THE ESTIMATED VALUES OF OLYMPIA'S URBAN TREES FOR STORMWATER MANAGEMENT USING A BENEFIT TRANSFER METHOD

by

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ABSTRACT

The Estimated Values of Olympia's Urban Trees for Stormwater Management Using a Benefit Transfer Method

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Urbanization creates a shift in landscape, replacing the natural environment with more impervious surfaces. These surfaces prevent water from infiltrating into the ground, obstructing with the environment's natural hydrology while picking up harmful pollutants from anthropgenic activity. This results in increased stormwater runoff and pollution, frequent and intesnse flooding, and impacts on drinking water sources. Urban trees and other types of natural infrastructure are known to have significant benefits in mitigating and treating stormwater. Unfortuantely, Olympia lacks data on green stormwater infrastructure, therefore little is known about Olympia's urban trees' role in stormwater management. Using a benefit transfer method from the city of Snoqualmie's 2020 *Natural Infrastructure Assessment*, I was able to estimate the annual dollar value per acre of Olympia's urban trees. I found that Olympia's urban trees are estimated to bring a significant amount of economic prosperity and savings in water quality if they are continued to be protected and healthy. These results not only show the importance of urban trees and natural infrastructure, but can also encourage more research on the unknown benefits of Olympia's urban trees.

Key Words: Urban Trees, Green Infrastructure, Urbanization, Stormwater

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Introduction

More than half of the world's population lives in cities and cities will house most of the population growth over the next four decades (United Nations, 2018). The increase in urban population poses many challenges and increases environmental pressures. In the United States, for example, urban tree canopy cover is projected to decline at a rate of about four million trees per year due to rapid urbanization along with tree diseases due to climate change (Wolf et al., 2020). These losses in land cover caused by urbanization trigger negative impacts on downstream ecosystems, hydrological functions, and urban communities. In fact, the degree of urban and suburban land use has been correlated with increases in flood intensity and frequency, peak flow, runoff volume, and pollutant yield (Woznicki et al., 2018). This growth and the associated changes in urban form, land use, and population growth have already produced environments that present several threats to ecosystem services and local communities (Felappi, 2020; Soz et al., 2016). Ecosystem services such as air and water quality, flood risk reduction, and waste treatment are all provided by green infrastructure. Without green infrastructure, these services, which are the foundation of economic and social importance, would not be beneficial (Caparros-Martinez et al., 2020; Nowak et al., 2014). Green infrastructure, specifically urban forests has emerged as a multifaceted strategy for transforming urban spaces to establish more habitable, healthy, and wildlife-friendly cities (Felappi, 2020).

According to the Environmental Protection Agency (EPA), urban stormwater is a significant reason why half of the United States rivers and streams don’t meet national water quality standards put forth by the Clean Water Act (Denchak, 2019). Urban lakes and estuaries also fail to meet water quality standards, including Olympia, WA’s Budd Inlet and Capitol Lake.

As a result, rapid urbanization without consideration of green space puts ecological functions and ecosystem services at risk (Monteiro et al, 2020).

This study aims to shed light on the advantages of urban trees and forests for stormwater runoff management in Olympia, WA, and was developed with two goals in mind: (1) What ecosystem services related to stormwater are provided by Olympia's urban trees and (2) What are the associated economic benefits of Olympia's urban trees in reducing nutrient contamination of stormwater, specifically to understand whether green infrastructure is a valuable component in management practices. Considering Olympia lacks data on green infrastructure stormwater management practices, Snoqualmie's 2020 Natural Infrastructure Assessment was used as a model for understanding Olympia's urban trees and their effective role in stormwater management.

Literature Review

1.1 Green Infrastructure vs Grey Infrastructure

1.1.1 Definitions

Green infrastructure (GI) is an interconnected system of green space, waterways, and other natural areas that maintain natural environmental functions while simultaneously providing socioeconomic benefits that grey infrastructure cannot provide (see Sec. 1.5) (Benedict & McMahon, 2002; Denchak, 2022; Seiwert and Rößler, 2018). The components of GI consist of a wide range of natural elements, restored ecosystems, and landscape features such as trees, shrubs, grasses, parks, ponds, wetlands and other ecological elements that provide nature-based solutions for urban communities (Benedict & McMahon, 2002). GI represents an ecological form of climate change resilience by combining engineering techniques and nature's mechanisms, mimicking the natural environment in urban communities (Beatly, 2012; Benedict et al., 2012; Choi et al., 2021).

Despite the co-benefits GI offers, it cannot replace grey infrastructure entirely, the conventional flood prevention system consisting of pipes, gutters, levees, and tunnels, to divert stormwater away from homes and into treatment facilities and then into our local waterways (Hoang and Fenner, 2014; Zhou, 2014). Grey infrastructure will always be a requirement for hydraulic control, water quality and transportation of water aways from built structures (US EPA, 2022; Water Portal, 2016).

Planners and communities have historically used grey infrastructure (US EPA, 2022; Soz et al., 2016). With rapid urbanization and increased intense flooding, grey infrastructure can break down and become less efficient, especially with the aging of grey infrastructure in many areas (US EPA, 2022; Xu et al., 2019), and its consistent need for repairs (Hoang and Fenner, 2015; William et al., 2017).

For instance, water mains in New York City have an average age of 66 years and have become more fragile over time. They also share underground space with power lines, stream pipes, and other critical infrastructure. In 2020, several water main breaks occurred in the first two months, warning of the city's inadequate and aging infrastructure, on which the city spends nearly $400 million a year to repair (Barron, 2020).

Similarly, local sewer systems also have combined drainage and wastewater management. Seattle, WA has three types of sewer systems: combined, separated, and partially separated, with separated being the least common. Combined sewer systems date back 70 to 100 years. Combined sewers transport wastewater from homes and businesses along with stormwater runoff from impervious surfaces. These sewer pipes transport both wastewater and stormwater to treatment plants. When too much water enters the pipes, wastewater can overflow into local waterways or inundate conveyance systems, exacerbating floods known as combined sewer overflows. While separate sewer systems may transport wastewater and stormwater in different pipes, only 27% of the wastewater in Seattle gets separated, meaning there are two separate systems for stormwater and sewage. In comparison, about 40% of Seattle's sewer system gets partially separated (Blackwell et al., 2012; Seattle Public Utilities, 2020).

The inclusion of GI elements can improve water quality by allowing natural filtration using plants and soils, can alleviate stress and pressure on pipes and prevent system overflows by retaining water that might otherwise drain into water and sewer systems. Considering the projected climate change-related hazards of frequent and intense rainstorms, GI and grey infrastructure should be used together to maximize each of their benefits (Dumuzere et al., 2014;

Xu et al., 2019). However, like conveyance systems, extreme rainstorm events can put stress on GI especially if they are not properly planned or overdesigned (Tu et al., 2020). Both GI and grey infrastructure can complement each other to reduce inundation of both types of stormwater systems (Water Portal, 2016).

1.2 Urbanization Impacts on Stormwater

1.2.1 More Development, More Impervious Surfaces

Urban growth has accelerated globally over recent decades, with about 55% of the world's population living in urban areas, a number projected to increase to 70% by 2050. That is nearly 2.5 billion more people living in urban areas than today (Nor et al., 2017; United Nations, 2018). With rapid urbanization comes an increase in total impervious areas, such as parking lots, roadways, rooftops, and any type of human-made hard surface (US EPA, 2022). The Puget Sound area, for example, has 359,500 acres (560 square miles) of impervious surface. That equals more than 272,300 football fields worth of asphalt and concrete (The Nature Conservatory, n.d.). With nearly 80,000 new people moving here annually, that number will likely increase.

Additionally, cities in the United States have a significant ecological footprint and exhibit unsustainable land use, but have historically given little consideration to ecological restraints (Beatly, 2013; Chen et al., 2019; Monteiro et al., 2020). The United States relies on automobiles; because of car-centric land use planning (Simek, 2021) most Americans favor more and larger shopping malls, and larger single-family homes with accompanying larger roofs (Frazer, 2005) and bigger driveways to accommodate three car garages. While impervious surfaces have existed for a while, according to a nationwide road census, 93% of America's roads were unpaved in

1903 (Arnold Jr. & Gibbons, 2007). This massive transformation of American cities was influenced by the preference of automobiles over train services in the early mid-century because it gave people more mobility and personal freedom. As a result, decisions on urban design were solely centered around car-centric infrastructure through the expansion of highways (Arnold Jr. & Gibbons, 2007; Simek, 2021). Additionally, the adoption of automobiles led to the growth of suburbia which typically had, and still has, poorly connected street networks (Ewing et al., 2002). Since then, our preference and dependence on automobiles has increased the amount of impervious surface area (Arnold Jr. & Gibbons, 2007).

1.2.2 Implications of Less Greenspace

Land use changes as a result of urban growth. Impervious surfaces are ubiquitous in urban environments, altering natural hydrological processes. Compared to the natural environment, urban environments limit stormwater absorption, increasing runoff volume and pollutant loads into our local waterways (Sohn et al., 2020).

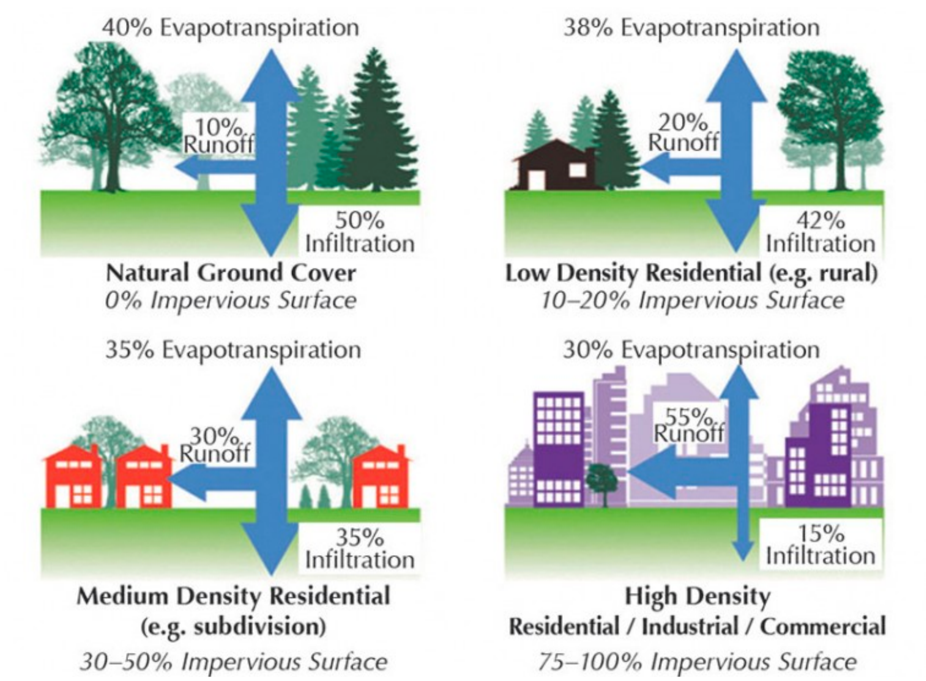
Many studies demonstrate how spatial patterns of land use effect urban flooding (Frazer, 2005; Hornet et al., 2022; Sohn et al., 2020; US EPA, 2013; Wendling, 2022). When precipitation falls over land, it takes various routes. Some of it evaporates, returning into the atmosphere, some infiltrates into the soil, and the rest becomes surface water, reaching different bodies of water. Greater impervious surface areas alter the volume of water that permeates into the soil, resulting in more flooding, as shown in Figure 1 (City of Olympia, 2018; Ebrahimian et al., 2019; McCarthy, 2016).

Additionally, when rainwater washes over impervious surfaces, it collects harmful pollutants that can often become very concentrated (e.g. nutrients, chemicals, oils, etc.), ultimately carrying them into our local waterways, degrading water quality and marine ecosystems (Chen et al., 2019; US EPA, 2022). For example, stormwater runoff is responsible for 75% of the toxic chemicals that enter Puget Sound, emphasizing the fact that impervious surfaces are associated with urban-environmental issues (The Nature Conservancy, n.d.).

Besides flooding and stormwater runoff, less green space results in urban heat islands (UHI), wildlife habitat fragmentation, poor air and water quality, and negative self-reported moods in urban neighborhoods (See Sec. 1.5) (Berland et al., 2017; Hoang and Fenner, 2014; McFarland et al., 2019). In other words, without the consideration of green spaces, rapid urbanization can lead to multiple socio-ecological consequences (Hamada et al., 2013; Piracha and Chaudbury, 2022).

Figure 1

Impervious Surfaces Impacts on Runoff and Infiltration



Note. Compares the water cycle between low-density (more permeable surfaces) and high-density (more impermeable surfaces) areas. In highly dense urban communities, runoff is more than 5x greater than in natural environments. Source: Dept. of Energy and Environment, Washington D.C.

Olympia, Washington, for instance, can be characterized as a moderately sized town, with a rapidly growing population (World Population Review, 2022) where land use is continuously changing with development (See Figure 2a-b). On top of that, the city has an impervious surface area that exceeds 3,000 acres. In a typical year, this can result in four billion gallons of runoff (City of Olympia Storm and Surface Water Utility, n.d.). Nearly 12,622 acres of Olympia generate stormwater that eventually gets dumped into South Puget Sound, mainly Budd Inlet (City of Olympia, 2018). Budd Inlet currently does not meet water quality standards for dissolved oxygen (WA Dept. of Ecology, n.d).

Figure 2a-b

Landuse Change Olympia (1984-2020)

Note. Shows the City of Olympia 1984 (top) and 2020 (bottom) and the changes in landscape due to development. Pictures are zoomed out due to pixelation and low photo quality on Google Earth. Source: Google Earth Timelapse.

1.3.3 Different Ways Trees Control Stormwater Pollution

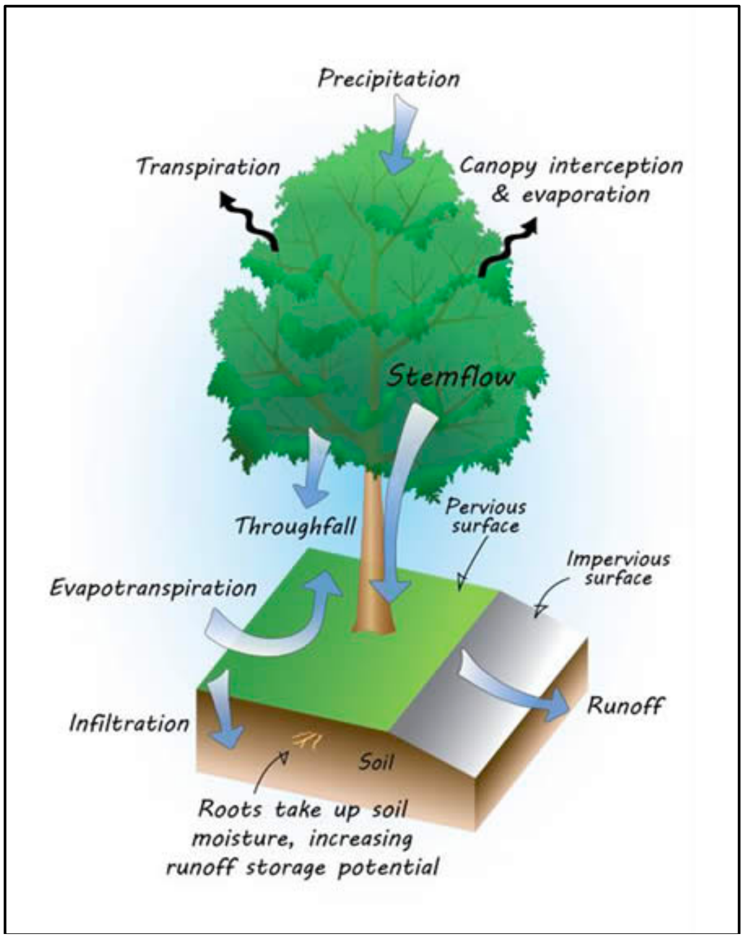
As opposed to impervious surfaces and the built environment which cause flooding and runoff, trees contribute to the water cycle in many ways, controlling polluted stormwater and providing water quality benefits to urban communities and marine ecosystems. There are several ways healthy urban trees contribute to stormwater management and water quality protection:

a. *Interception*: The quantity of rain that is captured by a canopy and then evaporates is known as canopy interception (Yan et al., 2020). When rain falls, water is temporarily stored on the tree's branches and leaves, preventing the majority of rain droplets from hitting the ground. This helps in reducing peak flows, delaying the onset of floods caused by rainstorms (US EPA, 2013).
b. *Transpiration and Evapotranspiration*: Transpiration is the term for the water movement that occurs when trees and other vegetation absorb water through their roots and release it through their leaves (See Figure 3). Water also evaporates from the leaves from interception catch and other surfaces, which in return cools the surrounding air temperature. Evapotranspiration is the collective name for these processes (Huang et al., 2017; Thom et al., 2020; Yang et al., 2019).
c. *Infiltration:* Trees and other plants play a critical role in groundwater infiltration. Root growth can help increase infiltration capacity rates, reducing landscape runoff (Tree Canopy BMP, n.d.). The amount of infiltration is crucial because it controls both the amount of stormwater that enters the soil and the absorption of nutrients and pollutants that are filtrated before it enters the water table (Kirkham, 2014).

d. *Phytoremediation:* A term that refers to plants' ability to sequester and break down contaminants from the soil through their root systems (US EPA, 2013). In order to accumulate heavy metals and control their bioavailability, plant roots play a vital role in the soil environment, creating rhizosphere micro-organisms that help to remediate soil contamination, maintaining and balancing soil health. (Yan et al., 2020).

Figure 3

Ways Healthy Urban Trees Treat Stormwater



Note. Visualizes the different ways trees prevent water pollution associated with their different terms. Source: US Environmental Protection Agency (2013).

1.3 Climate Change Projections in Western Washington

1.3.1 General Climate in Western Washington

The Northwest region has a greatly diverse climate, with substantial spatial variations, primarily due to interactions with the vast atmospheric circulation and the Coastal and Cascade Mountain ranges (Kunkel et al., 2022; UW Climate Impacts Group, 2009). Western Washington tends to be humid, mild, and temperate due to the Pacific Ocean providing moisture and frequent precipitation. Most of Washington's rain occurs during the winter, and the Cascades can receive up to 400 inches of snow annually. Winter seasons rely heavily on mountain snowpack accumulation because it provides an essential water source during the summer months (Frankson et al., 2022). But warmer winter temperatures combined with heavy precipitation may reduce Cascade snowpack.

1.3.2 Future Changes in Extreme Precipitation and Flooding

Climate change is likely to alter hydrological processes in urban areas, exacerbating the severity and frequency of flooding and precipitation events (Tabari, 2020). Winters won't always yield high snow depths because warmer winters will become more common, causing shifts in winter precipitation patterns from snow to rain (Global Change, 2009). Increased winter rainfall, as opposed to snowfall, won't be stored in our region's mountaintops resulting in more winter flooding, impacting urban communities (Frankson et al., 2022). Although heavier rainfall does not always lead to floods, it can increase their potential. Moderate precipitation events can still cause frequent flooding in urban areas where there is more impervious surface area, thus contributing to property and environmental damages (Denchak, 2019). Pollution from runoff is inevitable because impervious surfaces are everywhere in developed land (O'Driscoll et al., 2010).

Additionally, across most of the globe, flood intensity will be expected to increase. However, there could be considerable uncertainty in some locations. Climate characteristics have an impact on uncertainty in changes to extreme precipitation. While semi-humid and semi-arid regions show a lower percentage of land area with increasing flood intensity, accounting for 68.7% and 63.5%, respectively, humid regions show an increase in flood intensity on about 76% of the land area (Tabari, 2020). In Western Washington, the daily variation in relative humidity ranges from 85% at 4:00 am to 47% at 4:00 pm in July and about 87% at 4:00 am to 78% at 4:00 pm in January (NOAA NCDC, n.d.). That being said, Western Washington experiences moderate-high humidity, especially during the winter, which explains the frequent winter rainstorms. Although uncommon in Western Washington, hot temperatures and humidity can also cause heavy rain and thunderstorms which can lead to flash floods. These events are also likely to become more common as climate change progresses (Stalter, 2018).

1.4 Urban Ecosystem Services and Benefits

GI provides an interconnected network between ecosystems and humans, highlighting the multifaceted benefits that can simultaneously meet multiple socio-ecological needs and interests (Coutts and Hahn, 2015; Okpoko, 2020). Although GI is mostly recognized and utilized for stormwater management in the United States (Choi et al., 2021), its purpose has more use and benefits. These benefits include but are not limited to:

1.4.1 Ecological Benefits

a. Enhanced Biodiversity and Ecosystems

The anticipated rate of climate change, combined with habitat and greenspace fragmentation caused by increasing urbanization, has placed numerous species at risk. Additionally, rapid development causes migration barriers and will likely inhibit many species from migrating to more suitable habitats (Chambers and Pellant, 2008).

GI helps provide natural habitats and connectivity for urban wildlife and ecosystems (Lafortezza et al., 2013). Depending on vegetation and land cover types, such as urban trees, GI may promote species richness and support urban wildlife when properly maintained (Francine-Felappi et al., 2020). Much epidemiological research shows higher bird species richness or animal diversity in urban parks is associated with positive mental well-being among urban dwellers (Methorst et al., 2020; Wolf et al., 2020). GI also restores, modifies, and maintains natural ecosystems while simultaneously addressing societal challenges among urban communities (Benedict and McMahon, 2002).

b. Water Quality

Stormwater runoff is a significant contributor to water pollution. When rain falls on impervious surfaces, stormwater collects various contaminants, heavy metals, and nutrients from anthropogenic activity (see Table 1) and then discharged into nearby waterways rather than infiltrating into the soil (Chen et al., 2019; Madsen and Figdor, 2007). Excess nutrients, for example, cause fish kills, algae blooms, and the spread of invasive non-native plants (Hostetler et al., 2011; Morton, 2017). Stormwater contaminants are toxic to plants and animals, especially those symbolically and culturally important to the PNW including salmon, orcas, oysters, geoducks, eelgrass beds, and kelp forests (WA DNR, 2020).

Table 1

Common Stormwater Pollutants

Contaminant	Description	Sources
Pathogens	Disease-causing microorganisms that cause public health concerns	Animal fecal matter, animal agriculture, wastewater effluent and sludge
Natural Organic Matter (NOM)	Organisms (plant and animal) and their associated waste cause decreased dissolved oxygen in receiving waters	Food waste, decaying plant and animal matter, animal fecal matter
Synthetic Organic Chemicals (SOCs)[52]	Fabricated chemicals for anthropogenic use that are usually toxic and are persistent in soil and water environments	Car byproducts (oil, fuel, exhaust), road wear, detergents, pesticides, fertilizers
Nutrients	Nitrogen and phosphorus. Used heavily in agriculture. Can cause eutrophication and stimulate harmful algal blooms	Fertilizer, manure, pet waste, soil erosion, wastewater effluent, leaf and lawn litter
Heavy Metals	Common due to widespread residential, industrial, and commercial use. Toxic to aquatic life.	Tire wear, metallic road structures, traffic signs, industrial byproducts
Sediments	Small solids disrupt aquatic life by reducing light penetration, filling in critical small-life habitat, and providing a mobile sorption surface for contaminants	Every type of land use, but major sources include soil erosion from construction sites and road debris
Pharmaceuticals and Personal Care Products (PPCPs)[53]	Products used to prevent/treat disease or improve quality of life; persistent in environment and potential threats to environmental and public health	Pharmaceuticals, antibiotic resistant genes, disinfectants, sunscreen

Note. In-depth description and details of common pollutants in stormwater and their sources. Retrieved from: McFarland et al., 2019.

GI improves water quality, enhancing local aquatic ecosystems (Chambers and Pellant, 2008; Xu et al., 2019). For instance, pollutants like heavy metals, 6PPD-quinone from tires, motor oil, fertilizers, and many more collected from stormwater runoff in urban areas, are captured and filtered out by soil and permeable surfaces. By incorporating more permeable surfaces, healthy GI prevents stormwater pollutants and heavy metals from entering waterways (Dixon & Goh, n.d.; McFarland et al., 2019) through infiltration and phytoremediation.

c. Air Quality

Many cities suffer from air pollution because of poor planning and expanding urban environments (Piracha and Chaudhary, 2022). In the United States, the most common source of air pollution comes from mobile sources, such as cars, planes, buses, and trains (US NPS, 2018). Most US cities lack adequate public transportation so that residents rely on their cars as their main mode of transportation, causing carbon emissions and air pollution (Simek, 2021). Air pollution can be exacerbated by urban heat islands and a lack of green space, causing impacts on human health and urban ecosystems (EHN, 2021; Jesdale et al., 2021).

GI alleviates air pollution through carbon sequestration. Vegetation directly absorbs gaseous air pollution like carbon dioxide (CO_2) from the atmosphere through leaves' stomata (Nowak et el., 2013; Demuzere et al., 2014). Trees also act as a buffer against air pollution by removing ozone (O_3), particulate matter (PM), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), and carbon monoxide (CO) from the atmosphere (James et al., 2015). For example, in the United States, the amount of pollution sequestered by urban trees differs across major metropolitan areas, with an average of 711,000 tonnes of pollution removed per year. (Nowak et al., 2006; Nowak et al., 2013). Although the amounts of each pollutant sequestered vary, to put it into perspective, 1 ton of CO equals 102 gallons of gasoline consumed and 2,252 miles driven by an average gasoline-powered passenger vehicle (US EPA, 2022). This equals 72,420,000 gallons and 1,598,920,000 miles of CO_2 omitted from air pollution by urban trees.

1.4.2 Social Benefits

a. Urban Heat Islands (UHI)

Concrete, buildings, and other impervious surfaces from cities absorb, retain, and re-emit more heat than natural vegetation, causing urban heat islands (UHI) (Berland et al., 2017; O'Driscoll et al., 2010;). For example, daytime temperatures in cities are about 1-7 °F higher than in rural areas, and nighttime temperatures are about 2-5 °F higher (US EPA, 2022). Summer high temperatures in cities are becoming more severe, and UHI is considered a significant indicator, directly or indirectly, threatening human health such as heat-related illnesses (Huang et al., 2022).

Urban trees alone provide canopy shade on a hot day, and also cool through transpiration when surrounding air is cooled as water goes from liquid to vapor (Berland et al., 2017; Gao et al., 2020; Kong et al., 2016;). Urban trees also influence indoor temperatures by shading buildings and dramatically lowering the risk of indoor overheating (Pianella et al., 2020; Salmond et al., 2016). The cooling effects of urban trees and green space on the urban landscape ensure necessary UHI and heat-related illness prevention across urban communities (Hamada et al., 2013).

b. Physical and Mental Health

Human health and the built environment are inextricably linked. Poor mental health among urban dwellers has been associated with urban-environmental issues such as air and water pollution, UHI, noise pollution, and, depending on social conditions, increased criminal activity (Jesdale et al, 2015; Piracha and Chaudbury, 2022; van den Berg et al., 2014). Lack of GI can put underserved communities more at risk of poor mental and physical health, compared to wealthy neighborhoods that benefit from GI (Gruebner et al., 2017). For instance, studies in St.

Louis, Missouri found a correlation between violent behavior and excessive heat temperatures, especially across underserved communities (Mares, 2013; Miles-Novelo and Anderson, 2019). While neighborhood characteristics and socioeconomic factors, such as poverty and lack of green space, play a role in aggressive behavior, higher temperatures can also exacerbate or cause a range of mental health issues (PD&R, 2016; Seo, 2022).

Greenspaces, like urban trees, can alleviate negative natural and physical environmental conditions that may contribute to poor human health. For example, living near, or in the presence of greener environments is correlated with better self-perceived mental health (Cox et al., 2016; Lafortezza et al., 2013; Methorst et al., 2020), such as reduced negative thoughts and better-reported moods (Turner-Skoff and Cavender, 2019). Greenspace also encourages walking and biking while simultaneously providing critical habitat for urban ecosystems for bird and wildlife watching, which also contribute to protective measures against self-reported negative mental health outcomes (James et al., 2015; US EPA, 2017).

c. Equity

Low-income communities are not only disproportionately impacted by climate change-related hazards but also lack environmental amenities and access to green space (Homet et al., 2022; Meerow, 2019). Current evidence shows that historically redlined neighborhoods are some of the hotter parts of the city during the summer, with less tree cover and more pavement (Anderson, 2020; Plumer et al., 2020). Hoffman et al. (2018) conducted a spatial analysis to study the connection between historically redlined neighborhoods and urban surface temperatures. They explored 108 US Cities with Home Owners' Loan Corporation (HOLC) maps and discovered that 94% of the study area showed surface temperatures were, on average, up to 2.6 degrees Celsius higher in redlined neighborhoods than in non-redlined neighborhoods. Similarly, communities of color in urban areas tend to bear the burden of extreme heat events and are underserved, receiving inadequate environmental services such as urban trees (Jesdale et al., 2013).

GI provides a climate justice approach for vulnerable communities that have been historically and continuously disregarded and underserved. As mentioned, urban trees provide significant benefits in big cities. They offer countless environmental amenities for urban dwellers by alleviating flooding, environmental pollution, negative self-reported mental health, and UHI (Homet et al., 2022; Turner-Skoff and Cavender, 2019; US EPA, 2017). This will be essential in low-income neighborhoods that face uneven distribution of greenspace and environmental commodities (Soz et al., 2016).

1.4.3 Economic Benefits

a. *Lower Energy Costs*

Frequent heat waves can have significant impacts on the economy and environment because they lead to increased energy consumption. When it's hot out, homeowners and businesses turn on their air conditioning (AC) units and other cooling equipment to stay cool (Lemoine, 2021). AC systems in particular consume more than 50% of total electricity demand during heat waves, with a maximum consumption of up to 65% of total electricity demand during peak late afternoon hours (Sharma et al., 2018). Increase electricity use on hot days can strain electric grids, resulting in blackouts, which not only can be costly to the economy but also expose millions of residents to hazardous levels of heat (Lemoine, 2021; Sharma et al., 2019; Stone Jr. et al., 2020).

GI provides microclimate regulation of UHI and decreases the energy demand required for air conditioning in residential homes and businesses by providing shade and shelter, minimizing consumer costs (Blackwell et al., 2012; Lin et al., 2014). Tree canopies and forested parks, in particular, can have an average cooling effect of about 1 degree C (33.8 degrees F) in air temperature, but could also have a significant effect on thermal comfort, especially during heat waves (Lee et al., 2014; Kong et al., 2016; Venter et al., 2019).

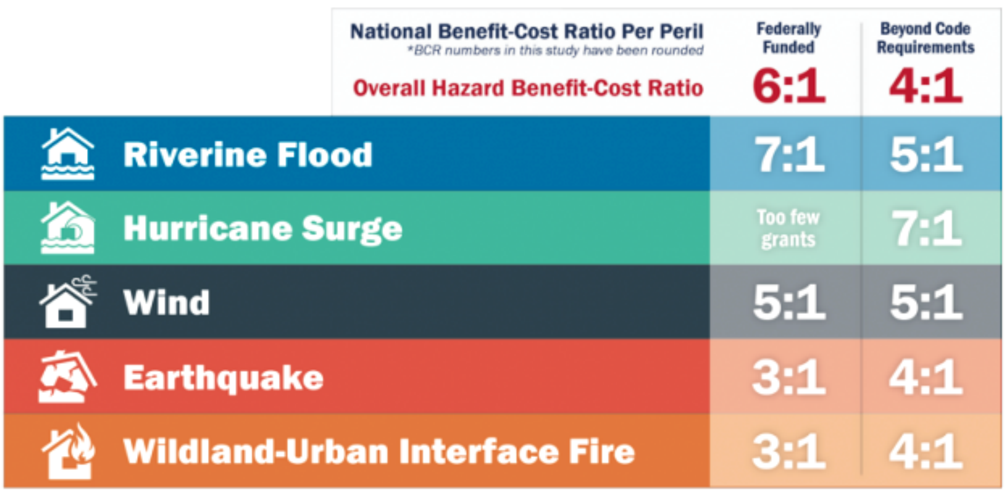
b. Prevention Loss and Disaster Risk Reduction

Grey infrastructure generally increases environmental costs by degrading the landscape and ecosystems due to the lack of permeable surfaces (Onuma and Tsuge, 2018). Flooding, for example, caused by heavy precipitation can cause widespread economic disruption by destroying roads and bridges, inundating homes, businesses, pipes, and other critical infrastructure such as transportation, and in some cases, kill or severely injure people (Madsen and Figdor, 2007). Additionally, cleaning and remediating water systems polluted by runoff can be not only difficult and long-term, but also expensive (Blackwell et al., 2012).

Hazard mitigation planning in terms of flooding ensures social, environmental, and economic protection. Preventing and preparing for major storm and flooding events protects life, habitat, and property which in return, lowers the cost of recovery (FEMA, 2018). GI, along with grey infrastructure, helps communities become more flood-resistant by focusing efforts on urban areas that remain vulnerable to floods. While some GI techniques may have high initial costs, such as green roofs, they eventually save more money in the long term by reducing the volume of stormwater entering conveyance systems and the rate of runoff (US EPA, 2015). “Beyond code” (surpassing minimal building requirements) hazard mitigation has an overall benefit-cost ratio of 4:1 (See Figure 5). This means you can save, on average, around $4 for every $1 you put into mitigation (FEMA, 2018).

Figure 4

Hazard Mitigation Cost-Benefit Ratio



Note. Riverine flood mitigation grants and beyond code projects save more money than they cost. Federally funded riverine flood mitigation projects save significantly more money than they cost (with a 7x return on investment). Occupant safety is improved by both above-code design and public-sector mitigation for riverine floods. Figure source: FEMA, 2018.

c. *Public and Environmental Health*

Runoff not only causes water uninhabitable for aquatic habitats but also threatens human health. Inappropriately managed water causes serious illnesses and transmission of diseases for people who come into contact with dirty sand or water (Hu, 2020). For example, Puget Sound has a lot of recreational and water activities such as kayaking, paddle boarding, scuba diving, fishing, and much more. However, some of the parameters of the Clean Water Act that negatively impact Puget Sound include fecal coliform, temperature, pH, fine sediment, and dissolved oxygen due to excess nutrients (City of Olympia, 2016). Poor water quality from stormwater runoff, such as the elements mentioned, cause polluted beaches that can be unsafe for recreation and marine wildlife (City of Olympia, 2016).

Environmental protection contributes to economic prosperity. For example, in 2021, Washington's fishing, hunting, and wildlife-watching activities contributed over $4.5 billion each year in overall economic activity (WDFW, 2022). Without proper protection and conservation policies for clean water, recreational opportunities are at risk, opportunities which are important for economic growth (O'Driscoll et al., 2010). GI also prevents people from becoming ill in contaminated groundwater and recreational waters (Blackwell et al., 2012). Besides alleviating poor air quality and urban heat islands, GI protects communities built on shorelines and watersheds, preventing pollution from system overflows during heavy rainstorms (Hu, 2020).

1.5 Significance of Urban Trees

We need more GI stormwater management in urban areas as cities and populations grow. GI serves a multifunctionality purpose providing many socio-ecological and economic benefits and services that are not limited stormwater management (Monteiro et al., 2020). Although grey infrastructure does have practical and effective hydrological functions, it does not have the same environmental advantages (Szoenyi and Svensson, 2019). The environmental, social, and economic impacts of switching to GI won't compare to the consequences of stormwater water runoff from built environments, but the implementation of GI does not result in eliminating grey infrastructure. GI can help reduce the need to expand and rely on conventional stormwater management as both practices are beneficially used together (Fung et al., 2016). In this study, I will look at the role of urban trees in Olympia, Washington for stormwater management, specifically analyzing the value of potential pollutant removal efficiency, while also looking at the value of Yauger Park in water treatment cost reductions.

Methods

I obtained data that allowed me to assess the economic advantages of Olympia's urban forests using a number of different methods.

First, I adopted a model outlined in Snoqualmie's 2020 *Natural Infrastructure Assessment* done by the project team, The Keystone Concept, Equilibrium Economics, and Ecosystem Sciences. Snoqualmie's *Natural Infrastructure Assessment* focused on the economic value of forest ecosystem services and stormwater management benefits provided by the city's urban forests and how those forests will continue to provide if continuously maintained and well managed. Considering Olympia, Washington lacks data on urban trees and their role in stormwater management, conducting an analysis like the one outlined in the *Natural Infrastructure Assessment* allowed me to understand the role of Olympia's urban forests. This assessment was chosen to draw implications for Olympia's urban forestry for five main reasons:

1. The publication year: Recent -- conducted within the last year.
2. The location of the study: Both in Western Washington.
3. Climate change adaption and mitigation efforts covered: Focus on stormwater management, reducing runoff and erosion.
4. The type of green infrastructure: Urban trees and urban forestry.
5. The quantitative information on the co-benefits related to climate benefits.

To demonstrate the benefits of retained forest land within the city for stormwater and water quality, the Snoqualmie project team focused on three different city-owned forest cover classifications. These forested lands are outlined in three different case studies: contiguous to the Snoqualmie River and its tributaries, within Snoqualmie Ridge, and within City-owned right-of-ways (ROW). The data I chose to analyze for Olympia's urban trees was based on the case studies and framed around stormwater nutrients sequestered by urban trees and the value these forests provide to the city in terms of water quality. That included:

1. The effectiveness of urban trees and forests in removing and infiltration pollutants such as phosphorus and nitrogen that are common in stormwater.
2. The economic value of urban trees and forests in providing water quality, such as treating stormwater pollution

Local projections of the nutrients and pollutants removed from stormwater by an acre of forests were combined with the marginal cost of grey infrastructure water treatment to develop the annual dollar value per acre of water filtration provided by Snoqualmie's forests: Compounds Filtered from Water of Urban Forests (kg/acre/yr) x Marginal Cost of Conventional Filtration Infrastructure ($/kg).

$$\frac{Compound\ filtered\ (kg)}{Area\ annually\ (acre/yr)} \times \frac{Capital\ Cost\ (\$)}{Compound\ filtered\ (kg)} = \textit{Total value (acre/year) of water quality benefit of natural infrastructure.}$$

How the data in the Snoqualmie report had been processed was kindly provided by reaching out to the project team, Lance Davisson of the Keystone Concept, and Zac Christian of Equilibrium Economics. According to the project team, a transfer of benefits and values from previous studies was used to analyze stormwater benefits, including the amount of nitrogen and phosphorus sequestered and the separate market values for those nutrients. Local estimates of compounds filtered from stormwater of urban forests (kg/acre), for instance, were used from a 2013 study by Hill et al., using a benefit transfer of values approach. The authors looked at the benefits forests nearby headwater streams and catchments in Washington State provide to water quality. Data on catchment attributes related to the reduction of nitrogen, phosphorus, and total suspended solids were collected as part of the EPA's National Rivers and Streams Assessment.

A transfer of values was also used for the marginal cost of filtration infrastructure, provided in the report. One of the selected market values came from the US EPA's 2009 publication “Water Quality Trading Toolkit for Permit Writers.” These values were selected based on the most current and relevant market values. Relevance was selected based on non-agricultural costs for nutrient reduction to prevent overestimating market values (Christin, Davisson, Maguire, & Anderson, 2020).

Local estimates of acres of urban trees were obtained by submitting a general Public Records Request through Olympia’s Request Center online, asking “How many acres of urban trees are within the city of Olympia?” Using similar data processes and values from the Snoqualmie Assessment, I calculated the annual water quality benefits for Olympia’s urban trees. Data from the report was used to estimate the benefits and assess the implications of the potential economic benefits of Olympia’s urban forests for water quality and stormwater management.

The *Green Values* Stormwater Management calculator estimated the potential cost benefits for using GI to mitigate urban flooding. Each benefit (energy cost reduction, CO2 sequestration, air quality, real estate value, water quality, etc.) was represented in table, broken down by who receives those benefits (community or homeowner) as well as the associated annual value per unit. Specific benefits were chosen based on the relevance of the type of GI and its association with water quality and stormwater management. These values were used to assess the water quality treatment of Olympia’s Yauger Park stormwater retention pond.

Benefit transfer values are a more cost-effective alternative to analyzing and drawing conclusions from other studies than conducting primary research at a site-specific location, which can be costly. By applying values from earlier research to current research at comparable location sites, it allows people to make quick quantitative, detailed estimates about the benefits and values of their research area (Plummer, 2009).

Results and Discussion

Using the benefit transfer of values from the study by Hill et al., nitrogen and phosphorus sequestration in the Western Mountain ecoregion were estimated at 33.6 kg/ha and 1.4 kg/ha, respectively. I converted the units to kg/acre to match the units represented in the Snoqualmie report, which came out to be 13.6 kg/acre for nitrogen and 0.54 kg/acre for phosphorus.

A transfer of values was also used for the marginal cost of filtration infrastructure, provided in the report. Table 2 shows the annual high and low nutrient market values used for nitrogen and phosphorus provided in US EPA's 2009 Toolkit. I used these values to assess the annual dollar per acre of water filtration.

According to Olympia's Public Works Department, as of 2013, there were about 1,727 acres of conifer trees and 1,343 acres of deciduous trees, for a total of 3,070 acres of urban trees. There isn't any new or updated data on urban tree acreage, according to the city of Olympia.

Putting these values into the water quality benefits equation, I determined the estimated annual dollar value of water filtration provided by Olympia's urban trees as shown in Table 3. The total was rounded to the nearest dollar.

Table 2

Annual Value of Nutrient Reduction per Acre

Nutrient	**Amount Sequestered (kg/acre/year)**	**Nutrient Market Value ($/kg)**		**Value of Nutrient Reduction ($/acre/year)**	
		Low	*High*	*Low*	*High*
Nitrogen	13.6	$3.13	$5.88	$42.56	$80
Phosphorus	0.6	$2.61	$57.66	$1.56	$34.6
			TOTAL	**$44**	**$115**

Note. Shows the high and low values of nitrogen and phosphorus reduction ($/kg/year) in stormwater by Olympia's urban forests using the marginal value of nutrient reduction multiplied by the amount sequestered each year.

Table 3

Total Annual Value of Nutrient Reduction for Olympia's Forests

		Value of Nutrient Reduction ($/acre/year)		**Value of Nutrient Reduction ($/year)**	
Tree/Forest Type	**Acres**	*Low*	*High*	*Low*	*High*
Coniferous	1727	$44	$115	$76,195	$197,914
Deciduous	1343			$59,253	$153,908
Total	3070			**$135,448**	**$351,822**

Note. The annual value of nutrient reduction for the entire forest was calculated using the value of nutrients per acre per year from table 2, multiplied by the area of each forest type.

By applying the annual cost per acre for the water filtration that forests provide, I found the annual value of nutrient reductions for all of Olympia's urban trees. Assuming these trees are mature and still remain, I conclude Olympia's urban trees generate $135,448 - $351,822 annually in water quality benefits across the entire city. In contrast, the city of Snoqualmie's annual value for improved water quality of urban forests ranges from $117,780 to $301,880 (Christin, Davisson, Maguire, & Anderson, 2020). While Olympia's water quality benefit values are higher, it's important to note Snoqualmie is a smaller city and therefore has less urban tree coverage.

Yauger Park Case Study

Figure 5

Olympia's Storm and Surface Water Utility

Using the *Green Values Calculator Methodology,* Green Values show estimates of the savings on energy costs the home or building owner will receive, community benefits, and estimated real estate value as a percentage of the current value represented in Table 4 below.

Table 4

Homeowner and Community Benefits of Urban Trees

Benefit	Annual Value	Unit
Owner Benefits		
Reduced Energy Use from Trees	$36	Per Tree
Community Benefits		
Reduced Air Pollutants from Trees	$0.18	Per Tree
Carbon Sequestration from Trees	$0.12	Per Tree
Compensatory Value of Trees	$275	Per Tree
Water Treatment Cost Reduction	$29.94	Per acre feet
Groundwater Replenishment	$86.42	Per acre feet

Note. Annual value of urban tree benefits. Source: Green Values Stormwater Calculator, n.d.

Yauger Park in Olympia is critical to the city's stormwater management system. In 1977, the park incorporated a stormwater facility consisting of 29-acre retention pond when the Capitol Mall was built. Before the city built the park's stormwater facility, rainstorms caused nearby roads to flood. By design, Yauger Park is intended to flood, serving as a giant stormwater retention pond during heavy rainstorms to reduce runoff. The pond can hold up to nearly 27 million gallons of stormwater when full, preventing flooding from nearby roadways, homes, and commercial development (Stream Team, 2021). The retained and excess stormwater slowly drains to Black Lake Meadows Reserve through a combination of conveyance pipes and wetland channels where it is eventually released into Budd Inlet (Stream Team, 2021). Using Yauger Park as an example, I was able to calculate the total water treatment cost reduction of stormwater of the retention pond represented in Table 6. I also converted acre-feet into U.S. gallons to match the unit of Yauger Park's retention volume capacity as shown in Table 5.

Table 5

Reduction Rate Conversion

Stormwater Benefit	**Reduction Rate**	
Water Treatment Cost Reduction	$/Acre Foot	$/gal
	1	325,852

Note. A common unit of measurement in hydrology is the acre foot, which measures the volume of one foot of water on an acre of land. This equals to about 325,852 U.S. gallons.

Table 6

Total Water Treatment Cost Reduction of Yauger Park

Amount of Stormwater Detained (U.S. Gal)	**Reduction Rate (Acre Foot)**	**Value/Unit (Acre Foot)**	**Total Reduction Cost Rate**
27 million	82.85	$29.94	**$2,481**

Note. Yauger Park detains up to 27 million gallons, which is equivalent to 82.85 acre-feet. Using the cost reduction value of $29.95/acre-foot, the cost reduction rate of Yauger Park is estimated to be around $2,480.

Based on the Green Values calculator, the total estimated cost of water treatment reduction for Yauger Park is $2,481. On average, Olympia, WA receives 57.7 inches of precipitation annually with January, November, and December being the wettest months out of the year (Weather and Climate, n.d.). Based on this, I was able to estimate the retention pond floods, on average, about three months out of the year. As a result, Yauger Park's retention pond will save about $223,241 annually on water treatment expenses, assuming it rains enough for the pond to reach its maximum 27 million gallons.

Economic Footprint

With these estimates, the values of Olympia's stormwater benefits for urban trees and Yauger Park alone equals to about $358,696 - $575,069 annually as shown in Table 7. This does not include other types of green infrastructure and vegetation in Olympia, such as grass cover, urban parks, rain gardens, porous pavement, etc., which undeniably contribute to the overall water quality values. It is important to note that these two values are not related and are two different benefit transfer methods. The annual water quality for urban trees takes in account the nutrients sequestered from stormwater while the water treatment of Yauger Park contributes to cost reduction of avoided runoff. Regardless, both values contribute to stormwater quality and mitigation for the city of Olympia.

Table 7

Annual Stormwater Benefits for Olympia's Urban Trees and Yauger Park

Annual Water Quality Benefits of Urban Trees		**Annual Water Treatment Cost Reductions of Yauger Park**	**Total**	
Low	High	$223,247	Low	High
$135,448	$351,822		$358,696	$575,069

Note. The combined annual values of stormwater quality and benefits from urban trees and Yauger Park. Totals are rounded to the nearest dollar.

In contrast, new and retrofitted grey infrastructure projects typically have large costs for planning, design, maintenance, and construction (EFC, 2019). Currently, more than 100 stormwater outfalls connect to the downtown drainage system with Budd Inlet and Capitol Lake. According to Olympia's Capital Facilities Plan, the total cost estimate to improve water quality and manageability in Olympia's surface water through projects that treat contaminated stormwater water is around $3,000,000. Projects under the Capital Facilities Plan cover periods of five years (2020-2025) and this cost was calculated on a per-year expenditure. Overall, these water quality values provided by Olympia's urban trees highlight the substantial cost savings natural infrastructure contributes to water quality and stormwater management. These cost savings will also continue to provide water quality benefits if they are continued to be protected and well taken care of.

Benefits

Using Snoqualmie's *Natural Infrastructure Assessment* to apply data to Olympia's urban forests and trees not only highlights the benefits the role of urban trees in Olympia has for stormwater management but also allows for more research into the unexplored possibilities of Olympia's natural infrastructure. Snoqualmie also represents a relatively small town that has experienced rapid development due to population growth over the past several decades, similar to Olympia. On top of that, as the effects of climate change are predicted to worsen, shifting investment priorities and policy toward the protection and restoration of ecological resources can offer a more stable and sustainable basis for future economic and societal progress in Olympia. The estimates from the analysis presented here can also help the city regulate, protect, and plant more trees or build more green infrastructure as investments in protecting and implementing more tree planting provisions as well as other green infrastructure types generate positive economic and social outcomes.

Additionally, attempting to quantify the value of urban trees and the benefits they provide for stormwater management allows planners and policymakers to compare the capital costs and value of conventional infrastructure and manage natural resources more sustainably (Blackwell et al., 2012). This can have an impact on current and future city planning budgets for stormwater and wastewater. A dollar is a unit of value that is universally recognized, makes it easier for people to understand not only their economic value but also their relational value and ecosystem services they provide for urban communities. In exchange, monetary values on environmental services can influence our behaviors toward the environment, such as putting more effort into protecting natural resources. In terms of costs and advantages, it can also be helpful prioritizing between gray infrastructure and green infrastructure (Baptista et al., 2020).

Limitations

There are inherent limitations and disadvantages to any study, especially when the subject includes complex natural systems and transfer values. Although benefit transfer methods have many advantages, they also have their downsides.

These cost-benefit estimates may not be accurate. Reporting of existing studies may be inadequate to draw needed implications and conclusions on Olympia forests and current stormwater quality conditions.

Hill et al.'s 2013 study used data and literature from 2000-2012, therefore unit values of estimates were outdated by the time the article was published. Additionally, although the Western Mountains ecoregion in the study included western Washington, it also included areas such as Montana, Utah, New Mexico, Colorado, and California. This is likely due to similar tree species composition, but sequestration rates may not represent Washington as a whole considering climate characteristics and location can affect forests' ability to sequester nutrients. This is also true for the health of the forest, growth rate, size and maturity, and demographic structure. Averaging nitrogen and phosphorus sequestration rates for different states while taking these different factors into consideration may not be illustrative of the PNW or western Washington in general.

Local estimates of urban trees within Olympia were also outdated. Considering the city of Olympia has become increasingly urban, has made plans to build more green infrastructure for stormwater management (US EPA, 2015), and on the surface has pro-environmental attitudes, it's unknown whether the acres of forest have increased or decreased. That being said, given the dire need for more green infrastructure due to climate change and a growing population, the City of Olympia should keep this data updated. Additionally, data related to forest types, such as private vs. public, right of ways, species of trees, etc., were also limited.

Lastly, nutrients in the study were also limited to nitrogen and phosphorus. These nutrients are not only common, extensively researched, and are typically filtered by grey infrastructure, but were also limited in Snoqualmie's assessment. Although nitrogen is the primary contributor to hypoxia, which causes algae blooms and extreme stress on aquatic ecosystems (City of Olympia Public Works Water Resources, 2010; Hostetler et al., 2011), other pollutants in stormwater, such as tire particles (6PPD-Quinone), motor oil, and other particles, were not included in the analysis. Knowing how much of these pollutants can be avoided from runoff by Olympia's urban trees is beneficial considering these pollutants are ubiquitous in urban environments and cause degradation to water quality and marine ecosystems (McFarland et al., 2019).

Conclusion

Rapid development, along with climate change, poses serious threats to urban communities. As our cities grow, the urban trees and vegetation are replaced with impervious surfaces. Roads and other components of the built environment pollute water sources, such as Budd Inlet and Capitol Lake in Olympia, WA. In contrast, urban trees provide ecosystem services that are the foundation of economic prosperity and environmental health, mitigating ecological calamities associated with growing cities specifically stormwater management and water quality benefits. Healthy urban trees and other types of green infrastructure (GI) generate less runoff (reduces the amount of stormwater), allow infiltration (recharges groundwater), and minimize pollutants (decreases surface water contact), that flow into local waterways.

In this study, I found that Olympia's urban trees provide an estimated $358,695 - $575,068 annually towards water quality and stormwater quality benefits. Olympia still lacks adequate data relating to GI and its role in stormwater management with outdated data on urban tree acreage. These limitations highlight the need for more research on the stormwater systems associated with green infrastructure in Olympia as well as keeping tree inventory data updated.

Despite the limitations to these estimated values, nature provides many services and benefits for human survival. Urban trees and forests provide significant stormwater services, enhancing water quality, while simultaneously providing other benefits such as economic prosperity and healthy urban environments. However, not everyone acknowledges the services and economic importance nature provides. As a result, some people may overlook the interconnectedness of life on Earth and unintentionally exploit their natural resources (Bilmes, 2021). When the value of natural systems is acknowledged, it becomes evident that conservation and restoration projects can generate valuable socio-economic and environmental benefits in return. Unlike built infrastructure, natural structures don't lose value over time. Protecting and preserving natural systems from deterioration, development, unsustainable extraction, and other effects is essential if they are to remain effective and sustainable. If Olympia’s forests are properly managed and continue to be healthy, the city's residents will receive these economic benefits each year and indefinitely. Thus, GI provisions are an essential component in climate change mitigation and resilience in urban communities.

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