1) tree in their front yard. The values represent the total, city-wide runoff [L] that would be avoided.				
Small Tree	148,497,924.84	3,251,818,472.04	28,850,268.00	698,103,467.04
Medium Tree	263,177,144.88	5,418,806,150.76	113,412,109.92	2,453,714,499.72
Large Tree	400,083,770.16	8,496,725,763.24	203,293,988.88	4,365,389,211.84

Currently, there is a recorded 79,368 residential lots that are zoned as single-family (67,239 RS) and two-family (12,127 RT) homes in Vancouver, BC (City of Vancouver, 2022). If we assumed that each residential lot planted *one small tree* in an effort to sustainably mitigate stormwater runoff, the city could avoid anywhere from 28.8 million L of runoff for a small, juvenile tree in the first year, up to 3.25 billion L for a mature and well-established, small tree over the next 20 years. For a large tree, the value could increase up to a cumulative 8.5 billion L over the next 20 years.

Similarly, this runoff avoided amount can be equated to a stormwater value, summarized in Table 10:

Table 10: Annual stormwater value

Annual Stormwater Value [$]				
Tree Species	**Excellent Condition, Mature Size**		**Fair Condition, Young Size**	
	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)
Snowbell (Small Deciduous)	$ 7.44	$ 161.46	$ 1.49	$ 35.94
Japanese Cherry (Medium Deciduous)	$ 11.98	$ 243.53	$ 1.61	$ 40.41
Katsura (Large Deciduous)	$ 17.29	$ 364.73	$ 4.75	$ 105.74
Baby Blue Spruce (Small Evergreen)	$ 2.94	$ 66.72	$ 0.75	$ 17.71
Southern Magnolia (Medium Evergreen)	$ 8.54	$ 179.91	$ 7.09	$ 148.15
Black Pine (Large Evergreen)	$ 14.15	$ 299.01	$ 10.86	$ 229.73
Average				
Total	$ 10.38	$ 219.23	$ 4.43	$ 96.28
Vancouver				
There are 79,368 RS and RT zoned lots in Vancouver. The below values assume that each residential lot would plant one (1) tree in their front yard. The values represent the total, city-wide stormwater costs [$] that could be avoided.				
Small Tree	$ 411,919.92	$ 9,055,095.12	$ 88,892.16	$ 2,129,046.60
Medium Tree	$ 814,315.68	$ 16,803,792.96	$ 345,250.80	$ 7,482,815.04
Large Tree	$ 1,247,664.96	$ 26,339,858.16	$ 619,467.24	$ 13,312,791.48

From the above, we can see that if each residentially zoned lot in Vancouver were to plant one tree in their front yard, the city could save anywhere from approximately $89,000 up to $1,250,000 in the first year. This stormwater saving could increase to up to $26,300,000 over the next 20 years as the trees matured. This is equivalent to a stormwater runoff reduction of approximately 400,000,000 L over 20 years.

A full table of valuations, including a stormwater value, overall value, and rainfall intercepted, can be found in Appendix D.

6 Recommendations

Given the data provided and current research done (case studies summarized in Appendix E), it is evident that trees can successfully and effectively be used as natural assets in rainwater management. Trees not only are successful at intercepting rainfall and mitigating runoff, but they are also a feasible natural addition to current stormwater infrastructure.

Promoting the use of trees in Vancouver for their stormwater benefits not only aligns with current City of Vancouver policies and strategies, such as the Urban Forest Strategy and Rain City Strategy, but trees are a sustainable asset that can be used for their co-benefits to help work towards a variety of additional goals. From a stormwater management lens, trees increase city canopy cover, promote permeability, biodiversity, and green space, and help to improve water quality through pollutant removal and runoff reduction. Outside of stormwater management, trees help to reduce the Urban Heat Island effect, sequester carbon, and enhance urban ecosystems – all aspects of city-wide goals and targets set for the future of Vancouver. Additional research and time should be spent looking into these additional benefits and how they further align with Vancouvers goals.

It would be beneficial to explore new policies that could be implemented to promote and encourage planting of trees, not only on single- and two-family residential lots, but on multifamily lots and commercial developments. When this is explored, recommendations could be made as to which tree species are most effective and feasible in decreasing urban heat island effect, sequestering carbon, removing air or other pollutants found within the city, or expanding on the existing tree canopy and green spaces, in addition to their stormwater benefits.

7 Conclusion

Regardless of type or species, all trees can help to sustainably manage stormwater in low-density residential zones. In residential zoning, green space can be limited due to the above and below ground infrastructure present and increasing impermeability of the space. However, if tree planting is considered and intentionally designed for during development and re-development, there is opportunity for trees to be used effectively as natural assets in stormwater management and beyond. The addition of designing with trees in mind will allow trees to grow and thrive and not only see a positive impact on rain and stormwater management throughout the city of Vancouver, but will allow for subsequent co-benefits that will help to further actions and goals set out in multiple city-wide strategies and plans. In particular, residential front yard planting will not only aid in rainwater management, but help to create beautiful urban landscapes, enhance habitat and support biodiversity, help mitigate and adapt to climate change, and contribute to a healthy city, all goals set in Vancouver's Urban Forest Strategy.

Planting trees and allowing them to thrive will help manage more rainwater in residential spaces, and ultimately decrease the necessity of stormwater infrastructure throughout the city. In fact, if each residentially zoned lot in Vancouver were to plant one tree in their front yard, the city could save anywhere from approximately $89,000 up to $1,250,000, or avoid 29,000,000 to 400,000,000 L of runoff in the first year. This stormwater saving could increase to up to $26,300,000 over the next 20 years as the trees matured. This is equivalent to a stormwater runoff reduction of approximately 8,500,000,000 L over 20 years. As Vancouver is forecasted to experience hotter, drier summers and warmer, wetter winters by 2050, the increasing presence of urban trees will help to sustainably stabilize the climate and safeguard the urban environment.

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Appendix A: Tree Benefits

The following tables were adapted from the Metro Vancouver *Design Guidebook: Maximizing Climate Adaptation Benefits with Trees* (Metro Vancouver, 2017, pp. 7-8).

Table 11: Direct climate adaption benefits

Direct Climate Adaption Benefits

Summer Shading	Trees provide shade. Specifically, summer shade keeps people cool and benefits building energy consumption and stream health and mitigates the urban heat island effect. Trees must be carefully placed and selected to yield benefits for building energy consumption in summer without also increasing shading in winter.
Cooling from Evapotranspiration	Trees and associated permeable surfaces cool ambient air through evapotranspiration. Evapotranspiration rates vary by species and tree health. Importantly, increasing the extent of permeable surfaces and available soil moisture around trees also increases evapotranspirative cooling effects.

Direct Climate Adaption Benefits

Stormwater Management	Trees reduce stormwater runoff and peak flow above ground by intercepting rainfall. Below ground, trees improve soil infiltration rates because water flows along tree roots. The magnitude of rainfall intercepted by the canopy varies with canopy density (leaf area index) and canopy persistence in winter. Importantly, increasing the extent of permeable surface around trees greatly increases stormwater benefits.
Air Pollution Reduction	Trees can benefit air quality or limit people's exposure to air pollutants in three ways: increasing air mixing helping to disperse air pollution, capturing small amounts of pollution on tree leaves, and by decreasing local air temperatures thereby reducing the formation of certain forms of air pollution (e.g., ground level ozone). However, some trees and vegetation can also contribution to air pollution as they naturally produce Volatile Organic Compounds that can contribute to ozone formation under certain conditions.
Water Quality	Surface water quality is strongly influenced by stormwater runoff. By intercepting and infiltrating rainfall, trees slow, store and filter water removing pollutants and improving water quality. To see substantial improvements or to maintain water quality in urban areas, increasing and maintaining healthy trees must be combined with strategies to reduce pollutant sources and the extent of impervious areas.
Erosion Control	With proper species selection (deep rooting species), trees can help mitigate soil erosion and reinforce slope and bank stability
Carbon Sequestration	Trees sequester and store carbon through photosynthesis. Large trees that have long life-expectancy and favourable growth conditions sequester more carbon. Keeping large and mature trees standing longer keeps the carbon stored, as carbon is released into the atmosphere after trees are cut down.
Wind Buffer	Tree canopies can reduce and redirect wind, providing a buffer to reduce wind chill and building energy consumption in winter. Effectiveness is based on tree spacing, canopy height, density, shape, and porosity.

Table 12: Accessory tree benefits

Accessory Benefits to Quality of Life in Cities

Aesthetics and Beautification	Research in Western cities has shown that people prefer landscapes that include trees and plants. People seek out the comfort of these places, are likely to spend more time outdoors, and prefer these locations for living and working.
Cultural and Spiritual	Urban residents tend to develop strong emotional ties to urban trees as symbols or landmarks, as well as features of places for contemplation and healing. Preferences for the urban forest are influenced by cultural and historical ties to certain types of landscapes, and people feel more at ease in the type of landscape they grew up in.
Connection to Nature	Residents develop emotional attachment to urban green spaces for their recreational use and restorative value. Attachments develop from early childhood. People who work in environmental stewardship often credit their childhood experiences with nature in their decision to pursue their careers.
Human Health and Well Being	Urban forests reduce stress and anxiety by instilling positive emotions and physiological reactions in people. The simple view of trees through a window has been associated with improved recovery from surgery and improved urban residents' well-being.
Social Strengthening	Green neighbourhoods encourage social interactions between neighbours and a sense of belonging. The presence of urban trees in public spaces fosters a better use of those spaces and more social connections. Stronger social ties are associated with lower homicide, anxiety and depression rates.
Recreation	The urban forest encourages people to use outdoor space for recreation and play.
Productivity	Views of greenery have been linked to improved attention span and improved cognitive functioning in children. Views of the urban forest

Accessory Benefits to Quality of Life in Cities

	are also linked to reduced stress levels, increased work and school productivity, and job satisfaction.
Noise Buffer	Trees attenuate noise by absorption, scattering and diffraction. Dense vegetation, including trees, taller than the receiver and located close to the source are most efficient at reducing noise.
Privacy	Trees and urban forested areas can fulfill urban residents' desire for privacy.
Crime Reduction	Crime rates are negatively correlated with canopy cover in some cities.
Road Safety	Landscaping that better defines road edges reduces car accidents and decreases the stress level and frustration of drivers. The presence of trees and plants around streets also attracts more pedestrians.
Food Production	Food-producing trees have the potential to improve food security and provide healthy, nutrient-dense food for urban populations that otherwise lack access to it.
Biodiversity and Habitat Value	Trees are keystone structures in urban parks that provide habitat resources for wildlife. Enhancing back-yards, planted boulevards and utility rights-of-way can support biodiversity in urban parks.

Appendix B: Setbacks and Restrictions

Further consideration needs to be given to what we can't see. Underground utilities and sewer lines may conflict with growing tree roots. All shrubs and trees should be planted with a setback of 10ft (3m) from sewer laterals and underground water lines (Black Diamond, 2013). Trees with spreading roots or that require more water should be planted 20ft (6m) from underground pipes or utility lines when space is available. Regardless of size, trees can have spreading or invasive roots that may grow and interfere with the underground utilities which is why it is important to consider the species of tree being planted and ensure it is the required distance from the buried utilities and services. When selecting a tree to be planted, it is important to consider the root system of the tree. Tree root systems will often be reflected in their canopy shape and habit; narrower trees typically have narrower root systems, while trees with broader spreading canopies tend to have larger spreading root systems. Other species with spreading or water-seeking root systems, such as some poplars, willows, American elm, silver maple, and fruitless white mulberry (Black Diamond, 2013), or trees with highly invasive roots, like some willows, aspens, bamboos, and maples (Ministry of Health, Government of British Columbia, 2014), should be avoided if able. The following graphic retrieved from BC Hydro (BC Hydro, 2022) illustrates the setbacks of planting and maximum heights of trees in residential lots in relation to the house and neighbouring utility poles.

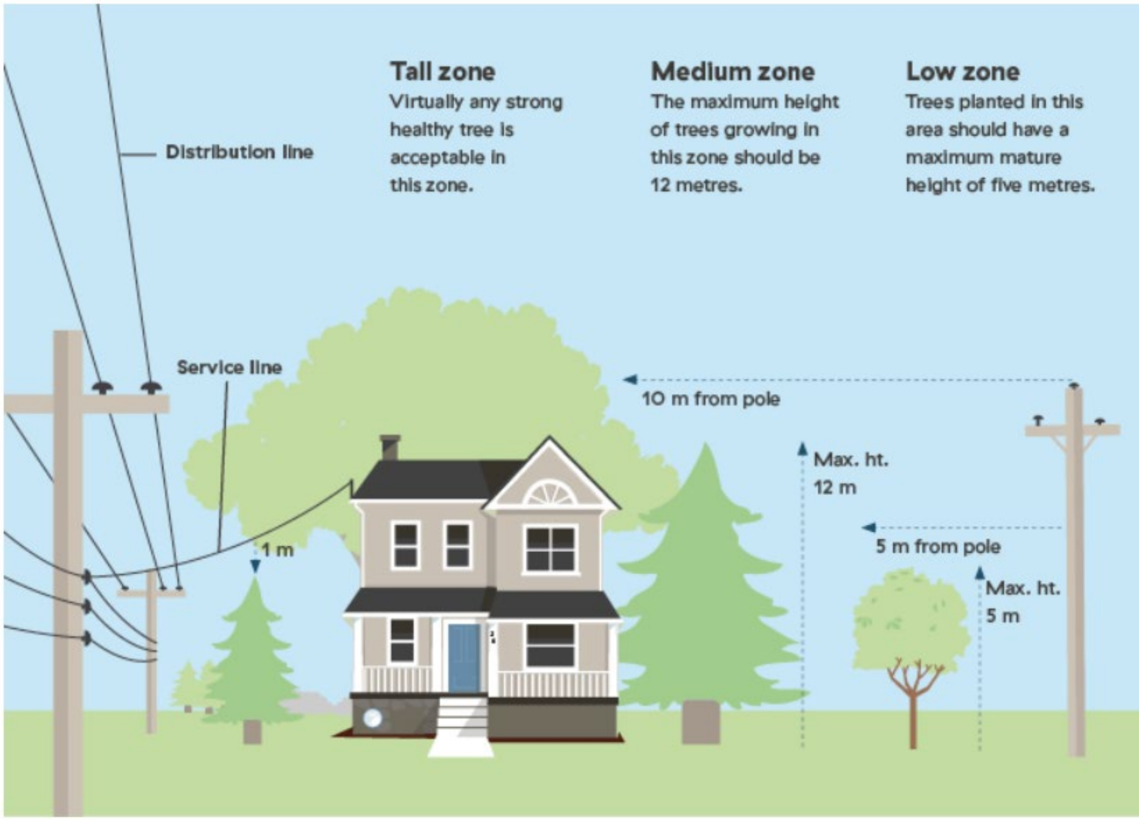

Figure 9: Graphic of planting restrictions and setbacks (BC Hydro, 2022). Retrieved from https://www.bchydro.com/safety-outages/trees-power-lines/planting-trees-plants.html

It is also important to note that Fortis BC has laid out some restrictions and recommendations for planting. When a natural gas line in running parallel or underneath the city sidewalk, only low-growing plants should be planted in the area 2.5-10m from the gas line, while trees and other larger shrubs can be planted outside that window, past 10m from the underground line. If overhead power lines are involved, there is required to be a 'clear zone' where there should be no planting for 5m on either side of the vertical power pole. 5-10m away is considered to be a 'low zone' where shrubs and low trees growing to a maximum height of 5m tall can be planted, and from 10m and beyond is the 'medium/tall zone' where anything can be planted. One caveat is that trees planted here should not grow tall enough that they would fall on top of the power line if blown over or uprooted (Fortis BC, 2022). Similar restrictions regarding planting around high pressure pipelines or pad mounted transformers can be found online (Fortis BC, 2022).

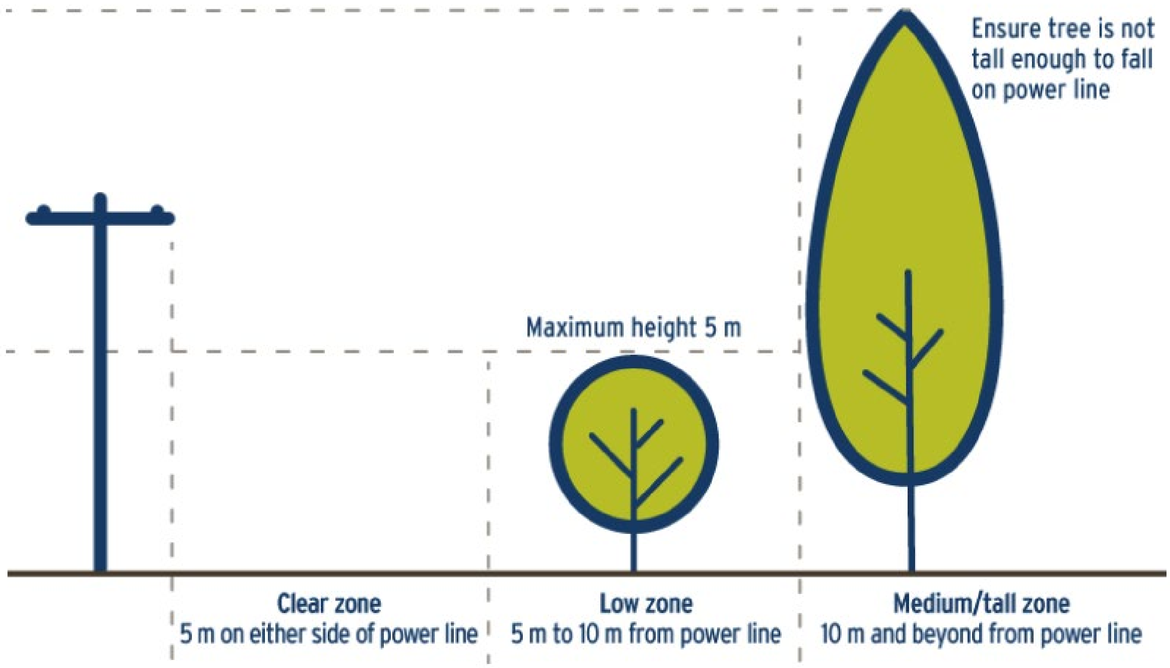

Figure 10: Figure B.2: Graphic of planting restrictions and setbacks (Fortis BC, 2022). Retrieved from https://www.fortisbc.com/safety-outages/safe-planting-near-utility-equipment

Trees should always be planted a minimum of 60cm in from the street or roadway, and if an awning or balcony extends from the front of the house further than 120cm, the base of the tree should be planted a minimum of 180cm away from the edge of the overhang (City of Vancouver, 2011, pp. 24-25). If the tree has an upright, columnar, rather than broad or spreading habit, then a minimum of 120cm can be used (City of Vancouver, 2011, pp. 24,28).

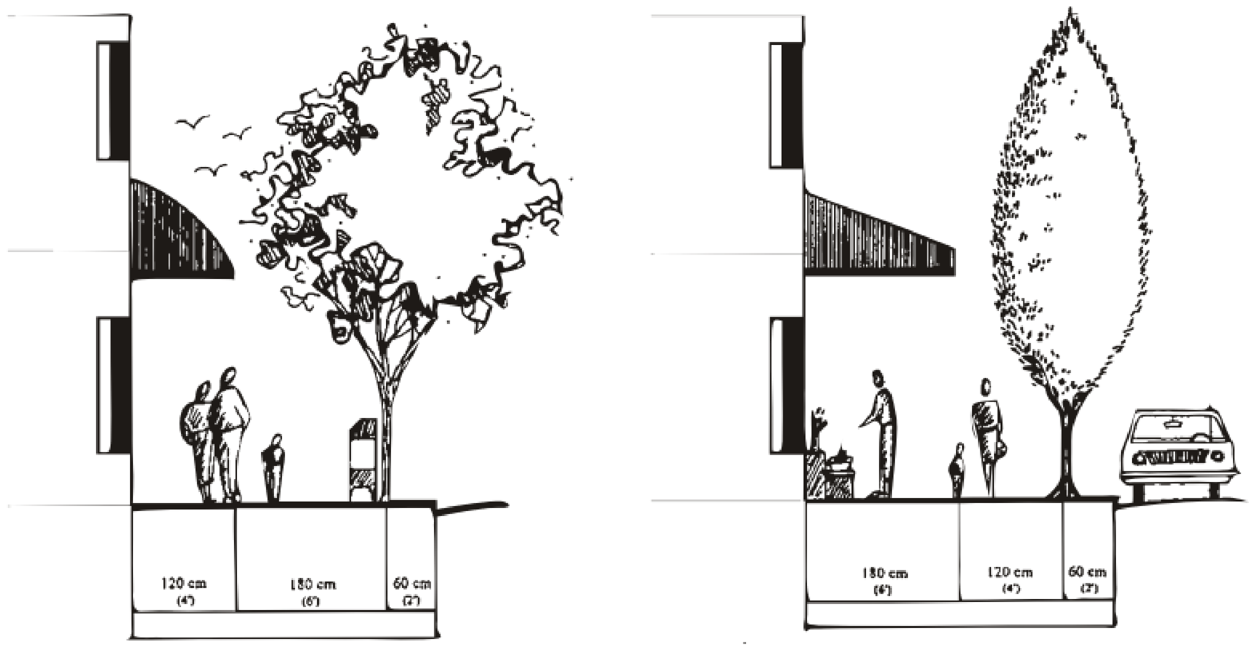

Figure 11: Street planting setbacks. Graphic taken from the City of Vancouver Street Tree Guidelines for the Public Realm, 2011 Revision (City of Vancouver, 2011, pp. 25,28)

There is also a list of questions that are brought up to readers as a reminder of what needs to be considered when planting trees in the city. Some of these questions ask (Metro Vancouver, 2017, p. 10);

- Is there sufficient soil volume to support a healthy tree to maturity?
- Is soil quality capable of supporting a healthy tree or can it be improved?
- Have permeable surfaces been maximized or can hard surfaces be converted to permeable surfaces?
- Are there opportunities to manage stormwater on-site?
- Are there underground utilities in place that restrict or prevent a tree being planted?
- Is there sufficient horizontal and vertical clearance for the tree?
- What level of maintenance can be expected and supported for the tree(s) on site?

For the full list of questions and considerations, refer to page 10 of the guidebook (Metro Vancouver, 2017).

Appendix C: Extensive Tree Lists

Urban Tree List for Metro Vancouver in a Changing Climate

The list of over 300 tree species below are from the Metro Vancouver Urban Forest Climate Adaptation Initiative's tree species selection database. These species have been assessed for their suitability to the current and projected future climate in the Metro Vancouver region. All project materials are available publically on the Metro Vancouver website. Please visit metrovancouver.org and search 'Urban Forest'.

VERY SUITABLE = species anticipated to tolerate a broad range of sites under future climate

Arbutus menziesii
Albizia julibrissin *
Arbutus unedo
Calocedrus decurrens *
Catalpa speciosa *
Cedrus deodara *
Celtis occidentalis *
Celtis sinensis •
Cercis canadensis
Cotinus coggygria
Crataegus crus-galli
Crataegus x lavalleei
Crataegus x mordenensis
Cupressus arizonica *•
Cupressus macrocarpa *
Cupressus sempervirens
Cupressus x leylandii
Eucommia ulmoides
Ficus carica *
Fraxinus ornus
Ginkgo biloba
Gleditsia triacanthos
Gymnocladus dioicus
Juglans major •
Juniperus chinensis
Juniperus virginiana *
Koelreuteria bipinnata *•
Koelreuteria paniculata *
Lagerstroemia x 'tuscarora'•
Maackia amurensis •
Maclura pomifera *•
Notholithocarpus densiorus
Nyssa sinensis
Olea europaea *•
Phellodendron amurense *
Pinus banksiana
Pinus contorta
Pinus exilis
Pinus mugo
Pinus nigra
Pinus pinea *•
Pinus ponderosa
Pinus sylvestris *
Pinus thunbergii *
Pistacia chinensis
Prunus dulcis •
Pyrus calleryana *
Pyrus pyrifolia •
Quercus acutissima *
Quercus agrifolia •
Quercus alba
Quercus coccinea
Quercus garryana
Quercus ilex •
Quercus imbricaria •
Quercus macrocarpa
Quercus shumardii
Quercus suber •
Quercus virginiana •
Rhus typhina
Sorbus aria
Ulmus propinqua •

SUITABLE = species anticipated to tolerate all but the driest sites under future climate

Abies concolor
Abies procera
Acer buergerianum •
Acer campestre *
Acer cappadocicum
Acer grandidentatum •
Acer griseum
Acer japonicum
Acer miyabei
Acer negundo *
Acer nigrum
Acer platanoides *
Acer pseudoplatanus *
Acer rubrum *
Acer saccharinum
Acer saccharum
Acer tataricum *
Acer triorum
Acer x freemanii
Aesculus hippocastanum *
Aesculus x carnea
Alnus cordata *
Alnus rubra
Amelanchier canadensis
Amelanchier laevis
Amelanchier x grandiora
Araucaria araucana
Arbutus 'marina' •
Betula alleghaniensis
Carpinus betulus
Carpinus japonica
Castanea mollissima
Castanea sativa
Catalpa bignonioides *
Cedrus atlantica
Cercis chinensis
Cercis occidentalis •
Cercis siliquastrum
Chamaecyparis obtusa
Chamaecyparis pisifera
Chionanthus retusus •
Cladrastis kentukea
Clerodendrum trichotomum
Cornus controversa
Cornus orida
Cornus mas
Corylus avellana *
Corylus colurna
Crataegus douglasii
Crataegus grignonensis •
Crataegus phaenopyrum *
Cryptomeria japonica *
Davidia involucrata
Eriobotrya japonica •
Eucalyptus pauciora •
Fraxinus angustifolia
Fraxinus excelsior
Fraxinus velutina
Heptacodium miconioides •
Hibiscus syriacus *
Juglans regia
Laburnum anagyroides *
Laburnum x watereri *
Lagerstroemia indica *•
Ligustrum japonicum * •
Ligustrum lucidum *•
Liquidambar styraciua
Liriodendron tulipifera
Magnolia grandiora
Malus baccata *
Malus domestica
Malus oribunda *
Malus pumila *
Malus sylvestris *
Malus transitoria
Malus tschonoskii •
Malus x moerlandsii •
Malus x zumi
Manglietia insignis
Morus alba *
Nothofagus antarctica
Ostrya carpinifolia
Ostrya virginiana
Oxydendrum arboreum
Parrotia persica
Photinia x fraseri •
Picea glauca
Picea omorika
Picea pungens
Pinus parviora
Pinus radiata *
Platanus x hispanica
Platycladus orientalis •
Populus alba *
Populus fremontii •
Populus nigra *
Prunus americana
Prunus armeniaca
Prunus avium *
Prunus caroliniana
Prunus cerasifera *
Prunus cerasus *
Prunus domestica *
Prunus emarginata
Prunus pendula •
Prunus salicina
Prunus sargentii
Prunus serotina
Prunus serrula
Prunus serrulata
Prunus subhirtella
Prunus virginiana *
Prunus x blireana
Prunus x yedoensis
Pseudotsuga menziesii
Pyrus communis *
Pyrus kawakamii •
Pyrus salicifolia
Quercus alba x robur
Quercus bicolor
Quercus frainetto
Quercus lobata •
Quercus robur *
Quercus rubra
Rhamnus purshiana
Salix scouleriana
Salix x sepulcralis
Sequoiadendron giganteum
Sophora japonica *
Sorbus x thuringiaca
Stewartia monadelpha
Stewartia pseudocamellia
Styrax japonicus
Syringa pekinensis •
Syringa vulgaris *
Taxodium distichum
Taxus baccata
Taxus brevifolia
Thuja occidentalis *
Tilia americana
Tilia cordata
Tilia platyphyllos
Tilia tomentosa
Tilia x euchlora
Tilia x europaea
Trachycarpus fortunei
Ulmus americana *
Ulmus parvifolia *
Ulmus procera *
Ulmus wilsoniana 'prospector' •
Ulmus x hollandica
xChitalpa tashkentensis
Zelkova serrata

MARGINAL = species anticipated to be restricted to moist sites under future climate

Abies grandis
Acer capillipes
Acer circinatum
Acer macrophyllum
Acer palmatum *
Acer pensylvanicum
Acer truncatum
Aesculus ava
Aesculus pavia
Alnus rhombifolia
Amelanchier arborea
Betula jacquemontii
Betula nigra
Betula papyrifera
Betula populifolia
Betula utilis
Carpinus caroliniana
Carya illinoinensis •
Cercidiphyllum japonicum
Chamaecyparis lawsoniana *
Chamaecyparis nootkatensis
Cornus kousa
Cornus nuttallii
Cornus x nuttallii
Cornus x rutgersensis *
Fagus grandifolia
Fagus sylvatica
Fraxinus americana
Fraxinus latifolia
Halesia carolina
Juglans cinerea
Juglans nigra *
Larix decidua
Laurus nobilis
Liriodendron chinense
Magnolia denudata
Magnolia 'galaxy'
Magnolia kobus
Magnolia sieboldii
Magnolia stellata
Magnolia virginiana
Magnolia x kewensis
Magnolia x loebneri
Magnolia x soulangeana
Malus fusca
Metasequoia
glyptostroboides
Nyssa sylvatica
Picea abies *
Picea sitchensis
Pinus halepensis •
Pinus monticola
Pinus strobus *
Platanus occidentalis
Populus balsamifera
Populus tremuloides
Prunus ilicifolia •
Prunus padus *
Prunus persica •
Quercus palustris *
Quercus phellos
Salix babylonica
Salix matsudana *
Sequoia sempervirens
Sorbus alnifolia
Sorbus americana
Sorbus intermedia •
Styrax obassia
Syringa reticulata
Thuja plicata
Thujopsis dolabrata
Tsuga canadensis
Tsuga heterophylla
Tsuga mertensiana
Ulmus davidiana
Ulmus glabra
Umbellularia californica •

* Invasive potential - capable of self-seeding so avoid planting in locations where seeds can disperse and germinate
• Trial - species is present in future analog (comparable) climates and has the potential for introduction to Metro Vancouver

Report

- Top 10% shows the best matches.
- All shows the entire ranked list.

Trees Recommended by i-Tree Species

This is a list of the top 10% of tree species based on the following functions.

Generated: 8/18/2022

Location: Vancouver, British Columbia, Canada

Hardiness: 8

Constraints:

- Minimum Height: None
- Maximum Height: None

Air Pollutant Removal (0-10 Importance)

- Overall: 0

Other Functions (0-10 Importance)

- Low VOC: 0
- Carbon Storage: 0
- Wind Reduction: 0
- Air Temperature Reduction: 0
- UV Radiation Reduction: 0
- Building Energy Reduction: 0
- Streamflow Reduction: 10
- Low Allergenicity: 0

S = Sensitive I = Intermediate S/I = Indeterminate

Species				Sensitivity			Pest Risk
Scientific Name	Common Name	Hardiness Zone	Invasive	Ozone (O3)	Nitrogen Dioxide (NO2)	Sulfur Dioxide (SO2)	Possible Pests
LIRIODENDRON TULIPIFERA	TULIP TREE	5 ~ 9		S			Polyphagous Shot Hole Borer
ULMUS AMERICANA	AMERICAN ELM	3 ~ 9			I/S		Asian Longhorned Beetle, Dutch Elm Disease, Winter Moth, Polyphagous Shot Hole Borer
MAGNOLIA GRANDIFLORA	SOUTHERN MAGNOLIA	7 ~ 10					Polyphagous Shot Hole Borer
TILIA AMERICANA	AMERICAN BASSWOOD	4 ~ 9		I	I		Gypsy Moth, Winter Moth, Polyphagous Shot Hole Borer
SEQUOIA SEMPERVIRENS	COAST REDWOOD	7 ~ 10					Sudden Oak Death
MAGNOLIA ACUMINATA	CUCUMBER TREE	4 ~ 8					
LIRIODENDRON CHINENSE	CHINESE TULIP TREE	5 ~ 9**					
MAGNOLIA OFFICINALIS	NCN - MAGNOLIA OFFICINALIS	6 ~ 8					
POPULUS DELTOIDES	EASTERN COTTONWOOD	3 ~ 9			I		Asian Longhorned Beetle, Winter Moth
PLATANUS OCCIDENTALIS	AMERICAN SYCAMORE	5 ~ 9		S			Polyphagous Shot Hole Borer
PLATANUS ORIENTALIS	ORIENTAL PLANETREE	7 ~ 9					
PLATANUS RACEMOSA	CALIFORNIA SYCAMORE	7 ~ 9					Polyphagous Shot Hole Borer
PLATANUS WRIGHTII	ARIZONA SYCAMORE	7 ~ 9					Polyphagous Shot Hole Borer
PINUS ELLIOTTII	SLASH PINE	8 ~ 11					Fusiform Rust, Pine Shoot Beetle, Sirex Wood Wasp, Southern Pine Beetle, Heterobasidion Root Disease

Species				Sensitivity			Pest Risk
Scientific Name	Common Name	Hardiness Zone	Invasive	Ozone (O3)	Nitrogen Dioxide (NO2)	Sulfur Dioxide (SO2)	Possible Pests
QUERCUS SHUMARDII	SHUMARD OAK	6 ~ 9					Gypsy Moth, Oak Wilt, Winter Moth, Polyphagous Shot Hole Borer
ACER RUBRUM	RED MAPLE	4 ~ 10		I	I		Asian Longhorned Beetle, Winter Moth
NOTHOFAGUS OBLIQUA	ROBLE	8 ~ 10					
ACER X FREEMANII	FREEMAN MAPLE	4 ~ 8					Asian Longhorned Beetle, Polyphagous Shot Hole Borer
CELTIS OCCIDENTALIS	NORTHERN HACKBERRY	3 ~ 9					Asian Longhorned Beetle
PLATANUS HYBRIDA	LONDON PLANETREE	5 ~ 8*					Asian Longhorned Beetle
CUNNINGHAMIA LANCEOLATA	BLUE CHINESE FIR	7 ~ 9					
METASEQUOIA GLYPTOSTROBOIDES	DAWN REDWOOD	5 ~ 8*					Polyphagous Shot Hole Borer
AESCULUS FLAVA	YELLOW BUCKEYE	4 ~ 8		S			Asian Longhorned Beetle
ZELKOVA SERRATA	JAPANESE ZELKOVA	5 ~ 8		S			Polyphagous Shot Hole Borer
ALNUS RHOMBIFOLIA	WHITE ALDER	8 ~ 11					Large Aspen Tortrix, Polyphagous Shot Hole Borer
CEDRUS DEODARA	DEODAR CEDAR	7 ~ 9					
CEDRUS LIBANI	CEDAR OF LEBANON	6 ~ 8					
PINUS PALUSTRIS	LONGLEAF PINE	7 ~ 10					Pine Shoot Beetle, Sirex Wood Wasp, Southern Pine Beetle, Heterobasidion Root Disease
ULMUS SEROTINA	SEPTEMBER ELM	5 ~ 8					Asian Longhorned Beetle, Dutch Elm Disease, Winter Moth
ACER MACROPHYLLUM	BIGLEAF MAPLE	7 ~ 10		I			Asian Longhorned Beetle, Winter Moth, Sudden Oak Death, Polyphagous Shot Hole Borer
POPULUS X CANADENSIS	CAROLINA POPLAR	4 ~ 9					Gypsy Moth
OSTRYA CARPINIFOLIA	HOP HORNBEAM	6 ~ 9					
JUGLANS NIGRA	BLACK WALNUT	4 ~ 9					Thousand Canker Disease, Butternut Canker, Polyphagous Shot Hole Borer
QUERCUS FALCATA	SOUTHERN RED OAK	7 ~ 9					Gypsy Moth, Oak Wilt, Sudden Oak Death, Winter Moth
QUERCUS PETRAEA	DURMAST OAK	5 ~ 8					Gypsy Moth, Oak Wilt
POPULUS X CANESCENS	GRAY POPLAR	4 ~ 9					Gypsy Moth
POPULUS FREMONTII	FREMONT COTTONWOOD	2 ~ 9					Winter Moth, Polyphagous Shot Hole Borer
LIQUIDAMBAR FORMOSANA	CHINESE SWEET GUM	6 ~ 9					Polyphagous Shot Hole Borer
FRAXINUS PENNSYLVANICA	GREEN ASH	3 ~ 9		S	S		Asian Longhorned Beetle, Emerald Ash Borer, Winter Moth
LIQUIDAMBAR STYRACIFLUA	SWEETGUM	6 ~ 9		S/I			Gypsy Moth, Polyphagous Shot Hole Borer

Species				Sensitivity			Pest Risk
Scientific Name	Common Name	Hardiness Zone	Invasive	Ozone (O3)	Nitrogen Dioxide (NO2)	Sulfur Dioxide (SO2)	Possible Pests
NOTHOFAGUS ALPINA	RAULÍ	8 ~ 11**					
MAGNOLIA MACROPHYLLA	BIGLEAF MAGNOLIA	5 ~ 8					
POPULUS ALBA	WHITE POPLAR	3 ~ 9					Gypsy Moth, Winter Moth
FRAXINUS AMERICANA	WHITE ASH	4 ~ 9		S			Emerald Ash Borer, Winter Moth
MORUS RUBRA	RED MULBERRY	5 ~ 9					
FRAXINUS UHDEI	EVERGREEN ASH	7 ~ 10					Emerald Ash Borer, Polyphagous Shot Hole Borer
SEQUOIADENDRON GIGANTEUM	GIANT SEQUOIA	6 ~ 8					
POPULUS ANGUSTIFOLIA	NARROWLEAF COTTONWOOD	3 ~ 10*			I		Gypsy Moth, Winter Moth
POPULUS X BRAYSHAWII	HYBRID BALSAM POPLAR	3 ~ 8**		S			Gypsy Moth
POPULUS X HEIMBURGERI	HEIBURGER'S POPLAR	3 ~ 8**					Gypsy Moth
POPULUS HETEROPHYLLA	SWAMP COTTONWOOD	3 ~ 8**					Gypsy Moth, Winter Moth
POPULUS X HINCKLEYANA	HINCKLEY POPLAR	3 ~ 8**					Gypsy Moth
POPULUS X INOPINA	NCN - POPULUS X INOPINA	3 ~ 8**					Gypsy Moth
POPULUS X JACKII	BALM-OF-GILEAD	3 ~ 8**					Gypsy Moth
POPULUS X PARRYI	PARRY'S COTTONWOOD	3 ~ 8**					Gypsy Moth
POPULUS X ROULEAUIANA	ROULEAUIANA COTTONWOOD	3 ~ 8**					Gypsy Moth
POPULUS X SMITHII	SMITH'S POPLAR	3 ~ 8**					Gypsy Moth
POPULUS TOMENTOSA	CHINESE WHITE POPLAR	3 ~ 8**					Gypsy Moth
POPULUS MAXIMOWICZII 'ANDROSCOGGIN'	JAPANESE POPLAR	3 ~ 8**					Gypsy Moth
FAGUS GRANDIFOLIA	AMERICAN BEECH	4 ~ 8					Beech Bark Disease, Gypsy Moth
FRAXINUS EXCELSIOR	EUROPEAN ASH	5 ~ 8					Emerald Ash Borer, Sudden Oak Death, Polyphagous Shot Hole Borer
ACER SACCHARUM	SUGAR MAPLE	5 ~ 8					Asian Longhorned Beetle, Winter Moth, Forest Tent Caterpillar
NYSSA BIFLORA	SWAMP TUPELO	6 ~ 9**					Forest Tent Caterpillar
NYSSA URSINA	BEAR TUPELO	6 ~ 9**					
TAXODIUM DISTICHUM	BALDCYPRESS	4 ~ 10					Polyphagous Shot Hole Borer
TAXODIUM ASCENDENS	POND CYPRESS	6 ~ 10					
TAXODIUM MUCRONATUM	MONTEZUMA CYPRESS	6 ~ 10**					

Species				Sensitivity			Pest Risk
Scientific Name	Common Name	Hardiness Zone	Invasive	Ozone (O3)	Nitrogen Dioxide (NO2)	Sulfur Dioxide (SO2)	Possible Pests
GINKGO BILOBA	GINKGO	4 ~ 8					
QUERCUS SUBER	CORK OAK	7 ~ 11					Gypsy Moth, Oak Wilt, Polyphagous Shot Hole Borer
POPULUS BALSAMIFERA	BALSAM POPLAR	3 ~ 9*			I		Asian Longhorned Beetle, Aspen Leafminer, Gypsy Moth, Large Aspen Tortrix, Winter Moth
POPULUS NIGRA	BLACK POPLAR	4 ~ 9*			S		Gypsy Moth, Winter Moth, Polyphagous Shot Hole Borer
CELTIS LAEVIGATA	SUGARBERRY	5 ~ 10					
MAGNOLIA TRIPETALA	UMBRELLA MAGNOLIA	5 ~ 8					
JUGLANS MAJOR	ARIZONA WALNUT	8 ~ 9					
PERSEA HUMILIS	SILK BAY	8 ~ 11**					
PERSEA KRUGII	CANELA	8 ~ 11**					
PERSEA LINGUE	LINGUE	8 ~ 11**					
PERSEA URBANIANA	AQUACATILLO	8 ~ 11**					
JUGLANS AILANTHIFOLIA	JAPANESE WALNUT	5 ~ 9**					
JUGLANS X BIXBYI	BIXBY WALNUT	5 ~ 9**					
JUGLANS X INTERMEDIA	INTERMEDIATE WALNUT	5 ~ 9**					
JUGLANS JAMAICENSIS	WEST INDIAN WALNUT	5 ~ 9**					
JUGLANS MICROCARPA	LITTLE WALNUT	5 ~ 9**					
JUGLANS X QUADRANGULATA	NCN - WALNUT	5 ~ 9**					
CUPRESSUS MACROCARPA	MONTEREY CYPRESS	7 ~ 9					
ULMUS PUMILA	SIBERIAN ELM	4 ~ 9					Asian Longhorned Beetle, Dutch Elm Disease, Winter Moth
PERSEA BORBONIA	REDBAY	8 ~ 11					Laurel Wilt
PERSEA PALUSTRIS	SWAMP BAY	8 ~ 11					Laurel Wilt
ULMUS CRASSIFOLIA	CEDAR ELM	7 ~ 9					Asian Longhorned Beetle, Dutch Elm Disease, Winter Moth

Hardiness zone derived from Horticopia database based on USDA Hardiness zones. For hardiness zones with decimal (e.g., 4.5) values were rounded down for maximum hardiness (e.g., 4) and up for minimum hardiness zone (e.g., 5)
* Some uncertainty to hardiness zone - hardiness zone estimates derived from Dirr (M.A. Dirr, 1975, Manual of Woody Landscape Plants. Stipes Publ. Co. Champaign IL. 1007 p.) and Sunset (1985, New Western Garden Book, Lane Publ. Co. Menlo Park, CA. 512 p.). As hardiness estimates or maps did not always exactly match USDA Hardiness zone ranges, some extrapolations were made to the closest hardiness zone.
** Moderate uncertainty to hardiness zone - hardiness zone estimate based on genera average of minimum and maximum hardiness zone based on Horticopia database and information from Dirr (1997) and Sunset (1985). Average value was rounded to nearest hardiness zone class (1 -11).
*** High uncertainty to hardiness zone - hardiness zone estimate based on family average of minimum and maximum hardiness zone based on Horticopia database and information from Dirr (1997) and Sunset (1985). Average value was rounded to nearest hardiness zone class (1 -11).
Sensitivity - "S" indicates sensitive to pollutant; "I" indicates intermediate rating between sensitive and tolerant to pollutant; and "S/I" indicates a mix of sensitive and intermediate ratings in the literature.

Database version: 12.0.19
i-Tree Species version: 2.2.0

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Version 2.2.0

Appendix D: Cost and Valuation

Integrating trees into stormwater management practices can be a challenge to urban forestry professionals, civil and stormwater engineers, city planners, builders, and developers. Implementation costs, tree canopy establishment timeframes, tree maintenance, and limited natural asset incentives are all challenges in urban developments (Asselmeier, et al., 2021, p. 28). The initial cost of tree planting relative to time may seem difficult to justify in the short term, however, if designers and developers are committed to best practices and low impact development then using trees as natural assets is a feasible and economic development avenue (Asselmeier, et al., 2021, p. 20).

Trees evidently offer many benefits to stormwater and other systems throughout the urban environment. If carefully considered and intentionally designed for, these trees can also save cities money that would otherwise be spent on improving infrastructure and mitigating environmental challenges. Trees innate ability to capture and treat stormwater can help to sustainably reduce water treatment costs, as well as a need for bigger or additional water treatment facilities. Throughout the United States, cost-benefit analysis' have been done between 2001 and 2009 with the aim of quantifying a dollar value that urban trees could save municipalities. Table 15, summarizing data from the *United States Forest Service i-Tree Streets Reference Cities,* highlights some of these measurable environmental benefits in dollars saved (McPherson, 2010):

Table 15: Stormwater benefits of trees in American cities

City	Number of Trees Studied	Annual Stormwater Benefit [$]	Annual Rainfall Interception [Mil. Gal.]
Albuquerque, NM	4,586	55,833	11.1
Berkley, CA	36,485	215,645	53.9
Bismarck, ND	17,821	496,227	7.1
Boise, ID	23,262	96,238	19.2
Boulder, CO	25,281	357,255	44.9
Charleston, SC	15,244	171,406	28.3
Charlotte, NC	85,146	2,077,393	209.5
Cheyenne, WY	17,010	55,301	5.7
Fort Collins, CO	31,000	403,597	37.4
Glendale, AZ	21,480	18,198	1.0
Honolulu, HA	235,800	350,104	35.0
Indianapolis, ID	117,525	1,977,467	318.9
Minneapolis, MO	198,633	9,071,809	334.8
New York City, NY	592,130	35,628,220	890.6

City	Number of Trees Studied	Annual Stormwater Benefit [$]	Annual Rainfall Interception [Mil. Gal.]
Orlando, FL	68,211	539,151	283.7
San Francisco, CA	2,625	466,554	99.2
Santa Monica, CA	29,229	110,784	3.2

From this, we can see that observed trees across the United States can help to save anywhere from $18,000 up to $35.5 Million USD (~ $23,000 – 45,000,000 CAD) annually. These savings would grow over the years as trees became more mature and were able to effectively manage more stormwater flow. This money saved on stormwater management would not only be a benefit in terms of infrastructure costs saved, but also benefit the urban environment in terms of canopy cover added along with the well-being benefits to urban residents.

Similarly, when looking at various tree species planted in residential front yards in Vancouver, BC, a dollar value can be estimated for each tree as an annual stormwater cost saved. From the *United States Department of Agriculture (USDA) Forest Service i-Tree Selector* online tool, we can estimate an overall value for different tree species, as well as the specific stormwater value saved per tree now, and in 20 years' time when the tree has grown to be more mature. The below table (Table 16) and graphics illustrate some of the estimated annual stormwater savings for a typical small, medium, and large tree found throughout Vancouver's residential front yards (USDA Forest Service, 2006b):

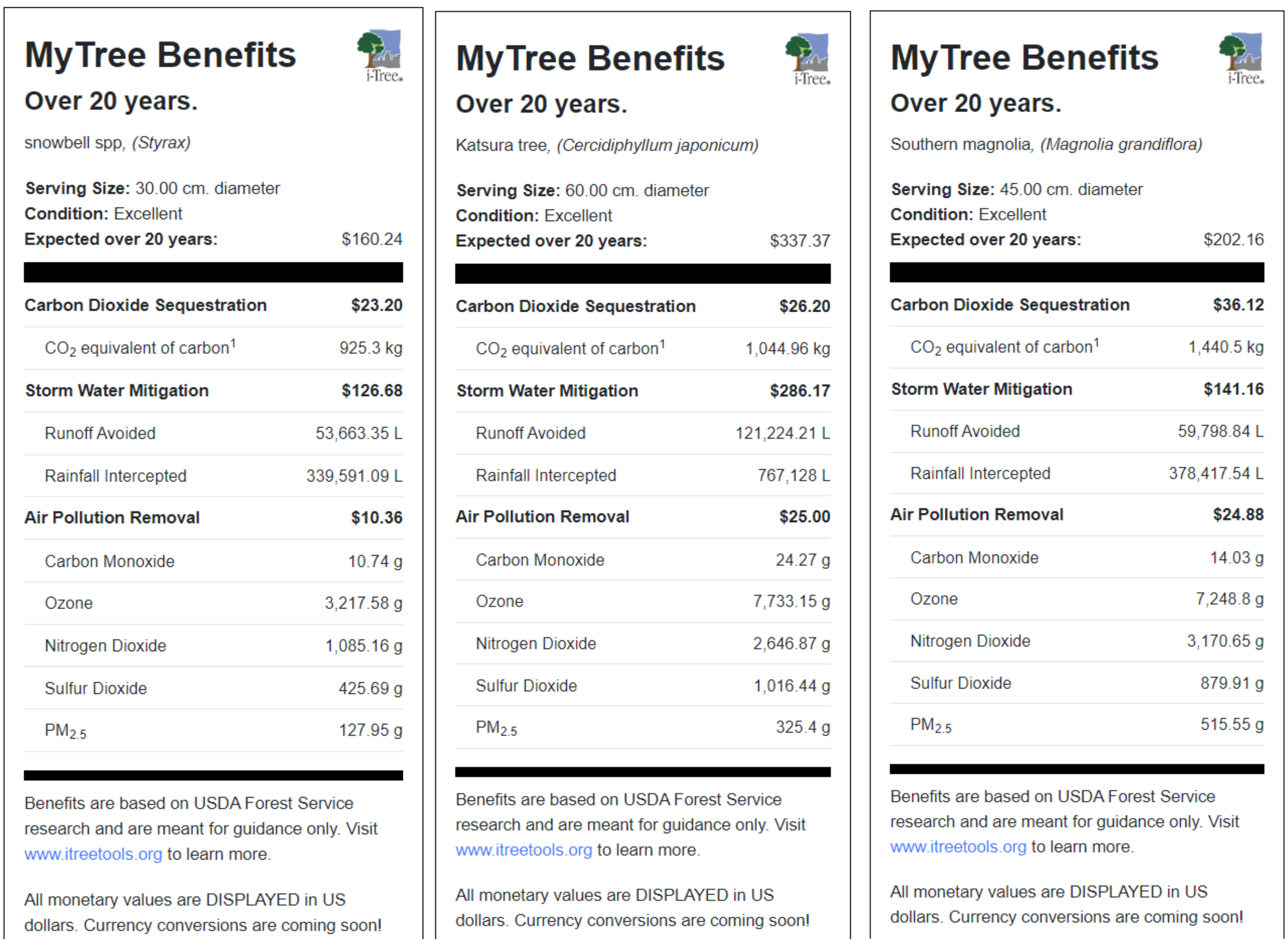
Table 14: Environmental benefits evaluation of various tree species

	Stormwater Value [$]				Annual Avoided Runoff [L]			
Tree Species	**Excellent Condition, Mature Size**		**Fair Condition, Young Size**		**Excellent Condition, Mature Size**		**Fair Condition, Young Size**	
	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)
Snowbell (Small Deciduous)	$ 7.44	$ 161.46	$ 1.49	$ 35.94	2,473.87	53,633.35	482.27	11,782.85
Japanese Cherry (Medium Deciduous)	$ 11.98	$ 243.53	$ 1.61	$ 40.41	3,794.06	76,750.05	530.91	13,252.03
Katsura (Large Deciduous)	$ 17.29	$ 364.73	$ 4.75	$ 105.74	5,735.54	121,225.21	1,558.93	34,674.65
Baby Blue Spruce (Small Evergreen)	$ 2.94	$ 66.72	$ 0.75	$ 17.71	1,268.14	28,309.46	244.73	5,808.71
Southern Magnolia (Medium Evergreen)	$ 8.54	$ 179.91	$ 7.09	$ 148.15	2,837.76	59,798.84	2,326.97	48,579.30
Black Pine (Large Evergreen)	$ 14.15	$ 299.01	$ 10.86	$ 229.73	4,346.20	92,884.40	3,563.89	75,329.11
	Average							
Total	$ 10.38	$ 219.23	$ 4.43	$ 96.28	3,409.26	72,105.05	1,451.95	31,571.11
	Vancouver							
	There are 79,368 RS and RT zoned lots in Vancouver. The below values assume that each residential lot would plant one (1) tree in their front yard.							
Small Tree	$ 411,919.92	$ 9,055,095.12	$ 88,892.16	$ 2,129,046.60	148,497,924.84	3,251,818,472.04	28,850,268.00	698,103,467.04
Medium Tree	$ 814,315.68	$ 16,803,792.96	$ 345,250.80	$ 7,482,815.04	263,177,144.88	5,418,806,150.76	113,412,109.92	2,453,714,499.72
Large Tree	$ 1,247,664.96	$ 26,339,858.16	$ 619,467.24	$ 13,312,791.48	400,083,770.16	8,496,725,763.24	203,293,988.88	4,365,389,211.84

Table 14: Environmental benefits evaluation of various tree species

	Rainfall Intercepted [L]				**Carbon Sequestriation, SWM, Air Pollution Removal [$]**			
Tree Species	**Excellent Condition, Mature Size**		**Fair Condition, Young Size**		**Excellent Condition, Mature Size**		**Fair Condition, Young Size**	
	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)	New Tree (1 Year Value)	Old Tree (20 Year Cumulative Value)
Snowbell (Small Deciduous)	15,655.06	339,591.09	3,077.23	74,563.91	$ 9.57	$ 204.73	$ 1.71	$ 45.74
Japanese Cherry (Medium Deciduous)	24,009.51	485,687.73	3,359.67	83,861.19	$ 13.18	$ 265.67	$ 1.92	$ 52.98
Katsura (Large Deciduous)	36,295.52	767,128.00	9,865.17	219,427.23	$ 20.52	$ 431.04	$ 5.44	$ 122.64
Baby Blue Spruce (Small Evergreen)	8,024.98	179,147.21	1,548.67	36,758.53	$ 3.94	$ 90.25	$ 0.88	$ 23.64
Southern Magnolia (Medium Evergreen)	17,957.86	378,417.54	14,725.44	307,418.29	$ 12.02	$ 258.29	$ 10.10	$ 214.01
Black Pine (Large Evergreen)	27,503.53	587,788.71	22,552.89	476,695.79	$ 19.74	$ 406.54	$ 15.63	$ 325.20
	Average							
Total	21,574.41	456,293.38	9,188.18	199,787.49	$ 13.16	$ 276.09	$ 5.95	$ 130.70
	Vancouver							
	There are 79,368 RS and RT zoned lots in Vancouver. The below values assume that each residential lot would plant one (1) tree in their front yard.							
Small Tree	939,718,707.36	20,585,610,697.20	183,574,215.60	4,417,719,708.96	$ 536,130.84	$ 11,705,986.32	$ 102,781.56	$ 2,753,275.92
Medium Tree	1,665,433,111.08	34,291,153,534.68	717,689,505.24	15,527,534,884.32	$ 1,000,036.80	$ 20,792,828.64	$ 477,001.68	$ 10,595,231.16
Large Tree	2,531,801,500.20	53,768,514,719.64	1,286,478,293.04	27,624,945,925.68	$ 1,597,677.84	$ 33,238,524.72	$ 836,141.88	$ 17,772,082.56

Currently, there is a recorded 79,368 residential lots that are zoned as single-family (67,239 RS) and two-family (12,127 RT) homes in Vancouver, BC (City of Vancouver, 2022). If we assumed an average stormwater value per small tree (deciduous or evergreen) of $5.19, and that each residential lot planted one tree in an effort to sustainably mitigate stormwater runoff, the city would save an average of $411,919.92 annually. In 20 years' time, this value would increase to $9,055,095.12 annually (or an average $144.09 per small tree). For larger trees, this value could increase to an annual average of $26,339,858.20 for the city (or $331.87 per large tree). This is an average value of $17,399,582.10 for a mix of tree sizes and types across the city in 20 years' time. Although in the overall budget and economic value at the city scale this amount may not seem huge, the annual cost saved in stormwater infrastructure is just an added benefit to all the additional co-benefits that trees offer to the well-being of urban residents and costs saved in carbon sequestration and air pollution removal, among others.



MyTree Benefits
Over 20 years.

snowbell spp, *(Styrax)*

Serving Size: 30.00 cm. diameter
Condition: Excellent

Expected over 20 years:	$160.24
Carbon Dioxide Sequestration	**$23.20**
CO_2 equivalent of carbon[1]	925.3 kg
Storm Water Mitigation	**$126.68**
Runoff Avoided	53,663.35 L
Rainfall Intercepted	339,591.09 L
Air Pollution Removal	**$10.36**
Carbon Monoxide	10.74 g
Ozone	3,217.58 g
Nitrogen Dioxide	1,085.16 g
Sulfur Dioxide	425.69 g
$PM_{2.5}$	127.95 g

Benefits are based on USDA Forest Service research and are meant for guidance only. Visit www.itreetools.org to learn more.

All monetary values are DISPLAYED in US dollars. Currency conversions are coming soon!

MyTree Benefits
Over 20 years.

Katsura tree, *(Cercidiphyllum japonicum)*

Serving Size: 60.00 cm. diameter
Condition: Excellent

Expected over 20 years:	$337.37
Carbon Dioxide Sequestration	**$26.20**
CO_2 equivalent of carbon[1]	1,044.96 kg
Storm Water Mitigation	**$286.17**
Runoff Avoided	121,224.21 L
Rainfall Intercepted	767,128 L
Air Pollution Removal	**$25.00**
Carbon Monoxide	24.27 g
Ozone	7,733.15 g
Nitrogen Dioxide	2,646.87 g
Sulfur Dioxide	1,016.44 g
$PM_{2.5}$	325.4 g

Benefits are based on USDA Forest Service research and are meant for guidance only. Visit www.itreetools.org to learn more.

All monetary values are DISPLAYED in US dollars. Currency conversions are coming soon!

MyTree Benefits
Over 20 years.

Southern magnolia, *(Magnolia grandiflora)*

Serving Size: 45.00 cm. diameter
Condition: Excellent

Expected over 20 years:	$202.16
Carbon Dioxide Sequestration	**$36.12**
CO_2 equivalent of carbon[1]	1,440.5 kg
Storm Water Mitigation	**$141.16**
Runoff Avoided	59,798.84 L
Rainfall Intercepted	378,417.54 L
Air Pollution Removal	**$24.88**
Carbon Monoxide	14.03 g
Ozone	7,248.8 g
Nitrogen Dioxide	3,170.65 g
Sulfur Dioxide	879.91 g
$PM_{2.5}$	515.55 g

Benefits are based on USDA Forest Service research and are meant for guidance only. Visit www.itreetools.org to learn more.

All monetary values are DISPLAYED in US dollars. Currency conversions are coming soon!

Figure 12: Example data for three trees from the USDA i-Tree Selector online tool (USDA Forest Service, 2006)

Appendix E: Case Studies

Over the last 30 years, research has been done around the globe on whether or not trees can play a role in effectively mitigating runoff and managing stormwater. To be considered a success, a tree would have to have a role in intercepting rainfall, slowing throughfall, and lessening overall runoff that reaches the ground and makes its way into storm water infrastructure. Thus far, research has been conducted for various deciduous and coniferous species through some states in the United States of America, urban centers in Slovenia, Belgium, and Sweden, and through the Pacific Northwest of Canada. Key findings are summarized in Table 17 below:

Table 17: Case study key findings

<table>
<tr><th>Tree Name</th><th>Deciduous or Evergreen</th><th>Location of Study</th><th>Duration of Study</th><th>Area Considered</th><th>Rainfall Events Measured</th><th>Number of Trees</th><th>Estimated Annual Rainfall Interception [%]</th><th>Estimated Annual Hydrologic Value [$]</th><th>Reference</th></tr>
<tr><td rowspan="2">Douglas Fir (Pseudotsuga menziesii)</td><td rowspan="2">Evergreen</td><td>Olympia, Washington</td><td>24 months</td><td>2 locations</td><td>174</td><td>21</td><td rowspan="2">75</td><td rowspan="2">745.31</td><td>(Jayakaran, et al., 2022)</td></tr>
<tr><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>14</td><td>(Asadian, 2010)</td></tr>
<tr><td rowspan="2">Western Red Cedar (Thuja plicata)</td><td rowspan="2">Evergreen</td><td>Olympia, Washington</td><td>24 months</td><td>2 locations</td><td>174</td><td>11</td><td rowspan="2">72</td><td rowspan="2">1010.63</td><td>(Jayakaran, et al., 2022)</td></tr>
<tr><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>14</td><td>(Asadian, 2010)</td></tr>
<tr><td>Copper Beech (Fagus sylvatica)</td><td>Deciduous</td><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>4</td><td>72</td><td>819.88</td><td>(Asadian, 2010)</td></tr>
<tr><td>Norway Maple (Acer platanoides)</td><td>Deciduous</td><td>Brussels, Belgium</td><td>24 months</td><td>-</td><td>39</td><td>1</td><td>61</td><td>320.26</td><td>(Smets, et al., 2019)</td></tr>
<tr><td>Small-Leaved Lime (Tilia cordata)</td><td>Deciduous</td><td>Brussels, Belgium</td><td>24 months</td><td>-</td><td>25</td><td>1</td><td>60</td><td>534.54</td><td>(Smets, et al., 2019)</td></tr>
<tr><td>Horse Chestnut (Aesculus hippocastanum)</td><td>Deciduous</td><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>2</td><td>58</td><td>526.83</td><td>(Asadian, 2010)</td></tr>
<tr><td rowspan="2">Bigleaf Maple (Acer macrophyllum)</td><td rowspan="2">Deciduous</td><td>Olympia, Washington</td><td>24 months</td><td>2 locations</td><td>174</td><td>15</td><td rowspan="2">45</td><td rowspan="2">560.68</td><td>(Jayakaran, et al., 2022)</td></tr>
<tr><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>14</td><td>(Asadian, 2010)</td></tr>
<tr><td>Cherry (Prunus sp.)</td><td>Deciduous</td><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>2</td><td>45</td><td>554.02</td><td>(Asadian, 2010)</td></tr>
<tr><td>Black Pine (Pinus nigra Arnold)</td><td>Evergreen</td><td>Ljubljana, Solvenia</td><td>42 months</td><td>600 m²</td><td>-</td><td>2</td><td>45</td><td>279.46</td><td>(Zabret & Sraj, 2019)</td></tr>
<tr><td>Water Oak (Quercus nigra)</td><td>Deciduous</td><td>Birmingham, Alabama</td><td>14 months</td><td>-</td><td>72</td><td>-</td><td>40</td><td>748.62</td><td>(Bean, et al., 2021)</td></tr>
<tr><td>Oak (Quercus sp.)</td><td>Deciduous</td><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>2</td><td>40</td><td>361.54</td><td>(Asadian, 2010)</td></tr>
<tr><td>Poplar (Populus sp.)</td><td>Deciduous</td><td>North Vancouver, British Columbia</td><td>21 months</td><td>4 locations</td><td>172</td><td>2</td><td>38</td><td>900.98</td><td>(Asadian, 2010)</td></tr>
<tr><td>Red Alder (Alnus rubra)</td><td>Deciduous</td><td>Olympia, Washington</td><td>24 months</td><td>2 locations</td><td>174</td><td>17</td><td>33</td><td>270.97</td><td>(Jayakaran, et al., 2022)</td></tr>
<tr><td>Silver Birch (Betula pendula Roth.)</td><td>Deciduous</td><td>Ljubljana, Solvenia</td><td>42 months</td><td>600 m²</td><td>-</td><td>2</td><td>23</td><td>230.95</td><td>(Zabret & Sraj, 2019)</td></tr>
<tr><td>Loblolly Pine (Pinus taeda)</td><td>Evergreen</td><td>Birmingham, Alabama</td><td>14 months</td><td>-</td><td>75</td><td>-</td><td>4</td><td>443.76</td><td>(Bean, et al., 2021)</td></tr>
</table>

North Vancouver, British Columbia, Canada

Beginning in 2007, a study was conducted by Yeganeh Asadian (Department of Forest Resources Management, University of British Columbia, Vancouver, Canada) and Markus Weiler (Institute of Hydrology, University of Freiburg, Fahnenbergplatz, Germany). This study looked to measure rainfall interception by urban trees in coastal British Columbia, with the intent of illustrating the necessity of looking at urban trees as a type of green infrastructure that would help reduce stormwater runoff and rainfall intensity (Asadian, Rainfall Interception in an Urban Environment, 2010). To successfully prove this, the authors studied interception loss in the North Shore of BC by "measuring throughfall under six different urban trees using a system of long polyvinyl chloride pipes hung beneath the canopy capturing the throughfall and draining it to a rain gauge attached to a data logger" (Asadian & Weiler, A New Approach in Measuring Rainfall Interception by Urban Trees in Coastal British Columbia, 2009, p. 16). Douglas fir (*Pseudotsuga menziesii*), and western red cedar (*Thuja plicata*) were studied as coniferous street trees, trees in parks, and in natural forested areas, both on public and private land, to ensure accurate throughfall variability over the course of one year (2007-2008). During this time, there were seven discrete storm events recorded for coniferous trees in the District of North Vancouver, with a cumulative gross precipitation of 377mm. "Average canopy interception during these events for Douglas fir and western red cedar were 49.1 and 60.9%, where it corresponded to average net loss of 20.4 and 32.3 mm, respectively. The interception loss varied depending on canopy structure, climatic conditions, and rainfall characteristics" (Asadian & Weiler, A New Approach in Measuring Rainfall Interception by Urban Trees in Coastal British Columbia, 2009, p. 16).

This study also looked at and evaluated species of Bigleaf maple (*Acer macrophyllum*), Oak (*Quercus sp.*), Copper beech *(Fagus sylvatica*), Horse chestnut (*Aesculus hippocastanum*), Cherry (*Prunus sp.*), and Poplar (*Populus sp.*), and their ability to effectively intercept rainfall in coastal British Columbia. Figures E.1 (Asadian, Rainfall Interception in an Urban Environment, 2010, pp. 42,43) below show the variation in interception loss for the species measured through the summer and winter. Interception loss was highest for the Douglas fir in both the summer and winter, while the interception was lowest for the Cherry trees in the summer and Poplar and Oak trees in the winter. Variability was quite high for all species examined in the summer, and Western red cedar in the winter.

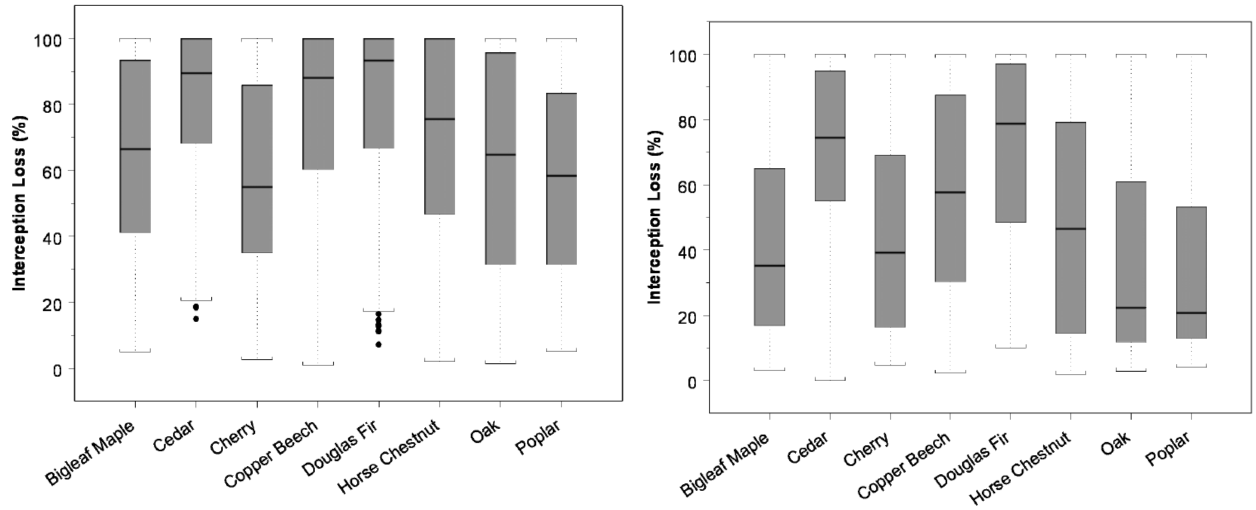


Figure 13: Box plot of percentage interception loss for different species in summer (left) and winter (right). The outliers are presented by black circles (Asadian, Rainfall Interception in an Urban Environment, 2010, pp. 42,43).

The percentage of interception loss throughout the summer and winter by the combined species in the study can be found in Table 18 and Table 19 below (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 43).

Table 18: Average summer interception loss

Average Interception Loss during Summer [%]

	Coniferous	Deciduous
Forest (control site)	78.8	55.6
Urban Environment	81.7	67.1

Table 19: Average winter interception loss

Average Interception Loss during Winter [%]

	Coniferous	Deciduous
Forest (control site)	74.1	36.5
Urban Environment	71.4	45.8

Concluded from the study, "the throughfall results indicate that interception is influenced by seasonal differences in foliation periods and rainfall characteristics" (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 66). This is obvious when looking at the deciduous species comparatively in the summer and winter. The interception loss was over 20% higher in the summer than in the winter, primarily due to foliation and high surface area of the leaves present in summer. Higher summer temperatures and gross precipitation characteristics (storm duration, amount, and intensity) may also play a role in rainfall interception. Overall, the coniferous species showed higher interception losses than the deciduous, and the urban trees performed better than the control trees within the forested areas.

Similar studies have been done looking at interception losses and throughfall. A temperate forests study (Link, Unsworth, & Marks, 2004) suggested that annual interception losses range from 11% to 36%, and 9% to 48%, of gross precipitation in deciduous and coniferous canopies respectively (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 68). Another reported 22.3% interception loss in a pine forest (Bryant, Bhat, & Jacobs, 2005). It was determined that these discrepancies may be due to the urban heat island (UHI) effect in some areas, greater distances between trees known as the edge effect, and differences in canopy growth. The UHI effect "occurs when cities replace natural land cover with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat" (United States Environmental Protection Agency, 2022). Because of this, there may be significant temperature differences between the urban and natural areas in some locations. A secondary consequence of increased development is the urban trees often end up becoming more isolated with greater distances between them. This results in higher exposure during sever weather events (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 68).

Tree health was also assumed to affect rainfall interception rate, however, it was determined that canopy structure played a larger role in interception rates than overall tree health (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 69). "The canopy structure (leaves) is primarily responsible for two main effects on throughfall. First, it affects the ratio of throughfall to gross precipitation. Deguchi et al. (2006) suggested a decrease in the number of leaves appeared to cause an increase in throughfall. The second effect is the throughfall spatial variability caused by seasonal changes in the canopy structure." (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 71). Nevertheless, though tree health didn't substantially affect interception rates, it does play a role in controlling time delay of precipitation falling through the tree, to the ground. In general, healthy, coniferous trees had higher time delays as compared to deciduous trees during rainfall events (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 69). This time delay can help to reduce throughfall intensity and therefore delay the water reaching the ground (by temporarily storing water on tree leaves and bark) ultimately reducing peak stormwater runoff, as well as reduce overall raindrop energy (by slowing down rainfall) helping to protect the soil surface and reduce chances of erosion (Pypker, Bond, Link, Marks, & Unsworth, 2005) (Xiao & McPherson, 2002). Comparably, urban beech and poplar trees common to the northeastern United States were studied and found to be that the rougher bark, lower branch inclination, thinner canopy of the poplar had greater losses compared to the beech trees, which allowed greater amounts of rainfall to reach underlying soil (Van Stan II, Levia Jr, & Jenkins, 2015). From this, it can be concluded that a tree's ability to effectively intercept rainfall is dependent on a variety of conditions. These include:

- the characterization and magnitude of rainfall events,
- air temperature, wind speed, and other meteorological factors,
- tree health and species (the growth form, canopy density, and structure).

When comparing the two types of conifers, "the western red cedars showed higher interception losses, longer time delays, and lower throughfall intensities compared with the Douglas firs" (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 24). Overall, both coniferous trees, whether standing as a single tree or in stands, was able to cause a delay in precipitation reaching the ground proving that trees have a vital role to play in managing stormwater and rainfall in urban developments. The same can be said for the deciduous trees studies as all the trees showed positive interception losses. "On average control trees located in forested areas showed 1.12 times less interception loss than urban trees" (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 74).

Using natural vegetation as a low impact development and best practice in urban planning is an effective method to help control stormwater runoff on site, as well as mitigate the impacts of urbanization on urban hydrology at a local scale (Asadian, Rainfall Interception in an Urban

Environment, 2010, p. 75). This is an effective strategy for both large scale, and individual property development.

Further results from the research performed is summarized in Table 20 below (Asadian, Rainfall Interception in an Urban Environment, 2010, p. 63):

Table 20: Seasonal storage capacity and canopy cover estimates

Seasonal Storage Capacity (S) [mm] & Canopy Cover Estimates

Species	Average Winter S [mm]	Average Summer S [mm]	Summer Canopy Gap [fraction]	Summer Canopy Cover [fraction]
Douglas fir	4.9	2.8	0.10	0.90
Western red cedar	4.4	2.6	0.10	0.90
Bigleaf maple	-	4.2	0.08	0.92
Cherry	-	3.4	0.10	0.90
Copper beech	-	5.5	0.13	0.87
Horse chestnut	-	4.6	0.11	0.89
Oak	-	3.7	0.09	0.91
Poplar	-	3.0	0.10	0.90

Ljubljana, Slovenia

During 2014 and 2015, rainfall interception was studied in the city of Ljubljana, Slovenia for silver birch (*Betula pendula Roth.*) and black pine (*Pinus nigra Arnold*). These trees were monitored for two years to measure how effective they were at reducing surface runoff in a parking lot. Urban parking lots are primarily composed of impermeable surfaces which lead to higher amounts of runoff as soil infiltration is limited. Unsurprisingly, the addition of both the silver birch and black pine trees helped to alleviate some of the surface runoff. The birch tree intercepted 23% of gross rainfall, while the pine tree intercepted 45% of gross rainfall (Zabret & Sraj, 2019), and both were more effective at intercepting rainfall while in the leafed period. Although the coniferous pine tree was more effective at intercepting rainfall, the deciduous birch tree still played a part in helping to reduce the runoff on site. It was measured that when 10% of the parking lot area was covered with these trees, there was an annual runoff reduction of 7.3% (Zabret & Sraj, 2019).

In Ljubljana, 2014 was a wet year, while 2015 was dry. This was considered in the analysis and showed that rainfall interception was highly influenced by rainfall intensity in wet conditions, but was less influential during dry conditions. It was found that in the dry year, air temperature was more influential to rainfall interception than rainfall intensity was. This is an important finding as climate change continues to alter typical summer and winter conditions. Generally, it was found that runoff reduction was higher in the wet year. These findings, along with data captured about different tree species and climate conditions, can benefit urban planners, landscape designers, and decision makers as they continue to look for natural solutions to stormwater management in urban areas.

Birmingham, Alabama, United States of America

In December 2018, through January 2020, a study was completed in Alabama, USA with the aims of quantifying how trees could intercept rainfall in different season and under various storm conditions. The study specifically looked into how rainfall interception by urban tree canopies changes with the seasons and type of tree, how interception values vary depending on precipitation levels and intensities, and how trees can benefit urban stormwater systems through interception. Completed by R. Bean, Robert E. Pitt , J. Voorhees and M. Elliott for the University of Alabama (2021), they were able to take a series of rainfall and interception measurements under urban trees in an open area to help answer some of these above questions.

This study specifically looked at deciduous water oak (Quercus nigra) and evergreen loblolly pine (Pinus taeda) trees. These trees were monitored and rain throughfall was measured over 85 different rain events over 14 months. It was concluded that canopy interception was most influenced by tree type, followed by rain amount, while seasonal effects played less of a role on interception rates. The evergreen loblolly pine trees only intercepted a fraction of what the deciduous water oak intercepted. The oak tree intercepted anywhere from 30-50% of the rainfall depending on the rain amount.

Another point of note in this study, was the realization that trees benefit to the stormwater systems was largely due to where the tree was located. It is noted that trees located in pervious areas, such as over lawns or other non-paved areas, do not count for as much relief to stormwater infrastructure as rainfall interception may not affect outfall runoff quantities. This is due to throughfall likely being able to infiltrate the ground with or without the presence of trees, however, trees would still improve soil characteristics by minimizing compaction and increasing infiltration. The study further went on to conclude that the largest hydrologic benefit of urban trees was seen when they were planted in impervious areas, such as part of green roofs, over walkways, or in parking areas or streets. When this was the case, trees that covered impervious areas directly connected to drainage systems led to the most stormwater management advantages.

The study concluded by summarizing the percentage of runoff reduction by varying coverage of both coniferous and deciduous trees in each season. This data is presented in the following tables (Table 21 and Table 22) (Bean, Pitt, Voorhees, & Elliott, 2021):

Table 21: Runoff reduction by coniferous trees

Runoff reductions [%] from paved areas shaded by conifers

	No Trees	10%	25%	50%	100%
Winter	0.0	0.2	0.6	1.2	2.3
Spring	0.0	0.1	0.4	0.7	1.5
Summer	0.0	1.0	2.4	4.9	9.7

Runoff reductions [%] from paved areas shaded by conifers

Fall	0.0	0.7	1.8	3.6	7.1
Annual	0.0	0.4	1.0	2.0	4.0

Table 22: Runoff reduction by deciduous trees

Runoff reductions [%] from paved areas shaded by deciduous trees

	No Trees	10%	25%	50%	100%
Winter	0.0	3.7	9.3	18.5	37.1
Spring	0.0	3.8	9.6	19.1	38.3
Summer	0.0	4.1	10.2	20.4	40.9
Fall	0.0	3.8	9.4	18.9	37.7
Annual	0.0	3.9	9.6	19.3	38.6

There was found to be a linear relationship between percentage of runoff decreases and the percentage of canopy coverage. The deciduous trees could provide up to nearly 40% of annual runoff reduction, while the coniferous trees would provide only a 4% reduction. This percentage would potentially increase if looking at more moderate rainfall events, as both coniferous and deciduous trees were able to effectively intercept the smallest of rainfall events monitored.

Overall, the projected runoff volume reduction through the use of urban trees was found to be 10% - 20%.

Olympia, Washington, United States

The following case study was conducted in Olympia, Washington and completed in March 2022. The aim was to measure the water use of individual, mature, tree species native to the Pacific Northwest to determine their stormwater management benefits. This study, a collaboration between the Washington Department of Natural Resources (DNR), Washington State University, City of Tacoma, The Evergreen State College, and Clemson University, worked to quantify annual transpiration, and canopy interception rates for both evergreen and deciduous trees, as well as estimate the hydrologic value of existing trees in the Pacific Northwest. The tree species that were considered span across several ecosystems for which development or redevelopment can potentially occur (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 2), these include Douglas Fir, Western Red Cedar, Bigleaf Maple, and Red Alder. These four native species encompassed 64 trees (17 Red Alder, 15 Bigleaf Maple, 21 Douglas Fir, and 11 Western Red Cedar) that were measured in two different locations for sap flux, canopy interception, and stemflow. Weather and soil moisture were also monitored over the two-year study.

The following tables (Table 23- 26) highlight the measurements collected and computed during the study for each species during both leaf-on and leaf-off periods (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 25):

Table 23: Median stemflow by species

Median Stemflow by Species

	Leaf Off		Leaf On		Annual Value	
Quantifying Storm Totals [cm]	57.1		24.3		81.4	
Tree Species	%	cm	%	cm	%	cm
Bigleaf Maple	0.032	0.02	0.003	0.00	0.023	0.02

Median Stemflow by Species

Red Alder	0.213	0.12	0.092	0.02	0.177	0.14
Douglas Fir	0.085	0.05	0.008	0.00	0.062	0.05
Western Red Cedar	0.054	0.03	0.002	0.00	0.038	0.03

The measured stemflow comprised a very small amount of the trees hydrologic value, generally less than 1% of the total precipitation incident on the tree canopy, which is fairly insignificant. As shown, the Red Alder recorded the highest annual stemflow, primarily due to its smooth bark (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, pp. 27,32).

Table 24: Median throughfall by species

Median Throughfall by Species

	Leaf Off		Leaf On		Annual Value	
Quantifying Storm Totals [cm]	57.1		24.3		81.4	
Tree Species	%	cm	%	cm	%	cm
Bigleaf Maple	72.4	41.3	39.3	9.6	62.5	50.9
Red Alder	69.1	39.5	60.7	14.7	66.6	54.2
Douglas Fir	44.5	25.4	36.7	8.9	42.2	34.4

Median Throughfall by Species

Western Red Cedar	37.7	21.5	36.0	8.8	37.2	30.3

Table 25: Median interception by species

Median Interception by Species

	Leaf Off		Leaf On		Annual Value	
Quantifying Storm Totals [cm]	57.1		24.3		81.4	
Tree Species	%	cm	%	cm	%	cm
Bigleaf Maple	27.6	15.8	60.7	14.8	37.5	30.5
Red Alder	30.6	17.5	39.2	9.5	33.2	27.0
Douglas Fir	55.4	31.6	63.3	15.4	57.7	47.0
Western Red Cedar	62.3	35.5	64.0	15.6	62.8	51.1

As summarized, Western Red Cedar trees had the lowest throughfall and are therefore most effective at intercepting rainfall, while the Red Alder was least effective. Looking at the deciduous species, The Bigleaf Maple was marginally less effective than the Red Alder during leaf-off period, but was much more effective during the leaf-on period (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 27). Interception rate was calculated by subtracting the throughfall and stemflow values from the total open canopy precipitation. It was determined that the Western Red Cedar was the most effective tree for rainfall interception, with a total of nearly 63% of annual precipitation intercepted and therefore effectively removed from peak flow to the stormwater system. The Red Alder was least effective, intercepting approximately 33% of annual rainfall, however, that is still a substantial number and would help to lessen the current demand on stormwater infrastructure. Overall, "evergreen trees intercepted more rainfall per unit canopy area than deciduous species during leaf-on and leaf-off seasons" (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 28), but both the deciduous and coniferous species are useful rainwater mitigation tools that can be used in developing urban areas.

Looking at the evergreen species, the discrepancies between leaf-on and leaf-off periods could be due to differences in rainfall intensity, intermittent dry periods, and total rainfall during each season (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, pp. 30,32).

Table 26: Median transpiration by species

Median Transpiration by Species

	Leaf Off		Leaf On		Annual Value	
Annual Average Storm Totals [cm]	124.8		42.9		167.6	
Tree Species	%	cm	%	cm	%	cm
Bigleaf Maple	-	-	65.8	28.2	17.7	29.7
Red Alder	-	-	36.9	15.8	10.2	17.1
Douglas Fir	1.8	2.3	9.8	4.2	3.9	6.5
Western Red Cedar	1.1	1.3	8.6	3.7	3.0	5.0

Transpiration Calculations, Table adapted from p. 30. Data for deciduous species during leaf-off period was considered to be too noisy, and therefore disregarded.

Transpiration was also measured during the study. It was found that the Bigleaf Maple had the highest transpiration rates during the leaf-on period, at an average of 65.8% of totally rainfall measured during that season. "Peak transpiration occurred in the month of July for bigleaf maples, when median transpiration was 400.6% … a volume of water that exceeds what fell directly on the tree canopy as rainfall by four times. These results suggest that bigleaf maples draw water from deeper strata in the soil profile or regions beyond the tree's dripline." (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 29). The Red Alder also had average leaf-on transpiration rates of approximately 36.9%, with a peak of 223.6% in July. Again, both deciduous species had transpiration rates exceeding 100% through the month of August. The evergreen species transpiration ranged from 0.2% to 44.6% (Douglas Fir), and 0.1% to 49.4% (Western Red Cedar). Although the deciduous species transpire primarily during leaf-on seasons, the evergreen species continue to transpire all year long.

Table 27 summarizes the total value of each tree species for the hydrologic budget. It is shown that although the effectiveness of each species differs, all of the trees studied did positively impact storm and rainwater management and should therefore be considered as effective natural assets in managing rainwater in urban developments.

Table 27: Median value by species

Median Value (Transpiration + Interception) by Species

	Leaf Off		Leaf On		Annual Value	
Storm Totals [cm]	124.8		42.9		167.6	
Tree Species	%	cm	%	cm	%	cm
Bigleaf Maple	27.6	34.4	126.5	54.3	52.9	88.7
Red Alder	30.6	38.2	76.2	32.7	42.3	70.9
Douglas Fir	57.2	71.4	73.1	31.3	61.3	102.7
Western Red Cedar	63.3	79.0	72.6	31.1	65.7	110.1

The study concluded “that when all the components of the hydrologic budget are summed, bigleaf maples can intercept or transpire more than the total volume of water incident on their canopies during the leaf-on season. The remaining species managed over 70% of the rainfall landing on their canopies during leaf-on. During leaf-off season, the two evergreens can transpire and intercept over half the rainfall landing on their canopies” (Jayakaran, Leonard, Fischer, Duberstein, & Barnes, 2022, p. 2).

Brussels, Belgium

Another study was conducted over a two-year period that examined the hydrological impact of a solitary Norway Maple (Acer platanoides) and a Small-leaved Lime (Tilia cordata) tree in an urban environment. These trees species are popularly used as street trees in urban environments due to their pollution removal abilities (Yang, Chang, & Yan, 2015) and their rapid growth rate (Moser, Rötzer, Pauleit, & Pretzsch, 2015). This research was done in Belgium which is considered to have a temperate oceanic climate, and rainfall averages between 750 and 850 mm annually and is fairly evenly distributed throughout the year (Smets, et al., 2019).

Similar to other case studies, rainfall data was collected and divided into interception, throughfall, and stemflow. Measurements were taken during leaf-on periods over the course on one year for each tree, summarized in Table 28 below (Smets, et al., 2019):

Table 28: Collected data by tree species studied

		Norway Maple	**Small-Leaved Lime**
Rainfall Events [#]		39	25
Rainfall Total [mm]		143.71	117.31
Throughfall	Total [mm]	88.03	70.35
	Percent [%]	61.26	59.97
	Total [mm]	55.61	44.12

		Norway Maple	Small-Leaved Lime
Interception Storage	Percent [%]	38.70	37.61
Stemflow	Total [mm]	0.19	0.11
	Percent [%]	0.13	0.09

Both deciduous trees show similar behaviour and hydrological characteristics. Interception is approximately 38% for each tree, and stemflow calculations can be considered negligible. It is important to note that defoliation periods were not considered in these calculations and as such, overall rainfall interception would be lower if they were included. For rainfall events of less than 10mm, these trees intercepted approximately 46% of rainfall, while for events with rainfall greater than 10mm, interception dropped down to approximately 26% (Smets, et al., 2019).

Tree rainfall interception is substantial in temperate climates such as in Brussels, or Vancouver. With relatively even rainfall distribution and typically long, low-intensity rainfall events trees can effectively help to mitigate rainfall runoff. With heavy, more intense rainfall events, interception capacity of trees is more quickly reaches and consequently trees become less effective in rainwater management. "Although urban trees alone cannot be considered a flood control measure, they help to delay and spread out peak runoff and reduce pollutant wash-off, thereby limiting the pressure on the drainage system (Szota, et al., 2019) (Wang, Endreny, & Nowak, 2008)" (Smets, et al., 2019).

Appendix F: Design and Management

When looking at trees as natural assets in rainwater management, it is important to understand how to best design for, implement, and incorporate trees into urban settings so they will survive and thrive. Trees, when they grow to maturity, are effective storm water utilities by acting to intercept, store, and filter large amounts of storm water. However, to perform well trees must become larger enough and soil must be able to absorb and drain water effectively. It was measured by the US Forest Service that a 30” tree will produce 70 times the ecological value of a 3” tree (Department of Environmental Resources, Prince George's County, Maryland, 1999), many of which benefits can be seen in stormwater advantages. Although, often in urban settings the soil in which trees grow is very compact, making adequate growth and functional contributions to stormwater management difficult. This is why proper consideration and design steps must be taken.

Looking closer at soil conditions can tell us a lot about how and if a tree will be able to grow well. When considering specifically the wellbeing of urban trees, access to oxygen in soil is the single most critical factor for a healthy tree (Stål, Alvem, & Embrén, 2014). Denser surface layers (typically from more compaction of soils), contribute to oxygen deficiency in the soil and a potential for carbon dioxide poisoning of tree roots. Another big issue for urban trees is a potential lack of water and input of organic matter. With development usually comes increased paving and hardscape. Having these paved surfaces adds to the impermeability of the area, diverting rainwater and not allowing planted trees to get the resources they need to grow – the amount of impervious cover on a site and surface runoff from that site are directly linked. On a site that’s composed solely of pervious, natural ground cover only 10% of rainfall ends up as runoff while 40% is evaporated back to the atmosphere and 50% is able to infiltrate the ground. When a small structure or impervious surface (10-20%) is introduced, 38% of rainfall is release back to the atmosphere, 42% infiltrates, and runoff doubles to 20%. Table 29 summarizes this relationship (Department of Environmental Resources, Prince George's County, Maryland, 1999):

Table 29: Impermeability and rainwater

Lot Type	Evapotranspiration [%]	Infiltration [%]	Runoff [%]
Natural (0% Impervious)	40	50	10
Rural (10-20% Impervious)	38	42	20
Developed (35-50% Impervious)	35	35	30
Urban Center (75-100% Impervious)	30	15	55

When considering stormwater management, generally each urban site, or residential lot, should be designed in such a way that both water quality and quantity are considered. For the most benefits, the volume of water entering the site, as well as the time it is held or retained, should be considered. Also, infiltration and evapotranspiration should be increased to reduce the overall surface runoff, pollutant loads, and water temperature (Department of Environmental Resources, Prince George's County, Maryland, 1999).

Perhaps a surprise to some, but after a study was conducted in Baltimore, Sarah Ponte (Ponte, Sonti, Phillips, & Pavao-Zuckerman, 2021) of the Department of Environmental Science and Technology at the University of Maryland, stated that, "We found that individually planted trees capture, store and release stormwater back into the atmosphere—a process called transpiration—at a rate three times that of trees in a forest," (Ponte, Rainwater Management, 2021). Ponte and her team were able to measure transpiration from Red Maple trees in three distinct urban settings; individual trees over turfgrass, clustered trees over turfgrass, and closed canopy forest, prior to reaching their conclusion. With this finding, it can be concluded that utilizing trees as natural assets in rain and stormwater management in low-density residential zoning is even more beneficial and an effective, sustainable solution to lessening the demand on stormwater infrastructure in growing, urban settings. "Understanding how different management contexts affect urban ecohydrologic fluxes, such as transpiration, can aid the development of policy on the application and effectiveness of urban tree canopy as a tool for stormwater runoff reduction at watershed and city scales," (Ponte, Rainwater Management, 2021). If cities are able to improve the growing conditions and root environments for mature urban trees, not only will the trees life be extended, but, if done properly, it can chance stormwater from a potential problem into a valuable resource (Stål, Alvem, & Embrén, 2014).

Appendix G: Urban Planting Support

Other studies have been done to quantify and justify benefits trees may provide a city. During the *Puget Sound Urban Tree Canopy and Stormwater Management Project* (Asselmeier, et al., 2021), many important key findings and recommendations were determined. It was found that replacing tree canopy with any other type of landcover, stormwater runoff would increase. To combat this, its recommended that trees should be retained and planted wherever possible. This includes planting trees strategically so they will overhang impervious areas to reduce runoff volume and pollution loads. It was also found that areas with higher amounts of existing canopy experience a lower magnitude of increased runoff volume when tree canopy is reduced (Asselmeier, et al., 2021, p. 25). For this reason, it is important to retain and expand tree canopy cover. Another important reason why trees should be valued during development is found in their quantifiable ability to reduce runoff during development. In the Puget Sound region of Washington, it was found that runoff increased a maximum of 2% during development when trees were retained on site, while runoff increased up to 5% when trees were not retained (Asselmeier, et al., 2021, p. 24). Besides aiming to retain existing canopy during development, development recommendations include integrating tree canopy cover when possible, and increasing tree canopy cover, in particular over impervious surfaces.

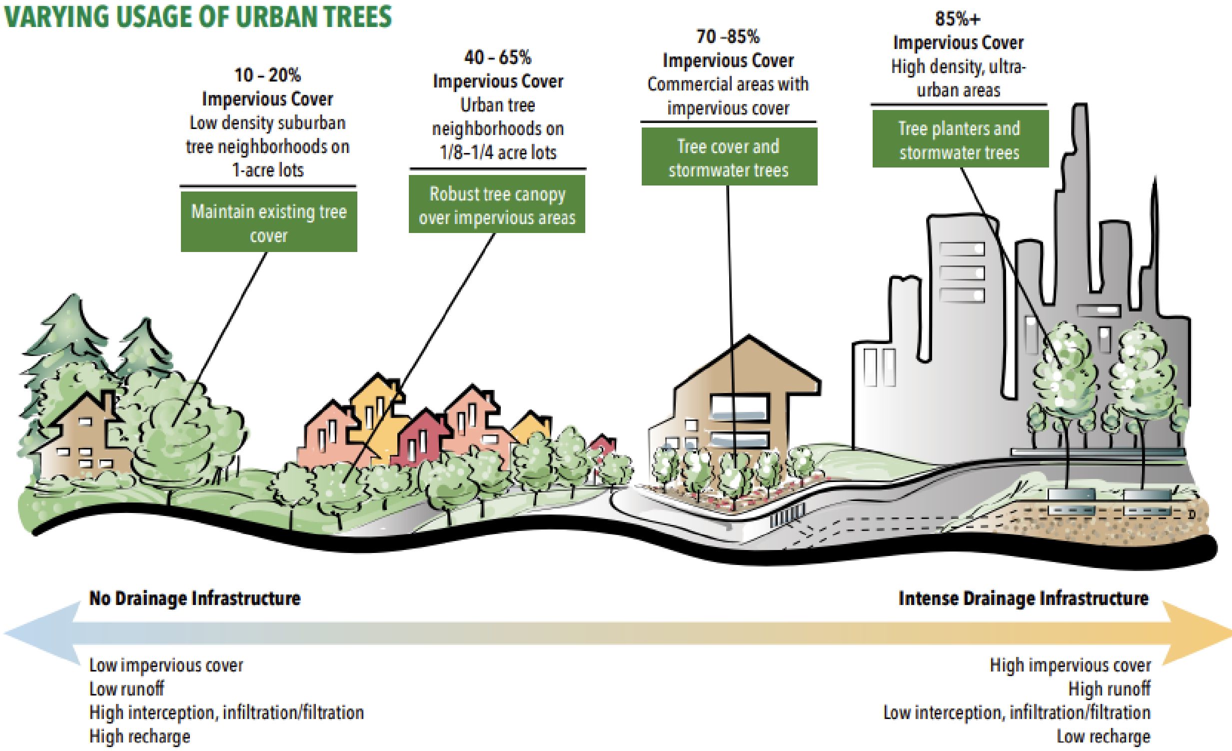


Figure 14: Varying usage of urban trees (Asselmeier, et al., 2021, p. 31).

When looking at trees as natural stormwater assets, there are many opportunities for collaboration among urban forestry and stormwater professionals, policy makers and implementors, builders and developers, and property owners. Collaboration can be compelling to drive support of urban canopy actions, as well as improve communication between professionals and community advocacy groups to achieve shared and sustainable goals (Asselmeier, et al., 2021, p. 30). "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" (Asselmeier, et al., 2021, p. 35).

Another benefit found through the *Puget Sound Urban Tree Canopy and Stormwater Management Project* was that by filtering runoff through trees, the stormwater was treated for some toxicity, provided water filtration, and was found to typically removes 80-90% of sediments and metals, 40-60% of nutrients, and provided temperature modification, cooling hot runoff in summer and warming cold runoff in winter (Asselmeier, et al., 2021, p. 39), all benefiting the surrounding ecosystems within the city. Additionally, urban trees have been found to help adapt cities and urban developments to changing climates and flooding risks. The graphic below (Asselmeier, et al., 2021, p. 41) illustrates how trees reduce stormwater and benefit flood mitigation strategies.

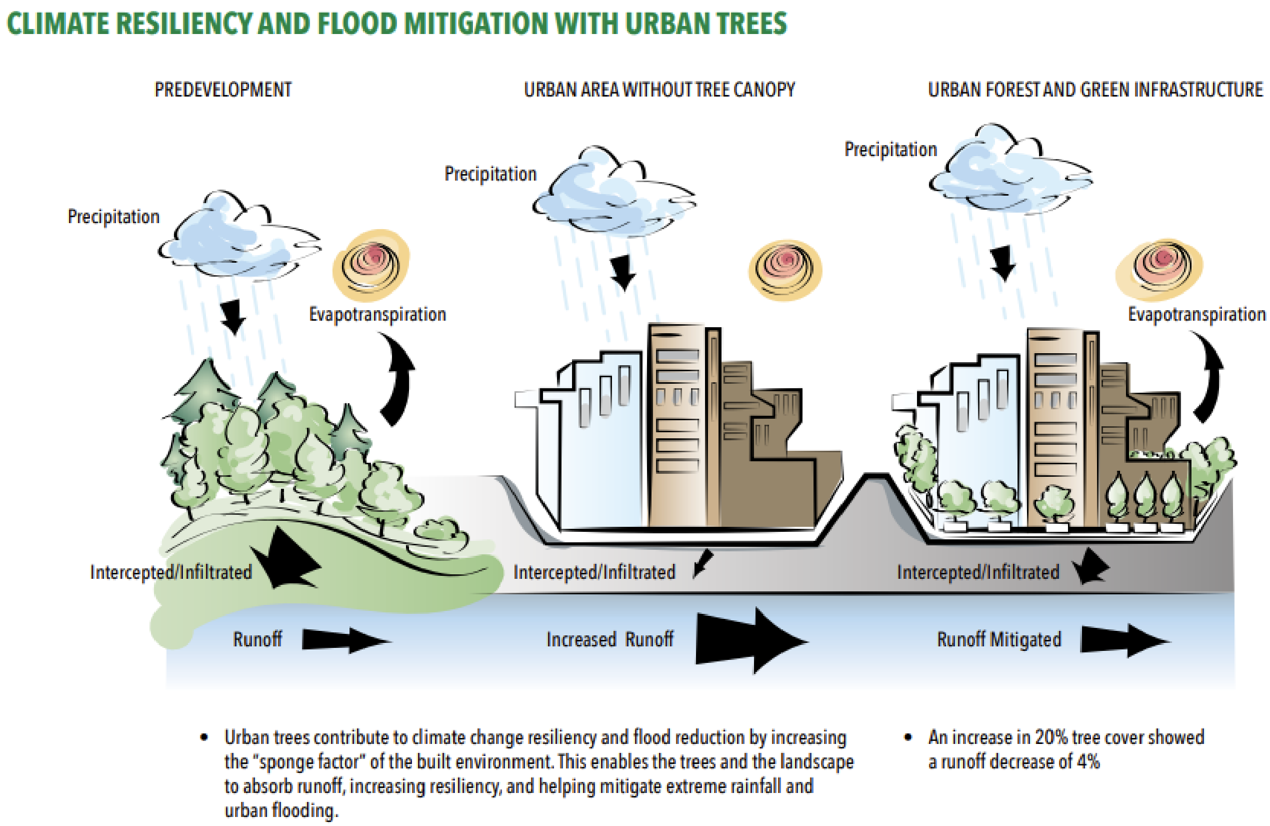


Figure 15: Climate resiliency and flood mitigation with urban trees (Asselmeier, et al., 2021, p. 41).

Major factors affecting the performance of trees as a stormwater measure as listed in table 1 (Van Stan II, Levia Jr, & Jenkins, 2015), include:

- Tree (evergreen / deciduous, phenology, size / age, health, leaf area index / morphology, branch angle, bark texture, evapotranspiration rate, root structure / depth, etc.)
- Atmosphere (climate zone, annual precipitation, precipitation intensity / duration / frequency, time between storms, temperature, wind, etc.)
- Soil (rooting volume, water holding capacity, fertility, compaction, drainage, green infrastructure, etc.)
- Landscape (surrounding land cover, impervious surfaces, watershed position, pollution, tree density, crown growth characteristics, ground cover, slope, etc.)

Many of the different studies researched over the years have helped to prove that all of these different factors should be considered when selecting the right tree to tackle stormwater management. Looking at a tree's structural characteristics, Van Stan II, Levia Jr, & Jenkins (2015) found that a Fagus grandifolia (American beech) had a 21.5% interception rate per storm event, while a similarly sized Liriodendron tulipifera (tulip tree) intercepted 27.8%. A study completed by Livesley, Baudinette, & Glover (2014) in Australia showed that interception rates would differ within the same genus when they noted that Eucalyptus nicholii intercepted 44.4%, while a Eucalyptus saligna tree intercepted 29.5%. In the previously mentioned case studies in Appendix E of this report it was also evident that phenology, or foliation periods and habits, as well as choosing between a coniferous or deciduous tree, will also affect how a tree performs through a stormwater management lens.

Similarly, even when looking at a broader scale of considering the soil or landscape, we can see how the idea of creating a suitable environment for tree planting can influence design and help reduce stormwater runoff. Armson, Stringer, and Ennos (2013) were able to record a 62% runoff reduction in Manchester, UK through the introduction of planting small trees in tree pits in the urban landscape. Despite the trees themselves having a somewhat insignificant role in stormwater management and mitigation due to their juvenile age, simply considering the soil and creating a suitable environment for the trees to grow in was able to aid in reducing runoff. It could be expected that these benefits would only increase as the trees continued to grow and provide more direct stormwater control through development of a larger and more significant canopy. Likewise, Bartens, Day, Harris, Dove, & Wynn (2008) were able to take subsoils compacted to mimic urban conditions and study the impacts that the presence of tree roots had on them. It was found that tree roots in the compacted soils increased infiltration by an average of 63% as compared to the treeless soils.

Although the cost of planting trees as a stormwater measure may seem high in as a short-term solution, the long-term benefits and accessory social, economic, and environmental benefits exceed this initial cost. By continuing to plant trees in the urban environment, not only will sustainable stormwater management be promoted, but other ecosystem services that we already rely on trees to provide will also be enhanced. Likewise, the existing trees in the urban environment will offer added benefits and advantages as the entire urban canopy increases throughout residential neighbourhoods and ultimately across the city.

Research has shown that trees and their surrounding environments can substantially decrease stormwater runoff through canopy interception, transpiration, facilitating infiltration, and when coupled with other green infrastructure such as using structural soils or constructing tree pits. This is just further bonus to the public appeal, relatively small footprint, aesthetic value, and mental benefits that trees provide when situated in the urban environment. However, further research is yet to be done, specifically in (Van Stan II, Levia Jr, & Jenkins, 2015):

- documenting the performance of trees as a stormwater control with respect to species and life stage
- considering the influences of local soil, atmospheric, and landscape conditions when determining the applicability of trees for stormwater control
- navigating arboricultural challenges to situate stormwater control in the context of other urban forestry goals,
- developing policy and economic mechanisms that encourage strategic tree planting and maintenance on public and private lands to promote cost effective management of stormwater runoff.

If this can be done, using trees as natural assets in rainwater management will not only be an effective and feasible alternative to traditional stormwater management methods, but accepted and encouraged throughout growing urban areas.

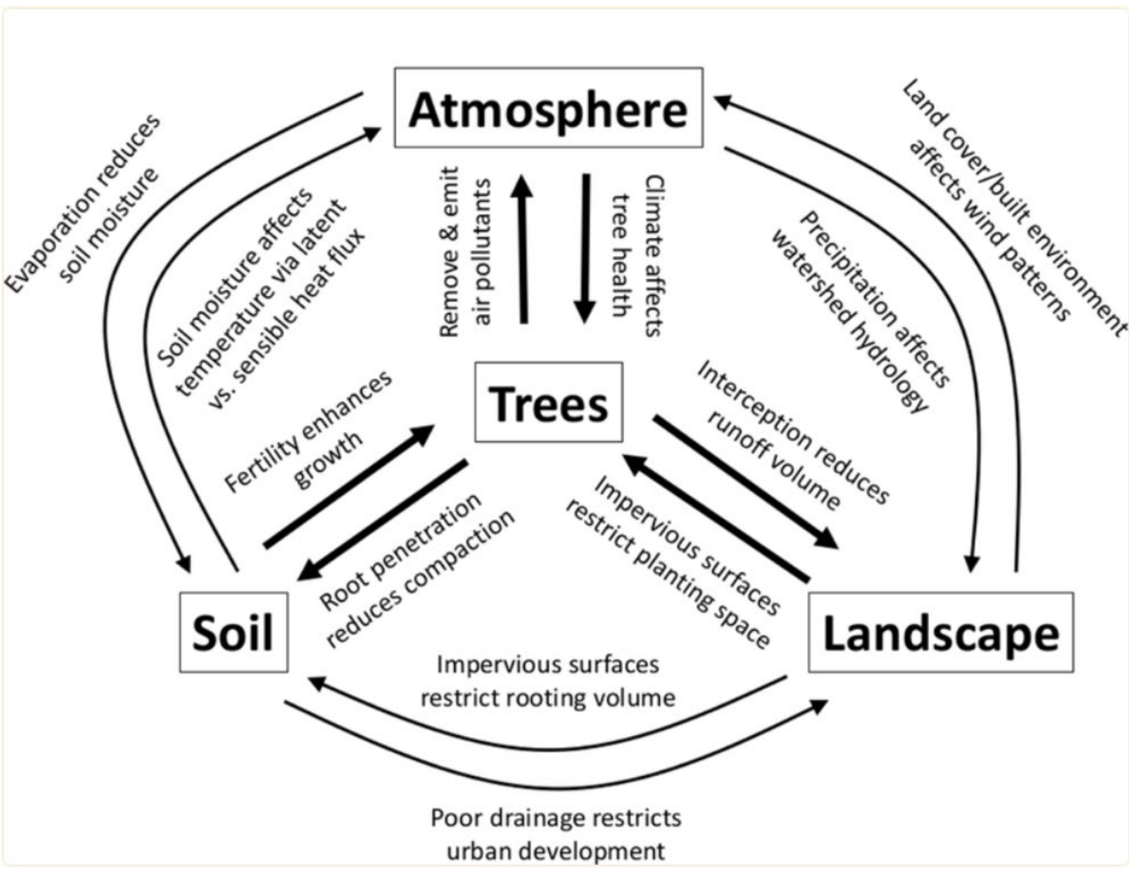


Figure 16: Trees relationship with atmosphere, soil, and landscape