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City of Tumwater
Tree Inventory and Maintenance Plan

February 28, 2024

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Funds for this project were provided by the USDA Forest Service Urban and Community Forestry Program, administered through the State of Washington Department of Natural Resources Urban and Community Forestry Program. The USDA is an equal opportunity provider and employer.

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i-Tree Glossary

The following terms and key concepts are referenced in this plan when evaluating trees for their environmental benefits. All field data was collected during the leaf-on season to properly assess tree canopies. The i-Tree *Eco* model uses inventory data, local hourly air pollution, and meteorological data to quantify the urban forest and its structure and benefits (Nowak & Crane, 2000), including:

- Urban forest structure (e.g., genus composition, tree health, leaf area, etc.).
- Amount of pollution removed hourly by the urban forest, and its associated percent air quality improvement throughout a year. Pollution removal is calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (<2.5 microns).
- Total carbon stored and net carbon annually sequestered by the urban forest.
- Structural value of the forest as a replacement cost.
- Potential impact of infestations by pests or pathogen.

Avoided surface water runoff value is calculated based on rainfall interception by vegetation, specifically the difference between annual runoff with and without vegetation. Although tree leaves, branches, and bark may intercept precipitation and thus mitigate surface runoff, only the precipitation intercepted by leaves is accounted for in this analysis. The U.S. value of avoided runoff, $0.01 gallon, is based on the U.S. Forest Service's Community Tree Guide Series (McPherson et al, 1999-2010; Peper et al, 2009; 2010; Vargas et al, 2007a-2008).

Carbon emissions were calculated based on the total City carbon emissions from the 2010 US per capita carbon emissions (Carbon Dioxide Information Analysis Center, 2010) This value was multiplied by the population of Tumwater (17,371) to estimate total City carbon emissions.

Carbon sequestration is removal of carbon from the air by plants. Carbon storage and carbon sequestration values are calculated based on $171 per short ton (EPA, 2015; Interagency Working Group on Social Cost of Carbon, 2015).

Carbon storage is the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation. Carbon storage and carbon sequestration values are calculated based on $171 per ton (EPA, 2015; Interagency Working Group on Social Cost of Carbon, 2015).

Diameter at Breast Height (DBH) is the diameter of the tree measured 4'5" above grade.

Household emissions average is based on average electricity kWh usage, natural gas Btu usage, fuel oil Btu usage, kerosene Btu usage, LPG Btu usage, and wood Btu usage per household in 2009 (EIA, 2013; EIA, 2014), CO_2, SO_2, and NO_3 power plant emission per KwH (Leonardo Academy, 2011), CO emission per kWh assumes 1/3 of one percent of C emissions is CO (EIA, 2014), PM_{10} emission per kWh (Layton 2004), CO_2, NO_3, SO_2, and CO emission per Btu for natural gas, propane and butane (average used to represent LPG), Fuel #4 and #6 (average used to represent fuel oil and kerosene) (Leonardo Academy, 2011), CO_2 emissions per Btu of wood (EIA, 2014), CO, NO_3 and SO_2 emission per Btu based on total emissions and wood burning (tons) from (British Columbia Ministry, 2005; Georgia Forestry Commission, 2009).

Leaf area was estimated using measurements of crown dimensions and percentage of crown canopy missing.

Monetary values ($) are reported in US dollars throughout the report.

Ozone (O_3) is an air pollutant that is harmful to human health. Ozone forms when nitrogen oxide from fuel combustion and volatile organic gases from evaporated petroleum products react in the presence of sunshine. In the absence of cooling effects provided by trees, higher temperatures contribute to ozone (O_3) formation.

Pollution removal is calculated based on the prices of $1,397 per ton (carbon monoxide), $1,376 per ton (ozone), $161 per ton (nitrogen dioxide), $47 per ton (sulfur dioxide), $119,426 per ton (particulate matter less than 2.5 microns), and $6,565 per ton (particulate matter less than 10 microns) (Nowak et al., 2014).

Potential pest impacts were estimated based on tree inventory information from the study area combined with i-Tree *Eco* pest range maps. The input data included species, DBH, total height, height to crown base, crown width, percent canopy missing, and crown dieback. In the model, potential pest risk is based on pest range maps and the known pest host species that are likely to experience mortality.

Pest range maps for 2011 from the Forest Health Technology Enterprise Team (FHTET) (Forest Health Technology Enterprise Team, 2014) were used to determine the proximity of each pest to Thurston County For the county, it was established whether the insect/disease occurs within the county, is within 250 miles of the county edge, is between 250 and 750 miles away, or is greater than 750 miles away. FHTET did not have pest range maps for Dutch elm disease and chestnut blight. The range of these pests was based on known occurrence and the host range, respectively (Eastern Forest Environmental Threat Assessment Center; Worrall 2007). Due to the dates of some of these resources, pests may have encroached closer to the tree resource in recent years.

Replacement value is based on the physical resource itself (e.g., the cost of having to replace a tree with a similar tree). Structural values were based on valuation procedures of the Council of Tree and Landscape Appraisers, which uses tree species, diameter, condition, and location information (Nowak et al 2002a; 2002b).

Ton is equivalent to a U.S. short ton, or 2,000 pounds.

1.0 Executive Summary

Trees play a vital role in the City of Tumwater. They provide numerous tangible and intangible benefits to residents, employees, visitors, and neighboring communities. The City of Tumwater recognizes that trees are a valued resource, a critical component of the urban infrastructure, and part of the City's identity. In 2023, the City of Tumwater contracted with Davey Resource Group, Inc. (DRG) to complete an inventory of city trees in parks, and at city facilities as well as plot sampling trees in natural areas (~201 Acres). The inventory data is being managed by the City of Tumwater using TreeKeeper, a tree asset management software system that allows managers to maintain current inventory specifics regarding tree characteristics, health, history, and maintenance needs. There are 7,345 sites in the TreeKeeper database. This includes a set of 5,286 tree sites that were previously collected by Tumwater community volunteers. The database also includes 2,062 trees added by Davey Resource Group inventory arborists in 2023.

To better understand Tumwater's inventoried tree resource, inventory data was analyzed using i-Tree's *Eco* benefit modeling software to develop a detailed and quantified analysis of the current structure, function, benefits, and value of this subset of the urban forest. Only 4,890 tree sites had sufficient data to be analyzed in i-Tree Eco. Plot sample data was analyzed separately to understand distinct species compositions, age distributions and condition of trees in natural areas. The natural areas were then analyzed with i-Tree's *Canopy* modeling software to evaluate the tree cover in natural areas as well as environmental benefits provided by all natural area trees. This report details the results of these analyses.

1.1 Structure

Analyzing the composition and structure of inventoried trees as a group was the first step towards understanding the benefits provided by the inventoried tree resource, as well as its management needs. As of 2023, Tumwater's inventoried trees includes 4,890 trees. Considering species composition and diversity, age distribution, condition, canopy coverage, and replacement value, DRG determined that the following information characterizes Tumwater's inventoried tree population:

- 110 unique tree species (Appendix B)
    - Norway maple (*Acer platanoides*, 15.3%) was the most common species, followed by Callery pear (*Pyrus calleryana*, 9.5%), and red maple (*Acer rubrum*, 9.2%)
- 44.5% of trees are less than 6-inches in diameter (DBH)[1] and 9.8% of trees are larger than 24-inches in diameter, indicating an established age distribution.
- 65.1% of inventoried trees are in very good condition.
- To date, Tumwater's inventoried trees are storing 1,968 tons of carbon (CO_2) in woody and foliar biomass.
- Replacement of the 4,890 inventoried trees with trees of equivalent size, species, and condition, would cost nearly $11.9 million.
- i-Tree *Eco* estimates 95% of trees are susceptible to 44 emerging pests and disease threats including Asian longhorned beetle, defoliating moths, and pine shoot beetle.

[1] DBH: Diameter at Breast Height. DBH represents the diameter of the tree when measured at 1.4 meters (4.5 feet) above ground (U.S.A. standard).

The following characterizes Tumwater's natural areas, estimated from sample plots:

- 42 plots with a total of 593 trees sampled.
    - 87% of sampled trees are in fair or better condition.
    - 41.3% of sampled trees had dieback/deadwood as the primary defect.
    - Sampled plots had an average of 14 trees and an average of 3 unique species.
- 16 distinct species of trees were found with a nearly ideal age-class distribution (41% of trees are less than 11" DBH, trees under 6" DBH were not collected).
- Public Property natural areas were estimated at 201 acres.
    - *I-Tree Canopy* indicates there are 116 acres of canopy in natural areas (58% +/- 4.03%)
    - There are an estimated 16,271 trees in natural areas (+/- 4,819 trees, 95% CI).
- To date, trees in Tumwater's natural areas are storing 4,003 tons of carbon (CO_2) in woody and foliar biomass.

1.2 Benefits

Annually, Tumwater's 4,890 trees analyzed in i-Tree Eco provide cumulative benefits to the community totaling more than $18,010. The average annual benefit per tree is $3.68. These benefits, and the benefits estimated from trees in natural areas (from plot samples) include:

- Inventoried trees intercepted 839,871 gallons of stormwater and reduced runoff, valued at $7,505, an average of $1.53 per tree.
    - Trees in natural areas intercepted 21,860 gallons of water and reduced 967 gallons of stormwater runoff (*i-Tree Canopy*).
- Inventoried trees removed 1.1 tons of air pollutants, including nitrogen dioxide, sulfur dioxide, carbon monoxide, ozone, and small particulate matter ($PM_{2.5}$) valued at $5,957, an average of $1.22 per tree.
    - Trees in natural areas removed 4.4 tons of air pollutants.
- Inventoried trees reduced costs and medical visits resulting from adverse health effects caused by air pollution, valued at $3,275.
- Inventoried trees directly sequestered 26.7 tons of additional carbon, valued at $4,548, an average of $0.93 per tree.
    - Trees in natural areas sequester 159 tons of carbon annually.

This is a limited and conservative accounting of the true environmental and socioeconomic benefits from Tumwater's inventoried and plot sampled trees. Many documented benefits from trees are unable to be quantified using current methods; for example, benefits to wildlife, property values, and public health and welfare (University of Washington, 2018; University of Illinois, 2018).

1.3 Management & Investment

This tree inventory is a dynamic resource that requires continued investment to maintain and realize its full benefit potential. Trees are one of the few community assets that have the potential to increase in value with time and proper management. Annually, the City invests approximately $1M in the management of trees in Tumwater. Most of these funds are used in the care of street trees and park trees.

Appropriate and timely tree care can substantially increase lifespan. When trees live longer, they provide greater benefits. As individual trees mature, and aging trees are replaced, the overall value of the inventoried forest and the amount of benefits provided grow as well. However, this vital living resource is vulnerable to a host of stressors and requires sustainable best management practices to ensure a continued flow of benefits for future generations.

Of the 4,890 trees in the inventory, there was maintenance work identified. The City anticipates prioritizing maintenance work and estimated costs on a four-year cycle:

- **Inspection** – 1,759 hours of inspection work are anticipated for 7,019 trees that should be inspected and updated in the database at an estimated cost of $41,770.
- **Priority Removals** – 56 trees were identified as higher priority tree removals. Trees would be planted to replace these trees. This was estimated as 1,568 person-hours at an estimated cost of $313,600.
- **Priority Pruning** – 29 Trees were identified requiring higher priority care at an estimated 232 person-hours, $44,800.
- **Large Tree Routine Pruning** – 208 trees were identified as large tree routine pruning at an estimated 1,664 person-hours or $499,200.
- **Small Tree Routine Pruning** - 59 trees were identified for small tree routine pruning at an estimated 236 person-hours or $47,200.
- **Unassigned Trees** – Within the database were trees identified for maintenance by community volunteers. These include 43 removals, 883 trees requiring crown raising, and 90 young trees with stakes to pull. While these trees should be inspected to confirm the work needs, a preliminary estimate is 8,141 person-hours at an estimated cost of $2,329,875.

The total workload and cost estimates discovered through this project are approximately $3,403,356 (or $850,839 on a 4-year cycle). These cost estimates assume prevailing wage rates apply and do not include additional costs such as program administration, emergency work or inflation.

Overall, the inventoried tree resource in Tumwater is in fair or better condition with an established age distribution. Although managers cannot foresee when a pest or pathogen may be introduced to the urban forest, being aware and equipped to identify potential threats allows the City to approach management and prevention in a way that fits the community's culture and available resources. Using best management practices to prepare for and/or manage pests and pathogens can lessen the detrimental impacts they have on the urban forest. With proactive management, planning, and new and replacement tree planting, the benefits from this resource will continue to increase as young trees mature.

1.4 Maintenance Plan Actions

Based on this maintenance report, the City would benefit from the following priority urban forest management actions:

- Maintain and Expand the Tree Inventory

  - Assign maintenance to all inventoried trees to proactively manage Tumwater's tree resource.
  - Prioritize planting replacement trees for those trees that have previously been removed.
  - Prioritize structural pruning for young trees and a regular maintenance cycle for all inventoried trees.
  - Regularly inspect trees to identify and mitigate structural and age-related defects to manage risk and reduce the likelihood of tree and branch failure.
  - Consider opportunities to further support wildlife habitat and pollinators, including protecting diverse vegetation and preserving snags and deadwood in natural areas where targets are unlikely.
  - Species that are adequately represented by established age distributions but lack recent plantings should receive priority care.
  - Inventory updates should be incorporated as regular maintenance is performed, including updating the diameter and condition of existing trees.
- Plant New Trees
  - Increase genus and species diversity in new and replacement tree plantings to reduce reliance on abundant groups.
  - Plant trees in priority areas to improve diversity, increase benefits, and further distribute the age distribution of inventoried trees.
  - Use the largest stature tree possible where space allows to optimize urban forest benefits.
  - Consider successional planting of important species, as determined by relative performance index (RPI) and the relative age distribution.

With adequate protection and planning, the value of the Tumwater's inventoried trees will continue to increase over time. Proactive management and a tree replacement plan are critical to ensuring that the community continues to receive a high level of benefits. Along with new tree installations and replacement plantings, funding for tree maintenance and inspection is highly recommended to preserve benefits, prolong tree life, and manage risk. Existing mature trees should be maintained and protected whenever possible since the greatest benefits accrue from the continued growth and longevity of the existing canopy. Managers can take pride in knowing that inventoried trees support the quality of life for residents and neighboring communities.

2.0 Introduction

The City of Tumwater boasts a thriving urban forest that's integral to its identity. Home to nearly 26,000 people, Tumwater is known for being the earliest American settlement in Washington. Today, the community has an extensive urban forest that benefits both the City and its people. Tumwater is located amongst many beautiful, natural landmarks and has thriving arts, culture, and recreational opportunities.

The community experiences a moderate climate with higher-than-average cloud cover. Tumwater's climate is characterized by summer daytime temperatures in the 70°F and winter daytime temperatures in the 40°F and 50°F (Sperling's, Best Places, n.d.). Tumwater's moderate climate allows a long growing season, where temperatures do not drop below freezing for a period of almost 9 months (March through November, Weather Spark. n.d.). Typically, Tumwater receives 44 inches of rain and 6 inches of snow each year, with the majority occurring between October and March (Sperling's, Best Places, n.d.). The moderate temperatures coupled with high precipitation allow many trees to thrive and some reach substantial heights.

The urban forest stands as vital green space for the community, contributing to the City's environmental health and community well-being. Individual trees play an essential role in the community of Tumwater by providing many benefits, tangible and intangible, to residents, visitors, and neighboring communities. Research demonstrates that healthy urban trees can improve the local environment and lessen the impact resulting from urbanization and industry (Center for Urban Forest Research, 2017). Trees improve air quality, reduce energy consumption, help manage stormwater, reduce erosion, provide critical habitat for wildlife, and promote a connection with nature. When taken together, the urban forest contributes to a healthier, more livable, and prosperous Tumwater.

The City first began monitoring their public trees as a discrete population with an inventory gathered by community volunteers in 2018. In 2023, the City of Tumwater commissioned **additional tree inventory** within City parks and at City facilities to further the efforts of understanding and managing their urban forest. Another tree population included in this report was a **plot sample inventory** of trees in natural areas (~201 Acres of public properties). Sample plots were selected from forest stands with full tree canopies. Plots were 1/10th of an acre and the data from the plots was used to extrapolate composition, structure, condition for trees in natural areas. Trees under 6" DBH were not collected.

This report provides the following information:

- A description of the structure of Tumwater's tree resource and an established benchmark for future urban forest management decisions
- The economic value of the benefits from the inventoried tree resource
- Data that may be used by resource managers in the pursuit of alternative funding sources and collaborative relationships with utility purveyors, non-governmental organizations, air quality districts, federal and state agencies, legislative initiatives, or local assessment fees

The tree data (inventoried trees) was analyzed with i-Tree *Eco* benefit-cost modeling software to generate this resource analysis. i-Tree's *Eco* (Eco v6.1.35) software application is designed to use inventory data collected in the field along with local hourly air pollution and meteorological data to quantify urban forest structure, environmental effects, and value to communities. Tumwater's natural Area trees were analyzed with i-Tree *Canopy* to quantify benefits provided to the City. These benefit estimations are limited but include carbon storage and annual carbon sequestration, annual air pollution removal, and hydrological benefits such as avoided stormwater runoff.

These models make estimates of the effects of urban forests based on peer-reviewed scientific equations to predict environmental and economic benefits. Although many of the socio-economic, human health, or wildlife sustainability benefits cannot be quantified, they are certainly an important benefit of Tumwater's inventoried tree resource and plot sampled natural areas resource. The baseline data from this analysis can be used to make effective resource management decisions, develop policy, and set priorities.

3.0 Inventory Results & Tree Resource Summary

Inventoried Trees

There were 7,375 sites catalogued in a tree inventory database for this project. Within this is a subset of 4,890 sites that had sufficient information to model their benefits in i-Tree. These 4,890 inventoried trees identified are more thoroughly understood through examination of composition and species richness of diversity. Consideration of stocking level, canopy cover, age distribution, condition, and performance, provide a foundation for planning and management strategies. Inferences based on this data can help managers understand the importance of individual tree species to the overall forest as it exists today and provide a basis to project the future potential of the resource.

Trees in Natural areas

Within the City of Tumwater there were approximately 201 acres categorized and managed as natural areas for this project. According to *i-Tree Canopy*, only 116 acres have tree canopy. The trees in these canopied areas typically receive care to mitigate safety concerns. For this reason, a sampling approach was used on the parcels to inspect and inventory a representative proportion of the population. Most trees are unmanaged and left to grow as part of the natural ecosystem processes, but some areas are being increasingly managed as the city grows in population and people increase their use of trails.

Information was gathered in 42 plots randomly selected from 8 different natural areas. Each plot was a circular plot of 1/10th of an acre. At each plot, the arborist inspected and inventoried trees to provide a statistical representation for the entire forest. The mean number of trees (>6" Diameter) found in each plot was 14.02 trees with a standard deviation of 7.93. Across 116 acres of tree canopy, the estimated number of trees 6" DBH or greater in the natural areas is 16,271 stems (+/- 4,819, 95% C.I.).

Table 1: Natural Areas and Number of Plots

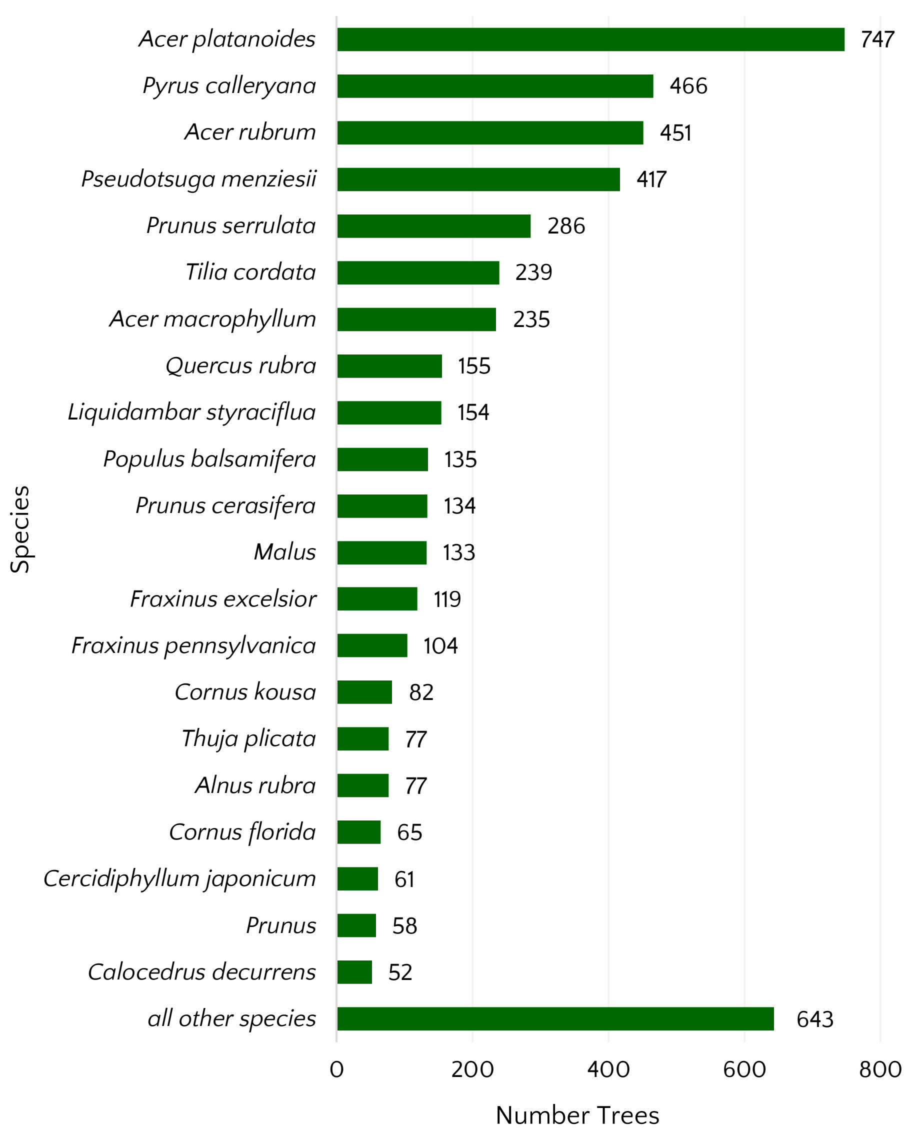
Site	Acres	Sample Plots
11th Ave SW (Storm Site)	6.2	3
2332 SW SAPP DR	11.8	3
Barnes Blvd SW Natural Area	7.3	2
436 LINWOOD AVE SW (Isabella Bush Park)	19.5	3
305 O ST SE (Palermo Pocket Park and maintenance shop)	20.5	9
5801 HENDERSON BLVD SE (Pioneer Park)	87.1	9
Trosper Lake Natural Area	18.3	6
115 Ridgeview Loop SW (Tumwater Hill Park)	29.0	6
Total		41

3.1 Species Composition & Richness

Inventoried Trees

The composition and richness of species was calculated as the proportion of species representing the inventoried forest population (Figure 1). The City of Tumwater's inventoried urban forest consists of trees spanning different size classes and growth forms so that the proportion of a species does not directly relate to the area it occupies. As an example, red maple (*Acer rubrum*) and Douglas-fir (*Pseudotsuga menziesii*) each comprise nearly 9% of the overall population, but red maple is a broad-leafed shade tree and therefore covers more surface area when compared to Douglas-fir.

Figure 1: Most Prevalent Species in Tumwater (Representing >1%)



The City of Tumwater's inventoried tree resource includes a mix of 110 unique species (Appendix C), with 19% of species native to Washington. The diversity in Tumwater's inventoried trees is less than the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 U.S. cities. The most prevalent species are Norway maple (*Acer platanoides*, 15.3%), Callery pear (*Pyrus calleryana*, 9.5%), and red maple (*Acer rubrum*, 9.6%) (Figure 1). Together, these three species make up 34% of the overall population. Tumwater's 21 most prevalent species (representing >1% of the overall population) make up 86.9% of the overall population.

Trees in Natural areas

Within the natural areas, 16 different species were identified dominated by big leaf maple (*Acer macrophyllum,* 28%), Douglas-fir (*Pseudotsuga menziesii,* 22%), red alder (*Alnus rubra,* 17%) and western red cedar (*Thuja plicata,* 15%). Twelve (12) other species represented the remaining 17% of the natural area tree population (Table 2). Further increasing biodiversity can increase the resilience of the natural areas and limit the reliance on any one species. This also helps protect the population from pests and disease.

Table 2: Sample Plot Tally of Species and Proportion of Population in Natural Areas

Species Breakdown	# of trees	% of trees
Acer macrophyllum	167	28.2%
Pseudotsuga menziesii	130	21.9%
Alnus rubra	101	17.0%
Thuja plicata	89	15.0%
Prunus species	22	3.7%
Populus balsamifera ssp. trichocarpa	17	2.9%
Tsuga heterophylla	15	2.5%
Picea sitchensis	13	2.2%
Fraxinus latifolia	9	1.5%
Crataegus species	7	1.2%
Acer circinatum	7	1.2%
Salix species	5	0.8%
Corylus species	5	0.8%
Arbutus menziesii	2	0.3%
Pinus monticola	2	0.3%
Ilex aquifolium	2	0.3%

Maintaining diversity in a public tree resource is important. Dominance of any single species or genus can have detrimental consequences in the event of storms, drought, disease, pests, or other stressors that can severely affect a community tree resource, the flow of benefits and costs over time. Catastrophic pathogens, such as Dutch elm disease (*Ophiostoma ulmi*), emerald ash borer (*Agrilus planipennis*), Asian longhorned beetle (*Anoplophora glabripennis*), and sudden oak death (*Phytophthora ramorum*) are some examples of unexpected, devastating, and costly pests and pathogens. They highlight the importance of diversity and the balanced distribution of species and genera.

Recognizing that all tree species have a potential vulnerability to pests and disease, urban forest managers have long observed a best management practice that no single species should represent greater than 10% of the total population and no single genus more than 20% (Santamour, 1990). Among Tumwater's tree population, at the species level, Norway maple (*Acer platanoides*) exceeds this rule. At the genus level, maples (*Acer spp.*) represent 31.2% of the overall population. To increase species diversity and promote greater resilience in the overall resource, future plantings should reduce reliance on species of maple trees.

3.2 Species Importance

To quantify the significance of any one species in Tumwater's inventoried tree resource, an importance value (IV) is derived for each of the most prevalent species. Importance values are particularly meaningful to community tree resource managers because they indicate a reliance on the functional capacity of a species. **i-Tree *Eco* calculates importance value based on the sum of two values: percentage of total population and percentage of total leaf area.** Importance value goes beyond tree numbers alone to suggest reliance on specific species based on the benefits they provide. The importance value can range from zero (which implies no reliance) to 100 (suggesting total reliance). A complete table, with importance values for all species, is included in Appendix B: Tables.

To reiterate from the previous section, research strongly suggests that no single species should dominate the composition of a community tree resource. Because importance value goes beyond population numbers, it can help managers to better comprehend the resulting loss of benefits from a catastrophic loss of any one species. When importance values are comparatively equal among the 10 to 15 most prevalent species, the risk of significant reductions to benefits is reduced. Of course, suitability of the dominant species is another important consideration. Planting short-lived or poorly adapted species can result in short rotations and increased long-term management costs.

Table 4 lists the importance values of the most prevalent species. These 21 species represent 86.9% of the overall population and 86.5% of the total leaf area for a combined importance value of 270. Of these, Tumwater relies heavily on Norway maple (*Acer platanoides*, IV=42.5). Tumwater also relies on the additional species Callery pear (*Pyrus calleryana*, IV=26.7), red maple (*Acer rubrum*, IV=17.2), and Douglas-fir (*Pseudotsuga menziesii*, IV=11.1). Combined these four species represent 42.6% of the inventoried tree resource, providing significant benefits and a sense of place. They are the key species to sustaining the benefits provided by the community tree resource, as well as preserving the essence of Tumwater for years to come.

For some species, low importance values are primarily a result of species stature and/or age distribution. Immature or small-stature species frequently have lower importance values than their representation in the inventory might suggest. This is due to their relatively small leaf area and canopy coverage. For example, little-leaf linden (*Tilia cordata*), a large-statured tree with a young age distribution, represents 4.9% of the overall population and 3.2% of total leaf area resulting in an importance value of 8.1. As this large-stature tree matures the leaf area and subsequent importance value will increase significantly.

Some species are more significant contributors to the urban forest than population numbers would suggest. For example, Callery pear (*Pyrus calleryana*), 9.5% of the population and has an importance value of 26.7. This medium-statured species is mainly represented by individuals in the 6-11 inches DBH category (35.6% are established and >6 inches in diameter), representing 17.1% of the leaf surface area.

Table 3: Inventoried Species Importance Value (IV) of Prevalent Species in Tumwater (Representing >1%)

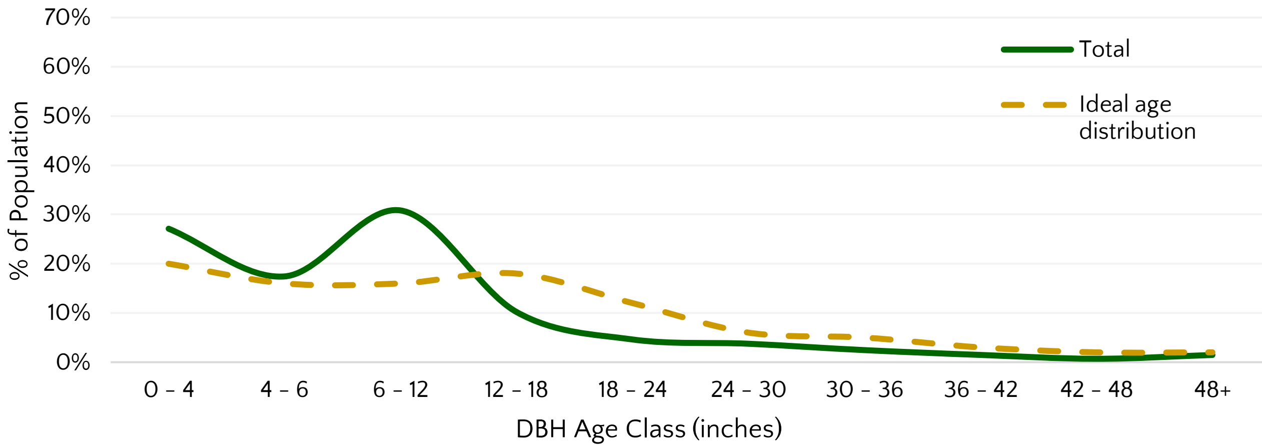
Species	# of Trees	% of Trees	% Leaf Area	IV
Acer platanoides	747	15.28	27.23	42.50
Pyrus calleryana	466	9.53	17.13	26.66
Acer rubrum	451	9.22	7.92	17.15
Pseudotsuga menziesii	417	8.53	3.54	11.07
Prunus serrulata	286	5.85	3.53	9.38
Tilia cordata	239	4.89	3.18	8.07
Acer macrophyllum	235	4.81	2.67	7.48
Quercus rubra	155	3.17	2.64	5.81
Liquidambar styraciflua	154	3.15	2.41	5.56
Populus balsamifera	135	2.76	2.22	4.98
Prunus cerasifera	134	2.74	2.11	4.86
Malus	133	2.72	1.80	4.52
Fraxinus excelsior	119	2.43	1.60	4.04
Fraxinus pennsylvanica	104	2.13	1.45	3.58
Cornus kousa	82	1.68	1.32	3.00
Alnus rubra	77	1.57	1.17	2.74
Thuja plicata	77	1.57	1.11	2.70
Cornus florida	65	1.33	0.92	2.25
Cercidiphyllum japonicum	61	1.25	0.87	2.11
Prunus	58	1.19	0.86	2.05
Calocedrus decurrens	52	1.06	0.76	1.83
all other species	643	13.15	13.52	26.67
Total	4,890	100%	100%	200

3.3 Relative Age Distribution

The relative age distribution of individual trees within the resource (or by species) influences present and future costs as well as the flow of benefits. Age distribution can be approximated by considering the DBH range of the overall inventory and of individual species. Trees with smaller diameters tend to be younger. An ideally aged population allows managers to allocate annual maintenance costs uniformly over many years and assures continuity in overall tree canopy coverage and associated benefits. A desirable distribution has a high proportion of young trees to offset establishment and age-related mortality as older trees decline over time (Richards, 1982/83). This ideal distribution, albeit uneven, suggests a large fraction of trees (~40%) should be young, with a DBH less than eight inches, while only 10% should be in the large diameter classes (>24 inches DBH).

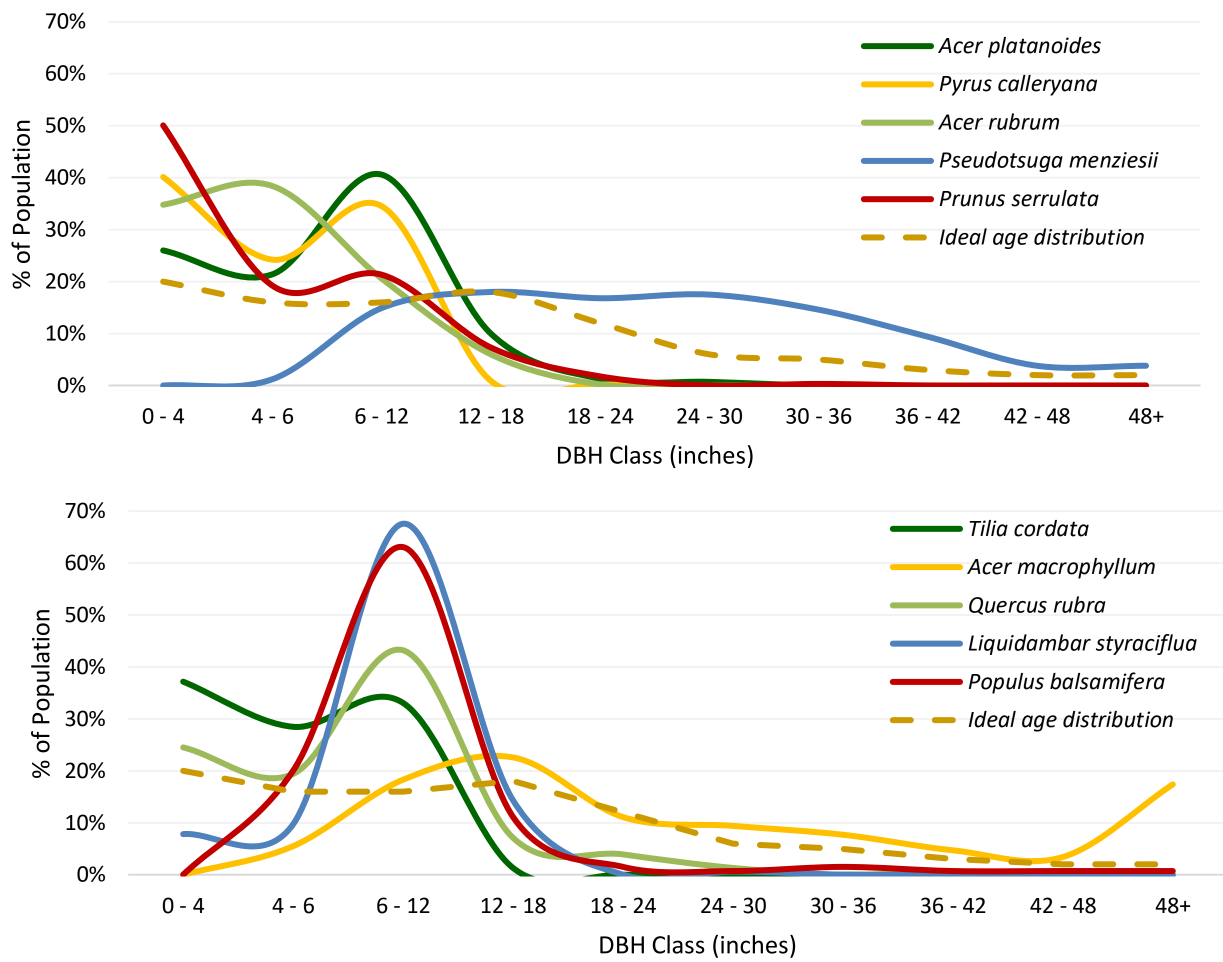
The age distribution of Tumwater's inventoried trees shows an established population. In total, 44.5% of trees are 6-inches or less in diameter (DBH) and approximately 9.8% of trees are larger than 24-inches in diameter (Figure 2). Relative age distribution can also be evaluated for each individual species. The 10 most prevalent inventoried tree species are compared against the ideal distribution in Figure 3.

Figure 2: Inventoried Tree Relative Age Distribution for Tumwater



The majority of the 10 most prevalent species in Tumwater's inventoried tree inventory have a young age distribution. For example, the age distributions of Norway maple (*Acer platanoides*), Callery pear (*Pyrus calleryana*), red maple (*Acer rubrum*), little-leaf linden (*Tilia cordata*), northern red oak (*Quercus rubra*), sweetgum (*Liquidambar styraciflua*), and balsam poplar (*Populus balsamifera*) all show that the majority of individuals are 0- to 11-inch DBH. While the majority of paper bark cherry (*Prunus serrulata*) are in the 0- to 11-inch DBH range, this is a small statured species and therefore many of these individuals may be mature rather than young. In contrast, the age distributions of Douglas-fir (*Pseudotsuga menziesii*) and bigleaf maple (*Acer macrophyllum*) show significant representation in the mature DBH ranges with few young trees.

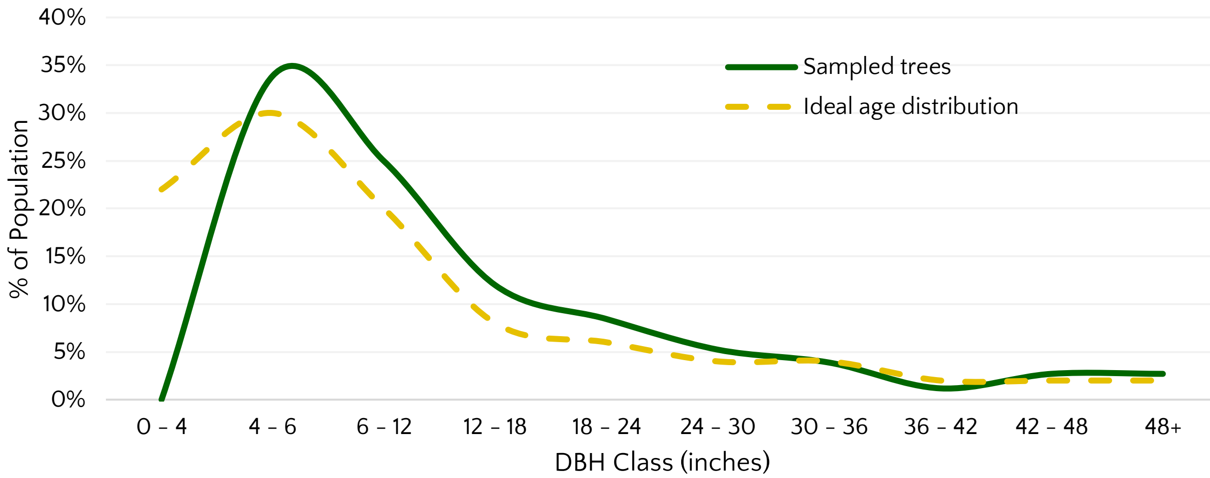
Figure 3: Relative Age Distribution of Tumwater's Top 10 Most Prevalent Inventoried Species



Relative Age Distribution of Trees in Natural Areas

Within the natural areas, the average diameter was 18" (+/- 1.05", 95% CI). Some of the largest specimens found in the natural area include a bigleaf maple (*Acer macrophyllum*, 122" DBH), a Douglas-fir (*Pseudotsuga menziesii*, 42"), an alder (*Alnus rubra*, 68") and a western red cedar (*Thuja plicata*, 81"). The age distribution of Tumwater's natural areas shows a moderately established population, characterized by many young trees dispersed among larger and older trees. In total, nearly 42% of trees are 12-inches or less in diameter (DBH) and approximately 16% of trees are larger than 24-inches in diameter (Figure 4). It is important to note trees with a DBH of less than 6 inches were not collected.

Figure 4: Relative Age Distribution of Tumwater's Natural Areas

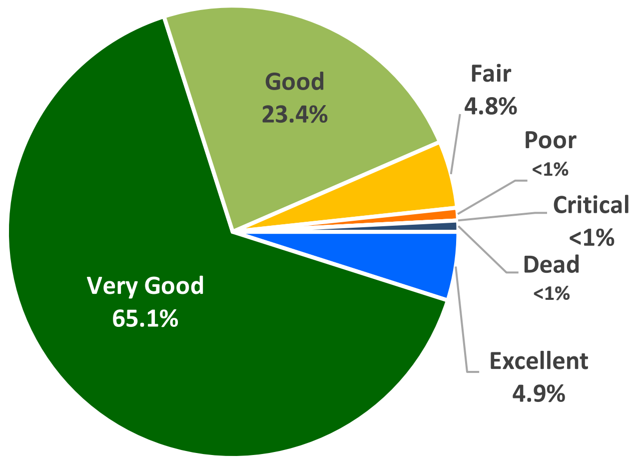


3.4 Tree Condition

Tree condition is an indication of how well trees are managed and how well they are performing in each site-specific environment (e.g., street, median, parking lot, park, etc.). Condition ratings can help managers anticipate maintenance and funding needs. In addition, tree condition is an important factor for the calculation of community tree resource benefits. A condition rating of good assumes that a tree has no major structural problems, no significant mechanical damage, and may have only minor aesthetic, insect, disease, or structural problems, and is in good health. When trees are performing at their peak, as those rated as good or better, the benefits they provide are maximized.

Inventoried trees in Tumwater are in overall fair or better condition. Of the trees, 98.2% are in fair or better condition. Approximately 1.8% are in poor or critical condition (Figure 5). There were six (6) dead trees excluded from further benefits analysis.

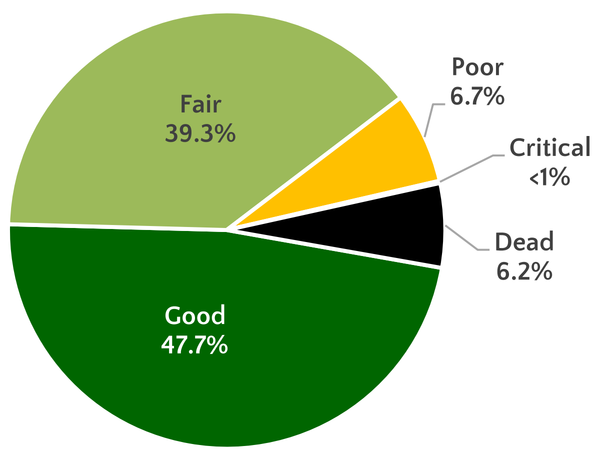
Figure 5: Tree Condition of Inventoried Trees



Trees in Natural Areas

Trees in natural areas in Tumwater are in overall fair or better condition. Of the trees, 87% are in fair or better condition. Approximately 6.2% are dead and 6.7% are in poor condition (Figure 6). Dead trees and snags are beneficial and provide habitat for wildlife.

Figure 6: Tree Condition of Trees in Natural Areas



3.5 Relative Performance Index

The relative performance index (RPI) is another method to further describe the condition and suitability of a specific tree species. The RPI provides an urban forest manager with a detailed perspective on how different species are performing in comparison to each other. The index compares the condition rating of each tree species with the condition ratings of every other tree species within the inventory. An RPI of 1.0 or better indicates that the species is performing as well or better than average. An RPI value below 1.0 indicates that the species is not performing as well in comparison to the rest of the population.

RPI could only be evaluated for the inventoried tree population. Among the 21 most prevalent tree species, 9 have an RPI of 1.0 or greater (Table 4). Red maple (*Acer rubrum*) has the highest RPI at 1.06, followed by Norway maple (*Acer platanoides*) with an RPI of 1.05 and Callery pear (*Pyrus calleryana*) with an RPI of 1.04. In contrast, red alder (*Alnus rubra*), has the lowest RPI at 0.82. However, there are many other species in the inventory that are performing well and better than average. Incorporating a greater variety of high-performing species in future plantings is recommended to increase diversity.

The RPI of a species can be a useful tool for urban forest managers. For example, if a community has been planting two or more new species, the RPI can be used to compare their relative performance. If the RPI indicates that one is performing relatively poorly, managers may decide to reduce or even stop planting that species and subsequently save money on both planting stock and replacement costs. The RPI enables managers to look at the performance of long-standing species as well. Established species with an RPI of 1.00 or greater have performed well over time. These top performers should be retained, and planted, as a healthy proportion of the overall population. It is important to keep in mind that, because RPI is based on condition at the time of the inventory, it may not reflect cosmetic or nuisance issues, especially seasonal issues that are not threatening the health or structure of the trees.

Table 4: Relative Performance Index of Most Prevalent Inventoried Species (Representing >1%)

Species	% Excellent	% Very Good	% Good	% Fair	% Poor	% Critical	% Dead	RPI	# of Trees	% of Trees
Acer platanoides	6.0	85.5	5.8	1.7	0.5	0.0	0.4	1.05	747	15.28
Pyrus calleryana	3.4	83.5	10.7	2.1	0.2	0.0	0.0	1.04	466	9.53
Acer rubrum	11.9	74.3	10.2	1.8	0.9	0.0	0.0	1.06	451	9.22
Pseudotsuga menziesii	0.0	65.2	31.7	1.7	0.0	0.0	1.4	0.99	417	8.53
Prunus serrulata	3.5	73.8	16.1	4.9	1.4	0.0	0.3	1.01	286	5.85
Tilia cordata	21.8	54.0	16.7	5.4	1.3	0.0	0.8	1.04	239	4.89
Acer macrophyllum	0.0	35.7	57.0	4.7	0.4	0.0	2.1	0.92	235	4.81
Quercus rubra	1.9	80.6	11.6	3.2	1.9	0.0	0.6	1.02	155	3.17
Liquidambar styraciflua	3.2	53.2	37.7	4.5	1.3	0.0	0.0	0.98	154	3.15
Populus balsamifera	0.0	56.3	11.6	31.1	0.0	0.0	0.0	0.93	135	2.76
Prunus cerasifera	0.7	39.6	40.3	18.7	0.7	0.0	0.0	0.92	134	2.74
Malus	7.5	39.8	42.1	9.8	0.8	0.0	0.0	0.96	133	2.72
Fraxinus excelsior	1.7	83.2	5.9	5.0	4.2	0.0	0.0	1.02	119	2.43
Fraxinus pennsylvanica	0.0	62.5	37.5	0.0	0.0	0.0	0.0	1.00	104	2.13
Cornus kousa	0.0	57.3	32.9	3.7	3.7	0.0	2.4	0.95	82	1.68
Alnus rubra	0.0	22.1	55.8	10.4	0.0	0.0	11.7	0.82	77	1.57

Thuja plicata	0.0	48.1	41.6	2.6	7.8	0.0	0.0	0.94	77	1.57
Cornus florida	0.0	46.2	38.5	6.2	6.2	0.0	3.1	0.91	65	1.33
Cercidiphyllum japonicum	11.5	72.1	14.8	1.6	0.0	0.0	0.0	1.05	61	1.25
Prunus	0.0	5.2	72.4	17.2	1.7	0.0	3.4	0.83	58	1.19
Calocedrus decurrens	0.0	36.5	55.8	7.7	0.0	0.0	0.0	0.94	52	1.06
all other species	5.0	58.3	31.0	4.5	0.3	0.0	0.9	0.99	643	13.15
Total	4.9%	65.1%	23.4%	4.8%	0.9%	0%	0.8%	1.00	4,890	100%

An RPI value less than 1.00 may be indicative of a species that is not well adapted to local conditions. Poorly adapted species are more likely to present increased safety and maintenance issues. Species with an RPI less than 1.00 should receive careful consideration before being selected for future planting choices. However, prior to selecting or deselecting trees based on RPI alone, managers should consider the age distribution of the species, among other factors. A species that has an RPI of less than 1.00 but has a significant number of trees in larger DBH classes, may simply be exhibiting signs of population senescence. A complete table, with RPI values for all species, is included in Appendix B.

RPI is also helpful for identifying underused species that are demonstrating reliable performance. Species with an RPI value greater than 1.00 and an established age distribution may indicate their suitability for the local environment. These species should receive consideration for additional planting. As an example, London plane (*Platanus x hybrida*) has an RPI of 1.03 and that is represented by young to mature trees (41.7% are less than 11-inches in diameter and 24.9% are more than 24-inches in diameter). Oregon white oak (*Quercus garryana*) is also performing well and adequately represented through the age distribution, (7.1% are less than 11-inches in diameter and 64.2% are more than 24-inches in diameter). The representation of the population and the age distribution of these species support the RPI values. Alternatively, European ash (*Fraxinus excelsior*, 2.4%) has an RPI of 1.02 and is primarily represented by trees less than 11-inches in diameter (99.2%). Although this species is likely to perform well in Tumwater, there are not enough mature trees to substantiate the high RPI due to the lack of evidence of long-term performance and longevity.

3.6 Replacement Value

The current replacement value of Tumwater's inventoried tree resource is nearly $11.9 million for the inventoried tree population. The replacement value accounts for the historical investment in trees over their lifetime. This value is also a way of describing the value of a tree population (and/or average value per tree) at a given time. The replacement value reflects current population numbers, stature, placement, and condition. There are several methods available for obtaining a fair and reasonable perception of a tree's value (Council of Tree and Landscape Appraisers, 2018; Watson, 2002). The trunk formula method used in this analysis assumes the value of a tree is equal to the cost of replacing the tree in its current state (Cullen, 2002).

Of the overall replacement value, 24.5% is attributable to Douglas-fir (*Pseudotsuga menziesii*), for a total of nearly $3 million (Table 5). Bigleaf maple (*Acer macrophyllum*) has the highest per tree replacement value of $10,006 per tree for a total replacement value of nearly $2.4 million. The average per tree replacement value is $2,435. To replace all 4,890 inventoried trees in Tumwater with trees of equivalent size and condition would cost nearly $11.9 million.

The replacement value for Tumwater's inventoried tree resource reflects the vital importance of these assets to the community. With proper care and maintenance, the value will continue to increase over time. It is important to recognize that replacement values are separate and distinct from the value of annual benefits produced by the inventoried tree resource and in some instances the replacement value of a tree may be greater than or less than the benefits that that tree may provide.

Table 5: Replacement Value for Most Prevalent Inventoried Species (Representing >1%)

Species	# of Trees	% of Pop.	Replacement Value ($)	% of Replacement
Acer platanoides	747	15.28	1,092,056	9.17
Pyrus calleryana	466	9.53	327,636	2.75
Acer rubrum	451	9.22	315,733	2.65
Pseudotsuga menziesii	417	8.53	2,916,093	24.49
Prunus serrulata	286	5.85	276,028	2.32
Tilia cordata	239	4.89	214,457	1.80
Acer macrophyllum	235	4.81	2,351,445	19.75
Quercus rubra	155	3.17	326,338	2.74
Liquidambar styraciflua	154	3.15	275,052	2.31
Populus balsamifera	135	2.76	144,963	1.22
Prunus cerasifera	134	2.74	253,427	2.13
Malus	133	2.72	172,095	1.45
Fraxinus excelsior	119	2.43	80,296	0.67
Fraxinus pennsylvanica	104	2.13	54,116	0.45
Cornus kousa	82	1.68	29,703	0.25
Alnus rubra	77	1.57	265,980	2.23
Thuja plicata	77	1.57	396,425	3.33
Cornus florida	65	1.33	37,342	0.31
Cercidiphyllum japonicum	61	1.25	95,088	0.80
Prunus	58	1.19	179,669	1.51
Calocedrus decurrens	52	1.06	70,969	0.60
all other species	643	13.15	2,032,813	17.07
Total	4,890	100%	$11,907,733	100%

Trees and urban forests provide tangible and quantifiable benefits to the community. They continuously mitigate the effects of urbanization and development and protect and enhance the quality of life within the community. The amount and distribution of leaf surface area is the driving force behind the ability of the urban forest to produce benefits for the community (Clark et al, 1997). If trees are healthy and vigorous, they often produce more leaf surface area each year.

Urban forests have important functional benefit values based on the environmental functions the trees perform. In addition to air quality benefits like producing oxygen and filtering out particulates, trees slow down and absorb stormwater as well as remove pollutants. Resulting in reduced stormwater management costs for municipalities. Tree growth sequesters carbon in the production of new woody stems and roots. The value of these ecosystem functions is calculated in terms of both volume and cost savings.

3.7 iTree Analysis & Environmental benefits

Annual environmental functional values tend to increase with increased number and size of healthy trees (Nowak et al, 2002). Through proper management, urban forest values can be increased over time as trees mature and with improved longevity. Climate, pest, and weather events can cause values to decrease as the amount of healthy tree cover declines. Excluding energy benefits of trees, Tumwater's inventoried trees provide annual environmental benefits valued at $18,010 (Figure 11). The annual environmental benefits provided by the inventoried tree resource are conservative estimates due to limitations in the i-Tree *Eco* program, which does not calculate benefit values for trees larger than 100-inches in diameter. As such, some trees in the inventory exceeded the maximum allowable diameter and were therefore assigned a default measurement of 100-inches in diameter to accommodate the analysis.

3.8 Air Quality

Urban trees improve air quality in five fundamental ways:

- Absorption of gaseous pollutants such as ozone (O_3), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2) through leaf surfaces
- Reduction of emissions from power generation by reducing energy consumption
- Increase of oxygen levels through photosynthesis
- Transpiration of water and shade provision, resulting in lower local air temperatures, thereby reducing ozone (O_3) levels
- Interception of particulate matter ($PM_{2.5}$), (i-Tree *Eco* analyzes particulate matter less than 2.5 micrometers which is generally more impactful on human health [i-Tree *Eco* User Manual, 2019])

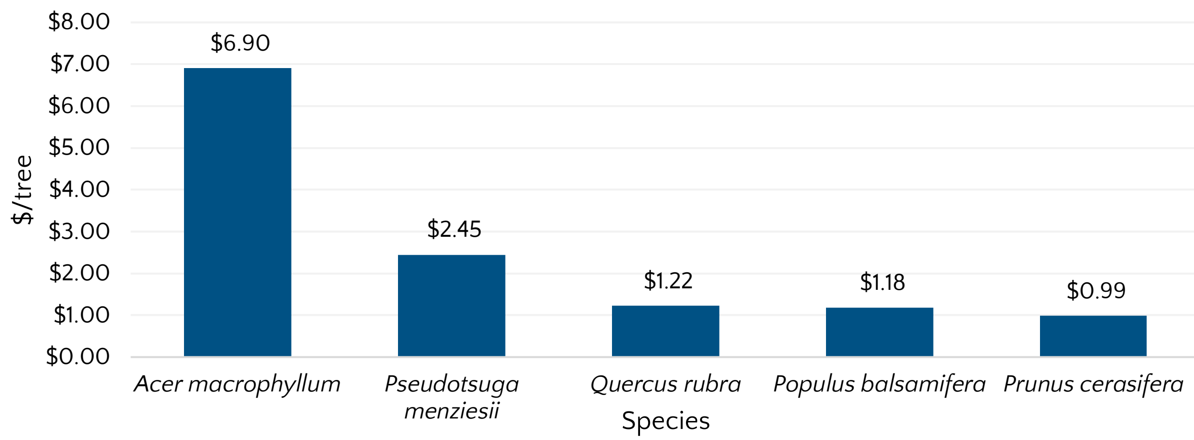
Air pollutants are known to contribute adversely to human health. Trees lessen the amount of air pollutants in the atmosphere, which can reduce the incidence of numerous negative health effects (Table 8).

Ozone is an air pollutant that is particularly harmful to human health. Ozone forms when nitrogen oxide from fuel combustion and volatile organic gases from evaporated petroleum products react in the presence of sunshine. In the absence of cooling effects provided by trees, higher temperatures contribute to ozone formation. Additionally, short-term increases in ozone concentrations are statistically associated with increased tree mortality for 95 large US cities (Bell et al, 2004). However, it should be noted that while trees do a great deal to absorb air pollutants (especially ozone and particulate matter); they also negatively contribute to air pollution. Trees emit volatile organic compounds (VOCs), which also contribute to ozone and carbon monoxide formation. i-Tree *Eco* analysis accounts for these VOC emissions in the air quality cumulative benefit.

Deposition, Interception, & Avoided Pollutants

Each year, nearly 2,181 pounds of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), small particulate matter ($PM_{2.5}$), and ozone (O_3) are intercepted or absorbed by Tumwater's inventoried trees, for a total value of $5,957, an average of $1.22 per tree. (Table 6). Among prevalent inventoried trees, bigleaf maple (*Acer macrophyllum*), Douglas-fir (*Pseudotsuga menziesii*), and Norway maple (*Acer platanoides*) remove the most pollutants, 27%, 17%, and 8% of the total pollutants removed, respectively (Figure 7). These species are the greatest contributors to air quality benefits and combined provide benefits of $5,957 annually.

Figure 7: Air Pollution Removal by Inventoried Trees



Trees produce oxygen during photosynthesis, and inventoried trees in Tumwater produce an estimated 71.1 tons of oxygen annually. Additionally, trees contribute to energy savings by reducing air pollutant emissions (NO_2, $PM_{2.5}$, SO_2, and VOCs) that result from energy production.

Table 6: Annual Air Pollution Removal Benefits of Inventoried Trees

Pollutant	Pollutant Removal (lb.)	Value ($)	% of Benefit
PM_{10}	811.93	2,665.19	44.74
$PM_{2.5}$	43.36	2,588.84	43.46
O_3	960.56	660.93	11.09
NO_2	299.56	24.08	0.40
CO	24.69	17.24	0.29
SO_2	41.00	0.95	0.02
Total	2,181	$5,957	100%

Inventoried trees in Tumwater are emitting 601.9 pounds of volatile organic compounds (VOCs) each year (232.1 tons of isoprene and 369.8 pounds of monoterpenes). Emissions vary based on species characteristics and amount of leaf biomass. Balsam poplar (*Populus balsamifera*) produce the second highest VOC emissions (64.4 lb/yr), followed by Douglas-fir (*Pseudotsuga menziesii*, 60.7 lb/yr). Overall, Northern red oak (*Quercus rubra*, 116 lb/yr) produce the greatest volume of VOC emissions and 19% of total emissions, largely due to their size (2.6% of overall leaf area) and prevalence in the inventory (3.2%).[2]

[2] Some economic studies have estimated VOC emission costs. These costs are not included here as there is a tendency to add positive dollar estimates of ozone removal effects with negative dollar values of VOC emission effects to determine whether tree effects are positive or negative in

Air quality impacts of trees are complex, and the i-Tree *Eco* software models these interactions to help urban forest managers evaluate the true impact of inventoried trees on Tumwater's air quality. The cumulative and interactive effects of trees on climate, pollution removal, VOCs, and power plant emissions determine the net impact of trees on air pollution. Local urban forest management decisions also can help improve air quality by prioritizing tree species recognized for their ability to improve air quality and planting next to large traffic corridors.

Air Pollution Removal in Natural Areas

Each year, around 8,733 pounds of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), small particulate matter ($PM_{2.5}$), and ozone (O_3) are intercepted or absorbed by Tumwater's trees in natural areas, for a total value of $27,898. (Table 7). Trees in natural areas removed 287.6 lb. of $PM_{2.5}$ for a value of $15,308 (54.9%). 5,629 lb. of O_3 was removed for a value of $7,312 (26.2%).

Table 7: Air Pollution Removal for Trees in Natural Areas

Pollutant	Pollutant Removal (lb.)	Value ($)	% of Benefit
$PM_{2.5}$	287.57	15,308	54.87
O_3	5,629.15	7,312	26.21
PM_{10}*	1,597.67	5,007	17.95
NO_2	728.72	159	0.57
CO	131.91	88	0.32
SO_2	358.23	24	0.09
Total	8,733	$27,898	100%

3.9 Atmospheric Carbon Dioxide Reductions

As environmental awareness continues to increase, governments are paying attention to global warming and the effects of greenhouse gas (GHG) emissions. As energy from the sun (sunlight) strikes the Earth's surface it is reflected into space as infrared radiation (heat). GHGs absorb some of this infrared radiation and trap heat in the atmosphere, modifying the temperature of the Earth's surface. Many chemical compounds in the Earth's atmosphere act as GHGs, including carbon dioxide (CO_2), water vapor, and human-made (gases/aerosols). As GHGs increase, the amount of energy radiated back into space is reduced, and more heat is trapped in the atmosphere. An increase in the average temperature of the Earth may result in changes in weather, sea levels, and land-use patterns, commonly referred to as "climate change" (NASA, 2020).

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relation to ozone. This combining of dollar values to determine tree effects should not be done, rather estimates of VOC effects on ozone formation (e.g., via photochemical models) should be conducted and directly contrasted with ozone removal by trees (i.e., ozone effects should be directly compared, not dollar estimates). In addition, air temperature reductions by trees have been shown to significantly reduce ozone concentrations (Cardelino and Chameides 1990; Nowak et al 2000) but are not considered in this analysis. Photochemical modeling that integrates tree effects on air temperature, pollution removal, VOC emissions, and emissions from power plants can be used to determine the overall effect of trees on ozone concentrations (itreetools.org).

The Center for Public Urban Forest Research (CUFR) recently led the development of the Public Urban Forest Project Reporting Protocol. The protocol, which incorporates methods of the Kyoto Protocol and Voluntary Carbon Standard (VCS), establishes methods for calculating reductions, provides guidance for accounting and reporting, and guides community tree resource managers in developing tree planting and stewardship projects that could be registered for GHG reduction credits (offsets). The protocol can be applied to urban tree planting projects within municipalities, campuses, and utility service areas anywhere in the United States.

While the inventoried tree resource in Tumwater may or may not qualify for carbon-offset credits or be traded in the open market, these City trees are nonetheless providing a significant reduction in atmospheric carbon dioxide (CO_2) for a positive environmental and financial benefit to the community.

Urban trees reduce atmospheric CO_2 in two ways:

- Directly, through growth and the sequestration of CO_2 in wood, foliar biomass, and soil.
- Indirectly, by lowering the demand for heating and air conditioning, thereby reducing the emissions associated with electric power generation and natural gas consumption.

As global temperatures rise this effect can be magnified in urban centers with plenty of hard surfaces, particularly concrete and asphalt, which retain heat and are slow to cool. Cities can be many degrees hotter than surrounding countryside. This effect is known as a 'heat island' and is explained in more detail in section 3.10. It can however be mitigated by having shade trees and an expansive urban forest. Therefore the percentage of canopy cover - the shade from trees - in a city is such an important metric. As with other infrastructure, this 'green' infrastructure can be unevenly distributed. Tree inventory databases can help redress the balance with targeted planting and maintenance programs."

To date, inventoried trees within Tumwater are estimated to have stored 1,968 tons of carbon (CO_2) in woody and foliar biomass valued at $335,667. Annually, the inventoried tree resource directly sequesters an additional 26.7 tons of carbon valued at $4,548 (Table 8).

Among prevalent inventoried tree species, bigleaf maple (*Acer macrophyllum*) contributes the most per tree to atmospheric carbon removal at $2.39, sequestering a gross 3.3 tons of carbon annually (11.4% of overall total benefits) (Figure 8).

Figure 8: Carbon Sequestration by Inventoried Trees

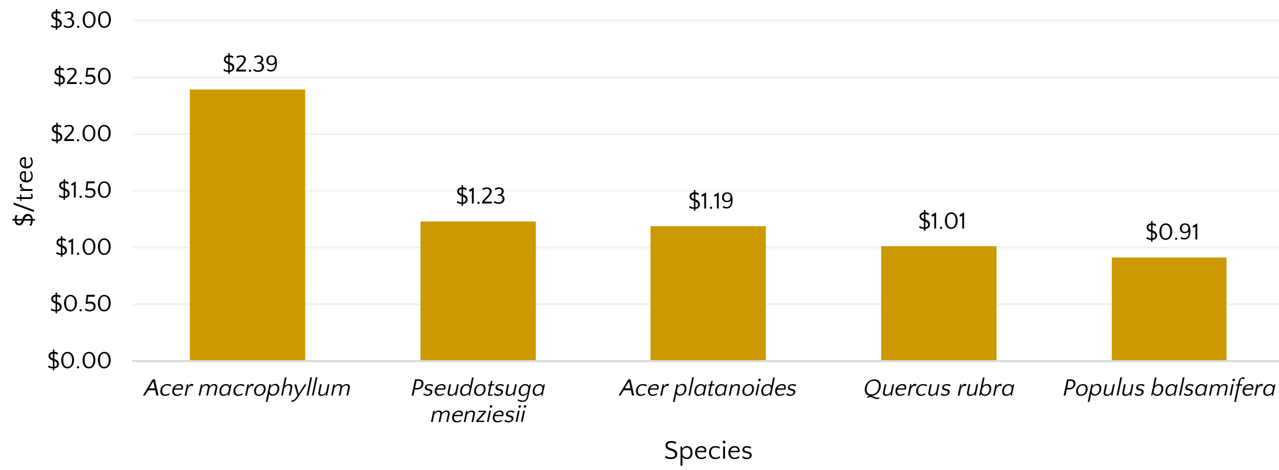


Table 8: Annual Gross Carbon Sequestration by Most Prevalent Inventoried Species

Species	# of Trees	% of Pop.	Carbon Sequestration (ton/yr.)	Carbon Sequestration ($/yr.)	Carbon Storage ($)	Average $/tree	% of Annual Benefit
Acer platanoides	747	15.28	5.20	887.46	22,368	1.19	19.51
Pyrus calleryana	466	9.53	1.59	271.52	5,529	0.58	5.97
Acer rubrum	451	9.22	2.20	375.05	6,903	0.83	8.25
Pseudotsuga menziesii	417	8.53	3.01	513.03	60,845	1.23	11.28
Prunus serrulata	286	5.85	1.16	198.14	8,592	0.69	4.36
Tilia cordata	239	4.89	0.65	110.77	2,307	0.46	2.44
Acer macrophyllum	235	4.81	3.30	562.62	92,572	2.39	11.37
Quercus rubra	155	3.17	0.92	156.77	6,304	1.01	3.45
Liquidambar styraciflua	154	3.15	0.63	107.56	2,577	0.70	2.37
Populus balsamifera	135	2.76	0.72	113.24	6,283	0.91	2.71
Prunus cerasifera	134	2.74	0.67	113.81	9,645	0.85	2.50
Malus	133	2.72	0.35	59.25	6,186	0.45	1.30
Fraxinus excelsior	119	2.43	0.36	61.45	2,328	0.52	1.35
Fraxinus pennsylvanica	104	2.13	0.23	39.14	833	0.38	0.86
Cornus kousa	82	1.68	0.09	15.43	385	0.19	0.34
Alnus rubra	77	1.57	0.41	70.17	6,008	0.91	1.54
Thuja plicata	77	1.57	0.18	30.34	6,432	0.39	0.67
Cornus florida	65	1.33	0.13	22.47	754	0.35	0.49
Cercidiphyllum japonicum	61	1.25	0.16	27.87	677	0.46	0.61
Prunus	58	1.19	0.36	61.51	10,039	1.06	1.35
Calocedrus decurrens	52	1.06	0.16	27.75	2,211	0.53	0.61
all other species	643	13.15	4.11	711.59	75,888	1.11	15.67
Total	4,890	100%	26.67	$4,548	$335,667	100%	100%

Carbon Sequestration in Natural Areas

Environmental benefit estimates for trees in natural areas were generated using *i-Tree Canopy*. To date, trees in natural areas within Tumwater are estimated to have stored 4,002.7 tons of carbon (CO_2) in woody and foliar biomass valued at $682,654. Annually, the trees in natural areas directly sequester an additional 159.4 tons of carbon valued at $27,182.

3.10 Energy Savings

Trees modify climate and conserve energy in three principal ways:

- Shading reduces the amount of radiant energy absorbed and stored by hardscape surfaces, thereby reducing the heat island effect.
- Transpiration converts moisture to water vapor, thereby cooling the air by using solar energy that would otherwise result in heating of the air.
- Reduction of wind speed plus the movement of outside air into interior spaces, and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson, 1998).

The heat island effect describes the increase in urban temperatures in relation to surrounding suburban and rural areas. Heat islands are associated with an increase in hardscape and impervious surfaces. Trees and other vegetation within an urbanized environment help reduce the heat island effect by lowering air temperatures 5°F (3°C) compared with outside the green space (Chandler, 1965). On a larger scale, temperature differences of more than 9°F (5°C) have been observed between city centers without adequate canopy coverage and more vegetated suburban areas (Akbari et al, 1997). The relative importance of these effects depends upon the size and configuration of trees and other landscape elements (McPherson, 1993). Tree spacing, crown spread, and vertical distribution of leaf area each influence the transport of warm air and pollutants along streets and out of urban canyons. Trees reduce conductive heat loss from buildings by reducing air movement into buildings and against conductive surfaces (e.g., glass, metal siding). Trees can reduce wind speed and the resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler, 1986).

Electricity & Natural Gas Reductions

Trees contribute to electric and natural gas savings through shading and climate buffering effects to buildings and structures. Energy reduction metrics can be calculated using data on tree distance and direction from buildings taken during the inventory process. The annual energy reductions from Tumwater's inventoried trees were not calculated because this data was not obtained during the inventory process. However, trees in Tumwater contribute to electric and natural gas savings through shading and climate buffering effects.

3.11 Stormwater Runoff Reductions

Rainfall interception by trees reduces the amount of stormwater that enters collection and treatment facilities during large storm events (Figure 6). Trees intercept rainfall in their canopy, acting as mini reservoirs, controlling runoff at the source. Healthy urban trees reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow which in turn will improve water quality.
- Tree canopies reduce soil erosion and surface flows by diminishing the impact of raindrops on bare soil.

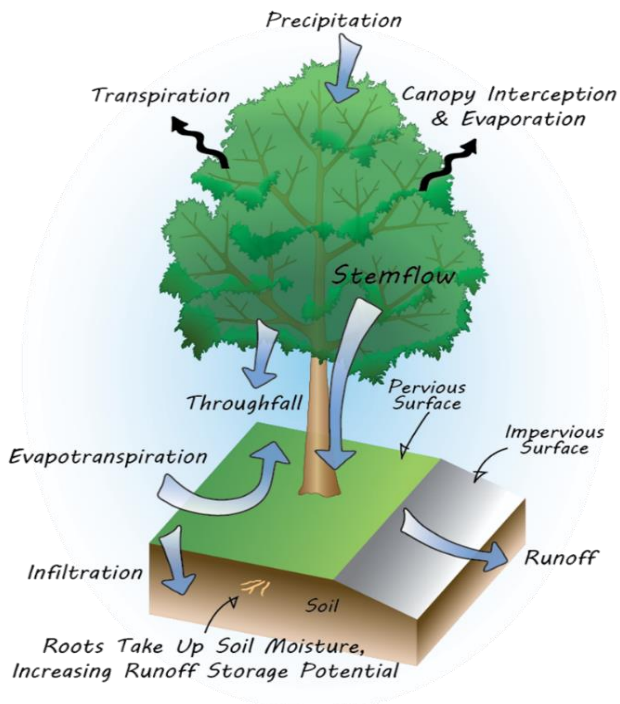


Figure 6: Trees Reduce Stormwater Runoff

Tumwater's inventoried tree resource is estimated to contribute to the avoidance of more than 829,870 gallons of stormwater runoff annually through the interception of precipitation on the leaves and bark of trees for an average of 172 gallons per tree.

Bigleaf maple (*Acer macrophyllum*) provides 27.2% of the estimated total avoided runoff (Figure 9; Table 9). Their abundance, coupled with the age distribution and stature of these trees, allow them to provide a larger benefit in comparison to other species. In contrast, the sixth most prevalent species, little-leaf linden (*Tilia cordata*) provides 1.8% of the estimated total avoided runoff value. The high proportion of young trees likely limits its ability to intercept stormwater. Characteristics that contribute to greater stormwater capture include large leaves, broad or dense canopies, and furrowed bark.

As trees grow, the benefits that they provide tend to grow as well. Some species provide more benefits than others, based on their architecture and leaf morphology. Some trees have characteristics that hinder their ability to be strong contributors to stormwater runoff reduction, possibly due to a tree having smaller leaves and thinner canopies.

Figure 9: Top 5 Inventoried Species for Stormwater Benefits

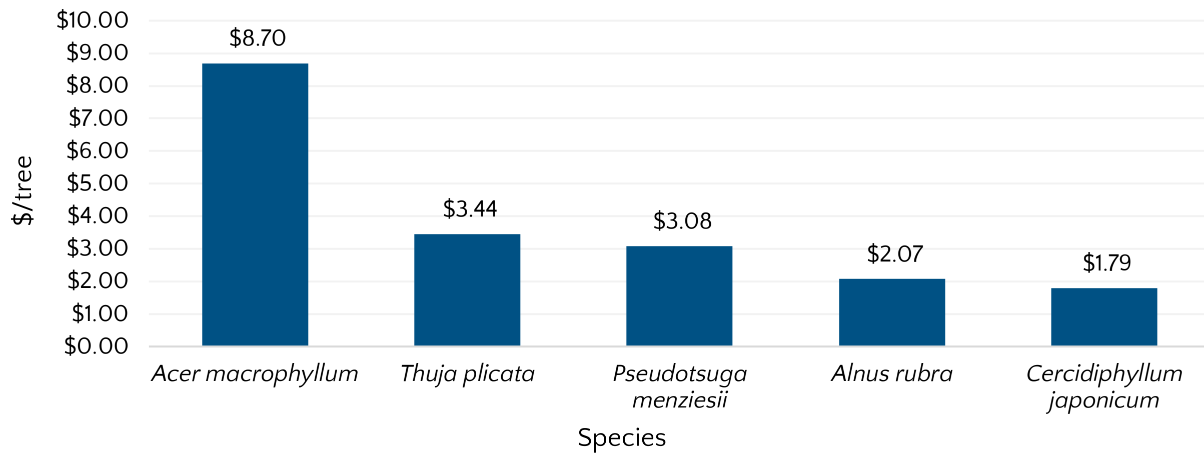


Table 9: Stormwater Benefits from Tumwater's Most Prevalent Species

Species	# of Trees	% of Pop.	Avoided Runoff (gal./yr.)	Avoided Runoff ($/yr.)	% of Benefit	$/tree
Acer platanoides	747	15.28	66,570	594.87	7.93	0.80
Pyrus calleryana	466	9.53	22,172	198.13	2.64	0.43
Acer rubrum	451	9.22	29,700	265.40	3.54	0.59
Pseudotsuga menziesii	417	8.53	143,886	1,285.76	17.13	3.08
Prunus serrulata	286	5.85	13,450	110.19	1.60	0.42
Tilia cordata	239	4.89	15,136	135.25	1.80	0.57
Acer macrophyllum	235	4.81	228,664	2,043.34	27.23	8.70
Quercus rubra	155	3.17	26,697	238.56	3.18	1.54
Liquidambar styraciflua	154	3.15	20,272	181.15	2.41	1.18
Populus balsamifera	135	2.76	22,473	200.82	2.68	1.49
Prunus cerasifera	134	2.74	18,625	166.43	2.22	1.24
Malus	133	2.72	6,290	56.20	0.75	0.42
Fraxinus excelsior	119	2.43	9,836	87.89	1.17	0.74
Fraxinus pennsylvanica	104	2.13	6,402	57.20	0.76	0.55
Cornus kousa	82	1.68	1,093	9.77	0.13	0.11
Alnus rubra	77	1.57	17,821	159.25	2.11	2.07
Thuja plicata	77	1.57	29,627	264.75	3.53	3.44
Cornus florida	65	1.33	1,556	13.90	0.19	0.21
Cercidiphyllum japonicum	61	1.25	11,202	109.04	1.45	1.79
Prunus	58	1.19	11,074	98.96	1.32	1.71
Calocedrus decurrens	52	1.06	7,299	65.23	0.87	1.25
all other species	643	13.15	119,027	1,152.98	15.36	1.79
Total	4,890	100%	839,871	$7,505	100	1.53

3. 13 Aesthetic, Property Value, & Socioeconomic Benefits

While perhaps the most difficult to quantify, the aesthetic and socioeconomic benefits from trees may be among their greatest contributions, including:

- Beautification, comfort, and aesthetics
- Shade and privacy
- Wildlife habitat
- Opportunities for recreation
- Reduction in violent crime
- Creation of a sense of place and history
- Human health
- Reduced illness and reliance on medication and quicker recovery from injury or illness

Some of these benefits are captured as a percentage of property values, through higher sales prices where individual trees and forests are located.

While some of the benefits of forests are intangible and/or difficult to quantify (e.g., the impacts on physical and psychological health, crime, and violence), empirical evidence of these benefits does exist (Kaplan, 1989; Ulrich, 1986). However, there is limited knowledge about the physical processes at work, and their interactions make quantification imprecise. Exposure to nature, including trees, has a healthy impact on humans, such as increased worker productivity, higher test scores, reduced symptoms of ADD, and faster recovery times following surgery. In addition, trees and forests have positive economic benefits for retailers. There is documented evidence that trees promote better business by stimulating more frequent and extended shopping and a willingness to pay more for goods and parking (Wolf, 2007). Trees further generate socioeconomic and health benefits by generating better school performance, less workplace illness, and increased concentration, all of which yield an increase to overall productivity. In addition, the trees throughout the built environment (and especially among vacant lot conversions and streets) promote active living connectors and reduce crime rates. Thus, trees provide for their community by generating new economic income and removing judicial system costs (Wolf, 2014).

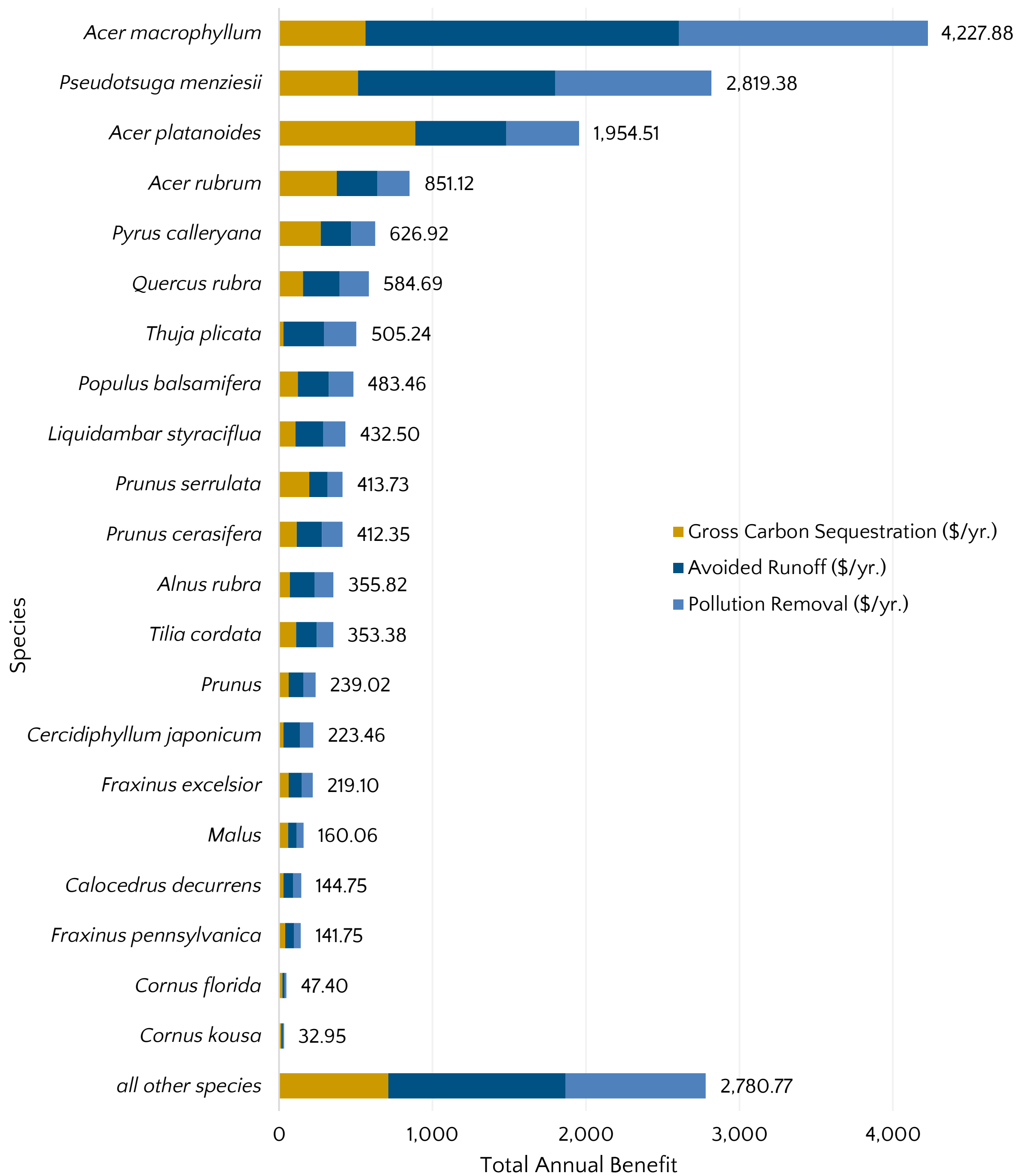
In addition, trees and forestlands provide critical habitat (foraging, nesting, spawning, etc.) for mammals, birds, and fish as well as other aquatic species, along with limitless opportunities for recreation, offering a healthful respite from the pressures of work and everyday stress.

Trees provide beauty in the urban landscape, privacy and screening, improved human health, a sense of comfort and place, and habitat for urban wildlife. In residential areas, the values of these benefits are captured as a percentage of the value of the property on which a tree stands. There is no current model for calculating the aesthetic benefits of an urban forest. Although, there are many indicators that suggest trees and tree canopy cover contribute significantly to quality of life and community well-being.

3.14 Annual Benefits of Most Prevalent Species

It is important to keep in mind that a benefits analysis provides a snapshot of the inventoried tree inventory as it exists today. The calculated benefits are based on the size and condition of existing trees. To provide greater context, the overall annual per species benefits of the most prevalent species was calculated (Figure 10, Table 10), but to determine if these benefits are a true indicator of performance, age distribution and stature of the species must also be considered (Table 3, Figure 2).

Figure 10: Summary of Annual Total Tree Benefits for Most Prevalent Inventoried Species



Of the most prevalent inventoried trees in Tumwater, bigleaf maple (*Acer macrophyllum*) is providing the greatest overall per tree benefit ($17.99). This large-stature species is represented by an established and mature population (23.8% are less than 11-inches in diameter and 42.6% are more than 24-inches in diameter). The age distribution indicates that some new trees are being planted to allow for replacement of aging individuals. These benefits should remain stable over time, especially if managers continue to plant new trees as the population ages.

In contrast, three of the most prevalent species are small -stature species, representing 5.7% of the overall inventory: apple species (*Malus*, $1.20), kousa dogwood (*Cornus kousa*, $0.40), and flowering dogwood (*Cornus florida*, $0.73). **Because of their small -stature, and smaller canopies, benefits from these species are unlikely to change much over time.**

Table 10: Summary of Annual Benefits for Most Prevalent Inventoried Species

Species	# of Trees	% of Pop.	Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)	Total Benefit ($)
Acer platanoides	747	15.28	887.46	594.87	472.18	1,954.51
Pyrus calleryana	466	9.53	271.52	198.13	157.27	626.92
Acer rubrum	451	9.22	375.05	265.40	210.67	851.11
Pseudotsuga menziesii	417	8.53	513.03	1185.76	1020.59	2,819.38
Prunus serrulata	286	5.85	198.14	110.19	95.40	413.73
Tilia cordata	239	4.89	110.77	135.25	107.36	353.38
Acer macrophyllum	235	4.81	562.62	2043.34	1621.92	4,227.88
Quercus rubra	155	3.17	156.77	238.56	189.36	584.69
Liquidambar styraciflua	154	3.15	107.56	181.15	143.79	432.50
Populus balsamifera	135	2.76	113.24	200.82	159.40	483.46
Prunus cerasifera	134	2.74	113.81	166.43	132.11	411.35
Malus	133	2.72	59.25	56.20	44.61	160.06
Fraxinus excelsior	119	2.43	61.45	87.89	69.76	219.10
Fraxinus pennsylvanica	104	2.13	39.14	57.20	45.41	141.75
Cornus kousa	82	1.68	15.43	9.77	7.75	32.95
Alnus rubra	77	1.57	70.17	159.25	116.40	355.82
Thuja plicata	77	1.57	30.34	264.75	210.15	505.24
Cornus florida	65	1.33	22.47	13.90	11.03	47.40
Cercidiphyllum japonicum	61	1.25	27.87	109.04	86.55	223.46
Prunus	58	1.19	61.51	98.96	78.55	239.02
Calocedrus decurrens	52	1.06	27.75	65.23	51.77	144.75
all other species	643	13.15	711.59	1152.98	915.20	2,780.77
Total	4,890	100%	$4,548	$7,505	$5,957	$18,010

3.15 Calculating Individual Tree Benefits

While all these tree benefits are provided by the urban forest, it can be useful to understand the contribution of just one tree. Individuals can calculate the benefits of individual trees to their property by using i-Tree *Design* (design.itreetools.org) or MyTree (mytree.itreetools.org).

3.16 Net Benefits

Tumwater receives substantial benefits from the inventoried tree resource. However, it is important to also understand the investment involved in preserving this tree resource and the benefits that it provides.

Benefits

Tumwater's inventoried tree resource has beneficial effects on the environment, and annually contributes to $18,010 in benefits to the community, a value of $3.68 per tree and $1.04 per capita (Table 9). Individual components of the environmental benefits include improved air quality $5,957 (33.1%), carbon reductions of $4,548 (25.3%), and stormwater management for $7,505 (41.7%) (Figure 11).

Figure 11: Annual Benefits of Inventoried Trees

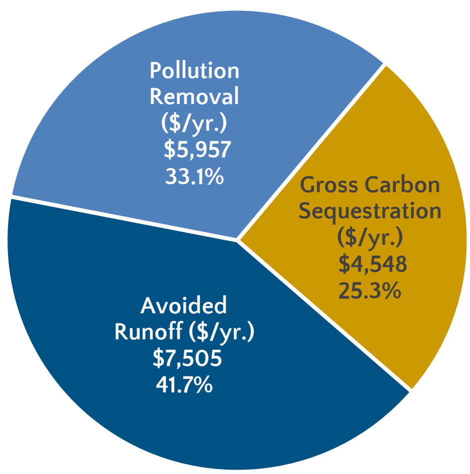


Table 11: Benefits from the Inventoried Tree Resource in Tumwater

Species	# of Trees	% of Pop.	Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)	Total Benefit ($)	% of Benefit	$/tree
Acer platanoides	747	15.28	887.46	595	472	1,955	2.62	2.62
Pyrus calleryana	466	9.53	271.52	198	157	627	1.35	1.35
Acer rubrum	451	9.22	375.05	265	211	851	1.89	1.89
Pseudotsuga menziesii	417	8.53	513.03	1,286	1,021	2,819	6.76	6.76
Prunus serrulata	286	5.85	198.14	120	95	414	1.45	1.45
Tilia cordata	239	4.89	110.77	135	107	353	1.48	1.48
Acer macrophyllum	235	4.81	562.62	2,043	1,622	4,228	17.99	17.99
Quercus rubra	155	3.17	156.77	239	189	585	3.77	3.77
Liquidambar styraciflua	154	3.15	107.56	181	144	433	2.81	2.81
Populus balsamifera	135	2.76	123.24	201	159	483	3.58	3.58
Prunus cerasifera	134	2.74	113.81	166	132	412	3.08	3.08
Malus	133	2.72	59.25	56	45	160	1.20	1.20
Fraxinus excelsior	119	2.43	61.45	88	70	219	1.84	1.84
Fraxinus pennsylvanica	104	2.13	39.14	57	45	142	1.36	1.36
Cornus kousa	82	1.68	15.43	10	8	33	0.40	0.40
Alnus rubra	77	1.57	70.17	159	126	356	4.62	4.62
Thuja plicata	77	1.57	30.34	265	210	505	6.56	6.56
Cornus florida	65	1.33	22.47	14	11	47	0.73	0.73
Cercidiphyllum japonicum	61	1.25	27.87	109	87	223	3.66	3.66
Prunus	58	1.19	61.51	99	79	239	4.12	4.12
Calocedrus decurrens	52	1.06	27.75	65	52	145	2.78	2.78
all other species	643	13.15	712.59	1,153	915	2,781	4.32	4.32
Total	**4,890**	**100%**	**$4,548**	**$7,505**	**$5,957**	**$18,010**	**100%**	**$3.68**

A limitation of the annual benefits summary is that it does not fully account for all benefits provided by the inventoried tree resource, as some benefits are intangible and/or difficult to quantify, such as impacts on psychological health, crime, and violence (University of Washington, 2018; University of Illinois, 2018).

Empirical evidence of these benefits does exist (Wolf, 2007; Kaplan and Kaplan, 1989; Ulrich, 1986), but there is limited knowledge about the physical processes at work and the complex nature of interactions make quantification imprecise. Tree growth and mortality rates are highly variable. A true and full accounting of benefits and investments must consider variability among sites (e.g., tree species, growing conditions, maintenance practices) throughout the City, as well as variability in tree growth. In other words, trees are worth far more than what one can ever quantify!

Investments

Annually, Tumwater invests approximately $1 million in the management of the inventoried tree resource[3] . Of the total investments, 25% is attributed to administration ($250,000), 20% pruning ($200,000), 15% inspections ($150,000), 10% irrigation ($100,000), and 10% removal ($100,000). The remaining 20% ($200,000) goes toward litter clean up, tree planting and maintenance, infrastructure repair, liability claims, and pest and disease control.

[3] Investment costs were provided by the City of Tumwater's staff

4.0 Urban Forest Pests and Pathogens

Involvement in the global economy and a highly mobile human population increase the risk of an invasive pest or pathogen introduction into Tumwater. To further investigate the risk of pests and pathogens, i-Tree *Eco* identifies the susceptibility of tree populations to 44 emerging and existing pests and pathogens in the United States (Table 12). According to the analysis, 4,624 (95%) of the 4,980 trees are susceptible to these pests and pathogens and the potential risk is estimated at nearly $11.3 million. The pests and pathogens identified as most relevant to Tumwater are included in Table 10. Anticipating and monitoring for these threats is an important part of urban forest management.

The Asian longhorned beetle (ALB, *Anoplophora glabripennis*) is an invasive insect that threatens many hardwood trees such as maple (*Acer*), willow (*Salix*), and elm (*Ulmus*) (USDA APHIS, n.d.). Currently, the state of Washington does not have any ALB infestations, but had an outbreak in nearby Tukwila in the last ten years. With 42.7% of Tumwater's inventoried trees susceptible to the borer, managers should regularly inspect trees and plant non-host species.

The pine shoot beetle (*Tomicus piniperda*) is an invasive beetle that is not present in Washington but was introduced to Ohio in 1992 and subsequently spread to several states in eastern USA (USDA, 2000). If this pest spreads, nearly 10% of Tumwater's inventoried trees are at risk. This beetle feeds on shoots of pine (*Pinus*), true fir (*Abies*), and Douglas-fir (*Pseudotsuga menziesii*) which results in stunting, deformed growth, and in severe cases tree death.

Defoliating moths, such as gypsy moth (*Lymantria dispar*) and winter moth (*Operophtera brumata*) threaten a broad range of tree hosts present in Tumwater (30% and 40% of the inventoried tree inventory is susceptible, respectively). Both moth species are present in western Washington. While winter moth has been established since the 1970s (WSU, 2020), gypsy moth was recently detected in Snohomish County and is approximately 85 miles north of Tumwater. Gypsy moth management is occurring through the state's monitoring and eradication program (WSDA, 2020). During moth outbreaks, the feeding damage weakens the tree host, and renders it more vulnerable to other pests and diseases (Collins, 1996). These moth species are known to feed on hundreds of species of trees and shrubs.

Pest Management

Although managers cannot foresee when a pest or pathogen may be introduced to the urban forest, being aware of potential threats is the first step in a preparedness program. Following Integrated Pest Management (IPM) protocol and best management practices when preparing for and addressing pest and diseases can help to minimize their economic, health, and environmental consequences (Wiseman and Raupp, 2016). Some management practices include:

- Obtain current information on emergent pests and pathogens
- Increase understanding of the biology of the pest and pathogen as well as the tree symptoms that indicate infestation/infection
- Identify procedures and protocols that will be followed in the case of an introduced pest or pathogen
- Complete training and licensing in the case of pesticide or fungicide use
- Plant tree species that are resistant or tolerant to identified pest and pathogen threats
- Choose healthy, vigorous nursery stock

- Diversify plantings at the genus level, as many pests threaten several species within a genus
- Prevent the movement of felled tree materials that may be harboring pests or pathogens such as untreated logs, firewood, and woodchips
- Participate in state sponsored pest preparedness program

Table 12: Pest & Pathogen Threats to Tumwater

Pest Name		Number of Trees		Replacement Value ($)		Leaf Area (%)		Leaf Area (ac)	
		Susceptible	Not Susceptible	Susceptible	Not Susceptible	Susceptible	Not Susceptible	Susceptible	Not Susceptible
asian longhorned beetle	*Anoplophora glabripennis*	2,088	2,802	4,879,443	7,028,290	49.6	50.4	105.2	106.8
winter moth	*Operophtera brumata*	1,943	2,947	4,839,153	7,068,580	48.9	51.1	103.8	108.2
spotted lanternfly	*Lycorma delicatula*	1,795	3,095	2,407,690	9,500,043	18.5	81.5	39.2	172.9
polyphagous shot hole borer	*Euwallacea nov. sp.*	1,543	3,347	4,095,707	7,811,026	42.2	57.8	89.4	112.6
gypsy moth	*Lymantria dispar*	1,482	3,408	2,325,587	9,582,146	19.4	80.6	41.1	170.9
sudden oak death	*Phytophthora ramorum*	941	3,949	5,817,875	6,089,858	49.6	50.4	105.1	106.9
heterobasidion root disease	*Heterobasidion irregulare/occidentale*	559	4,331	3,522,835	8,384,898	22.9	77.1	48.5	163.5
armillaria root disease	*Armillaria spp.*	553	4,337	3,422,027	8,485,706	21.9	78.1	46.4	165.6
black stain root disease	*Leptographium wageneri*	474	4,416	3,114,741	8,782,993	19.3	80.7	41.0	171.0
western spruce budworm	*Choristoneura occidentalis*	466	4,424	3,105,586	8,802,147	19.0	81.0	40.4	171.7
pine shoot beetle	*Tomicus piniperda*	464	4,426	3,038,409	8,869,324	18.6	81.4	39.3	172.7
Douglas-fir black stain root disease	*Leptographium wageneri var. pseudotsugae*	462	4,428	3,084,030	8,823,703	18.9	81.1	40.1	171.9
western blackheaded budworm	*Acleris gloverana*	431	4,459	2,979,498	8,928,236	17.7	82.3	37.5	174.5
spruce budworm	*Choristoneura fumiferana*	428	4,462	2,918,553	8,989,180	17.2	82.8	36.4	175.6
fir engraver	*Scolytus ventralis*	424	4,466	2,954,633	8,953,100	17.5	82.5	37.1	174.9
Douglas-fir beetle	*Dendroctonus pseudotsugae*	417	4,473	2,916,093	8,991,640	17.1	82.9	36.3	175.7
browntail moth	*Euproctis chrysorrhoea*	358	4,532	711,992	11,195,742	5.6	94.4	11.9	200.1
large aspen tortrix	*Choristoneura conflictana*	311	4,579	715,465	11,192,268	7.3	92.7	15.5	196.5
emerald ash borer	*Agrilus planipennis*	252	4,638	165,843	11,741,891	2.3	97.7	4.9	207.1
aspen leafminer	*Phyllocnistis populiella*	216	4,674	405,724	11,502,009	4.7	95.3	9.9	202.1
oak wilt	*Ceratocystis fagacearum*	182	4,708	659,317	11,248,416	4.9	95.1	10.5	201.5
forest tent caterpillar	*Malacosoma disstria*	165	4,725	520,082	11,387,651	4.2	95.8	8.9	203.1
dogwood anthracnose	*Discula destructiva*	151	4,739	74,987	11,832,746	0.4	99.6	0.8	211.3

Pest Name		Number of Trees		Replacement Value ($)		Leaf Area (%)		Leaf Area (ac)	
		Susceptible	Not Susceptible	Susceptible	Not Susceptible	Susceptible	Not Susceptible	Susceptible	Not Susceptible
southern pine beetle	*Dendroctonus frontalis*	65	4,825	186,563	11,721,170	2.0	98.0	4.3	207.7
Mediterranean oak borer	*Xyleborus monographus*	57	4,833	118,741	11,788,992	1.0	99.0	2.0	210.0
sirex wood wasp	*Sirex noctilio*	47	4,843	112,316	11,785,417	1.4	98.6	3.0	209.0
mountain pine beetle	*Dendroctonus ponderosae*	38	4,852	106,150	11,801,583	1.2	98.8	2.6	209.4
western five-needle pine mortality	*western five-needle pine mortality summary*	18	4,872	86,416	11,821,317	0.9	99.1	2.0	210.1
white pine blister rust	*Cronartium ribicola*	18	4,872	86,416	11,821,317	0.9	99.1	2.0	210.1
Dutch elm disease	*Ophiostoma novo-ulmi*	17	4,873	40,042	11,867,691	0.3	99.7	0.6	211.4
balsam woolly adelgid	*Adelges piceae*	15	4,875	40,210	11,867,523	0.4	99.6	0.8	211.2
Jack pine budworm	*Choristoneura pinus*	14	4,876	19,444	11,888,289	0.3	99.7	0.6	211.4
pine black stain root disease	*Leptographium wageneri var. ponderosum*	14	4,876	19,444	11,888,289	0.3	99.7	0.6	211.4
aspen running canker	*Neodothiora populina*	13	4,877	15,787	11,891,946	0.1	99.9	0.2	211.8
hemlock sawfly	*Neodiprion tsugae*	13	4,877	62,077	11,845,657	0.6	99.4	1.2	210.8
spruce beetle	*Dendroctonus rufipennis*	11	4,879	2,460	11,905,273	0.1	99.9	0.1	211.9
bur oak blight	*Tubakia iowensis*	6	4,884	54,640	11,853,093	0.4	99.6	0.8	211.2
Port-Orford-cedar root disease	*Phytophthora lateralis*	6	4,884	29,510	11,878,224	0.2	99.8	0.3	211.7
northern spruce engraver	*Ips perturbatus*	5	4,885	2,170	11,905,563	0.1	99.9	0.1	211.9
butternut canker	*Sirococcus clavigignenti juglandacearum*	3	4,887	9,825	11,897,909	0.1	99.9	0.2	211.8
chestnut blight	*Cryphonectria parasitica*	2	4,888	29,890	11,877,843	0.2	99.8	0.3	211.7
beech leaf disease	*Litylenchus crenatae mccannii*	1	4,889	2,460	11,905,274	0.1	99.9	0.1	211.9
fusiform rust	*Cronartium quercuum f. sp. Fusiforme*	1	4,889	694	11,907,040	0.1	100.0	0.1	211.0
thousand canker disease	*Geosmithia morbida*	1	4,889	5,095	11,902,639	0.1	100.0	0.1	211.9
All Pests		4,624	266	$11,295,873	$611,860	95.3	4.7	202.1	9.9

5.0 Tree Maintenance and Costs

Appropriate and timely tree care can substantially increase lifespan. When trees live longer, they provide greater benefits. As individual trees mature, and aging trees are replaced, the overall value of the tree resource and the amount of benefits provided grow as well. However, this vital living resource is vulnerable to a host of stressors and requires ecologically sound and sustainable best management practices to ensure a continued flow of benefits for future generations.

The City of Tumwater has a total of 4,890 inventoried trees located in areas around the City. Of that population, 7.3% were recommended some sort of maintenance tree care and 14% of inventoried trees had a primary defect (Table 11, Table 13).

Trees in natural areas were sampled using 42 1/10-acre plots. In total, 16 species representing 593 trees were sampled. Trees less than 6 inches were excluded. Estimations for benefits and area of trees in the natural areas was preformed using i-tree canopy. There is approximately 201 acres of natural areas in Tumwater and an estimated 16,271 trees.

Pruning

Trees needing some form of pruning treatment had specific treatments recommended. The most common pruning treatment was for large tree routine prune (4.3% of the population). Other pruning treatments such as structural pruning and prioritized pruning were prescribed in lesser proportions (between 2.2% and 0.4%).

Removals

There were 51 trees recommended for removal in the inventoried tree population. The significance of this workload is better understood by considering the size distribution of these trees. Smaller trees are typically less costly to remove and are also likely a lower risk to public safety.

Other Maintenance Treatments

Various other maintenance treatments were prescribed for the inventoried tree populations. The most common treatments were to raise (910 trees) and clean/deadwood (144 trees). There are 3,353 (69%) trees inventoried that have a recommended maintenance of "unassigned". Trees with structural defects and unassigned maintenance may require priority maintenance or removal. Those trees in good condition with minimal defects could be assigned large or small tree routine prune. All inventoried trees should be given some type of maintenance task to manage Tumwater's urban forest more proactively and better predict future funding.

Table 13: Recommended Maintenance of Inventoried Trees

Recommended Maintenance	# of Trees
Unassigned	3,353
No Maintenance	1,074
Large Tree Routine Prune	208
Other- see notes	104
Small Tree Routine Prune	59
Priority 3 Removal	39
Priority 2 Pruning	19
Additional Inspection	16
Priority 2 Removal	11
Training Prune	4
Priority 1 Pruning	2
Priority 1 Removal	1
Total	4,890

Table 14: Summary of Maintenance Tasks for Inventoried Trees

Maintenance Task	# of Trees
Unassigned	2,386
None	1,145
Raise	910
Clean/Deadwood	144
Structural Prune	108
Remove	86
Remove Stakes	80
Monitor	14
Reduce	8
Water	5
Install/Inspect Cables	4
Total	4,890

Table 15: Summary of Primary Defects of Inventoried Trees

Primary Defect	# of Trees
Other – See Site Comments	2,993
None	693
Unassigned	418
Dieback/Deadwood	218
Poor Structure/Taper	214
Suppressed	88
Pruning History	53
Stem/Root Girdling	33
Serious Decline	31
Broken Limbs/Hangers	29
Cavity/Decay/Nest hole	25
Signs of Stress	25
Included Bark/Weak Union(s)	18
Mechanical Damage	15
Unbalanced Crown	11
Fungal Fruiting Bodies	7
Oozing through bark	5
Uncorrected Lean	4
Crack/Seams	3
Previous Failure(s)	3
Cankers/Galls/Burls	1
Root Plate Lifting	1
Soil heaving	1
Total	4,890

5.1 Cost of Tree Care

Where the City has responsibility for maintaining trees, achieving the greatest efficiency or lowest costs is derived from proactive scheduled maintenance of the trees. Proactive maintenance includes regular inspection and routine tree care activities that are critical to tree health and public safety. **The City intends to proactively manage its inventoried tree population on a 4-year maintenance cycle.** In this approach, the following services were modeled for maintenance in the management of Tumwater's trees:

- **Inspection.** A one-person crew qualified to inspect trees, update tree records, and prescribe tree care and maintenance.
- **Priority Removals.** A 3-person crew with all necessary equipment to safely remove a tree.
- **Priority Pruning.** A 2-person crew with all necessary equipment to safely prune a tree.
- **Large Tree Routine Pruning.** A 2-person crew with all necessary equipment to safely prune a tree that may require bucket truck or climbing.
- **Small Tree Routine Pruning.** A 1 or 2-person crew with all necessary equipment to safely prune a tree from the ground.
- **Unassigned Trees.** These trees have legacy tree data and should be inspected to confirm work prescriptions and tasks.

The following considerations and assumptions were used to estimate service costs:

- Inspections
    - Initial tree inspection verifies existing inventory data and identifies maintenance tasks and priorities. All crews caring for trees would be trained to provide tree inventory updates to basic tree information upon completion of tree work. Post-work administrative costs to keep inventory updated are included in pruning, removal, and planting. Costs do not include tree inventory management software.
- Pruning a Removal Work
    - Routine work would be provided by contracted tree-care professionals at prevailing wage rates. Equipment, vehicles, personnel, and training costs are included in the costs.
    - Various routine pruning tasks can be performed on the same visit, with the same crew complement, which allows for a standard cost per tree to prune. Most trees benefit from routine pruning to direct growth, optimize structure, and remove branches that are crowded, have poor angles of attachment, or conflict with clearance or infrastructure. Routine pruning allows trees and urban infrastructure to coexist in the built environment, reduces the formation of hazards, and prolongs tree longevity.
    - Debris removal and disposal is included in all pruning and tree removal estimates.
    - Tree removal costs include underground utility location, grinding of the resulting stump and site preparation for a replacement tree.
    - All removed trees would have a tree planted to replace them.
- Emergency Hazard Abatement

    - Emergencies are not included since these are performed with more urgent timeframes. Costs for urgent work are often greater than scheduled work due to additional safety precautions and mobilization.
- Tree Planting
    - Planting costs include labor and equipment necessary for tree installation, including planting day services such as watering, structural pruning, and mulching.
    - Average standard nursery stock is estimated to cost $250 for a 1.5" - 2.5" caliper tree, stakes, ties, and mulch. Tree costs are excluded so the model can be adjusted by program managers based on actual nursery stock costs when the program begins.
    - Establishment Care is Not Included
        - Young tree establishment care is an essential component of replacement tree planting. For every tree planted, 3 years of establishment care should be provided, and one post-establishment care visit is required in the 5th-8th year of the tree's life.
        - Watering, mulching, and weeding are considered the basic services of Establishment Care and are confined to the tree well or adjacent planting strip only.
        - Structural pruning is performed within the first two years following planting and is considered part of Establishment Care and Post Establishment Care.

Inspection Costs

The inventory database has two sets of trees, those that were collected as part of the 2023 tree inventory (arborist data), and those that had been collected using City volunteers (volunteer data). The arborist data was collected following the ISA BMPs for tree inventory and can be used to implement tree work. The volunteer data had inconsistent details on tree maintenance needs and may require additional inspections. This resulted in a total of 7,019 trees being identified for further inspection over the next 4 years. This effort should be completed with a 1-person crew and is estimated as 1,759 hours of work (~450 person-hours per year). At a crew rate of $95 per hour, this would be $41,770 per year for tree inspection effort.

Priority Removals

There were 56 trees identified for removal at various sizes. Each tree identified for removal was evaluated as 8 hours of effort to remove by a tree removal crew at the rate of $600 per hour. This was estimated as 448 crew hours for a total cost of $268,800 over a 4-year cycle (or $67,200 per year, average of $4,800 per tree).

Priority Pruning

There were 29 trees identified as requiring priority pruning. These trees all have branch issues that could impact public safety. Tree pruning could likely be accomplished with a smaller crew complement (2-person crew, $400 per hour) at an average rate of 4 hours per tree. This was estimated as a total of 116 hours for a total cost estimate of $46,400 over 4 years ($11,600 per year, average $1,600 per tree).

Large Tree Routine Pruning

Various tree maintenance tasks fall into this category. These tasks were identified by the arborist without any urgency as they are low-risk maintenance needs. Most importantly, these trees are considered large-stature trees that would typically require a climbing crew or lift-truck to accomplish the pruning required averaging 4 hours per tree. There were 208 trees identified in this category and a crew rate of $600 per hour for a total of 832 crew hours ($499,200 over 4 years) or $114,800 per year.

Small Tree Routine Pruning

Various tree maintenance tasks fall into this category. These tasks were identified by the arborist without any urgency as they are low-risk maintenance needs. Most importantly, these trees are considered small-stature trees that would typically be pruned from the ground with a pole-pruner or hand tools. There were 59 trees identified in this category and a crew rate of $400 per hour for a total of 118 crew hours ($47,200 over 4 years) or $11,800 per year.

Unassigned Trees

Although most tree records in the database have unassigned maintenance, a small proportion are recommended for removal, crown raising or stake removal. Removal tasks in this category were evaluated the same as priority removals (eg. 8 hours per tree). Crown raising was also evaluated as a pruning task (eg 4 hours per tree) and stake removal is considered a low-skill tree maintenance task estimated at 30 minutes per tree. The total cost estimated for managing the recommended maintenance on these trees was $2,329,875 ($582,469 per year).

5.2 Summary of Costs

For the City to manage their tree population on a 4-year cycle, the City should set a target budget of $850,839 annually for tree care and maintenance of existing trees (Table 16). This cost could be managed or controlled through proactive planning and competitive bidding processes.

Table 16: Annual Labor & Equipment Cost Estimates for Tree Care of Inventoried Tree Population

Recommended Maintenance TASK	# of Trees	Hours per Tree	Crew Size (persons)	Person Hours	Crew Hours	Crew Cost ($)/Hour	4-year budget	Annual Budget
Inspection								
Unassigned Maintenance	5264	0.25	1	1316	1316	$95	$115,020	$31,255
No Maintenance	1635	0.25	1	408.75	408.75	$95	$38,831	$9,708
Other -See Notes	104	0.25	1	26	26	$95	$2,470	$618
Additional Inspection	16	0.5	1	8	8	$95	$760	$190
Priority Removals (1, 2 & 3)	56	8	3	1344	448	$600	$268,800	$67,200
Tree Planting to replace removals	56	2	2	224	111	$400	$44,800	$11,200
Priority Pruning (1 & 2)	29	4	2	232	116	$400	$46,400	$11,600
Large Tree Routine Pruning								
Crown Cleaning	116	4	2	928	464	$600	$278,400	$69,600
Crown Raising	30	4	2	240	110	$600	$72,000	$18,000
Structural Pruning	59	4	2	472	236	$600	$141,600	$35,400
None/Unassigned	3	4	2	24	11	$600	$7,200	$1,800
Small Tree Routine Pruning								
Crown Cleaning	11	2	2	48	24	$400	$9,600	$2,400
Crown Raising	6	2	2	24	11	$400	$4,800	$1,200
Structural Pruning	39	2	2	156	78	$400	$31,200	$7,800
None/Unassigned	2	2	2	8	4	$400	$1,600	$400
Unassigned Trees (see inspection first)								
Removal	43	8	3	1032	344	$600	$206,400	$51,600
Crown Raising	883	4	2	7064	3532	$600	$2,119,200	$529,800
Remove Stakes	90	0.5	1	45	45	$95	$4,275	$1,069
						TOTAL	$3,403,356	$850,839

6.0 Priority Planting Analysis

An analysis was conducted to assess priority planting locations for the city of Tumwater. Data sources were considered for a variety of factors that contribute toward optimizing tree canopy benefits for the City. Analysis included data sets from the city of Tumwater, US Department of Agriculture, American Forests, and the Washington State Department of Health. The resulting analysis found plantable areas in both public and private properties across the city and will help the City increase its canopy coverage and optimize environmental benefits of trees,

The current canopy layer provided by Tumwater (2019 data) was used to help locate possible planting areas. In addition, the 2021 NAIP imagery was used to create an impervious layer as well to aid with finding plantable space. An analysis to identify the most suitable locations was conducted by analyzing each planting location to assign a priority ranking for benefit factors such as **stormwater, urban heat island and environmental equity (social equity)**. Each data source utilized the most current version available and described in the subsequent sections. Stormwater uses the most recent NAIP imagery, soil data, hydrography data, and elevation data. Heat islands were derived from averaging Landsat 8 surface temperature data from July 28, 2022 and August 15, 2023 data to find hotspots at varying points in time to locate areas of potential heat mitigation.

Planting location polygons were created by taking all grass/open space and bare ground areas and combining them into a single dataset. Non-feasible planting areas such as agricultural fields, recreational fields, major utility corridors, airports, etc. were restricted and noted as a searchable attribute in the final GIS dataset. This layer was reviewed and approved by the city of Tumwater before the analysis proceeded. The remaining planting space was consolidated into a single feature and then, exploded to multipart features creating separate, distinct polygons for each location. The final step broke polygons up again to note planting restrictions as their own feature.

6.1 Social Equity

To identify and prioritize planting potential based on Social Equity, data was analyzed including Environmental health disparities and the Tree Equity Score. Each factor was separated to its own grid map. The values were broken into five classes and ranked from 0 - 4 (with zero being the lowest priority and 4 being the highest priority). These factors were classified into five final rankings from

Very Low to Very High for each of the social equity and public health criteria using quantile classification breaks within ArcGIS. This step of the process was completed to statistically subset data evenly into five classes of increasing importance. Higher priorities of social equity give a focused effort of providing trees and tree canopy to all community members regardless of social status. These priority areas are deemed to have the greatest return due to their importance of providing residents of the community equal access to nature.

6.2 Stormwater

To identify and prioritize planting potential based on the stormwater analysis, locations were assessed with several environmental features, including proximity to hardscape, proximity to canopy, floodplain proximity, soil permeability, slope, and soil erosion factor (K-factor). These factors are based on numerous historic projects completed by DRG for stormwater analysis. Each factor was assessed using data from various sources and analyzed using separate grid maps. Values between zero and four (with zero having the lowest priority) were assigned to each grid assessed. A value of zero indicates that this classified piece of information yielded little or no overall value within the dataset. The grids were overlain with the values averaged to determine the priority levels at an area on the map. A priority ranging from Very Low to Very High was assigned to areas on the map based on the calculated average of all grid maps using quantile classification breaks within ArcGIS. This step of the process was completed to statistically subset data evenly into five classes of increasing importance. Areas of higher potential for runoff and erosion were considered higher priority due to their ability to diminish water quality within urban areas.

6.3 Urban Heat Island

To identify and prioritize planting potential based on heat islands, a land surface temperature analysis was conducted. Using Landsat 8 imagery data from the United States Geological Survey (USGS), a calculation of land surface temperature by using the both Landsat 8 thermal bands. Imagery from July 28, 2022 and August 15, 2023 was used to find the radiance, at-satellite brightness temperature and proportion of vegetation, which were used to calculate the land surface temperature for each year. Surface temperatures were averaged and a priority ranking of Very Low to Very High was assigned based on the averaged temperatures using quantile classification breaks within ArcGIS. This step of the process was completed to statistically subset data evenly into five classes of increasing importance. Higher surface temperatures were considered higher priority due to the adverse effects of elevated microclimates within urban areas.

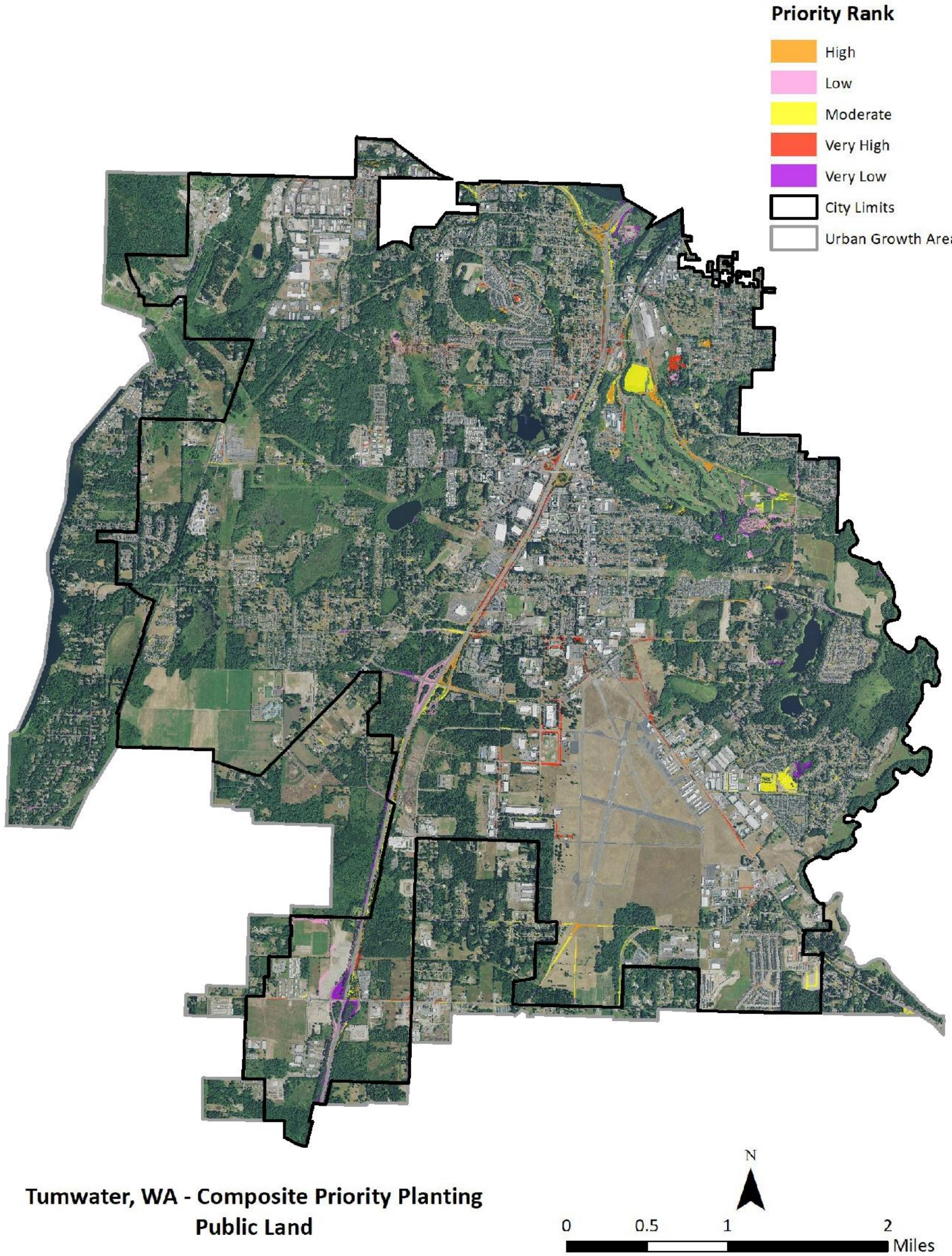
6.4 Composite Priority

Using zonal statistics, each raster data for stormwater, heat island, and social equity were used to calculate a total aggregate value for each individual planting location polygon. The values for each factor were statistically binned into five classes using quantile classification within ArcGIS. This classification method distributes values into groups that have an equal number of values. The higher numbers indicate higher priority for planting when assessing all factors through the same scope. These classes ranged from Very Low to Very High to mirror the criteria group rankings. These rankings were then used to combine all criteria to create a composite ranking based on all analytical factors pertaining to the city.

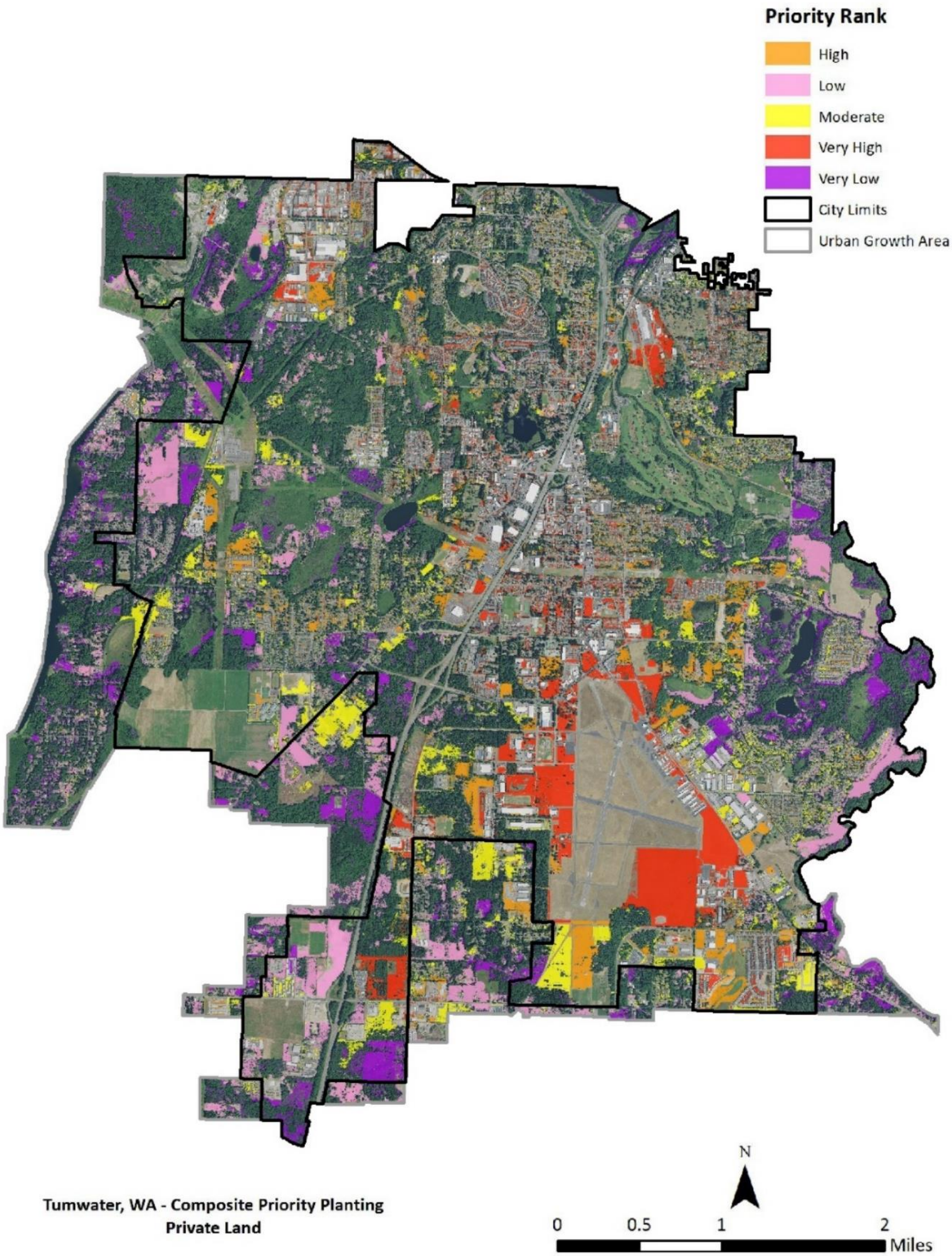
Table 17: Data Sources for Composite Priority Planting Analysis

Group	Criteria	Data Origin	Last Update	Weighting
Stormwater	Distance to Hardscape	Tumwater Urban Tree Canopy Assessment	2022	0.10
	Distance to Canopy	Tumwater Urban Tree Canopy Assessment	2022	0.20
	Floodplain	National Hydrologic Dataset	2022	0.10
	Soil Permeability	Natural Resource Conservation Service	2022	0.20
	Soil Erosion	Natural Resource Conservation Service	2022	0.20
	Slope	National Elevation Dataset	2022	0.20
Urban Heat Island	Heat Islands – July 28, 2022	Earth Explorer - USGS	2022	
	Heat Islands – August 15, 2023	Earth Explorer - USGS	2023	
Census	Environmental Health Disparities	Washing State Department of Health	2022	
	Tree Equity Score	American Forests	2023	

Map 1: Public Land Priority Planting Composite



Map 2: Private Land Priority Planting Composite



6.4 Tree Planting Strategy

Working with the priority planting area composite results clarified the tree planting opportunities in Tumwater. Areas of the city where additional tree canopy is possible were evaluated, including grass, low-lying vegetation, and bare soil. Some locations were excluded because they are not suitable or realistic planting locations due to soil quality and/or conflicts with the intended use of the site. Examples of this include areas designated and intended to be open and free from trees and canopy cover such as sports fields or airports. The land cover assessment determined a total of 4,390 acres (Public: 1,663 acres, Private: 2,727 acres) with the potential to support tree canopy (Map 1 & Map 2).

While available planting sites may ultimately be planted over the next several decades, the trees that are planted in the next several years should be planned for areas of greatest need and where they will provide the most benefits and return on investment. The composite planting analysis of **stormwater, urban heat island and environmental equity (social equity)** identified the following acres for priority planting:

Public Property

- Very High– 479.67 acres
- High– 281.19 acres
- Moderate– 327.79 acres
- Low– 388.69 acres
- Very Low– 185.99 acres

Private Property

- Very High– 599.46 acres
- High– 410.46 acres
- Moderate– 497.71 acres
- Low– 725.70 acres
- Very Low– 494.49 acres

A tree placement model was developed to estimate the number of large, medium, and small stature trees that could be planted based on the identified potential planting areas. In the tree placement model, a total of 18,650 public sites and 68,321 private sites were identified as suitable spaces. Under this model, each tree would have an average crown radius of 35 feet at maturity. The actual number of trees to plant would depend on species selection and could be more should the city choose smaller stature trees at some sites.

Table 18: Tree Placement by Public and Private Land Planting Sites

Priority Rank	Total Sites	Public Sites	Private Sites
Very Low	16,075	1,741	14,334
Low	16,971	3,394	13,577
Moderate	17,648	4,199	13,449
High	18,157	4,940	13,217
Very High	18,110	4,376	13,744
Total	86,971	18,650	68,321

7.0 Maintenance Plan Actions

The analysis of the tree inventory through the i-Tree models provides the City with a detailed understanding of Tumwater's tree resource. Using established numerical modeling and statistical methods provides the City a general accounting of the benefits. Trees provide quantifiable benefits to air quality, reduction in atmospheric CO_2, stormwater runoff, and aesthetic benefits. **Tumwater's 4,890 inventoried trees provide cumulative annual benefits worth $18,010, a value of $3.68 per tree and $1.04 per capita. Benefits from trees in the natural areas in Tumwater were estimated using i-Tree Canopy and are providing benefits worth almost $55,100 annually.** While not a complete accounting of every tree within the city limits, this summary of benefits provides a reference benchmark of the quality and conditions associated with the urban forest resource.

Urban forestry best management practices suggest that no one tree species should represent more than 10% of the urban forest. As of 2024, at the species level, Norway maple (*Acer platanoides*) exceeds this rule. Additionally, no one genera should represent more than 20% of a population. In Tumwater, maples (*Acer* spp.) represent 30.4% of the overall inventoried tree population. Future new and replacement tree plantings should focus on increasing species diversity and reducing reliance on a particular species.

Tumwater's inventoried tree resource (7,345 tree sites) has an established age distribution in fair or better condition with 110 distinct species. In the natural areas, the tree species diversity drops to an estimated 14 distinct species, has an estimated 16,271 trees, and a nearly ideal age distribution. However, trees under 6 inches were not included in the plot sampled data. This means that the health and condition of young trees in Tumwater's natural forests remains uncertain.

Regarding tree maintenance needs, 9.5% have some type of maintenance recommended and 69% of trees have unassigned maintenance. Developing a proactive maintenance schedule and budget can greatly control future costs. The City should continue to focus resources on preserving existing and mature trees to promote health, strong structure, and tree longevity. Structural and training pruning for young trees will maximize the value of this resource, reduce long- term maintenance costs, reduce risk, and ensure that as trees mature, they provide the greatest possible benefits over time.

Based on this analysis, the city would benefit from the following priority urban forest management actions:

- Maintain and Expand the Tree Inventory
    - Schedule maintenance to all inventoried trees to proactively manage Tumwater's tree resource.
    - Prioritize planting replacement trees for those trees that have previously been removed.
    - Prioritize structural pruning for young trees and a regular maintenance cycle for all inventoried trees.
    - Regularly inspect trees to identify and mitigate structural and age-related defects to manage risk and reduce the likelihood of tree and branch failure.

    - Consider opportunities to further support wildlife habitat and pollinators, including protecting diverse vegetation and preserving snags and deadwood in natural areas where targets are unlikely.
    - Species that are adequately represented by established age distributions but lack recent plantings should receive priority care.
    - Inventory updates should be incorporated as regular maintenance is performed, including updating the diameter and condition of existing trees.
- Plant New Trees
    - Increase genus and species diversity in new and replacement tree plantings to reduce reliance on abundant groups.
    - Plant trees in priority areas to improve diversity, increase benefits, and further distribute the age distribution of inventoried trees.
    - Use the largest stature tree possible where space allows to optimize urban forest benefits.
    - Consider successional planting of important species, as determined by relative performance index (RPI) and the relative age distribution.

Current tree inventory data will help staff to efficiently plan maintenance activities and provide a strong basis for making informed management decisions that align with greater city-wide strategic goals. Urban forest managers can anticipate future trends with this understanding of the status of the tree population. They can also anticipate challenges and devise plans to increase the current level of benefits. Performance data from this analysis can be used to make determinations regarding species selection, distribution, and maintenance policies.

Documenting current structure as provided in this plan is an important step for establishing goals and performance objectives and can serve as a benchmark for measuring future success. A continued commitment to planting, maintaining, and preserving these trees will support the health and welfare of the City and the community at large.

Appendix A: References

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Appendix B: Priority Planting Analysis Data Sources

Stormwater

Distance to Hardscape
Source: Tumwater Impervious Assessment
Data: Distance to Impervious
Distance to hardscape is derived by selecting the impervious surfaces data from the Tumwater landcover layer. This impervious raster is used as an input layer into the Euclidean Distance tool within ArcGIS to create a layer that measures straight-line distance from each impervious surface location within the city. These distances are grouped into five classes from 0 - 4 with 4 being the closest to impervious surfaces and, therefore, the highest priority. The further a location is from an impervious surface, the lower the ranking it receives. A ranking of 0 is given to locations that are currently represented as impervious surfaces in the land cover data while the value of 4 indicates that the open area next to the impervious surface is available for planting trees to reduce the amount of runoff and sedimentation.

Distance to Hardscape	
Rank	Distance to Impervious (ft)
0	0
1	Over 100
2	51 - 100
3	26 – 50
4	1 – 25

Distance to Canopy

Source: Tumwater Canopy layer
Data: Distance to Canopy
Distance to canopy is derived by selecting the tree canopy data from the Tumwater landcover layer. This canopy raster is used as an input layer into the Euclidean Distance tool within ArcGIS to create a layer that measures straight-line distance from each canopy location within the city. These distances are grouped into five classes from 0 - 4 with 4 being the closest to Canopy and therefore the highest priority. The further a location is from the canopy, the lower the ranking it receives. A ranking of 0 is given to locations that are currently occupied by tree canopy and not plantable. Higher values in this ranking will prioritize areas that have small gaps that can be filed in order to increase tree canopy closure, which has great impact of wildlife habitat by providing larger corridors to support a variety of different species.

Distance to Canopy	
Rank	Distance to Canopy (ft)

0	0
1	Over 200
2	101 - 200
3	51 - 100
4	1 - 50

Floodplain

Source: National Hydrologic Dataset – USDS Geospatial Data Gateway
Link: https://datagateway.nrcs.usda.gov/
Data Attribute: Cost Distance
The floodplain is derived by using the hydrography lines from the United States Department of Agriculture (USDA) website and the Slope Percent Rise (found by calculating Slope using the Digital Elevation Model (DEM) from the USDA website). The Cost Distance tool within ArcGIS was used with these layers to create a raster dataset that shows a cost-weighted distance from the hydrography lines based on the percent rise of the land. This process identifies the first major slope break which indicates the normal stream bank channel that will fill during flooding events. The resulting data layer will show locations of where water will travel during periods of flood. These distances are grouped into five classes from 0 - 4 with 4 being in the floodplain area and therefore the highest priority. The further a location is from the floodplain, the lower the ranking it receives. A ranking of 0 is given to locations that are the furthest from the floodplain.

Floodplain - Cost Distance	
Rank	Cost Distance (ft)
0	Over 2,500
1	1,001 - 2,500
2	501 - 1,000
3	101 - 500
4	0 - 100

Soil Permeability

Source: Natural Resource Conservation Service – USDA Web Soil Survey
Link: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
Data Attribute: Hydrologic Soils Group (HSG)
Soil Permeability is found by analyzing the Hydrologic Soils Group (HSG) information from the USDA Soil Surveys. This data is classified into four classes: A, B, C and D. Group A soils have a high infiltration rate, Group B has a moderate infiltration rate, Group C has a slow infiltration rate, and Group D has a very slow infiltration rate. The remaining values are classified as W denoting water. These areas are typically larger bodies of water such as ponds, lakes or rivers. The rankings range from 0 - 4 with 4 being the highest priority. A ranking of 4 is given to the D classification due to its low infiltration rate. Planting in these locations will increase stormwater uptake and therefore, reduce the amount of runoff. Lower rankings are given to the A, B and C classes as these classes have higher infiltration rates where water is able to percolate through the soil without creating

surface runoff leading to an decrease in harmful pollutants and sediment into streams and stormwater infrastructure over time. The W class is given a 0 ranking because these areas are classified as water and have no bearing of runoff.

Soil Permeability - HSG	
Rank	Threat
0	W
1	A
2	B
3	C
4	D

Soil Erosion

<u>Source:</u> Natural Resource Conservation Service – USDA Web Soil Survey
<u>Link:</u> *https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx*
Data Attribute: K-factor
Soil Erosion is found by analyzing the K-factor information from the USDA Soil Surveys. This data is classified into decimal numbers that range from 0.02 – 0.69. The higher numbers within this range mean that the area is more susceptible to sheet and rill erosion by water. Remaining values are given a value of 0 of which can represent water, quarries, pits, and other harder surface types. Water features are typically ponds, lakes and rivers. Rankings for this data are based on the susceptibility to erosion. A 0 ranking is given to areas that have little to no risk of erosion. The ranking increases as the risk of erosion increases with the highest ranking being 4. Planting in these priority areas will help decrease erosion vulnerability.

Soil Erosion – K-factor	
Rank	K-factor (expressed as whole numbers)
0	0 - 10
1	11 - 20
2	21 - 30
3	31 - 37
4	Over 38

Slope

<u>Source:</u> National Elevation Dataset – USDA Geospatial Data Gateway
<u>Link:</u> *https://datagateway.nrcs.usda.gov/*
Data: DEM
Slope is calculated by using the Digital Elevation Model (DEM) from the USDA and finding the slope percent rise of the DEM. The Percent Rise results were grouped into five classes from 0 - 4 with 4 being the highest priority as shown below. The rankings for this data are based on the percent rise of the area. The larger the percent rise of the land, the higher the planting priority. A ranking of 0 is

given to areas of no percent rise and the rankings then increase as the percent rise increase with the highest ranking being 4. Planting trees on areas of high percent rise can help decrease stormwater runoff.

Slope – Percent Rise	
Rank	Percent Rise
0	0
1	0 - 3
2	3 - 6
3	6 - 11
4	Over 11

Urban Heat Islands

Land Surface Temperature (LST)
Source: Earth Explorer (USGS) Landsat 8 Thermal Imagery
Link: *https://earthexplorer.usgs.gov/*
Data Attribute: Land Surface Temperature (LST)
Land surface temperature is calculated using Landsat 8 imagery thermal bands. Using both thermal bands, a conversion from Digital Number (DN) to radiance, at-satellite brightness temperature and proportion of vegetation can be calculated. These values are used to find the land surface temperature. Imagery from July 28, 2022 and August 15, 2023 was used to create two separate surface temperature raster datasets. The two years were averaged and binned into five class from 0 - 4 based on a quantile classification with ArcGIS. Rankings are determined by the surface temperature ranges. The lowest surface temperature range received a 0 ranking. The ranking will increase as the surface temperature increases with the high rank being 4. Planting in areas of high surface temperature helps mitigation urban heat islands by providing more shade to cool not only air temperature but heat absorbed by pavements.

Land Surface Temperature – July 28, 2022 and August 15, 2023	
Rank	Temperature (Fahrenheit)
0	50 – 76
1	76 – 80
2	80 – 84
3	84 – 88
4	88 – 95

Social Equity Data

Environmental Health Disparities
Source: Washington State Department of Health
Link: https://fortress.wa.gov/doh/wtnibl/WTNIBL/
Data Attribute: Environmental Health Disparities V 2.0

The Washington Environmental Health Disparities Map evaluates environmental health risk factors in communities by census tract and ranks them on a scale of 1 - 10. These ranks are classified into five groups within ArcGIS and ranked from 0 - 4 based on the given rank. A ranking of 4 is given to areas with ranks 8 or over. The lower the environmental health rank is, the lower the priority planting ranking. A ranking of 0 is given to areas that have an environmental health rating of 3 or under. Planting in these high priority areas may help address social equity issues and provide residents equal access to nature.

Environmental Health Disparities V 2.0	
Rank	Environmental Health Disparities Rank
0	3 and Under
1	4
2	5 -6
3	7
4	8 and Over

Tree Equity Score

Source: American Forests
Link: https://www.treeequityscore.org/map#11.56/46.9955/-112.8872
Data Attribute: Tree Equity Score & Priority
The Tree Equity Score was developed to help address environmental and social inequities by prioritizing tree planting in areas of need by block group. Using the Tree Equity Score's existing ranking system, the block groups were binned into 5 groups and ranked from 0 – 4. A Tree Equity Score priority of 'Highest' which is a Tree Equity Score number under 70 was given a rank of 4 (none of the block groups in Tumwater had this score). The rank decreased as the Tree Equity Score priority decreased and the Tree Equity Score Number increased. A rank of 0 was given to block groups with a Tree Equity Score priority of 'None' and a Tree Equity Score number of 100. Planting in these high priority areas may help address social equity issues and provide residents equal access to nature as well as the environmental and health benefits from trees.

Tree Equity Score	
Rank	Score and Priority
0	100 and 'None'
1	90 – 99 and 'Low'
2	80-89 and 'Moderate'
3	70-79 and 'High'
4	Below 70 and 'Highest'

Stormwater

In urban areas, the substantial extent of impervious surface increases the amount of surface runoff and the cost of infrastructure a community must invest to manage stormwater for the safety of residents and property. Tree planting provides an opportunity to help mitigate the risk of flooding by reducing the volume of stormwater runoff that enters bodies of water. Research has demonstrated that strategic plantings of trees affect the peak height of a flood in an urban location (University of Birmingham, 2016).

The majority of areas identified as high and very high priority planting to mitigate the effects of stormwater runoff occur in the north and east parts of Tumwater (Map 2). In the tree placement model to mitigate stormwater runoff, 43.7% of potential planting sites are located within high or very high public planting areas (Table 14) and 38.1% of potential planting sites are located within high or very high private planting areas (Table 14).

Table 19: Potential Planting Priority Sites for Stormwater Management

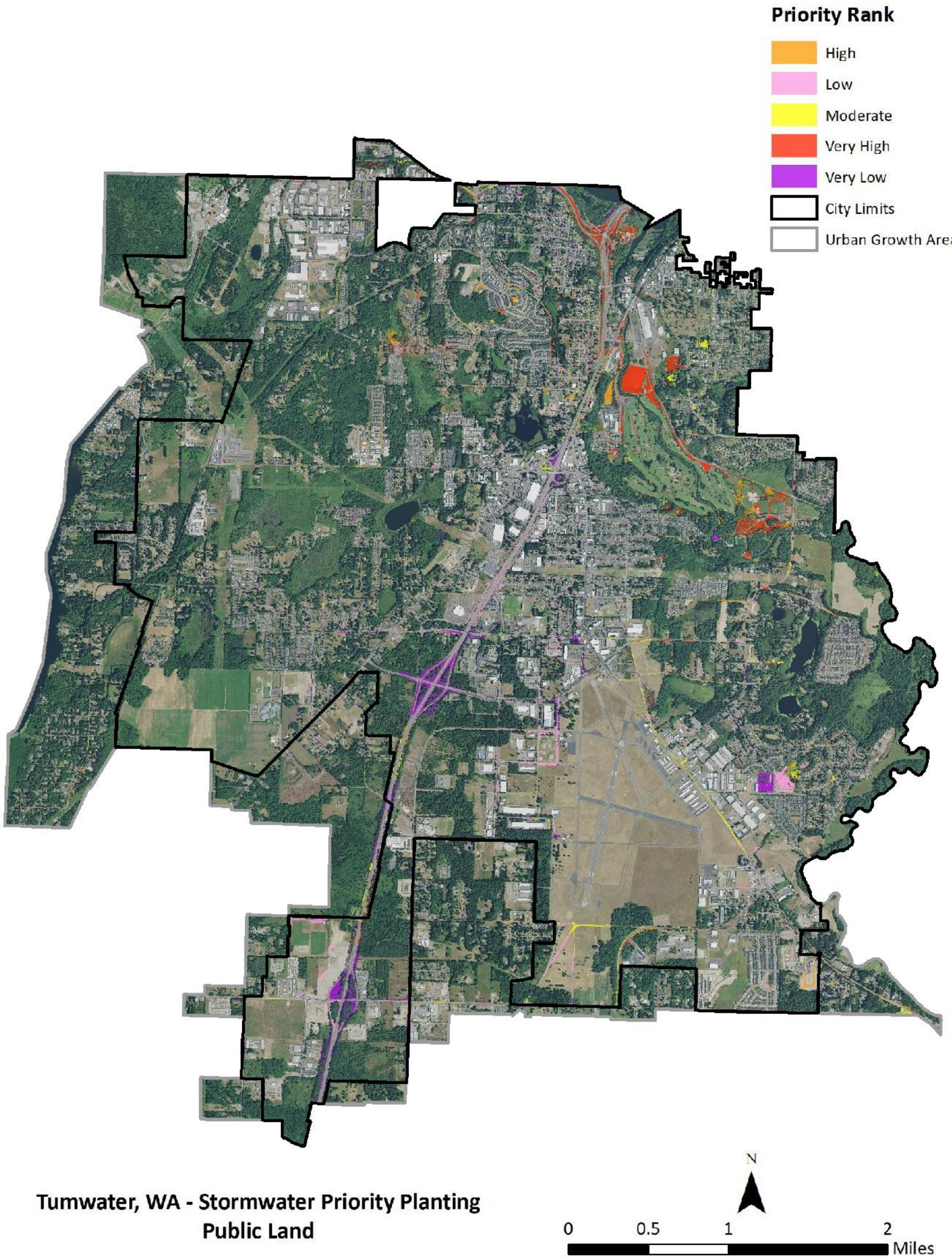
Public

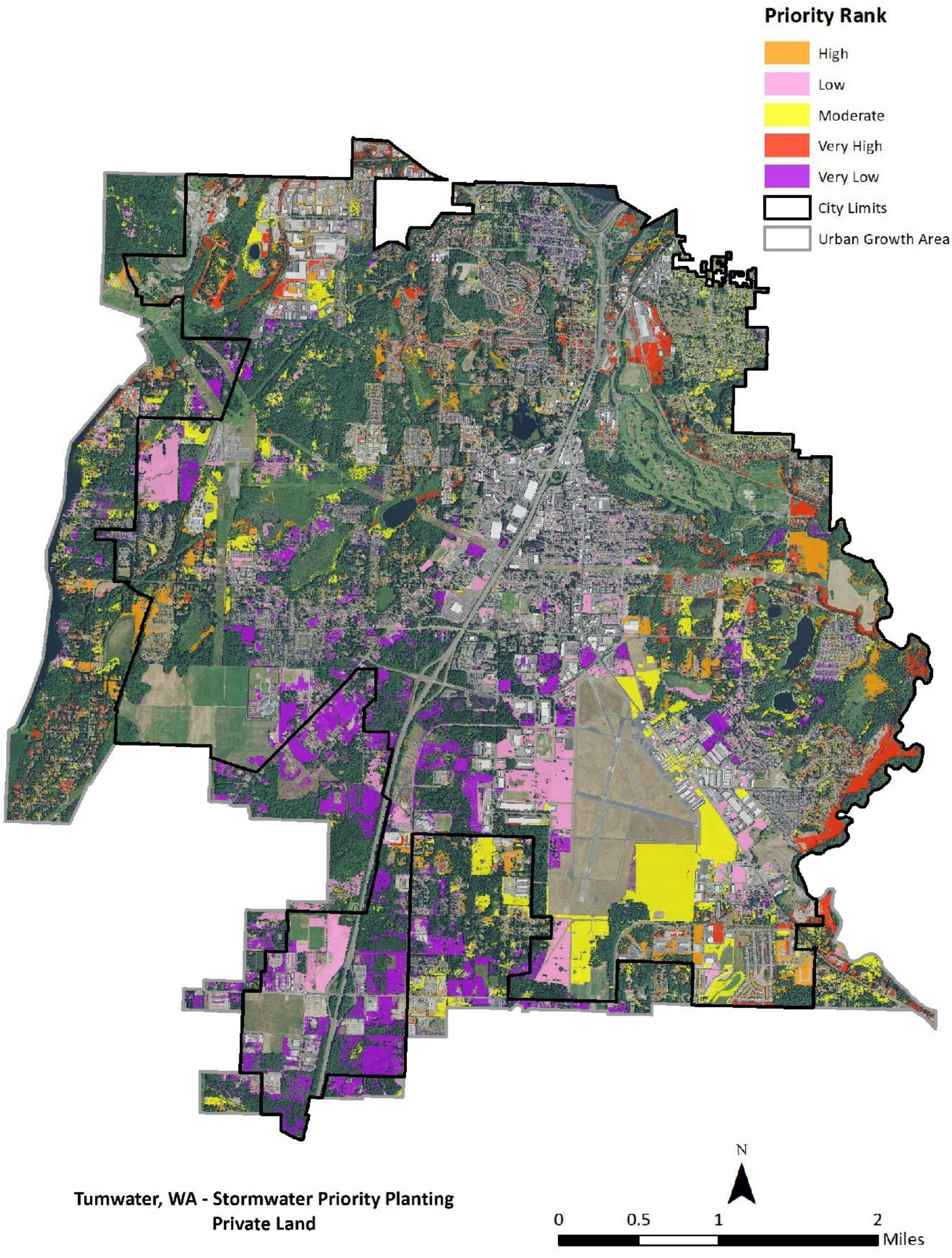
Priority Rank	Number of Locations	Square Feet	Acres
Very Low	3,000	18,879,040	433.40
Low	4,218	17,734,780	407.13
Moderate	3,273	18,077,207	415.00
High	3,815	8,567,087	196.67
Very High	4,344	9,196,704	211.13
Total	18,650	72,454,819	1,663

Private

Priority Rank	Number of Locations	Square Feet	Acres
Very Low	14,148	31,288,813	718.29
Low	14,483	23,867,654	547.93
Moderate	13,631	28,434,766	652.77
High	13,263	16,334,050	374.98
Very High	11,796	18,883,564	433.51
Total	68,321	118,808,847	2,727

Map 3: Public and Private Priority Planting for Stormwater





Tumwater, WA - Stormwater Priority Planting
Private Land

Heat Island

The heat island effect describes the increase in temperatures of urban or metropolitan areas in relation to surrounding suburban and rural areas. Heat islands are associated with an increase in hardscape and impervious surfaces. Trees and other vegetation within an urbanized environment help reduce the heat island effect by lowering air temperatures 5°F (3°C) compared with outside the green space (Chandler, 1965). On a larger citywide scale, temperature differences of more than 9°F (5°C) have been observed between city centers without adequate canopy coverage and more vegetated suburban areas (Akbari et al, 1992). The relative importance of these effects depends upon the size and configuration of trees and other landscape elements (McPherson, 1993). Tree spacing, crown spread, and vertical distribution of leaf area each influence the transport of warm air and pollutants along streets and out of urban canyons. Because trees contribute to reducing the effects of urban heat islands, tree planting can be targeted to reduce urban heat islands.

This analysis isolates the methodology and weighting scheme used to identify and prioritize planting potential for heat islands (Table 11). Areas across the city were ranked from high to low to show at a larger scale where priority planting would mitigate the effects of urban heat islands (Map 3). In the tree placement model to mitigate heat islands, 45.1% of potential planting sites are located within high or very high planting areas for public land (Table 15) and 37.9% for private land (Table 15). Overall, the City of Tumwater would benefit greatly from increased canopy cover.

Table 20: Potential Planting Priority Sites for Stormwater Management

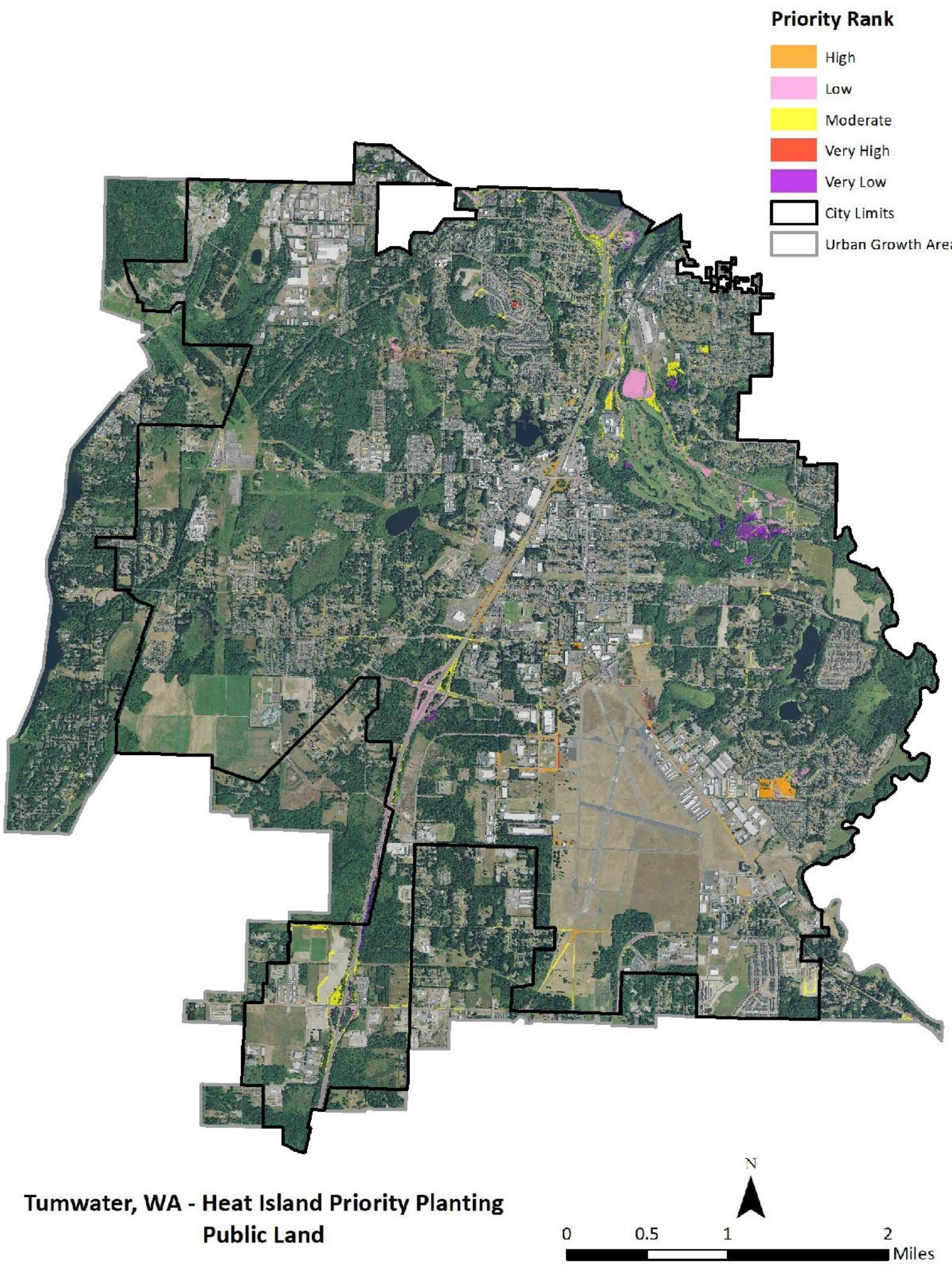
Public

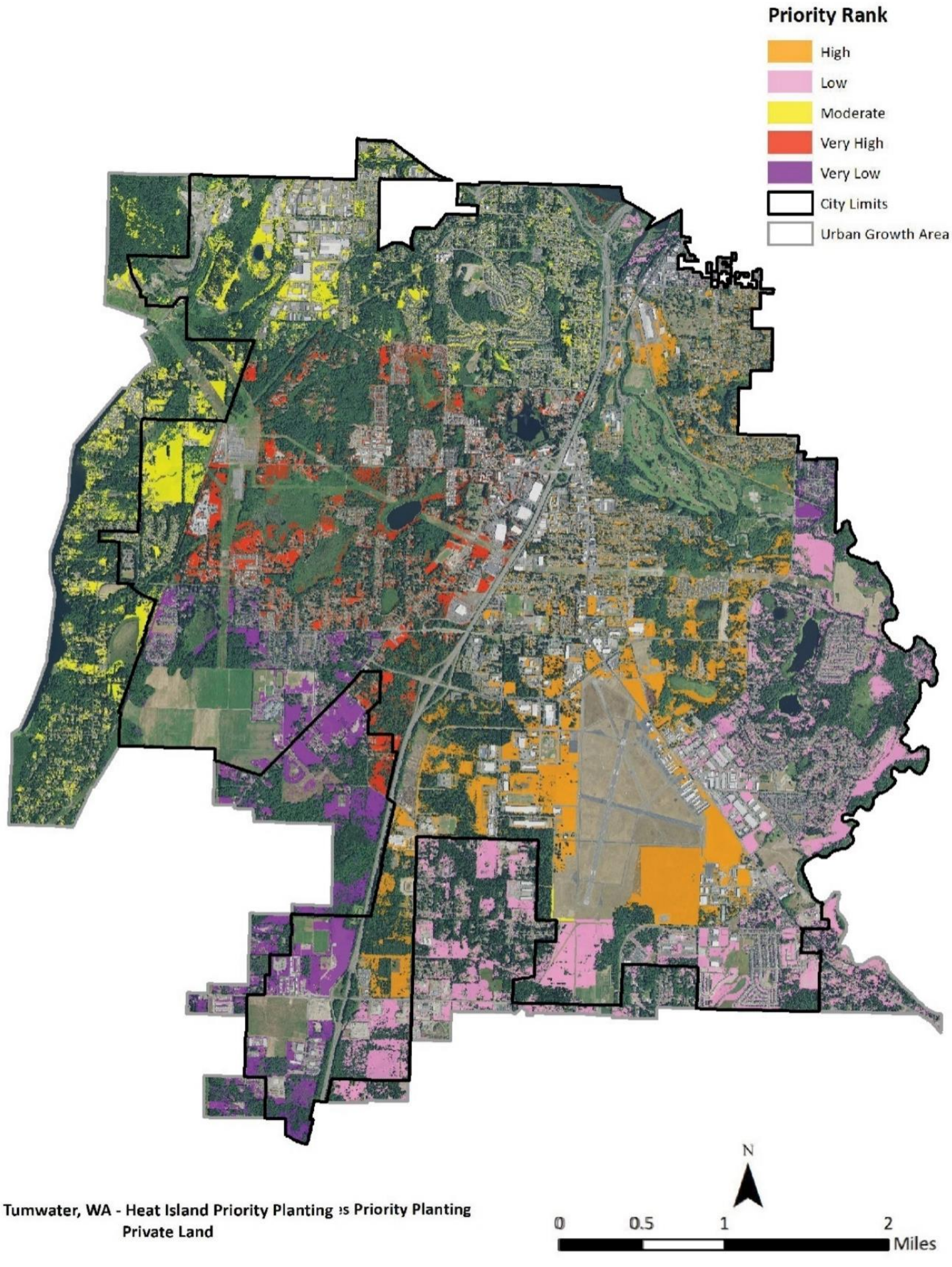
Priority Rank	Number of Locations	Square Feet	Acres
Very Low	319	3,322,521	76.27
Low	3,293	13,276,793	304.79
Moderate	6,628	29,296,486	672.55
High	7,080	24,663,362	566.19
Very High	1,330	1,895,657	43.52
Total	18,650	72,454,819	1,663.33

Priority Rank	Number of Locations	Square Feet	Acres
Very Low	3,741	8,977,066	206.09
Low	17,245	31,900,288	732.33
Moderate	21,414	41,964,659	963.38
High	20,794	32,000,657	734.63
Very High	5,117	3,966,177	91.05
Total	68,321	118,808,847	2,727

Private

Map 4: Public and Private Priority Planting for Heat Islands





Tumwater, WA - Heat Island Priority Planting :s Priority Planting
Private Land

Environmental Health Disparities

This analysis isolates the methodology and weighting scheme used to identify and prioritize planting potential for environmental health disparities (Table 16). Areas across the city were ranked from high to low to show at a larger scale where priority planting would mitigate the effects of environmental health disparities (Map 4). In the tree placement model to mitigate environmental health disparities, 46% of potential planting sites are located within high or very high planting areas for public land (Table 16) and 42% for private land (Table 16). Overall, the City of Tumwater would benefit greatly from increased canopy cover.

Table 21: Potential Planting Priority Sites for Health Disparities

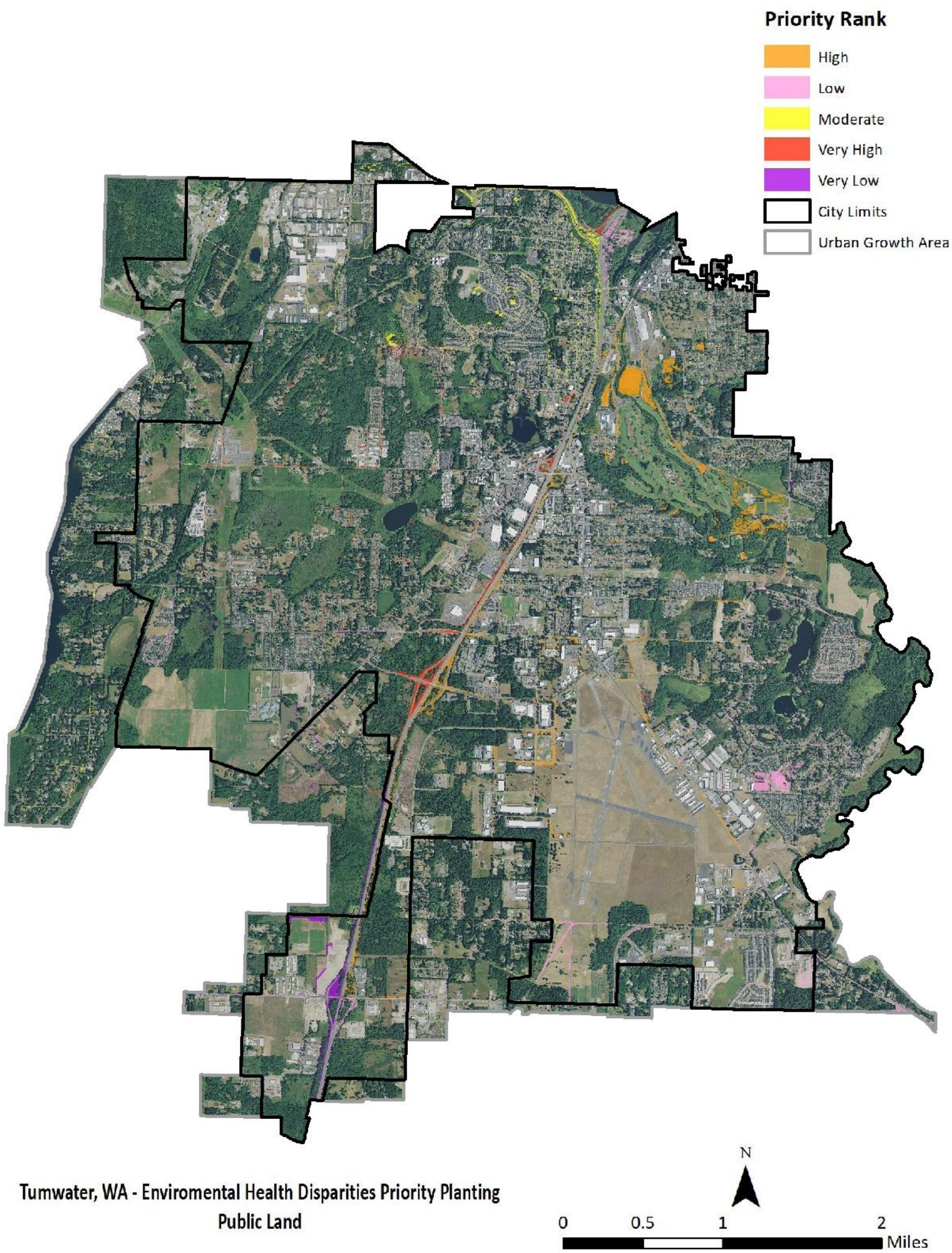
Public

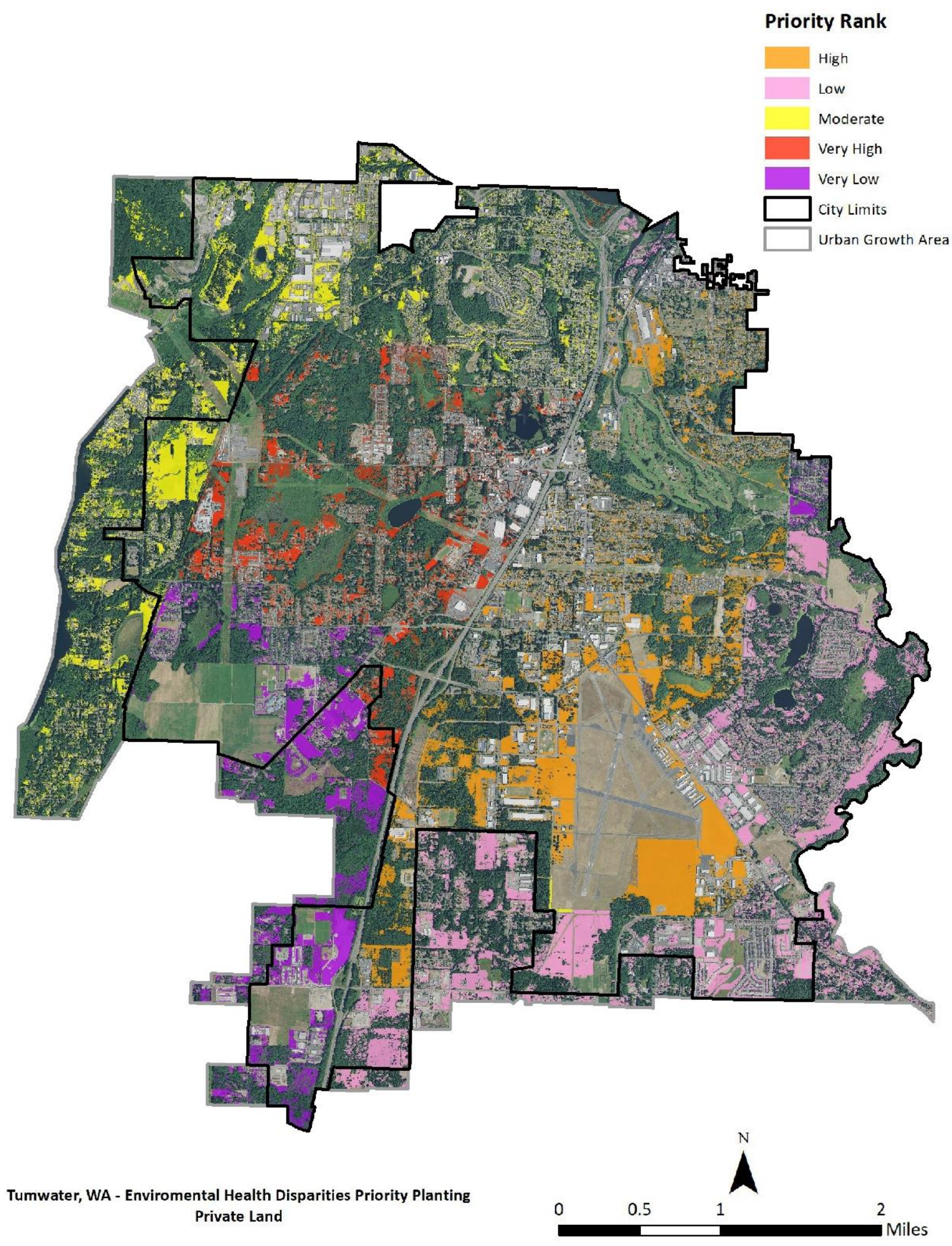
Priority Rank	Number of Locations	Square Feet	Acres
Very Low	1,357	10,341,638	237.41
Low	3,866	20,619,348	473.36
Moderate	4,809	9,469,303	217.39
High	5,628	26,391,586	605.87
Very High	2,990	5,632,945	119.31
Total	18,650	72,454,819	1,663

Priority Rank	Number of Locations	Square Feet	Acres
Very Low	6,767	15,839,045	363.61
Low	14,348	35,726,111	820.16
Moderate	18,393	20,303,410	466.10
High	15,801	34,211,718	785.42
Very High	13,011	11,727,563	292.18
Total	68,321	118,808,847	2,727

Private

Map 5: Public and Private Priority Planting for Environmental Health Disparities





Tree Equity

This analysis isolates the methodology and weighting scheme used to identify and prioritize planting potential for tree equity (Table 17). Areas across the city were ranked from high to low to show at a larger scale where priority planting would mitigate the effects of low tree canopy (Map

5). In the tree placement model to mitigate low tree canopy 8.2% of potential planting sites are located within high planting areas for public land (Table 17) and 9.2% for private land (Table 17). Overall, the City of Tumwater has fairly even canopy cover throughout the city and other factors may have greater impact on the inventoried tree resource.

Table 22: Potential Planting Priority Sites for Tree Equity

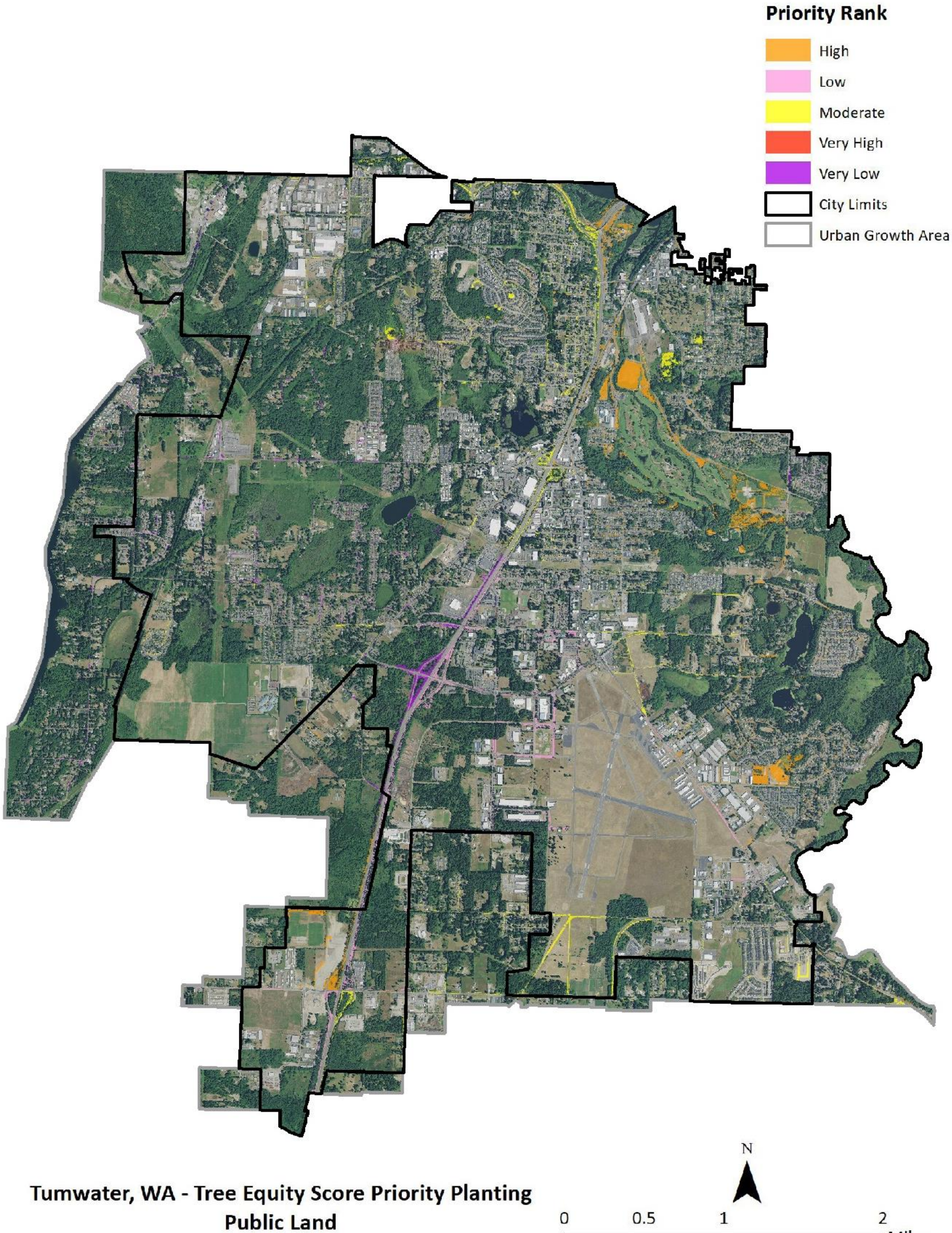
Public

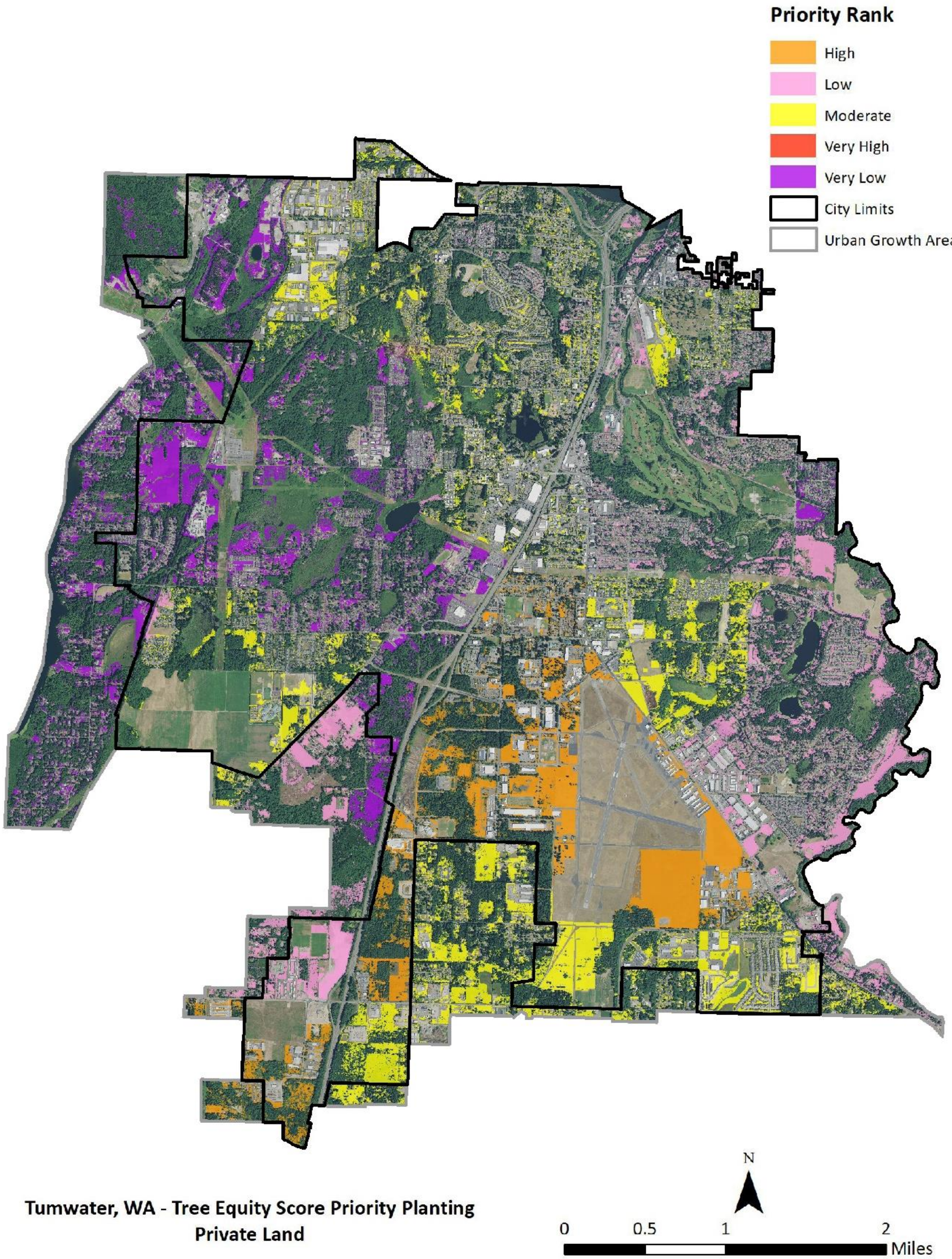
Priority Rank	Number of Locations	Square Feet	Acres
Very Low	3,550	11,176,529	256.58
Low	5,783	17,961,705	411.34
Moderate	7,793	25,184,892	578.17
High	1,524	18,131,693	416.25
Very High	0	0	0
Total	18,650	72,454,819	1,663

Priority Rank	Number of Locations	Square Feet	Acres
Very Low	19,178	25,589,959	587.46
Low	16,957	31,550,627	724.30
Moderate	25,887	38,506,447	883.99
High	6,299	23,161,814	531.72
Very High	0	0	0
Total	68,321	118,808,847	2,727

Private

Map 6: Public and Private Priority Planting for Tree Equity





Tumwater, WA - Tree Equity Score Priority Planting Private Land

Social Equity

To prioritize planting areas based on social equity, a model was produced comparing tree canopy cover and median household income, while stormwater was excluded from the analysis. Areas with low canopy cover were prioritized over areas with high canopy cover, as well as areas with low median income were prioritized over those with higher median income. Areas with very high priority for planting are areas where both the tree canopy cover is low, and the median household income is also low (Map 6).

The result identified the following acres for priority planting that would positively contribute to equitable distribution of canopy cover for social equity 37.9% of potential planting sites are located within high or very high planting areas for public land (Table 18) and 54.9% for private land (Table 18). Overall, the City of Tumwater would benefit greatly from increased canopy cover.

Table 23: Potential Planting Priority Sites for Social Equity

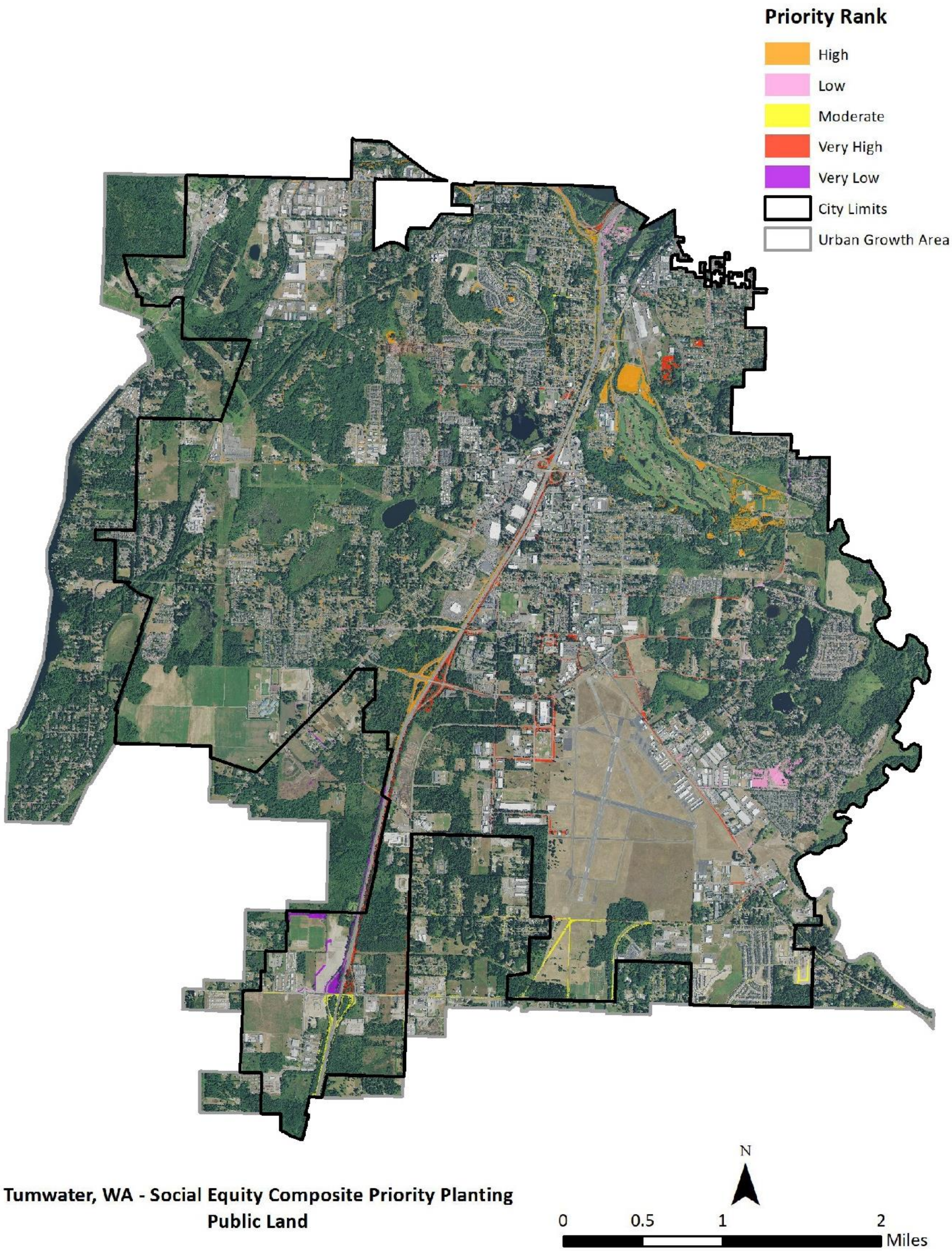
Public

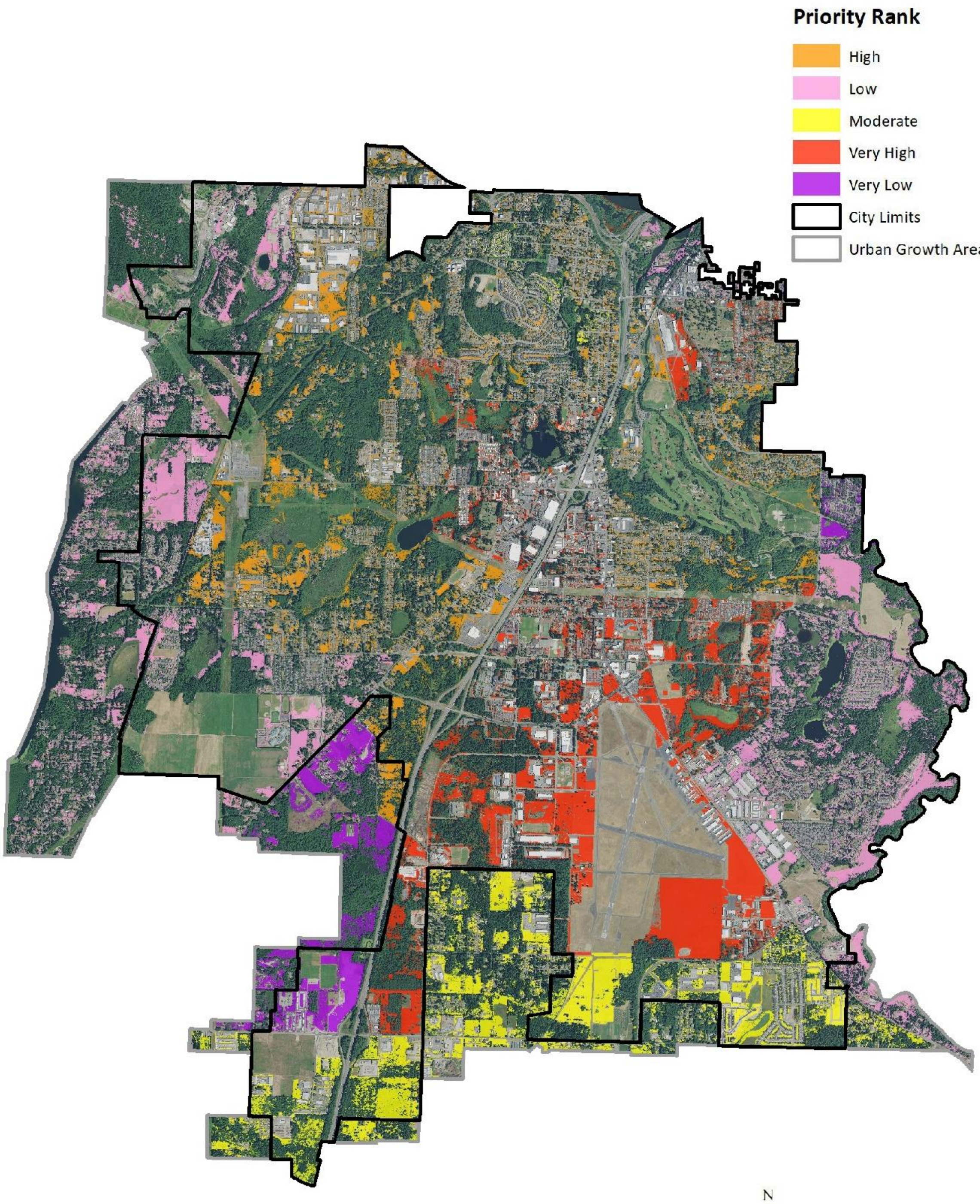
Priority Rank	Number of Locations	Square Feet	Acres
Very Low	642	7,026,411	161.30
Low	3,829	14,326,158	328.88
Moderate	2,098	14,945,936	343.11
High	8,542	11,909,734	296.37
Very High	3,539	23,246,581	533.67
Total	18,650	72,454,819	1,663

Priority Rank	Number of Locations	Square Feet	Acres
Very Low	2,876	9,659,576	221.75
Low	19,316	34,111,474	783.09
Moderate	8,596	21,638,172	496.74
High	24,114	22,117,977	507.76
Very High	13,409	31,281,647	718.13
Total	68,321	118,808,847	2,727

Private

Map 7: Public and Private Priority Planting for Social Equity





Tumwater, WA - Social Equity Composite Priority Planting Private Land

Appendix C: Inventoried Tree Tables

Table 24: Botanical and Common Names of All Inventoried Tree Species

Species		# of Trees	% of Trees
Norway maple	*Acer platanoides*	747	15.28
Callery pear	*Pyrus calleryana*	466	9.53
red maple	*Acer rubrum*	451	9.22
Douglas-fir	*Pseudotsuga menziesii*	417	8.53
Japanese flowering cherry	*Prunus serrulata*	286	5.85
little-leaf linden	*Tilia cordata*	239	4.89
bigleaf maple	*Acer macrophyllum*	235	4.81
northern red oak	*Quercus rubra*	155	3.17
sweetgum	*Liquidambar styraciflua*	154	3.15
balsam poplar	*Populus balsamifera*	135	2.76
cherry plum	*Prunus cerasifera*	134	2.74
apple spp	*Malus*	133	2.72
European ash	*Fraxinus excelsior*	119	2.43
green ash	*Fraxinus pennsylvanica*	104	2.13
Kousa dogwood	*Cornus kousa*	82	1.68
red alder	*Alnus rubra*	77	1.57
western red cedar	*Thuja plicata*	77	1.57
flowering dogwood	*Cornus florida*	65	1.33
Katsura tree	*Cercidiphyllum japonicum*	61	1.25
plum spp	*Prunus*	58	1.19
incense cedar	*Calocedrus decurrens*	52	1.06
black tupelo	*Nyssa sylvatica*	38	0.78
European hornbeam	*Carpinus betulus*	27	0.55
bigtooth maple	*Acer grandidentatum*	25	0.51
black locust	*Robinia pseudoacacia*	23	0.47
Nootka cypress	*Xanthocyparis nootkatensis*	23	0.47
hedge maple	*Acer campestre*	21	0.43
narrow-leafed ash	*Fraxinus angustifolia*	21	0.43
serviceberry spp	*Amelanchier*	18	0.37
western white pine	*Pinus monticola*	18	0.37
black hawthorn	*Crataegus douglasii*	17	0.35
English elm	*Ulmus procera*	17	0.35
juniper spp	*Juniperus*	15	0.31
lodgepole pine	*Pinus contorta*	14	0.29
Oregon white oak	*Quercus garryana*	14	0.29
Himalayan white birch	*Betula utilis ssp. jacquemontii*	13	0.27

Species		# of Trees	% of Trees
quaking aspen	*Populus tremuloides*	13	0.27
western hemlock	*Tsuga heterophylla*	13	0.27
European white birch	*Betula pendula*	11	0.25
London planetree	*Platanus x hybrida*	11	0.25
sweet cherry	*Prunus avium*	11	0.25
Japanese maple	*Acer palmatum*	11	0.22
Acer truncatum x A. platanoides	*Acer truncatum x platanoides*	11	0.22
eastern service berry	*Amelanchier canadensis*	11	0.22
hawthorn spp	*Crataegus*	11	0.22
bitter cherry	*Prunus emarginata*	9	0.18
Atlas cedar	*Cedrus atlantica*	8	0.16
tulip tree	*Liriodendron tulipifera*	8	0.16
American sycamore	*Platanus occidentalis*	8	0.16
common pear	*Pyrus communis*	8	0.16
grand fir	*Abies grandis*	7	0.14
boxelder	*Acer negundo*	7	0.14
Leyland cypress	*x Hesperotropsis leylandii*	7	0.14
loquat tree	*Eriobotrya japonica*	7	0.14
Austrian pine	*Pinus nigra*	7	0.14
giant sequoia	*Sequoiadendron giganteum*	7	0.14
Norway spruce	*Picea abies*	6	0.11
Bur oak	*Quercus macrocarpa*	6	0.11
willow spp	*Salix*	6	0.11
vine maple	*Acer circinatum*	5	0.10
Amur maple	*Acer tataricum ssp. ginnala*	5	0.10
horse chestnut	*Aesculus hippocastanum*	5	0.10
paper birch	*Betula papyrifera*	5	0.10
Italian cypress	*Cupressus sempervirens*	5	0.10
English holly	*Ilex aquifolium*	5	0.10
white spruce	*Picea glauca*	5	0.10
Japanese snowbell	*Styrax japonicus*	5	0.10
sycamore maple	*Acer pseudoplatanus*	4	0.08
ash spp	*Fraxinus*	4	0.08
Oregon ash	*Fraxinus latifolia*	4	0.08
black poplar	*Populus nigra*	4	0.08
European buckthorn	*Rhamnus cathartica*	4	0.08
Scouler willow	*Salix scouleriana*	4	0.08
lilac spp	*Syringa*	4	0.08
Japanese zelkova	*Zelkova serrata*	4	0.08
silver maple	*Acer saccharinum*	3	0.06
sugar maple	*Acer saccharum*	3	0.06

Species		# of Trees	% of Trees
Port Orford cedar	*Chamaecyparis lawsoniana*	3	0.06
Hinoki cypress	*Chamaecyparis obtusa*	3	0.06
hazelnut spp	*Corylus*	3	0.06
Pacific dogwood	*Cornus nuttallii*	3	0.06
Arizona cypress	*Cupressus arizonica*	3	0.06
pin oak	*Quercus palustris*	3	0.06
paperbark maple	*Acer griseum*	2	0.04
American chestnut	*Castanea dentata*	2	0.04
deodar cedar	*Cedrus deodara*	2	0.04
ginkgo	*Ginkgo biloba*	2	0.04
butternut	*Juglans cinerea*	2	0.04
dawn redwood	*Metasequoia glyptostroboides*	2	0.04
pine spp	*Pinus*	2	0.04
scarlet oak	*Quercus coccinea*	2	0.04
European mountain ash	*Sorbus aucuparia*	2	0.04
fir spp	*Abies*	1	0.02
Nordmann fir	*Abies nordmanniana*	1	0.02
birch spp	*Betula*	1	0.02
camellia	*Camellia japonica*	1	0.02
dogwood spp	*Cornus*	1	0.02
Japanese red cedar	*Cryptomeria japonica*	1	0.02
blue Chinese fir	*Cunninghamia lanceolata*	1	0.02
beech spp	*Fagus*	1	0.02
holly spp	*Ilex*	1	0.02
black walnut	*Juglans nigra*	1	0.02
golden-chain tree	*Laburnum anagyroides*	1	0.02
southern magnolia	*Magnolia grandiflora*	1	0.02
star magnolia	*Magnolia stellata*	1	0.02
eastern cottonwood	*Populus deltoides*	1	0.02
Lombardy poplar	*Populus nigra v. italica*	1	0.02
oak spp	*Quercus*	1	0.02
swamp white oak	*Quercus bicolor*	1	0.02
Babylon weeping willow	*Salix babylonica*	1	0.02
Total		4,890	100%

Table 25: Population Summary for All Inventoried Tree Species

		DBH Class (inches)									
Species	# of Trees	0 - 4	4 - 6	6 - 11	11 - 18	18 - 24	24 - 30	30 - 36	36 - 42	42 - 48	48+
Acer platanoides	747	194	160	303	75	10	5	0	0	0	0
Pyrus calleryana	466	187	113	161	4	1	0	0	0	0	0
Acer rubrum	451	157	173	93	27	1	0	0	0	0	0
Pseudotsuga menziesii	417	0	5	62	75	70	73	61	39	16	16
Prunus serrulata	286	143	55	61	21	5	0	1	0	0	0
Tilia cordata	239	89	68	79	3	0	0	0	0	0	0
Acer macrophyllum	235	0	13	43	53	26	22	18	11	8	41
Quercus rubra	155	38	30	67	11	6	2	0	1	0	0
Liquidambar styraciflua	154	11	15	104	22	0	1	0	0	0	0
Populus balsamifera	135	0	27	85	15	2	1	2	1	1	1
Prunus cerasifera	134	22	6	54	39	11	0	0	1	0	0
Malus	133	68	13	41	1	1	7	0	2	0	0
Fraxinus excelsior	119	72	11	34	0	0	0	0	0	0	1
Fraxinus pennsylvanica	104	67	15	19	3	0	0	0	0	0	0
Cornus kousa	82	61	19	1	1	0	0	0	0	0	0
Alnus rubra	77	0	4	29	21	10	5	5	0	1	2
Thuja plicata	77	3	2	21	14	9	10	10	5	2	1
Cornus florida	65	47	11	5	1	0	1	0	0	0	0
Cercidiphyllum japonicum	61	2	2	56	1	0	0	0	0	0	0
Prunus	58	0	3	29	14	6	2	3	0	0	1
Calocedrus decurrens	52	0	26	10	10	2	4	0	0	0	0
Nyssa sylvatica	38	15	20	3	0	0	0	0	0	0	0
Carpinus betulus	27	15	3	2	7	0	0	0	0	0	0
Acer grandidentatum	25	25	0	0	0	0	0	0	0	0	0
Robinia pseudoacacia	23	0	0	14	3	1	3	1	0	0	1
Xanthocyparis nootkatensis	23	4	9	8	1	0	0	0	0	0	1
Acer campestre	21	16	5	0	0	0	0	0	0	0	0
Fraxinus angustifolia	21	21	0	0	0	0	0	0	0	0	0
Amelanchier	18	0	1	9	1	2	2	1	1	0	1
Pinus monticola	18	0	0	0	2	2	13	1	0	0	0
Crataegus douglasii	17	0	2	7	2	4	2	0	0	0	0
Ulmus procera	17	0	2	11	1	2	0	1	0	0	0
Juniperus	15	0	3	7	3	0	1	1	0	0	0
Pinus contorta	14	1	3	2	4	3	1	0	0	0	0

Species	# of Trees	DBH Class (inches) 0 – 4	4 – 6	6 – 11	11 – 18	18 – 24	24 – 30	30 – 36	36 – 42	42 – 48	48+
Quercus garryana	14	0	1	0	2	2	1	1	4	2	1
Betula utilis ssp. jacquemontii	13	1	3	9	0	0	0	0	0	0	0
Populus tremuloides	13	0	1	8	4	0	0	0	0	0	0
Tsuga heterophylla	13	0	0	5	2	1	2	0	2	1	0
Betula pendula	11	0	0	5	5	1	1	0	0	0	0
Platanus x hybrida	11	2	2	1	0	4	1	1	0	1	0
Prunus avium	11	0	1	3	5	1	2	0	0	0	0
Acer palmatum	11	2	0	1	4	4	0	0	0	0	0
Acer truncatum x platanoides	11	10	0	1	0	0	0	0	0	0	0
Amelanchier canadensis	11	11	0	0	0	0	0	0	0	0	0
Crataegus	11	0	1	4	1	3	1	1	0	0	0
Prunus emarginata	9	0	0	1	3	4	1	0	0	0	0
Cedrus atlantica	8	0	0	1	5	2	0	0	0	0	0
Liriodendron tulipifera	8	0	0	0	3	3	0	2	0	0	0
Platanus occidentalis	8	0	2	6	0	0	0	0	0	0	0
Pyrus communis	8	5	0	0	1	2	0	0	0	0	0
Abies grandis	7	0	0	1	0	0	4	2	0	0	0
Acer negundo	7	4	1	2	0	0	0	0	0	0	0
Eriobotrya japonica	7	3	2	2	0	0	0	0	0	0	0
Pinus nigra	7	0	0	2	5	0	0	0	0	0	0
Sequoiadendron giganteum	7	0	0	1	0	2	2	2	0	0	0
x Hesperotropsis leylandii	7	0	0	1	2	3	0	0	0	0	1
Picea abies	6	6	0	0	0	0	0	0	0	0	0
Quercus macrocarpa	6	0	0	2	1	0	1	2	0	0	0
Salix	6	0	0	1	2	1	0	2	0	0	0
Acer circinatum	5	1	0	0	1	3	0	0	0	0	0
Acer tataricum ssp. ginnala	5	5	0	0	0	0	0	0	0	0	0
Aesculus hippocastanum	5	0	0	0	2	0	1	0	1	0	1
Betula papyrifera	5	1	3	1	0	0	0	0	0	0	0
Cupressus sempervirens	5	1	3	1	0	0	0	0	0	0	0
Ilex aquifolium	5	0	1	1	2	1	0	0	0	0	0
Picea glauca	5	0	1	4	0	0	0	0	0	0	0
Styrax japonicus	5	5	0	0	0	0	0	0	0	0	0
Acer pseudoplatanus	4	0	0	0	0	1	2	0	1	0	0
Fraxinus	4	0	0	3	1	0	0	0	0	0	0

Species	# of Trees	DBH Class (inches) 0 - 4	4 - 6	6 - 11	11 - 18	18 - 24	24 - 30	30 - 36	36 - 42	42 - 48	48+
Fraxinus latifolia	4	0	0	0	1	2	0	0	1	0	0
Populus nigra	4	0	1	0	0	1	1	0	1	0	0
Rhamnus cathartica	4	0	0	3	1	0	0	0	0	0	0
Salix scouleriana	4	0	0	2	0	0	0	0	0	1	1
Syringa	4	0	1	0	1	1	1	0	0	0	0
Zelkova serrata	4	4	0	0	0	0	0	0	0	0	0
Acer saccharinum	3	0	0	0	0	0	3	0	0	0	0
Acer saccharum	3	0	0	2	0	0	0	1	0	0	0
Chamaecyparis lawsoniana	3	0	2	1	0	0	0	0	0	0	0
Chamaecyparis obtusa	3	0	0	1	0	0	0	1	0	0	1
Cornus nuttallii	3	0	1	0	1	1	0	0	0	0	0
Corylus	3	0	0	0	0	1	2	0	0	0	0
Cupressus arizonica	3	0	1	0	2	0	0	0	0	0	0
Quercus palustris	3	0	1	1	0	0	1	0	0	0	0
Acer griseum	2	1	0	1	0	0	0	0	0	0	0
Castanea dentata	2	0	0	0	0	1	0	0	0	1	0
Cedrus deodara	2	0	0	0	0	2	0	0	0	0	0
Ginkgo biloba	2	0	1	0	1	0	0	0	0	0	0
Juglans cinerea	2	0	0	1	1	0	0	0	0	0	0
Metasequoia glyptostroboides	2	0	0	1	1	0	0	0	0	0	0
Pinus	2	0	0	0	2	0	0	0	0	0	0
Quercus coccinea	2	0	0	2	0	0	0	0	0	0	0
Sorbus aucuparia	2	2	0	0	0	0	0	0	0	0	0
Abies	1	0	0	0	1	0	0	0	0	0	0
Abies nordmanniana	1	1	0	0	0	0	0	0	0	0	0
Betula	1	0	0	1	0	0	0	0	0	0	0
Camellia japonica	1	0	0	0	0	0	0	0	1	0	0
Cornus	1	1	0	0	0	0	0	0	0	0	0
Cryptomeria japonica	1	0	0	0	0	1	0	0	0	0	0
Cunninghamia lanceolata	1	0	0	0	0	0	1	0	0	0	0
Fagus	1	0	0	1	0	0	0	0	0	0	0
Ilex	1	0	0	1	0	0	0	0	0	0	0
Juglans nigra	1	0	0	0	0	1	0	0	0	0	0
Laburnum anagyroides	1	0	0	1	0	0	0	0	0	0	0
Magnolia grandiflora	1	0	0	1	0	0	0	0	0	0	0
Magnolia stellata	1	0	0	0	0	1	0	0	0	0	0
Populus deltoides	1	0	1	0	0	0	0	0	0	0	0
Populus nigra v. italica	1	0	0	0	0	0	0	0	0	0	1
Quercus	1	0	1	0	0	0	0	0	0	0	0

Species	# of Trees	DBH Class (inches) 0 - 4	4 - 6	6 - 11	11 - 18	18 - 24	24 - 30	30 - 36	36 - 42	42 - 48	48+
Quercus bicolor	1	0	0	0	0	1	0	0	0	0	0
Salix babylonica	1	1	0	0	0	0	0	0	0	0	0
all other species	643	164	80	150	87	65	50	20	11	6	9
Total	4,890	1,326	852	1,507	498	226	183	110	72	34	72

Table 26: Importance Values for All Inventoried Tree Species

Species	# of Trees	% of Trees	% Leaf Area	IV
Acer platanoides	747	15.28	27.23	42.50
Pyrus calleryana	466	9.53	17.13	26.66
Acer rubrum	451	9.22	7.92	17.15
Pseudotsuga menziesii	417	8.53	3.54	11.07
Prunus serrulata	286	5.85	3.53	9.38
Tilia cordata	239	4.89	3.18	8.07
Acer macrophyllum	235	4.81	2.67	7.48
Quercus rubra	155	3.17	2.64	5.81
Liquidambar styraciflua	154	3.15	2.41	5.56
Populus balsamifera	135	2.76	2.22	4.98
Prunus cerasifera	134	2.74	2.11	4.86
Malus	133	2.72	1.80	4.52
Fraxinus excelsior	119	2.43	1.60	4.04
Fraxinus pennsylvanica	104	2.13	1.45	3.58
Cornus kousa	82	1.68	1.32	3.00
Alnus rubra	77	1.57	1.17	2.74
Thuja plicata	77	1.57	1.11	2.70
Cornus florida	65	1.33	0.92	2.25
Cercidiphyllum japonicum	61	1.25	0.87	2.11
Prunus	58	1.19	0.86	2.05
Calocedrus decurrens	52	1.06	0.76	1.83
Nyssa sylvatica	38	0.78	0.75	1.53
Carpinus betulus	27	0.55	0.60	1.16
Acer grandidentatum	25	0.51	0.55	1.06
Robinia pseudoacacia	23	0.47	0.55	1.02
Xanthocyparis nootkatensis	23	0.47	0.45	0.92
Acer campestre	21	0.43	0.41	0.84
Fraxinus angustifolia	21	0.43	0.38	0.81
Amelanchier	18	0.37	0.37	0.74
Pinus monticola	18	0.37	0.37	0.74
Crataegus douglasii	17	0.35	0.35	0.70
Ulmus procera	17	0.35	0.33	0.68
Juniperus	15	0.31	0.33	0.64
Pinus contorta	14	0.29	0.33	0.61
Quercus garryana	14	0.29	0.32	0.61

Species	# of Trees	% of Trees	% Leaf Area	IV
Betula utilis ssp. Jacquemontii	13	0.27	0.30	0.56
Populus tremuloides	13	0.27	0.30	0.56
Tsuga heterophylla	13	0.27	0.29	0.56
Betula pendula	11	0.25	0.29	0.54
Platanus x hybrida	11	0.25	0.29	0.53
Prunus avium	11	0.25	0.29	0.53
Acer palmatum	11	0.22	0.28	0.51
Acer truncatum x platanoides	11	0.22	0.28	0.50
Amelanchier canadensis	11	0.22	0.27	0.50
Crataegus	11	0.22	0.21	0.43
Prunus emarginata	9	0.18	0.20	0.39
Cedrus atlantica	8	0.16	0.20	0.36
Liriodendron tulipifera	8	0.16	0.19	0.36
Platanus occidentalis	8	0.16	0.19	0.35
Pyrus communis	8	0.16	0.18	0.35
Abies grandis	7	0.14	0.18	0.33
Acer negundo	7	0.14	0.18	0.32
Eriobotrya japonica	7	0.14	0.17	0.31
Pinus nigra	7	0.14	0.16	0.30
Sequoiadendron giganteum	7	0.14	0.16	0.30
x Hesperotropsis leylandii	7	0.14	0.14	0.28
Picea abies	6	0.11	0.14	0.26
Quercus macrocarpa	6	0.11	0.14	0.26
Salix	6	0.11	0.13	0.25
Acer circinatum	5	0.10	0.13	0.23
Acer tataricum ssp. Ginnala	5	0.10	0.13	0.23
Aesculus hippocastanum	5	0.10	0.11	0.21
Betula papyrifera	5	0.10	0.11	0.21
Cupressus sempervirens	5	0.10	0.10	0.20
Ilex aquifolium	5	0.10	0.09	0.20
Picea glauca	5	0.10	0.09	0.20
Styrax japonicus	5	0.10	0.09	0.19
Acer pseudoplatanus	4	0.08	0.09	0.17
Fraxinus	4	0.08	0.08	0.17
Fraxinus latifolia	4	0.08	0.08	0.17
Populus nigra	4	0.08	0.06	0.14
Rhamnus cathartica	4	0.08	0.06	0.14
Salix scouleriana	4	0.08	0.06	0.14
Syringa	4	0.08	0.06	0.14
Zelkova serrata	4	0.08	0.06	0.14
Acer saccharinum	3	0.06	0.06	0.11
Acer saccharum	3	0.06	0.06	0.11
Chamaecyparis lawsoniana	3	0.06	0.06	0.11
Chamaecyparis obtusa	3	0.06	0.05	0.11

Species	# of Trees	% of Trees	% Leaf Area	IV
Cornus nuttallii	3	0.06	0.05	0.11
Corylus	3	0.06	0.05	0.11
Cupressus arizonica	3	0.06	0.05	0.11
Quercus palustris	3	0.06	0.05	0.11
Acer griseum	2	0.04	0.04	0.08
Castanea dentata	2	0.04	0.04	0.08
Cedrus deodara	2	0.04	0.04	0.08
Ginkgo biloba	2	0.04	0.04	0.08
Juglans cinerea	2	0.04	0.04	0.08
Metasequoia glyptostroboides	2	0.04	0.03	0.07
Pinus	2	0.04	0.02	0.06
Quercus coccinea	2	0.04	0.02	0.06
Sorbus aucuparia	2	0.04	0.02	0.06
Abies	1	0.02	0.02	0.04
Abies nordmanniana	1	0.02	0.01	0.03
Betula	1	0.02	0.01	0.03
Camellia japonica	1	0.02	0.01	0.03
Cornus	1	0.02	0.01	0.03
Cryptomeria japonica	1	0.02	0.01	0.03
Cunninghamia lanceolata	1	0.02	0.01	0.03
Fagus	1	0.02	0.01	0.03
Ilex	1	0.02	0.00	0.03
Juglans nigra	1	0.02	0.00	0.03
Laburnum anagyroides	1	0.02	0.00	0.03
Magnolia grandiflora	1	0.02	0.00	0.03
Magnolia stellata	1	0.02	0.00	0.03
Populus deltoides	1	0.02	0.00	0.03
Populus nigra v. italica	1	0.02	0.00	0.02
Quercus	1	0.02	0.00	0.02
Quercus bicolor	1	0.02	0.00	0.02
Salix babylonica	1	0.02	0.00	0.02
Total	4,890	100%	100%	200

Table 27: Condition and RPI for All Inventoried Tree Species

Species	% Excellent	% Very Good	% Good	% Fair	% Poor	% Critical	% Dead	RPI	# of Trees	% of Trees
Acer platanoides	6.0	85.5	5.8	1.7	0.5	0.0	0.4	1.05	747	15.28
Pyrus calleryana	3.4	83.5	10.7	2.1	0.2	0.0	0.0	1.04	466	9.53
Acer rubrum	11.9	74.3	10.2	1.8	0.9	0.0	0.0	1.06	451	9.22
Pseudotsuga menziesii	0.0	65.2	31.7	1.7	0.0	0.0	1.4	0.99	417	8.53
Prunus serrulata	3.5	73.8	16.1	4.9	1.4	0.0	0.3	1.01	286	5.85
Tilia cordata	21.8	54.0	16.7	5.4	1.3	0.0	0.8	1.04	239	4.89
Acer macrophyllum	0.0	35.7	57.0	4.7	0.4	0.0	2.1	0.92	235	4.81
Quercus rubra	1.9	80.6	11.6	3.2	1.9	0.0	0.6	1.02	155	3.17

Species	% Excellent	% Very Good	% Good	% Fair	% Poor	% Critical	% Dead	RPI	# of Trees	% of Trees
Liquidambar styraciflua	3.2	53.2	37.7	4.5	1.3	0.0	0.0	0.98	154	3.15
Populus balsamifera	0.0	56.3	11.6	31.1	0.0	0.0	0.0	0.93	135	2.76
Prunus cerasifera	0.7	39.6	40.3	18.7	0.7	0.0	0.0	0.92	134	2.74
Malus	7.5	39.8	42.1	9.8	0.8	0.0	0.0	0.96	133	2.72
Fraxinus excelsior	1.7	83.2	5.9	5.0	4.2	0.0	0.0	1.02	119	2.43
Fraxinus pennsylvanica	0.0	62.5	37.5	0.0	0.0	0.0	0.0	1.00	104	2.13
Cornus kousa	0.0	57.3	32.9	3.7	3.7	0.0	2.4	0.95	82	1.68
Alnus rubra	0.0	22.1	55.8	10.4	0.0	0.0	11.7	0.82	77	1.57
Thuja plicata	0.0	48.1	41.6	2.6	7.8	0.0	0.0	0.94	77	1.57
Cornus florida	0.0	46.2	38.5	6.2	6.2	0.0	3.1	0.91	65	1.33
Cercidiphyllum japonicum	11.5	72.1	14.8	1.6	0.0	0.0	0.0	1.05	61	1.25
Prunus	0.0	5.2	72.4	17.2	1.7	0.0	3.4	0.83	58	1.19
Calocedrus decurrens	0.0	36.5	55.8	7.7	0.0	0.0	0.0	0.94	52	1.06
Nyssa sylvatica	36.8	55.3	5.3	2.6	0.0	0.0	0.0	1.11	38	0.78
Carpinus betulus	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	27	0.55
Acer grandidentatum	0.0	92.0	8.0	0.0	0.0	0.0	0.0	1.05	25	0.51
Robinia pseudoacacia	0.0	43.5	43.5	13.0	0.0	0.0	0.0	0.94	23	0.47
Xanthocyparis nootkatensis	4.3	91.3	4.3	0.0	0.0	0.0	0.0	1.06	23	0.47
Acer campestre	14.3	57.1	28.6	0.0	0.0	0.0	0.0	1.04	21	0.43
Fraxinus angustifolia	42.9	33.3	19.0	4.8	0.0	0.0	0.0	1.09	21	0.43
Amelanchier	0.0	5.6	94.4	0.0	0.0	0.0	0.0	0.9 0	18	0.37
Pinus monticola	0.0	38.9	55.6	0.0	0.0	0.0	5.6	0.92	18	0.37
Crataegus douglasii	0.0	0.0	52.9	29.4	5.9	0.0	11.8	0.73	17	0.35
Ulmus procera	0.0	35.3	47.1	17.6	0.0	0.0	0.0	0.92	17	0.35
Juniperus	0.0	0.0	100. 0	0.0	0.0	0.0	0.0	0.89	15	0.31
Pinus contorta	0.0	50.0	35.7	14.3	0.0	0.0	0.0	0.95	14	0.29
Quercus garryana	7.1	57.1	35.7	0.0	0.0	0.0	0.0	1.01	14	0.29
Betula utilis ssp. jacquemontii	7.7	84.6	7.7	0.0	0.0	0.0	0.0	1.06	13	0.27
Populus tremuloides	0.0	61.5	38.5	0.0	0.0	0.0	0.0	0.99	13	0.27
Tsuga heterophylla	0.0	46.2	23.1	7.7	0.0	0.0	23.1	0.79	13	0.27
Betula pendula	0.0	83.3	16.7	0.0	0.0	0.0	0.0	1.03	11	0.25
Platanus x hybrida	16.7	58.3	16.7	8.3	0.0	0.0	0.0	1.03	11	0.25
Prunus avium	0.0	91.7	8.3	0.0	0.0	0.0	0.0	1.05	11	0.25
Acer palmatum	0.0	63.6	18.2	18.2	0.0	0.0	0.0	0.97	11	0.22
Acer truncatum x platanoides	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	11	0.22
Amelanchier canadensis	0.0	0.0	90.9	9.1	0.0	0.0	0.0	0.87	11	0.22
Crataegus	0.0	9.1	81.8	9.1	0.0	0.0	0.0	0.89	11	0.22
Prunus emarginata	0.0	0.0	88.9	11.1	0.0	0.0	0.0	0.87	9	0.18
Cedrus atlantica	0.0	62.5	37.5	0.0	0.0	0.0	0.0	1.00	8	0.16
Liriodendron tulipifera	0.0	75.0	25.0	0.0	0.0	0.0	0.0	1.02	8	0.16
Platanus occidentalis	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	8	0.16
Pyrus communis	0.0	11.5	75.0	11.5	0.0	0.0	0.0	0.89	8	0.16
Abies grandis	0.0	57.1	42.9	0.0	0.0	0.0	0.0	0.99	7	0.14
Acer negundo	0.0	71.4	0.0	28.6	0.0	0.0	0.0	0.96	7	0.14

Species	% Excellent	% Very Good	% Good	% Fair	% Poor	% Critical	% Dead	RPI	# of Trees	% of Trees
Eriobotrya japonica	0.0	85.7	0.0	0.0	14.3	0.0	0.0	0.99	7	0.14
Pinus nigra	0.0	71.4	28.6	0.0	0.0	0.0	0.0	1.01	7	0.14
Sequoiadendron giganteum	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	7	0.14
x Hesperotropsis leylandii	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	7	0.14
Picea abies	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	6	0.11
Quercus macrocarpa	0.0	83.3	16.7	0.0	0.0	0.0	0.0	1.03	6	0.11
Salix	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.97	6	0.11
Acer circinatum	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	5	0.10
Acer tataricum ssp. ginnala	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	5	0.10
Aesculus hippocastanum	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	5	0.10
Betula papyrifera	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	5	0.10
Cupressus sempervirens	0.0	80.0	20.0	0.0	0.0	0.0	0.0	1.03	5	0.10
Ilex aquifolium	0.0	60.0	40.0	0.0	0.0	0.0	0.0	0.99	5	0.10
Picea glauca	0.0	80.0	20.0	0.0	0.0	0.0	0.0	1.03	5	0.10
Styrax japonicus	0.0	80.0	0.0	20.0	0.0	0.0	0.0	0.99	5	0.10
Acer pseudoplatanus	0.0	75.0	25.0	0.0	0.0	0.0	0.0	1.02	4	0.08
Fraxinus	0.0	75.0	25.0	0.0	0.0	0.0	0.0	1.02	4	0.08
Fraxinus latifolia	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	4	0.08
Populus nigra	0.0	25.0	75.0	0.0	0.0	0.0	0.0	0.93	4	0.08
Rhamnus cathartica	0.0	25.0	75.0	0.0	0.0	0.0	0.0	0.93	4	0.08
Salix scouleriana	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	4	0.08
Syringa	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	4	0.08
Zelkova serrata	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	4	0.08
Acer saccharinum	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	3	0.06
Acer saccharum	0.0	66.7	33.3	0.0	0.0	0.0	0.0	1.00	3	0.06
Chamaecyparis lawsoniana	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	3	0.06
Chamaecyparis obtusa	0.0	66.7	33.3	0.0	0.0	0.0	0.0	1.00	3	0.06
Cornus nuttallii	0.0	33.3	66.7	0.0	0.0	0.0	0.0	0.94	3	0.06
Corylus	0.0	0.0	66.7	33.3	0.0	0.0	0.0	0.83	3	0.06
Cupressus arizonica	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	3	0.06
Quercus palustris	33.3	33.3	0.0	33.3	0.0	0.0	0.0	1.00	3	0.06
Acer griseum	0.0	50.0	0.0	50.0	0.0	0.0	0.0	0.89	2	0.04
Castanea dentata	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Cedrus deodara	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Ginkgo biloba	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Juglans cinerea	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Metasequoia glyptostroboides	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Pinus	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	2	0.04
Quercus coccinea	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04
Sorbus aucuparia	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	2	0.04

Species	% Excellent	% Very Good	% Good	% Fair	% Poor	% Critical	% Dead	RPI	# of Trees	% of Trees
Abies	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Abies nordmanniana	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Betula	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	1	0.02
Camellia japonica	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Cornus	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	1	0.02
Cryptomeria japonica	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Cunninghamia lanceolata	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	1	0.02
Fagus	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Ilex	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Juglans nigra	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	1	0.02
Laburnum anagyroides	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Magnolia grandiflora	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Magnolia stellata	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Populus deltoides	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Populus nigra v. italica	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Quercus	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.89	1	0.02
Quercus bicolor	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Salix babylonica	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1.06	1	0.02
Total	4.9%	65.1%	23.4%	4.8%	0.9%	0%	0.8%	1.00	4,890	100%

Table 28: Annual Benefits for All Inventoried Tree Species

Species	# of Trees	% of Pop.	Carbon Storage ($)	Gross Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)
Acer platanoides	747	15.28	22,368	887.46	594.87	472.18
Pyrus calleryana	466	9.53	5,529	271.52	198.13	157.27
Acer rubrum	451	9.22	6,903	375.05	265.40	210.67
Pseudotsuga menziesii	417	8.53	60,845	513.03	1185.76	1020.59
Prunus serrulata	286	5.85	8,592	198.14	110.19	95.40
Tilia cordata	239	4.89	2,307	110.77	135.25	107.36
Acer macrophyllum	235	4.81	92,572	562.62	2043.34	1621.92
Quercus rubra	155	3.17	6,304	156.77	238.56	189.36
Liquidambar styraciflua	154	3.15	2,577	107.56	181.15	143.79
Populus balsamifera	135	2.76	6,283	113.24	200.82	159.40
Prunus cerasifera	134	2.74	9,645	113.81	166.43	132.11
Malus	133	2.72	6,186	59.25	56.20	44.61
Fraxinus excelsior	119	2.43	2,328	61.45	87.89	69.76
Fraxinus pennsylvanica	104	2.13	833	39.14	57.20	45.41
Cornus kousa	82	1.68	385	15.43	9.77	7.75
Alnus rubra	77	1.57	6,008	70.17	159.25	116.40
Thuja plicata	77	1.57	6,432	30.34	264.75	210.15
Cornus florida	65	1.33	754	22.47	13.90	11.03

Species	# of Trees	% of Pop.	Carbon Storage ($)	Gross Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)
Cercidiphyllum japonicum	61	1.25	677	27.87	109.04	86.55
Prunus	58	1.19	10,039	61.51	98.96	78.55
Calocedrus decurrens	52	1.06	2,211	27.75	65.23	51.77
Nyssa sylvatica	38	0.78	222	15.78	13.34	10.59
Carpinus betulus	27	0.55	785	19.38	28.80	22.86
Acer grandidentatum	25	0.51	5	1.68	0.52	0.41
Robinia pseudoacacia	23	0.47	4,132	53.37	40.97	32.52
Xanthocyparis nootkatensis	23	0.47	2,254	31.11	15.40	11.23
Acer campestre	21	0.43	84	4.90	6.95	5.52
Fraxinus angustifolia	21	0.43	18	2.81	2.89	2.29
Amelanchier	18	0.37	4,875	13.88	24.77	19.66
Pinus monticola	18	0.37	2,699	38.93	69.31	55.01
Crataegus douglasii	17	0.35	1,909	5.84	11.80	10.16
Ulmus procera	17	0.35	1,240	25.91	21.27	16.88
Juniperus	15	0.31	1,206	9.21	21.80	17.30
Pinus contorta	14	0.29	596	11.66	22.42	17.80
Quercus garryana	14	0.29	7,502	26.86	84.30	66.92
Betula utilis ssp. jacquemontii	13	0.27	218	10.28	13.86	11.00
Populus tremuloides	13	0.27	354	14.21	7.48	5.94
Tsuga heterophylla	13	0.27	1,407	8.75	41.49	32.93
Betula pendula	11	0.25	1,078	31.36	33.94	26.94
Platanus x hybrida	11	0.25	1,883	19.77	45.16	35.85
Prunus avium	11	0.25	1,904	11.58	22.00	17.46
Acer palmatum	11	0.22	1,082	2.54	21.52	17.08
Acer truncatum x platanoides	11	0.22	65	3.63	4.43	3.51
Amelanchier canadensis	11	0.22	9	1.34	0.40	0.32
Crataegus	11	0.22	1,649	5.71	14.99	11.90
Prunus emarginata	9	0.18	2,142	7.02	20.36	16.16
Cedrus atlantica	8	0.16	758	11.91	14.62	11.61
Liriodendron tulipifera	8	0.16	1,804	31.61	64.62	51.30
Platanus occidentalis	8	0.16	71	4.26	8.23	6.53
Pyrus communis	8	0.16	636	2.73	6.69	5.31
Abies grandis	7	0.14	1,151	11.26	27.61	21.92
Acer negundo	7	0.14	60	3.63	3.54	2.81
x Hesperotropsis leylandii	7	0.14	2,967	31.60	24.59	19.52
Eriobotrya japonica	7	0.14	89	3.84	1.70	1.35
Pinus nigra	7	0.14	242	5.50	9.85	7.82
Sequoiadendron giganteum	7	0.14	3,107	28.68	30.44	24.16
Picea abies	6	0.11	9	0.49	0.48	0.38
Quercus macrocarpa	6	0.11	1,504	13.84	27.86	22.11
Salix	6	0.11	1,513	9.22	22.23	17.65
Acer circinatum	5	0.10	856	1.98	24.92	19.78
Acer tataricum ssp. ginnala	5	0.10	9	1.11	0.94	0.75

Species	# of Trees	% of Pop.	Carbon Storage ($)	Gross Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)
Aesculus hippocastanum	5	0.10	2,923	14.97	23.92	18.99
Betula papyrifera	5	0.10	67	4.27	4.26	3.38
Cupressus sempervirens	5	0.10	77	3.31	1.53	1.21
Ilex aquifolium	5	0.10	434	2.33	7.18	5.70
Picea glauca	5	0.10	75	1.91	3.92	3.11
Styrax japonicus	5	0.10	2	0.27	0.22	0.17
Acer pseudoplatanus	4	0.08	1,892	17.23	26.53	21.06
Fraxinus	4	0.08	196	4.87	9.92	7.88
Fraxinus latifolia	4	0.08	950	9.47	15.18	11.05
Populus nigra	4	0.08	1,330	14.33	14.10	11.19
Rhamnus cathartica	4	0.08	114	3.80	1.52	1.21
Salix scouleriana	4	0.08	2,727	3.36	21.53	17.09
Syringa	4	0.08	949	2.55	6.80	5.40
Zelkova serrata	4	0.08	2	0.34	0.40	0.32
Acer saccharinum	3	0.06	889	11.22	20.91	16.60
Acer saccharum	3	0.06	650	6.24	10.75	8.54
Chamaecyparis lawsoniana	3	0.06	37	1.62	1.08	0.86
Chamaecyparis obtusa	3	0.06	1,422	4.84	10.52	8.35
Corylus	3	0.06	718	6.74	10.48	8.32
Cornus nuttallii	3	0.06	216	4.10	2.86	2.27
Cupressus arizonica	3	0.06	160	3.72	2.73	2.17
Quercus palustris	3	0.06	316	6.31	11.87	9.42
Acer griseum	2	0.04	34	0.72	0.95	0.75
Castanea dentata	2	0.04	994	5.91	11.81	9.37
Cedrus deodara	2	0.04	311	5.49	6.44	5.11
Ginkgo biloba	2	0.04	30	0.64	3.01	2.39
Juglans cinerea	2	0.04	74	2.69	4.69	3.73
Metasequoia glyptostroboides	2	0.04	57	2.00	6.36	5.05
Pinus	2	0.04	118	2.19	4.77	3.79
Quercus coccinea	2	0.04	70	3.25	3.49	2.77
Sorbus aucuparia	2	0.04	3	0.49	0.17	0.13
Abies	1	0.02	38	0.85	1.24	0.99
Abies nordmanniana	1	0.02	2	0.13	0.09	0.07
Betula	1	0.02	20	0.79	0.90	0.71
Camellia japonica	1	0.02	1,401	0.18	3.07	2.44
Cornus	1	0.02	1	0.11	0.04	0.03
Cryptomeria japonica	1	0.02	111	2.23	4.14	3.28
Cunninghamia lanceolata	1	0.02	181	1.79	4.13	3.27
Fagus	1	0.02	50	1.57	3.93	3.11
Ilex	1	0.02	29	1.01	0.77	0.61
Juglans nigra	1	0.02	165	3.41	3.74	2.97
Laburnum anagyroides	1	0.02	28	1.65	0.72	0.57
Magnolia grandiflora	1	0.02	47	1.32	2.30	1.82
Magnolia stellata	1	0.02	268	0.06	4.35	3.45
Populus deltoides	1	0.02	8	0.66	0.58	0.46
Populus nigra v. italica	1	0.02	1,410	0.45	8.27	6.56

Species	# of Trees	% of Pop.	Carbon Storage ($)	Gross Carbon Sequestration ($/yr.)	Avoided Runoff ($/yr.)	Pollution Removal ($/yr.)
Quercus	1	0.02	17	0.72	0.49	0.39
Quercus bicolor	1	0.02	158	3.19	4.75	3.77
Salix babylonica	1	0.02	0	0.09	0.08	0.06
Total	4,890	100%	$335,667	$4,548	$7,505	$5,957

Appendix D: Plot Sampled Park Trees

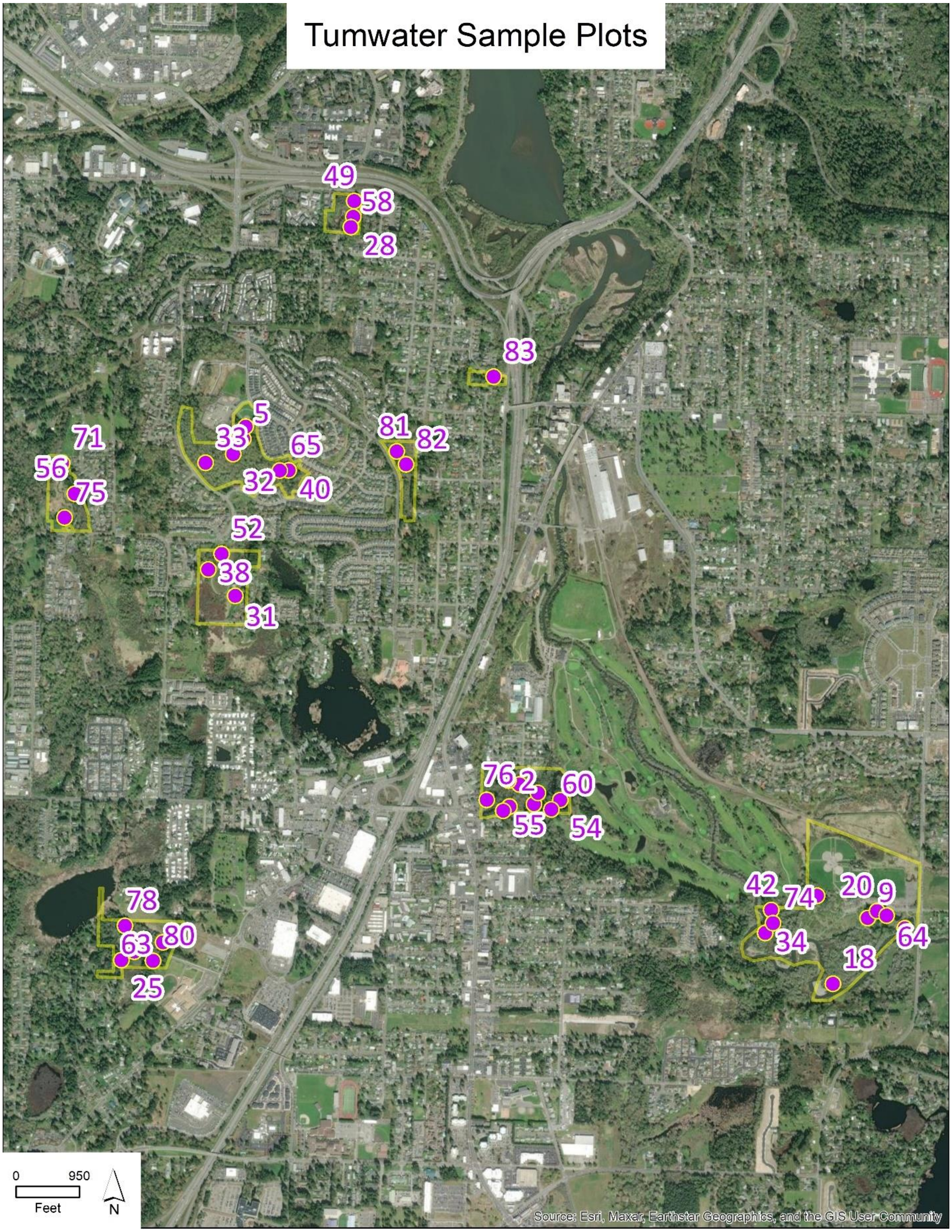
Table 29: Primary Defects of Plot Sampled Trees

Defects of Plot Sampled Trees in Natural Areas	
Plot 2	9
Cavity/Decay/Nest hole	1
Dieback/Deadwood	1
Included Bark/Weak Union(s)	1
None	2
Uncorrected Lean	4
Plot 5	10
Cankers/Galls/Burls	4
Dieback/Deadwood	4
Poor Structure/Taper	1
Serious Decline	1
Plot 9	25
Dieback/Deadwood	8
Fungal Fruiting Bodies	1
None	2
Poor Structure/Taper	14
Plot 15	6
Cavity/Decay/Nest hole	1
None	3
Poor Structure/Taper	1
Unbalanced Crown	1
Plot 17	11
Dieback/Deadwood	1
Included Bark/Weak Union(s)	1
Mechanical Damage	1
None	4
Poor Structure/Taper	1
Previous Failure(s)	2
Signs of Stress	1
Uncorrected Lean	1
Plot 18	11
Dieback/Deadwood	1
Mechanical Damage	2
None	1
Poor Structure/Taper	2
Previous Failure(s)	2
Serious Decline	1
Unbalanced Crown	2
Uncorrected Lean	1
Plot 20	11
Plot 47	7
Cavity/Decay/Nest hole	1
Included Bark/Weak Union(s)	1
None	3
Previous Failure(s)	2
Plot 49	45
Cavity/Decay/Nest hole	2
Dieback/Deadwood	16
None	4
Poor Structure/Taper	14
Previous Failure(s)	1
Serious Decline	1
Suppressed	4
Unbalanced Crown	2
Uncorrected Lean	1
Plot 52	13
Dieback/Deadwood	11
Poor Structure/Taper	2
Plot 54	5
Dieback/Deadwood	4
None	1
Plot 55	9
Dieback/Deadwood	2
Included Bark/Weak Union(s)	1
None	1
Poor Structure/Taper	3
Serious Decline	1
Unbalanced Crown	1
Plot 56	30
Dieback/Deadwood	17
Included Bark/Weak Union(s)	1
Poor Structure/Taper	4
Previous Failure(s)	3
Suppressed	5
Plot 57	19
Dieback/Deadwood	11
Poor Structure/Taper	7
Previous Failure(s)	1
Site 58	19
Dieback/Deadwood	9

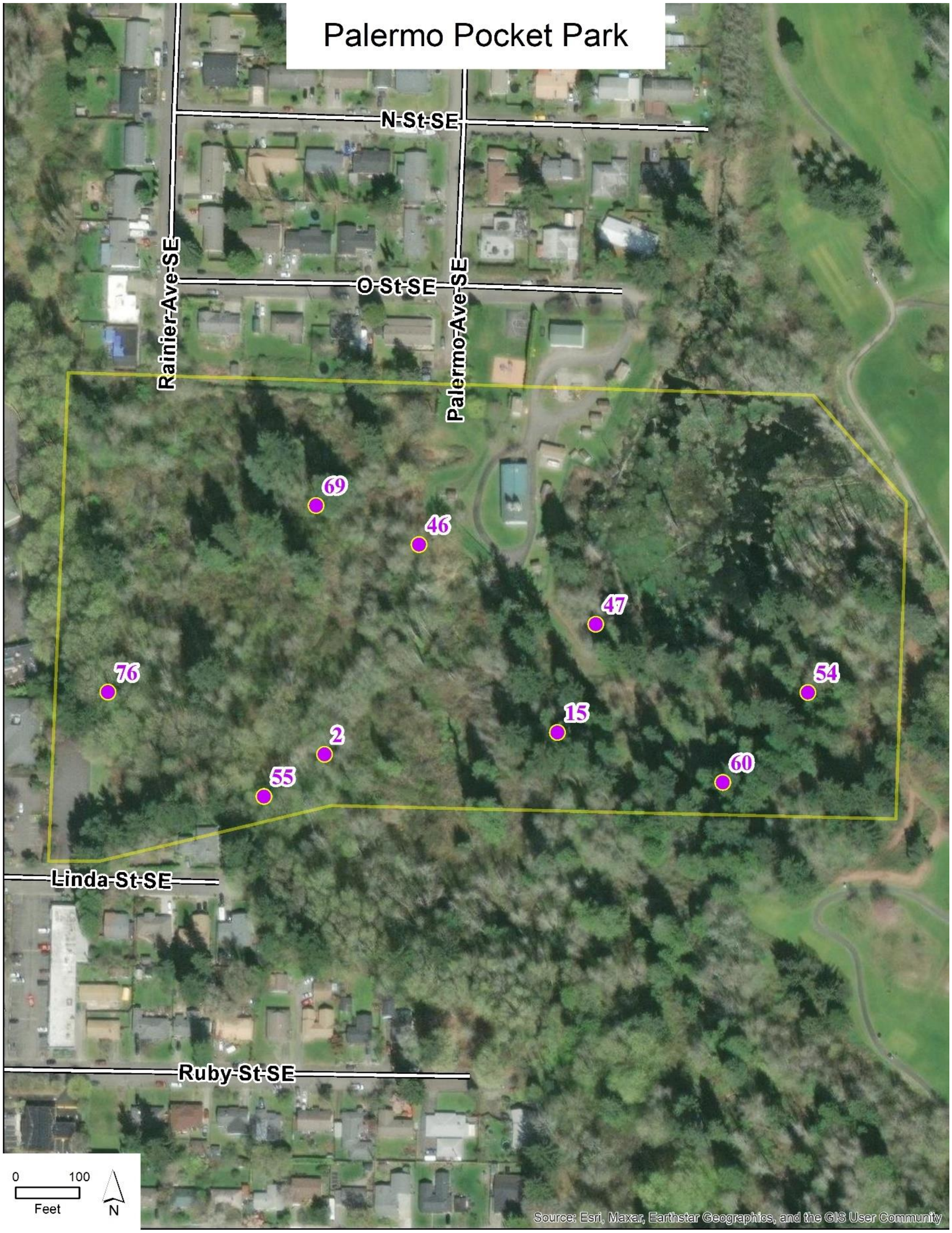
Dieback/Deadwood	2
None	1
Poor Structure/Taper	1
Root Plate Lifting	1
Serious Decline	1
Signs of Stress	5
Plot 21	17
Dieback/Deadwood	7
Fungal Fruiting Bodies	1
Mechanical Damage	1
None	1
Poor Structure/Taper	3
Serious Decline	3
Unbalanced Crown	1
Plot 22	17
Dieback/Deadwood	3
None	6
Poor Structure/Taper	3
Signs of Stress	1
Suppressed	4
Plot 24	19
Cankers/Galls/Burls	1
Dieback/Deadwood	15
Poor Structure/Taper	1
Previous Failure(s)	2
Plot 25	15
Dieback/Deadwood	14
Uncorrected Lean	1
Plot 28	20
Dieback/Deadwood	1
None	2
Poor Structure/Taper	8
Serious Decline	6
Signs of Stress	1
Suppressed	2
Plot 31	28
Dieback/Deadwood	5
None	1
Poor Structure/Taper	16
Previous Failure(s)	1
Serious Decline	4
Suppressed	1
Plot 32	5
Dieback/Deadwood	5
Plot 33	8
Dieback/Deadwood	4
None	1
Poor Structure/Taper	3
Serious Decline	1
Suppressed	4
Uncorrected Lean	1
Plot 60	11
Dieback/Deadwood	5
None	3
Poor Structure/Taper	2
Suppressed	1
Plot 63	22
Cavity/Decay/Nest hole	1
Dieback/Deadwood	16
Poor Structure/Taper	3
Suppressed	1
Uncorrected Lean	1
Plot 64	11
Dieback/Deadwood	8
Included Bark/Weak Union(s)	2
None	1
Plot 65	11
Crack/Seams	1
Dieback/Deadwood	2
Fungal Fruiting Bodies	1
Poor Structure/Taper	6
Serious Decline	1
Plot 69	8
Cavity/Decay/Nest hole	1
Dieback/Deadwood	1
Included Bark/Weak Union(s)	1
Poor Structure/Taper	2
Suppressed	2
Unbalanced Crown	1
Plot 71	16
Dieback/Deadwood	5
Poor Structure/Taper	3
Suppressed	8
Plot 74	8
Dieback/Deadwood	6
Poor Structure/Taper	1
Previous Failure(s)	1
Plot 75	7
Cavity/Decay/Nest hole	1
Dieback/Deadwood	1
Suppressed	1
Unbalanced Crown	4

Serious Decline	4
Plot 34	10
Dieback/Deadwood	3
None	2
Poor Structure/Taper	2
Uncorrected Lean	3
Plot 38	19
Cankers/Galls/Burls	2
Crack/Seams	1
Dieback/Deadwood	7
None	1
Poor Structure/Taper	5
Previous Failure(s)	2
Serious Decline	1
Plot 40	14
Dieback/Deadwood	6
None	1
Poor Structure/Taper	4
Serious Decline	1
Unbalanced Crown	1
Uncorrected Lean	1
Plot 42	10
Crack/Seams	1
Dieback/Deadwood	6
Fungal Fruiting Bodies	1
Poor Structure/Taper	1
Previous Failure(s)	1
Plot 46	8
Dieback/Deadwood	2
Mechanical Damage	1
None	2
Serious Decline	1
Soil heaving	1
Unbalanced Crown	1
Plot 76	11
Dieback/Deadwood	3
None	2
Poor Structure/Taper	4
Unbalanced Crown	1
Uncorrected Lean	1
Plot 78	17
Dieback/Deadwood	11
Poor Structure/Taper	1
Suppressed	4
Uncorrected Lean	1
Plot 80	13
Cankers/Galls/Burls	1
Dieback/Deadwood	8
Poor Structure/Taper	4
Site 81	14
Dieback/Deadwood	9
Included Bark/Weak Union(s)	1
Poor Structure/Taper	4
Site 82	14
Dieback/Deadwood	8
None	1
Poor Structure/Taper	5
Site 83	8
Dieback/Deadwood	6
None	1
Poor Structure/Taper	1

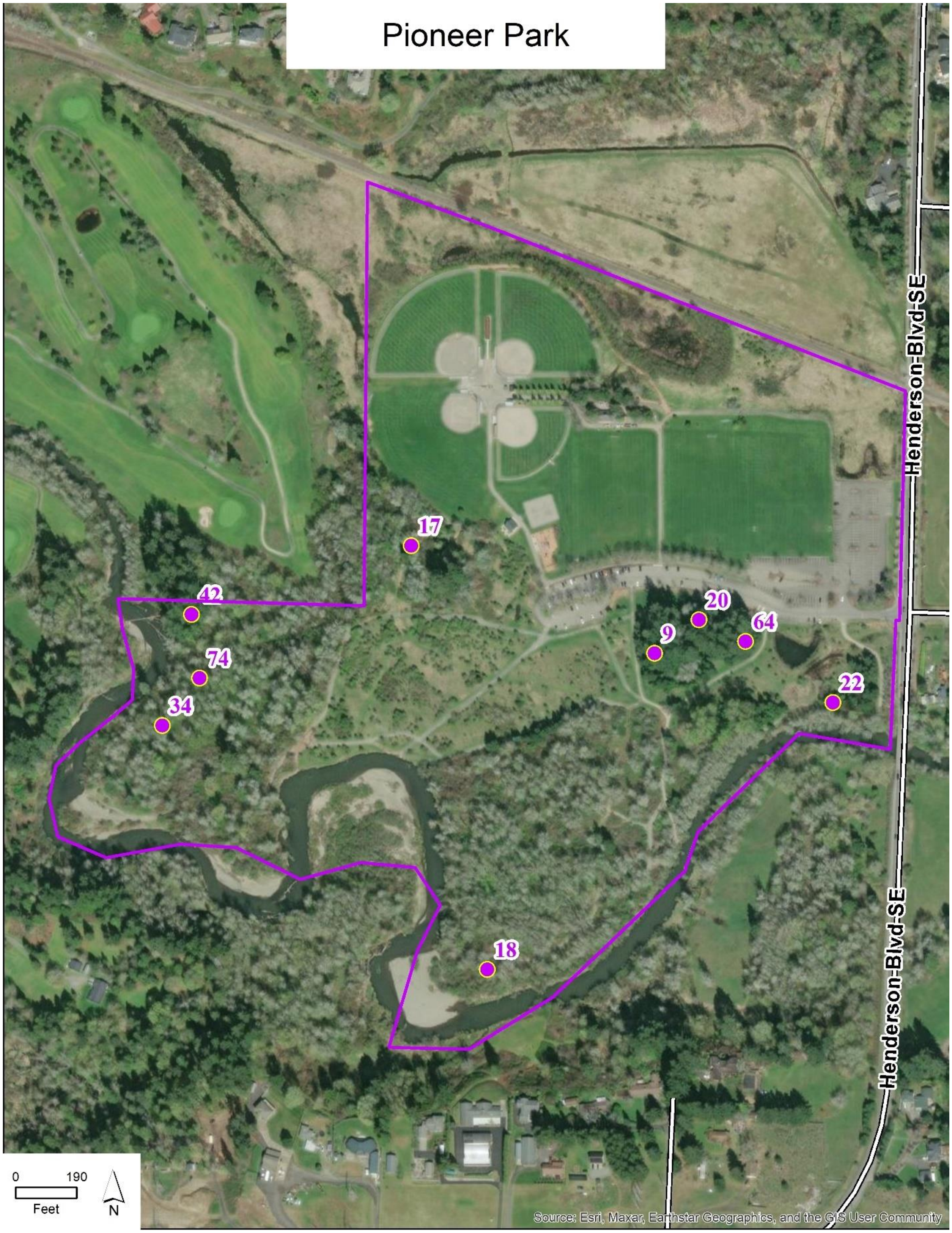
Appendix C (Map 7): Overview location of Tumwater Sample Plots



Appendix C (Map 8): Sample Plots in Palermo Pocket Park

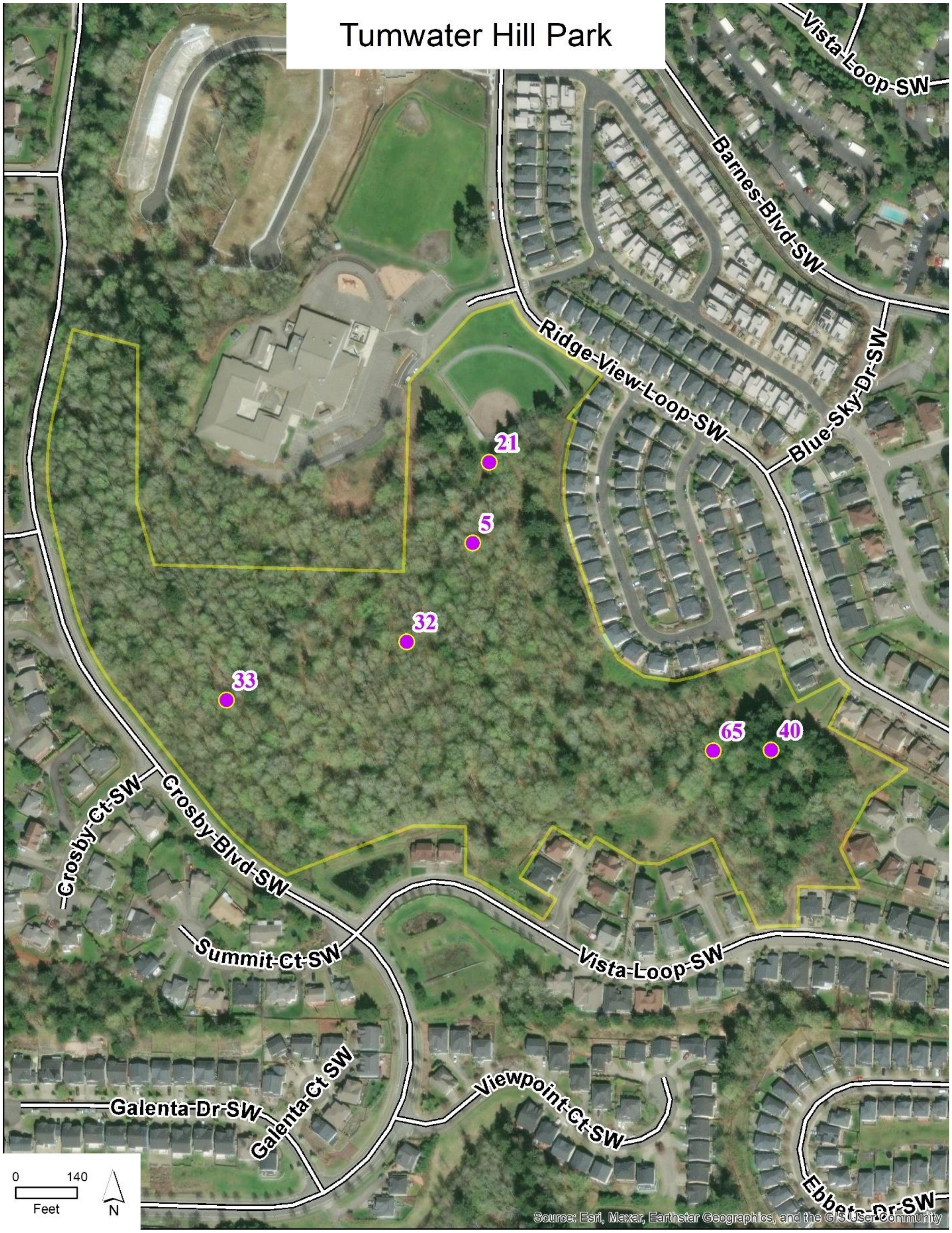


Appendix C (Map 9): Sample Plots in Pioneer Park



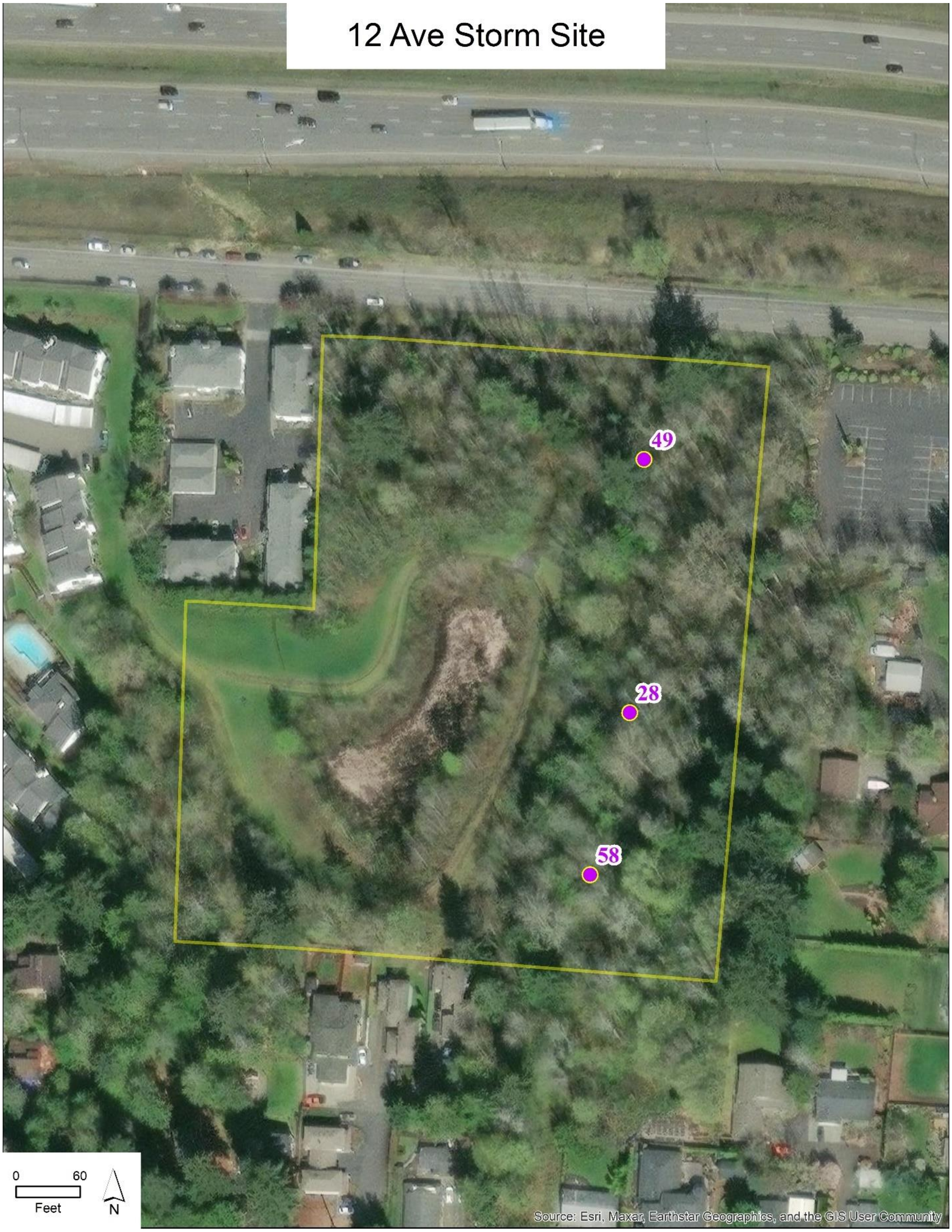
Appendix C (Map 10): Sample Plots in Trosper Lake Park

Appendix C (Map 11): Sample Plots in Tumwater Hill Park



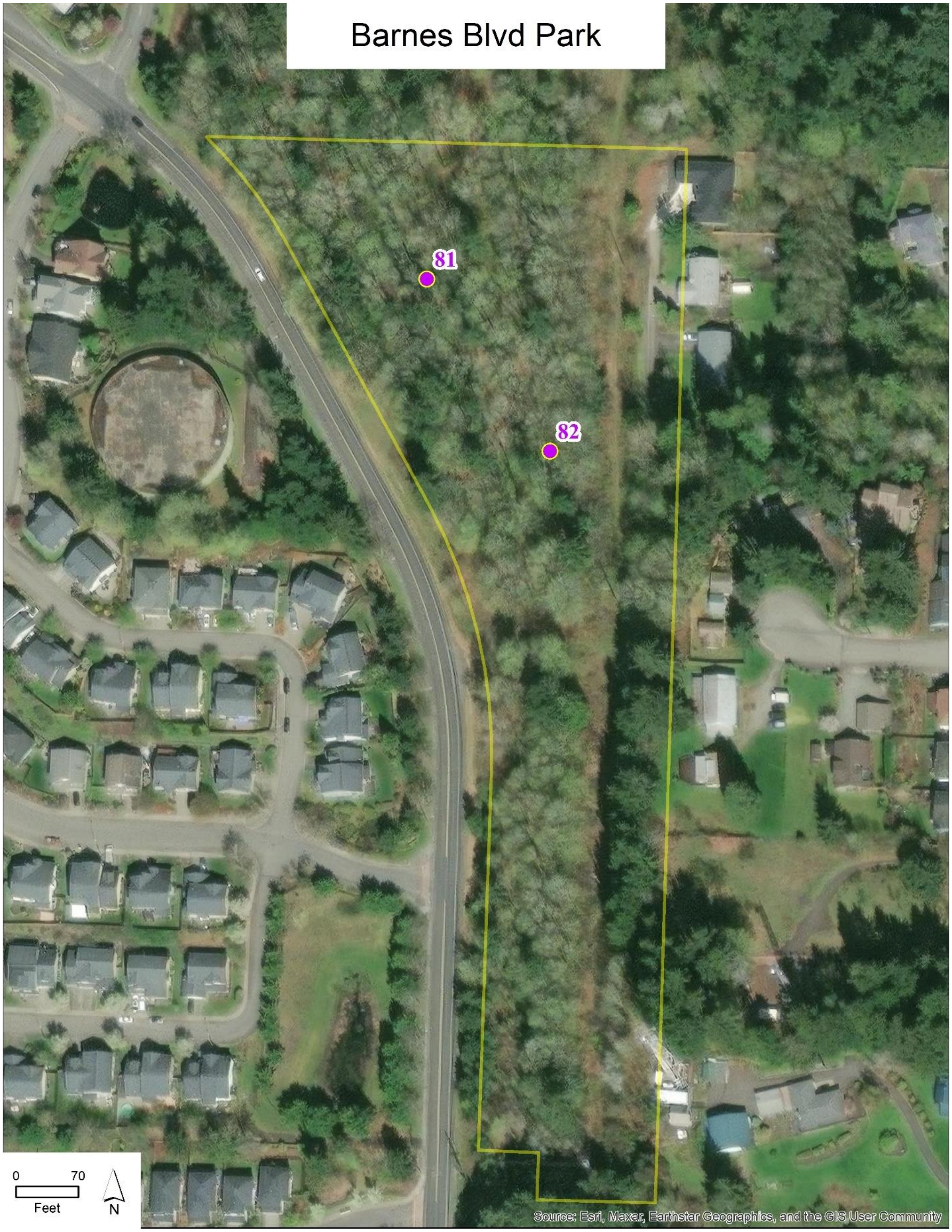
Appendix C (Map 12): Sample Plots in Isabella Bush Park

Appendix C (Map 13): Sample Plots in 12th Ave Storm Site



Appendix C (Map 14): Sample Plots in 2332 SW Sapp Dr

Appendix C (Map 15): Sample Plots in Barnes Blvd Park



Appendix C (Map 16): Sample Plots in N 4th Ave SW