City of Edmonds, Washington

Urban Tree Canopy Assessment

2017

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DAVEY RESOURCE GROUP
A Division of The Davey Tree Expert Company

Edmonds, Washington

Urban Tree Canopy Assessment

2017

Prepared for:
City of Edmonds
Attention: Shane Hope
121 Fifth Avenue North
Edmonds, WA 98020

Prepared by:
Davey Resource Group
A Division of the Davey Tree Expert Company
6005 Capistrano Avenue, Suite A
Atascadero, California 93422
Phone: 805-461-7500
Toll Free: 800-966-2021
Fax: 805-461-8501
www.davey.com/drg

All Photos Provided by the City of Edmonds or Davey Resource Group unless otherwise noted.

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Executive Summary

Edmonds is located 11 miles north of Seattle, Washington on the coast of the Puget Sound. This waterfront location allows Edmonds to serve as a port in the Washington State Ferries service. The community's location along the west-facing slopes of Puget Sound provides many comforts, including extensive views of the water and the Olympic Mountains, access to four beaches and waterfront parks, and easy access to a compact, walkable downtown area. The city is home to more than 40,000 residents in just over 9.5 square miles of land. Residents enjoy average summer temperatures of 64.5°F, dropping during the winter months to about 42.2°F. Although the community generally receives around 37.2 inches of precipitation throughout the year, mostly during the winter months, summers are comparatively dry (City of Edmonds Website 'About', 2018). The trees in Edmonds' urban forest play a significant role in maintaining this favorable and healthy environment. The urban forest includes all trees located within the city limits. Every tree, private and public, is a component of the urban forest and the urban tree canopy.

To evaluate the urban forest, Edmonds contracted with Davey Resource Group (DRG) in 2017 to conduct a comprehensive Urban Tree Canopy (UTC) Assessment. The UTC Assessment provides a birds-eye view of the entire urban forest and establishes a tree canopy baseline of known accuracy and classification methodology. This helps managers understand several factors about the tree canopy, including:

- Quantity and distribution of existing tree canopy
- Potential impacts of tree planting and removal
- Quantified annual benefits trees provide to the community
- Benchmark canopy percent values

The City of Edmonds has instated a coordinated set of plans and programs designed to lead the City toward sustainability. The Comprehensive Plan of Edmonds includes a Community Sustainability Element. Components of the element include a reduction in energy consumption and carbon emissions. Canopy distribution was evaluated at several levels, including by parks and zoning. Functional values, including carbon sequestration and stormwater, were also determined. In this way, as Edmonds strives for a healthy urban tree canopy, the city is also demonstrating their progress towards managing energy demands and reductions in carbon emissions.

Land Cover

The City of Edmonds encompasses a total area of 9.5 square miles (6,095 acres). Edmonds contains 2.9 square miles (1,844 acres) of tree canopy (Figure 1). Excluding 3.3 square miles of impervious surfaces (2,080 acres) and 0.6 square miles of open water (402 acres), Edmonds includes 2.6 square miles (1,651 acres) with the potential to support additional tree canopy. Using high-resolution aerial imagery from August 7th, 2015 (USDA, Farm Service Agency) and GIS analysis, Davey Resource Group (DRG) determined the following land cover characteristics within the City of Edmonds:

- 30% existing canopy, including trees and woody shrubs (525 acres)
- 57% total possible canopy, considering suitable planting areas (1,651 acres) and the existing canopy (1,844 acres), for a total of 3,495 acres
- The zoning class Private has most of the canopy (83%), followed by Public (13%), and Residential (4%) zones.
- Among Parks, Snohomish County park has the most canopy cover (117 acres) followed by Yost Memorial Park (44 acres) and Meadowdale Beach Park (26 acres). Maplewood Hill Park and Willow Creek Park have the highest canopy cover at 100%.
- From 2005 to 2015 tree canopy decreased from 32.3% to 30.3%
- 2% (99 acres) dry vegetation and bare ground
- 7% (402 acres) open water, where tree canopy is unfeasible
- 27% (1,670 acres) of grass and low-lying vegetation
- 34% impervious surfaces, including roads, parking lots, and structures (2,080 acres)

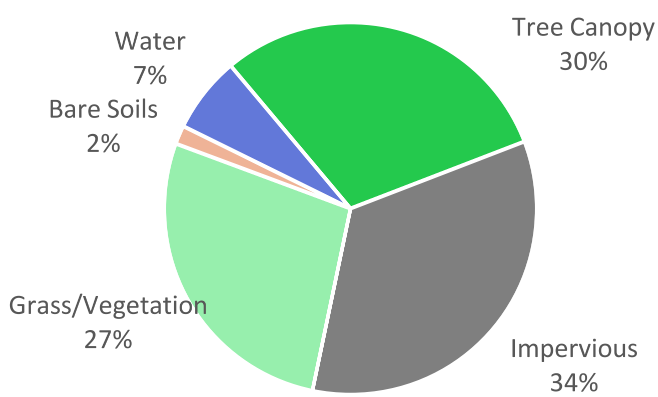


Figure 1. Land Cover Classes

Benefits

Edmond's land cover data was used with i-Tree Canopy (Appendix B) to estimate the environmental benefits from the entire urban forest (all public and private trees). The trees in Edmond's are providing air quality and stormwater benefits worth nearly $1.6 million annually. To date, trees in Edmonds are storing 187,590 tons of carbon in their leaves and woody biomass. The stored carbon is valued at $6.8 million.

Annually, tree canopy in Edmonds provides the following environmental services:

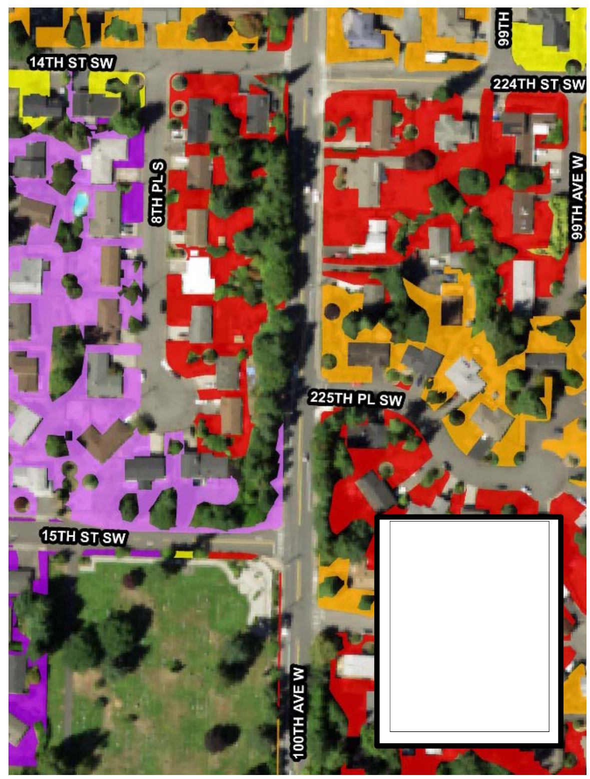
- Reduces 42.8 million gallons of stormwater runoff, a benefit worth nearly $1.2 million
- Improves air quality by removing 42.2 tons of pollutants (CO, NO_2, O_3, SO_2, and PM_{10}), valued at $146,823
- Sequesters 6,294 tons of carbon, valued at $221,885 annually

Management Applications

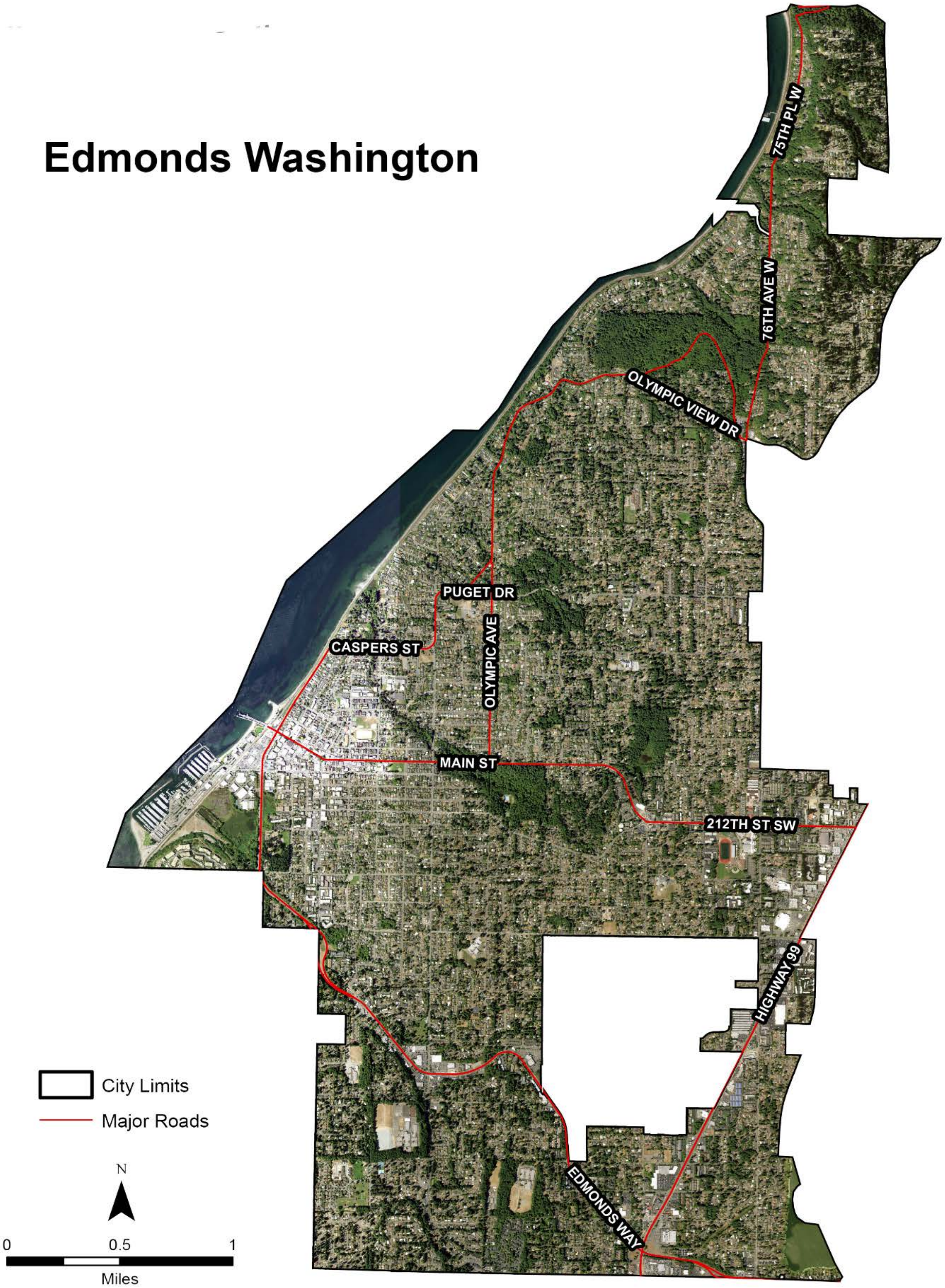
Understanding the location and extent of tree canopy is key to developing and implementing sound management strategies that promote the sustainability of Edmond's urban forest resource and the benefits it provides. The data, combined with existing and emerging urban forestry research, enable managers to uncover a balance between urban development and tree preservation by identifying and assessing urban forestry opportunities. Spatial understanding of the past, present, and potential future for tree canopy is an essential consideration to help managers align urban forestry activities with the community's vision.

Edmonds has an existing tree canopy of 30.3%, and 1,651 acres of potential planting area. To help identify the most beneficial sites for canopy expansion, potential sites were mapped and then prioritized based on weighted regional factors (Figure 2). These maps guide tree canopy expansion strategies. Recommendations for maintaining healthy trees and canopy include:

- Define canopy goals for the community and identify actions that will support these goal(s).
- Use priority planting site analysis to identify new tree planting locations to reduce erosion and soil degradation.
- Use GIS canopy and land cover mapping to explore under-treed neighborhoods and identify potential planting sites.
- Incentivize tree planting on private property, particularly in very high planting priority areas.
- Increase canopy in areas of patch and fragmented canopy to reduce forest fragmentation and improve wildlife habitat and corridors.
- Conducting outreach to the community with this report as an important tool for engaging public interest and support.
- Developing strategic planting plans with prioritized GIS maps to increase the tree population and canopy that will enhance the numerous benefits provided by trees.



- Siting projects which must meet the 30% native vegetation requirement in ECDC 23.90.040.C (Retention of Vegetation on Subdividable, Undeveloped Parcels) in undeveloped (or redeveloped) subdividable lands zoned in RS-12 or RS-20, that contain a stream or stream buffer, or a wetland or wetland buffer. Conducting outreach to the community with this report as an important tool for engaging public interest and support.



Map 1. Aerial Overview of Edmonds

Introduction

Urban tree canopy is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. Since trees provide benefits to the community that extend beyond property lines, the assessment considers all tree canopy within the borders of the community. To contextualize tree canopy and better understand its relationship within the community, the assessment included other landcover classifications. These land classes include impervious surfaces, pervious surfaces, bare soils, and open water.

Urban Tree Canopy and Geographic Information Systems

As more communities focus attention on environmental sustainability, community forest management has become increasingly dependent on geographic information systems (GIS). GIS is a powerful tool for urban tree canopy mapping and analysis. Understanding the extent and location of the existing canopy is key to identifying various types of community forest management opportunities, including:

- Future planting plans
- Stormwater management
- Water resource and quality management
- Impact and management of invasive species
- Preservation of environmental benefits
- Outreach and education

High-resolution aerial imagery (2015) and infrared technology were used to remotely map tree canopy and land cover (Figure 3). The results of the study provide a clear picture of the extent and distribution of tree canopy within Edmonds. The data set developed during the assessment becomes an important part of the City's GIS database and provides a foundation for developing community goals and urban forest policies. With these data, managers can determine:

- The location and extent of canopy over time
- The location of available planting space (potential planting area)
- The best strategies to increase canopy in underserved areas

In addition to quantifying existing UTC, the assessment illustrates the potential for increasing tree canopy across Edmonds. The data, combined with existing and emerging urban forestry research and applications, can provide additional guidance for determining a balance between growth and preservation. The data also aids in identifying and assessing urban forestry opportunities.

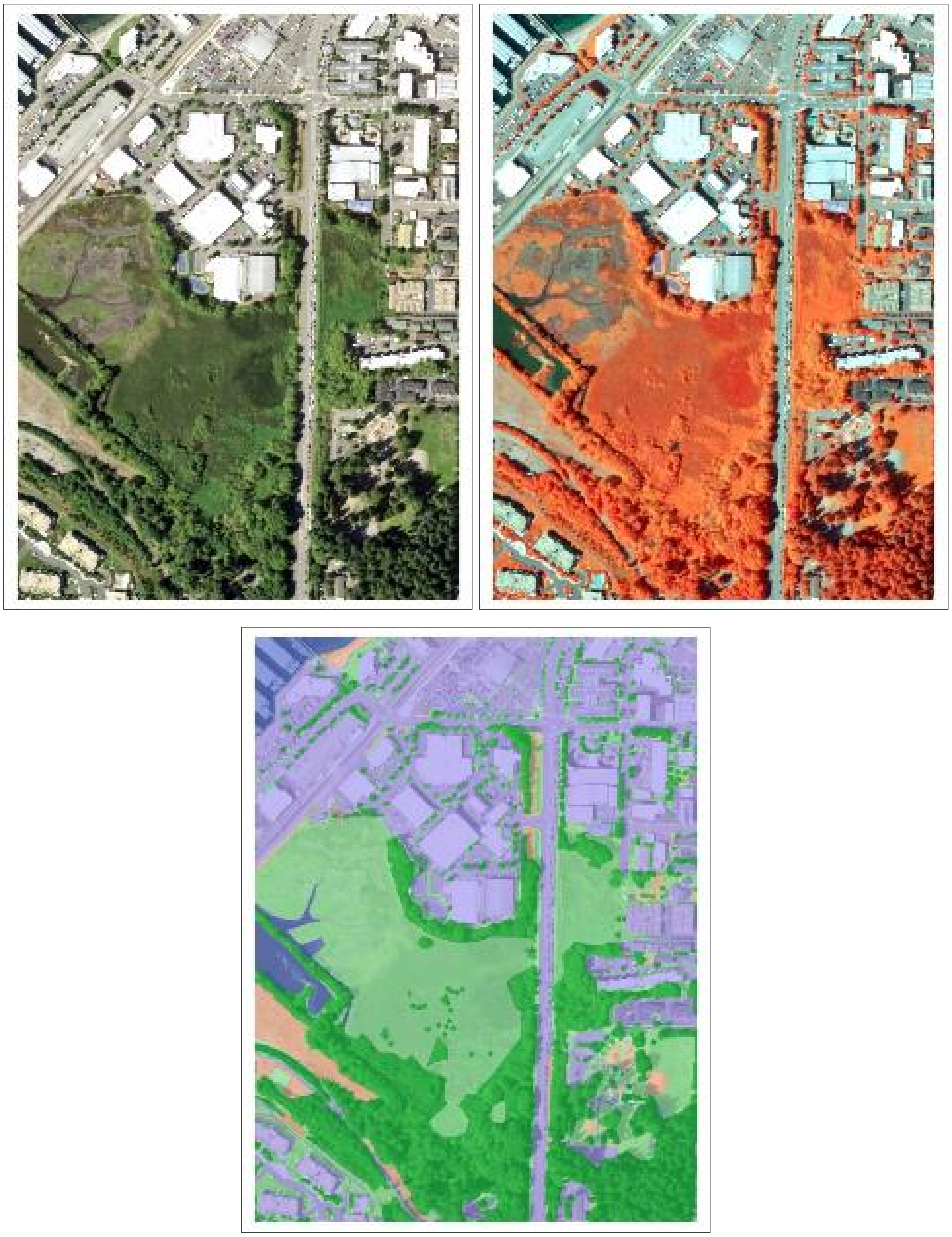


Figure 3: High-resolution aerial imagery (Top Left) is used to remotely identify existing land cover. Infrared technology delineates living vegetation including tree canopy (Top Right). Remote sensing software identifies and maps tree canopy and other land cover (Bottom).

Benefits of Urban Tree Canopy

Urban forests continuously mitigate the effects of urban development and protect and enhance lives within the community. The amount and distribution of leaf surface area are the driving forces behind the urban forest's ability to produce benefits (Clark et al, 1997). The environmental, socio-economic, and aesthetic benefits of trees and urban forests include:

Air Quality

Urban trees improve air quality in five fundamental ways:

- Reducing particulate matter (dust)
- Absorbing gaseous pollutants
- Providing shade and transpiration
- Reducing power plant emissions
- Increasing oxygen levels

Urban trees protect and improve air quality by intercepting particulate matter (PM_{10}), including dust, ash, pollen, and smoke. The particulates are filtered and held in the tree canopy. Trees and forests also absorb harmful gaseous pollutants like ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Shade and transpiration reduce the formation of O_3, which is created during higher temperatures. In fact, scientists are now finding that some trees may absorb more volatile organic compounds (VOC's) than previously thought (Karl, T. et al; Science NOW, 2010). VOC's are a class of carbon-based particles emitted from automobile exhaust, lawnmowers, and other human activities. By reducing energy needs, trees also reduce emissions from the generation of power. Also, through photosynthesis, trees and forests increase oxygen levels.

In Edmonds, trees annually improve air quality by removing 42.2 tons of pollutants (CO, NO_2, O_3, SO_2, and PM_{10}), valued at $146,823.

Carbon Reduction

Trees and forests directly reduce CO_2 in the atmosphere through growth and sequestration of carbon as woody and foliar biomass. Indirectly, trees and forests reduce CO_2 by lowering the demand for energy and reducing the CO_2 emissions from the consumption of natural gas and the generation of electric power.

As environmental awareness continues to increase, governments and individuals are paying attention to climate change and the effects of greenhouse gas emissions. In 2015, a greenhouse gas cap-and-trade system, aimed at reducing atmospheric CO_2 and other greenhouse gases was announced by the US Environmental Protection Agency (US EPA). The program was released as part of the Clean Power Plan, with a goal of strengthening the trend toward cleaner and lower-polluting energy (US EPA, 2016). In a cap-and-trade system, an upper limit (or cap) is placed on levels of greenhouse gas emissions and the regulated entities are required to either reduce emissions to required limits or purchase emissions allowances to meet the cap (Williams et al, 2007).

The concept of purchasing emission allowances (offsets) has led to the acceptance of carbon credits as a commodity that can be exchanged for financial gain. Thus, some communities are exploring the concept of planting trees to develop a carbon offset (or credit). UESPD and USDA Forest Service recently led the development of Urban Forest Greenhouse Gas Reporting Protocol (McPherson et al, 2008/2010). The protocol incorporates methods of the Kyoto Protocol and Voluntary Carbon Standard and establishes methods for calculating reductions, provides guidance for accounting and reporting, and guides urban forest managers in developing tree planting and stewardship projects that could be registered for greenhouse gas reduction credits.

In Edmonds, community trees store 187,590 tons of carbon, valued at $6.8 million. Trees in Edmonds' community forest also annually sequester an additional 6,294 tons of carbon, valued at $221,885.

Stormwater Runoff Reduction

Trees and forests improve and protect the quality of surface waters, such as creeks, rivers, and lakes, by reducing the impacts of stormwater runoff through:

- Interception
- Increasing soil capacity and rate of infiltration
- Reducing soil erosion

Trees intercept precipitation in their canopy, which acts as a mini-reservoir (Xiao et al, 1998). During storm events, this interception reduces and slows runoff. In addition to catching stormwater, canopy interception lessens the erosive impact of raindrops on bare soil. Root growth and root decomposition increase the capacity and rate of soil infiltration by rainfall and snowmelt (McPherson et al, 2002). Each of these processes greatly reduces the flow and volume of stormwater runoff, avoiding erosion and preventing sediments and other pollutants from entering local creeks and waterways.

Energy Savings

Urban trees and forests modify climate and conserve energy in three principal ways:

- Shading dwellings and hardscape
- Transpiration
- Wind reduction

Shade from trees reduces the amount of radiant energy absorbed and stored by hardscapes and other impervious surfaces, thereby reducing the heat island effect, a term that describes the increase in urban temperatures in relation to surrounding locations. Transpiration releases water vapor from tree canopies, which cools the surrounding area. Through shade and transpiration, trees and other vegetation within an urban setting modify the environment and reduce heat island effects. Temperature differences of more than 9°F (5°C) have been observed between city centers without adequate canopy cover and more vegetated suburban areas (Akbari et al, 1997).

Trees reduce wind speeds relative to their canopy size and height by up to 50%. Trees also influence the movement of warm air and pollutants along streets and out of urban canyons. By reducing air movement into buildings and against conductive surfaces (e.g., glass and metal siding), trees reduce conductive heat loss from buildings, translating into potential annual heating savings of 25% (Heisler, 1986). Reducing energy needs has the bonus of reducing carbon dioxide (CO_2) emissions from fossil fuel power plants. Energy savings from providing shade to structures contributes positively to the city's community sustainability element that includes decreasing Edmonds's energy demands.

Aesthetics and Socioeconomics

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 and ecosystem health
- Opportunities for recreation
- Creation of a sense of place and history
- Human health

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

Calculating 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 the National Tree Benefit Calculator or with **i-Tree Design**. (design.itreetools.org).

Calculate My Tree Benefits

Wikimedia Commons. 2005. Edmonds Fountain. Edmonds Fountain 7824.jpg. Photo.

Figure 4: Tree canopies in Edmonds' business districts encourage people to stay and shop longer.

Land Cover in Edmonds

Overall Land Cover

The City of Edmonds encompasses a total area of 9.5 square miles (6,095) (Figure 5, Map 2). Within this total area exists 1,844 acres of tree canopy (Table 1). Land cover classification within the city limits includes 30% tree canopy, 27% grass and low vegetation, and 34% impervious surfaces, including roads and buildings. Bare soil, grass, and low vegetation are considered the eligible planting areas which cover 1,769 acres, 29% of the community. Considering the existing tree canopy and possible tree canopy over impervious areas, the canopy potential of Edmonds is 57%%, although the actual potential may be higher where tree canopy can shade impervious surfaces such as roads, parking lots, and buildings.

The potential future tree canopy can be estimated by comparing the area of existing canopy to the area of low-lying vegetation and impervious surface. This analysis excludes sports fields, cemeteries, and other sites not suitable for trees. Based on this methodology, the analysis found an additional 1,651 acres (27.1%) where trees could be planted to augment existing canopy. If Edmonds were to plant trees to cover all this area, then the overall tree canopy could be increased to 57.4%.

Table 1. Land Cover Classes

Class	Acreage	Percentage
Tree Canopy	1,844	30.3
Impervious	2,080	34.1
Grass/Vegetation	1,670	27.4
Bare Soils	99	1.6
Water	402	6.6
Total	**6,095**	**100**

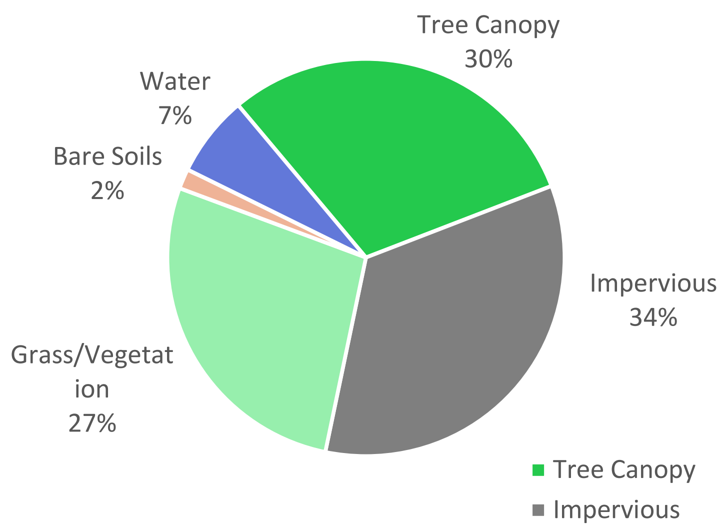
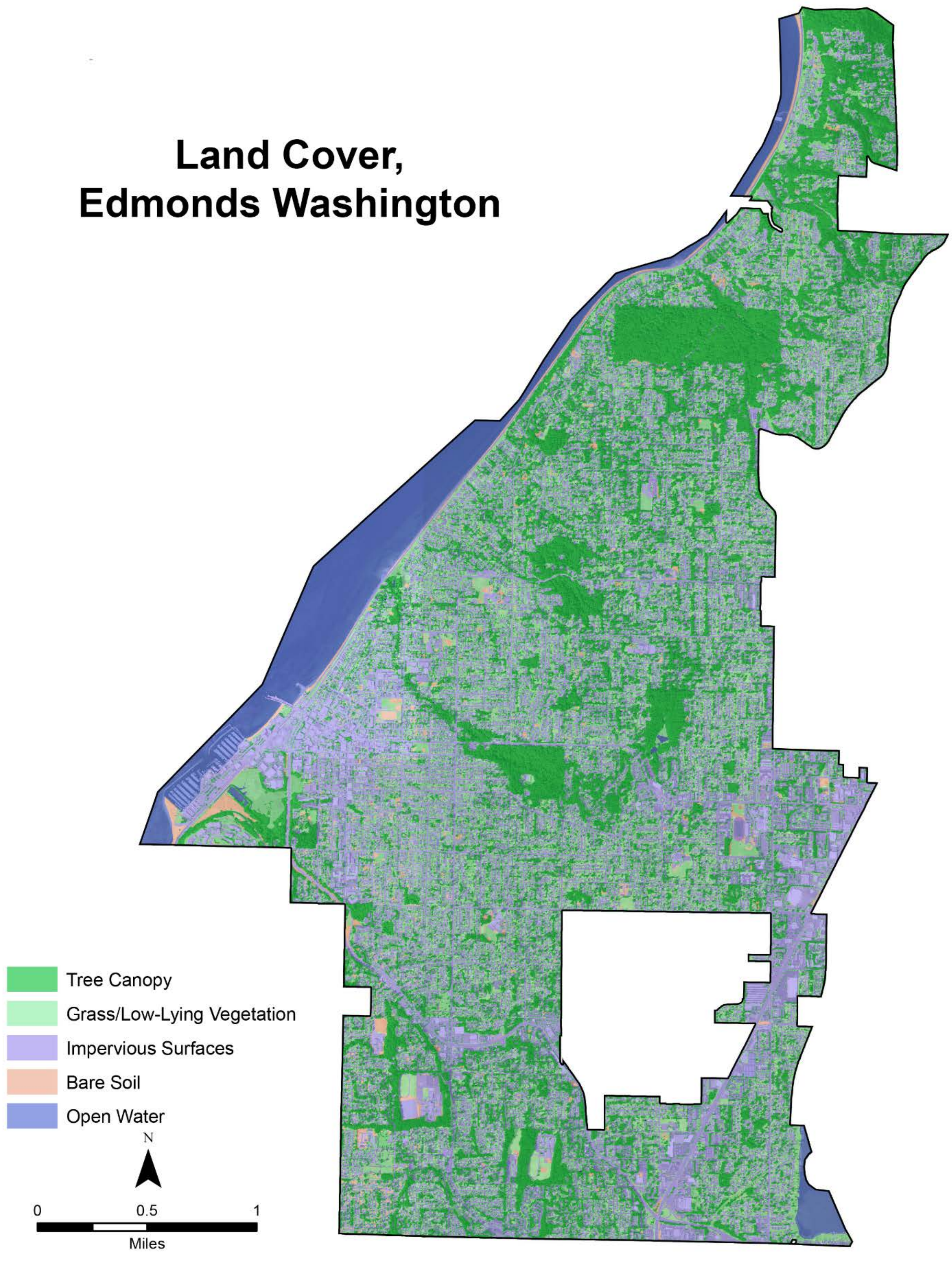


Figure 5. Land Cover Class



Map 2. Land Cover Classes in Edmonds

Tree Canopy and Historic Change

The 2005 land cover percentages were estimated using i-Tree Canopy by plotting 1,000 points in the application. Those 1,000 points were then placed into Google Earth for a land change analysis using a 2005 image from Google Earth timescale slider. The points were changed if the land cover was different than the current land cover. Through this method, a difference in canopy over time was determined. This provided information which closely matched the land cover percentages from the UTC mapping.

Because the 2005 land cover percentages were derived using point sampling statistics, they are not considered as accurate as the percentages from the UTC. When comparing these years, there could be some noise in the data based on how they were estimated. From 2005 to 2015, the population of Edmonds grew from about 39,541 residents to 40,689 residents. That's an increase of nearly 3% in 10 years. During this population growth, impervious surfaces decreased by 16% which suggests that there has been some reversion of the city's hardscape back into pervious surface. This could mean more opportunities for new tree planting. However, the tree canopy decreased by 6%, further suggesting that while more space has opened up, new trees have not been planted at a pace better than the rate of canopy loss. (Table 2).

Table 2. Tree Canopy Change over Time

Land Cover Classification	% in 2005	% in 2015	% Change
Tree Canopy	32.3	30.3	-6.2
Impervious Surfaces	40.6	34.1	-16.0
Population	39,541	40,689	+2.9
Total			

While continued growth and development is vital to the social and economic well-being and sustainability of the community, the growth and preservation of sufficient tree and forest canopy is equally vital to the continued livability and attractiveness of the community. Enacting proactive preservation strategies is much more cost-effective then trying to rebuild a healthy, working urban forest. Smart growth involves consideration of natural resources, and an effective strategy aims to conserve, and increase, the overall level of tree canopy.

Tree Canopy in Neighboring Communities

Several communities in the Pacific Northwest have employed canopy studies as a metric in their urban forestry management strategies (Figure 6). Among these communities, the average tree canopy cover is 32%. Bonney Lake had the highest tree canopy cover (43%, 2012), and the City of Tacoma has had the lowest tree canopy cover (13%,2012). Edmonds, with a tree canopy cover of 30%(2015) is just below the average. Since the timing of these studies varied, it's important to note that similar canopied cities like Shoreline and Renton may have lost additional canopy in subsequent years. Ultimately, the total canopy coverage percentages for these communities are not directly comparable to Edmonds because of different land use patterns, and the year when these analyses were performed. What they do provide is suitable context for understanding the variety of canopy coverage found around municipalities in the region.

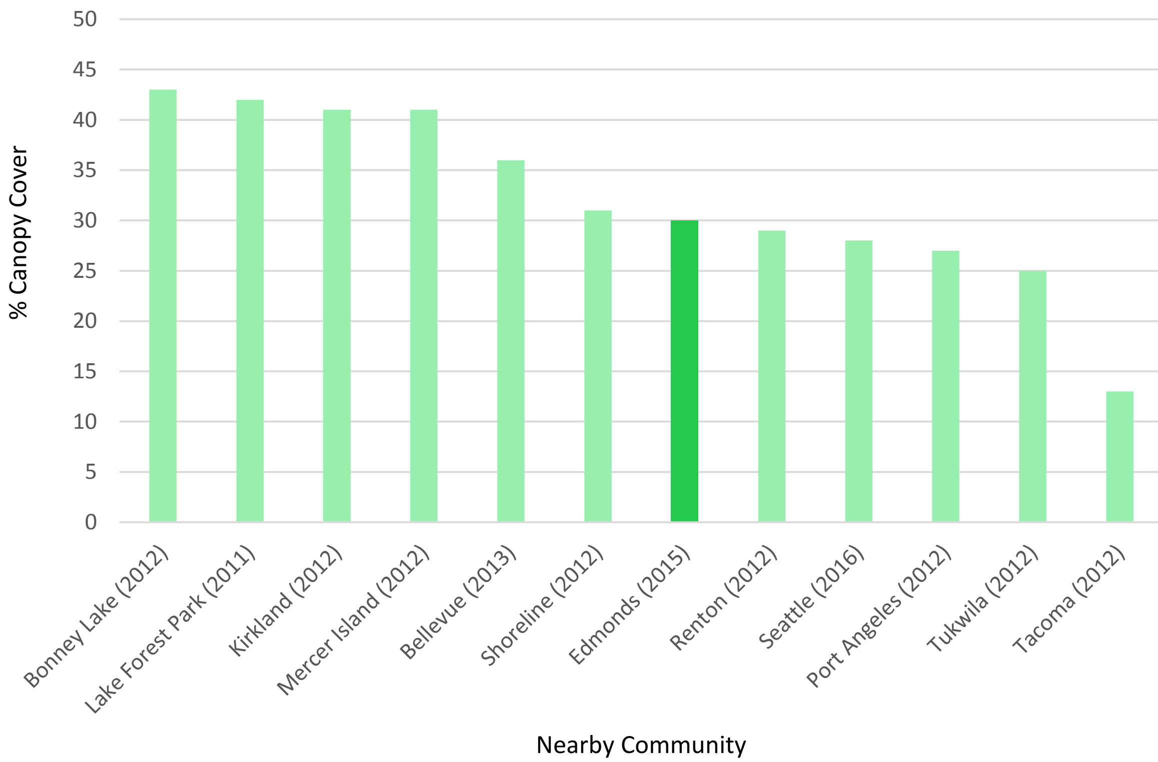


Figure 6. Percent (%)Tree Canopy in Neighboring Communities

Environmental Benefits

Edmonds' land cover data was used with i-Tree Hydro (v5.0) and Canopy (v6.1) (Appendix B) to estimate the environmental benefits from urban tree canopy. These models estimate the Carbon sequestered by trees, their value for stormwater mitigation and air quality for a total estimated benefit of $1.5 Million (Figure 7.)

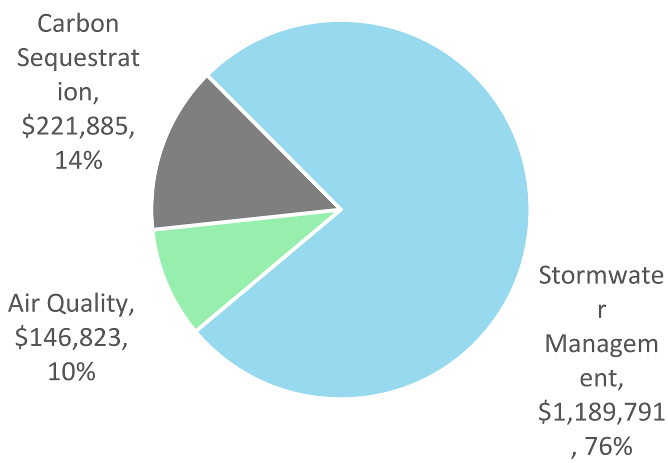


Figure 7. Annual Environmental Benefits

Carbon sequestration and Storage

Climate change is an issue of global concern. Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by altering energy use in buildings, and consequently altering carbon dioxide emissions from fossil-fuel based power plants (Nowak & Dwyer, 2007). Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. In Edmonds, trees sequester 6,294 tons of carbon valued at $221,885 annually.

As trees grow they store more carbon as wood. When trees die and decay, they release much of the stored carbon back to the atmosphere. In urban environments, most trees that die are removed and chipped or disposed of as firewood, releasing stored carbon. Thus, carbon storage is an indication of the amount of carbon that can be lost if trees are allowed to die and decompose. Trees in Edmonds are storing 187,590 tons of carbon in their leaves and woody biomass. The stored carbon is valued at $6.8 million.

Stormwater Runoff Benefits

Surface runoff is a cause for concern in many urban areas as it contributes pollution to streams, wetlands, rivers, lakes, and oceans. During precipitation events, some portion of the precipitation is intercepted by vegetation (trees, grasses, forbs, and shrubs) while the other portion reaches the ground (Figure 8). The portion of the

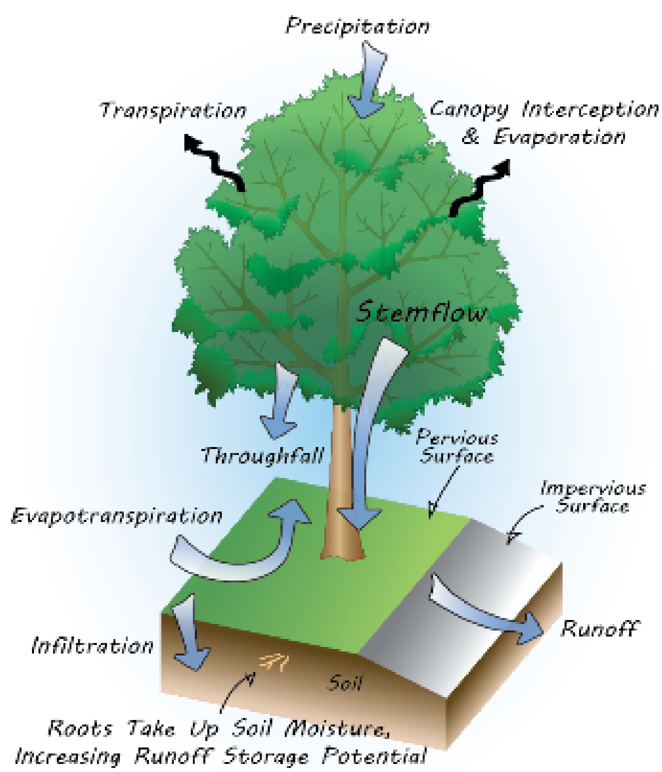


Figure 8. Role of Trees in Reducing Stormwater Runoff

precipitation that reaches the ground and does not infiltrate into the soil becomes surface runoff (Hirabayashi, 2012). In urban areas, the large extent of impervious surfaces increases the amount of surface runoff, and the cost of infrastructure a community must invest in managing stormwater for the safety of residents and property. In Edmonds, trees are estimated to reduce an average of 42.8 million gallons of stormwater runoff, a benefit worth nearly $1.2 million annually (Table 3).

Table 3. Avoided Runoff and Pollutant Load

Year	Rainfall (Inches)	Total Runoff (Gallons)	Avoided Runoff (Gallons)	Total Pollutant Load (Mean lbs.)
2005	28	2,042,042,480	43,454,683	39,013
2006	35	2,777,203,093	46,034,032	42,007
2007	29	2,050,827,626	63,114,310	65,658
2008	27	1,937,608,262	44,172,596	41,215
2009	28	2,186,003,461	30,221,382	30,223
2010	34	2,655,550,276	54,200,460	58,783
2011	31	2,323,228,346	35,735,762	40,263
2012	41	3,382,916,626	25,575,944	23,109
Average	32	2,419,422,521	42,813,646	42,534

Air Quality Benefits

Poor air quality is a common problem in many urban areas. It can lead to decreased human health, damage to trees and shrubs and ecosystem processes, and reduced visibility. The urban forest can help improve air quality by reducing air temperature, directly removing pollutants from the air, and reducing energy consumption in buildings, which consequently reduces air pollutant emissions from the power plants. Trees also emit volatile organic compounds that can contribute to ozone formation. However, integrative studies have revealed that an increase in tree cover leads to reduced ozone formation (Nowak & Dwyer, 2007).

Trees improve and preserve air quality by absorbing and intercepting harmful gases and particulates. Annually, the tree canopy in Edmonds improves air quality by removing 42.2 tons of pollutants (CO, NO_2, O_3, SO_2, and PM_{10}), valued at $146,823 (Table 4).

Table 4. Air Quality Benefits

Air Quality	Units (lbs)	Value ($)
CO	1,114	$740
NO_2	10,980	$2,209
O_3	47,640	$78,402
SO_2	3,820	$278
PM_{10}	20,880	$65,194

Figure 9. The canopy from a mature ash tree in Edmonds provides $116 in annual environmental benefits

Tree Canopy by Land Use

Edmonds' UTC was analyzed across three major land use categories; public lands, private lands, and commercial properties (Table 5, Figure 10, Map 3). Public lands include all government-owned properties. Private lands are residential homes. Commercial properties include retail, commercial, and industrial land uses. The private zoning class has the highest canopy cover (83%), as well as the largest overall acreage of canopy (1,526 acres). The public lands zoning class has 13% canopy cover with 238 acres of canopy. This zoning class includes all parks that are maintained by the Parks and Recreation Department. In addition, this zoning class has the potential to increase its canopy cover with 15 acres of possible planting area. Commercial zoning class has the lowest canopy acreage at 75 acres (4%). This is typical, based on site uses.

Table 5. Proportion of Tree Canopy Cover by Land Use Type

Land Use Type	Acreage	Percentage
Commercial	75	4.1
Public	238	12.9
Private	1,526	83.0
Total Canopy	**1,839**	**100**

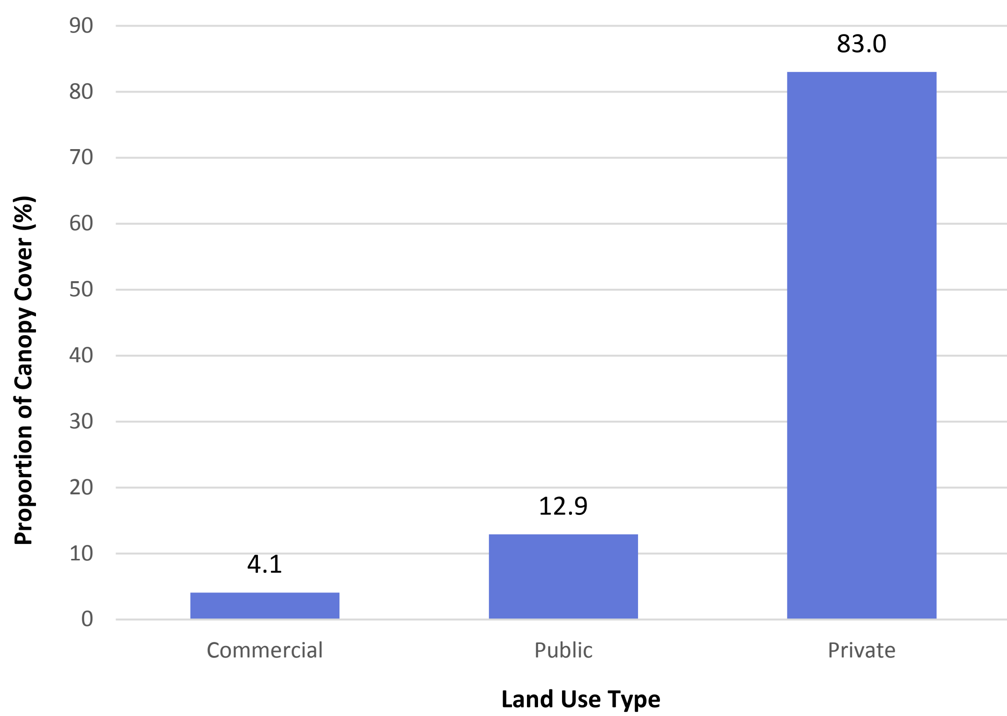
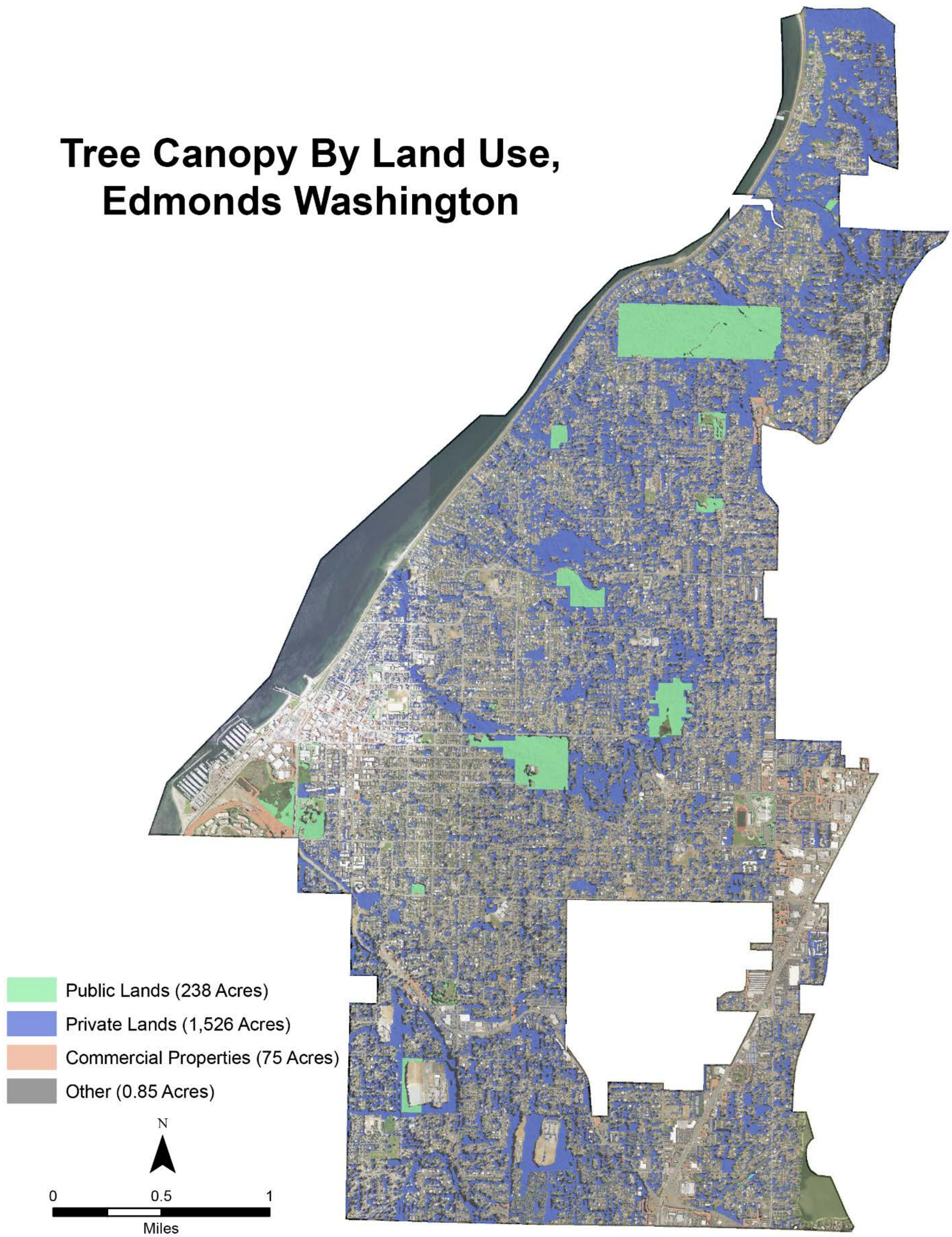


Figure 10. % Tree Canopy by Land Use Type



Map 3. Tree Canopy according to Land Type in Edmonds

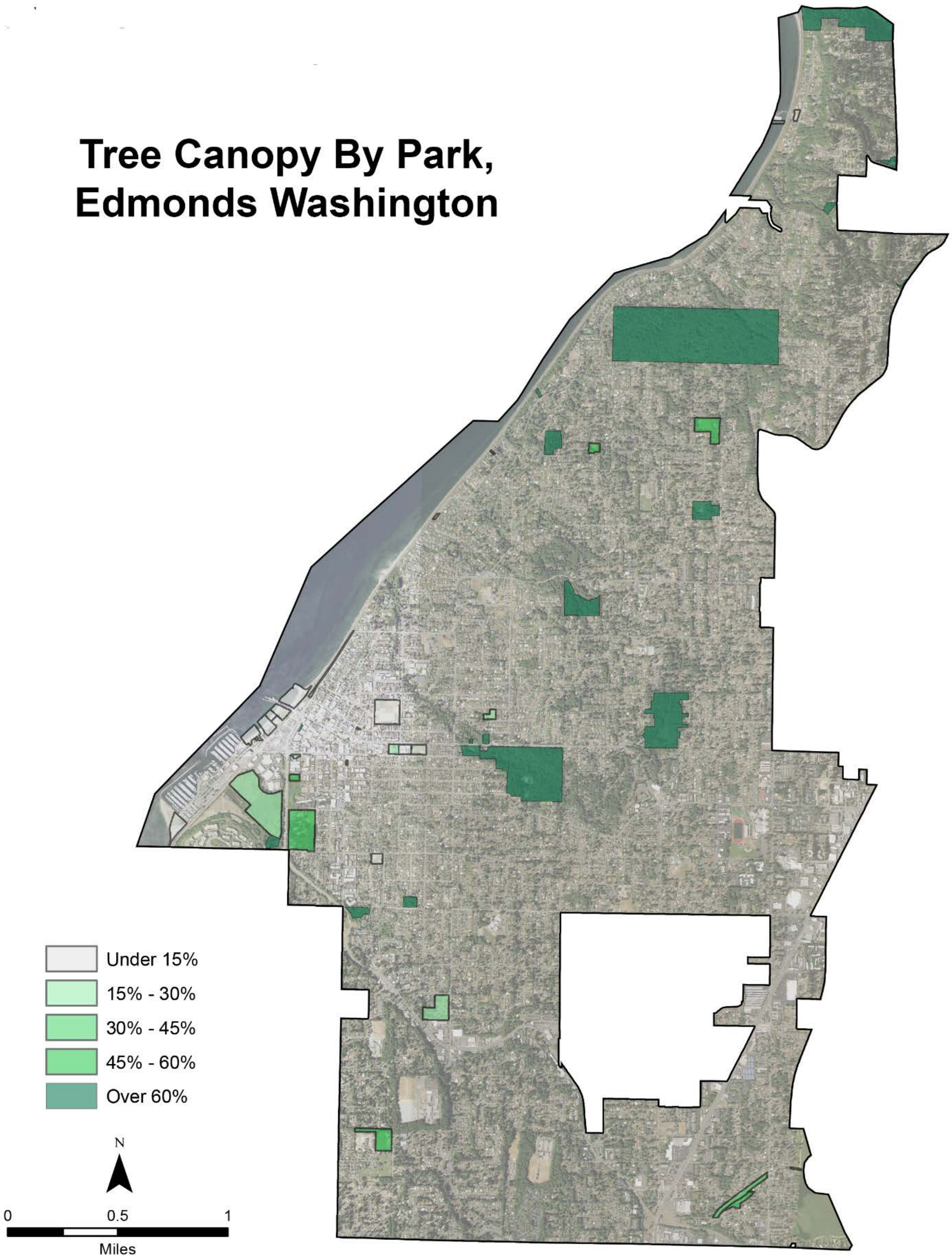
Tree Canopy by Park

The City of Edmonds includes 47 parks covering 343.7 acres and 5.6% of all land area (Map 4, Table 6) The average tree canopy cover is 44.1%. Centennial Plaza is the smallest park (0.1 acres) and Snohomish County Park (118.6 acres) is the largest. Centennial Plaza contains 19.9% canopy cover and Snohomish County Park has 98.7%. The 8th largest park, Civic Center Playfield, has only 1.8% canopy and 24.2% impervious land cover. There is a wide range of potential canopy cover amongst these parks because parks have different physical environments and uses.

Of the four largest parks (Snohomish County, Yost Memorial, Meadowdale Beach, and Pine Ridge) all have high tree canopy potential (greater than 96%). However, of these parks, only Pine Ridge Park is not currently near maximum potential canopy. An acceptable strategy is to focus attention on the parks where there is a much larger gap between current canopy cover and potential canopy cover. For example, Mathay Ballinger Park has 54.4% canopy cover, but the potential is 93.8%. Haines Wharf is another example where the potential canopy (40.6%) is much higher than the existing canopy (11.9%). Although this method provides a measurable target for increased canopy, it doesn't exclude sites where views or other landscaping considerations would limit planting opportunities.

Figure 11. Haines Wharf Park has a high potential for tree canopy compared to what exists today but may not get trees to avoid view conflicts with the shoreline.

Tree Canopy By Park, Edmonds Washington



Map 4. Canopy Cover in Parks in Edmonds

Table 6. Land Cover by Park

Park Name	Total Acres	Canopy Acres	% Canopy	% Impervious	% Pervious	% Potential Canopy*
Snohomish County Park	118.6	117.1	98.7	0.5	0.6	99.5
Yost Memorial Park	44.1	41.3	93.5	2.1	4.4	97.5
Meadowdale Beach Park	25.5	25.2	98.5	0.2	1.3	99.8
Pine Ridge Park	23.8	21.4	89.8	0.1	6.8	96.7
Edmonds Marsh	23.4	5.7	24.2	0.0	73.9	24.9
City Park	14.0	8.3	59.3	11.5	25.2	75.2
Maplewood Hill Park	10.0	10.0	100.0	0.0	0.0	100.0
Civic Center Playfield	7.9	0.1	1.8	24.2	38.6	2.5
Edmonds Memorial Cemetery	6.6	1.3	19.6	6.8	71.0	19.6
Seaview Park	6.1	3.1	51.5	7.0	37.0	57.9
Hickman Park	5.6	2.5	45.1	10.0	41.6	45.9
Sierra Park	5.5	3.6	64.8	3.8	26.8	70.9
Brackett's Landing North	5.1	0.1	2.1	13.1	1.8	2.1
Hutt Park	4.5	4.5	98.9	0.0	1.1	100.0
Interurban Trail	4.0	1.2	30.2	5.9	62.9	30.2
Marina Beach Park	3.4	0.3	7.6	25.1	20.8	7.6
Olympic Beach	2.9	0.0	0.7	15.2	14.6	0.7
Senior Center	2.6	0.2	6.5	44.1	4.1	6.5
Wade James Theatre	2.3	1.7	70.8	21.0	8.2	79.0
Willow Creek Park	2.3	2.3	100.0	0.0	0.0	100.0
Brackett's Landing South	2.2	0.2	8.8	8.8	41.0	8.8
Frances Anderson Center Field	1.9	0.1	6.0	0.1	83.6	21.9
Elm St Park	1.9	1.6	86.9	0.0	11.2	100.0
Mathay Ballinger Park	1.8	1.0	54.4	6.2	37.7	93.8
Willow Creek Hatchery	1.7	1.4	83.5	9.4	7.0	90.6
Frances Anderson Center	1.6	0.2	12.7	65.7	17.9	34.3
Pine St Park	1.5	0.0	2.3	15.1	60.5	5.0
Seaview Reservoir	1.3	0.7	51.8	0.0	15.0	100.0
Edmonds Library and Plaza Room	1.3	0.4	28.1	61.8	9.4	38.2
Hummingbird Hill Park	1.2	0.3	25.5	3.2	68.9	37.4
Sunset Ave	1.1	0.0	0.0	4.1	85.5	92.4
Meadowdale Clubhouse	1.1	0.7	63.1	21.2	15.7	78.8
Meadowdale Natural Areas	1.1	1.0	92.5	0.0	7.5	100.0
Shell Creek Open Space	1.0	1.0	98.2	0.0	1.8	100.0
144 Railroad Ave Tidelands	0.9	0.0	0.1	3.8	3.4	0.1
Edmonds Marsh Open Space	0.8	0.4	48.0	0.0	52.0	69.0
Haines Wharf	0.7	0.1	11.9	25.0	63.0	40.6
Olympic View Open Space	0.5	0.4	85.6	0.0	14.4	100.0
Haines Tidelands	0.4	0.0	0.0	0.0	0.0	0.0
Stamm Overlook	0.4	0.3	77.0	3.7	19.3	96.3
Dayton St Plaza	0.4	0.1	27.5	49.2	23.3	50.8
Ocean Ave Viewpoint	0.2	0.0	2.2	75.1	17.4	24.9
Lake Ballinger Access	0.2	0.0	0.0	19.7	52.9	52.9
Richard F. Anway Park	0.2	0.1	76.8	11.3	11.9	88.7
Wharf Street	0.1	0.1	42.1	2.9	46.0	97.1
Hazel Miller Park	0.1	0.0	5.1	94.9	0.0	5.1
Centennial Plaza	0.1	0.0	19.9	38.7	41.3	61.3

*Potential Canopy is proposed from computer models to help prioritize planting opportunities and may not reflect actual site conditions. Park sites should be field verified for actual planting potential.

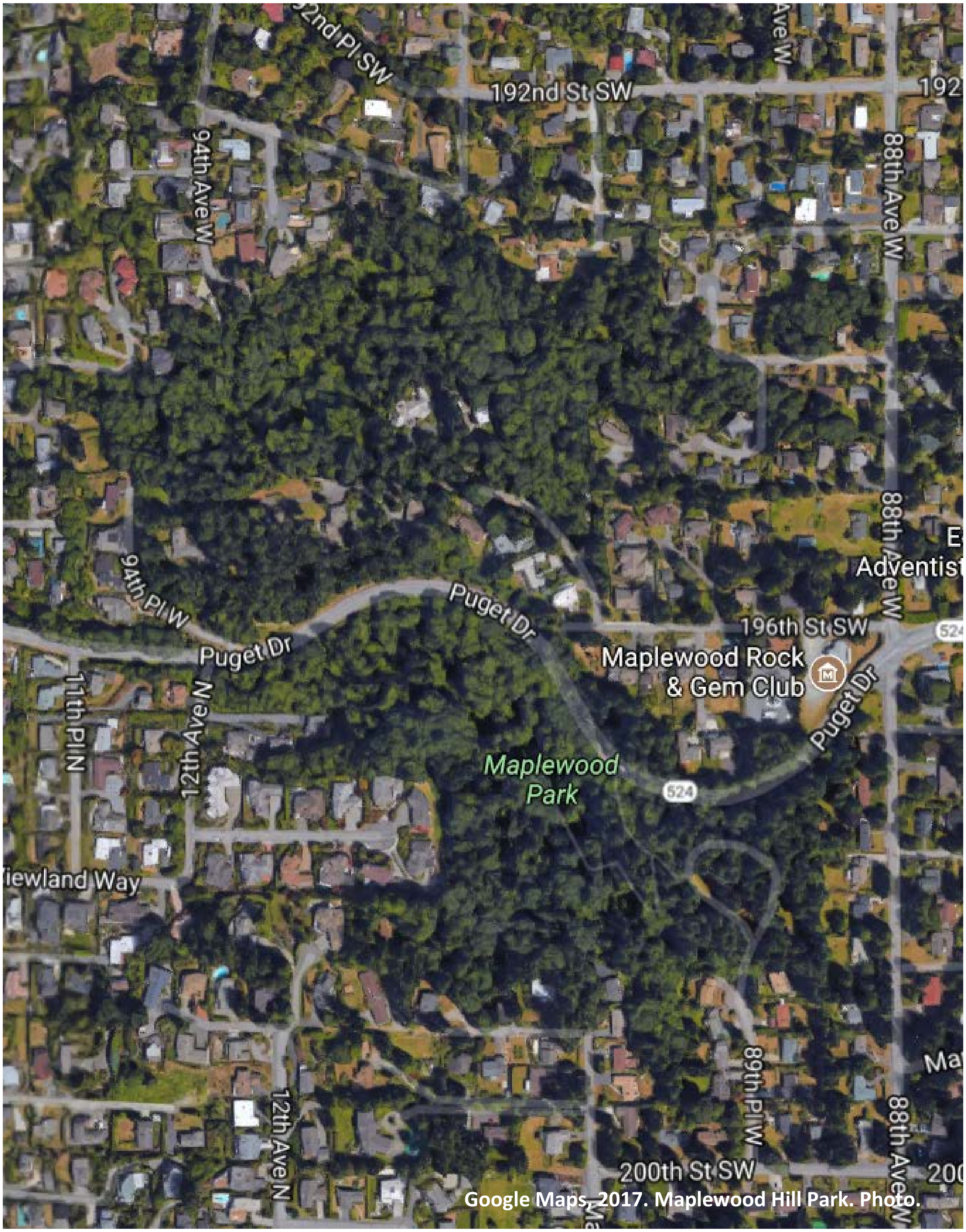


Figure 12. Maplewood Hill park is considered fully stocked with 100% tree canopy cover

Canopy Fragmentation

The urban ecosystem is extremely complex and diverse; existing in a multitude of small, functional ecosystems that together form a larger system. The overall health of the urban ecosystem depends highly on the ability of the trees, plants, wildlife, insects, and humans to interact. A key factor impacting urban forest health is urban build-up and sprawl. This human development can lead to the removal and decrease of canopy across a community (Figure 13). This often causes canopies to become fragmented which leads a decline in habitat quality and the degradation of ecosystem health. Furthermore, this degradation causes an imbalance to microclimates which increases their risk and susceptibility to invasive species damaging urban forest health and sustainability.

As a part of the UTC assessment, Edmonds' existing UTC was analyzed for fragmentation to discover the distribution of canopy (Map 5). Often, the health and diversity of the overall canopy will vastly improve by creating linkages between multiple patches of forest. The analysis found that Edmonds' urban forest includes the following:

- 10.3% (190 acres) of Core Canopy: Tree canopy that exists within and relatively far from the forest/non-forest boundary (i.e., forested areas surrounded by more forested areas).
- 8.2% (151 acres) of Perforated Canopy: Tree canopy that defines the boundary between core forests and relatively small clearings (perforations) within the forest landscape.
- 55.5% (1,023 acres) of Patch Canopy: Tree canopy of a small-forested area that is surrounded by non-forested land cover.
- 26.0% (480 acres) of Edge Canopy: Tree canopy that defines the boundary between core forests and large core forests and large non-forested land cover features, approximately 328ft (Ritters et al, 2000). When large enough, edge canopy may appear to be unassociated with core forests.

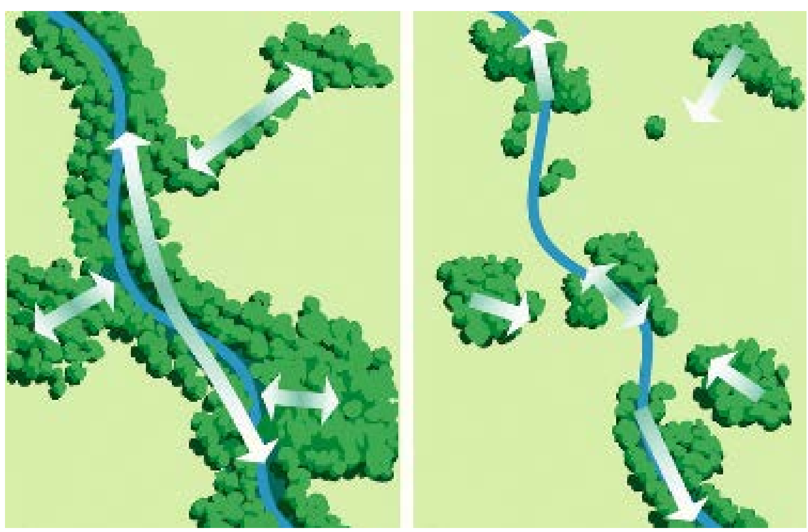
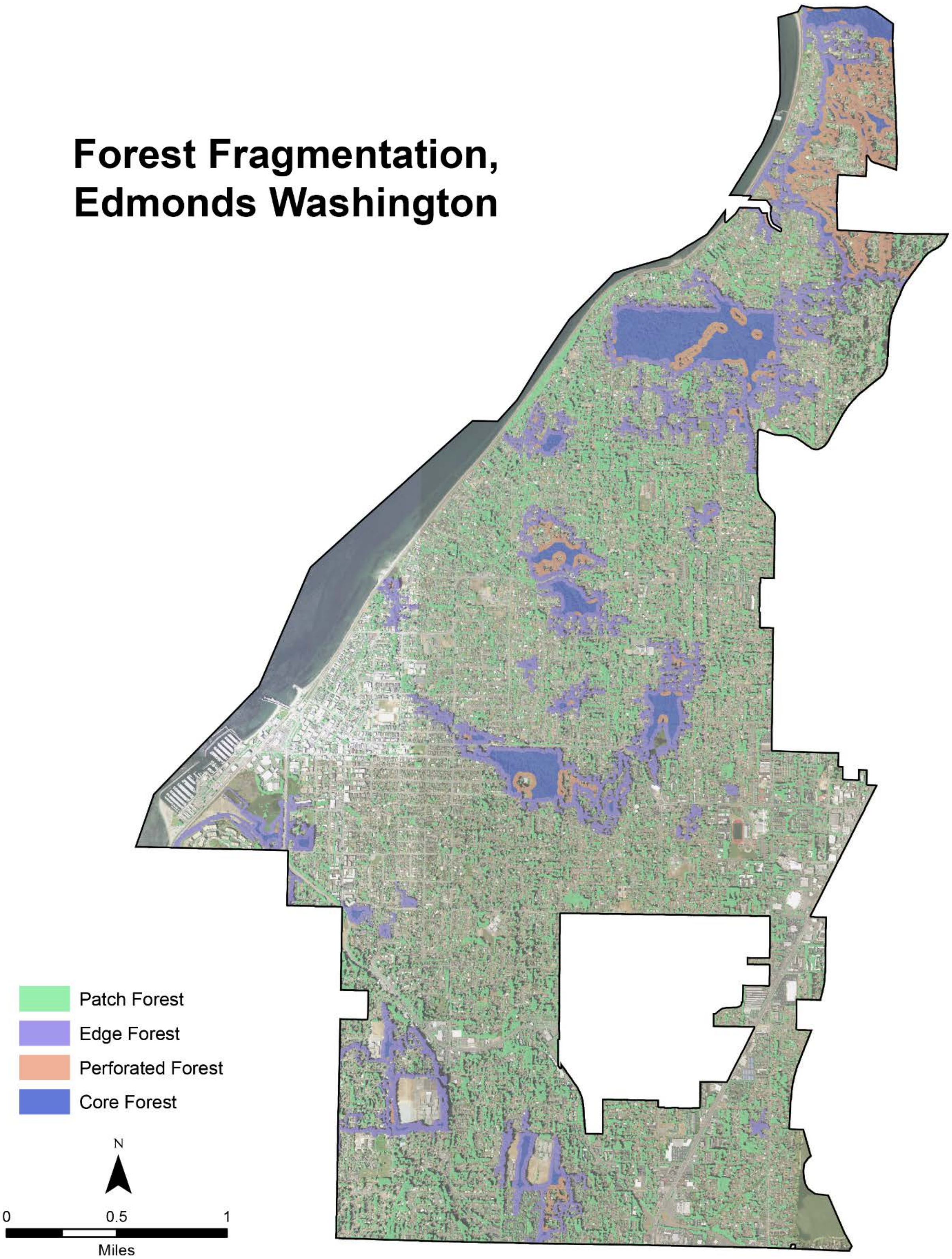


Figure 13: Canopy Fragmentation Comparison

Wildlife corridors (far left) link habitats while fragmented forests (left) lead to a decline habitat quality.



Map 5. Forest Fragmentation in Edmonds

Critical Areas

The Washington State Growth Management Act (GMA) mandates that all cities and counties in Washington are required to adopt critical areas regulations. The GMA states that critical areas include the following categories and ecosystems (Table 7):

- Wetlands
- Areas with a critical recharging effect on aquifers used for potable water
- Fish and wildlife habitat conservation areas
- Frequently flooded areas; and
- Geologically hazardous areas

Analysis of critical areas in conjunction with tree canopy can reveal the important relationship that trees provide in the conservation and protection of these environments. Two critical area designations are especially important to urban forest management in Edmonds; sensitive areas and steep slopes (Table 6). Sensitive areas include high priority habitats and species that have been identified for conservation and management. DRG analyzed the relationship between forest fragmentation and the following priority habitat and species list categories:

- Biodiversity and Corridor Areas (Breeding and Refuge)
- Nesting Habitat (Blue Heron)
- Sensitive Aquatic Habitat (Trout/Salmon)
- Sensitive Habitat (Bald Eagle)
- Wetlands Area

The assessment provides a new metric, the percentage of fragmented tree canopy, as a benchmark to support management objectives within these sensitive areas.

Table 7. Sensitive Areas by Forest Fragmentation Class

Sensitive Area (Acres)	Total	Patch Forest	Edge Forest	Perforated Forest	Core Forest	Non Forest
Biodiversity Areas and Corridor	252	1	54	27	148	22
Nesting Habitat Area (Great Blue Heron)	3	0	1	0	0	1
Sensitive Aquatic Habitat Area	118	11	35	5	17	51
Sensitive Habitat Area (Bald Eagle)	78	14	9	0	3	51
Wetlands Area	81	5	14	1	2	59
Sensitive Area (Percentage)						
Biodiversity Areas and Corridor	--	0.5%	21.4%	10.8%	58.6%	8.7%
Nesting Habitat Area (Great Blue Heron)	--	1.4%	25.0%	0.0%	15.7%	58.0%
Sensitive Aquatic Habitat Area	--	8.9%	29.9%	3.9%	14.0%	43.4%
Sensitive Habitat Area (Bald Eagle)	--	18.6%	11.9%	0.2%	3.5%	65.8%
Wetlands Area	--	6.8%	16.8%	0.6%	2.2%	73.6%

Biodiversity Areas and Corridors

Biodiversity areas and corridors, identified by the Washington Department of Fish and Wildlife are areas of habitat that are relatively important to various species of native fish and wildlife. Biodiversity areas receive this designation through rigorous scientific assessments which show biological diversity. Areas can also be designated as biodiversity area if they are within an urban growth area which contains valuable habitat for wildlife and is mostly comprised of native vegetation. Corridor areas are relatively undisturbed tracts of relatively continuous vegetation that connects fish and wildlife habitat conservation areas, priority habitats, or valuable habitats within a city (Washington Department of Fish and Wildlife, 2008). In Edmonds, most of the biodiversity areas and corridors are in core (58.6%) or edge (21.4%) forest. This is congruent with what theory would suggest, because corridors are continuous areas of habitat. Edmonds should focus plantings on areas that will reduce patch and perforated canopy to improve this forest continuity.

Nesting Habitat (Great Blue Heron)

Nesting habitat for the Great Blue Heron is comprised of several elements; the nesting colony, year-round and seasonal buffers, foraging habitat, and a pre-nesting congregation area. For a given nesting area, habitats are delineated by a buffer created from the outermost perimeter of Great Blue Heron nests. In addition, there is a larger seasonal buffer to reduce human noise pollution during the breeding months (February-September). Unusually loud land use activity must be a minimum of 656 feet from the nesting habitat and blasting noise must be 3,280 feet from nesting habitat (Washington Department of Fish and Wildlife, 2012).

Nesting habitat in Edmonds is located primarily in non-forest areas (58%). This value warrants further investigation to determine optimal canopy levels. Great Blue Herons tend to create nests in trees adjacent to water and feeding sites. For Edmonds, only 25% of nesting habitat is in the edge forest canopy which suggests challenges to habitat quality. However, Great Blue Herons have also been observed nesting on ground level when the area is safe from predators, which could moderate any concerns about the high non-forest percent.

Sensitive Aquatic Habitat (Trout/Salmon)

Sensitive aquatic habitat is determined by in-stream physical characteristics (temperature, water quantity, structure, substrate conditions, etc.). However sensitive aquatic habitat is also strongly influenced by watershed processes beyond the waterline, including canopy cover, riparian condition, large woody debris, impervious surfaces and stormwater discharge, sediment delivery, road location and maintenance, watershed hydrology, and nutrient dynamics (Washington Department of Fish and Wildlife, 2009). Therefore, planning for salmon, steelhead, and trout habitats must address the condition and extent of water-related resources as well as upland processes that influence aquatic habitat.

Sensitive aquatic habitat can include open water. In Edmonds, 43.4% of sensitive aquatic habitat is found in non-forest areas. The second largest forest fragmentation category for sensitive aquatic habitat is edge forest (29.9%). These figures are sensible because this edge forest includes the trees along watersheds where the forest meets riparian zones.

Sensitive Habitat (Bald Eagle)

Since 2011, when the Washington Fish and Wildlife Commission changed the bald eagle's status from "threatened" to "sensitive," many of the state's special protective measures for bald eagles have been eliminated. Currently, the primary responsibility for managing bald eagles falls to the U.S. Fish and Wildlife Service for the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act (Washington Department of Fish and Wildlife, 2017). In addition to immediate impacts, this also covers impacts that result from human-induced alterations around nest sites during a time when eagles are not present.

Nesting habitat for bald eagles is typically defined by areas of large, mature trees close to large bodies of water and generally buffered from human activity (Department of Fish and Wildlife, 2016). This nesting behavior is reflected in the 11.9% of nesting area located in edge forest. However, nest trees are often among the largest trees in a forest patch (Department of Fish and Wildlife, 2016). This tree preference is reflected in 18.6% of nesting habitat being found in patch forest. The height or position of the selected tree typically provides easy access on approach and good visibility of the surrounding landscape. Nests are often used for more than one year, so protecting the area from disturbance is vital to minimizing negative impacts.

Human development has a significant impact on eagle behavior and nest site selection. Several studies conducted in Washington have demonstrated bald eagle sensitivity to human disturbance (Department of Fish and Wildlife, 2016), including behavior changes and avoidance of areas with visible or audible human activity. The sensitive habitat for bald eagles is defined by a buffer area of at least 330 feet around recorded nests. Of the bald eagle sensitive habitat in Edmonds, 65.8% is in non-forest areas, which suggests the raptors are selecting non-traditional nest sites further from human activity. An increase of edge forest close to open water, and with good sightlines, will provide an improved nesting environment for bald eagles.

Wetlands Area

Under Washington's Growth Management Act, local governments are required to use the best available science when reviewing and revising their policies and regulations on wetlands. The Washington Department of Ecology defines buffers as vegetated areas adjacent to aquatic resources that can reduce impacts from adjacent land uses (Washington Department of Ecology, 2013). Buffers also provide some of the terrestrial habitats necessary for wetland-dependent species that require both aquatic and terrestrial habitats. 73.6% of wetlands was classified in non-forest areas, and 16.8% were classified in edge forest, with only 2.2% in the core forest.

Geologically Sensitive Slopes

The protection of steep slopes against landslides and erosion is a key benefit of vegetation (Washington Department of Ecology, 2017). Trees provide several benefits to the structural integrity of slopes and the prevention of soil erosion:

- Foliage intercepts rainfall, causing absorptive and evaporative losses that reduce rainfall available for infiltration.
- Roots extract moisture from the soil which is lost to the atmosphere via transpiration, leading to a lower pore-water pressure.
- Roots reinforce the soil, increasing soil shear strength.

It is important to understand the significance of steep slopes because of their influences on local wildlife and habitat quality. For example, increased erosion can negatively impact spawning salmon by increasing sediment and particulates in streams and other water bodies. In this way, riparian vegetation which prevents erosion protects critical habitat for wildlife. Steep slopes were categorized by land cover class (Table 8).

Table 8. Steep Slope by Land Cover Class

Slope Severity	Total Area	Canopy	Impervious	Pervious	Bare Soils	Water	Preferred Plantable	Potential UTC (%)
Slopes over 12 degrees (Acres)	296	196	42	56	2	0	57	85%
Slopes over 12 degrees (Percentage)	--	66.1%	14.3%	19.0%	0.6%	0.0%	19.3%	85%

Most steep slopes (66.1%) are in areas with tree canopy. This figure presents an excellent baseline, as trees are a vital tool for securing soil and minimizing erosion. However, 19% of slopes over 12 degrees are in pervious areas. These areas are prone to flooding and may pose additional challenges to stormwater management. A key management recommendation is that planting strategies should focus tree planting efforts in steep slope areas to provide these structural benefits.

U.S. Fish and Wildlife Service, October 13, 2016. Bald Eagle. Photo.

Wikimedia Commons. 2007. Blue Heron. Japanese Garden – Seattle – heron 01.jpg. Photo.

Figure 14. Bald Eagles (upper) and Great Blue Heron (lower) need tree canopy in order to have suitable habitat.

Priority Planting

Tree planting at certain sites will produce a greater return on investment over other sites. DRG identified priority planting sites based on possible planting sites and then comparing how a tree planted in these sites would impact several environmental benefits. These benefits are related to stormwater interception and erosion control, urban heat islands, and proximity to tree canopy. Increasing the number and size of trees in high priority sites will yield the highest return on investment. There are 1,619.55 acres ranked as priority planting areas.

Although all grass, low-lying vegetation, and bare soil cover types are potential planting locations, realistically, not all areas are suitable planting sites due to intended site uses. Examples of sites with limited canopy potential include Golf courses, cemeteries, and sports fields. To identify and prioritize planting potential, Davey Resource Group assessed several environmental features, including proximity to hardscape and canopy, soil permeability, slope, soil erosion factor (K-factor), and urban heat island. Each factor was assessed using data from various sources and analyzed using separate grid maps (Table 9).

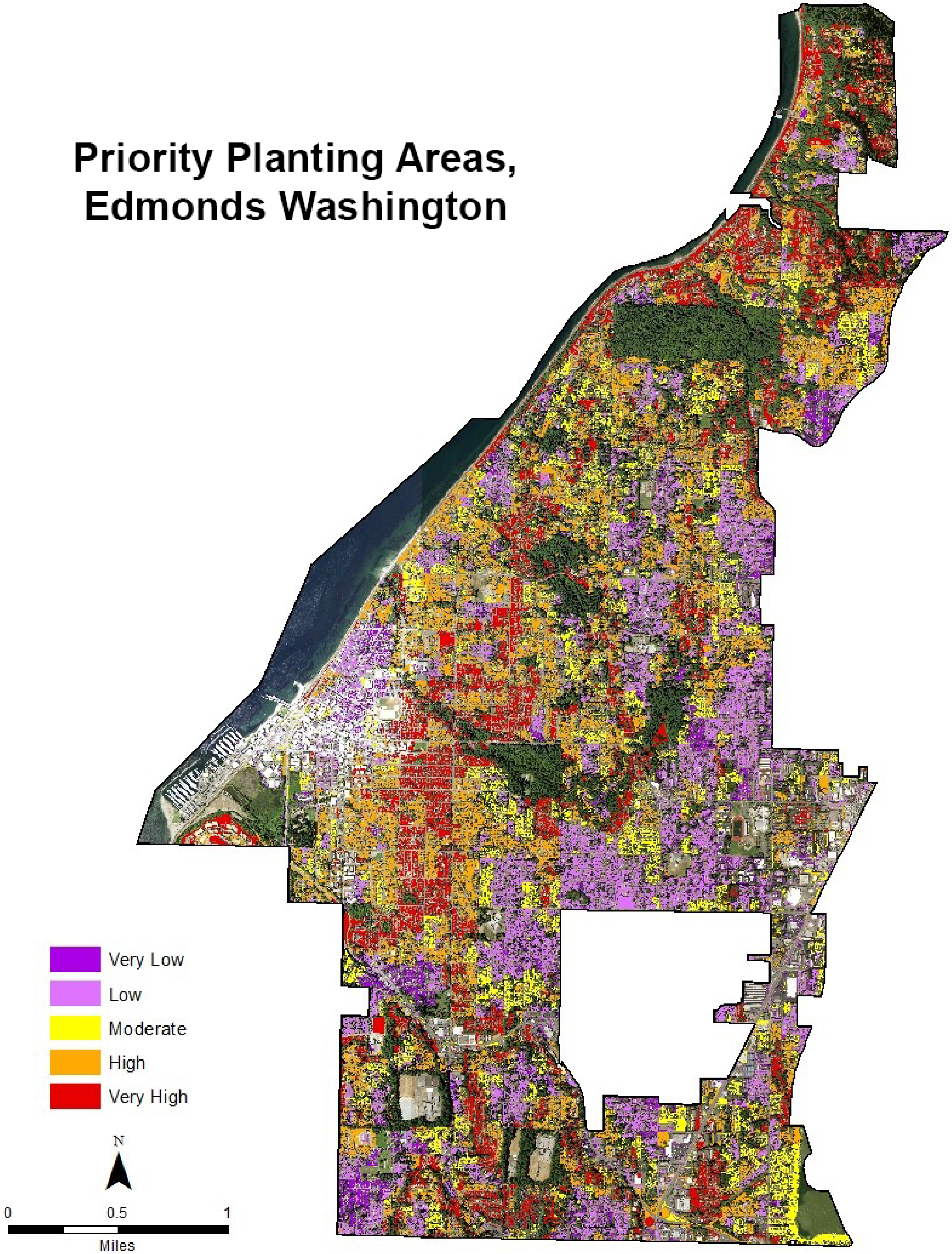
Table 9. Factors Used to Prioritize Tree Planting Sites

Dataset	Source	Weight
Proximity to Hardscape	Urban Tree Canopy Assessment	0.30
Slope	National Elevation Dataset	0.25
Road Density	National Hydrologic Dataset	0.15
Soil Permeability	Natural Resource Conservation Service	0.10
Soil Erosion (K-factor)	Natural Resource Conservation Service	0.10
Canopy Fragmentation	Urban Tree Canopy Assessment	0.10

Sites were given an overall priority rank based on a composite of stormwater reduction and urban heat island mitigation priorities. The averages were binned into five (5) classes ranging from Very Low to Very High with the higher numbers indicating a higher priority for planting (Table 10). While available planting sites may ultimately be planted over the next several decades, trees that are planted in the next several years should be planned within the acres of greatest need, and where they will provide the most benefits and return on investment. A very low priority area is one where planting a tree will have a lesser impact on stormwater, heat islands, and environmental conditions. A very high priority planting site likely has high rankings in at least two factors, and thus tree planting in these areas is highly strategic, addressing multiple urban issues at once (Map 6). City leadership should incentivize tree planting in very high planting priority areas.

Table 10. Tree Planting Priorities

	Priority Level	Potential Acres
	Very Low	101.7
	Low	388.1
	Moderate	284.0
	High	459.0
	Very High	383.6



Map 6. Planting Priority in Edmonds

Conclusion

In 2004 Edmonds' tree canopy was 32.3%. Today, Edmonds' existing tree canopy 30.3%. Action must be taken to reverse the loss of canopy. Continued planting, maintenance, and protection of this resource is essential if the community is to continue to realize the level of benefits trees provide. Proactive preservation, mitigation policies, and ongoing tree replacement can ensure that canopy cover grows over time. Based on the existing land cover, Edmonds has a maximum canopy potential of 3,495 acres (57.4%). Although this may not be a realistic goal, it does highlight the opportunity to improve upon the environmental services provided by the urban forest.

This Urban Tree Canopy Assessment establishes a GIS data layer that can be used in conjunction with other infrastructure layers to prioritize planting sites and increase canopy cover strategically by neighborhood, park, or land use. This assessment establishes a baseline for developing urban forest management strategies and measuring the success of those strategies over time.

Based on this assessment, urban forest managers have the following opportunities:

- Define canopy goals for the community and identify actions that will support these goal(s).
- Use priority planting site analysis to identify new tree planting locations to reduce erosion and soil degradation.
- Use GIS canopy and land cover mapping to explore under-treed neighborhoods and identify potential planting sites.
- Incentivize tree planting on private property, particularly in very high planting priority areas.
- Increase canopy in areas of patch and fragmented canopy to reduce forest fragmentation and improve wildlife habitat and corridors.
- Conducting outreach to the community with this report as an important tool for engaging public interest and support.
- Developing strategic planting plans with prioritized GIS maps to increase the tree population and canopy that will enhance the numerous benefits provided by trees.
- Siting projects which must meet the 30% native vegetation requirement in ECDC 23.90.040.C (Retention of Vegetation on Sub dividable, Undeveloped Parcels) in undeveloped (or redeveloped) sub dividable lands zoned in RS-12 or RS-20, that contain a stream or stream buffer, or a wetland or wetland buffer. Conducting outreach to the community with this report as an important tool for engaging public interest and support.

The accompanying GIS layer that maps the location and extent of existing landcover can support a vast range of additional analysis when used in conjunction with other data layers. The data supports analysis from an overall community level down to the neighborhood level and can provide an important tool for investigating the relationship of tree canopy in correlation with other important issues, including transportation, walkability, human health, and social and economic concerns. This spatial understanding of existing canopy is a valuable tool to help managers align urban forestry management strategies with canopy goals.

Figure 15. Tree Canopy objectives can vary throughout the City from the shoreline to upland areas, but overall canopy cover across the city needs to be sustained.

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Appendix B: Methods

Land Cover Assessment

Davey Resource Group utilized an object-based image analysis (OBIA) semi-automated feature extraction method to process and analyze current high-resolution color infrared (CIR) aerial imagery to remotely-sensed data to identify tree canopy cover and land cover classifications. The use of imagery analysis is cost-effective and provides a highly accurate approach to assessing your community's existing tree canopy coverage. This supports responsible tree management, facilitates community forestry goal-setting, and improves urban resource planning for healthier and more sustainable urban environments.

Advanced image analysis methods were used to classify, or separate, the land cover layers from the overall imagery. The semi-automated extraction process was completed using Feature Analyst, an extension of ArcGIS®. Feature Analyst uses an object-oriented approach to cluster together objects with similar spectral (i.e., color) and spatial/contextual (e.g., texture, size, shape, pattern, and spatial association) characteristics. The land cover results of the extraction process was post-processed and clipped to each project boundary prior to the manual editing process in order to create smaller, manageable, and more efficient file sizes. Secondary source data, such as planimetric (buildings, roads, other impervious), hydrology, and parks provided by Edmonds', and custom ArcGIS® tools were used to aid in the final manual editing, quality checking, and quality assurance processes (QA/QC). The manual QA/QC process was implemented to identify, define, and correct any misclassifications or omission errors in the final land cover layer.

Classification Workflow

1) Prepare imagery for feature extraction (resampling, rectification, etc.), if needed.
2) Gather training set data for all desired land cover classes (canopy, impervious, grass, bare soil, shadows). Water samples are not always needed since hydrologic data are available for most areas. Training data for impervious features were not collected because the City maintained a completed impervious layer.
3) Extract canopy layer only; this decreases the amount of shadow removal from large tree canopy shadows. Fill small holes and smooth to remove rigid edges.
4) Edit and finalize canopy layer at 1:2000 scale. A point file is created to digitize-in small individual trees that will be missed during the extraction. These points are buffered to represent the tree canopy. This process is done to speed up editing time and improve accuracy by including smaller individual trees.
5) Extract remaining land cover classes using the canopy layer as a mask; this keeps canopy shadows that occur within groups of canopy while decreasing the amount of shadow along edges.
6) Edit the impervious layer to reflect actual impervious features, such as roads, buildings, parking lots, etc. to update features.
7) Using canopy and actual impervious surfaces as a mask; input the bare soils training data and extract them from the imagery. Quickly edit the layer to remove or add any features. Davey Resource Group tries to delete dry vegetation areas that are associated with lawns, grass/meadows, and agricultural fields.
8) Assemble any hydrological datasets, if provided. Add or remove any water features to create the hydrology class. Perform a feature extraction if no water feature datasets exist.
9) Use geoprocessing tools to clean, repair, and clip all edited land cover layers to remove any self-intersections or topology errors that sometimes occur during editing.

10) Input canopy, impervious, bare soil, and hydrology layers into Davey Resource Group's Five-Class Land Cover Model to complete the classification. This model generates the pervious (grass/low-lying vegetation) class by taking all other areas not previously classified and combining them.
11) Thoroughly inspect final land cover dataset for any classification errors and correct as needed.
12) Perform accuracy assessment. Repeat Step 11, if needed.

Automated Feature Extraction Files

The automated feature extraction (AFE) files allow other users to run the extraction process by replicating the methodology. Since Feature Analyst does not contain all geoprocessing operations that Davey Resource Group utilizes, the AFE only accounts for part of the extraction process. Using Feature Analyst, Davey Resource Group created the training set data, ran the extraction, and then smoothed the features to alleviate the blocky appearance. To complete the actual extraction process, Davey Resource Group uses additional geoprocessing tools within ArcGIS®. From the AFE file results, the following steps are taken to prepare the extracted data for manual editing.

1) Davey Resource Group fills all holes in the canopy that are less than 30 square meters. This eliminates small gaps that were created during the extraction process while still allowing for natural canopy gaps.
2) Davey Resource Group deletes all features that are less than 9 square meters for canopy (50 square meters for impervious surfaces). This process reduces the number of small features that could result in incorrect classifications and helps computer performance.
3) The Repair Geometry, Dissolve, and Multipart to Singlepart (in that order) geoprocessing tools are run to complete the extraction process.
4) The Multipart to Singlepart shapefile is given to GIS personnel for manual editing to add, remove, or reshape features.

Accuracy Assessment Protocol

Determining the accuracy of spatial data is of high importance to Davey Resource Group and our clients. To achieve the best possible result, Davey Resource Group manually edits and conducts thorough QA/QC checks on all urban tree canopy and land cover layers. A QA/QC process was completed using ArcGIS® to identify, clean, and correct any misclassification or topology errors in the final land cover dataset. The initial land cover layer extractions was edited at a 1:1500 quality control scale utilizing the most current high-resolution aerial imagery to aid in the quality control process.

To test for accuracy, random plot locations were generated throughout the project area and verified to ensure that the data meet the client standards. Each point was compared with the most current NAIP high-resolution imagery (reference image) to determine the accuracy of the final land cover layer. Points were classified as either correct or incorrect and recorded in a classification matrix. Accuracy was assessed using four metrics: overall accuracy, kappa, quantity disagreement, and allocation disagreement. These metrics were calculated using a custom Excel® spreadsheet.

Land Cover Accuracy

The following describes Davey Resource Group's accuracy assessment techniques and outlines procedural steps used to conduct the assessment.

1) *Random Point Generation*—Using ArcGIS, 1,000 random assessment points are generated.

2) *Point Determination*—Each point is carefully assessed by the GIS analyst for likeness with the aerial photography. To record findings, two new fields, CODE and TRUTH, are added to the accuracy assessment point shapefile. CODE is a numeric value (1–5) assigned to each land cover class and TRUTH is the actual land cover class as identified according to the reference image. If CODE and TRUTH are the same, then the point is counted as a correct classification. Likewise, if the CODE and TRUTH are not the same, then the point is classified as incorrect. In most cases, distinguishing if a point is correct or incorrect is straightforward. Points will rarely be misclassified by an egregious classification or editing error. Often incorrect points occur where one feature stops and the other begins.
3) *Classification Matrix*—During the accuracy assessment, if a point is considered incorrect, it is given the correct classification in the TRUTH column. Points are first assessed on the NAIP imagery for their correctness using a "blind" assessment—meaning that the analyst does not know the actual classification (the GIS analyst is strictly going off the NAIP imagery to determine cover class). Any incorrect classifications found during the "blind" assessment are scrutinized further using sub-meter imagery provided by the client to determine if the point was incorrectly classified due to the fuzziness of the NAIP imagery or an actual misclassification. After all random points are assessed and recorded; a classification (or confusion) matrix is created.

Table 11. Classification Matrix

Classification Data								
Classes	Tree Canopy	Impervious	Grass/ Vegetation	Bare Soils	Water	Row Total	Producer's Accuracy	Errors of Omission
Tree Canopy	275	7	23	1	0	306	89.87%	10.13%
Impervious	0	344	27	1	1	373	92.23%	7.77%
Grass/ Vegetation	3	3	233	0	0	239	97.49%	2.51%
Bare Soils	0	0	0	15	1	16	93.75%	6.25%
Water	0	0	0	0	66	66	100.00%	0.00%
Column Total	278	354	283	17	68	1000		
User's Accuracy	98.92%	97.18%	82.33%	88.24%	97.06%		Overall Accuracy	93.30%
Errors of Commission	1.08%	2.82%	17.67%	11.76%	2.94%		Kappa Coefficient	0.906

Reference Data

Following are descriptions of each statistic as well as the results from some of the accuracy assessment tests.

- *Overall Accuracy* – Percentage of correctly classified pixels; for example, the sum of the diagonals divided by the total points ((102+298+182+232+9)/1,000 = 82.30%).
- *User's Accuracy* – Probability that a pixel classified on the map actually represents that category on the ground (correct land cover classifications divided by the column total [102/107 = 95.33%]).
- *Producer's Accuracy* – Probability of a reference pixel being correctly classified (correct land cover classifications divided by the row total [102/138 = 73.91%]).
- *Kappa Coefficient* – A statistical metric used to assess the accuracy of classification data. It has been generally accepted as a better determinant of accuracy partly because it accounts for random chance agreement. A value of 0.80 or greater is regarded as "very good" agreement between the land cover classification and reference image.
- *Errors of Commission* – A pixel reports the presence of a feature (such as trees) that, in reality, is absent (no trees are actually present). This is termed as a false positive. In the matrix above, we can determine that 4.67% of the area classified as canopy is most likely not canopy.
- *Errors of Omission* – A pixel reports the absence of a feature (such as trees) when, in reality, they are actually there. In the matrix above, we can conclude that 26.09% of all canopy classified as another land cover type. This type of error usually occurs around the transition pixels in the imagery where it is difficult to determine which class the point falls.

Allocation Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less than optimal match in the spatial allocation (or position) of the classes.

Quantity Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less than perfect match in the proportions (or area) of the classes.

- *Confidence Intervals* – A confidence interval is a type of interval estimate of a population parameter and is used to indicate the reliability of an estimate. Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter based on the observed probability of successes and failures. Since all assessments have innate error, defining a lower and upper bound estimate is essential.

Table 12. Confidence Intervals

Landcover Assignment

Class	Acreage	%	Lower Bound	Upper Bound
Tree Canopy	1,844	30%	30%	31%
Impervious	2,080	34%	34%	35%
Grass/Vegetation	1,670	27%	27%	28%
Bare Soils	99	2%	1%	2%
Water	402	7%	6%	7%
Total	**6,095**			

Statistical Metrics Summary:	%
Overall Accuracy =	93%
Kappa Coefficient =	0.9057
Allocation Disagreement =	2%
Quantity Disagreement =	5%

Accuracy Assessment

Class	User's Accuracy	Lower Bound	Upper Bound	Producer's Accuracy	Lower Bound	Upper Bound
Tree Canopy	0.99	98%	100%	90%	88%	92%
Impervious	0.97	96%	98%	92%	91%	94%
Grass/Vegetation	0.82	80%	85%	97%	96%	99%
Bare Soils	0.88	80%	96%	94%	88%	100%
Water	0.97	95%	99%	100%	100%	100%

Benefit Calculations

Stormwater

The i-Tree Hydro v5.0 Model was used to quantify the value of ecosystem services for stormwater runoff. i-Tree Hydro was designed for users interested in analysis of vegetation and impervious cover effects on urban hydrology. This most recent version (v5.0) allows users to report hydrologic data on the city level rather than just a watershed scale giving users more flexibility. For more information about the model, consult the i-Tree Hydro v5.0 manual (http://www.itreetools.org).

To calculate ecosystem services for the study area, land cover percentages derived for the project area were used as inputs into the model. Precipitation data from 2005-2012 was modeled within i-Tree Hydro to best represent the average conditions over an eight-year time period. Model simulations were run under a Base Case as well as an Alternate Case. The Alterative Case set tree canopy equal to 0% and assumed that impervious and vegetation cover would increase based on the removal of tree canopy. Impervious surface was increased 6% based on the amount of impervious surface under tree canopy and the rest was added to the vegetation cover class. This process was completed to assess the runoff reduction volume associated with tree canopy since i-Tree Hydro does not directly report the volume of runoff reduced by tree canopy. The volume (in cubic meters) was converted to gallons to retrieve the overall volume of runoff avoided with the current tree canopy.

Through model simulation, it was determined that tree canopy decreases the runoff volume in the project area by 44.7 million gallons per year using precipitation data from 2005-2012. This equates to approximately 47,809 gallons per acre of tree canopy (44.7 million gals/934.6 acres).

To place a monetary value on stormwater reduction, the cost to treat a gallon of storm/waste water was given by the City of Edmonds. This value was $0.0118 per gallon. Tree canopy was estimated to contribute roughly $527,000 to avoided runoff annually to the project area.

Pollutant Removal

Using i-Tree software, the amount of pollutants in storm water runoff were generated. Data spanning from 2005-2012 was analyzed to get the average pollutant runoff within the city limits. This is essential in determining water quality measures and setting goals focused on stream restoration or preservation. Estimated average annual pollutant runoff for total suspended solids, oxygen compounds, phosphorus, nitrogen, and other pollutants was reported.

Davey Resource Group used the i-Tree Hydro model to help clarify the impacts of changes in surface cover and vegetation on pollutant load in streams by making use of a statistical parameter known as event mean concentration (EMC). An EMC value represents the flow-proportional average concentration of a given pollutant during a storm event and is measured in units of mass per volume, usually milligrams per liter. EMC can be multiplied by actual flow to estimate the mass of pollutants entering a body of water. Changes in flow resulting from changes in tree canopy cover will be reflected in changes in pollutant load.

i-Tree Hydro uses EMC population means and medians for 10 pollutants based on a study by Smullen et al. in 1999. The study pools results from the EPA's Nationwide Urban Runoff Program of 1977 with two other nationwide pollutant loading studies. Other studies are: the U.S. Geological Survey urban-stormwater data base for 22 metropolitan areas throughout the United States (Driver et al., 1985); and monitoring results from the National Pollutant Discharge Elimination System (NPDES). For more info on NPDES data, a more recent study of that data source is available online from Maestre et al., 2005.

For a more detailed explanation of Hydro nationwide pollutant load calculations is in the user manual: www.itreetools.org/resources/manuals/Hydro_Manual_v5.1.pdf#page=59.