Trees for Green Streets

An Illustrated Guide

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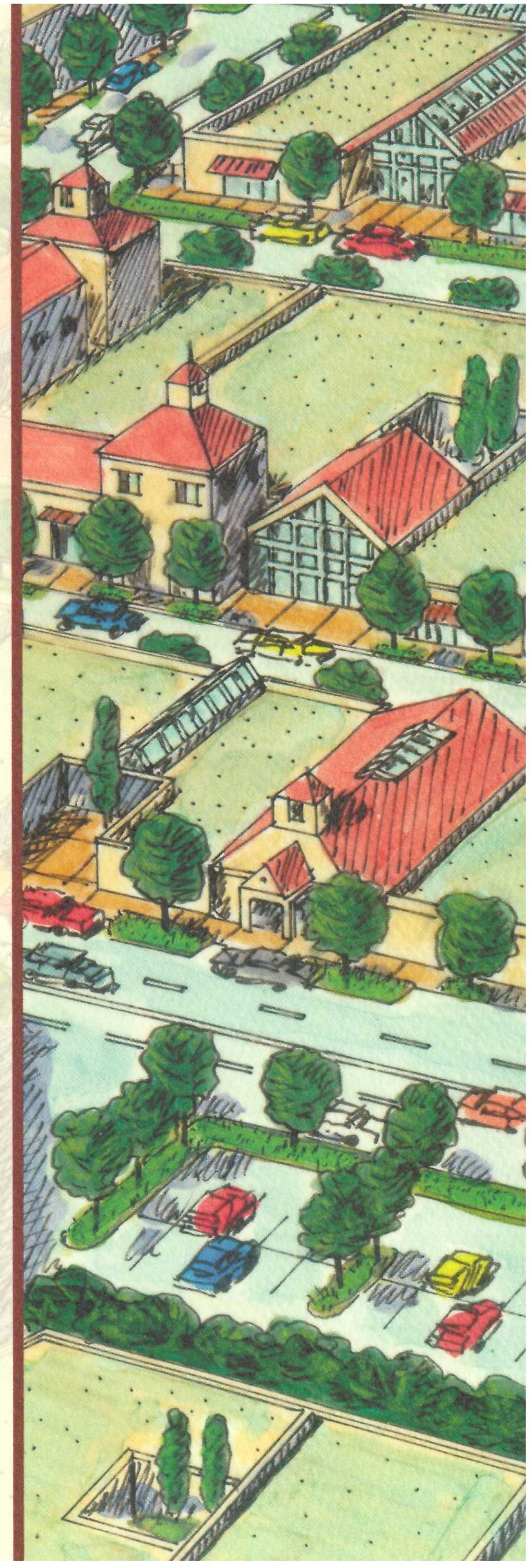

Trees for Green Streets

An Illustrated Guide

Selecting street trees that reduce stormwater runoff from streets and improve water quality

First edition
June 2002

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About Metro

Metro serves 1.3 million people who live in Clackamas, Multnomah and Washington counties and the 24 cities in the Portland metropolitan area. The regional government provides transportation and land-use planning services and oversees regional garbage disposal and recycling and waste reduction programs.

Metro manages regional parks and greenspaces and owns the Oregon Zoo. It also oversees operation of the Oregon Convention Center, the Portland Center for the Performing Arts and the Portland Metropolitan Exposition (Expo) Center, all managed by the Metropolitan Exposition Recreation Commission.

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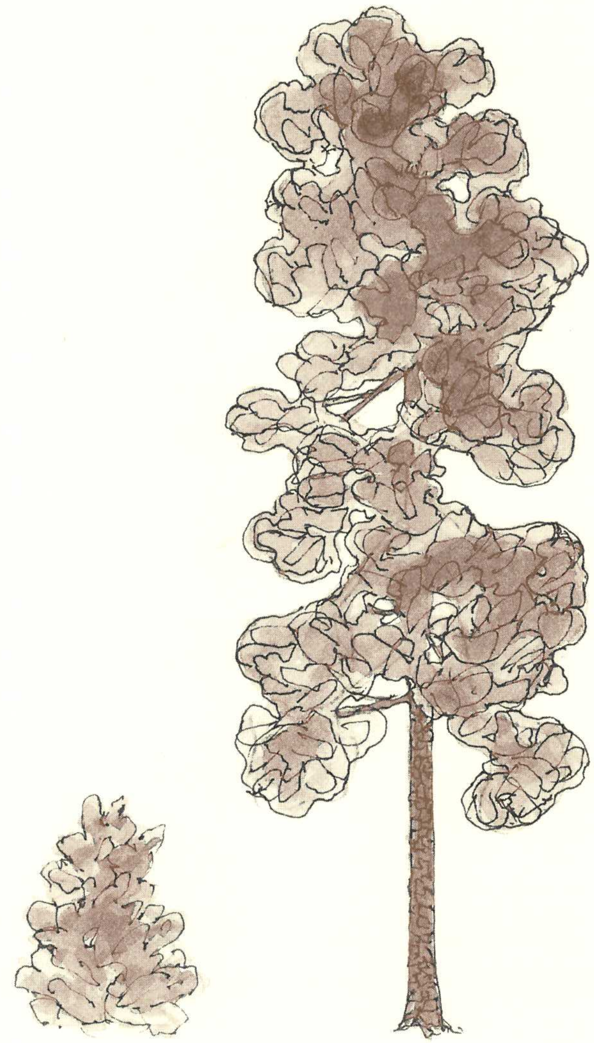

Ponderosa pine
(Pinus ponderosa)

Printed on recycled-content paper;
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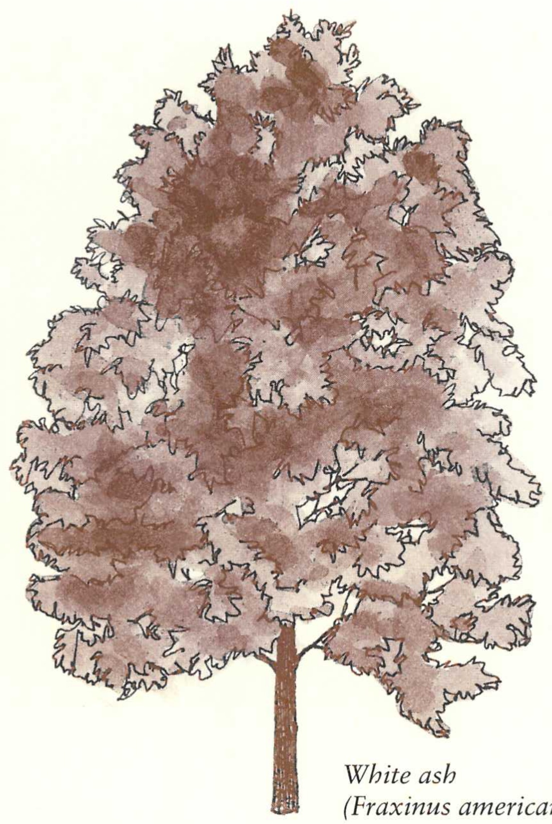
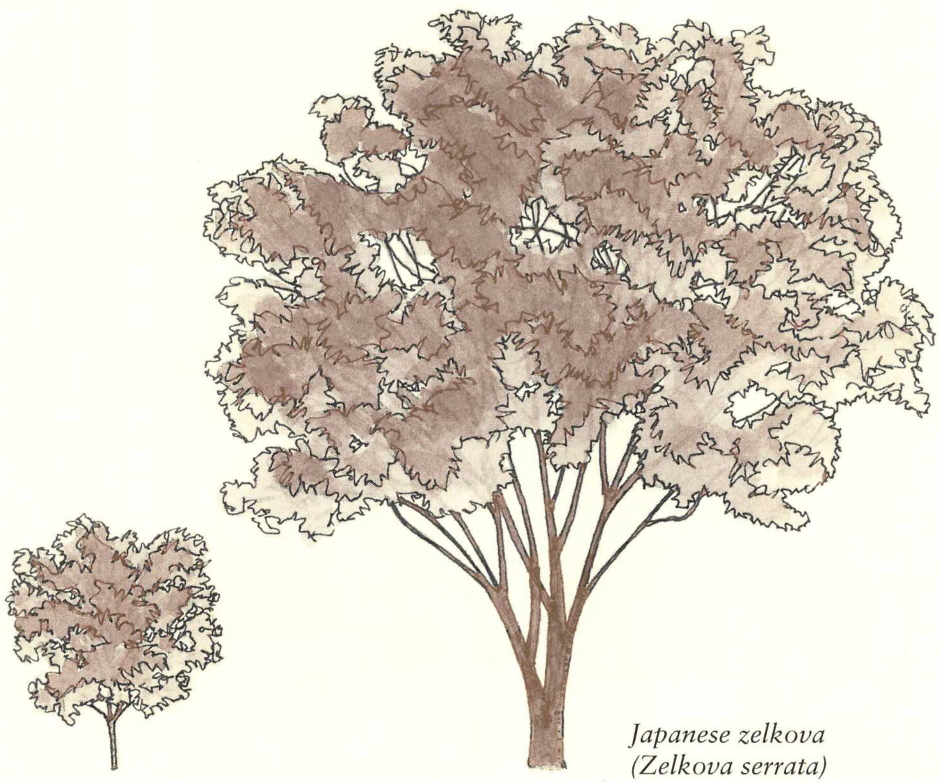


White ash (Fraxinus americana)



Japanese zelkova
(Zelkova serrata)

Benefits of street trees

Trees improve the water quality of our rivers and streams by capturing rainfall and by reducing erosion and runoff.

Trees provide shade and cooling of streams, which is essential to fish and other aquatic life.

Trees in the combined stormwater and sanitary areas prevent millions of gallons of rainwater from entering the sewage treatment plant.

Trees prevent millions of gallons of polluted runoff from entering streams and rivers.

Trees improve our air by capturing pollution particles, reducing carbon dioxide and producing oxygen.

Trees provide food and shelter for wildlife that would otherwise be displaced.

Trees provide shade and can keep homes and buildings up to 20 degrees cooler in the summer.

Trees provide privacy and help reduce noise and glare.

Trees help reduce stress. The sight, sound, smell and touch of plants can reduce stress levels.

Crime levels in communities are reduced when there are extensive street tree systems and well-landscaped parks.

How to Use this Manual

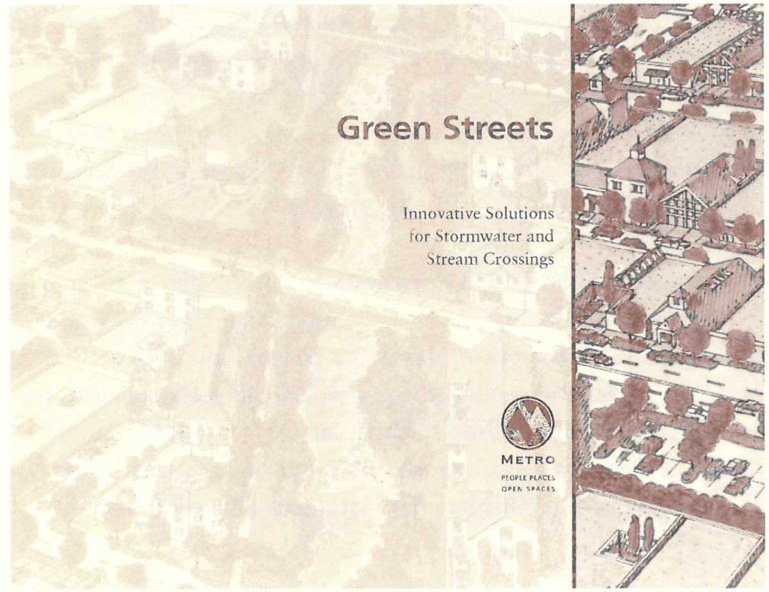
Trees for Green Streets – An Illustrated Guide is intended to be used in conjunction with Metro's *Green Streets – Innovative Solutions for Stormwater and Stream Crossings* handbook, produced in June 2002, and *Creating Livable Streets – Street Design Guidelines,* produced in November 1997 and revised in a second edition June 2002.

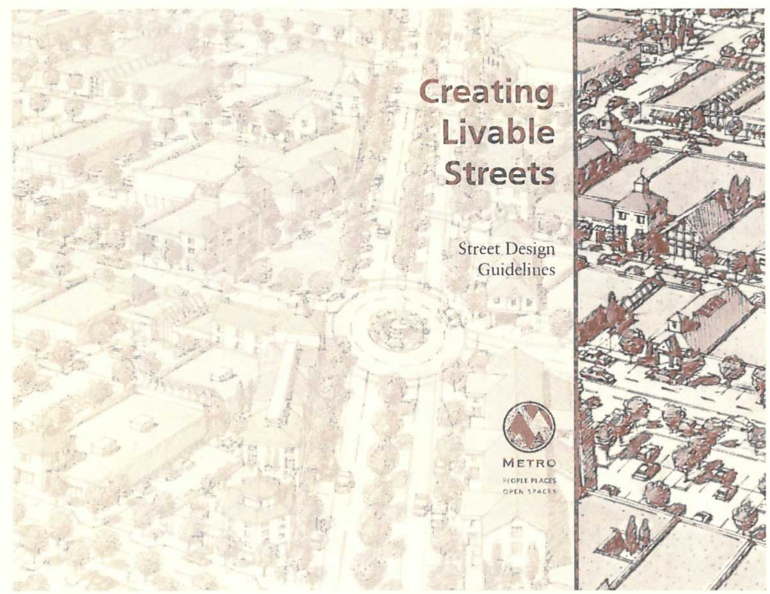
The result of more than nine months of research and interviews, this manual explains some of the principles of using street trees as a stormwater management tool. It provides illustrated examples of how trees can be incorporated along residential streets to create "green streets." Advantages and disadvantages are listed for each tree.

Local codes, ordinances and street-tree planting lists should be consulted before applying these concepts and selecting tree species.

Information provided in this manual is a first step toward understanding the stormwater mitigation functions that trees provide within urban areas. The list of trees will be refined as the concepts are applied, tested and evaluated.

For more information about this and other publications, call Metro's planning hotline at (503) 797-1900.





Introduction

Street trees perform many functions and provide many benefits to urban residents. Some of the recognized benefits of trees are providing shade and moderating the climate. Trees, if appropriately placed and selected, conserve energy and water. Trees have aesthetically pleasing branches, leaves, bark and flowers and often produce pleasant smells and sounds.

There has been considerable research on the role that trees play in improving air quality and conserving energy. Trees have been recognized for their role in preventing soil erosion, replenishing moisture in soil and groundwater, and absorbing and transpiring rainfall; however, very little research has been conducted about their ability to intercept, absorb, filter and cleanse stormwater runoff from streets. This manual investigates how different street tree species can be used as a primary stormwater management tool in green street projects.

Street trees perform many functions that help reduce the volume and rate of stormwater runoff entering the piped stormwater system. Trees intercept precipitation before it lands on street surfaces through absorption, evapotranspiration, and conveyance to the area immediately around the tree trunk, where it may infiltrate into the soil. Trees planted in bioswales help detain stormwater run-off by slowing down water flow and allowing it to infiltrate into the soil and evaporate into the atmosphere thereby reducing runoff volumes and delaying the onset of peak flows.

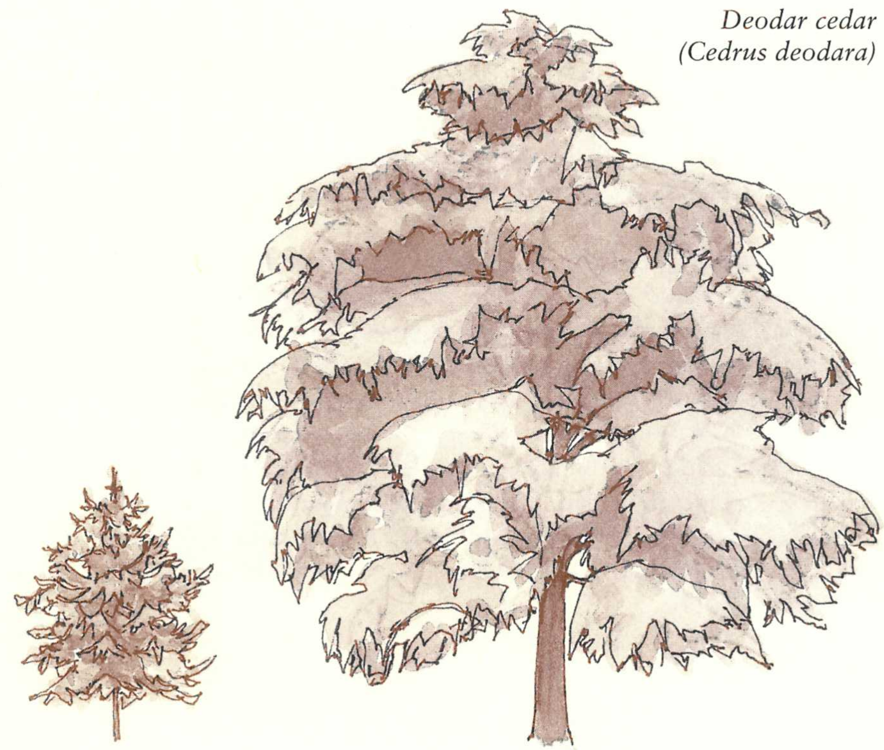
These streets in Southeast Portland demonstrate how street trees and street design may affect stormwater issues. The wider pavement widths of the street on the left have more surface area to catch precipitation and are more difficult to shade with tree cover. Smaller planting strips next to the pavement reduce the ability of trees to grow to their full potential and may limit the ability to plant large tree species, further limiting tree canopy cover of the pavement area. Large tree species branch over the paved portion of the street on the right, intercepting more of the precipitation that falls in the street right of way. Because the pavement is shaded from direct sunlight, the precipitation that does reach the pavement drains at a cooler temperature to nearby streams.

Finally, trees can reduce the temperature and concentration of pollutants in stormwater. All street tree species perform these functions; particular species may perform them better than others and for a longer period depending on characteristics such as:

- persistent foliage
- canopy spread
- longevity
- growth rate
- drought tolerance
- tolerance to saturated soils
- resistance to urban pollutants
- tolerance to poor soils
- root pattern
- bark texture
- foliage texture
- branching structure
- canopy density.

Green Streets

Green streets create opportunities for capturing and infiltrating stormwater runoff from streets, using street designs that incorporate street-side bioswales and large street trees with wide-spreading canopies. Impervious surface area is reduced and replaced with vegetation that can absorb and treat stormwater runoff. Streets of this design provide a visual indication that the street right of way serves multiple public purposes, not simply the movement of motor vehicles. The resulting street character is one that is comfortable and inviting.



Deodar cedar (Cedrus deodara)

Stormwater Concepts

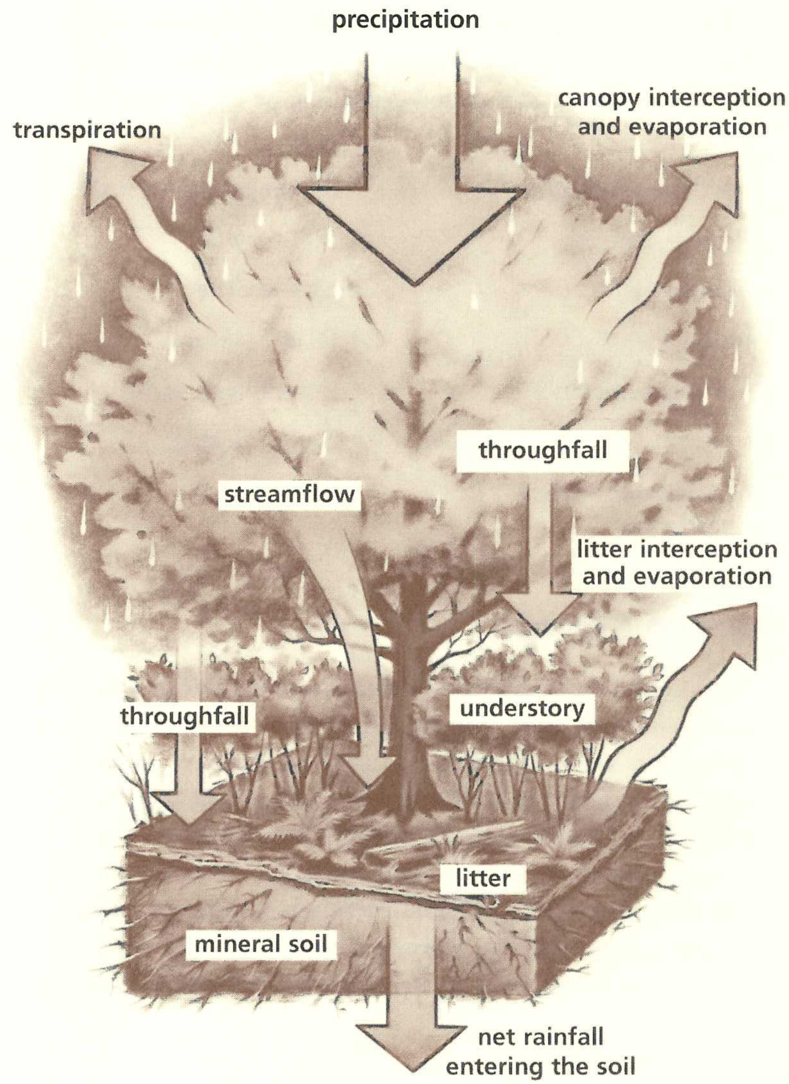
Runoff Reduction and Detention

Interception

Interception is the precipitation that falls on the surfaces of trees, including foliage surfaces, bark and branches. Intercepted water is either evaporated directly into the atmosphere, absorbed by the canopy surfaces or transmitted to the ground surface via stemflow. Interception of rainfall by street trees reduces the volume and velocity of water flow and temporarily stores rainfall in the canopy layer.

Leaves, needles, twigs, branches, trunks and bark all capture, absorb and transpire rainfall. Branching structure, foliage and bark texture and canopy density are all elements that determine how much rainfall is intercepted. Trees with vertically oriented limbs produce more stemflow and less crown surface drip (drip from foliage). Trees with large leaves will intercept more rainfall, and throughfall will be primarily from foliage drip. Large trees with many small leaves are thought to be more efficient at intercepting rainfall because of the dense canopy they create.

It is estimated that some deciduous tree species that have vertical branching structure, dense canopy and rough bark surfaces will have improved interception rates during winter months. Species such as sweetgum and pin oak that retain their leaves late into the winter season can intercept more rainfall simply because they maintain their canopy surface area. Even when deciduous trees lose their leaves, their branches can intercept up to 15 percent of the rainfall and direct it to the trunk and eventually into the soil area around the trunk.[1] Trees with rough bark surfaces increase lag time of captured rainfall, thereby increasing the potential for water absorption.



Typical pathways for forest rainfall. A portion of precipitation never reaches the ground because it's intercepted by vegetation and other surfaces (Portland Bureau of Environmental Services, 2000).

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[1] Tom Liptan, personal communication, 2001

Trees with persistent foliage such as conifers and broadleaf evergreens will intercept rainfall throughout the year. Coniferous trees have needles with many sharp angles that can trap water droplets and absorb moisture from precipitation and transpiration; however, many conifers have columnar forms and do not achieve considerable canopy spread.

Other factors that influence the amount of rainfall intercepted by tree canopy include relative humidity, temperature, wind speed and the characterization and magnitude of rainfall events.[2] For example, during periods of low temperature, the amount of evaporation from the tree surfaces is reduced. During light rainfall, coniferous trees have greater water-retention ability than deciduous trees.[3]

In the Pacific Northwest, precipitation events are low intensity and low volume and occur generally from October to May, increasing the potential for interception. If there are several overlapping canopies and a thick litter layer, there may have to be up to one inch of rainfall before water reaches the soil.[4]

According to the Portland Bureau of Environmental Services, a single mature tree with a 30-foot crown can intercept up to 4,600 gallons of water per year.[5] It has been determined that by adding

Table 1
Interception rate for small, medium and large trees through 40-year life (in gallons per year per tree)

	year 5	year 10	year 15	year 20	year 25	year 30	year 35	year 40	40-year average	average yearly cost savings*
 Large tree (red oak)	14	109	265	449	636	816	978	1,122	549	$15.25
 Medium tree (Norway maple)	16	85	180	288	402	499	602	698	346	$9.62
 Small tree (purple-leaf plum)	6	47	107	169	225	270	304	325	182	$5.05
No street tree planting	0	0	0	0	0	0	0	0	0	$0

**To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were used based on minimum requirements for stormwater management in western Washington.*

For a 10-acre single-family residential development on permeable soils, it costs approximately $20.79/Ccf ($0.02779/gal) to treat and control flows stemming from a six-month 24-hour storm.

Runoff control for very large events (100-year, 24-hour storm) was omitted as the effective interception by trees diminishes once surfaces have been saturated. To calculate stormwater run-off benefits, the management cost was multiplied by gallons of rainfall intercepted after the first 0.078 inches had fallen for each storm (24 hours without rain) during the year.

[2] Xiao, et al, 2000
[3] Robinette, 1972
[4] Watershed Hydrology, 1995
[5] BES, 2000

4,000 acres of trees, tree canopy and native vegetation to the urban forest, the volume of stormwater runoff can be reduced by as much as 495 million gallons per year.

The March 2002 report from the Center for Urban Forest Research, *Western Washington and Oregon Community Tree Guide: Benefits, Costs and Strategic Planting*, used a numerical simulation model to estimate annual rainfall interception of three common street tree species of small, medium and large stature. The model includes rainfall intercepted, as well as the amount of throughfall and stem flow. Tree canopy parameters included species, leaf area, shade coefficient (visual density of the crown) and tree height. The study found that the average annual benefits of a tree increase with age and that larger trees produce more water quality savings (see Table 1).

The largest tree in the study was a red oak (*Quercus rubra*), which intercepts 549 gallons/year on average with an implied value of $15.27 per year. After 20 years the red oak intercepts up to 449 gallons of rainfall with an annual value of $12.47.

The medium tree was a Norway maple *(Acer platanoides)*, whose bark and foliage intercepts 346 gallons a year on average with a value of $9.72. After 20 years, the Norway maple intercepts 288 gallons of rainfall with an annual value of $8.01.

The smallest tree in the study was a purple-leaf plum *(Prunus cerasifera)*, which provides more than $5 in stormwater management savings. After 20 years, the plum intercepts 169 gallons of rainfall with an annual value of $4.70.

This study also measured the benefits these trees provide for other environmental factors such as air quality and electricity savings and other benefits such as property values. In addition, costs associated with street trees such as maintenance and irrigation were measured. Overall, average annual benefits of 20 year old trees average from three to six times (depending on tree size) the annual cost associated with those trees.

Throughfall

Throughfall is the portion of precipitation that reaches the ground directly through gaps in the vegetation canopy and drips from leaves, twigs and stems. Leaf surface area, canopy density and branching structure determine how much throughfall there will be during a normal storm. Excessively heavy rainfall and wind will increase the amount of throughfall.

Evapotranspiration

Evapotranspiration is the process by which plants release moisture in the form of water vapor. A single tree can transpire up to 100 gallons of water in a day, and one acre of vegetation can transpire up to 1,600 gallons of water on a sunny summer day.

Evapotranspiration rates are fairly well known for large stands of forests, but are rarely calculated for individual trees in urban settings. Transpiration ratios are used to calculate water use efficiency. (Arid regions will have higher transpiration rations per tree stand than humid regions.[6]) Data does not exist for tree species in the Pacific Northwest, although a generalization of this concept shows that transpiration ratios are high in the summer and low in the winter. Trees that can capture and evapotranspire large amounts of water can significantly reduce the amount of rainfall that becomes stormwater runoff.

Conveyance Attenuation

During periods of heavy rainfall, when water is being conveyed through biofiltration swales, filter strips or linear detention facilities, trees can act as check dams, slowing water and increasing the potential for infiltration. Trees are particularly effective at conveyance attenuation where the slope of the swale exceeds two percent.

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[6] Cannell and Last, 1976

Water Quality Mitigation

Shade and Temperature Reduction

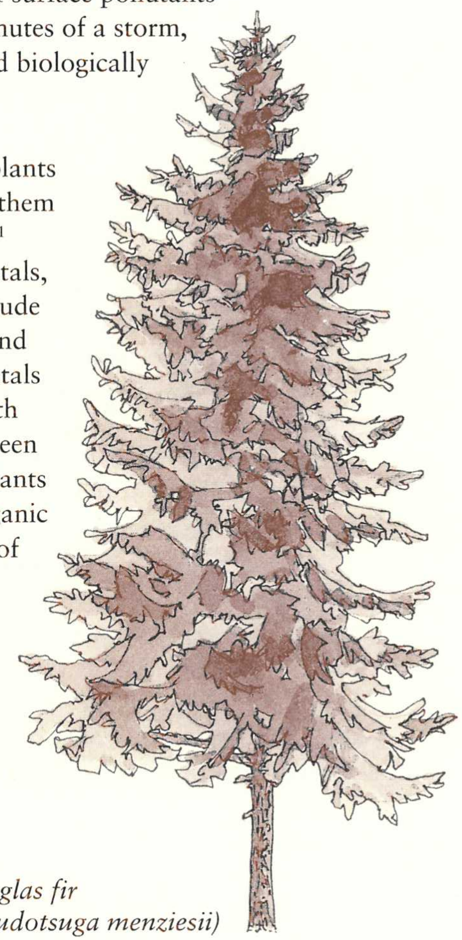
Urban areas have a high percentage of impervious surfaces that absorb and radiate heat, causing the urban heat island effect. Although the urban heat island effect is commonly used to describe an increase in air temperatures, it has far reaching impacts on water quality. Cool rainfall collects on hot impervious surfaces, is warmed and conveyed by a system of curbs to stormwater drains. These drains are connected to a series of underground pipes that discharge the warm polluted water to local streams and rivers. This increase in water temperature removes the amount of dissolved oxygen in the stream, making it difficult for fish and aquatic organisms to survive.

Trees control temperature by absorbing and reflecting solar radiation, controlling windflow, and intercepting, transpiring and evaporating rainfall. The amount of temperature reduction and shade depends upon the species of tree. Temperature measurements in Sacramento have shown that neighborhoods with considerable tree cover are three to six degrees cooler than newer neighborhoods lacking tree cover.[7] By shading impervious street surfaces, street trees help reduce the temperature of stormwater runoff.

Phytoremediation

The process of using plants to remove contamination from soil and water is called phytoremediation. Many plants have the ability to absorb excess nutrients, filter sediments and break down pollutants commonly found in stormwater runoff.[8] Pollutants partially controlled by trees include nitrogen oxides, sulfur dioxides, carbon monoxide, carbon dioxide, ozone and small particulates less than 10 microns in size.[9] Plants with deep roots improve these functions by breaking up soils and keeping them permeable. Tree roots absorb and transpire water, and some tree roots can stabilize waterborne pollutants from runoff. It is estimated that up to 47 percent of surface pollutants can be removed in the first 15 minutes of a storm, including pesticides, fertilizers and biologically derived materials and litter.[10]

Scientists have found that many plants can stabilize toxins by absorbing them and storing them in their tissues.[11] Plants can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons and landfill.[12] Plants actually need metals such as zinc and copper for growth and most do not distinguish between these and other metals.[13] Some plants enlist soil bacteria to detoxify organic compounds.[14] Phytoremediation of toxic heavy metals reduces the overall volume of contaminated material according to Leon Kochian, an USDA scientist and professor of plant biology at Cornell University.[15]



Douglas fir
(Pseudotsuga menziesii)

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[7] EPA, 1992
[8] CHI, 2000
[9] Coder, 1996
[10] Coder, 1996
[11] Black, 1995
[12] EPA, 1998
[13] Black, 1995
[14] Black, 1995
[15] Black, 1995

Phytoremediation research shows that there are six biological processes at work:

- phytoextraction
- rhizofiltration
- phytostabilization

use plants to stabilize or remove metals from soil and/or groundwater

- phytodegradation
- rhizodegradation
- phytovolatization

use plants to stabilize, degrade and/or remove organic contaminants (those that commonly contain carbon and hydrogen atoms).[16]

These biological processes remove, metabolize, neutralize, sequester, filter and contain toxins, metals, sediment, minerals, salts and pollutants on the move.[17] The services performed by these processes include contaminate accumulation and uptake in the soil, filtration of surface water, uptake of groundwater, and carbon sequestration in the atmosphere. Plants also can act as "hydraulic pumps" when roots reach deep into the soil and take up large quantities of water.[18]

Phytoextraction pulls contaminants, such as lead, through the roots into the upper part of the plants. During rhizofiltration, the roots filter dissolved contaminants, and during phytostabilization, plants immobilize contaminants, such as lead, copper and selenium. A plant's metabolism breaks down contaminants during phytodegradation. Rhizodegradation is when the roots work symbiotically with yeast, fungi and bacteria in the root zone to degrade contaminants. Phytostabilization is the process of transpiring contaminants through the plant leaves to the atmosphere, and hydraulic pump refers to plants that can uptake large quantities of water, acting as a dam to "pollutants on the move."[19] Phytoextraction and phytostabilization may not be appropriate along streets because they store heavy metals in their stems and leaves. This can poison wildlife, causing bioaccumulation of that substance in the higher order species.[20]

Trees that have been used in one or more of these processes include species of willow, poplar (aspen, cottonwood hybrids), giant sequoia and mulberry.[21] Poplar trees use enzymes to degrade organic compounds and stimulate chemical-degrading bacteria around their roots.[22] Poplar trees also can transpire between 50 to 300 gallons of water out of the ground in one day.[23] This type of consumption contains and controls the migration of contaminants.[24] One sugar maple (one foot in diameter) along a roadway removes 60 mg cadmium, 140 mg chromium, 820 mg nickel and 5,200 mg lead from the environment in one growing season.[25]

There also are many grasses and other herbaceous plants that have deep root systems that remediate environmental contamination. For example, Indian mustard takes up selenium and converts it to dimethyl selenide, a gas that is relatively nontoxic.[26]

The goal for landscaping with trees for the purposes of phytoremediation is to provide rapid tree cover while establishing a long-term landscape design with longer lived trees.[27] Retaining tree canopy and ground cover reduces the risk of exposure through hand-to-mouth exchange of contaminated soil.[28]

[16] EPA, 1998
[17] Puckette, 2001
[18] EPA, 1998
[19] Puckette, 2001
[20] Puckette, 2001
[21] Puckette, 2001
[22] Black, 1995
[23] EPA, 1998
[24] EPA, 1998
[25] Coder, 1996
[26] Black, 1995
[27] Puckette, 2001
[28] Black, 1995

Desirable Characteristics of Trees for Green Streets

The elements of trees thought to influence how well they reduce the volume and velocity of stormwater runoff, and mitigate pollutants commonly found in stormwater runoff, include:

- persistent foliage
- wide-spreading canopies
- long-lived
- fast growing
- tolerant of summer drought
- tolerant of winter inundation or saturated soils
- resistant to urban pollutants (air and water)
- tolerant of poor soils
- extensive root systems
- rough bark
- tomentose or dull foliage surface
- vertical branching structure
- dense canopies.

Although there is minimal research about how these characteristics influence a tree's ability to reduce the volume and velocity of stormwater runoff and improve the quality of runoff, these characteristics have been used as a preliminary mechanism for selecting street trees for green streets. As more species-specific data is collected for the Pacific Northwest, particularly in urban areas, these characteristics can be tested and other characteristics identified.

Persistent Foliage

Many broadleaf evergreens and conifers are better stormwater performers simply because they do not lose their leaves during the rainy season. Broadleaf evergreens such as Southern magnolia *(magnolia grandiflora)* retain their leaves through the winter, providing large dense canopies for slowing rainfall. Broadleaf evergreens, unlike conifers, are more accepted as street trees although they are not very common along Portland streets.

Conifers are not popular street trees because they often are seen as potential hazards because of their size. They also do not allow solar access in the winter and may uproot during windstorms if planted in a space that is too small. Young conifers typically have low branches that obstruct views and paths. Despite these drawbacks, conifers are native to the Pacific Northwest and can be accommodated along street rights of way where planting areas are wide enough and appropriately designed.

In the winter, when deciduous trees do not have leaves, they still capture some rainfall on their branches, where it flows toward the trunk and into the ground (stemflow). Some deciduous trees, such as pin oak *(Quercus palustris)* and sweetgum *(Liquidambar styraciflua)*, hold their leaves well into the winter months, providing a canopy with more surface area than those that lose their leaves. However, during years of early snowfall, these trees can become dangerous as their limbs succumb to the weight of the snow.

Wide-Spreading Canopies

Street trees with wide-spreading canopies provide more shade over impervious surfaces and intercept more rainfall. Trees with significant canopy spreads (30 feet) can significantly reduce the volume and velocity of stormwater runoff by temporarily holding water in the canopy layer.

Long-Lived

Trees that are long-lived will provide more stormwater benefits over time simply because they are alive longer. The conditions in which trees are planted influence how long they will live, how large they will grow, how healthy they will be and how much short and long-term maintenance they will need. Long-lived trees are those that live more than 100 years, which is optimistic for an urban tree; however, green street designs are creating ideal conditions for healthy tree growth, so it is assumed that street trees will live longer along green streets.

Fast Growers

Trees that achieve their mature size (height/spread) quickly will potentially intercept more rainfall for longer period of time, particularly if they are also long-lived trees. It is difficult to find tree species that both grow fast and live long.

Tolerate Portland Summer Drought

Unlike many East Coast and Midwest cities, Portland does not have heavy summer rain. Most of Portland's rainfall is in the winter, and is light and persistent. Trees that tolerate Portland summer drought are preferred because after the first three years of planting, street trees receive very little care, such as watering during the summer. If trees are planted in areas with considerable soil volume and good soil structure, they will form more extensive roots systems and be able to better tolerate drought.

Tolerate Portland Winter Inundation or Saturated Soils

If stormwater runoff is being directed to planter strips (the area between the sidewalk and the curb), these areas will become saturated more quickly. Finding street trees that can tolerate saturated soils, and potentially inundation, between November and May will have a better chance of survival. In addition to being able to tolerate summer drought, trees that can tolerate Portland's winter moisture are preferred. In the green street designs, stormwater runoff from streets is directed to the planter strip, where trees are planted. Although these areas are designed to infiltrate water, Portland receives enough rain from November to May to keep soils saturated. Trees that can tolerate saturation and periodic inundation will thrive in these areas.

Tolerate Urban Pollutants

Trees that can tolerate both air- and water-borne pollutants will live longer in urban areas then those that cannot. The green street designs direct stormwater runoff that contains numerous chemical constituents that could be harmful to trees. For this reason, trees that can tolerate this pollution are preferred. Pollutants commonly found on streets and stormwater runoff include:

- lead
- copper
- mercury
- nickel
- zinc
- sediment
- polyaromatic hydrocarbons
- oil and grease
- excess nitrogen and phosphorous
- trash and leaf debris.

These contaminants are the primary cause of urban water quality problems. The primary source of these contaminants is automobiles. Reducing the impact of automobiles on water quality requires, among other things, improved street designs that capture, infiltrate and treat stormwater runoff. Common air pollutants are sulfur dioxide, nitrous oxide and carbon monoxide. Some urban trees can absorb gaseous pollutants such as ozone, nitrogen oxides and sulfur dioxide through leaf surfaces. Trees also intercept dirt, smoke, dust and other airborne particulates.

Tolerate Poor Soils

Poor soils are those that are compacted, nutrient deficient or poorly drained. The primary cause of street tree decline is soil compaction. It is important to provide trees with appropriate soil volume and organic material to encourage proper drainage. Mulching around trees can also improve moisture retention and biological activity in the soil. Tree species that can tolerate poor soils are more likely to survive urban conditions where proper soil volumes and structure are not implemented. Green streets are designed for stormwater management, which requires nutrient-rich, well-drained soils; however, existing urban streets have poor soil conditions that are difficult to rebuild without damaging the tree.

Extensive Root Systems

In typical clay-loam soils, nearly 99 percent of all roots are within the top three feet of soil[29] (varies by species). However, for stormwater purposes trees with deep roots or extensive root systems are preferred because they improve soil porosity and drainage and are more likely to tolerate drought. Trees with extensive root systems can access water within the soil profile that is typically not available to plants, and use water more efficiently, which in turn prevents or postpones drought injury.[30]

Feeder roots, which account for the major fraction of the surface of a tree's root system, take up water and nutrients that are essential for healthy tree growth.[31] The value of the root zone to a tree's long-term health should not be underestimated, and the planter strip should be designed with an emphasis on soil volume and structure, drainage and microbial activity and nutrient availability. Soil volume and quality will determine how long trees will survive and how much stress they will endure during their lifetime. Typically, a large tree needs up to 150 cubic meters of soil.[32]

The availability of water is the single most important factor limiting growth and distribution of tree roots.[33] Therefore, when designing planting areas for stormwater treatment and infiltration, it is important to maintain the porosity of the soil. In order to maintain soil porosity, nutrients must be replenished through the natural breakdown of organic material, which can be accomplished by mulching leaf debris around trees. The presence of mycorrhizal fungi improve the uptake of nitrogen, phosphorous and potassium because of the improved hyphae and rhizomorphs extending into the soil.[34] Mycorrhizal fungi can be injected into the soil, however, it is important to determine the appropriate type for each species.

Rough Bark

The texture of a tree's bark determines how quickly water flows down the trunk and into the ground. A tree with rough bark may have higher interception and absorption rates, as intercepted rainfall gets trapped in the many fissures and plates associated with rough bark. Water will flow more quickly across a tree with smooth bark, although the significance of this increased flow rate is unknown and potentially negligible. In addition, most trees have smooth bark when they are young and on new branches.

Dull or Tomentose Foliage Surface

Foliage that is dull or hairy (tomentose) has the potential to detain more water for a longer period of time than those with glossy or leathery surfaces.

Vertical Branching Structure

Trees with vertical branches capture rainfall and direct it toward the trunk, where it slowly infiltrates into the soil. This type of flow pattern, called stemflow, results in reduced flow rates and volume reduction by allowing more opportunities for absorbing rainfall. However, it is important that the tree also achieve a wide-spreading canopy, which may mean that it has horizontal branches. A tree with horizontal branches creates more canopy drip and potentially more soil erosion.

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[29] Thomas, 2000
[30] Cannell and Last, 1976
[31] Thomas, 2000
[32] Thomas, 2000
[33] Zimmerman and Brown, 1974
[34] Zimmerman and Brown, 1974

Dense Canopies

It is assumed that large leaf surfaces and/or dense canopies (many little leaves for example) improve interception when rainfall is light and persistent. Leaf area can be calculated using readily available information about leaf dimensions. Most encyclopedias or field identification manuals provide information about leaves size and structure, although it is difficult to translate this information into total surface area of a mature canopy. Leaf area index is a measure of the area of leaf surface per unit area of ground surface and is commonly used to determine evapotranspiration rates.

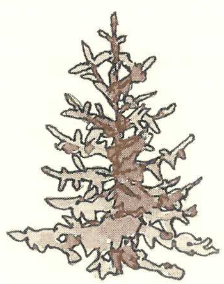
A note about native tree species

Planting native plants ensures the continued viability and diversity of indigenous animal and plant communities by providing habitat, food and protection and other symbiotic relationships between different adapted species. This may be critical for the long-term survival of native species that are threatened or endangered.

Planting native plants generally increases the chance for long-term health and survival of the plant because these species are naturally adapted to local conditions. This natural adaptation also means native trees typically require less maintenance. When planted along streets, native trees should be clustered with other native plants commonly found in Portland's plant communities and provided plenty of room to grow. The typical linear structure of planting strips can be adjusted to allow for a more natural planting scheme.

Providing enough space for native trees along streets can enhance the biodiversity of urban ecosystems. Planting native plant communities along streets can help to restore biodiversity inherent in natural systems. Native species are strongly encouraged for the planting strip when streets are located in or adjacent to ecologically sensitive areas such as wetlands or stream corridors.

In addition to their environmental benefits, native trees provide us with a "sense of place," which in turn helps urban residents reconnect with the natural heritage of the Pacific Northwest Bioregion and provides opportunities for urban communities to become stewards of their native street-side natural area.



Douglas fir
(Pseudotsuga menziesii)

Evaluation of Characteristics of Trees for Green Streets

Foliage persistence: Evergreens retain their canopy in the winter, when the Portland metropolitan area receives most of its rainfall

Height/spread (at maturity in favorable conditions): Wide-spreading trees intercept more rainfall

Longevity: Long > 100 years; medium @100 years; short < 100 years. Long-lived trees provide more benefit over time

Rate of growth: Fast-growing trees achieve height/spread quickly, which improves interception potential

Tolerates Portland summer drought: Trees that can survive drought conditions from June through September have a higher chance of survival (particularly if they can also handle winter saturation)

Tolerates Portland winter inundation or saturated soils: Runoff is being directed to planting area, so trees need to be able to handle saturated conditions from November to May (see comments above).

Tolerates urban pollutants: Both air and water borne pollutants, such as sulfur dioxide and hydrocarbons

Tolerates poor soils: Soils that are compacted, nutrient deficient and somewhat poorly drained

Root pattern: Pattern attained under ideal soil conditions (root pattern varies with soil compaction, structure and nutrient and water availability). Trees with extensive root systems absorb more water.

Bark texture (at maturity): Rough bark surfaces have the potential to capture and absorb more water, particularly on deciduous trees in the winter when they have no leaves

Foliage surface: Tomentose (hairy) and dull leaf surfaces hold more water then glossy surfaces

Canopy structure (at maturity): Trees with dense canopies and vertical branches intercept more rainfall

Native to metro region: Natives are encouraged particularly in environmental zones

Street Tree Characteristics Chart

Oregon icon is used to highlight trees native to the Portland metropolitan region

Blank cells indicate no available information

All references in reference section

Common name	Botanical name	Foliage: deciduous, evergreen, persistent	Native to Portland metro region	Height/spread	Longevity: short, medium, long	Rate of growth: fast, medium, slow	Tolerates Portland summer drought	Tolerates winter inundation or saturated soils	Tolerates urban pollutants: good, average, poor	Tolerates poor soils: good, average, poor	Root pattern: shallow, extensive	Bark texture: rough, smooth	Foliage surface: glossy, dull, tomentose	Canopy structure: vertical/ horizontal:opn/dense	Comments
Small trees (up to 25 feet in height)															
Vine maple	*Acer circinatum*	d	yes	20/10	short	fast	no	yes	average	good	shallow	smooth	dull	v:d	
Western serviceberrry	*Amelanchier alnifolia*	d	yes	25/25	short	slow	no	yes	average	good	shallow	smooth	dull	v:d	
Eastern redbud	*Cercis canadensis*	d	no	25/30	med.	slow	yes	yes	good	good	shallow	rough	dull	v:o	
Medium trees (30-40 feet in height)															
American hornbeam	*Carpinus caroliniana*	d	no	35/35	med.	slow	yes	yes	good	good	extensive	smooth	dull	h:d	
Southern catalpa	*Catalpa bignonioides*	d	no	40/30	med.	fast	no	yes	good	good	extensive	rough	dull	v:o	messy
American yellowwood	*Cladrastis kentuckea*	d	no	40/35	short	slow	yes	no	poor	good	extensive	smooth	dull	h:o	roots, branches may split and crack during storms
Flowering dogwood	*Cornus florida*	d	no	30/30	med.	slow	yes	yes	poor	good	shallow	rough	glossy	h:d	susceptible to anthracnose
Black hawthorne	*Crataegus douglasii*	d	yes	35/25	med.	med.	yes	yes	good	good	extensive	rough	glossy	v:d	
Golden rain	*Koelreuteria paniculata*	d	no	30/30	med.	med..	yes	yes	good	good	extensive	rough	dull	v:d	
Western crabapple	*Malus fusca*	d	yes	30/35	short	med..	yes	yes	average	good	shallow	rough	glossy	h:d	
Bitter cherry	*Prunus emarginata*	d	yes	30/20	med.	med.		yes	good	yes	shallow	rough	glossy	h:o	
Cascara	*Rhamnus purshiana*	d	yes	40/25	short	slow	no	yes	poor	good	shallow	smooth	glossy	h:d	
Blue elderberry	*Sambucus cerulea*	d	yes	30/20	short	slow	yes	yes	average	good	extensive	rough	dull	h:d	
Large trees (more than 50 feet in height)															
Grand fir	*Abies grandis*	e	yes	100/40	long	med.	yes	yes	average	good	extensive	rough	dull	v:d	
Big leaf maple	*Acer macrophyllum*	d	yes	100/75	med.	fast	yes	yes	average	poor	shallow	rough	glossy	h:d	leaves play important role enriching the soil
Norway maple (cultivars only)	*Acer platanoides*	d	no	50/30	long	fast	yes	yes	good	good	shallow	rough	glossy	v:d	
Sycamore maple	*Acer pseudoplatanus*	d	no	60/50	long	med.	yes	yes	good	good	shallow	rough	dull	v:o	
Red maple	*Acer rubrum*	d	no	50/40	med.	fast	yes	yes	good	average	extensive	rough	dull	v:d	
Sugar maple	*Acer saccharum*	d	no	60/35	long	med.	no	yes	good	average	shallow	rough	dull	h:d	
White alder	*Alnus rhombifolia*	d	no	70/30	short	fast	yes	yes	good	good	shallow	rough	dull	v:d	captures nitrogen, recycles nutrients; falls apart
Red alder	*Alnus rubra*	d	yes	50/25	short	fast	no	yes	good	good	shallow	smooth	glossy	v:d	captures airborne nitrogen and makes available in soil
River birch	*Betula nigra*	d	no	60/40	med.	fast	no	yes	poor	good	shallow	rough	glossy	v:o	

Street Tree Characteristics Chart

Oregon icon is used to highlight trees native to the Portland metropolitan region

Blank cells indicate no available information

All references in reference section

Common name	Botanical name	Foliage: deciduous, evergreen, persistent	Native to Portland metro region	Height/spread	Longevity: short, medium, long	Rate of growth: fast, medium, slow	Tolerates Portland summer drought	Tolerates winter inundation or saturated soils	Tolerates urban pollutants: good, average, poor	Tolerates poor soils: good, average, poor	Root pattern: shallow, extensive	Bark texture: rough, smooth	Foliage surface: glossy, dull, tomentose	Canopy structure: vertical/horizontal:open/dense	Comments
Large trees (more than 50 feet in height)															
Paperbark birch	*Betula papyrifera*	d	no	50/35	short	fast	no	no	average	poor	shallow	smooth	dull	h:o	bark is water resistant
European hornbeam	*Carpinus betulus*	d	no	50/50	long	med.	yes		good	good	extensive	smooth	glossy	v:d	
Western catalpa	*Catalpa speciosa*	d	no	60/35	med.	fast	yes	yes	good	good	extensive	rough	dull	v:d	messy
Deodar cedar	*Cedrus deodara*	e	no	80/60	long	med.	yes	yes	good	average	extensive	rough	dull	h:d	
Atlas cedar	*Cedrus libani ssp. atlantic*	e	no	60/60	long	med.	yes	yes	good	good	extensive	rough	dull	h:d	
Common hackberry	*Celtis occidentalis*	d	no	60/35	long	med.	yes	yes	good	good	extensive	rough	glossy	v:o	
Pacific dogwood	*Cornus nutallii*	d	yes	50/20	med.	med.	yes	no	poor	poor	extensive	smooth	glossy	v:o	susceptible to Anthracnose
European beech	*Fagus slyvatica*	d	no	100/60	long	fast	yes	no	good	poor	shallow	smooth	glossy	h:d	
White ash	*Fraxinus americana*	d	no	70/60	long	med.	yes	yes	average	poor	shallow	rough	dull	v:d	
Oregon ash	*Fraxinus latifolia*	d	yes	50/30	med.	med.	yes	yes	average	good	shallow	rough	tom	v:o	
Green ash	*Fraxinus pennsylvanica*	d	no	60/40	med.	fast	no	yes	good	good	shallow	rough	dull	h:d	
Ginkgo	*Ginkgo biloba (male only)*	d	no	60/30	long	slow	yes	yes	good	good	extensive	rough	dull	v:d	
Thornless honeylocust	*Gleditsia triacanthos inermis*	d	no	80/40	med.	fast	yes	yes	good	good	extensive	rough	dull	v:o	
Sweetgum	*Liquidambar styraciflua*	d	no	80/40	long	med.	yes	yes	good	good	shallow	rough	dull	v:d	messy
Tulip tree	*Liriodendron tulipifera*	d	no	90/40	long	med.	yes	no	good	good	extensive	rough	glossy	h:d	
Southern magnolia	*Magnolia grandiflora*	e	no	80/60	med.	slow	yes	no	good	average	shallow	rough	glossy	h:d	messy
Tupelo	*Nyssa sylvatica*	d	no	60/40	med.	slow	yes	yes	good	good	extensive	rough	glossy	h:d	
Sitka spruce	*Picea sitchensis*	e	no	150/80	long	med.	yes	yes	poor	good	shallow	rough	dull	h:o	
Ponderosa pine (W. Valley)	*Pinus ponderosa*	e	yes	150/80	long	slow	yes	yes	poor	poor	extensive	rough	dull	h:o	
London plane	*Platanus x acerifolia*	d	no	100/65	long	fast	yes	yes	good	good	shallow	rough	dull	h:d	
Balsam poplar	*Populus balsamifera*	d	no	100/30	short	fast	no	yes	good	good	shallow	rough	glossy		
Black cottonwood	*Populus balsamifera ssp. trichocarpa*	d	yes	100/30	short	fast	yes	yes	good	good	shallow	rough	glossy		stores large quantities of water
Hybrid black poplar	*Populus x canadensis*	d	no	100/35	short	fast	no	yes	good	good	shallow	rough	glossy		
Douglas fir	*Pseudotsuga menziesii*	e	yes	120/40	long	med.	yes	yes	good	good	shallow	rough	dull	h:o	

Street Tree Characteristics Chart

Oregon icon is used to highlight trees native to the Portland metropolitan region

Blank cells indicate no available information

All references in reference section

Common name	Botanical name	Foliage: deciduous, evergreen, persistent	Native to Portland metro region	Height/spread	Longevity: short, medium, long	Rate of growth: fast, medium, slow	Tolerates Portland summer drought	Tolerates winter inundation or saturated soils	Tolerates urban pollutants: good, average, poor	Tolerates poor soils: good, average, poor	Root pattern: shallow, extensive	Bark texture: rough, smooth	Foliage surface: glossy, dull, tomentose	Canopy structure: vertical/horizontal:open/dense	Comments
Large trees (more than 50 feet in height)															
Swamp white oak	*Quercus bicolor*	d	no	60/45	long	med.	yes	yes	average	good	shallow	rough	glossy	v:d	
Scarlet oak	*Quercus coccinea*	d	no	60/45	long	med.	yes	no	good	average	extensive	rough	glossy	h:o	
Forest green hungarian oak	*Quercus frainetto*	d	no	50/30	long	slow	yes	yes	good	good	extensive	rough	glossy	v:d	
Oregon oak	*Quercus garryana*	d	yes	65/45	long	slow	yes	no	poor	average	extensive	rough	glossy	v:d	
Shingle oak	*Quercus imbricaria*	d	no	50/35	long	slow	no	yes	good	good	extensive	rough	glossy	v:o	leaves persist late into season
Burr oak	*Quercus macrocarpa*	d	no	80/40	long	slow	yes	yes	good	average	shallow	rough	glossy	h:d	
Pin oak	*Quercus palustris*	p	no	70/40	med.	med.	yes	yes	good	average	shallow	rough	glossy	v:d	
Willow oak	*Quercus phellos*	d	no	70/50	long	med.	yes	yes	good	average	extensive	rough	glossy	v:d	
English oak	*Quercus robur*	d	no	60/40	long	med.	yes	yes	good	good	shallow	rough	dull	v:d	
Northern red oak	*Quercus rubra*	d	no	75/50	med.	med.	yes	yes	good	average	extensive	rough	glossy	v:d	
Shumardii oak	*Quercus shumardii*	d	no	70/50	long	med.	yes	yes	good	good	extensive	rough	glossy	h:o	
Pacific willow	*Salix lucida spp.lasiandra*	d	yes	50/30	short	fast	yes	yes	good	poor	shallow	smooth	glossy	h:d	
Chinese scholar tree	*Sophora japonica*	d	no	50/40	long	slow	yes	yes	good	average		rough	dull	v:d	
Bald cypress	*Taxiodium distichum*	d	no	75/40	long	slow	yes	yes	average	good	extensive	rough	dull	h:o	
Western red cedar	*Thuja plicata*	e	yes	100/60	long	slow	yes	yes	good	average	shallow	rough	glossy	h:d	does not like direct sun
American linden	*Tilia americana*	d	no	70/35	med.	med.	no	yes	average	average	shallow	rough	glossy	v:d	attract bees/subject to aphids
Littleleaf linden	*Tilia cordata*	d	no	50/30	long	fast	yes	yes	good	good	extensive	rough	dull	h:d	attract bees/subject to aphids
Bigleaf linden	*Tilia platyphyllos*	d	no	60/60	long	med.	yes	yes	good	good	extensive	rough	dull	v:d	attract bees/subject to aphids
Silver linden	*Tilia tomentosa*	d	no	60/40	med.	fast	yes	yes	good	good	shallow	smooth	dull	v:d	attract bees/subject to aphids
Western hemlock	*Tsuga heterophylla*	e	yes	125/40	long	slow	no	yes	average	average	shallow	rough	glossy	h:d	prefers windscreen
American elm hybrids	*Ulmus hybrids*	d	no	50/50	med.	fast	yes	yes	good	average	extensive	rough	dull	v:d	
Lacebark elm	*Ulmus parvifolia*	d	no	60/50	med.	fast	yes	yes	good	good	med.	rough	dull	h:d	
Oregon myrtle	*Umbellularia californica*	e	no	75/50	long	slow	yes	yes	good	average	extensive	smooth	dull	v:d	
Japanese zelkova	*Zelkova serrata*	d	no	60/40	long	med.	yes		average	good	med.	rough	dull	v:d	

Trees for Green Streets

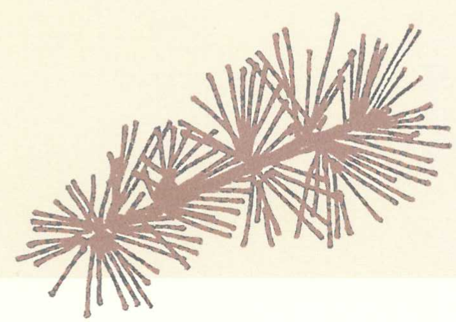
Illustrated species The following species met the top four criteria set by Metro for green streets (wide spreading canopy, long-lived, tolerate Portland summer drought and winter soil saturation):

Common name	Scientific name	Page
White ash	*Fraxinus americana*	21
Western catalpa	*Catalpa speciosa*	22
Deodar cedar	*Cedrus deodara*	23
Western red cedar	*Thuja plicata*	24
Chinese scholar tree	*Sophora japonica*	25
Bald cypress	*Tax odium distichum*	26
Accolade elm	*Ulmus x accolade*	27
Douglas fir	*Pseudotsuga menziesii*	28
Grand fir	*Abies grandis*	29
Ginkgo	*Ginkgo biloba (male only)*	30
Golden rain	*Koelreuteria paniculata*	31
Common hackberry	*Celtis occidentalis*	32
Black hawthorne	*Crataegus douglasii*	33
Bigleaf linden	*Tilia platyphyllos*	34
Littleleaf linden	*Tilia cordata*	35
Thornless honeylocust	*Gleditsia triacanthos finermis*	36
Norway maple	*Acer platanoides*	37
Red maple	*Acer rubrum*	38
Sycamore maple	*Acer pseudoplatanus*	39
Oregon myrtle	*Umbellularia californica*	40
Burr oak	*Quercus macrocarpa*	41
English oak	*Quercus robur*	42
Red oak	*Quercus rubra*	43
Shumardii oak	*Quercus shumardii*	44
Swamp white oak	*Quercus bicolor*	45
Willow oak	*Quercus phellos*	46
Ponderosa pine (W. Valley)	*Pinus ponderosa*	47
London plane	*Platanus x acerifolia*	48
Sitka spruce	*Picea sitchensis*	49
Sweetgum	*Liquidambar styraciflua*	50

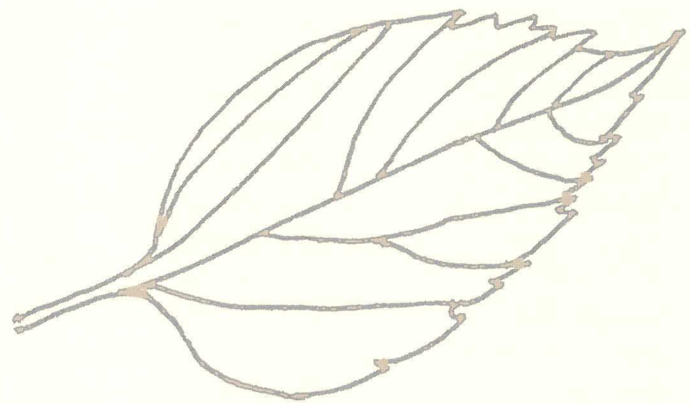
Other good performers

The following species met three out of the four top criteria set by Metro for green streets:

Common name	Scientific name
American ash	*Fraxinus americana*
European beech	*Fagus slyvatica*
Western crabapple	*Malus fusca*
Chinese elm	*Ulmus parvifolia*
Western hemlock	*Tsuga heterophylla*
American hornbeam	*Carpinus caroliniana*
European hornbeam	*Carpinus betulus*
Silver linden	*Tilia tomentosa*
Bigleaf maple	*Acer macrophyllum*
Sugar maple	*Acer saccharum*
Italian oak	*Quercus frainetto*
Oregon white or Garry oak	*Quercus garryana*
Pin oak	*Quercus palustris*
Scarlet oak	*Quercus coccinea*
Shingle oak	*Quercus imbricaria*
Tulip tree or yellow poplar	*Liriodendron tulipifera*
Tupelo, sour gum or black gum	*Nyssa sylvatica*
Japanese zelkova	*Zelkova serrata*



Tree Illustrations

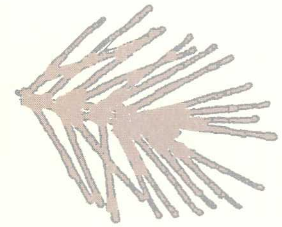


Process for Illustrating Tree Species

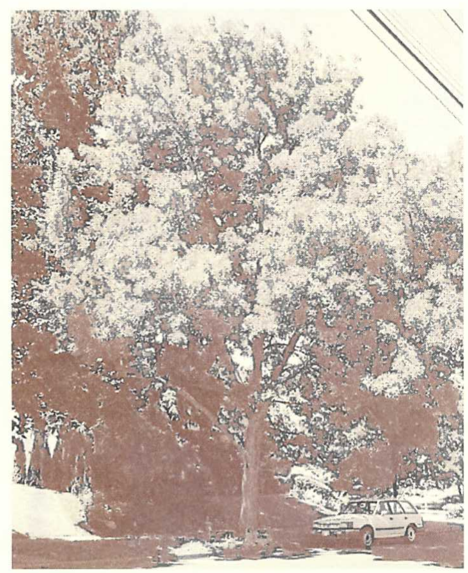
The first step was to determine the relative sizes of 5-year-old and 30-year-old trees for each species. Michael Dirr's estimates were used along with more generous estimates obtained from several local nurseries. Dirr, horticulturist and author of *The Manual of Woody Landscape Plants*, states that slow growth is 12 inches or less per year, medium is 13 inches to 24 inches per year and fast growth is more that 25 inches per year. Oregon's climate allows a faster growth rate than Dirr's Georgia environment. In addition, it was assumed that saplings grow more quickly in youth then when they approach maturity (i.e., growth rate is faster during the younger years).

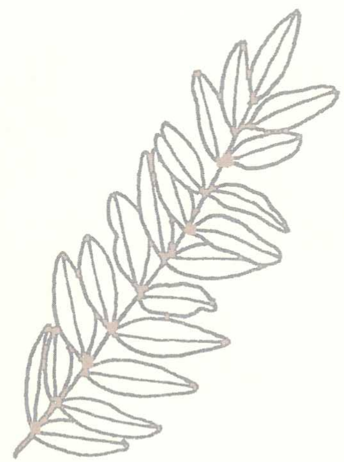
The next step was reviewing illustrations, photos and the Oregon State Unversity web page to determine the form of each tree. A series of sketches were made until a generalized composite form emerged that was representational of the character of the species. There are many factors that determine the size, form and health of a tree including soil conditions, drainage, water availability, light, exposure and root space.

To expedite this process, tracing paper was used to add to the more successful areas. A final graphite sketch of the winter forms of the trees served as a template for each species. A graphite transfer process was used to transfer the drawing onto multi purpose paper. The winter forms were inked and the foliage and trunks were water colored, followed by inking the details such as leaves and needles. Remaining areas of pencil were erased, leaving smooth consistent renderings of the trees.



Douglas fir (Pseudostuga menziesii), *Irvington District*

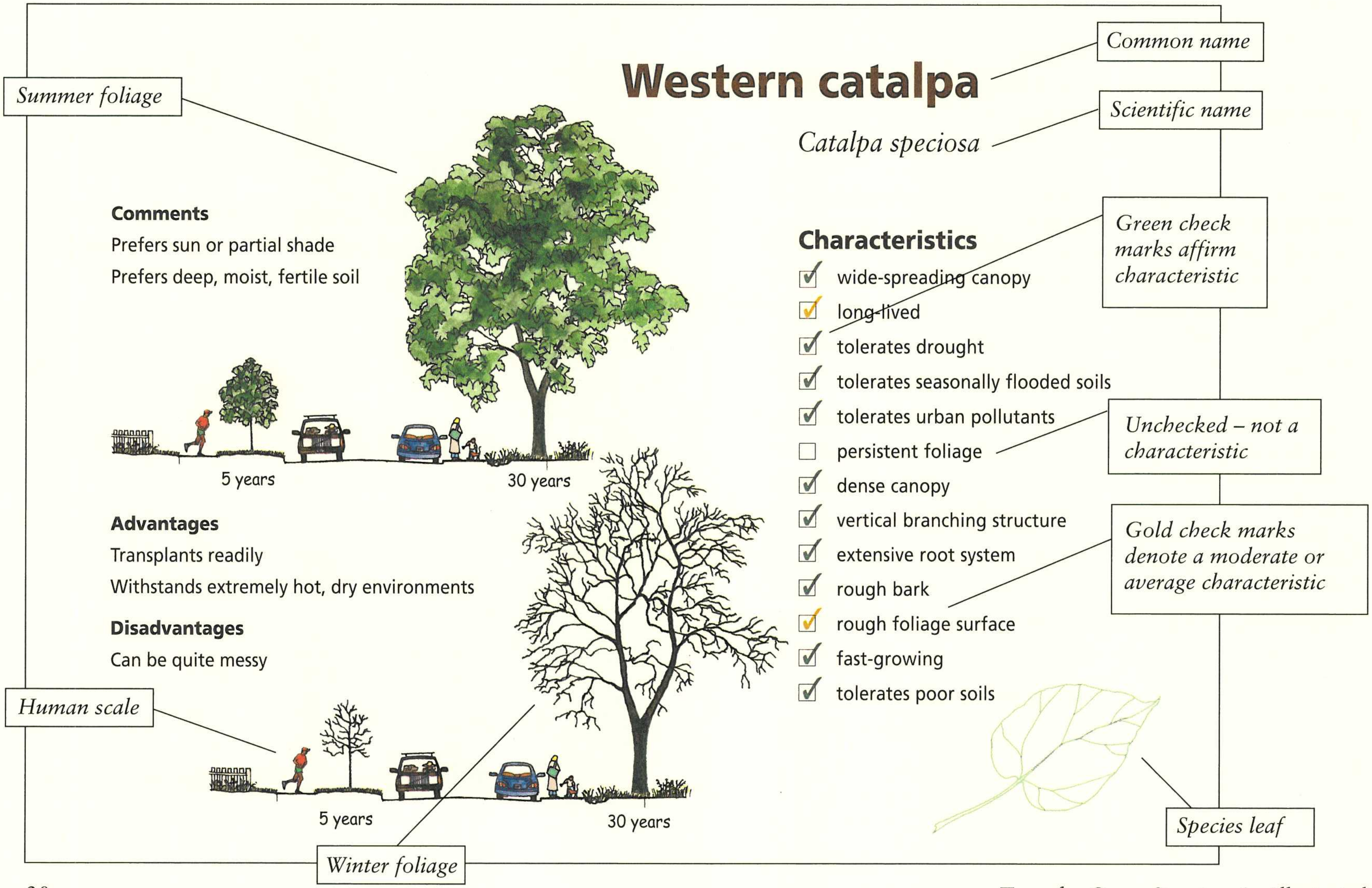




Thornless honeylocust (Gleditsia tiacanthos inermis), *Irvington District*

Using the tree species guide

The best trees for streets in this guide are chosen according to criterion set by Metro for green streets (wide-spreading canopy, long-lived, tolerate Portland summer drought and winter soil saturation). Their characteristics, including their advantages and disadvantages and additional comments, can be found in more detail on pages 14-16 within the street tree characteristics charts.



White ash

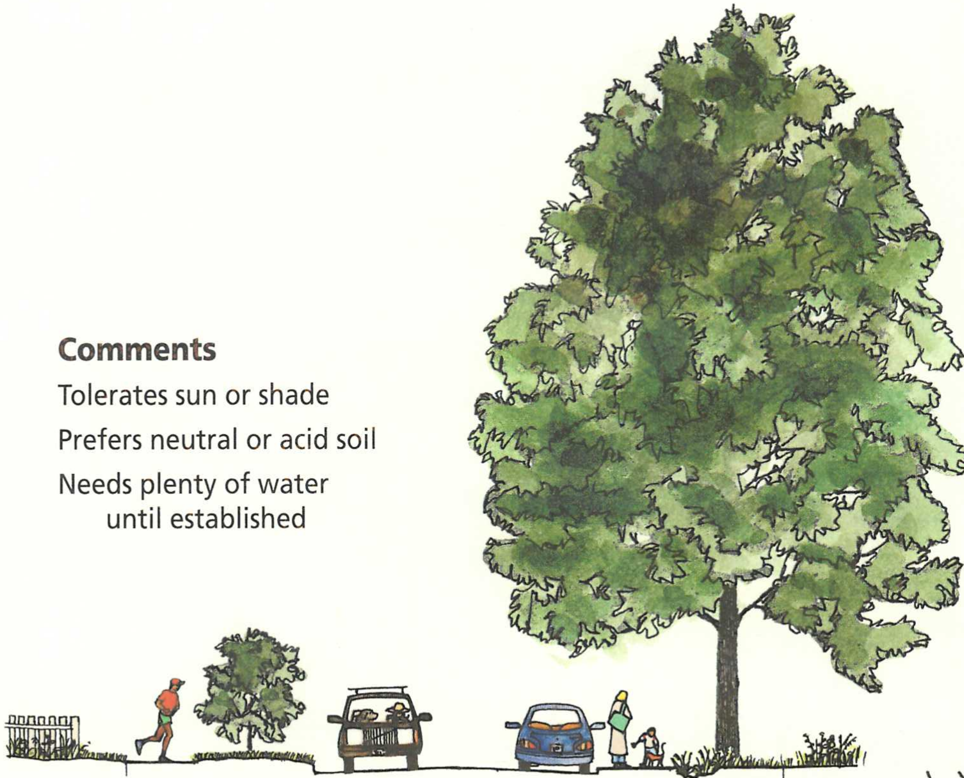
Fraxinus americana

Comments

Tolerates sun or shade

Prefers neutral or acid soil

Needs plenty of water until established



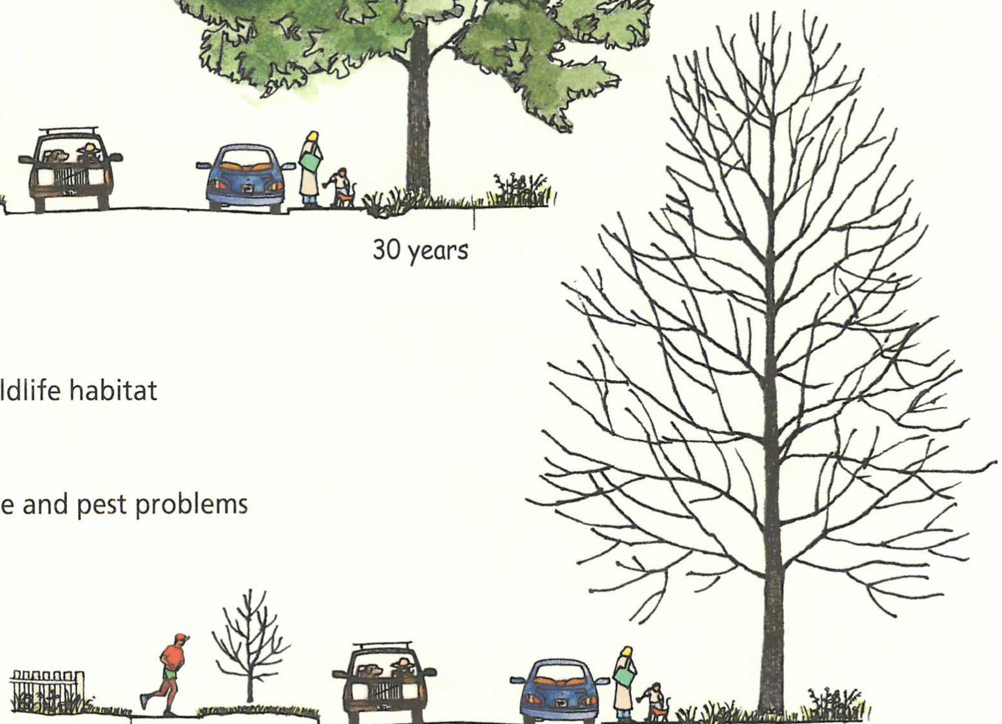
Advantages

Easily transplanted

Provides valuable wildlife habitat

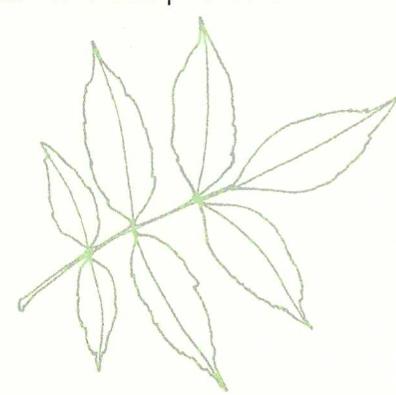
Disadvantages

Susceptible to disease and pest problems



Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
- [x] tolerates urban pollutants
- [ ] persistent foliage
- [x] dense canopy
- [x] vertical branching structure
- [ ] extensive root system
- [x] rough bark
- [x] rough foliage surface
- [x] fast-growing
- [ ] tolerates poor soils



Western catalpa

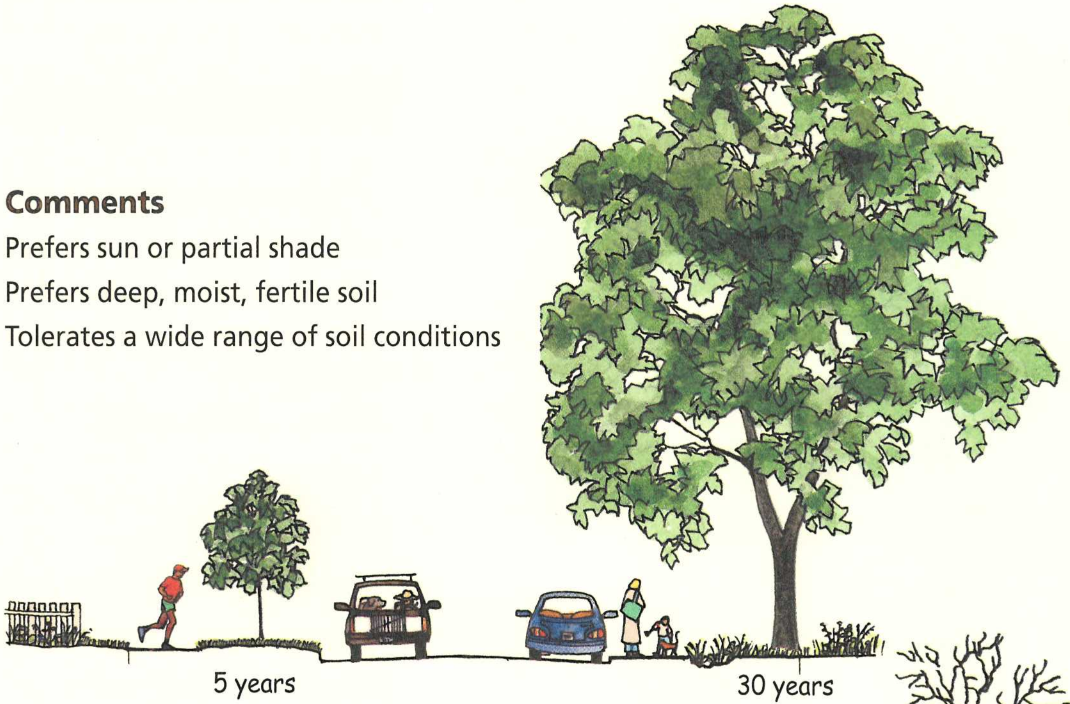
Catalpa speciosa

Comments

Prefers sun or partial shade

Prefers deep, moist, fertile soil

Tolerates a wide range of soil conditions



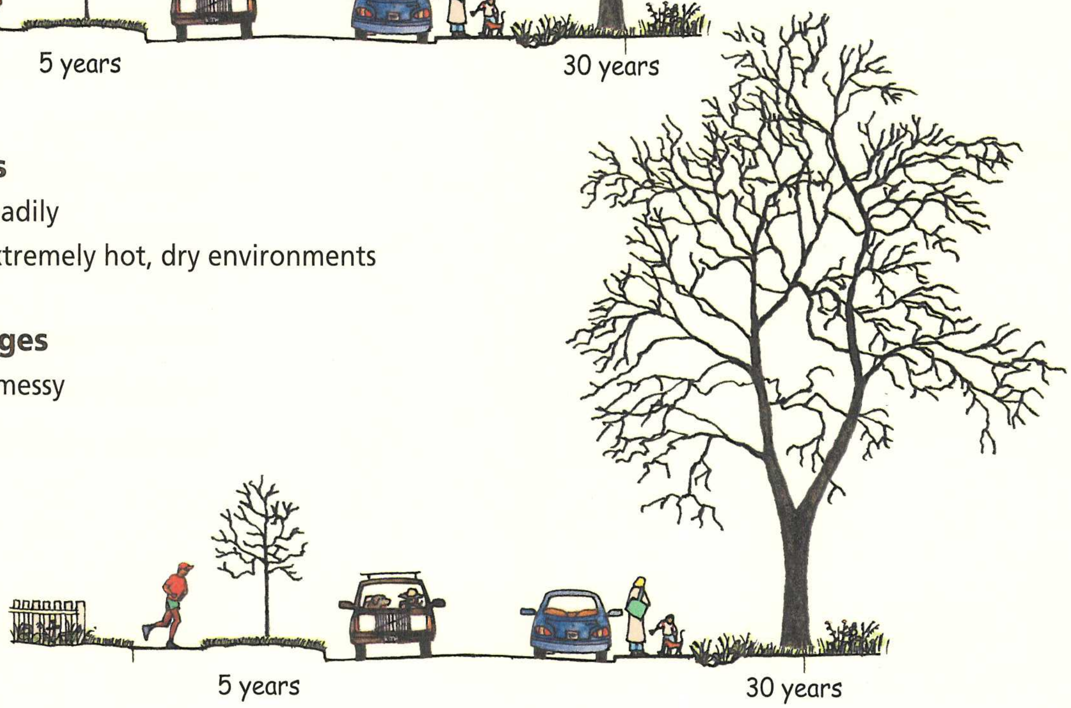
Advantages

Transplants readily

Withstands extremely hot, dry environments

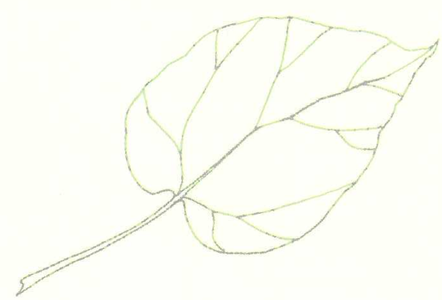
Disadvantages

Can be quite messy



Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
- [x] tolerates urban pollutants
- [ ] persistent foliage
- [x] dense canopy
- [x] vertical branching structure
- [x] extensive root system
- [x] rough bark
- [x] rough foliage surface
- [x] fast-growing
- [x] tolerates poor soils

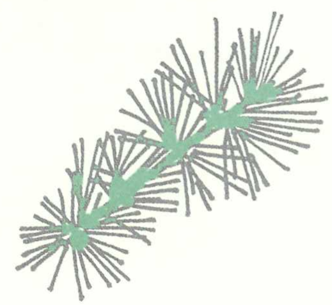


Deodar cedar

Cedrus deodara

Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
- [x] tolerates urban pollutants
- [x] persistent foliage
- [x] dense canopy
- [ ] vertical branching structure
- [x] extensive root system
- [x] rough bark
- [x] rough foliage surface
- [x] fast-growing
- [x] tolerates poor soils



Comments

Tolerates sun or partial shade

Prefers deep, well-drained, fairly rich loam with a moderate amount of moisture

Prefers acid soil, tolerates alkaline soils

Advantages

Cold hardy and ice resistant

Disadvantages

Older trees may be damaged by wet, heavy snow

Western red cedar

Thuja plicata

Comments

Prefers shade, tolerates partial sun

Tolerates wide range soil moisture and nutritional content

Prefers moist, well-drained sites

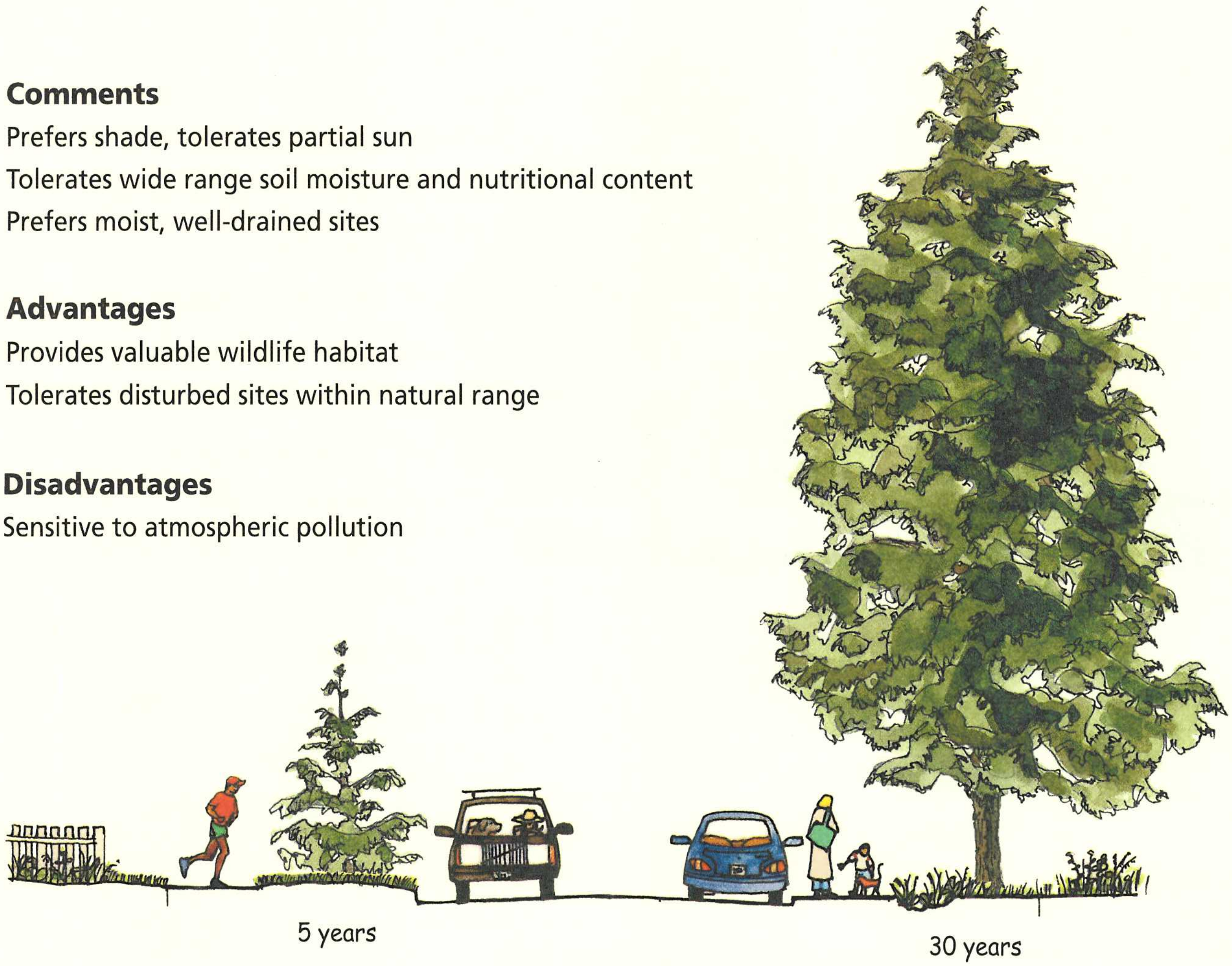
Advantages

Provides valuable wildlife habitat

Tolerates disturbed sites within natural range

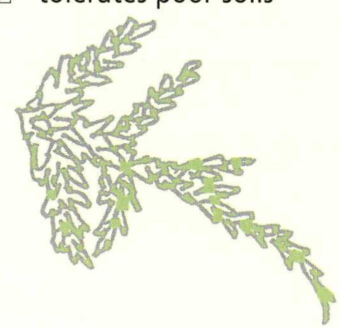
Disadvantages

Sensitive to atmospheric pollution



Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
- [x] tolerates urban pollutants
- [x] persistent foliage
- [x] dense canopy
- [ ] vertical branching structure
- [ ] extensive root system
- [x] rough bark
- [ ] rough foliage surface
- [ ] fast-growing
- [x] tolerates poor soils



Chinese scholar tree

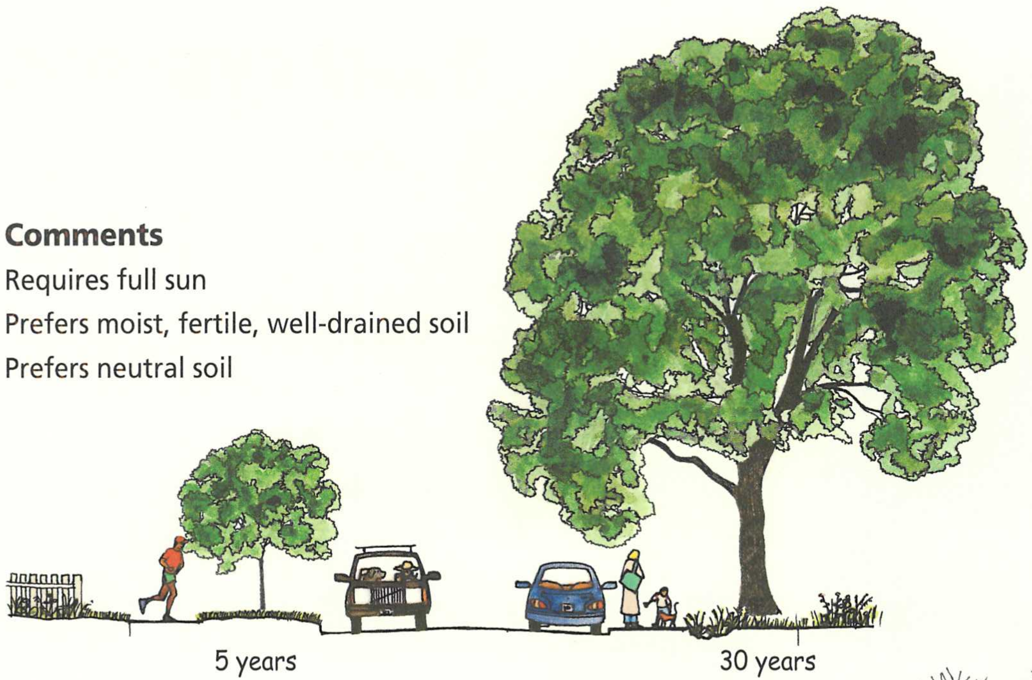
Sophora japonica

Comments

Requires full sun

Prefers moist, fertile, well-drained soil

Prefers neutral soil

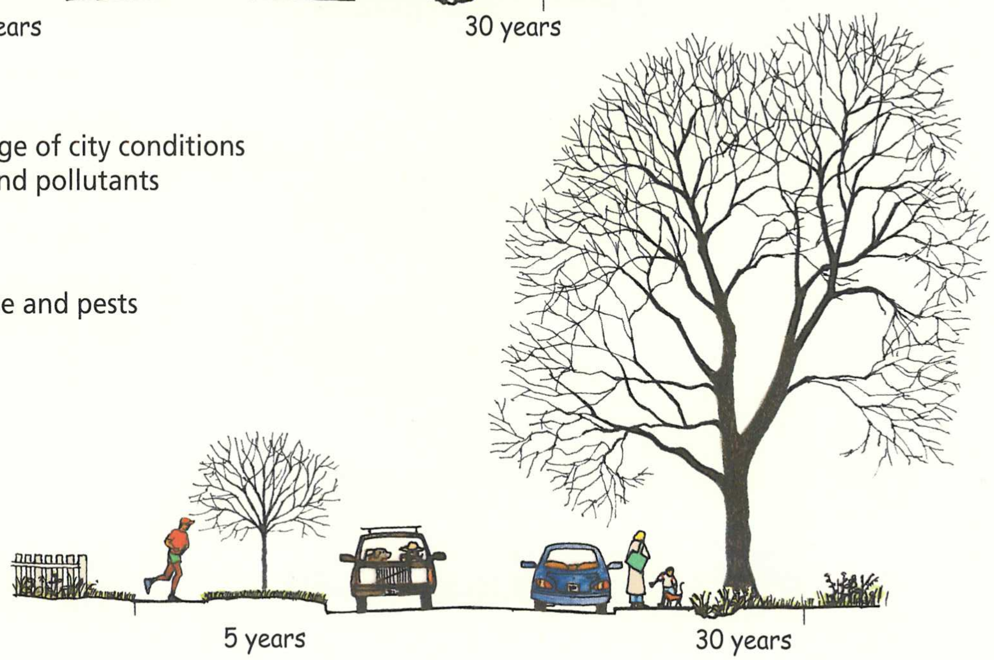


Advantages

Tolerates a wide range of city conditions including heat and pollutants

Disadvantages

Susceptible to disease and pests



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- [x] rough bark
- [x] rough foliage surface
- [ ] fast-growing
- [x] tolerates poor soils

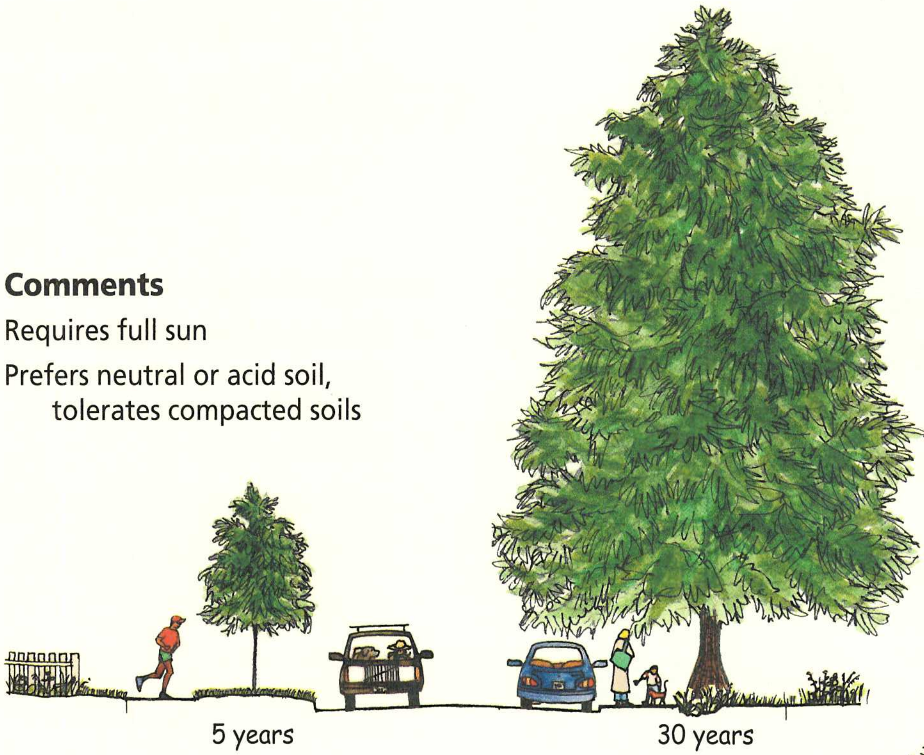
Bald cypress

Taxiodium distichum

Comments

Requires full sun

Prefers neutral or acid soil,
tolerates compacted soils



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- [x] rough bark
- [x] rough foliage surface
- [ ] fast-growing
- [x] tolerates poor soils

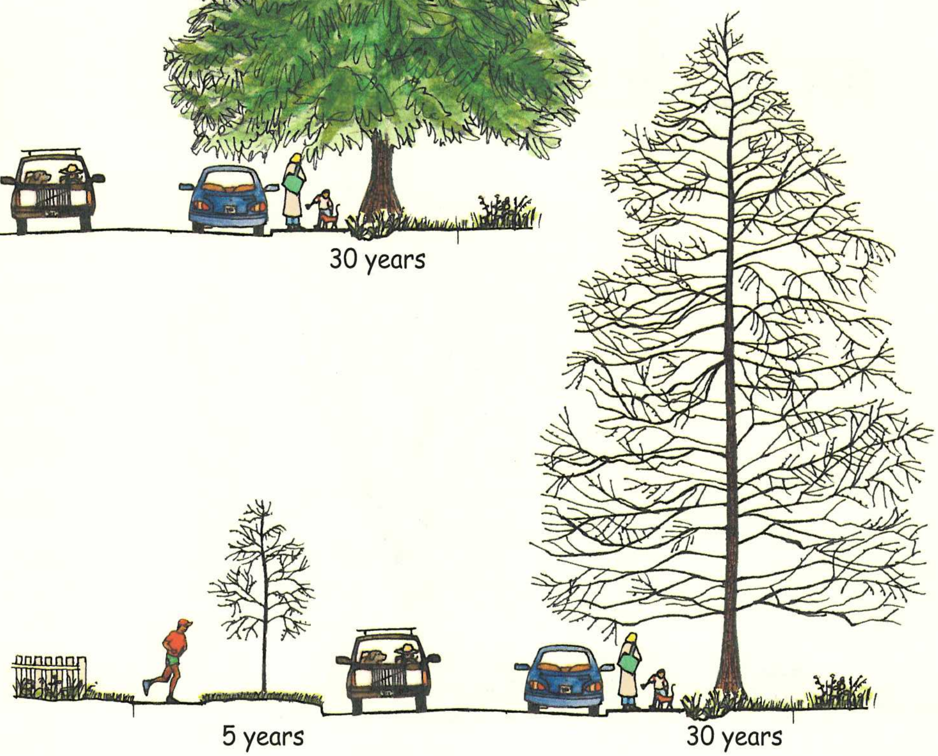
Advantages

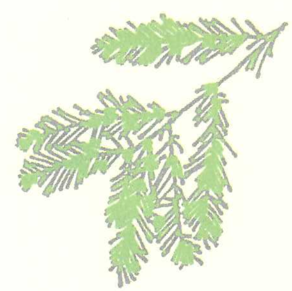
Resists disease and pests

Tolerates wet sites

Disadvantages

Intolerant to shade





'Accolade' elm

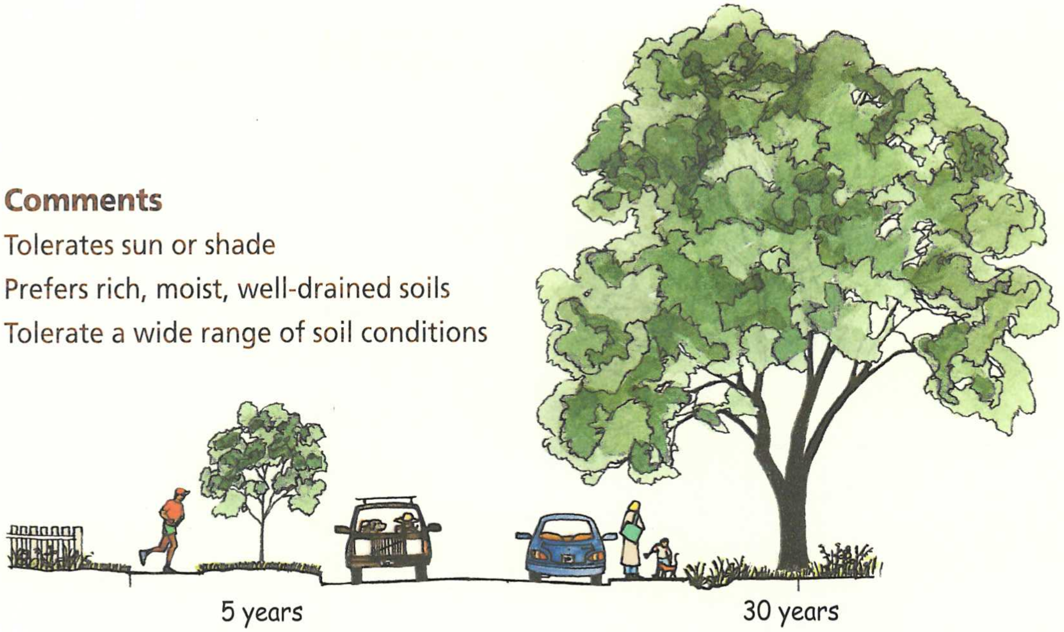
Ulmus hybrids

Comments

Tolerates sun or shade

Prefers rich, moist, well-drained soils

Tolerate a wide range of soil conditions



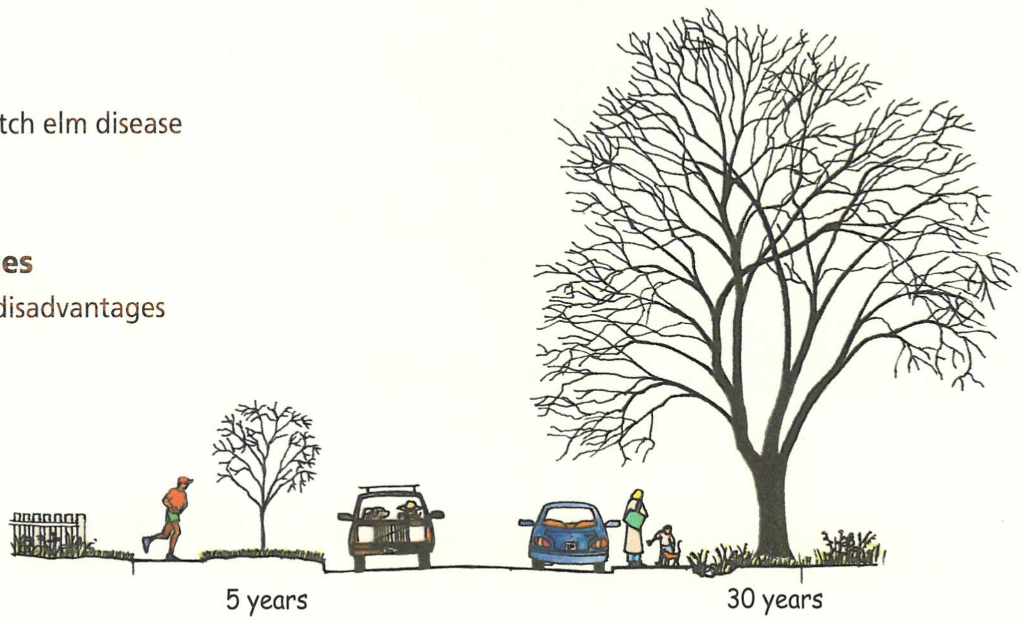
Advantages

Resistant to dutch elm disease

Tolerates salt

Disadvantages

No significant disadvantages



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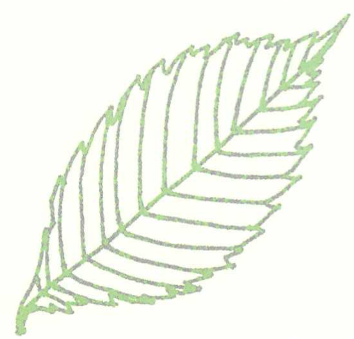


Douglas fir

Pseudotsuga menziesii

Comments

Prefers sun, tolerates sun or shade

Prefers neutral or slightly acid, well-drained, moist soils; tolerates a wide range of soil conditions

Prefers high atmospheric moisture levels

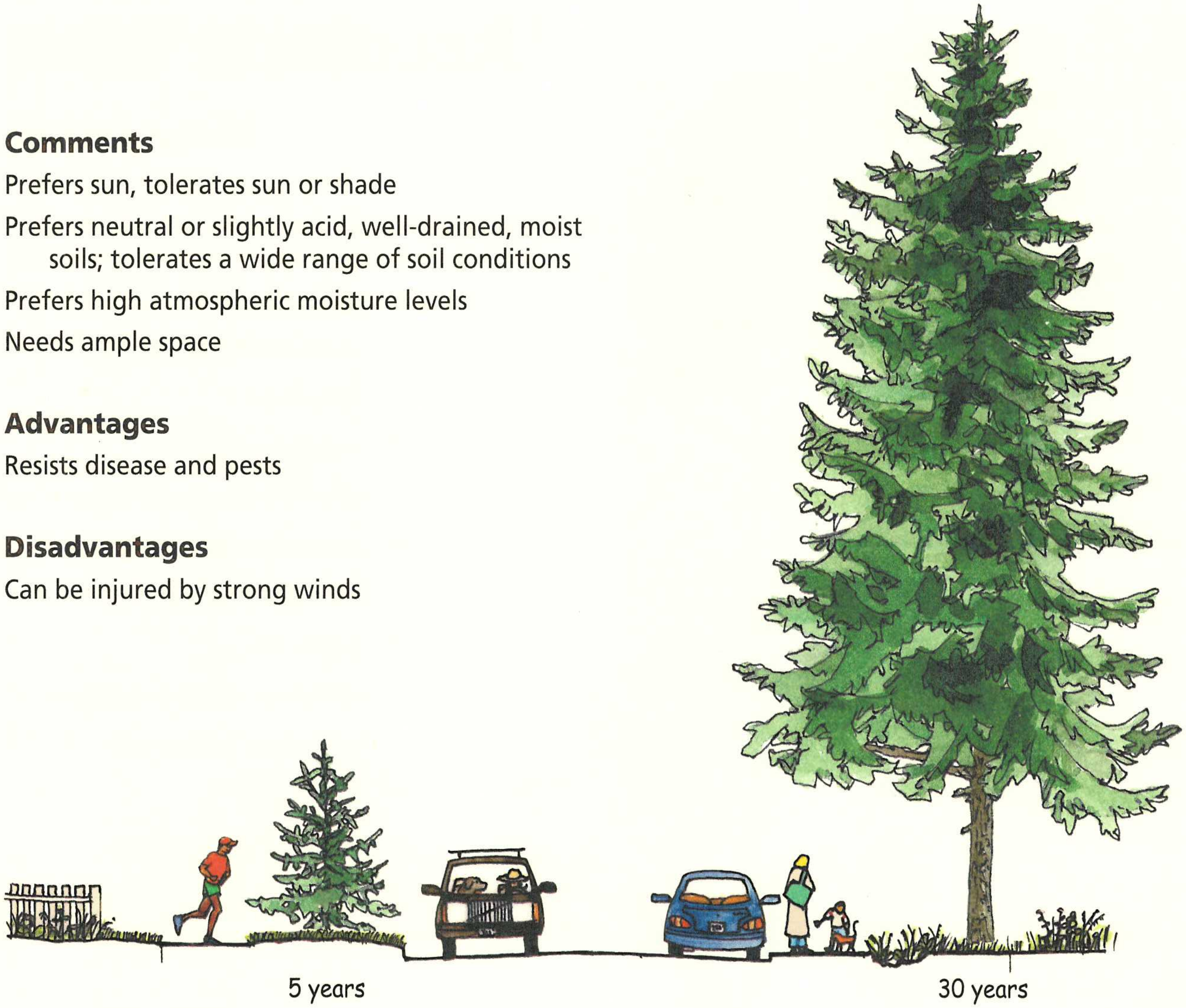
Needs ample space

Advantages

Resists disease and pests

Disadvantages

Can be injured by strong winds



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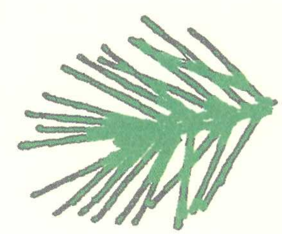

Grand fir

Abies grandis

Characteristics

- ☑ wide-spreading canopy
- ☑ long-lived
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- ☑ tolerates seasonally flooded soils
- ☑ tolerates urban pollutants
- ☑ persistent foliage
- ☑ dense canopy
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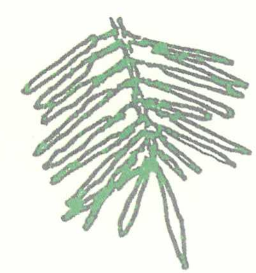
- ☑ fast-growing
- ☑ tolerates poor soils



Comments

Prefers full to partial sun, tolerates shade

Prefers moist, well-drained soils

Needs ample space

Prefers high atmospheric moisture

Crown becomes rounded in older trees

Advantages

Resists disease and pests

Disadvantages

Does not tolerate air pollution

Ginkgo

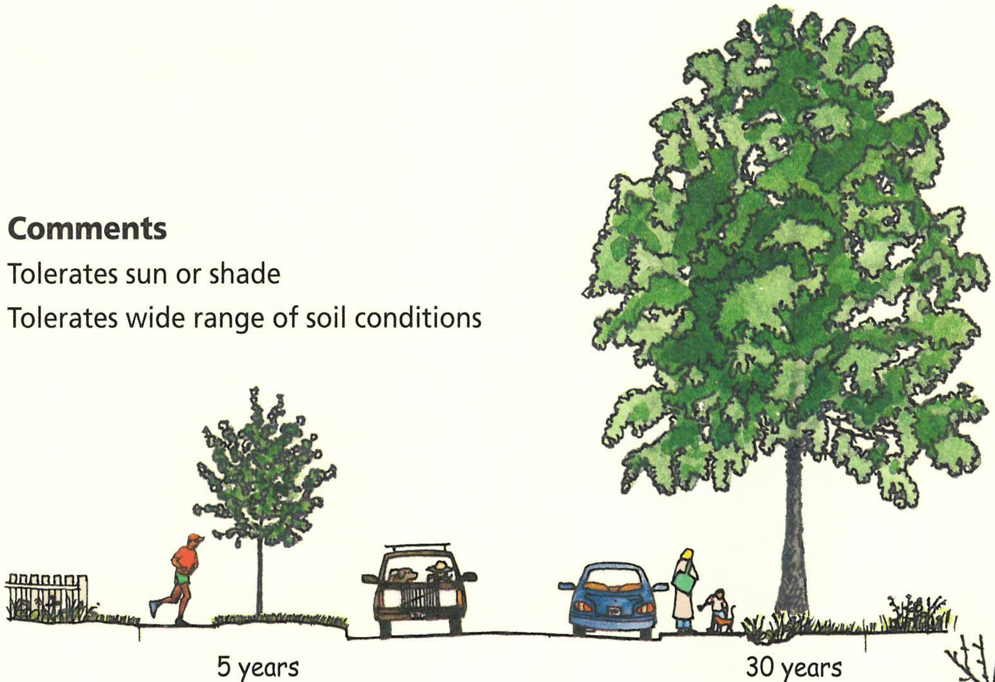
(male only)

Ginkgo biloba

Comments

Tolerates sun or shade

Tolerates wide range of soil conditions

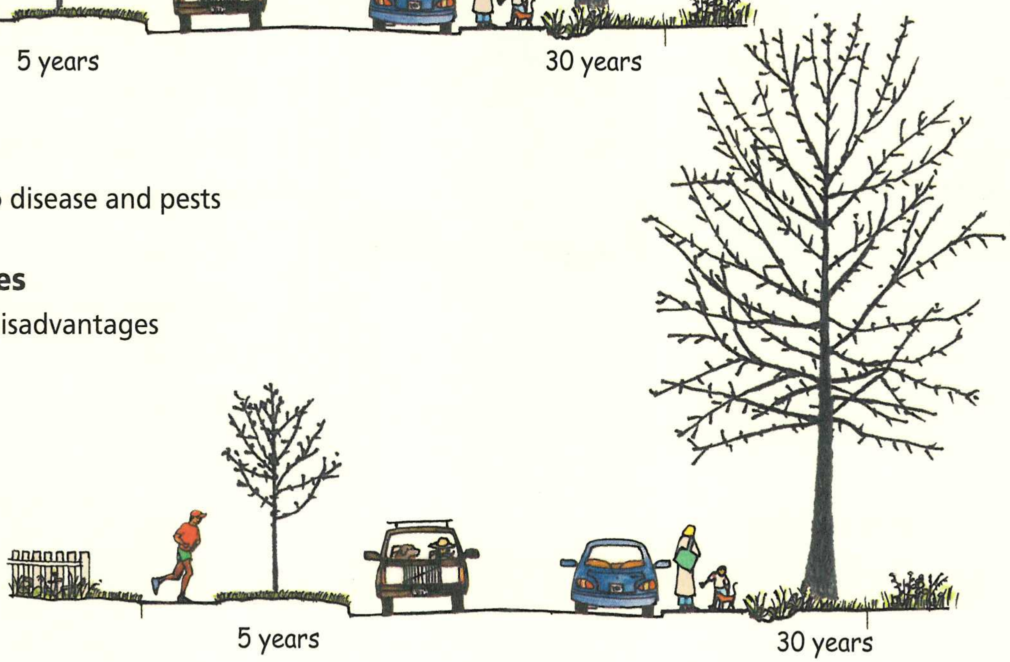


Advantages

Very tolerant to disease and pests

Disadvantages

No significant disadvantages



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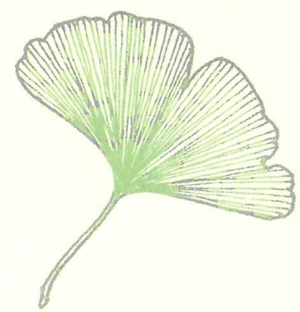


Goldenrain

Koelreuteria paniculata

Comments

Prefers sun

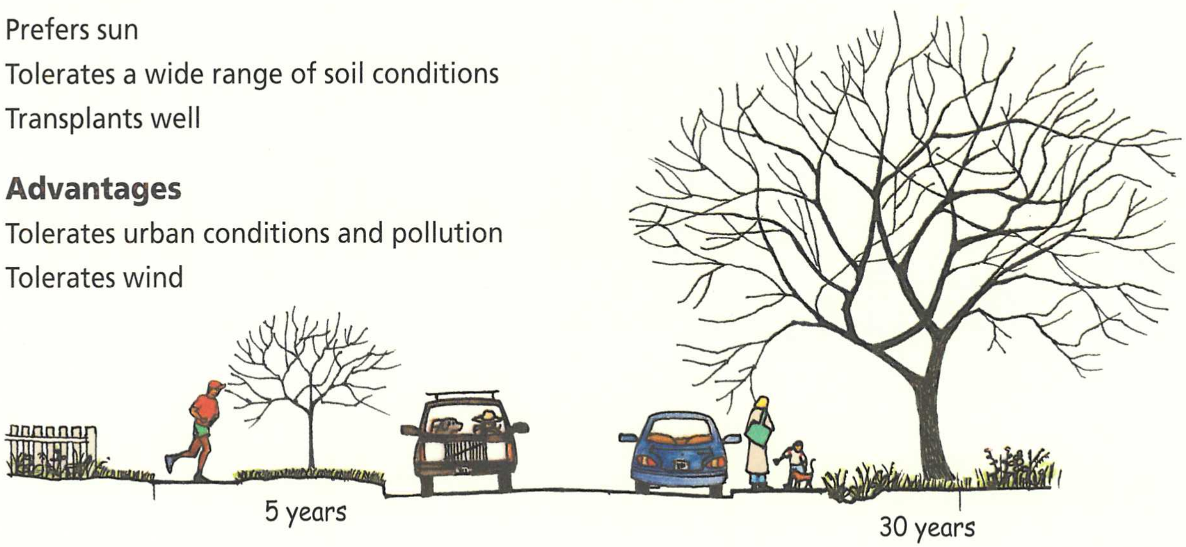
Tolerates a wide range of soil conditions

Transplants well

Advantages

Tolerates urban conditions and pollution

Tolerates wind



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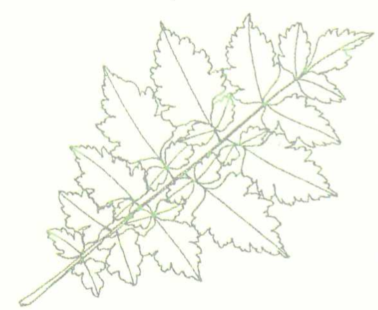
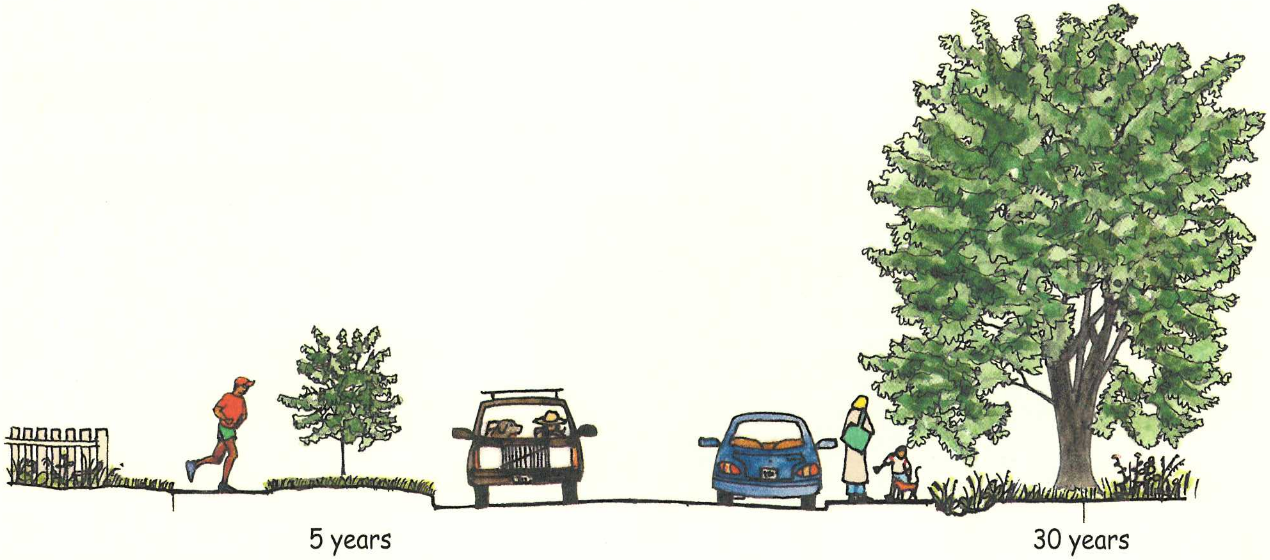


Common hackberry

Celtis occidentalis



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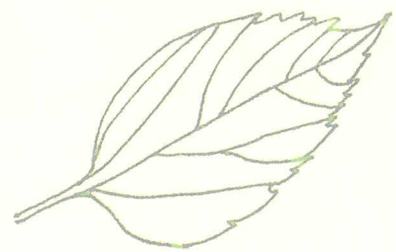

Comments

Tolerates sun or shade

Wide tolerance of acid or alkaline soil

Needs ample room

Attracts birds and butterflies

Advantages

Tolerates compacted, droughty and poorly drained soil

Disadvantages

Does not tolerate surprise frost

Susceptible to nipple-gall and witches broom

Black hawthorne

Crataegus douglasii

Characteristics

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- [x] long-lived
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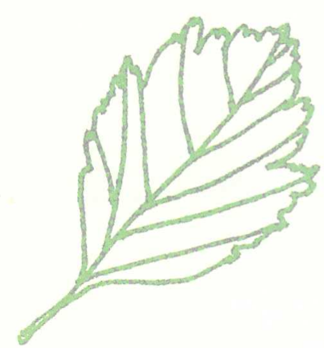


Comments

Tolerates sun or shade

Prefers deep, moist, fine-textured soil

Advantages

Tolerates wet sites

Provides valuable wildlife habitat

Bigleaf linden

Tilia platyphyllos

Comments

Prefers partial sun

Prefers moist, deep, fertile well-drained soil

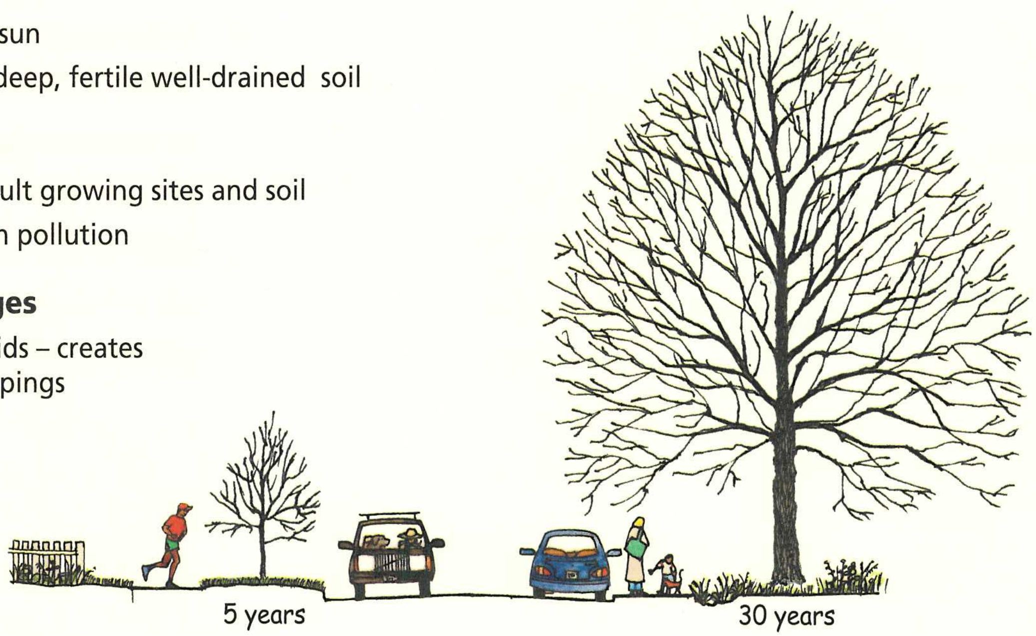
Advantages

Tolerates difficult growing sites and soil

Tolerates urban pollution

Disadvantages

Subject to aphids – creates sticky droppings



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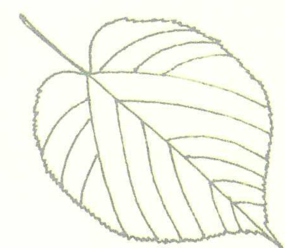


Littleleaf linden

Tilia cordata

Comments

Prefers moist, well-drained silt loam soil

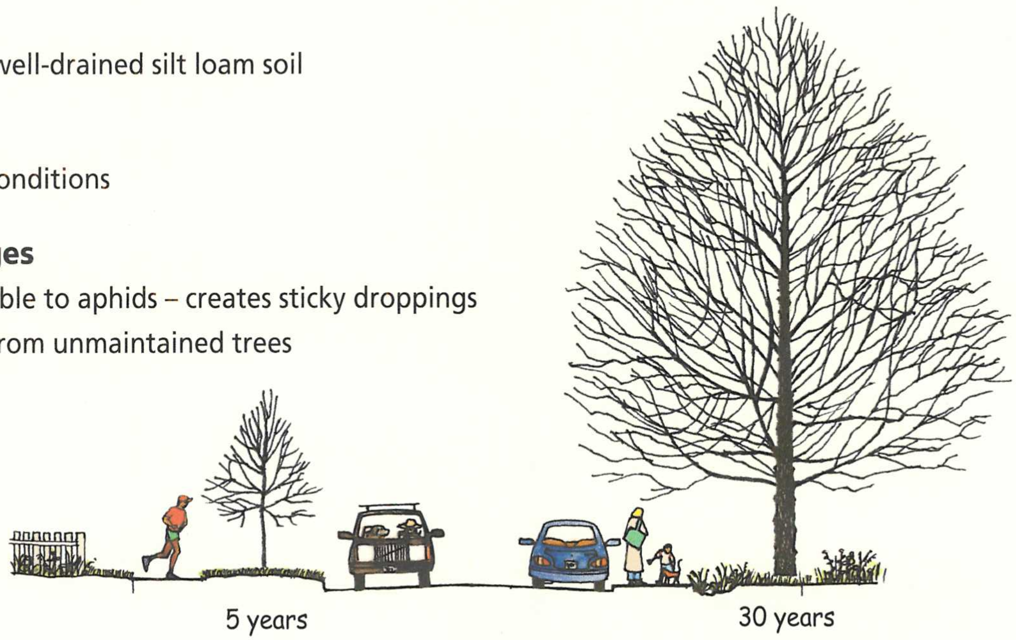
Advantages

Tolerates salt conditions

Disadvantages

Highly susceptible to aphids – creates sticky droppings

Suckers grow from unmaintained trees



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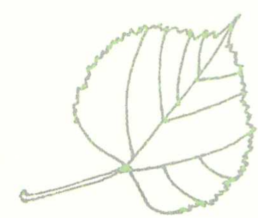


Thornless honeylocust

Gleditsia triacanthos inermis

Comments

Intolerant of shade

Prefers moist, well-drained soils

Tolerates a wide range of soil conditions

Roots need ample space

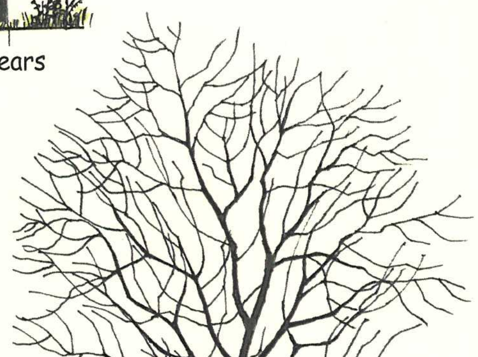

Advantages

Tolerates flooding

Very urban tolerant

Disadvantages

Susceptible to some disease and pest problems

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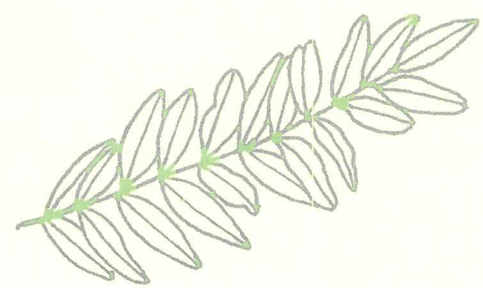


Norway maple

(wide-spreading cultivars only)

Acer platanoides

ERRATA

The hardiness and resistance to stressful conditions that make Norway maple a successful street tree also help Norway maple to invade and degrade our sensitive natural areas. For this reason, Norway maple is no longer a recommended street tree for the Portland metropolitan area.

Comments

Tolerates sun or shade

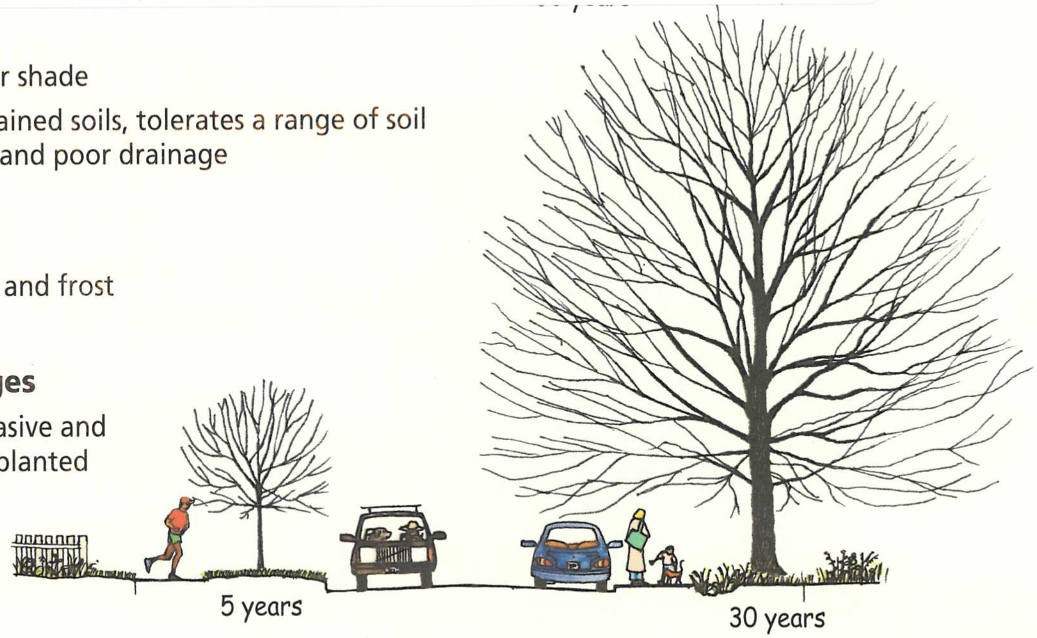
Prefers well-drained soils, tolerates a range of soil conditions and poor drainage

Advantages

Tolerates wind and frost

Disadvantages

Potentially invasive and often overplanted



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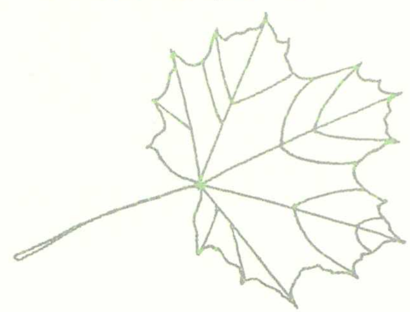


Red maple

Acer rubrum

Comments

Tolerates sun or shade

Prefers moist soils

Prefers acid to neutral soils

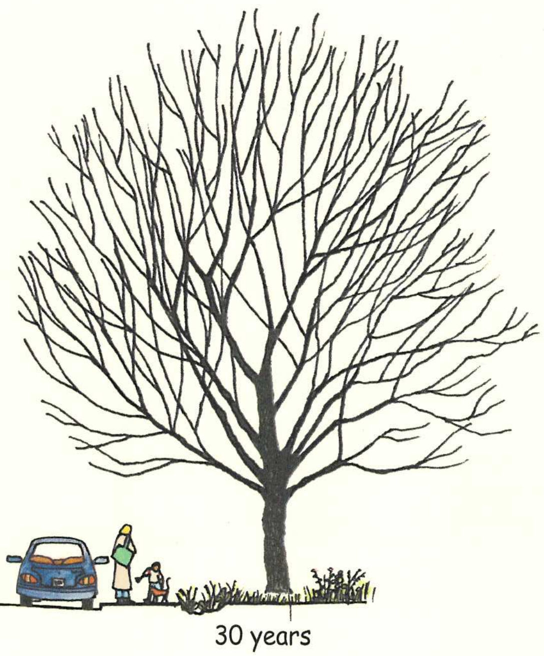
Advantages

Tolerates wind

Proven success in stormwater facilities

Disadvantages

May need watering during drought



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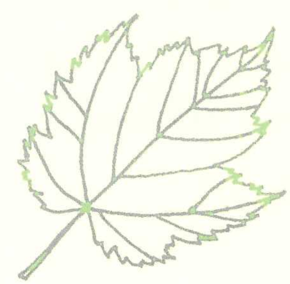


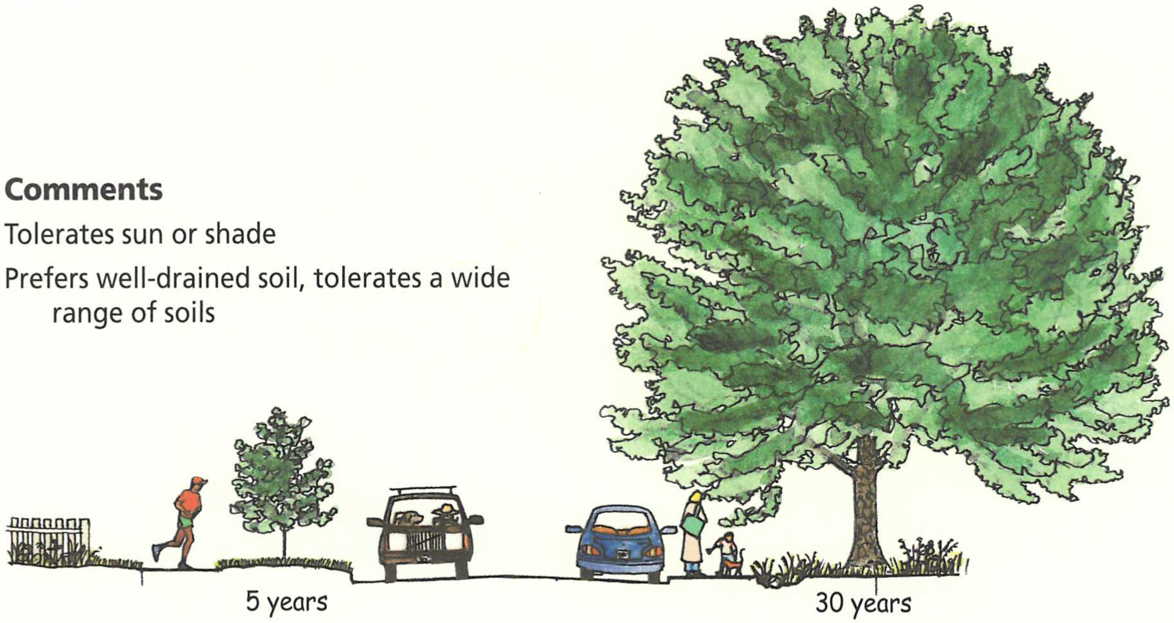
Sycamore maple

Acer pseudoplatanus

Comments

Tolerates sun or shade

Prefers well-drained soil, tolerates a wide range of soils



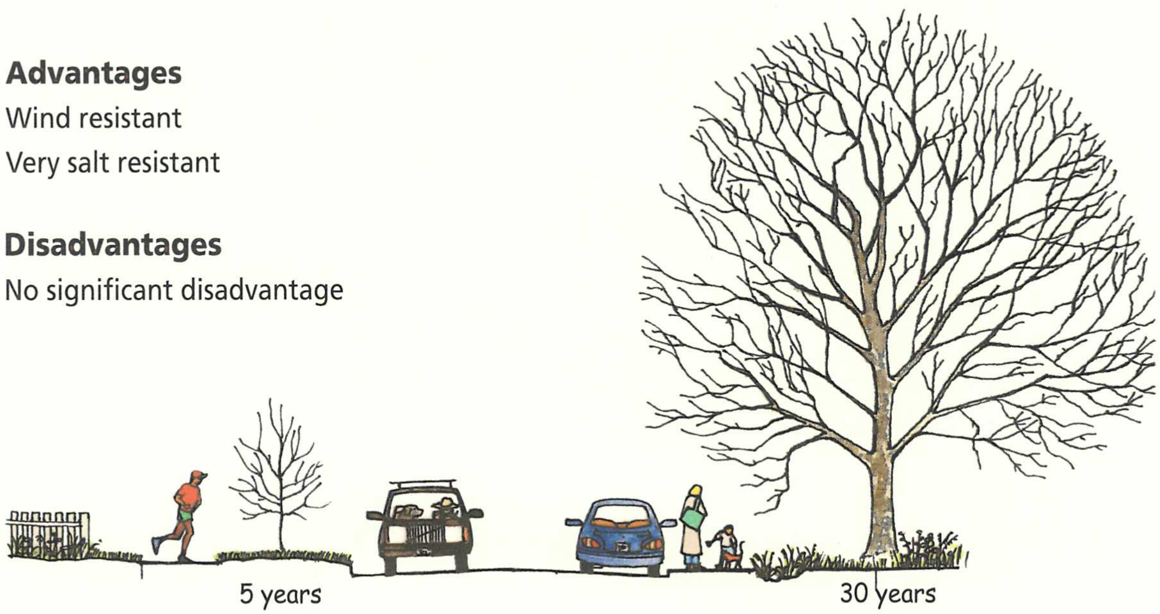
Advantages

Wind resistant

Very salt resistant

Disadvantages

No significant disadvantage



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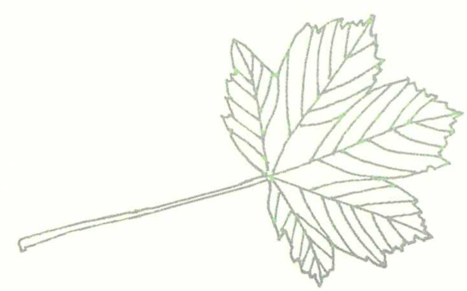

Oregon myrtle

Umbellularia californica

Characteristics

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- ☑ long-lived
- ☑ tolerates drought
- ☑ tolerates seasonally flooded soils
- ☑ tolerates urban pollutants
- ☐ persistent foliage
- ☑ dense canopy
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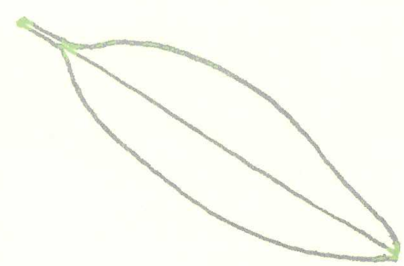


Comments

Thrives in full sun

Prefers rich, moist, well-drained soil

Will reach maximum height (75 feet) if given ample space

Advantages

Resists disease and pests

Tolerates aridity once established

Disadvantages

May be difficult to transplant and requires summer irrigation until established

Burr oak

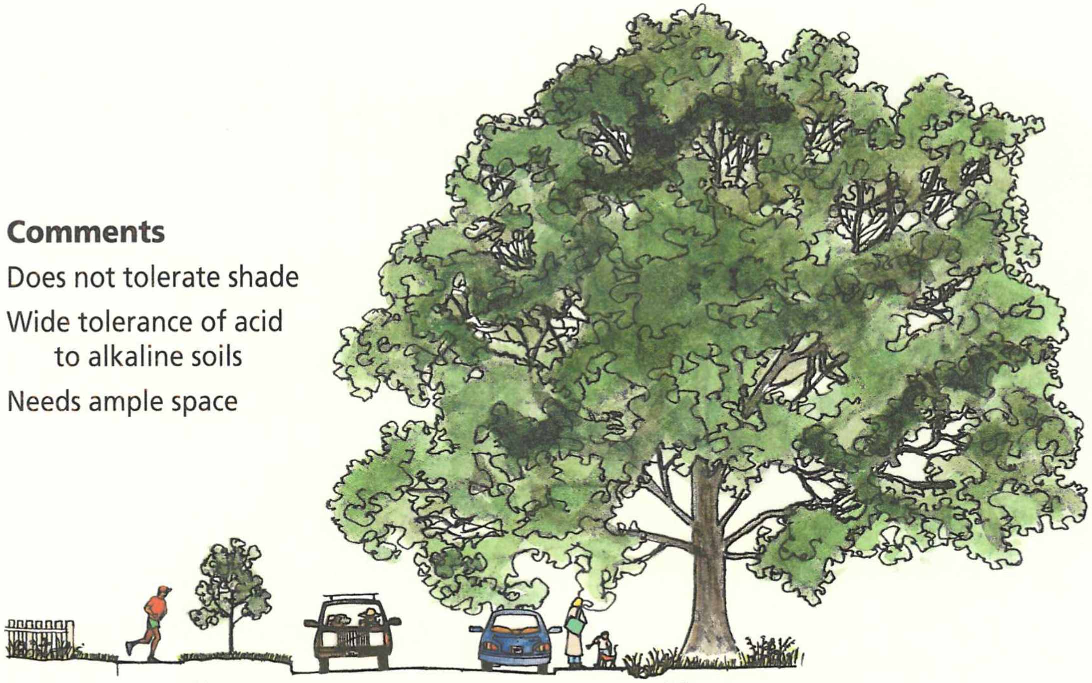
Quercus macrocarpa

Comments

Does not tolerate shade

Wide tolerance of acid to alkaline soils

Needs ample space

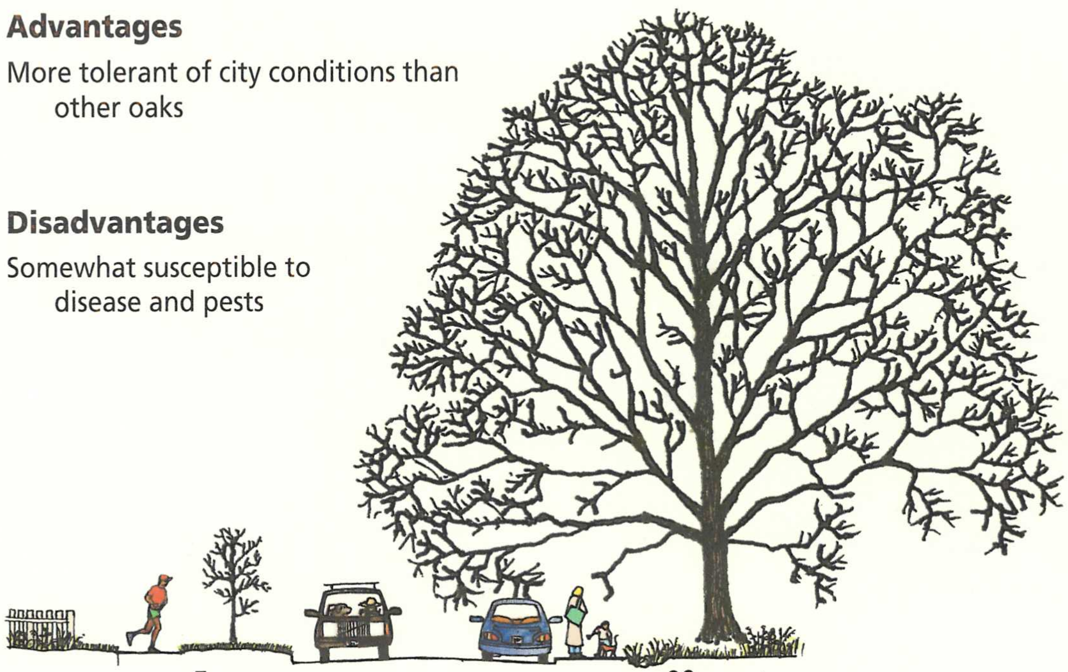


Advantages

More tolerant of city conditions than other oaks

Disadvantages

Somewhat susceptible to disease and pests



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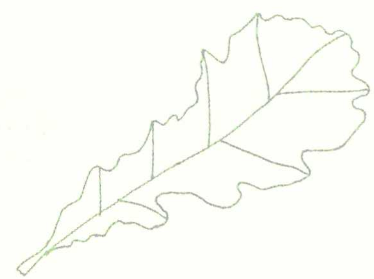

English oak

Quercus robur

Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
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- [x] dense canopy
- [x] vertical branching structure
- [ ] extensive root system
- [x] rough bark
- [x] rough foliage surface
- [x] fast-growing
- [x] tolerates poor soils

Comments

Prefers sun, moderately intolerant of shade

Tolerates a wide range of soil pH levels

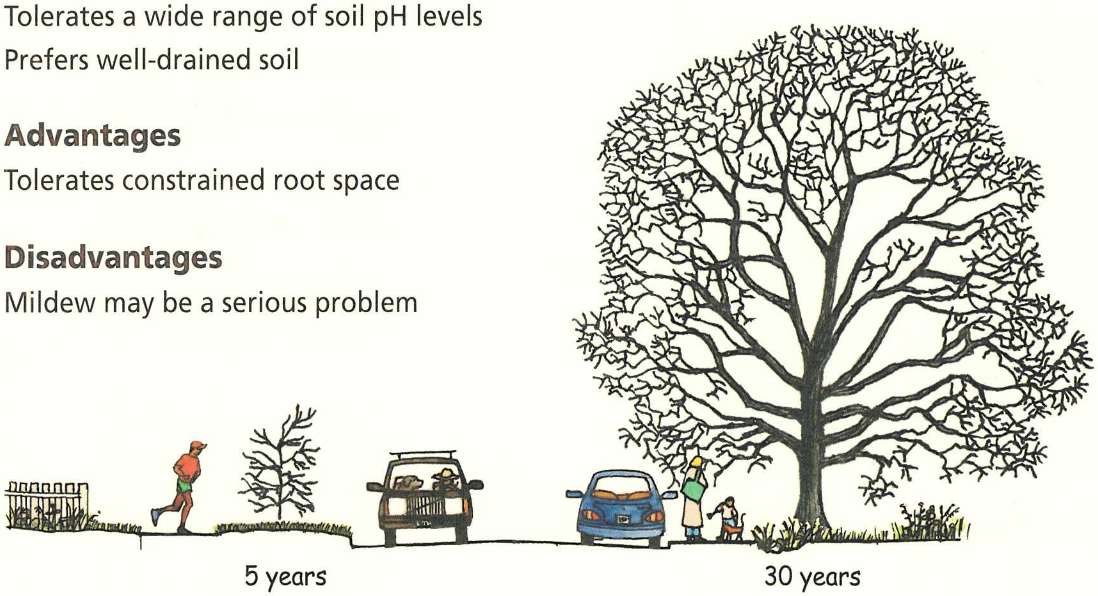
Prefers well-drained soil

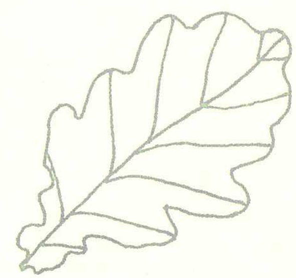
Advantages

Tolerates constrained root space

Disadvantages

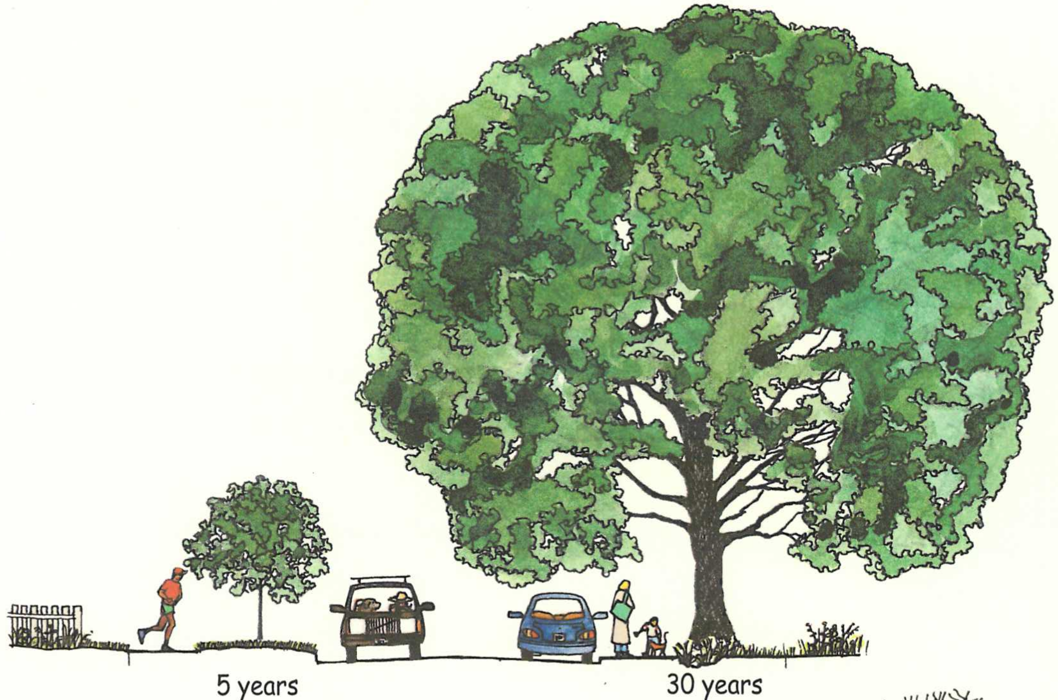
Mildew may be a serious problem





Red oak

Quercus rubra



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- [x] extensive root system
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- [ ] rough foliage surface
- [x] fast-growing
- [x] tolerates poor soils

Comments

Tolerates sun or shade

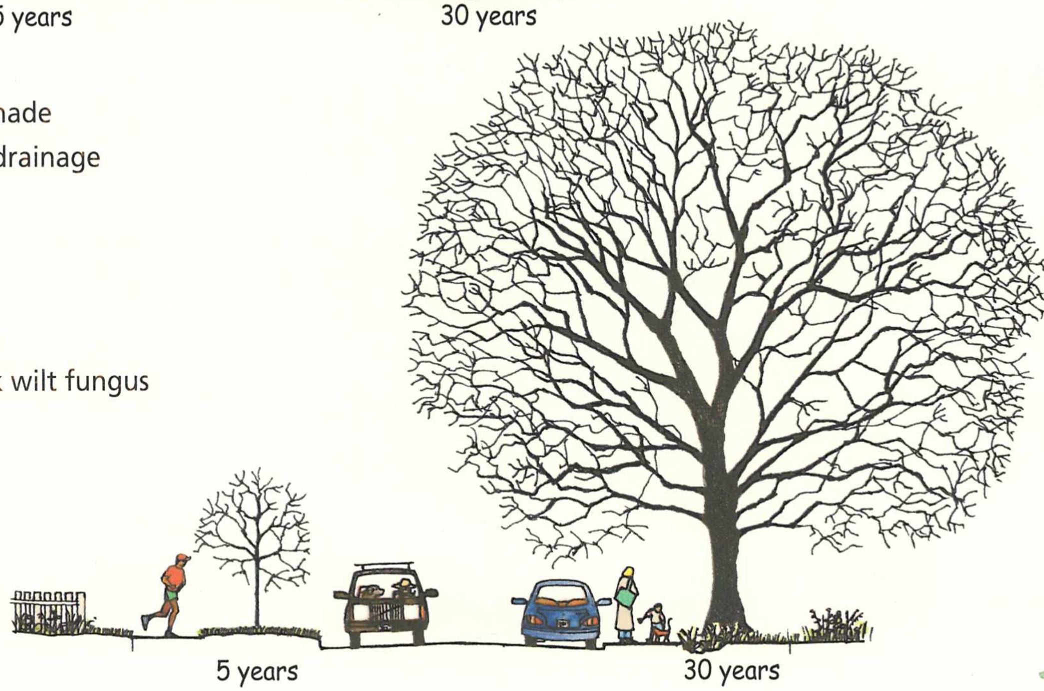
Prefers good soil drainage

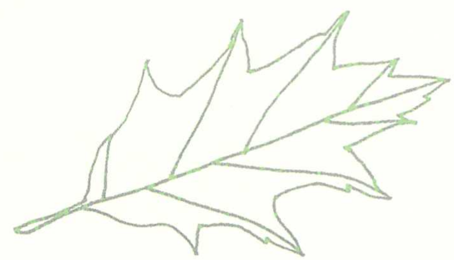
Advantages

Tolerates salt

Disadvantages

Susceptible to oak wilt fungus





Shumardii oak

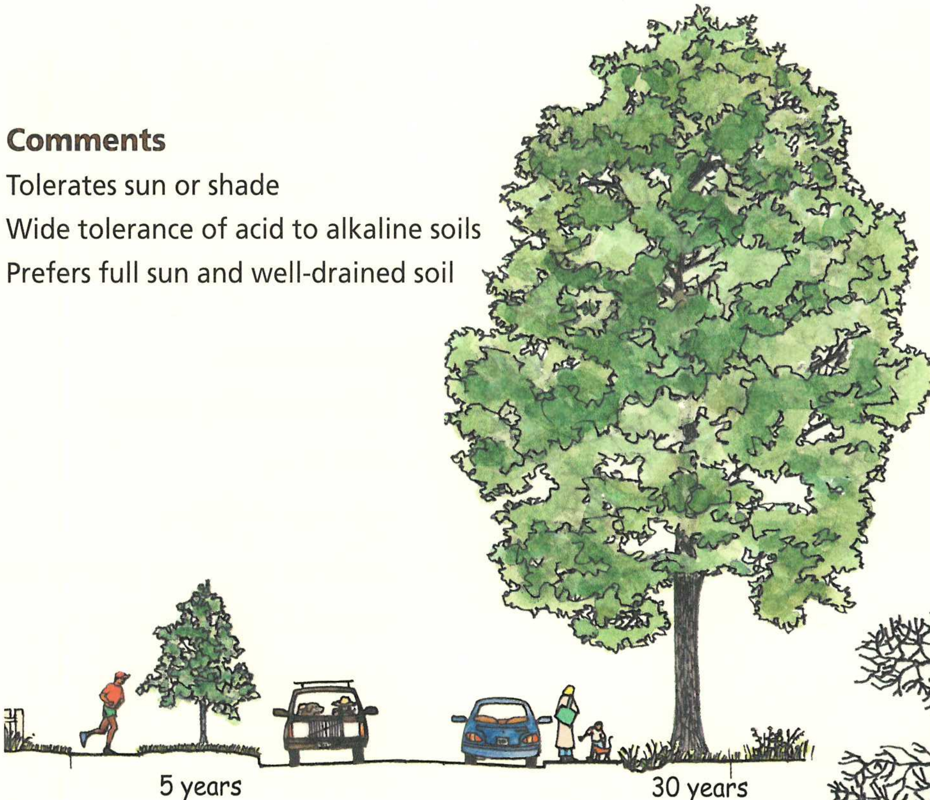
Quercus shumardii

Comments

Tolerates sun or shade

Wide tolerance of acid to alkaline soils

Prefers full sun and well-drained soil

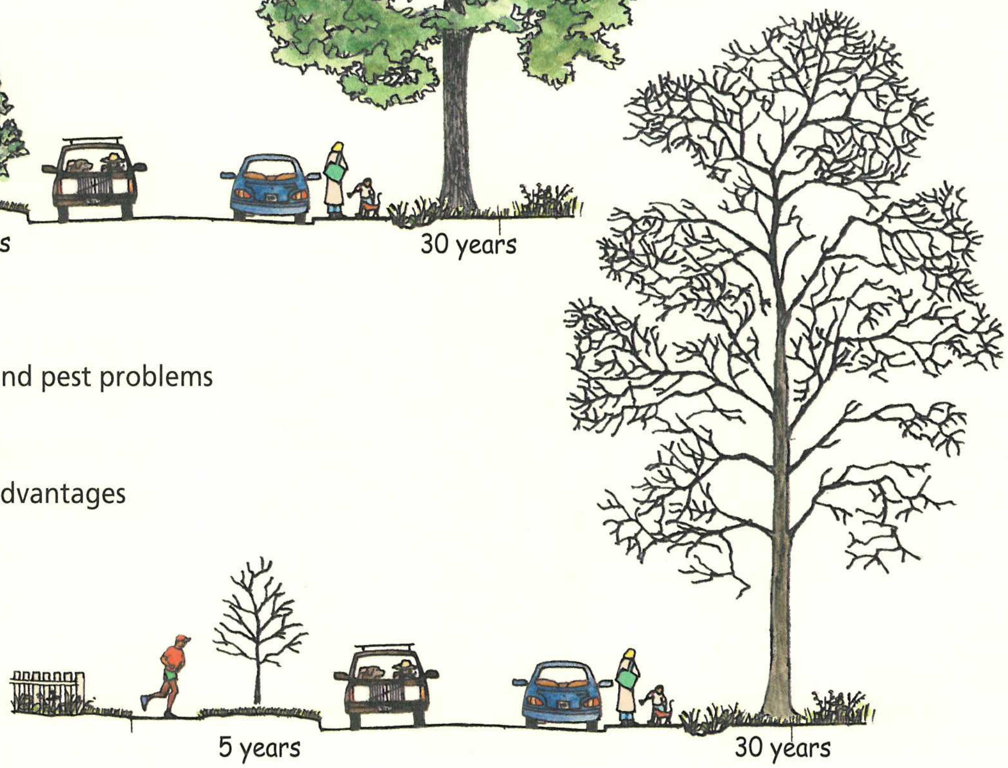


Advantages

Very few disease and pest problems

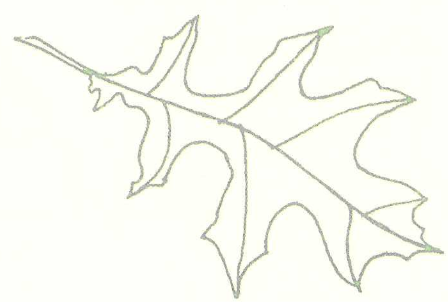
Disadvantages

No significant disadvantages



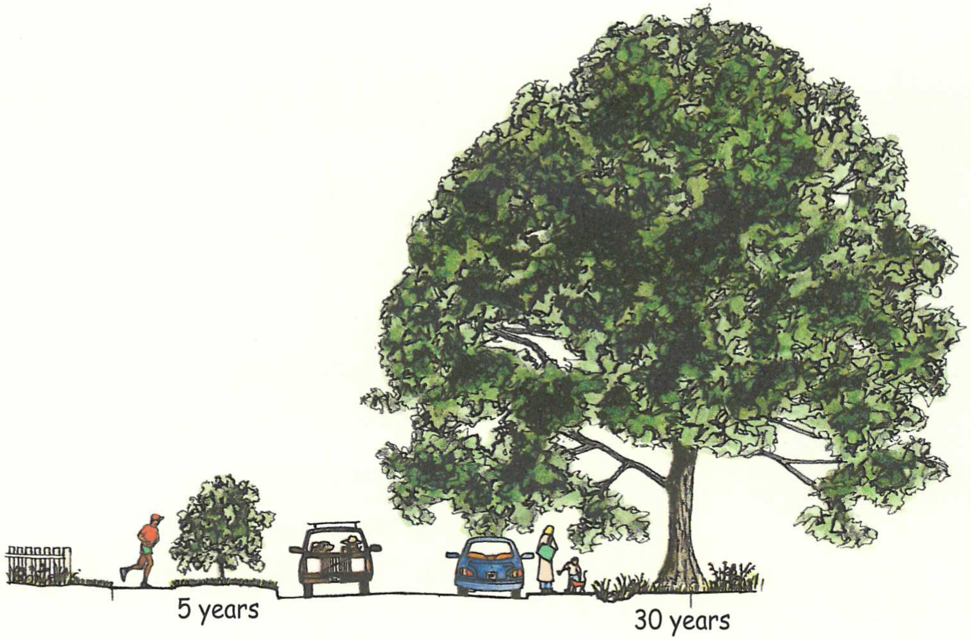
Characteristics

- [x] wide-spreading canopy
- [x] long-lived
- [x] tolerates drought
- [x] tolerates seasonally flooded soils
- [x] tolerates urban pollutants
- [ ] persistent foliage
- [ ] dense canopy
- [ ] vertical branching structure
- [x] extensive root system
- [x] rough bark
- [ ] rough foliage surface
- [x] fast-growing
- [x] tolerates poor soils



Swamp white oak

Quercus bicolor



Comments

Tolerates sun or shade

Tolerates compacted, droughty or poorly drained soils

Prefers acid soil and ample room

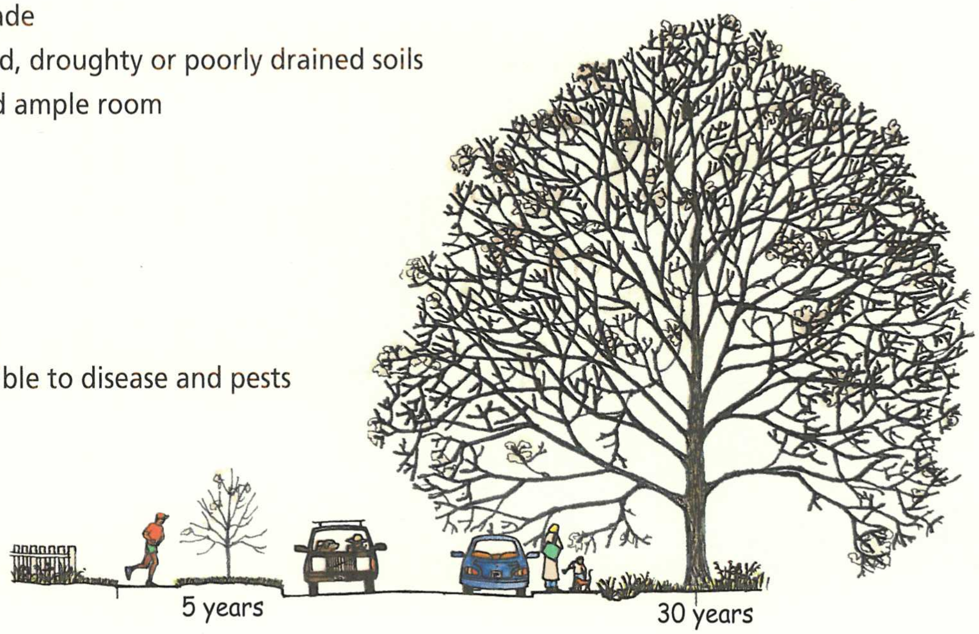
Advantages

Tolerates salt

Tolerates wet sites

Disadvantages

Somewhat susceptible to disease and pests



Characteristics

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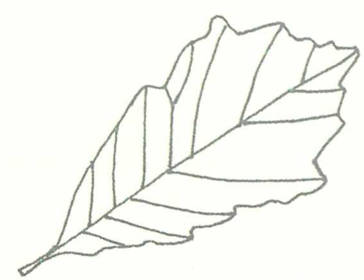
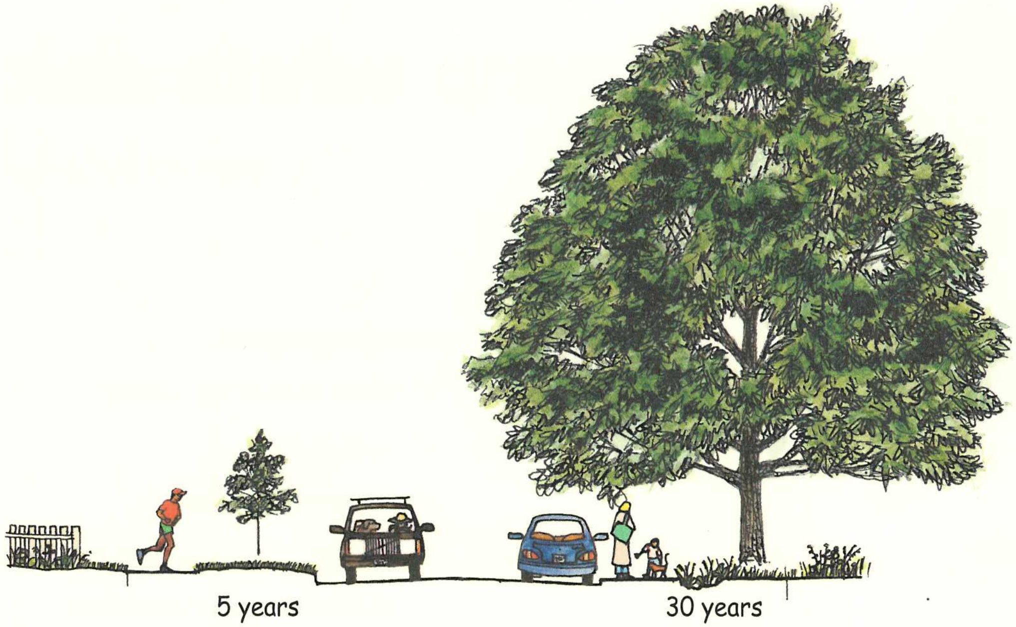


Willow oak

Quercus phellos



Comments

Prefers full sun; tolerates sun or shade

Prefers acid soil

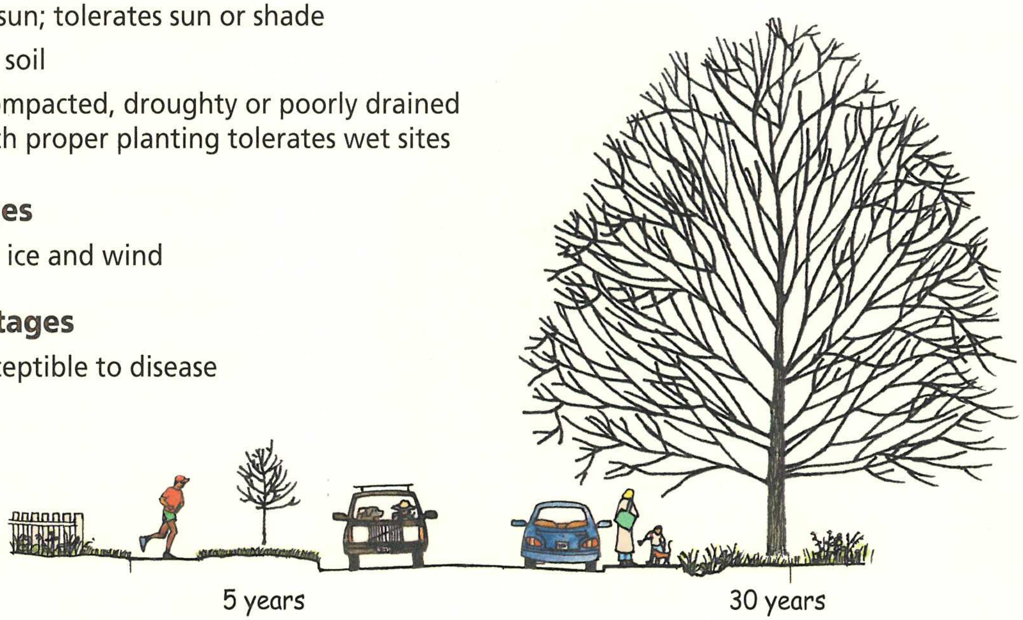
Tolerates compacted, droughty or poorly drained soils with proper planting tolerates wet sites

Advantages

Resistant to ice and wind

Disadvantages

May be susceptible to disease



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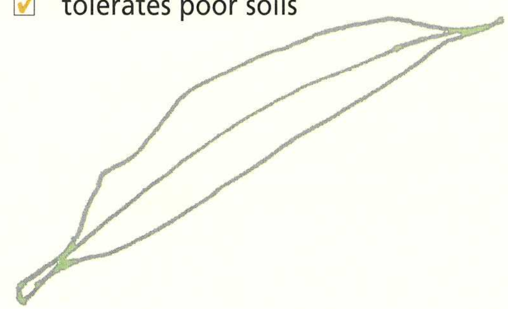


Ponderosa pine

Pinus ponderosa

Comments

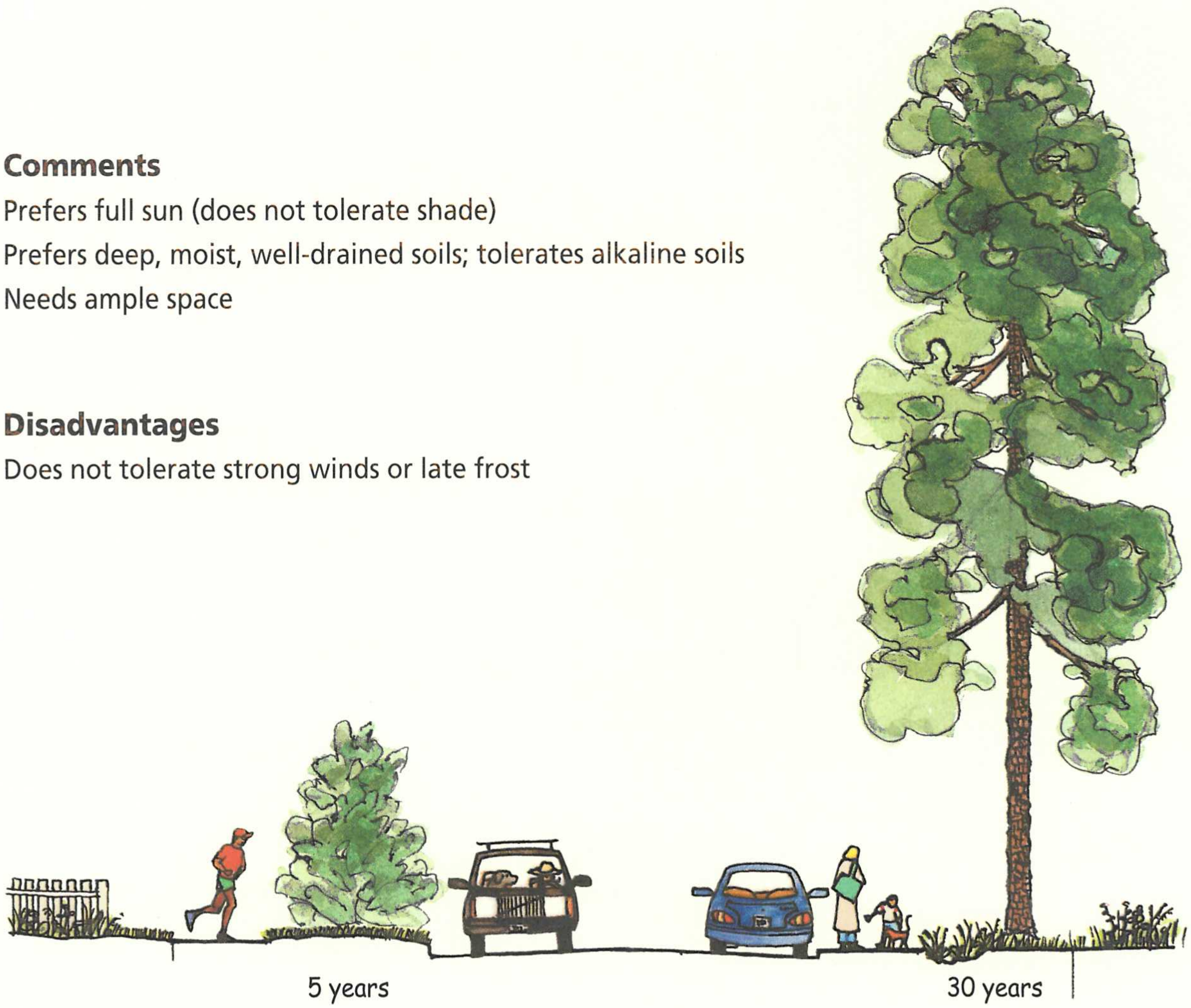
Prefers full sun (does not tolerate shade)

Prefers deep, moist, well-drained soils; tolerates alkaline soils

Needs ample space

Disadvantages

Does not tolerate strong winds or late frost



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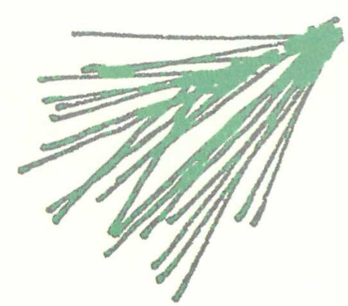


London plane

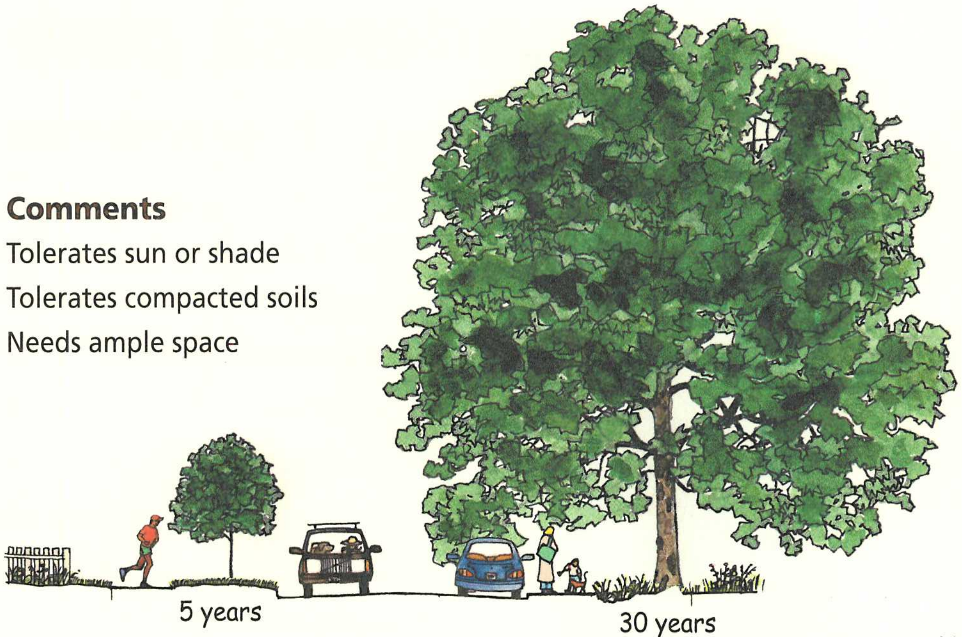
Platanus x. acerofolia

Comments

Tolerates sun or shade

Tolerates compacted soils

Needs ample space



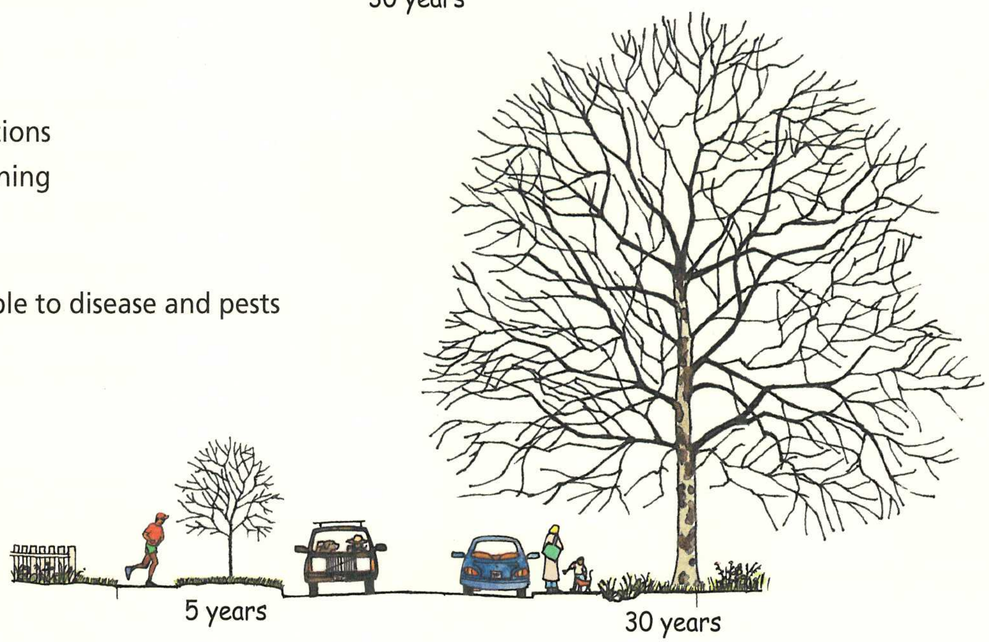
Advantages

Tolerates city conditions

Tolerates heavy pruning

Disadvantages

Somewhat susceptible to disease and pests



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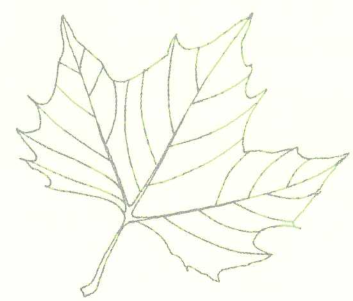


Sitka spruce

Picea sitchensis

Comments

Tolerates sun or shade

Prefers moist atmosphere and soil

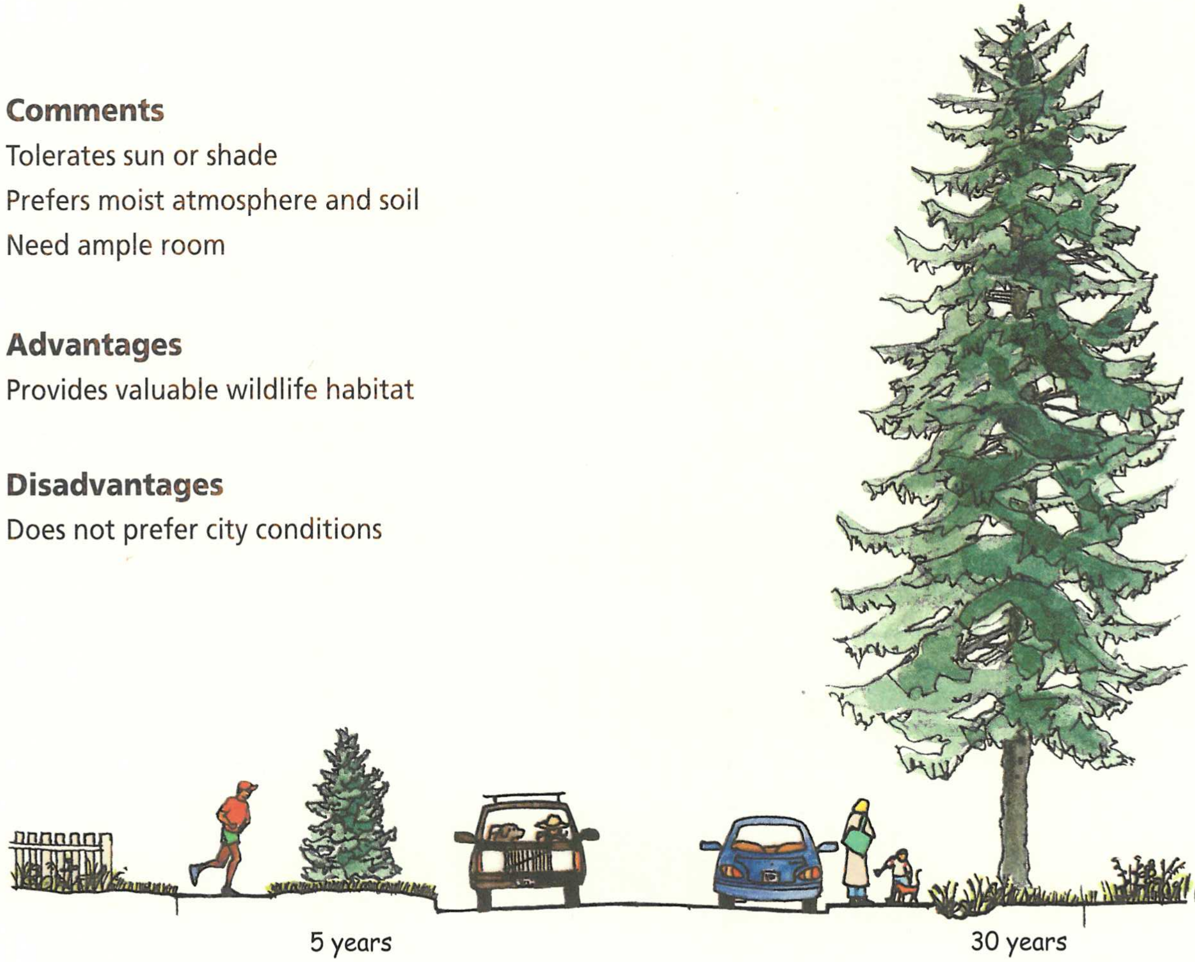
Need ample room

Advantages

Provides valuable wildlife habitat

Disadvantages

Does not prefer city conditions



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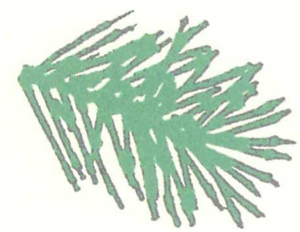


Sweetgum

Liquidambar styraciflua

Comments

Prefers acid soil and full sun

Needs ample root space

Needs ample room

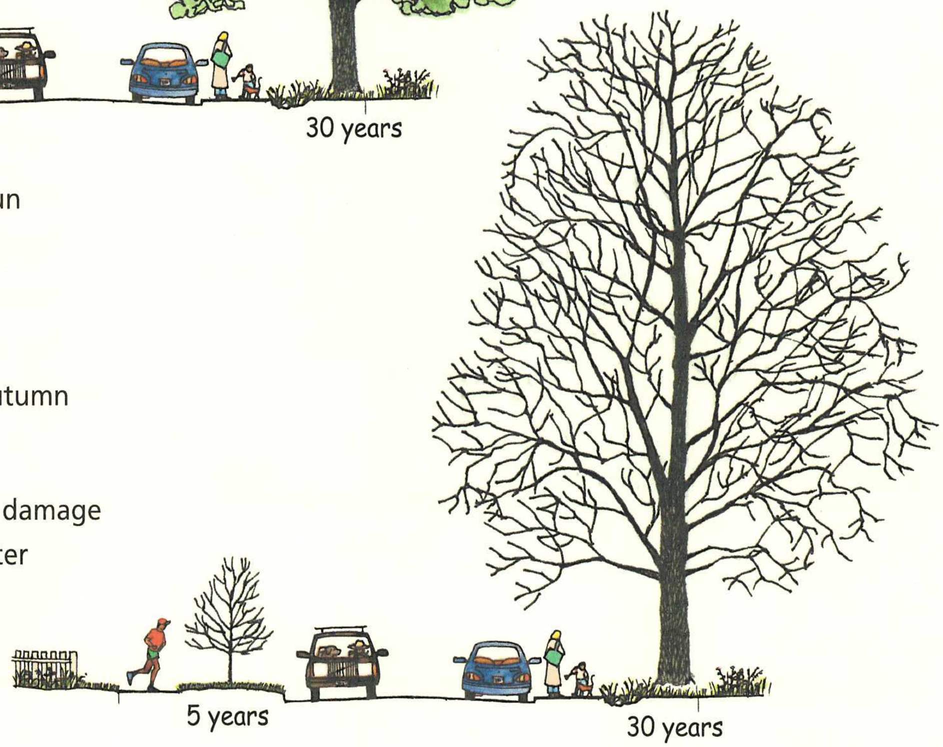
Advantages

Leaves stay on late into autumn

Disadvantages

Roots may cause sidewalk damage

Large, prickly seed pod litter



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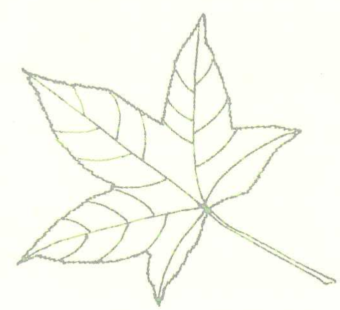
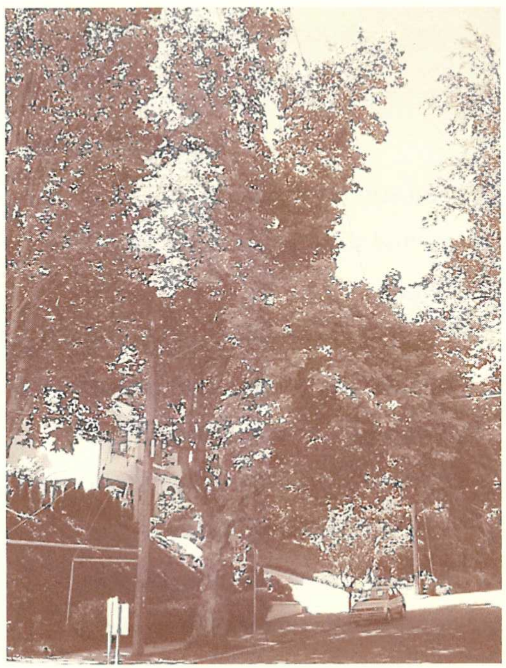


Golden rain (Koelreuteria paniculata), Hawthorne District



London planetree (Platanus x acerifolia), West Hills District

Selecting Your Street Tree Species

The first step in selecting a street tree is determining specific site conditions. The Site Assessment Checklist on page 52 can be used to gather pertinent information such as soil conditions, microclimate and hydrology. It also is important to determine how much space is available and what type of preparation will occur before planting.

The next step is to conduct an inventory of street trees within the neighborhood to determine species diversity, age and potential problems. Use the Street Tree Inventory on pages 53 and 54 to gather information such as species name, age and health of each tree. Tree location should be noted using either street addresses or, if available, a geographical positioning system (GPS) device.

If green street designs are being implemented, information about hydrology and soil conditions should be noted. For example, will there be standing water in the planter strip for a long period? Or will there be excessive drainage and very little water available for plants? This type of information can be noted on the Site Assessment Checklist. If there are particular goals that the project is trying to achieve, such as 100 percent canopy cover over street surfaces after 15 years, these should be used along with other collected information to make a street tree selection.

After gathering as much data about site conditions, use the street tree characteristics chart to create a list of five to 10 species that meet site conditions, achieve species diversity in the neighborhood and meet project goals. The chart provides a diverse list of trees including both deciduous and evergreen species that can be appropriately integrated into a variety of street types. Check with your city or county planning office to make sure the trees you have selected are on their approved street tree list.

Site Assessment Checklist

Site location ______________________

Site description ______________________

____

Average annual temperature

Summer ______________

Winter ______________

Microclimate factors

Re-reflected heat load ______________

Frost pocket* ______________

Wind ______________

Shaded area ______________

Other ______________

Irrigation levels

- ❑ No supplemental irrigation
- ❑ Automatic irrigation system

Irrigation amount and rate: ______________

Onsite drainage

- ❑ Poorly drained (<1"/hour)
- ❑ Moderately drained (1"-6"/hour)
- ❑ Excessively drained (>6"/hour)

*Areas subject to localized freezing patterns

Constraints

Overhead wire height ______________

Signage, telephone poles, etc. ______________

Proximity to buildings/structures ______________

Proximity to underground utilities ______________

Proximity to sidewalks and other infrastructure ______________

Soil volume in root zone ______________

Other ______________

Soil factors

Range of pH levels ______________

Texture

- _____ % clay
- _____ % loam
- _____ % sand

Compaction Levels

- ❑ severely compacted
- ❑ moderately compacted
- ❑ uncompacted

Sunlight Levels

- ❑ Full sun (six hours or more)
- ❑ Partial sun or filtered light
- ❑ Shade

Other soil considerations

- ❑ Indications of soil layer disturbance
- ❑ Evidence of recent construction
- ❑ Presence of construction debris likely
- ❑ Noxious weeds present
- ❑ Evidence of excessive salt use
- ❑ Erosion of soil evident
- ❑ Use that compacts soil

Street Tree Inventory

Use with site assessment checklist

				TREE CHARACTERISTICS					
Tree ID number	Species name (botanical/common name)	Location (GPS)	Site information	Height	Height at maturity	DBH (diameter breast height)	Tree caliper	Crown spread	Tree condition
			See site assessment sheet						

Street Tree Inventory

Use with site assessment checklist

Constraints						Opportunities	
Distance from curb/buildings (feet)	Proximity to nearest ulility pole (feet)	Proximity to nearest tree (feet)	Overhead line (y - n/height in feet)	Underground utilities (y - n/depth in feet)	Other constraints	Management needs	Planting potential

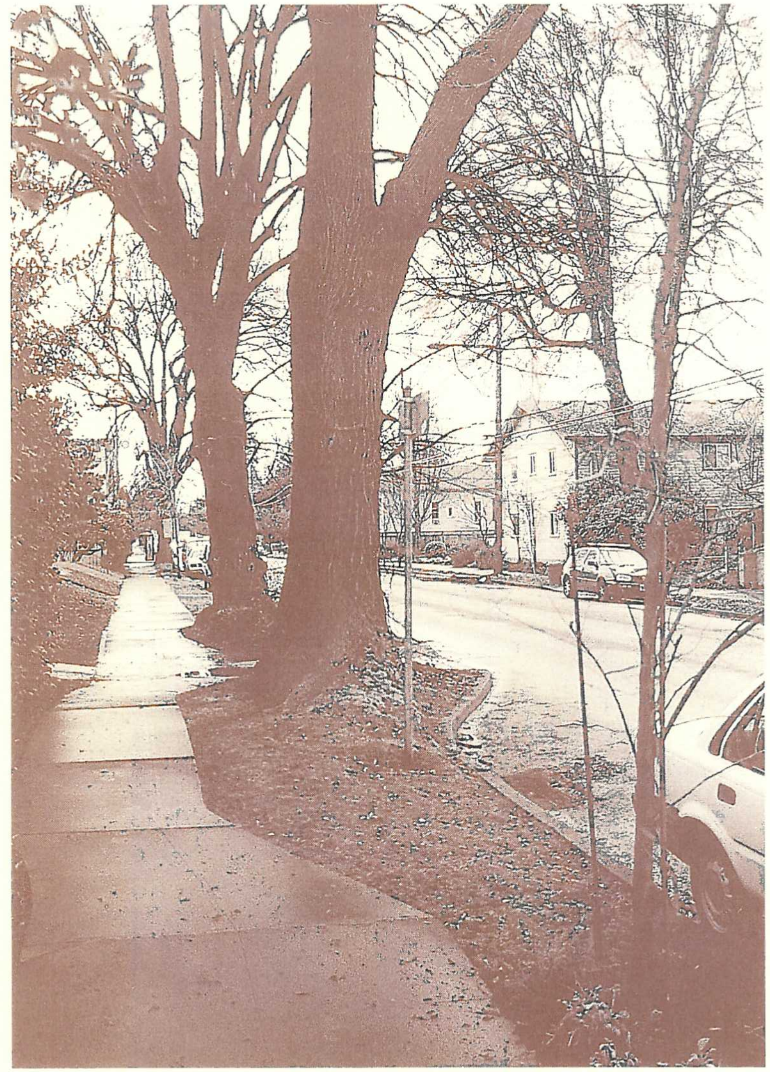
Implementation

Retrofitting a Street That Has Existing Mature Trees

When retrofitting a street to incorporate green street elements such as bioswales, it is important to preserve existing street trees. If the tree species are compatible with the green street tools being used, the mature trees should be incorporated into the street design where possible. Furthermore, efforts should be made in the street-design process to improve the conditions for the health and longevity of the existing trees.

One way to accomplish this is to create more space between the sidewalk and the curb around existing trees. This is typically done at intersections to allow a refuge for pedestrians as they prepare to cross the street. This also can be done at mid-block locations, which creates onstreet parking bays.

Another is to meander or slim a sidewalk around existing large trees whose trunk and root system have outgrown their space in the planting strip and are encroaching on or uplifting a sidewalk.



The curb and sidewalk on Southeast 12th Avenue in Portland was retrofitted to create adequate space around these mature street trees and to provide refuge for pedestrians crossing the vehicle lanes.

Planting New Trees

Figure 1 shows the proper way to plant a tree. In existing neighborhoods where street design has confined the area in which trees can grow, it is important to determine what a large tree needs in order to be healthy. There are many ways to increase the space allocated to trees and to improve the quality of the soils, particularly if design treatments from Metro's *Green Streets – Innovative Solutions for Stormwater and Stream Crossings* handbook are being implemented into the street right of way.

To accommodate large long-lived trees, Metro recommends streets be constructed with an 8-foot-wide planting area. Constrained right of way areas may reduce the planting area to 6 feet in width. Commercial districts with street tree wells should provide a 5-foot by 5-foot tree well, surrounded by pavers that can be removed as the tree grows. Where there are existing overhead wires, trees should be planted so that at maturity they can be properly pruned as shown on page 58.

Because urban soils have been compacted and disturbed it is important to improve the drainage as much as possible to prevent the drowning of the roots. If existing planting strips cannot be enlarged, structured soils may be used to provide space for large trees and their accompanying roots.

Figure 2 shows the patented detail for using structured soils. Structural soil is a designed medium that can meet or exceed pavement design and installation requirements while remaining root penetrable and supportive of tree growth. Cornell's Urban

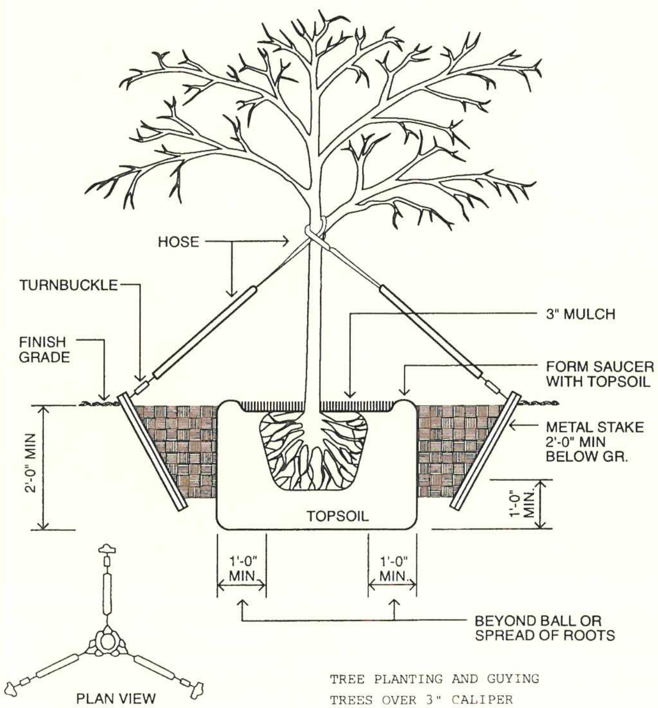


Figure 1. Tree-planting detail

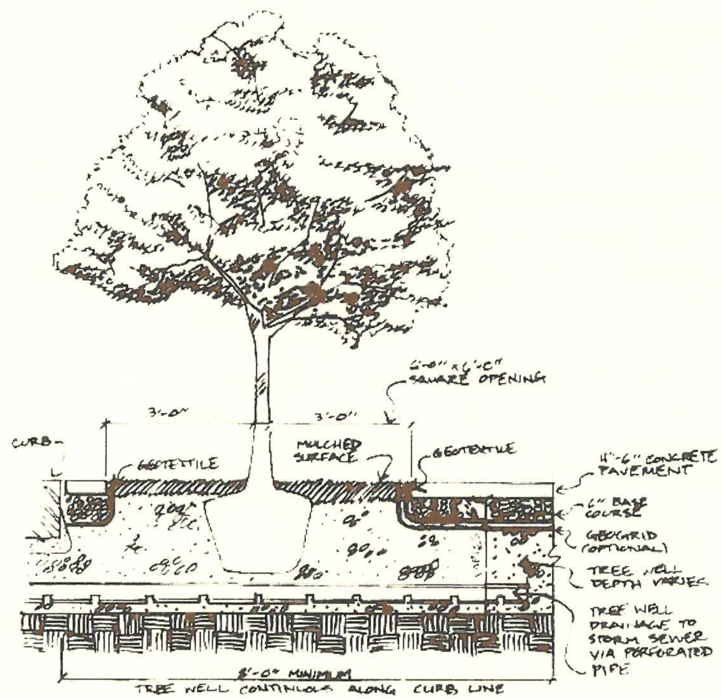


Figure 2. Structural soil planting detail

Horticulture Institute has been testing a series of materials during the past five years focused on characterizing their engineering as well as horticultural properties. The materials tested are gap-graded gravels that are made up of crushed stone, clay loam and a hydrogel stabilizing agent. The materials can be compacted to meet design requirements that support pavement materials yet allow for sustainable tree root growth. These soils shift designs away from individual tree pits to an integrated, root penetrable, high-strength pavement system.

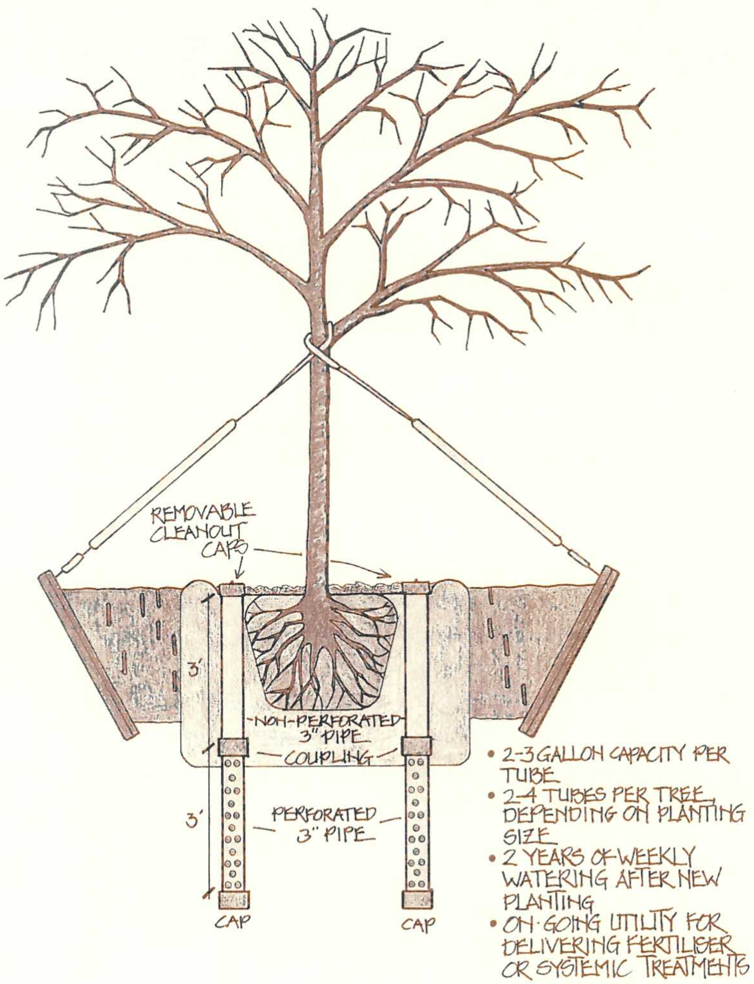


Figure 3. Watering tube detail

The structural soil has been patented and trademarked under the name CU-Soil. The purpose of this is to insure quality control. Installers must be licensed. To find out more about structural soils or to become a sub-licensee, contact Fernando Erazo, at Amereq Inc., 19 Squadron Blvd., New York City, New York 10956; phone (914) 634-2400 or 1(800) 832-8788. Four documents related to CU-soil can be downloaded at www.hort.cornell.edu/department/faculty/bassuk/uhi/pubs.html.

In order to prevent sidewalk drainage, it is essential to encourage deep roots. Deep, extensive root systems increase the potential for water uptake. This can be done through deep watering using a watering tube as shown in Figure 3. Watering tubes can provide an opportunity to ensure adequate water during the first few years of planting and a method to encourage deep root growth. Illustrated in Figure 3, watering tubes allow water to be seep into the soil below the roots of recently planted trees. After the trees have been established (about three years after planting), the tubes can be capped and only used if needed for years of drought or for application of systemic treatments.

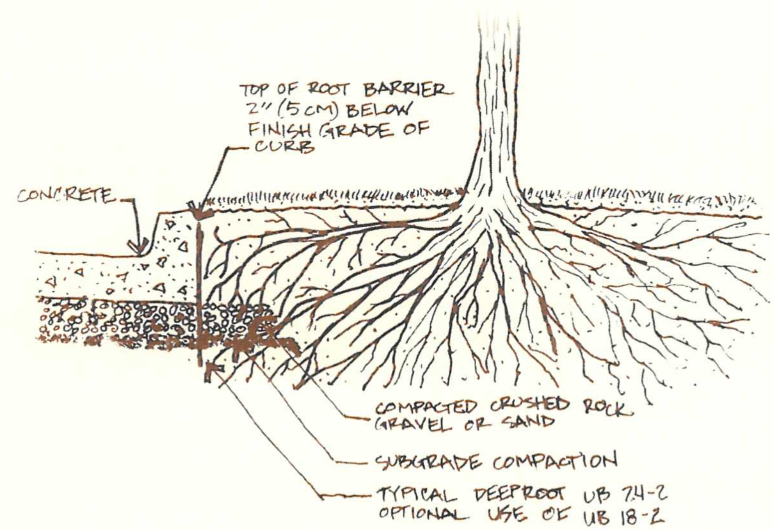
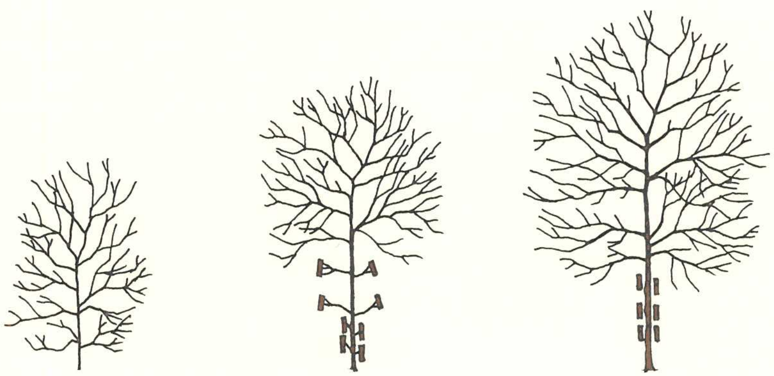


Figure 4. Root barrier planting detail

Root barriers can be used where there is potential for sidewalk or roadway damage by surface roots. The root barrier is placed between the sidewalk or curb and the tree well or planter strip, generally to a depth of 18 inches. Figure 4 is an example of a root barrier designed by DeepRoot. More information about this product can be found at www.deeproot.com/details.html

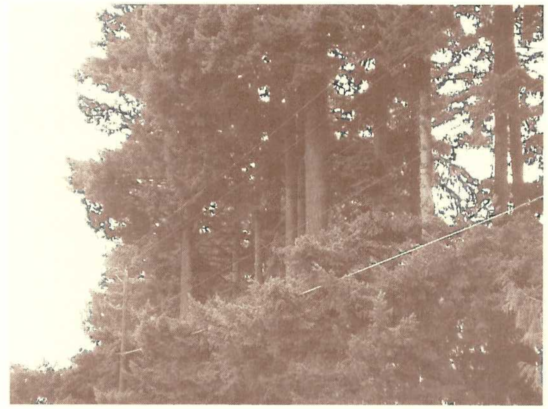
Reducing Maintenance Costs and Keeping Trees Healthy

To maximize the stormwater benefit of street trees, they should be provided an environment and care that allows full potential for growth and be kept alive as long as possible. In order for this to be achieved, trees must be planted properly and given plenty of room to grow. Preventing conflicts with sidewalks, roadways, overhead wires and underground utilities increases the chance for a long, healthy tree life that minimizes the need for perenial maintenance issues and premature tree removal.



Newly planted — *2-inch diameter trunk* — *Mature tree*

Figure 5. Trimming lower branches



A clear zone from branches of trees with single leader trunks may be needed to prevent conflicts with utility wires.

Trees without a single leader trunk may be pruned around utility wires.

Young trees become established faster and form stronger trunks if their lower branches are left to develop for the first few years after planting. If branches become too long or vigorous during this time, shorten them during the dormant season (generally, October through January). Once the trunk is at least two inches in diameter, begin removing the lower branches gradually, over a period of several years [(1)] (See Figure 5). Branches should be trimmed to allow a minimum 11-foot clearance above the roadway area of local streets and a minimum 15-foot clearance above the roadway area of regional streets and highways at the time a tree reaches its mature height. This will prevent damage to the tree and conflicts with road maintenance equipment.

Large trees that are planted near overhead utility lines can cause damage to those lines during windy or freezing weather. To prevent those problems, a qualified arborist trained in utility line pruning may be able to prune the tree branches so that when the tree reaches mature height the branches will be trained around a clear zone to the utility wires. This will reduce conflicts of tree branches damaging the wires during inclement weather.

---

(1) Sunset, October 2001

Additional Strategies for Reducing Maintenance Costs

1. Planting natives
2. Planting trees that can survive wet winters and dry summers
3. Prevent compaction of soils
4. Provide soils that are well-drained
5. Provide consistent maintenance during the first three years, including
   a. thorough watering to encourage deep roots
   b. removal of weeds around the tree
   c. not planting other plants close to the tree trunk
   d. mulching around tree with leaf debris from the tree (make sure mulch does not touch the trunk)
   e. monitoring for signs of pests and disease
   f. not applying herbicides.

Next Steps

This *Trees for Green Streets* manual is an initial step toward better understanding how street trees can be used as a primary stormwater management tool in the urban environment. The manual should be used in conjunction with both the *Creating Livable Streets* and *Green Streets – Innovative Solutions for Stormwater and Stream Crossings* handbooks, which present design guidelines for reducing the impact of streets on streams.

In the next five years Metro hopes to make funding available for pilot projects, strengthen street design and street tree ordinances throughout the region, and update and refine the concepts in this manual.

Implementing Green Street Designs

Pilot "green" street projects would provide the opportunity to better understand the role of street trees in reducing the amount of rainfall that is intercepted at various stages of a tree's life and to measure the overall impact of street trees on urban water quality. Projects would help refine the information provided in this manual and the types of plant communities recommended along streets. Projects also would demonstrate how to balance and achieve transportation and environmental objectives simultaneously. Metro will investigate the possibility of directing regional flexible transportation dollars and other funding to pilot projects during the next five years.

Ongoing Regional Coordination with Local Jurisdictions

Three primary recommendations of this manual are to:

- protect existing trees
- plant large trees
- plant trees that are long-lived.

In order to accomplish this, local jurisdictions may need to readdress their street tree ordinance, including the approved street tree list. Local cities have street tree lists of small, medium and large trees that are recommended based on the width of the planting strips. It is unclear if these lists are helping or hindering us from achieving urban forestry management goals.

Metro will continue to work with local jurisdictions to remove the constraints to planting large long-lived street trees. Local codes and design guidelines should reflect the potential increase in planting strip widths and tree well dimensions proposed in the *Green Streets – Innovative Solutions for Stormwater and Stream Crossings* handbook. Metro will continue to work with local planners to merge the environmental, land-use and transportation objectives of street rights of way, and to help promote the care and maintenance of street trees.

Ideally, the region needs a regional urban and community forest management plan. The city of Portland is currently working on a revision of a management plan that emphasizes coordination between the goals of the different agencies and bureaus – air quality improvement, water quality improvement, canopy cover and education.

A regionwide education and outreach campaign also is needed to raise awareness about the importance of trees in the urban environment. Metro will continue to work with local jurisdictions on educating citizens about the economic, social and environmental benefits of the urban forest.

Refinement and Updates

Metro may seek opportunities to work with research institutions to measure the performance of pilot projects over time. The monitoring program would be used to determine the effectiveness of these improved streets designs and which designs provide the highest potential for mitigating the impacts of stormwater runoff on streams. Monitoring and evaluation will also help us determine the type and degree of ongoing maintenance needed to maintain a healthy street tree canopy.

The work in this manual will continue to be refined and updated as more species-specific data for the Pacific Northwest is collected during pilot project monitoring and evaluation studies. Independent research projects are needed to investigate the degree to which the street tree characteristics intercept rainfall and improve the quality of water entering our streams.

10.3 Livable Streets Handbooks Order Form

Creating Livable Streets – Street Design Guidelines
$14.95

Originally published in 1997, the updated second edition of this award-winning handbook describes how communities can reclaim major auto-oriented streets through better designs that integrate streets with nearby land uses. Street design elements such as sidewalks, crosswalks, bikeways, street trees, landscaping, street lighting, bus shelters and corner curb extensions provide a safer environment that can slow traffic and encourage walking, bicycling and transit use. (softbound)

Green Streets – Innovative Solutions for Stormwater and Stream Crossings
$14.95

This is a new resource for designing environmentally sound streets that can protect streams and wildlife habitat. This handbook describes stormwater management strategies and illustrates street designs with features such as street trees, landscaped swales and special paving materials that allow infiltration and limit runoff. Green Streets provides guidance on balancing the needs of protecting stream corridors and providing street access across these streams, including case studies of how this approach has been applied elsewhere. (softbound)

Trees for Green Streets – An Illustrated Guide
$9.95

This guide explains how to use street trees as a stormwater management tool. Intended to be a first step toward understanding the many functions that trees perform in urban areas, this guide provides illustrated examples of how trees can be used along streets. (softbound)

Geographic area of interest

Metro's handbooks relate to land-use and transportation plans adopted for the Portland, Ore., metropolitan region. Concepts in the two street design handbooks could apply to almost any city in the US. The street tree guide focuses on the Portland region but the tree suggestions apply to any West Coast temperate climate from Vancouver B.C., to parts of Northern California.

Who can use these handbooks

Anyone who is concerned about the design of urban streets would be interested in these handbooks. Citizen activists, urban planners, civil engineers, architects and landscape architects, college teachers and neighborhood organizers would find these handbooks valuable. For a preview of each book, including a table of contents and sample illustrations, visit www.metro-region.org/DRC.

How to order

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