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Connecting Urban Residents to Their Watershed with Green Stormwater Infrastructure: A case study of Thornton Creek in Seattle, Washington

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A case study of Thornton Creek in Seattle, Washington

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*Photo on cover page: Author.

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TERMS AND DEFINTIONS

Point Source

A point source of water pollution that comes from an identifiable polluter, such as a factory or a sewer line, and flows into a waterbody.

Non-point Source

A non-point source of water pollution is a source of pollution that comes from many polluters that are not easily identifiable. Non-point source pollution sources include street runoff containing harmful heavy metals, or domesticated pet waste.

Stormwater

Water that falls in an urbanized landscape and flows to the receiving waterbody through constructed drainage systems throughout the city.

Impervious surface

Impervious surfaces are surfaces where water cannot percolate into the groundwater such as packed dirt, concrete and rooftops. Connected impervious area in urban watersheds conveys stormwater quickly and in high volumes to receiving waterbodies.

Conventional 'Grey' infrastructure

Conventional or grey infrastructure refers to the hard, engineered systems to capture and convey stormwater, such as gutters, storm sewers, culverts, detention basins, and related systems.

Green infrastructure

Green infrastructure is stormwater management that utilizes natural flows of water to enhance overall environmental quality and utility services, with combined goals of increasing other capacities such as water supply, community engagement, and quality of life.

Green infrastructure technologies

Green infrastructure technologies utilize natural systems of water management, such as infiltration and evapotranspiration, and the qualities of soils and plants to slow and filter stormwater. Sometimes called low-impact development (LID) technology, green infrastructure includes: rooftop vegetation to control stormwater and reduce energy use, restoring wetlands to retain floodwater, installing permeable pavement to mimic natural hydrology, and capturing and re-using water more efficiently on site, through bioswales, cisterns and rain gardens.

Swale, bioswale

A bioswale is designed to gather stormwater runoff. It is a low point or depression with underlying soils and rocks that are good at infiltrating stormwater runoff, usually with native vegetation that captures pollutants and soaks up water.

Best management practice

The management practices used for a site or area to collect, convey, or infiltrate stormwater. Can be either conventional or green infrastructure techniques.

Designated uses

The ways a waterbody is used, such as primary recreational contact. Water quality standards for waterbodies are associated with the designated uses of the water.

PROLOGUE

Fifteen years ago, public service announcements about stormwater from Seattle Public Utilities caught my attention. They featured Bert the Salmon, and Bert told me not to dump paint or wash my car in the street because rainfall on the streets drained to salmon-bearing streams in the city. My elementary school, named Thornton Creek, used salmon life-cycle curriculum in science classes. I volunteered with my classmates to restore small sections of native plantings in Thornton Creek natural areas. My family and I worked in volunteer groups to stencil the words “Dump No Waste, Drains to Stream” on storm drains throughout the neighborhood to raise awareness that our streets connected to the creek.

On a summer day in Seattle in 2013, I drove through curved residential streets, searching for the park, Ravenna Natural Area, indicated on a handwritten map from 1999. The map was made by a devoted naturalist and resident of the Thornton Creek watershed. A watershed resident myself, I was surprised I could not find this park. I had never been there before but it was only a few blocks away from my old high school. Frustrated, I parked my car behind “The Shutter Shop,” where a wall of green vegetation came up to meet the line of buildings. Ravenna Natural Area should be here.

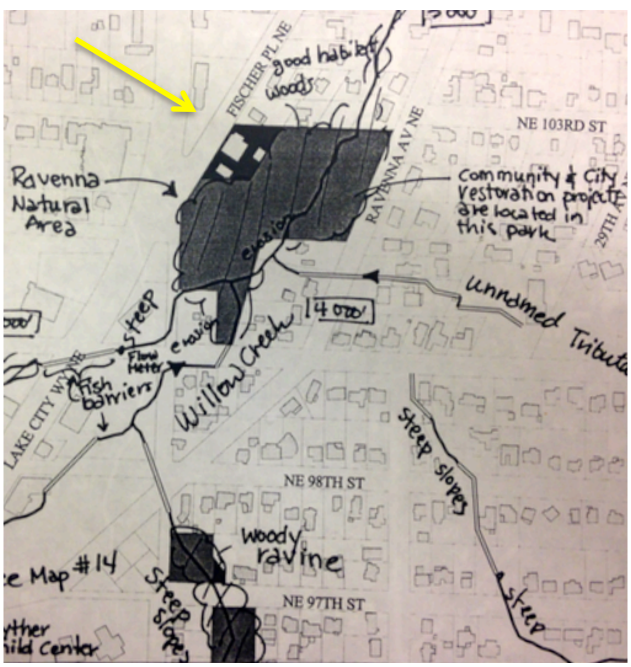

Figure 1. A portion of the watershed with hand-drawn details of habitat and stream shows the Ravenna Natural Area, also called Thornton Creek Natural Area. The yellow arrow marks where I tried to enter the park. (Thornton Creek Project 1999).

Figure 2. The view from the Ravenna Natural Area, indicated on the map in Figure 1, looking toward Fischer Place N.E. The entrance to the publically owned park is informal and unmarked. Photo by author.

walked toward the urban wilderness, feeling uneasy about whether or not I was trespassing to access the public park. Just past a dumpster and a pile of woodchips, I spotted the sign "Thornton Creek Natural Area. Preserved as an Open Space, City of Seattle Department of Park and Recreation." A small beaten path snaked down the slope to the right of the sign, leading eventually to the creek. The allure of finding the creek in the park led me a few yards forward, but then I looked back – not a soul in sight. I was well out of view of the busy street behind me. My pulse quickened as I realized the small pathway beaten down before me was used by those seeking a hiding place. I was afraid of what I might find. Quickly, I turned back to my car and joined the stream of cars on Lake City Way, people driving through the Thornton Creek watershed without a second thought of the mysterious and inaccessible wilderness below.

As a college student researching Thornton Creek, I found that the water quality in the creek is significantly worse since the passage of the Clean Water Act in 1972. Many residents in the watershed are not aware and engaged in the natural environment interspersed in the urban environment. I wondered if something could be done.

THORNTON CREEK WATERSHED MAPS

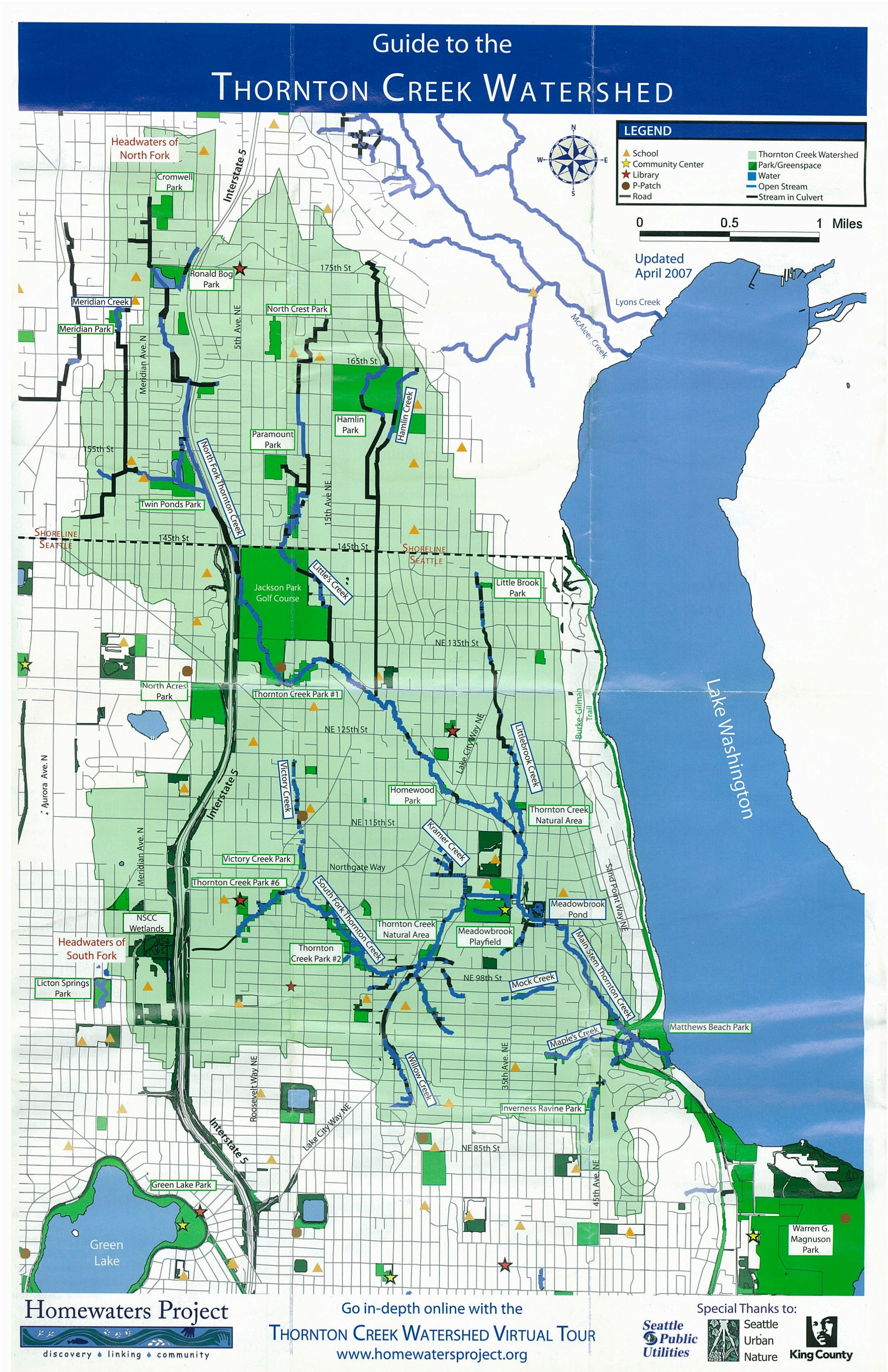

Figure 3. Thornton Creek watershed map shows boundaries, tributaries, parks and street grid. (Homewaters Project 2007).

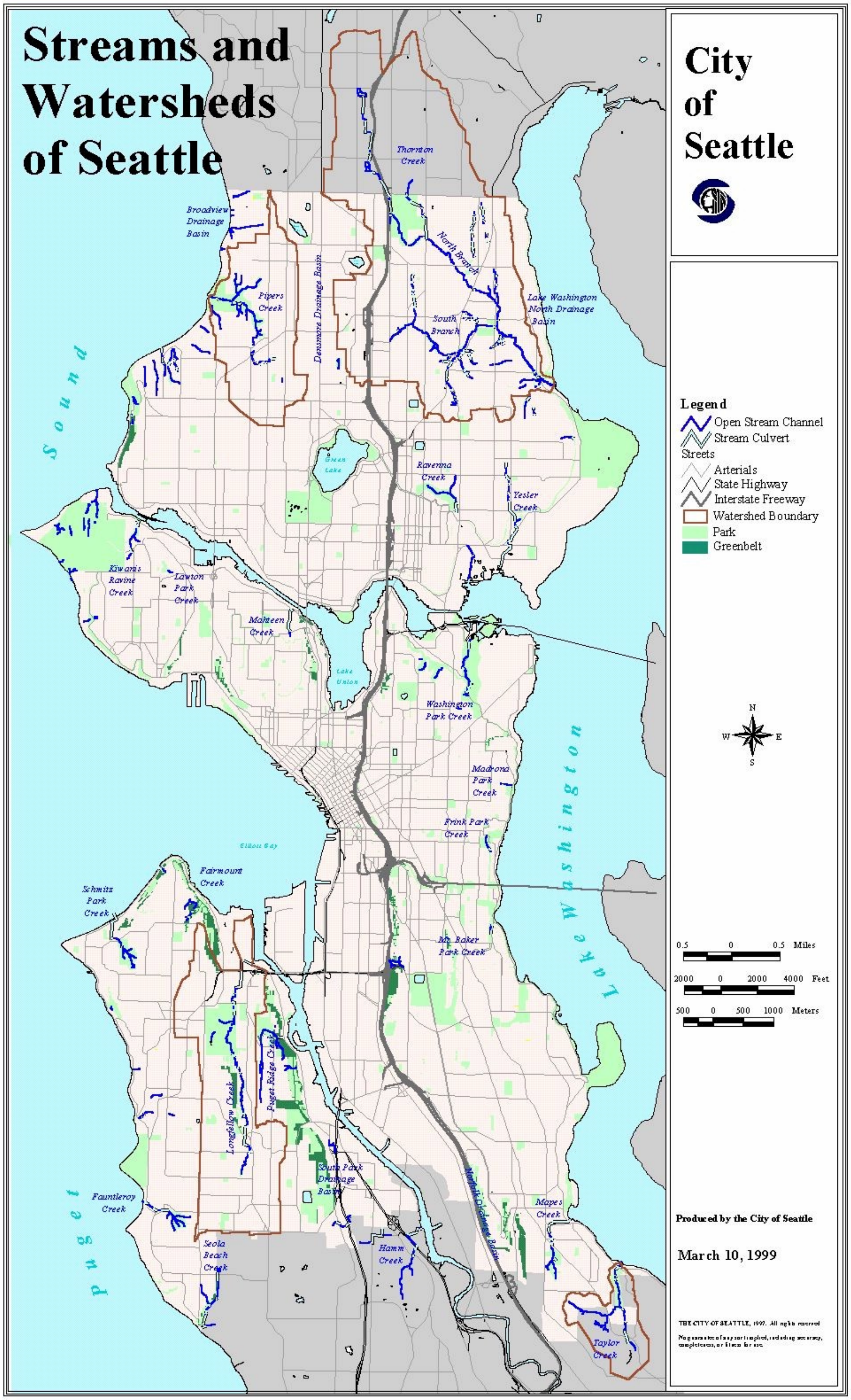

Figure 4. The Thornton Creek Watershed, highlighted in brown, lies in the northeast corner of the City, including the City of Shoreline to the north and drains into Lake Washington on the right. (Seattle.gov).

CHAPTER 1: INTRODUCTION

We all live in watersheds. These geographic boundaries carry water above or below ground that flows to the same place, such as a lake, stream, or ocean. As of 2013, there are 41,000 impaired water bodies nationwide (EPA 2013a). Polluted runoff from watersheds is the most common source of water pollution, but 78% of Americans do not understand that water running through watersheds in agricultural and urban landscapes is a leading source of pollution; in fact 47% believe that industrial sources, such as metals and toxics from a factory, account for most water pollution (NEEFT 2005). Despite regulations from the Clean Water Act in 1972 and subsequent actions by the Environmental Protection Agency to eliminate pollution discharges in U.S. waterbodies, many receiving waters from urbanized areas are highly contaminated from non-point sources of pollution, namely stormwater (EPA 2013b; EPA 2013a; Puckett 1995). Thornton Creek in Seattle, Washington, is a prime example of the problems in urban watersheds in the United States. Thornton Creek is a fully urbanized watershed and receives stormwater drainage from a mostly residential landscape (Trotter et al. 2009). The management of stormwater in cities focused on moving water as quickly as possible through the landscape and into receiving waters for the majority of the 20th century (Carter 1961). In 1987, the Environmental Protection Agency began regulating stormwater as a major source of pollution (EPA 2012). Stormwater accumulates pollutants from urban landscapes and moves them directly to receiving water bodies, increased flow volumes of stormwater also cause harmful erosion and flood damage (EPA 2013b).

Recently, planners, engineers, and designers have started to re-imagine the role of stormwater in our cities by viewing it as a resource, not a waste (De Guzman 2007). Green infrastructure enables this reimagining. Green infrastructure techniques manage the way stormwater flows through a watershed by restoring the natural filtration and movement of water through a watershed. Green infrastructure combines the benefits of improved water quality and flood control with the benefits of connecting residents the natural systems that filter and process water.

A Joint Report by American Rivers, the Water Environment Federation, the

American Society of Landscape Architects and ECONorthwest from April 2012 (Odefey et al. 2012) proposes the powerful notion that:

> "By shifting away from traditional “grey” [conventional] infrastructure and stormwater management to green infrastructure approaches to runoff management, American communities may realize significant cost savings, and reap additional economic and community benefits—in effect, creating healthier, more livable communities while addressing pressing water quality needs"

The promise of cost-savings and community benefits in stormwater management is appealing. Previous studies attest to the cost savings and water quality improvements from green infrastructure case studies (Horner and Chapman 2010; Council 2005; CNT 2010; Roy et al. 2008; Dawson and Cornwall 2007). The effectiveness of green infrastructure to improve overall community benefits from urban watersheds is largely untested. This thesis asks *can green infrastructure improve urban watersheds?*

I first approached the study of Thornton Creek as a study of water quality; I wanted to know if regulations and citizen activism on behalf of the creek had positive impacts on water quality. Upon investigation of the history, regulation, and quality of Thornton Creek I found that tracing water quality is only part of the story of the watershed's health and quality. The health of Thornton Creek depends on ecosystem services like access, education, and connection to the community. I wondered how a new stormwater management approach, green infrastructure, could improve the overall watershed health of Thornton Creek, not just water quality. Green infrastructure enhances natural systems and brings multiple benefits to communities.

I use a literature review and case study methodology of Thornton Creek to analyze whether green infrastructure can transform the political, social, and ecological factors leading to poor watershed health. The Thornton Creek watershed drains 12 square miles of the Cities of Seattle and Shoreline. The North, South, and Main branches of the creek cover 18 miles: it is the biggest and most polluted watershed in Seattle (Trotter et al. 2009; SPU 2007). The watershed contains 50% impervious surface, and Thornton Creek is on the Environmental Protection Agency's 303(d) List of Impaired Waters for violating temperature, dissolved oxygen, and fecal coliform standards (Ecology 2002; Ecology 2012). Thornton Creek is also underutilized: in 1998, half of watershed residents did not know that they lived in a watershed and could not name Thornton Creek (Watershed Characterization Report 2000). These problems compound each other by making broad-based political action difficult and cleanup efforts hard to enforce, thereby perpetuating underutilization of the city's largest watershed ecosystem.

Chapter 2 shows that conventional stormwater management and urban land use degrade water quality in urban watersheds. It introduces the green infrastructure approach to stormwater management through a review of ecosystem services and urban planning literature. Green infrastructure presents new ideas of infrastructure that enhance and mimic natural systems, providing benefits even when full restoration of an urban creek is not possible. The last section of this chapter explores how urban creeks can function as integrated and beneficial public spaces. Pedestrian safety on public streets can be enhanced by increased diversity and frequency of use. Similarly, pedestrian safety through urban creeks and natural areas can make urban creeks integral and special places within the city environment.

Chapter 3 tells the story of Thornton Creek's natural and political history, showing that residents have fought for meaningful integration of Thornton Creek into the urban environment, with partial success due to insufficient funding and political support for protection. Chapter 4 shows how framing regulation and projects in Thornton Creek around improving water quality has actually hampered improvements to overall watershed health. A singular focus on water quality miscalculates the successes and failures of a waterbody to provide meaningful services. Although water quality is important to delivering economic and community benefits, it should be one of many benefits promoted by City of Seattle, Environmental Protection Agency (EPA), and community groups.

Chapter 5 uses case studies of green infrastructure projects in Seattle, Washington and Sun Valley, California to show how green infrastructure in its design to improve both water quality and quality of life in urban watersheds, has promise. To successfully unite these goals into multi-beneficial green stormwater infrastructure, projects must consider community buy-in and long-term maintenance. Thornton Creek is indicative of many polluted urban creeks in the United States; the multiple benefits of green infrastructure have implications for deteriorating natural areas in all American cities.

In a highly urbanized watershed like Thornton Creek, full restoration to a functioning creek ecosystem is infeasible with current methods to mitigate stormwater pollution (Maxted and Shaver 1998; Galli 1990; Booth and Reinelt 1993). Thornton Creek may never function as a thriving salmon habitat and return to its pre-urbanization quality, but it can still provide other ecosystem services that are also key indicators of health in the watershed. These benefits include: wildlife habitat, rainwater storage and re-use, access to trails and bikeways, public spaces for community engagement education system engagement, shade protection, safe swimming contact, accessible open space/recreational opportunities, and aesthetics of the built and natural environment (Council for Watershed Health 2011).

Currently, the Thornton Creek watershed is missing a great opportunity to provide accessible open space, educational opportunities, and walkability for the vast majority of residents. These services are important to bring into city environments to improve health outcomes and make streets and neighborhoods safer (Jackson 2003; Cozens 2002). Urban creeks, similar to city streets, can be essential and meaningfully places in the city when they are accessible and safe (Jacobs 1961). As a set of technologies and an institutional approach to improving overall watershed health, green infrastructure, when implemented successfully, is a feasible solution to Thornton Creek's problems with water quality, flooding, safe access, and beneficial use. Green infrastructure, in its ability to achieve multiple benefits, can improve urban watersheds.

CHAPTER 2:
URBANIZED WATERSHEDS

Watersheds are areas of land bounded by hilltops or ridges, where all water above or below the ground runs to the same receiving waterbody. They are considered ecological boundaries; flows of nutrients, species, and water move within them. Watersheds naturally provide aesthetic and recreation value, increased property value, riparian habitat for wildlife, habitat for migratory birds and fish, natural filtration of pollutants, groundwater storage, sources of fresh water, and educational opportunities for residents and students (Costanza 1997). There are over 2,000 watersheds in the U.S. and the majority of watersheds are negatively impacted by urbanization.

Watershed Impairment and Urban Land Use

Researchers have identified that increased urbanization causes deleterious effects on watershed ecosystems. Degradation of biotic and abiotic watershed components from the harmful effects of urbanization jeopardizes and impairs the beneficial uses of watersheds (National Research Council 2009). The beneficial uses of watersheds to human beings and wildlife can deteriorate even with small changes in land use, from forest and riparian area to urban (Brabec 2002). The intensity of urbanization is connected to and represented by percentage impervious surface cover within a watershed (Epsy et al. 1966; Stankowski 1972). Impervious surfaces are usually cement or compacted soils that water cannot run through. Impervious surface cover correlates to degraded habitat health and the quality of receiving waters (Arnold and Gibbons 1996; Booth and Jackson 1997). The most common measurement of biotic degradation is the Benthic Integrity Biodiversity Index (BIBI), which measures species richness, abundance, and local indicator species. Impacts to BIBI such as declines in fish and macro-invertebrate abundance and diversity have been seen at 3.6-15% imperviousness in a watershed (Brabec 2002). Abiotic quality measurements such as stream habitat and chemical water quality were degraded from 4-50% imperviousness (Brabec 2002).

Impervious surface cover of a watershed is not the sole cause of water and stream quality changes, but rather indicates the combination of factors that cause deterioration.

These include changes in land use, constructed drainage systems, and non-point source pollutants. Urbanization involves the removal of vegetation and natural land cover, which takes away the water-retaining and evapo-transpirating functions of the natural landscape, decreasing groundwater stores and increasing runoff to receiving waters (National Research Council 2009). For many years, the primary concern of stormwater management was to move the highest volume of water off the land in the shortest period of time through constructed drainage systems (Carter 1961; Ellis and Marsalek 1996). Constructed drainage systems increase the frequency of rain events that contribute harmful sediments and alter streamside habitat by a factor of 10 or more (Booth 1991; Booth and Fuerstenberg 1994). Impervious surface replaces natural filtration and sequestration properties of vegetation and soil, and increases the conveyance of pollutants from urban landscapes to receiving waters (Arnold and Gibbons 1996). All of these changes in water volume and flow rate combine with the introduction of pollutants associated with lawn care, domesticated animals, motor vehicles and industry in urban landscapes, and contribute degraded water quality to receiving waters (National Research Council 2009; Booth and Jackson 1997).

Thornton Creek is estimated to have total land cover of approximately 50% impervious surface.[1] Horner et al. (1997), find that above 45% imperviousness in a watershed, riparian buffers ceased to protect biological integrity in case studies of Western Washington watersheds. Minimizing the deforestation and the harmful transformation of natural land cover is the most effective way to reduce negative urbanization effects (Bisson et al. 1987; Richards and Host 1994). In a developed watershed like Thornton Creek, forms of mitigation such as Best Management Practices (BMPs) and riparian buffers are less effective (Horner et al. 1997; Maxted and Shaver 1998; Booth and Reinelt 1993). Opportunities to save natural land cover passed at the turn of the 20th century when the land was logged and deforested, and again when the watershed was developed into residential and commercial land use from 1940-1980

[1] I used Geographic Information Systems (GIS) and land use data and estimations of impervious surface cover form the City of Seattle to analyze impervious surface, this map is provided in the Appendix. Total impervious area (TIA) has been estimated in the Thornton Creek watershed to be 59% (SPU 2007). My estimate and other studies of urbanized watersheds try to measure effective impervious area (EIA), which measures the impervious area that is connected to drainage, thus contributing runoff to receiving waters (Booth and Jackson 1997). Most of the literature on urbanization and watershed effects do not distinguish between EIA and TIA, as methods to estimate EIA are not standardized (Brabec 2002).

(Trotter et al. 2009). Literature on watershed management suggests that high levels of urbanization (30-50% effective impervious area) make poor in-stream habitat and water quality inevitable. The impacts of urbanization can be mediated at moderate levels, usually measured between 10-30% impervious surface (Brabec 2002).

Conventional infrastructure causes ecological damage through conveying high water volumes, collecting pollutants on impervious surfaces, and clearing native and existing vegetation. Conventional stormwater infrastructure also removes other beneficial aspects of natural systems to urban areas and residents such as public access to streams, walking trails, shade protection, noise reduction, and green space for recreation and learning. Examples of conventional infrastructure abound: highways, street drains, large water treatment plants, rooftop drains, parking lots and driveways. Conventional mitigation strategies for stormwater problems such as flooding and water quality degradation often fail to effectively reverse the damage of these drainage systems on water and stream quality. Mitigation strategies include retention and detention (R/D) ponds and bypass drains that hold large amounts of water. These prevent flooding downstream or take stormwater flows directly from an upstream catchment to the receiving water body, bypassing areas at risk to flooding. Booth and Jackson (1997) evaluated the efficacy of R/D ponds in Western Washington to reduce stream channel augmentation and found that this technique rarely succeeded in the stated goals of the project. In theory, these ponds reduce peak runoff volume and duration, preventing the deleterious effects of high volumes on stream channels and ecosystems. In practice, R/D ponds are not built large enough to correct flow changes, and do not make economic and social sense to planners and developers (Booth and Jackson 1997).

In the United States there is a long legacy of building cities with single use infrastructure to control and change flows of water and nutrients, as opposed to mimicking natural systems. New ideas about the role of infrastructure expand the management of stormwater from a drainage project to an ecosystem project, and combine the natural services of functioning ecosystems into planning and engineering (Wells 2013). In Thornton Creek it is not feasible to consider full restoration, but there are other actions that can mediate the problems of flooding while also making the community more livable and welcoming (R. Horner, pers. comm., 8/5/13).

Green Infrastructure, Mimicking Natural Flows

Green infrastructure, sometimes called low-impact development, is an approach to stormwater and set of management techniques that improve water quality, reduce stormwater quantity and provide community and economic benefits (EPA 2013b). Green infrastructure approaches allow cities and residents to improve other ecosystem benefits even when large reduction of impervious surface and noticeable water quality improvement is possible. The EPA has endorsed green infrastructure as a solution that mitigates stormwater effects such as flooding and water quality impairment, while also providing benefits to communities in the form of open space and aesthetics (EPA 2013b). Green infrastructure technologies slow the flow of stormwater through urban watershed and remove pollutants from the water effectively (Horner and Chapman 2010; De Guzman 2007, Council 2005). These technologies include: downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, green roofs, urban tree canopy and land conservation (EPA 2013c). Green infrastructure captures and infiltrates stormwater at the site of runoff production using bioswales, cisterns, infiltration, permeable pavement, and native vegetation. Green infrastructure can make stormwater infrastructure multi-beneficial, improving community aesthetics, recreation, and connection to nature through redesigning urban interactions with water, connecting residents to the larger hydraulic and natural systems that flow through the city.

Richard Horner, professor at the University of Washington and noted stormwater analyst, commented there has been a promising change over the past ten years to integrate multi-beneficial stormwater management in Seattle and the Pacific Northwest, but even more so in California and Los Angeles (personal communication, 8/5/13). Adel Hagekhalil, assistant director for the Los Angeles Bureau of Sanitation (2013) explained at the LA River Watershed Conference that the department is shifting its focus to incorporate green infrastructure. This is a paradigm shift away from the large, centralized projects of stormwater conveyance, toward decentralized and ecosystem specific management of stormwater, utilizing the natural systems that deal with water filtration and storm events. Table 1 identifies key differences between conventional and green infrastructure approaches to managing stormwater.

Table 1. Features of conventional and green infrastructure, adapted from Walker Wells (2013).

Conventional Infrastructure	Green Infrastructure
Large-scale	Small to medium scale
Centralized	Decentralized
Demand-based	Service-based
Single function	Multiple functions
Energy or chemically intensive	Energy efficient, no or low chemical use
Disconnected from natural processes	Builds on or supports natural processes

Green infrastructure mimics ecosystem functions that provide multiple types of direct and indirect services to humans (Wells 2013). The ecosystem functions provide both direct (ex: food productions) and indirect (ex: pollutant removal through groundwater infiltration) ecosystem services (Costanza 1997). Many of the ecosystem services in cities are indirect because food, water, and materials production is imported from outside of metropolitan areas. Urban ecosystems provide unique benefits to city residents that are still vital to quality of life. These include air filtration, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values (Bolund and Hunhammer 1999). Table 2 lists all benefits of green infrastructure identified by the EPA and case studies throughout the United States.

Table 2. Green infrastructure delivers a multitude of ecosystem services. These can be divided into community, economic, and ecosystem benefits (Watershed Characterization Report 2000; Bolund and Hunhammer 1999; Nonpoint Source Control Branch 2007; Roy 2008; CNT 2010).

Community benefit	Economic benefit	Ecosystem Benefit
✓ Recreation active use ✓ Recreation passive use ✓ Education ✓ Aesthetics ✓ Cultural heritage ✓ Community gathering ✓ Traffic calming ✓ Reduced heat-island effect (micro-climate regulation) ✓ Noise reduction	✓ Property value increase ✓ Avoided flood costs ✓ Non-potable water use ✓ Lower infrastructure capital costs	✓ Air filtration ✓ Pollutant filtration ✓ Wildlife habitat ✓ Groundwater recharge ✓ Peak flow regulation ✓ Climate change resiliency

Ecosystem services are not usually included in cost-benefit analyses, leading them to be undervalued and underrepresented in decision-making (Scarlett and Boyd 2011). The EPA and state and local agencies promote green infrastructure as an approach to water quality permit compliance (Ecology 2013) and as a way to protect, utilize, and enhance the ecosystem functions that humans enjoy (EPA 2013d; SvR Design 2009, Hagekhalil 2013).

Various green infrastructure projects have been implemented throughout the United States over the past 20 years. Results from these projects show improved ecosystem function and services delivery as well as costs savings over conventional infrastructure. The City of Seattle reduced infrastructure capital costs by investing in natural landscaping to reduce stormwater runoff, these technologies cost 25% less than equivalent conventional or grey infrastructure (Scarlett and Boyd 2011). Three case studies from Virginia identified reductions in infrastructure costs of 47.2%, 14.5%, and 49% compared to conventional development (CWP 2000). The Oregon Museum of Science and Industry in Portland saved $78,000 by using vegetated swales instead of conventional stormwater management to convey and treat runoff (Lehner et al. 1999). Developers of Prairie Crossing (a residential development) in Grayslake, Illinois saved $2.7 million by using swales, prairie, and wetlands for stormwater conveyance and treatment, and eliminating curb and gutter (Lehner et al. 1999; CWP 1998).

Green stormwater infrastructure removes pollutants more cost-effectively. While conventional infrastructure mitigation strategies such as R/D ponds are capable of removing considerable amounts of pollutants e.g. 65% removal of total suspended solids; (Wossink and Hunt 2003), green stormwater infrastructure can provide nearly complete removal of many contaminants from small runoff events (Lloyd et al. 2001; 2002). Intact riparian forest buffers remove an estimated 21 lbs. of nitrogen (a pollutant in stormwater) per acre per year for $0.30 per pound, compared to $3 to $5 per pound for Washington, D.C. area wastewater treatment facilities (CBP 1998).

Some green infrastructure techniques involve ‘smart growth,’ development or redevelopment designed to minimize impervious surface and retain or increase vegetated areas. Smart growth includes building sidewalks on one side of the street, minimizing culdesacs, using bioswales in appropriate locations, reducing parking lot coverage, using on-site stormwater control measures, and implementing land use regulation that limits concrete coverage. Building in this way can result in 45% more land preserved, 45% less in infrastructure costs to a city developer, and a 50% reduction in impervious surface due to roads (Siemon, Larsen and Purdy, 1990). This yields considerable cost-savings: the cost to treat the quality and quantity of stormwater from a single impervious acre can range from $30,000 to $50,000 (CWP 1997).

Green infrastructure techniques and design can provide economic benefits to residents, and provide ecosystem services such as climate control. Developers in Maryland say they receive 10 to 15% premiums for lots adjacent to forest and natural buffers (CBP 1998). Homes near seven California stream restoration projects had 3 to 13% higher property values than homes on unrestored streams. Most of the perceived value was due to enhanced buffers, habitat, and recreation afforded by the restoration (Streiner and Loomis 1995).

Economic costs such as capital, maintenance, and pollution control are easily quantified. Many benefits from green infrastructure projects are not easily quantified, but they are still real benefits. The Tualatin Basin in Oregon combined Clean Water Act permit renewals for four wastewater treatment plants and a stormwater permit into an action to meet water quality standards for water temperature. This action subsidized payments to farmers for planting trees on adjacent property along the river, costing $6 million to cool the river water to ambient standards. A conventional infrastructure solution, refrigerating systems at the treatment plants, would cost $60 million (Scarlett and Boyd 2011). This approach cooled the river more cost-effectively while also increasing community use of the river and mitigating wind and temperature extremes in the area (Scarlett and Boyd 2011).

There is a growing trend in stormwater management to unite ecosystem benefits such as park space, energy-savings, wildlife habitat, and street greening into the traditional duties of stormwater infrastructure. Evidence from previously conducted studies shows that green infrastructure technology and projects can yield community, ecosystem, and economic benefits to urban areas. If implemented on the watershed scale green infrastructure can be a more sustainable and cost-effective management of stormwater (Dawson and Cornwall 2007; Roy et al. 2008).

Despite its benefits, green infrastructure is still a hard sell. As recently as 2008, the vast majority of new stormwater management infrastructure utilized stormwater drains with limited treatment from conventional infrastructure solutions such as detention ponds (Roy et al. 2008). This is because the impacts of small green infrastructure installations have uncertain and variable effects on stormwater volume or pollutant load, and represent a risky investment to drainage utilities and city governments charged with pollution and flood control (K. Lynch, pers. comm., 7/19/13). However, the other ecosystem services provided by green infrastructure, such as walkability, green space, education, reduced traffic speeds, and increased property values, all make these investments less risky even if water quality benefits on the watershed appear small.

Landscapes and Infrastructure: Integrating nature into city life

Management of stormwater in urban watersheds is dominated by single purpose infrastructure. Through the gradual division of disciplines in city and regional governments – parks and recreation, public health, public utility, transportation – naturally unified systems within cities are split (Wells 2013). City organizations and regulatory agencies split responsibilities over a watershed separately into engineering, design, and planning. For example, the City of Seattle Department of Park and Recreation is involved in the design and maintenance of Thornton Creek parks while Seattle Public Utilities manages Thornton Creek flooding and water quality problems. This inhibits the collaboration needed to develop multifunctional, environmentally sound infrastructure (Wenk 2007).

Infrastructure engineers have a limited focus on water quality or flood control and compliance with federal and state water quality standards and permits. Requirements for drainage utilities are framed in terms of water quality and flood management (Ecology 2013), inhibiting the ability for infrastructure to include other benefits that are degraded through the urbanization and neglect of watershed ecosystems, such as human interaction with natural systems (Wenk 2007). This usually results in single-use projects that add little value to the community other than to reduce engineering costs and comply with regulations, missing opportunities to enhance and connect the specificities of climate and environment to community services (Wenk 2007).

William Wenk, a contemporary expert in Landscape Architecture, develops multi-benefit solutions to non-point source pollution problems. Wenk updates the landscape theory of Ian McHarg's 1969 *Design with Nature.* McHarg advocates architecture, design, and planning that work with regional ecological attributes; he described an approach to designing with natural flows of water and habitat, and building to reduce harm to ecosystem functions. Wenk (2007) fills the gap between McHarg's ideas of regional ecological planning and the reality that city governments and planners must design within existing development. He creates urban spaces that serve as formal and designed urban parks and are also effective in the management of stormwater cleaning. His green infrastructure approach unites natural processes such as water flow and infiltration with resource conservation, protection, and also recreation, and aesthetics, and education (Wells 2013).

The health and quality of urban watersheds suffer from being used as drainage for the city surrounding them. The traditional division of city departments limits restoration and redevelopment in urban watersheds in the United States. Green stormwater infrastructure reimagines the confines of stormwater management and can provide benefits for the community in ways that conventional infrastructure does not.

Eyes on the Urban Creek: Increasing public investment through safety

In urban spaces, such as city streets, diversity and frequency of pedestrian use make public spaces safe, accessible, and special to the surrounding community (Jacobs 1961). Jane Jacobs, an urban planner from New York famous for her controversial and ultimately triumphant theories of urban development, can be adapted to problems facing urban creeks. Jacobs' concept of safe streets can be applied to urban parks with clear applications for effective stormwater management projects. If safe streets encourage community buy-in and engagement, similarly, safe parks in urban environments should encourage community buy-in and engagement.

Jacob's 1961 treatise, *The Death and Life of Great American Cities* revolutionized urban planning (PPS 2006). Jacobs advocated a place-based, community-centered approach to cities (Wells 2013). Her ideas came from observations of city life; she held no degree in urban planning or accreditation. Jacobs' planning ideas such as mixed-use development, short blocks, and dense urban centers with office and housing space starkly contrasted the popular ethic of post World War II designers (PPS 2006). Jacobs believed in the spontaneous and often-messy arrangement of people and purpose within a city, and that through this conglomeration of use and humanity, thriving and functional elements come forth. This functionality in urban design is also a key criterion for functional stormwater management projects. Project managers call this 'community buy-in,' when the community develops pride of ownership over a park, sidewalk, median, or other public fixture and multiple uses come forth (E. Alduenda, pers. comm., 11/7/13). The level of involvement through the design and implementation process affects community buy-in to any public project. This is particularly true for stormwater projects that involve vegetation and natural areas, these projects work when the public feels safe using the space created by the project (E. Alduenda, pers. comm., 11/7/13).

Jacobs argued that irregular or disorderly street patterns promoted multi-use and made streets safer and more livable. Jacobs' "The Use of Sidewalks: Safety" pinpoints streets as the heart of the city, the most distinguishable component of city life (Jacobs 1961). If a street is safe and interesting, then the city is safe and interesting. Her theory of street safety called 'eyes on the street' comes from the observation that safety, particularly for women and children, in urban environments comes from the use of the space by an ample and wide variety of people. Jacobs has three main criteria for safe streets: clear demarcations between private and public space, buildings oriented toward the streets, and a continuous flow of people. These criteria work to create a sense of safety, where strangers can pass and co-inhabit the city. When approaching a street or area that is regarded as unsafe, planners can incentivize business to the street as a way to increase human activity. Increased foot traffic and business in an area can also attract casual recreation for those who wish to people watch. Whether the co-inhabitants of the space are friends or complete strangers, a busy public space provides a feeling of safety, that a constant stream of people is watching the area (Jacobs 1961). Conversely, if a street has the reputation of being dangerous, those in fear will avoid it, the diversity of people on the street will decrease, frequency of visits will decrease and the street will become less safe (Jacobs 1961).

Thornton Creek parks are mostly concealed from view of the streets in surrounding neighborhoods and lack formal signage and entrances. In Seattle, residents have a high portion of parks in the city, but the parks of Thornton Creek run through residential areas and are cut between heavy arterial roads. Most of these areas are hidden from the view of the street and regarded by the community as a ravine; these parks are also utilized for illegal dumping. There are exceptions to this, for each park there are members of the community who host work parties to remove invasive species and plant native species of plants. For them, the parks provide reprieve from urban life. But to the unfamiliar visitor, the parks seem unwelcoming and potentially dangerous. Perceptions of danger in a public space are self-perpetuating: improving the perception of safety in Thornton Creek natural areas can increase use, while perceptions of danger are associated with avoidance and decreased use (Schweitzer, Kim and Macklin 1999; Werekle and Whitzman 1996; Koskela and Pain 2000; Nassar and Julian 1995; Nassar 1998). Visual and physical access to greenery and natural spaces in urban environments improves health outcomes (Jackson 2003). The lack of access to Thornton Creek's parks presents a key missed opportunity for residents.

Jacobs' safe streets include clearly marked public spaces; this encourages and invites people to move through them (Jacobs 1961). Achieving the clear delineation of public and private property in Thornton Creek is difficult. The creek runs through over 700 backyards and 15 publically owned parks and natural areas.[2] In Thornton Creek many areas are not clearly marked as public or private and these distinctions are unclear to residents (Watershed Characterization Report 2000).

Natural areas and green belts in cities can have the dual effect of decreasing crime and improving health outcomes while also increasing perceptions of danger. Depending on the level of coverage and clear sightlines between vegetation, a natural area can improve the feeling of safety in an urban area or make it worse. Residents in urban areas do value having trees and nature integrated into the cityscape, but also express concern about lack of visibility from vegetation (Kaplan and Talbot 1988). Placing trees in the right-of-way, transforming vacant lots into parks, and implementing green landscaping have all been found to reduce violent and petty crime (Wolf 2010; Lorenzo and Wims 2004; Donovan and Prestemon 2012). Safety ratings from 17 urban parks and recreation areas show that people feel most vulnerable in densely vegetated and forested areas, and felt the safest in green spaces with open and mowed lawns (Schroeder and Anderson 1984). Greenways have been found to have no significant difference in increasing crime

[2] There are two additional parks, privately owned but open to the public: Meadowbrook Pond, owned by Seattle Public Utilities, and North Seattle Community College Wetlands.

in adjacent homes, though residents express increased feelings of insecurity with proximity to green spaces (Crewe 2001). Community buy-in depends on involvement through the design and implementation process, but in particular for stormwater projects that involve vegetation and natural areas, depends on considering the perceptions of safety and access in the project.

Urban watersheds suffer from a legacy of stormwater management that harms ecosystem function, as well as urban planning that divides the natural watershed functions between departments, further estranging and breaking up the functions of ecosystems in urban creeks. Green infrastructure has potential to address problems in urban creeks. Restoration in conjunction with the creation of public space and green infrastructure can produce combined benefits that are more impactful than any one endeavor. To effectively implement green infrastructure requires a high level of public understanding and buy in.

CHAPTER 3: HISTORY OF THORNTON CREEK

"Can you really have it all? Buildings and cities and salmon? That's the question."[3]

Seattle, the Emerald City, is home to 634,535 residents and brimming with greenery - tree-canopy covers 23% of the city (City of Seattle 2013).[4] Lake Washington, Elliot Bay, and the Puget Sound surround the city (See Figure 4), and residents are proud of the natural beauty woven seamlessly into the city (Mapes 2010). The City has worked to conserve and promote valuable natural resources; 14% of land use in the city is park and green space (DPD 2013) and the City of Seattle has recently implemented policy and planning to increase tree-canopy cover, increase alternative transportation, and incentivize green building to cut down on waste production and energy consumption (The Economist 2011). Thornton Creek is the largest of five watersheds within the city but the most polluted and despite Seattle's commitment to green space and conservation, Thornton Creek contains only 9% park and open space and has more heavy commercial land use than any other watershed in the city (SPU 2007). The following section tells the history of land use and political action in Thornton Creek. It shows how the ecosystem holds a special place in the urban landscape, but citizens lack tools to protect parts of Thornton Creek and government agencies have not prioritized maintaining the community benefits of the ecosystem.

The Creek Is Cared For But Not Clean

Seattle residents share an affinity for the wildlife of the Pacific Northwest. Salmon in particular are an emblem of the region; figures and stories of salmon are important pieces of Seattle residents' sense of community. The waterways in Seattle support many species of pacific salmon: Chinook, Chum, Coho, Pink, Sockeye, Cutthroat Trout, and Steelhead (Grishman 2013). Sockeye salmon migrate from the Cedar River Watershed, a healthy and functioning watershed, through Lake Washington, and other highly developed waterways to the sea. However, the last Sockeye fishing season was in

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3 Pat Pattillo, in Mapes 2010.

4 Tree canopy cover in Seattle is behind Portland (29.9%) and ahead of Los Angeles (21%). Seattle population lies between Portland (603,106) and San Francisco (825,863)

2006, and in 2010 sockeye counts were the lowest on record (Mapes 2010).

In September of 2010 the Seattle Times' Lynda Mapes contrasted residents' love for salmon and the sobering reality that Seattle's waterways can no longer support these creatures. Despite declines of salmon and loss of habitat (Grishman 2013) salmon feature prominently in public festivals and school curricula. Pat Pattillo works in the Department of Fish and Wildlife, his testimony paints this problem clearly,

> "[Pattillo] grew up in Seattle back in the days when you could grasp salmon right out of Thornton Creek — today one of the city's most hammered urban streams. But nobody's giving up on it, either; we've spent millions to improve and even daylight stretches of the creek through the baking pavements of North Seattle. "It's really about the values of the Northwest," Pattillo says. "There have always been salmon, and we want to believe there will always be salmon.'"

Thornton Creek is a valuable asset to the community as a symbolic representation of nature; residents of the watershed and of Seattle treasure the creek system and dream that one day they may catch a glimpse of a heron catching a trout or Coho salmon swimming up the creek to spawn (Mapes 2010). However this general interest falls short of advocacy and involvement in Thornton Creek. In May 1998, a marketing firm hired by Seattle Public Utilities surveyed 1% of households in the watershed. The 95% confidence interval for this survey is +/- 5.3%. Only 31% of respondents could name Thornton Creek. Of those respondents who were familiar with Thornton Creek, about half thought the streams were private, half perceived no pollution problems, and half were not aware that the stream still supported some salmon. About 61% of those aware of Thornton Creek felt creek restoration was a source of community pride. The most important benefit to improving Thornton Creek was fish and wildlife habitat, and the second was enhancing community image (Watershed Characterization Report 2000).

Despite the care and consideration for Seattle's waterways and rich natural history, Thornton Creek is not clean. Indicators of water quality have worsened over time[5] and watershed health is low. Many ecosystem services are impaired to the extent that the surrounding community cannot enjoy them. For a creek like Thornton Creek that is very polluted and impacted by the urbanization, it would take a really big, fundamental change in the watershed to get an incremental increase in the prevalence of sensitive

[5] Water quality data in Thornton Creek from 1971-2013 can be found in Figures 6 and 7, and Tables 3 and 4.

species such as salmon. Unsafe levels of E. coli found in the creek from samples taken over the past three years indicate that Thornton Creek is no longer safe for other beneficial uses such as primary and secondary human contact (Frodge 2013). Sources of this E. coli may come from old and collapsed sewer lines, leaching sewage through the groundwater and into Thornton Creek, and illegal RV sewage dumping and homeless living on the banks of Thornton Creek (Frodge 2013).

Thornton Creek: Natural history and land use change

The Thornton Creek watershed covers approximately 12 square miles of what is now Northeast Seattle and a portion of the City of Shoreline in King County, Washington (Figure 4). David Buerge (1984) wrote a piece for Seattle Weekly "Indian Lake Washington," describing the cultural and natural history of pre-European settlement in Thornton Creek. The Lake Washington ecosystem provided rich resources for an estimated 18 Native American tribes in the area who lived there for over 5,000 years, Buerge (1984) explains,

> "The large lakes of the area provided their early users with an amazingly rich variety of resources… the lakes had their own large resident populations of species like the kokanee and others like suckers, chubb and peamouth…. There were also waterfowl and large populations of muskrats, beaver, otters and other animals that were hunted and trapped. And there were edible plants too, like the wapato, the water lily whose seeds ground to paste, and the cattail whose root was edible and whose pithy stalk was used to make mats."

The Tu-oh-beh-DAHBSH tribe lived at the mouth of Thornton Creek and relied on the rich fishery in Thornton Creek and the cranberry bog at the origination of the South Fork, now the site of Northgate Mall, America's first mall (Watershed Characterization Report 2000). They employed a system of cooperative fishing weirs, splitting up rights to fish at different times of the year between groups (Watershed Characterization Report 2000). European settlers logged the mature stands of conifer forest that covered the Lake Washington area; US Geological Survey (USGS) maps dating back to 1894 reveal that the entire Thornton Creek watershed, indeed much of area west of Lake Washington, had been logged by then (Watershed Characterization Report 2000). Native American groups lived at Thornton and around Lake Washington until 1860, but most of the population was either removed to reservations or had vacated the area by 1890. In 1916 the US

Army Corps of Engineers created the Ship Canal between the Puget Sound and Lake Washington, significantly decreasing the lake level, by as much as 9 feet (Buerge 1984). Buerge describes that ecological and social effect on the entire Lake Washington ecosystem,

> "The marshes that sheltered vast populations of waterfowl were left to dry out and be overgrown with willow and cottonwood, and even though they eventually restored themselves at a lower level, the birds never returned in anything like their former numbers. Nor did the muskrats, the Sockeye, and any of the other fish whose gravel spawning beds were exposed to the air. The water lilies and cattails took years to reestablish themselves, but the wapato seems to have disappeared altogether. And so, the wading root gatherers and the flickering lights of the duck hunters were seen no more…"

From the 1910's to 1940's land use in the watershed continued to change as the area was developed into agricultural land and rural residential housing (Trotter et al. 2009). Although water quality data from this era does not exist, historic accounts of Thornton Creek give evidence that fish populations thrived in the creek system, along with many other types of wildlife. Dorothea Nordstrand (1916-2011) lived close to Thornton Creek during the 1930s. Her stories capture the essence of Thornton Creek as a rural, remote, and wild place (Nordstrand 2001):

> "It was a lovely, wooded area, the first such just a few blocks north of our Green Lake community. A pathway ran beside it. There was a canopy of trees, and mounds of tender undergrowth which ran down to the mossy banks. There were fish, and lots of wildlife. Many wild birds, the darting kingfishers, and an occasional Great Blue Heron to wade in the clear shallows. Squirrels, muskrats, raccoons, and mink lived there. Thornton Creek was a lovely, green place. Many neighborhood folks fished there, and had picnics on its banks. It's pleasant to remember. "

Urban and residential development grew rapidly in Thornton Creek after World War II. The population grew from 2,898 in 1920 to 17,500 in 1940 and reached 43,680 by 1950 (Lake City Journal 1977 in Watershed Characterization Report 2000). The area was developed under King County jurisdiction, not yet annexed by the City of Seattle, and streets were built under much more lax development codes. Most of the streets lacked grading, sidewalks, or gutters – creating issues of walkability and property damage, while stormwater runoff increased to the creek, gouging deeper and altered streams and flow patterns (Watershed Characterization Report 2000). By the 1950s the watershed was served by a sanitary sewer system. The Lake City Sewer District used a separate sewer system and treatment plant to treat wastewater and discharge into Lake Washington but stormwater runoff was directed into Thornton Creek (Brown and Caldwell 1958).

Activism on behalf of Thornton Creek as a cultural and ecological cornerstone of the community began in 1969, after the majority of the major roads, commercial districts, and infrastructure was in place. In the late 1960s and early 70s, Thornton Creek was still characterized by large and wild open spaces (Duncan 1961), but the development of the watershed led to exacerbated problems of flooding (McKim 1968). Intensifying development of Thornton Creek's remaining open spaces caused citizens to band together and demand protection of the watershed's natural areas. Citizens advocated for updated zoning to restrict development, city funds to buy out land for conservation, and the creation of trails through the watershed (Schwartz 1969; Lane 1970; Suffia 1969).

In 1969, a section of land adjacent to Thornton Creek was zoned for duplex housing and apartment complex was planned for the area (Schwartz 1969). Neighbors were appalled because the development would drastically impact the Thornton Creek natural area that was a haven for wildlife, including squirrels, songbirds, beavers, raccoons, and pheasants, and had healthy underbrush and beaten trails through the wilderness for children played in (Schwartz 1969). James De Shazo, regional biologist for the State Game Department commented, "[Thornton creek is in] pretty good shape for the area it's in, salmon still spawn in the creek and enough trout are there for children to fish in the creek," (Schwartz 1969). The neighborhood organized with a lawyer and petition to fight what they saw as "spot zoning," an illegal form of zoning that zones against the character of surrounding development. They were unsuccessful and the apartment complex was built, though the developers were halted for violating Department of Fish and Wildlife regulations against polluting the creek with sediments from construction (Schwartz 1969b). Partially in response to this loss of green space in Thornton Creek, residents organized and pressured the Seattle Parks Department to purchase 16 parcels of land on along the creek, and construct connecting trails through the urban greenway (Suffia 1969), but the budget for this project fell from $2 million to $410,000 and only two properties were purchased (Lane 1970).

In the mid-century, a square lake, constructed south of the Northgate Shopping

Mall provided flood prevention in winter and base flow to the creek in winter months (Henderson 1971). Square Lake, aptly named, was also a part of the community but the lake was filled in for an office building in 1971. Neighbors objected because they feared the changes in ecosystem function of the creek, and the loss of a frequently use recreational resource would decrease property values in their neighborhood (Henderson 1971). They formed the Citizens Committee to Save Square Lake, but this was not enough, the City of Seattle and Washington State Department of Ecology did halt the project, and the developer obtained the permit to fill in the lake (Henderson 1971).

Existing stormwater infrastructure steadily became inadequate to handle the increased flow volumes as more of the watershed was developed and covered with impervious surface. Through the 1970's the Thornton Creek watershed suffered significant flooding that damaged stream integrity and private and public property. In 1977, Don Hawkins's home at the confluence of the north and south forks of Thornton Creek was inundated by stormwater flooding the creek (Wilson 1977). Hawkins, commented, "A department spokesperson said the city would like to help, but it doesn't have the money. A drainage system planned for the area, to feed stormwater to Lake Washington, was never completed, and two bond issues were defeated." Reports in the Seattle Times told of flood events in '68, '77, and '81 and cited the debilitating damage inflicted on residents positioned near the confluence of the North and South fork and roadways build around portions of the creek (McKim 1968; Wilson 1977; Guillen 1981).

In 1988 neighborhoods organized to manage the protection and stewardship of Thornton Creek, and this effort was supported and integrated into government efforts to serve constituents (Lilly 1988). The King County surface water utility: Metro, the City of Seattle, and the Washington State Departments of Ecology and Fisheries sponsored a neighborhood group, SWAT, the Surface Water Action Team, to stencil "Dump no waste, drains to stream" on storm drains around North Seattle (Lilly 1988). Most of North Seattle has a separated sewer system, storm drains flow directly into water bodies like Thornton and sewage drains to a central treatment facility. This means that harmful pollutants like motor oil and pesticides flow directly into the creek from residential streets (Figure 5).

Figure 5. A stormwater outfall into the Kingfisher Natural Area, formerly Thornton Creek Park #2. Photo by author.

This education project impacted me as a child. I participated in community events to stencil storm drains and learning that there was a creek in my neighborhood and furthermore, that my actions impacted it too. I also began to understand the watershed's health and fragile state.

In 1993 Thornton Creek the Citizens Open Space Oversight Committee that was created by the park Department to spend the $41 million allocated for Seattle from the 1989 King County Open Space Bond Issue; there was $15 million allotted for saving vanishing open space (Lilly 1993). The King County bond came from a long-term King County property tax fund called the Conservation Futures Levy. This money was not nearly enough, in the eyes of residents, to protect the precious woody spaces and wetlands in amongst the urbanized city landscape (Lilly 1993). Citizens from neighborhoods all over Seattle pushed for action to open more funds from the bond to purchase properties while prices were low and before developers build on the precious and little open space left in urban Seattle (Lilly 1993). As a result of the Conservation Futures Fund, six parks were purchased in Thornton Creek. These parks were quickly forgotten by City departments – the parks remained in obscurity, named Thornton Creek Park #1- #6 until they were recently renamed. Primary observation shows that the remaining parks were inaccessible and obscured from public access and street view.

In 1992, teachers from the Lakeside School and North Seattle Community College, both located in the headwaters of Thornton Creek's South Fork, developed the Thornton Creek Project, renamed the Homewaters Project (Homewaters Project 2008). This was a major source of education and involvement in Thornton Creek (Bush 2004). During the 2003-04 school year, the project was staffed by four full-time educators, and interacted with 1,250 students and 50 teachers in more than 30 Seattle-area schools. In the 2007-08 school year Homewaters served 2,013 students, 63 teachers, 44 primary and secondary schools and 285 additional community members through their programming (Homewaters Project 2008). The project led tours through the watershed, connecting residents with the flow of the creek system and providing them with an escape from the urban environment for a 3-4 hour hike through the two main branches and main channel of Thornton, to its mouth at Lake Washington (Bush 2004). This project was funded through June 2008 but has since lost funding and support as key members moved away, and now does not exist in the watershed.

Citizens in the Thornton Creek watershed have organized on behalf of the aesthetic, recreational, and ecological functioning of the creek, with limited support from government sources of funding. The City of Seattle, Washington State Department of Ecology, and King County Water and Land Resources Division fund more studies and data collection in Thornton Creek than any other watershed in Seattle, but these efforts have not coalesced into action. Dreams of large urban trails and spaces to explore and connect with nature have gone unrealized – now the few parks that do remain in Thornton Creek go largely unnoticed by watershed residents. The following chapter shows how current regulations and methods to protect Thornton Creek are limited to a focus on water quality and lack collaboration across different stakeholders.

CHAPTER 4:
CHALLENGES TO CLEANING UP THORNTON CREEK

Water quality has worsened over time in Thornton Creek, this can be attributed to land use change and stormwater pollution, especially from impervious surface cover and pollution from commercial areas and high traffic volume. The regulations, government agencies, and citizen groups poised to assist Thornton Creek have not effectively reversed deterioration in water quality, or raised awareness of the natural area. Framing regulation and projects in Thornton Creek around improving water quality has actually hampered the delivery of other ecosystem benefits to the community. Although water quality is important to delivering economic and community benefits, it should be one of many benefits promoted by City of Seattle, EPA, and community groups. The focus on water quality ignores the specific needs of urban ecosystems to be safe and accessible in order to contribute meaningfully to city life.

Thornton Creek: Slipping through the regulatory cracks

Relative to streams in similar urban conditions, Thornton Creek's water quality is not good. Water quality has been measured in Thornton Creek by the King County Stream and River Water Quality Monitoring service since 1971 from a testing station at the mouth of the creek near Matthews Beach, the outlet of the creek into Lake Washington. There have been significant increases in water temperature, total phosphorus, turbidity, conductivity, and decreased dissolved oxygen in Thornton Creek since 1971 (King County Department of Water and Land Resources 2007). All these changed in quality damage the viability of Thornton Creek as a healthy creek ecosystem. In general in King County, levels of fecal coliform have decreased, an improvement in water quality. Contrary to the regional trend, levels of fecal coliform have increased in Thornton Creek, the creek had the third highest metals concentrations (King County Department of Water and Land Resources 2007). However, there has been some improvement in ortho-phosphates and nitrate concentration, indicating that watershed residents are improving lawn care and residential stream care (King County Department of Water and Land Resources 2007).

Thornton Creek has been on the EPA 303(d) List of Impaired Waterways for violating Clean Water Act standards for fecal coliform since 1996, and for temperature and dissolved oxygen since 2004 (EPA 2012). This means that the Washington State Department of Ecology observed a significant exceedance in Thornton Creek samples of these water quality indicators (EPA 2004). Figures 6 and 7 show the trend in fecal coliform and turbidity over the period 1971-2013.

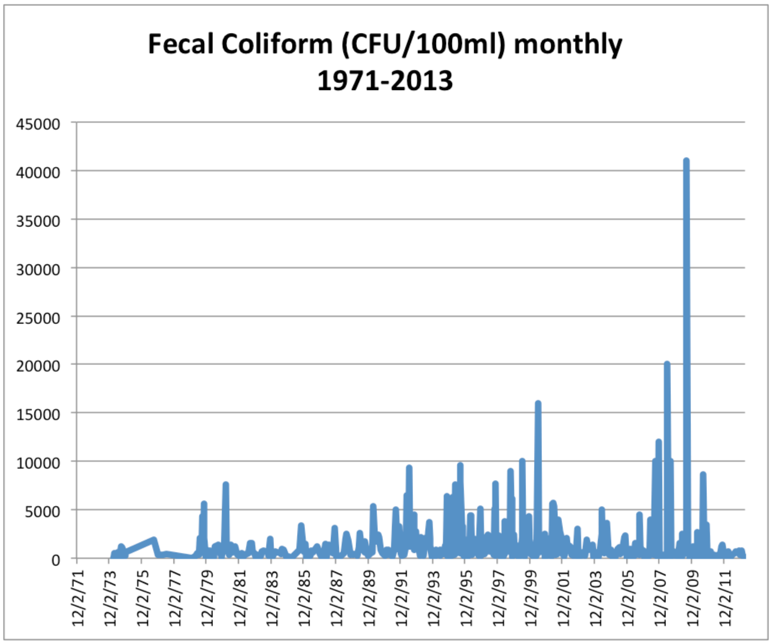


Figure 6. Fecal Coliform (CFU/100ml) collected monthly at station 0434 from 1971 – 2013. Data from *Stream report for Thornton Creek 0434* Bouchard and Abella 2013.

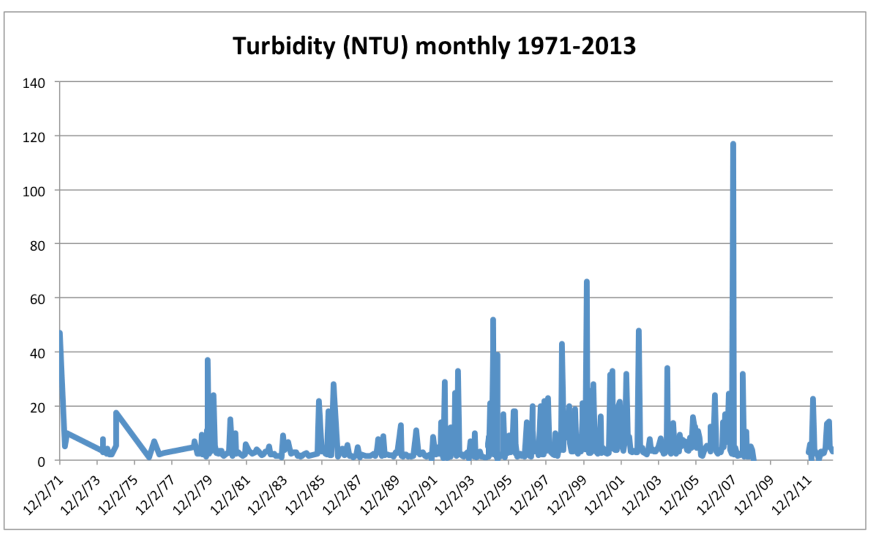


Figure 7. Turbidity (NTU) collected monthly at station 0434 from 1971 – 2013. Data from *Stream report for Thornton Creek 0434* Bouchard and Abella 2013.

Turbidity correlates with problems of water quantity and changes in the hydrology in the watershed, and generally should not exceed 50 NTU (173-201A WAC). Stormwater pollution is difficult to monitor and track, the peaks in turbidity and fecal coliform come from rainfall events when stormwater brings pollutants or high water volume into Thornton Creek. Even though there are low levels of each pollutant at the end of the collection period, this does not mean that concentrations of fecal coliform or measurements of turbidity have improved. Generally, summer months have less rainfall and the connected impervious surface in the watershed contributes less pollutants. The ambient quality standard for fecal coliform is 50 CFU/100ml, set for health and safety of primary human contact (173-201A). The Washington Administrative Code (WAC) sets standards for fecal coliform and allows no more than 10% of samples to exceed this maximum. The majority of measurements far exceed 50 CFU/100ml, and many exceed the standard for secondary human contact of 200 CFU/100ml. Thornton Creek has been designated for use as Primary Contact and "Core Summer Salmonid Habitat" with additional temperature requirements for September 15th through May 15th to protect salmon (Bouchard and Abella 2013); this is listed in parenthesis in Tables 3 and 4. Table 3 and Table 4 compile summary statistics for fecal coliform, DO, and temperature, in routine monitoring and storm monitoring respectively.

Storm events bring a flush of pollutants and water volume through urban watersheds. Results from long-term monitoring show that in both storm events and in routine monitoring ambient water quality exceeds standards. In both storm and routine monitoring the mean fecal coliform at testing station 0434 was far above water quality standards. Over the period, measurements of temperature in Thornton Creek have not exceeded standards for in a large portion of samples, but this parameter has worsened over time and by 2004 was listed as a Category 5 impaired waterway on the Dept. of Ecology's submittal to the EPA 303(d) List (Ecology 2004).

Table 3. Summary statistics for station 0434 routine monitoring from 1971-2013. Data from *Stream report for Thornton Creek 0434* Bouchard and Abella 2013.

Parameter	# Of samples	Mean	Min	Max	Median	Criteria (WAC173-201A)	Standard Deviation
Dissolved oxygen (mg/L)	193	10.5	7.3	13.6	10.6	9.5	1.3
Temp. (C)	328	10.6	1.6	17.6	10.6	16 (13)	3.7
Fecal Coliform (CFU/100ML)	329	929	14	10000	500	50	1228

Table 4. Summary statistics for storm monitoring for station 0434 from 1971 2013 data from *Stream report for Thornton Creek 0434* Bouchard and Abella 2013.

Parameter	# Of samples	Mean	Min	Max	Median	Criteria (WAC173-201A)
Dissolved oxygen (mg/L)	45	10.2	7.8	12.8	10.6	9.5
Temp. (C)	71	10.8	4.2	17.4	10.4	16 (13)
Fecal Coliform (CFU/100ML)	71	4793	150	41000	3200	50

Measurements of the degradation of stream and habitat quality are harder to quantify and track than changes in water quality parameters. These are important measurements to make because in Thornton Creek they show where restoration efforts have had marginal impacts in improving a highly degraded ecosystem, even though water quality metrics for the watershed in aggregate have not improved.

Benthic Integrity Biodiversity Index (BIBI) scores measure the diversity of benthic organisms present in an ecosystem.[6] If a waterbody is healthy then the score is high and unhealthy waterbodies have a low score, indicating a lack of diversity in benthic organisms and lack of sensitive species. A low BIBI score may correlate with poor water quality conditions, high stream flows, and low-quality riparian and in-stream habitat (Bouchard and Abella 2013).

King County's Benthic Invertebrate program monitored the BIBI for the South Fork of Thornton Creek in 2002 and 2003 and SPU has measured BIBI in Thornton

[6] The Benthic index scores are: 10-16 very poor, 18-26 poor, 28-36 fair, 38-44 good, 46 – 50 excellent (SPU 2007).

Creek every other year from 1996 to 2007 (SPU 2007). The King County study concluded that in both 2002 and 2003 conditions in Thornton Creek for benthic invertebrates were very poor (10-16). The Puget Sound Benthos Monitoring with SPU monitored ten sites over the study period and the creek system as a whole scored a 15, very poor for benthic invertebrates and no testing site scored over the poor category (19 was the highest). However, there were key differences between testing sites. The North Branch generally had higher scores, and within the North Branch, the area south of Jackson Golf Course (18.7) and Little's Creek (19) had the highest scores (SPU 2007; Puget Sound Benthos 2012). Testing points in the Beaver Pond Natural Area in the South Branch also had relatively higher scores (16).

Studies of in-stream habitat quality and riparian habitat quality over the past 15 years provide qualitative data on the functioning and fish and wildlife habitat in Thornton Creek. The majority of Thornton Creek's North, South, and Main branches and tributaries suffer from historic stream bank hardening, culverting, and channelization (SPU 2007; Watershed Characterization Report 2000). Most of Thornton Creek has been channelized either through concrete manmade channels or from high flows of stormwater (SPU 2007). Maps from the SPU (2007) show the in-stream quality and riparian quality of the creek. The areas that have relatively better stream quality tend to be surrounded by park areas or residential areas, and the sites of citizen restoration projects either funded by government grants, such as Beaver Pond, or neighborhood restoration such as Maple Creek (SPU 2007).

Despite overall water quality problems within the watershed, the available data allows us to trace areas of much worse quality and areas where improvements have been made. BIBI scores show that Beaver Pond, the area south of Jackson Golf Course, and Little's Creek have been restored and protected in ways that increase the quality of the riparian and in-stream habitat, resulting in relatively higher diversity of sensitive benthic invertebrates, an indicator of overall stream health. This data helps us to understand where we can make marginal gains in fish and wildlife habitat restoration.

Yet this data is still incomplete. Measurements of biodiversity and species abundance can capture more nuanced improvements in habitat, which is an improvement in how success and benefits in urban creeks are measured. However, making progress on watershed health involves more metrics such as resident use and awareness. The following section shows how the focus on water quality from a regulatory standpoint limits peoples' thinking about the broader range of items that improve urban waterbodies. This in turn prevents useful collaborations between watershed stakeholders with different goals.

Bringing in the Big Guns: Why federal regulations have not worked

The EPA regulates stormwater pollution under the Clean Water Act, but regulations have not been successful in transforming land use and impervious surface cover, which are the main stressor on waterways. The Clean Water Act (CWA) passed in 1972 gave authority to the U.S. Environmental Protection Agency (EPA) to regulate pollution discharges into waterbodies by requiring permits for point source of pollution through the National Pollution Discharge Elimination System (NPDES) program (Field 2013). The CWA created water quality standards designed to bring waterbodies into compliance with their designated uses (Roy et al. 2008). Though the system worked well to limit large point source pollution, NPDES and water quality standards did not target stormwater directly (Prehalad and others 2007). Urban stormwater has traditionally been regarded as a flood threat, and only in the past 25 years have governments in the United States begun to recognize the water quality risks associated with stormwater (National Research Council 2009).

The EPA uses Total Daily Maximum Load (TMDL) and NPDES permits to address the requirements of the Clean Water Act (EPA 2013a). These programs use water quality standards and technology-based pollutant discharge limits to improve waterways. In 1987 the EPA expanded the NDPES Stormwater program under the CWA to regulate large municipalities (populations over 100,000) to obtain permits for stormwater discharges called MS4 permits (Field 2013). Municipal permit holders are required to implement stormwater best management practices for new development and redevelopment. Seattle Public Utilities is changing building and planning code to prevent further development and redevelopment that contributes stormwater pollution (Ehlers 2013; SPU 2001).

This regulatory approach is ineffective in controlling stormwater pollution because it fundamentally does not address the scientific and political realities of stormwater. MS4 permits for municipalities under the NPDES are very recent, and often only address changes in new development. The current approach to deal with stormwater has little to do with retroactive projects that fix infrastructure and development that is currently causing stress to waterbodies (L. Mann, pers. comm., 7/1/13). Changing new development is not enough to reverse the damage from stormwater pollution and urban land use. Like many urban creeks, Thornton Creek violates Clean Water Act standards and legally, government agencies, either the EPA or state agencies, are charged with setting TMDL permits for those waterbodies to facilitate cleanup in addition to MS4 permits.

The EPA's policy is to implement TMDL permits 8-13 years after impairment has been identified in a waterbody through the EPA 303(d) List program (Ecology 2004). The TMDL program creates pollutant budgets for waterways to meet environmental goals, meeting water quality standards and designated uses (EPA 2013a). The TMDL program was always a part of the original legislation, but was not used by the EPA. In 1991 the NW Environmental Advocates and the NW Environmental Defense Center sued EPA and Ecology for conducting TMDL studies slowly and not working to remove waterways from the 303(d) List. The lawsuit resulted in a Memorandum of Agreement committing Ecology to address 1,576 TMDL permits on 666 waterbodies from the 1996 303(d) List (Ecology 2002). Thornton Creek was included in these 666 waterbodies, and 15 years later does not have a TMDL written.

A TMDL permit involves the writing of limits and regulations on pollutant loads, but does not require implementation of projects to achieve those pollutant loads (J. Gable and L. Mann, pers. comm., 7/3/13). Progress in non-point source pollution reduction through the TMDL program is fostered through pairing the TMDL with financial resources to incentivize pollution reduction, assistance with technology improvements, restoration efforts aimed at reducing non-point sources of pollution and education (J. Nolan pers. comm., 7/3/13).

A TMDL permit in Thornton Creek has been a low priority (R. Svrjcek, pers. comm. 7/3/13). TMDL permits in Washington State are prioritized based on the severity of the pollution problem, how clustered the waterbody is with other impaired areas, how easily the pollution problem can be solved, local support for cleanup, and the interest from non-profit groups, city government, and county agencies in implementing the TMDL once it is written (R. Svrjcek, pers. comm., 7/3/13). The TMDL program works well in watersheds where there are a few key polluters, and a group in the watershed is impacted heavily by that pollution and can provide financial and political backing to the program. This is not the case in Thornton Creek, where there are many small polluters with de-centralized liability and the pollution of Thornton Creek does not impinge on local water supply. A waterbody like Thornton Creek, where implementation is uncertain, is not an efficient investment of time and energy for the Dept. of Ecology.

Without either a polluter or plaintiff with financial backing and legal power, a TMDL permit in Thornton Creek would likely not result in any significant implementation. TMDL permits work well when a stakeholder group has a large stake in the health of the creek system. The major financial stakeholders in Thornton Creek do not have a large stake in the overall health of the watershed. This, however, does not address overall watershed health, especially the co-benefits of improving human needs such as recreation, walkability, and green space within the city environment.

Seattle Public Utilities (SPU) overwhelms the budget of any other stakeholder involved in the improvements and management of Thornton Creek, and operates on a budget that is funded mostly through ratepayer revenues (City of Seattle 2011). SPU is charged, "to protect life, property, and natural resources from loss or damage caused by uncontrolled stormwater runoff," through developing the City's Stormwater Management Program in conjunction with the requirements of the Clean Water Act and protection of salmonid species in the Endangered Species Act (SPU 2001). SPU minimizes risk of flood damage, minimizes harmful erosion, and minimizes environmental degradation. SPU had a budget of $377,608,275 in 2012 for the drainage and wastewater utility. Its projects and expenditures are bound to fulfill drainage duties for ratepayers and commitments to minimize environmental degradation. Other City of Seattle departments with influence but little interest in Thornton Creek include; the Seattle Department of Transportation with an annual budget of 310,651,001 in 2012, and the Seattle Parks Department with an annual budget of $122,956,412 in 2012 (City of Seattle 2011).

Historically, it is the involvement of citizen groups that makes projects for Thornton Creek happen, and citizen activism has gone in waves over the past 40 years. Relative to the influence of City of Seattle departments over Thornton Creek, activist and advocate involvement in Thornton Creek is small. The total budgets for City of Seattle Departments dwarfs the budget for the most expensive multi-stakeholder project to date in the watershed – the $14,718,111 Thornton Creek Water Quality Channel completed in 2009 (SvR Design 2009). The Thornton Creek Alliance has a membership of 115 paid members, with 14 Board Members, and 4-5 members actively advocating and organizing at a time (R. Williams, pers. comm., 7/9/13). The Thornton Creek Watershed Oversight Council, a council of stakeholders staffed by SPU, under an agreement with the Seattle City Council to implement the five-year plan recommendations of the Watershed Action Plan from 2003 (TCWOC 2008). The Oversight Council now meets voluntarily, but is not connected to SPU. This organization of stakeholders worked well, but is not permanently funded.

There are some other ways to fund and organize projects for non-point source pollution such as stormwater. Clean Water Act Section 319 Grants are allocated for non-point source pollution projects on the state and local level (L. Mann, pers. comm., 7/1/13) but the distribution of these funds is inefficient. Seattle Public Utilities often uses funding from the EPA 319 Grants through the Ecology Centennial Grant Program to fund studies on Seattle's waterways. In May 2013 Jonathan Frodge, a stormwater scientist from Seattle Public Utilities, supported by funding from the Centennial Grant, published a report on the bacteriological contamination of Thornton Creek. Thornton Creek has some of the highest bacteria counts of streams in King County, much higher than nearby creeks with similar land use patterns (Frodge 2013). Results indicate that human-source E. coli in Thornton Creek is present at unsafe levels for human contact (Frodge 2013). One potential contributing factor to the contamination is aging infrastructure from developed commercial areas in the watershed. An additional but unconfirmed source of the contamination could be from homeless encampments in the natural areas and illegal RV dumping wastes in the watershed.

Frodge commented that the second step to this process, searching and identifying sources of E. coli, needs additional funding (pers. comm., 7/3/13). Joan Nolan, Environmental Specialist, Department of Ecology, is confident that this key step of the investigation is supported and underway (pers. comm., 7/3/13). Frodge knows that a part of the City of Seattle's MS4 permit requirements, the Illicit Discharge Detection and Elimination (IDDE) Minimum Control Measure works well to find sources of discharges in urban watersheds – the system helped locate two illegal connections to a stormwater drain that were contaminating Thornton Creek in 2010 (Frodge 2013). However, the set up of the MS4 permit for Seattle does not allocate enough time or resources to continue the IDDE to find all sources of illegal pollution discharges in Thornton Creek. There are tools and technology to identify and solve the worst problems in Thornton Creek, but financial and political systems for non-point source pollution do not direct efforts toward resolving non-point source problems completely. The nature of federal funding for non-point source pollution projects as one-time, and grants based, makes adequate follow-through and follow up monitoring and maintenance difficult.

According to Dave Garland, Regional Water-Quality Planning Coordinator, Ecology is searching for the correct approach for improving Thornton Creek, (D. Garland, pers. comm., 8/1/13). Another option for Thornton Creek is a Straight to Implementation plan that would be carried out directly by the City of Seattle. The City of Seattle is not partial to this approach, though it has been used to solve non-point source pollution problems in Eastern Washington where the sources of contamination were known and mostly from agricultural sources (D. Garland, pers. comm., 8/1/13). Something must be done, but just what needs to happen remains undecided. Ecology is severely limited in their approach because they must target water quality goals first and foremost. Significant changes in water quality in Thornton Creek are almost impossible and support for a TMDL is lacking. There are improvements that would increase the value of Thornton Creek to the community as a public space, outdoor classroom, and cornerstone of the community and marginal benefits to water quality; these improvements would likely garner broad-based support.

Local support and demands for action are key steps to the implementation of federal regulations to deal with pollution in urban creeks. Implementing clean up takes volunteers, and takes a core of interested citizens who are educated and passionate. These citizens are key to successfully implementing new regulations or requirements for watersheds. If there is no grass-roots support the community rejects projects and policies as outside regulations; citizens must ask for action and pressure leaders (D. Garland, pers. comm., 8/1/13). The recent development of Frodge's (2013) study and resultant publicity and concern in the community (Lactis 2013) may kick start more conversation and organizing to protect the recreational use of the creek, particularly the popular beach at the mouth of Thornton Creek that has at times been shut down due to bacterial contamination (Frodge 2013). However, Thornton Creek is in a dilemma; improving watershed health in Thornton Creek requires active and engaged residents, but residents are not active and engaged when overall watershed health is poor. Improving overall watershed health requires projects that can draw together diverse groups of stakeholders. This multi-faceted collaboration is lacking in federal and state regulations for Thornton Creek.

Projects in Thornton Creek: A lack of combined effort

Projects to improve multiple beneficial uses of Thornton Creek have been hard to implement. The groups involved in Thornton Creek come from different backgrounds and often frame goals for the creek in different ways. For example, members of the Thornton Creek Alliance view Thornton Creek as primarily a space for wildlife habitat and refuge, while the Seattle Parks Department values Thornton Creek as an area for passive and active human use.

Throughout my case study research I asked regulators, government scientists, and neighborhood organizers, "If money were no object, what would you do for Thornton Creek?" Answers to this question reveal that the end goals for Thornton Creek differ between groups. Neighborhood organizers would place an emphasis on improving access and education opportunities within Thornton Creek while also bringing water and habitat quality up to pre-urbanization standards. This second goal is virtually impossible as the degradation of Thornton Creek comes from the intense urban land use around it, but education and outreach is something that can be achieved, and currently is lacking in most parks and open areas. Regulators and scientists shared a more technical approach, and suggested to increase buffer zones, purchase property, reconnect flood plains, repair inadequate and faulty sewage and drainage lines, and increase low-impact development and green infrastructure. These steps could all bring the creek to water quality compliance, but do not necessarily improve the outreach and educational opportunities within Thornton Creek, even though this is clearly a goal of neighborhood groups and homeowners. There is a disconnect between the way goals for Thornton are articulated at the regulatory level, in terms of water quality only, and the full value of Thornton to the community as a place of heritage, wildlife, and also recreational and educational use.

Past projects show that stakeholders look to the creek to provide multiple types of valuable ecosystem services despite its degradation and urban location. They also illustrate the competing interests of different groups. The Thornton Creek Water Quality Channel, an water improvement and park space in a large residential and commercial development, enhanced community image and walkability but did not provide significant habitat or improvements to water and stream quality. Beaver Pond has been the site of successful restoration, but was recently vandalized by residents concerned about safety and undesirable activity in the natural area. The goals and benefits of these projects are misunderstood or undervalued by other stakeholders; there appears to be much room for collaboration between stakeholders who all generally agree that Thornton Creek is important and should be improved.

Northgate and the Thornton Creek Water Quality Channel

The Thornton Creek Water Quality Channel is a community driven project that brought together the Mayor, City Council, citizen groups, and developers to consider the community benefits of Thornton Creek restoration. The Thornton Creek Legal Defense Fund (TCLDF) was a citizen group that wanted the planned redevelopment of a Northgate mall property and parking lot (between NSCC Wetlands and Thornton Creek Park #6 in Figure 3) to involve restoration of Thornton Creek to a daylighted stream (Reed 2012; TCLDF 1999). TCLDF sued for the protection of the creek that ran under flowed under the mall and I-5 on the grounds that the creek does exist, despite years of existing in a 60-inch pipe 40 feet underground. In a key ruling the King County Superior Court Judge agreed with TCLDF that Thornton Creek does indeed exist underneath the parking lot (Reed 2012). The group won the support of Seattle Mayor Paul Schell (1998-

2002) and the Seattle City Council to sue the Northgate developer and property owner, Simon Properties to change the development plan.

The Thornton Creek Legal Defense Fund produced and distributed a VHS to Mayor Schell and the City Council and used the video to engage neighbors who may be interested in improving their community through this action for Thornton Creek. The video from 1999 shows how neighborhood residents viewed redevelopment of the Northgate Mall and surrounding commercial district as a potential neighborhood enhancement and Thornton Creek could be a special part of this improvement (TCLDF 1999). TCLDF used water quality arguments to base their claims for changing the development plan, saying that improving the water quality of Thornton Creek can help the salmon that sometimes find habitat in the main channel of the stream; this helped draw crucial funding from SPU.

The video shows Mayor Schell on a local news channel, expressing concerns that the community's vision of daylighting Thornton Creek would not provide water quality improvements to Thornton Creek, the driving justification for the project. Daylighting the creek in this area would not meet requirements for a habitat corridor; the project could only accommodate a 15-20 ft. buffer zone, where 100 ft. is required for a legal habitat corridor (TCLDF 1999). Similarly, the water temperature in that section of Thornton Creek could still far exceed livable conditions for salmon after construction of the channel. However, residents saw daylighting the creek as much more than an opportunity to improve water quality, "The redevelopment of the Northgate mall and the south parking lot will impact your community, not just the water and habitat quality," (TCLDF 1999). The residents were upset by the legacy of stormwater infrastructure with conventional infrastructure, like R/D ponds that do not invite or welcome multi-purpose use by the community. The community created a neighborhood plan that outlined a vision of increasing walkability and cohesion between the built environment and the natural environment. The proposed development by Simon Properties did not respond to these goals and was a violation of the community's vision (TCLDF 1999).

By 2001 the legal battles were over and citizen groups and the City Council found a developer willing to integrate the plans for including Thornton Creek into the redevelopment. In 2009 construction on the Thornton Creek Water Quality Channel and related mixed-use residential and commercial development was completed (Reed 2012). The Water Quality Channel drains 688 acres of the watershed in the South Fork headwaters. The Water Quality Channel is on a property of 2.7 acres and flows between two apartment developments (Figure 8). This project combines public access to the space and education about the ecosystem and residential development into a cohesive space. Like many projects though, the results are mixed and questioned.

Figure 8. The Thornton Creek Water Quality Channel and surrounding high-density retirement living is publicly accessible by pathways and bridges. The Channel is also equipped for maintenance by SPU as it collects sediments. Photo by author.

To the community, this is a huge success, but the actual effect of the Water Quality Channel on the water quality of Thornton Creek is slight. The Water Quality Channel is a good wetland, great landscape and public space, and provides minimal water quality benefits. The project is framed as a water quality project (Ma 2009) but Jonathan Frodge and Brian Landau, Surface Water and Environmental Services Program Manager at City of Shoreline, view the channel as more of a failure because it did not address water quality. Frodge noted, “the name Water Quality Channel is a bit of a stretch,” (J. Frodge, pers. comm. 12/3/12). The sediment filtration system of the channel is effective, but bacterial contamination, the leading pollution problem in the creek, is mostly unaffected (J. Frodge, pers. comm., 12/3/12; SvR Design 2009). Landau agrees (pers. comm., 12/13/12), in terms of water quality improvements, the channel is highly inefficient. The project led to an expensive development, which turns out to have little positive effect on water quality and likely would not happen again (J. Frodge, pers. comm., 12/3/12; B. Landau, pers. comm., 12/13/12). Although the effectiveness of the channel to actually improve water quality is very low, citizens effectively brought a park and community space into the neighborhood and involved city officials in their plans. The development of the Water Quality Channel is a good illustration that community involvement and activism drives collaboration between advocates, developers, the City, and SPU and that the integration of a natural element can enhance the overall quality of an urban development. Because improvements to Thornton Creek and protection of the ecosystem must be framed in terms of water quality this project was over-sold as a water quality project and in this way viewed as a failure.

Beaver Pond: The problem of urban crime and urban parks

Another impediment to multi-beneficial action is the fractured goals of watershed residents. Most members of the Thornton Creek Alliance have backgrounds in biology, ecology, and natural systems science. For them a healthy Thornton Creek park includes minimal human intervention and adheres to the needs of the ecosystem first (TCA 2013). A park that is a healthy riparian zone with a healthy understory of growth is often a park without clear sightlines to deter crime (Watershed Characterization Report 2000) the trade off between restoration and safety divides residents in Thornton Creek.

Thornton Creek natural areas are mostly shaded, woody, and hidden spaces down steep slopes and out of view of streets. There are few formal entrances to the natural areas, pathways are narrow and informal, and the areas lack signage. The Beaver Pond Natural Area (formerly Thornton Creek Park #6) is a good example of these problems. There are wide open spaces for gathering under trees, the ravine provides coverage from street views and the lack of any formal entrance or signage makes this area of the park seem less like a nature area and more like a hidden space. There is very little foot traffic and according to the Thornton Creek Alliance President, Ruth Williams (pers. comm. 7/18/13), the area is used for homeless encampments and for illegal underage drinking.

Due to the prevalence of one-time funding and grants for Thornton Creek land acquisition and improvements, Thornton Creek parks are not maintained well. Upkeep of signage and trails is difficult. Additionally, restoration by volunteers often focuses on restoring the areas to encourage wildlife and fish habitat rehabilitation, this work does not bridge the gap between residents interested in restoration for wildlife, and restoration for human use.

On December 15th, 2011, Ruth Williams, then vice-president of TCA, reported the vandalism of 47 trees in Beaver Pond, a 7-acre park just past the Water Quality Channel, close to Northgate Mall. Branches were illegally cut off of trees and saplings in the park, falling on young plantings that work crews of restoration volunteers had planted.

Figure 9. Branches up to 10 ft. were cut off of mature and young conifers to clear a sightline from the backyards of neighborhood houses to a bridge, known for criminal activity. Photo in Ling 2011.

The incident sparked a debate amongst community members on the Maple Leaf Community blog (Ling 2011). Though the restoration project and hard work of Williams and others was clearly the victim of the vandalism, many in the community felt the crime was a boon – a deterrent to the steady stream of break-ins and nefarious activity in the neighborhood (Ling 2011). The comments show the frustration from neighbors directly adjacent to the natural area. Residents in the comments section weighed in on the news about the vandalism, revealing a general sense of unease about the natural area, and concern that restoration efforts were one-sided and did not involve the safety concerns of residents,

> "Having walked through that section of park a number of times, I was always surprised at the level of visual isolation in there... While I appreciate the volunteers who have turned that area from a junkpile into a parkland, perhaps they could incorporate a concern for personal/property safety into their activities and trim trees in a way that allows for both aesthetic purity and the concerns of the neighbors about creating hiding places?"
>
> "I won't take my kids through there anymore, which is a shame since we live within a block of the park. What's the point of having a wildlife park if you're scared to bring your kids into the "wildlife" because of the folk that hang out there. I know my neighbors feel the same and purposely take the longer route around the park for the same reasons."
>
> "Look, I like having the trees and the beaver pond back there. I would like to have something close to what used to be here before the houses and mall came in post-war. But this forested area is natural cover for the criminal element in this area. TCA needs to actually SPEAK to those of us who actually LIVE next to No. 6/Beaver Pond. I think I've seen one flyer from them, once, in the couple years I've lived here. They've never asked me for help, much less asked me about my concerns or what I think."
>
> "The lack of visibility in that area was also an issue for property crimes. My wife witnessed an attempted break-in two weeks ago and the perpetrators fled into that area. When my house was burglarized the individuals utilized that area."

Efforts to restore parts of Beaver Pond for improved fish and wildlife habitat only meet partial needs of the urban ecosystem. Immediate residents around Beaver Pond are disadvantaged by the current uses of the space, and feel unwelcomed and afraid to use the space. More inviting and clearly maintained natural areas could increase foot traffic and diversity of uses, increasing safety and enhancing the cultural and educational value of Thornton Creek to the community.

Residents care about maintaining Thornton Creek as a place for wildlife and fish, and as a place that enhances the image of the community (Watershed Characterization Report 2000). The current state of Thornton Creek natural areas reflects poorly on the community and is often associated with undesirable behavior, and a refuge for criminal activity (Ling 2011). An approach to Beaver Pond that linked both the social and ecological needs of the community would produce a much larger benefit for the surrounding community. The ecological benefits of increased wildlife and fish habitat need to be weighed with the social needs for safe use and access in urban watershed.

There are ways to design and restore an urban natural area with crime prevention in mind. Crime Prevention Through Environmental Design, a broad set of principles that aim to influence behavior through design (Cozens 2002), is being used in a natural area in the Beacon Hill neighborhood of Seattle (Ling 2011). A major part of this restoration is the construction of a bike and pedestrian accessible trail through the greenway; a project that many community members think will decrease crime and increase the time that youth spend positively connecting with nature (Beacon Bike Park 2013). The Thornton Creek Alliance however, does not support a trail project like this through Thornton Creek (TCA 2013); construction and irresponsible users could harm the wildlife and fish habitat. Domesticated pets contribute to fecal coliform contamination in urban waterways and even well intentioned visitors may litter, walk off of designated paths, and damage sensitive restoration projects (R. Williams, pers. comm., 7/18/13). Primary observations show that irresponsible use and littering is already a problem in Thornton Creek parks. The current approach to improving the health of the areas for both wildlife and for humans is not enough and directing improvements toward better recreational activity in the natural areas may garner more broad-based community engagement in the water quality and health of the watershed.

Focusing on the health and safety of the water within Thornton Creek and viability for fish and wildlife only tells a partial story of the full watershed health and safety. Only focusing on water quality improvements will not fundamentally change the apathy that has led to a gradual decline in the quality of the creek. Making Thornton Creek appear and feel more safe and accessible to the public will increase awareness and public involvement in the acute water quality problems now facing the creek system. Green infrastructure is a potential solution for Thornton Creek because it builds realistic benefits to the community in the short term such as increased accessibility and awareness, without giving up on long-term goals of transforming the impervious surfaces and stormwater pollution that stress fish and wildlife in Thornton Creek.

CHAPTER 5:
MAKING GREEN INFRASTRUCTURE WORK

The problems facing Thornton Creek are ecological, political, and social. Green infrastructure is viable for Thornton Creek because it is inherently multi-beneficial and approaches more than just water quality problems. In addition to filtering pollutants and slowing stormwater flow, green infrastructure raises awareness and connectedness to urban watershed functions. The Environmental Projection Agency's regulations and projects to improve the health of urban watersheds in the United States depend largely on community support and involvement (pers. comm. J. Nolan 7/3/13; pers. comm. D. Garland 8/1/13). Green infrastructure can provide social and economic benefits to watershed communities that develop political and financial investment in further watershed improvement – providing immediate enhancement of the urban environment and long-term support and advocacy for the watershed.

Green infrastructure can involve multiple indicators of watershed health and engage stakeholders with different goals. It enhances natural systems and can bring multiple types of benefits to communities (EPA 2013a). These include reducing the harmful flow of pollutants and water volume to the receiving water body, increasing habitat, providing noise reduction from traffic and shade production in urban heat centers, creating community awareness and engagement in the watershed functions, increasing property values, and increasing recreational and aesthetic enjoyment of the urban ecosystem. Further, green infrastructure costs less compared to some conventional infrastructure (CNT 2010).

Economic, social, and ecological services can all accrue from natural systems, but green infrastructure technologies alone do not provide these services without engagement from governments and citizens. For green infrastructure to be truly multi-beneficial, multiple stakeholders must be involved from the onset of the project (City of Seattle 2007; Dawson and Cornwall 2007). Past studies of green infrastructure show the most successful projects have five or more stakeholders (Dawson and Cornwall 2007). Implementation is successful when government organizations adopt new maintenance agreements and when there is ongoing investment from the community to care for and maintain the natural systems that green infrastructure depends on.

Examples from Seattle and Los Angeles show the necessary elements for multi-beneficial green infrastructure as well as the key pitfalls. The specific ecosystems of Seattle and Los Angeles present slightly different problems and necessitate different approaches. Native vegetation in Los Angeles does not obstruct views as easily as native Seattle vegetation and there are fewer concerns about sight distance and overgrown plantings. In Los Angeles both storm water treatment agencies and water supply agencies have an investment in green infrastructure. Green infrastructure can filter pollutants from stormwater and can increase groundwater supplies by capturing stormwater before it runs into receiving waters. Fewer parties are interested in investing in green infrastructure in Seattle because safely infiltrating stormwater into the ground does not contribute to local water supply.

The following analysis compares the perceived and realized array of benefits from green infrastructure projects in Seattle and Los Angeles, showing that community buy-in and integration of safety concerns create successful green infrastructure projects that meaningfully involve the surrounding community and residents for the long term. They also show that questions of long-term maintenance are yet to be resolved.

Green Grid: Good intentions and limited follow-through

Starting in 1999, SPU, in collaboration with other agencies constructed five Street-Edge-Alternative Streets (SEA-Streets) throughout the city (SPU 2006). This served as a learning laboratory for green infrastructure. The Pinehurst Green Grid is a part of the City of Seattle's Natural Drainage System (NDS) pilot program. The Pinehurst project is within the Thornton Creek Watershed. NDS streets are designed to direct runoff from the parking strip into vegetated bioswales and permeable pavements that capture, slow, and filter stormwater runoff (Andrew and Ward 2004; SPU 2006). SPU received a $3.7 million low interest loan for the construction of the Pinehurst Green Grid; the project drains 12 city blocks, approximately 49 acres, within the Thornton Creek Watershed (SPU 2006). This redesign has with multiple goals and potential benefits (Andrew and Ward 2004):

- Decrease flood risk to downstream residents
- Decrease water quantity flows to Thornton Creek by infiltrating stormwater from a 2 year flood event
- Provide water quality improvements
- Improve neighborhood walkability and aesthetics
- Improve neighborhood safety by narrowing and curving street to slow cars
- Provide a learning laboratory for the Seattle Department of Transportation and SPU to improve coordination between departments, modeling methods, and design and construction – increasing cost-effectiveness of future green streets.
- Could provide improvements to adjacent property values

Observation of water quality showed that water quality improved through conveyance in the NDS project but pollutants were not reduced to water quality standards. Two similar NDS projects in Seattle, the Broadview Green Grid and NW 107th Cascade were monitored for water quantity and quality performance. The monitoring results Horner and Reiners (2009) showed that the projects effectively "protect Pipers Creek from elevated discharges in the largest storms and wettest conditions, when the risks to the channel and its habitats are the greatest," (p 14). NDS installations reliably reduced effluent concentration but were not effective at reducing effluents to a level within Clean Water Act quality standards. In very polluted waterways these installations may have an aggregate impact and improve ambient water quality, but do not individually reduce stormwater pollutants to acceptable levels (Horner and Reiners 2009).

Primary observations of the Pinehurst site five years after project completion show that the community benefits of the project are different than predicted, and that potential benefits were limited by confusion over long-term maintenance. This street was chosen for its hydrology and geographic location within the watershed. There was a low risk of flooding and a manageable amount of stormwater accumulation (SPU 2006). The project was pitched to the neighborhood as a project that would reduce flooding and decrease pollutant loading and stormwater flow to Thornton Creek. Erik Butterworth and Margaret McKibben, residents on the project site, were happy to participate (pers. comm., 7/30/13). Not all neighbors were pleased with SPU's decision; one neighbor organized legal action against SPU, but the project went on anyway. I spoke with Butterworth and McKibben in July 2013 about the long-term effects of this project.

In the summer of 2013, five years after project completion, there was little ongoing involvement between SPU and the residents of the projects. During project design and construction, they were involved in meetings and education about caring for the new vegetation on the street. The neighborhood was involved in choosing plantings for the parking strip in front of their house, the site of the bioswales and infiltration trenches in the project. There had never been any functionality problems with the new bioswales but there were problems with the maintenance of the vegetation in the bioswales. There was an agreement as to who was responsible for maintaining the vegetation in the bioswales. Most responsibility fell to residents but residents have not been able to properly maintain and prune this natural vegetation. Unlike traditional storm water conveyances, ditches or pipes that the utility maintained, these bioswales were essentially plantings in homeowners' front yards. Figure 10 shows the costs and benefits to the Pinehurst Green Street for the Butterworth-McKibbens. The most surprising cost to this project was the nuisance of overgrown vegetation. This overgrowth made it difficult to see pedestrians and cars when pulling in and out of driveways. Additionally, the overgrowth sometimes covered sidewalks, making the street less inviting to walk through.

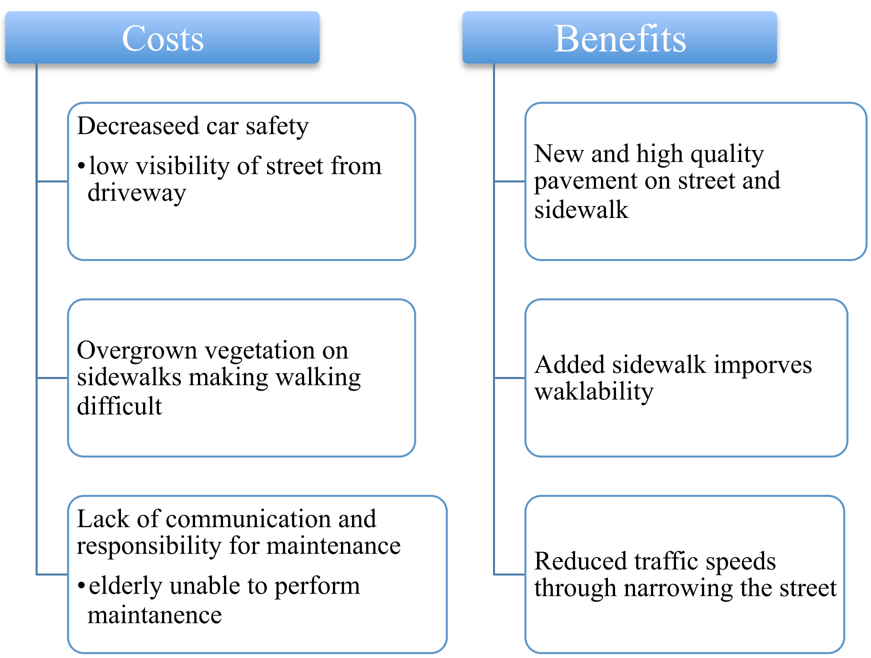


Figure 10. Important costs and benefits to Natural Drainage System in Pinehurst to residents (E. Butterworth and M. McKibben, pers. comm., 7/30/13)

McKibben (pers. comm., 7/30/13) says the most beneficial aspect of the project was the reduction of traffic speeds along their street. The street parallels a major arterial; some cars would drive by daily far over the speed limit.

Butterworth and McKibben would like to see Thornton Creek undergo more improvement– a walking trail connecting the green spaces along the watershed would be useful and pleasant. They think that Thornton Creek is a place where wildlife lives and a small natural area can grow, but Butterworth commented that Thornton Creek seems to be the place where the homeless in the community hang out, and the natural area by his home is filled with garbage and grocery carts (pers. comm., 7/30/13). Speaking with the residents of a green infrastructure project shows that what matters most is how the project changes their quality of life in a city environment.

The support for street redesign with green infrastructure in Seattle has waned. The mixture of success and failure in the NDS and other green infrastructure projects show that improved flood storage and water quality are variable between projects, while conventional infrastructure delivers reliable results (K. Lynch, pers. comm., 7/19/13). However, four more projects are planned for the next ten years (SPU 2013b). It would be helpful for SPU to revisit the sites of old green streets and monitor the extent that vegetation has provided safe walking and vehicle traffic, and ask residents how to better provide long-term maintenance of the green infrastructure.

A Focus on LA: Community engagement in green infrastructure

The LA Basin Water Augmentation Study investigates the feasibility of infiltrating stormwater to augment the Los Angeles area water supply. Case studies in the Los Angeles area analyze the effectiveness of green infrastructure to remove pollutants from stormwater as they enter the groundwater supply. These studies provide evidence for the feasibility of green infrastructure techniques to clean pollutants in the Thornton Creek watershed. Lessons learned through implementation also show that, as with the Pinehurst project, issues of long-term maintenance, public/private responsibility, and the meaningful inclusion of residents and their concerns are all important to creating multi-benefit green infrastructure.

In 2005 the study looked at six completed sites: two industrial sites, an elementary school, a commercial office building, a private residence and a public park (Council 2005). These study sites utilized different infiltration strategies from simple landscaped swales to large-scale underground infiltration fields. In these case studies, soil was shown to be efficient at removing bacteria from stormwater (Council 2005). In all but one of the six case studies, fecal coliform and E. coli were detected and high total coliforms were detected in all samples before entering green infrastructure installments. Bacteria were detected in very low levels or not at all in groundwater samples after treatment in the natural filtration through green infrastructure (Council 2005).[7]

Despite efficacy of green infrastructure technology to infiltrate stormwater and filter pollutants in the Water Augmentation Study, many other benefits of green infrastructure were not met because projects lacked long-term funding or communication between different stakeholders. De Guzman (2007) analyzes some of these projects. The Hall House, a single home retrofit project in South Los Angeles, switched hands from the original owner to her daughter, who was less interested in working with non-profits and government agencies and maintaining the home as a case study for green infrastructure (De Guzman 2007). This led to diminished functionality and aesthetics of the green infrastructure on the property and decreased use of the Hall House as an educational tool for future development (De Guzman 2007).

The green infrastructure at the Broadous Elementary School in Pacoima, California transformed the school landscaping through increased grass and tree cover, cooling the play areas and creating more inviting and interesting places for children to play (De Guzman 2007).[8] The green infrastructure was advertised to be a long-term source of education but this element has been lost: no funding for interpretive signage was included in the project and the outdoor areas are not used as classrooms as originally intended (De Guzman 2007). Additionally, maintenance of the management elements fell to district personnel who lacked training and understanding of the infiltration and pollution treatment systems. A large part of the project, a section of bioswale that led to

[7] With the exception of one sample at the Broadous Elementary School study site.

[8] Green spaces like the play areas constructed at Broadous generate more creative play: Taylor and Wiley (1998) found that in barren space levels of play are approximately half of levels in green spaces with trees and grass, and that creative play in barren spaces is significantly lower than in green spaces.

an infiltration field underground, was paved over to allow truck access for other maintenance needs. De Guzman (2007) summarizes these failures in follow-through, "Despite the intensive resource demands of the planning and implementation phase, the project does not end once construction is completed. The project will only fulfill its purpose if there is sustained interest and a plan for continuity," (p 29). The case studies from the LA Basin Water Augmentation Study show the general lack of funding for long-term stewardship and maintenance follow-up in green infrastructure, as is also evident in the studies from Seattle. One-time grant funding and political pressure to complete green infrastructure projects makes sustaining interest in the project and planning for continuous stewardship of a project site difficult.

The Elmer Avenue Neighborhood Retrofit Project and related Elmer Paseo projects incorporated some of the lessons learned from the shortcomings of past green infrastructure to supply multiple benefits. Completed in 2010, another part of the LA River Augmentation Study transformed the 700 block of Elmer Avenue in Sun Valley (Landscape Architecture Foundation 2011). The process was highly collaborative and embraced the approach of green infrastructure as a multi-beneficial endeavor. The project planning and implementation involves city and county municipalities, city departments of sanitation, water and power, transportation, and engineering, as well as non-profits and residents. The Elmer Avenue Neighborhood Retrofit Project provides storm drainage for a 40-acre area and uses green infrastructure technology to drain and infiltrate stormwater, and water saving techniques to retrofit homes on the block. The project vastly improved the walkability of the street, improving walkability satisfaction of the residents from 2% to 92% (Landscape Architecture Foundation 2011). The project was successful because it prevented flooding that damaged property on the street prior to the project and meaningfully incorporated the expertise of many different stakeholders and infiltrated stormwater. This process of collaboration can be a template for future planning and construction but there is room for improvement. The technology used to collect and infiltrate has been effective but is not functioning entirely as planned. More water flows to certain areas of the retrofit than intended, which complicates the construction of additional stormwater retrofit to the south in the Paseo alley. Additionally, the bioswales in the public right-of-way are collecting more trash and sediments than was predicted (E. Alduenda, pers. comm., 11/7/13).

In Elmer Avenue, homeowners had the choice to participate in private property retrofits. The homeowners who participated had different options for design, plants, technology and landscaping of their property, and were provided with individual consultations with a landscape architect. Those who participated and shared a similar land aesthetic with native planting and impervious pavements flourished under the retrofit. The owner of this house (Figure 11) took extra care to tend to plants and integrate water-saving techniques and stormwater BMPs into the entire aesthetic of his property.

Figure 11. A resident on 700 Elmer Ave. took the tools provided by the Retrofit Project to enhance the value and aesthetics of his property through landscaping, while also integrating all of the available green infrastructure components into his property. Photo by author.

The retrofits were paid for by the project and cost $10,000 per home. The improvements to the homes and neighborhood have been linked to significant increase in property values on Elmer Avenue (N. Steele, pers. comm., 11/7/13). Increased property values adjacent to green infrastructure projects indicate that improvements bring aesthetic and economic value to the community (CNT 2010).

Valuable lessons have been learned about public participation through Elmer Avenue. As properties on the street turn over to new owners, much of the knowledge about the landscaping, water saving technology, and bioswales in the project are lost. In the future, for properties with green infrastructure, a provision could be attached to the homeowner's deed, so that the next homeowner can be aware of and implement proper care (E. Alduenda, pers. comm., 11/7/13).

In a tour of the Elmer Avenue Retrofit, Mike Antos from the Council for Watershed Health described how the problem of maintenance on Elmer Avenue has been the largest institutional stumbling block to new implementation of similar projects (11/7/13). The City of Los Angeles requires private residents to maintain vegetation in the right-of-way in front of their house but on Elmer Avenue, the right-of-way is not just vegetation - it is also infrastructure that the city may have responsibility to maintain. These bioswales straddle the line between public and private ownership, making proper maintenance of the technology difficult. Green infrastructure maintenance will require a new balance between public and private responsibility. Proper care for green infrastructure may require a move away from traditional notions of infrastructure and maintenance, toward a type of stewardship that is participatory and involves multiple stakeholders (M. Antos, pers. comm., 11/7/13). An interim solution to negotiating public/private responsibilities of the right-of-way may be implementing street designs that use medians as bioswales. A bioswale in the median solves the problem of private ownership in green infrastructure by placing the technology in a clearly public space, private maintenance may be voluntary but maintenance responsibility should fall on public agencies (M. Antos, pers. comm., 11/7/13).

Community buy-in is a key component to the long lasting success of Elmer Avenue and a related project, the Elmer Paseo. The Elmer Paseo is just south of the residential block and drains an additional 7 acres of stormwater. This project is also regarded as a success; it provided safe and dry passage for middle school students walking to school in a significant rain event and was implemented and managed by the Council with participation and support form the community. Project Manager Eileen Alduenda from the Council for Watershed Health explained (11/7/13) that the Paseo was heavily vandalized, made of degrading asphalt, and attracted litter and shopping carts. The alley was also identified by the city as an area of concern and undesirable activity. Through the design and planning phase, the Council introduced plans to incorporate benches and trees into the area, but both ideas were unpopular with the community who wanted clear sight lines and greater safety in the Paseo. Residents perceived these aspects as contributors to nefarious activity in the area. The Council accommodated these concerns, with the understanding that benches and trees could be phased into the design overtime (E. Alduenda, pers. comm., 11/7/13). The design addressed concern about graffiti head-on. The project's first priority was to phase out the use of the alley for graffiti through a public and participatory art project that used stencil representations of native vegetation and wildlife, and educational phrases in Spanish and English (Figure 12). The materials used to paint and paste the mural project are protected by an anti-graffiti coating, making graffiti removal easier. Alduenda has already witnessed a 'respect' for the new painting and artwork – graffiti has shown up in the alley but around where the artwork has been pasted (E. Alduenda, pers. comm., 11/7/13).

Pride of ownership in the project is something that Alduenda recognizes as key to the success of the project. She is encouraged by the fact that homeowners adjacent to the Paseo painted their fences to match the green walls of the Paseo, and is forging an educational and stewardship relationship between the nearby middle school and the Paseo (E. Alduenda, pers. comm., 11/7/13).

Figure 12. Residents and visitors to the Elmer Paseo walk through on the newly constructed permeable pavement path. Elmer Paseo infiltrates stormwater from 7 acres and is designed as a safe community space. Photo by author.

The Pinehurst Green Grid, LA Basin Water Augmentation Study sites, the Elmer Avenue Neighborhood Retrofit Project, and Elmer Paseo show that on a small scale, projects can improve water quality and reduce flood risk while also improving economic and social benefits to the community and involved agencies. However, stormwater effects are measured at the watershed scale - small case studies do not yield aggregate effects on watershed health (National Research Council 2009). Ecosystem health has been linked to the proportion of untreated impervious area in the upstream watershed (Walsh and others 2005), indicating that a widespread adoption of stormwater source control through green infrastructure is necessary for measureable water quality improvement. Ensuring social benefits of community pride, ownership, recreation, aesthetics, and property value in green infrastructure projects can help popularize the approach and support watershed-wide implementation in urban areas.

One Size Does Not Fit All: Challenges to scaling up

Scaling up green infrastructure for a watershed is complex and more challenging than conventional infrastructure. Most green infrastructure relies on infiltrating water into the groundwater and the effectiveness of those methods depends on the soils and geology of the specific site – not all streets can be green streets. Through studying and recreating the natural hydrology of a watershed before urbanization, planners and engineers can pinpoint the places within a watershed that used to function as catchments and make larger infiltration projects there. However, all homeowners and property owners in urban watersheds can practice water harvesting through rain barrels, disconnect downspouts from their sanitary sewer connection, and plant native vegetation or drought tolerant species. Green infrastructure is not one-size fits all and depends inherently on the specificities of the natural geology and hydrology of underlying land. In addition, planning, designing, and maintaining green infrastructure is unlike conventional infrastructure. Green infrastructure fails to bring full benefits when ample time and energy is not put toward legal agreements to ensure long-term maintenance and liability, and community and educational benefits of the project dwindle (De Guzman 2007). To scale up green infrastructure, developers need to incorporate in time costs from the beginning phases of planning.

Progress toward watershed-wide implementation can be made through continuing to implement and document the successes and failures of green infrastructure. Learning laboratories test green infrastructure technology and approaches effectively. The uncertainty of green infrastructure's costs and benefits can prevent many projects from being pursued (K. Lynch, pers. comm., 7/19/13). The results of successes and failures with green infrastructure should be made available to new projects in the region (E. Alduenda, pers. comm., 10/29/13; National Research Council 2009). Standardizing green infrastructure practices will help reduce the costs associated with implementing these approaches such as permit costs, research and development, uncertainty of outcomes (E. de Guzman, pers. comm., 10/1/13). Case studies such as Elmer Avenue show the legal, regulatory and administrative barriers to implementation and analysis of these existing projects helps to identify performance measures, funding sources, and models for stakeholder collaboration.

Stormwater experts and watersheds managers understand the need for new configuration of long-term green infrastructure maintenance and creative collaborations of stakeholders in a watershed before project planning and implementation. Green infrastructure is new and unexplored. Successful long-term maintenance will require national coordination of new maintenance configurations from the EPA (M. Antos, pers. comm., 10/25/13) and continued research of small case studies throughout the United States.

Green infrastructure can improve community indicators of health and wellness like walkability, recreation, aesthetics, and increased community pride and ownership. The potential for green infrastructure to meet the needs of urban watershed health depends on the care and consideration of project developers and managers to follow the construction of the project up with meaningful stewardship and collaboration with communities. When green infrastructure does not consider community buy-in and new configurations of maintenance and liability, it can fail to improve community health in urban watersheds.

CHAPTER 6:
CONCLUSIONS

In Thornton Creek restoration to pre-development ecosystem functions is not feasible, but there are other improvements that help make the community more livable and welcoming. Restoring Thornton Creek to a safe habitat for fish is not financially or ecologically efficient, but that does not mean restoration is not good for other reasons. Making Thornton Creek safe and welcoming to human beings is a crucial first step to a better and healthier human community and a healthier creek ecosystem.

Degraded water quality in Thornton Creek is a symptom of the underlying problems in urban watersheds: citizens are uninvolved and uninterested in watershed functions. Green infrastructure works well to address this by treating stormwater and by engaging residents through participatory infrastructure. This can also improve the aesthetics and health of urban environments by reconnecting and integrating natural systems into the city landscape. There can be a multitude of goals with restoration, park, redevelopment, and stormwater projects. Green infrastructure is multi-beneficial and unites differing ideas for improvement, drawing together sources of funding and expertise from a variety of fields and experiences. The approach of green infrastructure necessitates collaborative funding and management, making green infrastructure a viable solution to divisions between stakeholder goals and approaches to improving watershed health.

Green infrastructure could address the legacy of land use and political apathy that has led to deterioration of Thornton Creek's ecosystem functions. However its impact depends on how projects approach safety concerns and successful projects may require compromising restoration goals for urban park design. Green infrastructure can change the framing of benefits to include recreation and aesthetic goals. Green infrastructure usually straddles the line between private and public property and requires a new type of maintenance that engages residents in long-term stewardship, secures funding for staff support, and retrains city employees to care for the infrastructure. Sustained community buy-in and investment in green infrastructure requires meaningful engagement from the design phase of the project, and consideration of the actual safety, accessibility, and use of the space once construction is completed. In the end, community support is necessary to the long-term viability. Incremental measures that are understood and supported by the communities show great ability to facilitate eventual integration of watershed function into urban life.

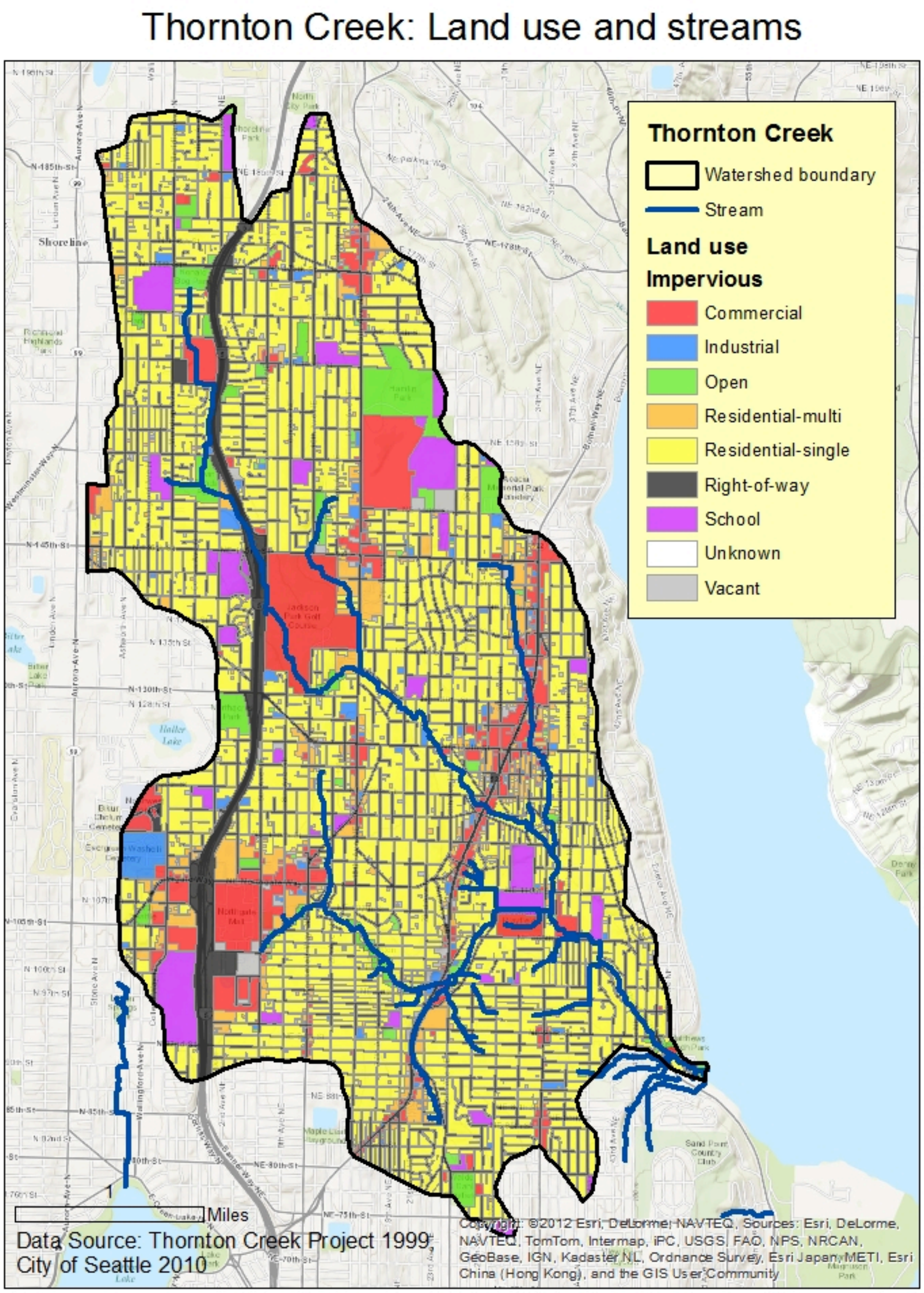
Thornton Creek is like all urban creeks. A legacy of development and re-engineering in urban watersheds leaves waterways stressed by degraded water quality and changes to quantity, even at very low levels. The Clean Water Act manages urban watersheds in the U.S. inefficiently. The Clean Water Act is inadequate to improve water quality and watershed health in urban creeks. Green infrastructure can manage stormwater better than conventional measures and can enhance the array of ecosystem benefits in an urban watershed.

There is a dearth of ecosystems integrated into the built environment of cities, and enhancing the involvement and engagement of city residents in their natural watersheds is a viable step toward bringing the many benefits of ecosystem functions into the urban environment, benefits which have long been paved over and degraded through city development. Jane Jacobs observed that diversity of human elements in city environments enhances the essential elements of city life, providing the spontaneity and interest that make cities attractive and healthy places to live. Similarly, enhancing the natural ecosystems present in a city environment can bring out the essential elements of city life in a new way that unites the natural and built worlds, improving the functioning of city environments for human beings and ecosystems.

Continued funding and experimentation in small-scale green infrastructure will build the reliability and knowledge within watershed management to begin implementing these techniques effectively on a larger scale. Improving quality of life is the most important part of green infrastructure for residents. Projects that improve water quality and quality of life for residents can appease residents, regulators, city governments, and activists. More research needs to be done on how to ensure long-term stewardship of green infrastructure. This is critical to the acceptance of green infrastructure and improvements in watershed health.

APPENDIX

Thornton Creek by land use type. Map by author. Data source: Thornton Creek Project 1999 and City of Seattle 2010.



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