Green Stormwater Infrastructure
Urban Forests and Integrated Water Systems
For Forterra - Stewardship Department

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1 – Introduction

The city of Seattle has seen a drastic reduction in its abundance of old growth forest over the last 150 years. That forest cover, which once surpassed an area of 53,000 acres, now has been reduced to a meager 3,200 acres (and just 200 acres of old growth forest) within the city (UFMP 2007). Much of that decrease can be attributed to booming population growth, the resulting urban development that follows, and of course the logging industry. The Puget Sound and surrounding waterways have paid a steep price for this urbanization. As the city started developing and replacing forests with impervious surfaces (parking lots, rooftops, housing, etc), it caused a landscape transformation, which in today's climate currently allows for swift transfer of stormwater runoff into the region's waterways. This runoff includes fertilizers from farmlands and residential yards, oil and grease from roadways, and even sewage during heavy rain events. The result is that water quality becomes degraded; salmon and other aquatic habitats decrease in numbers, beaches and other recreational areas close due to contamination, as well as a host of other damaging consequences.

Continuing this rate of land change will only exacerbate the problem. According to the Puget Sound Partnership's 2012 State of the Sound report, an average of 2,176 acres of forest in the Puget Sound basin were converted to developed surfaces during the years 2001 to 2006. This is a trend that simply isn't sustainable (the PSP has a stated goal of reducing yearly average amounts to 1,000 acres). In addition to deforestation for the sake of development, the city of Seattle has an additional problem – its forests are declining in health[1]. It is estimated that within 20 years, 70% of Seattle's forested parklands will be an ecological "dead zone" where invasive plants predominate, where trees are dead or dying, and where native wildlife habitat is gone.[2] Clearly, that doesn't paint a picture of a sustainable future.

Human intervention must take place before the Puget Sound ecological system transforms into a state of non-resiliency, meaning it will no longer have the capacity to continue absorbing

1 Green Seattle Partnership
2 Green Seattle Partnership, 20-Year Plan

these losses in forest cover, while still providing key ecological functions (such as reducing the flow of stormwater runoff). It is important to understand the functions of these forests and why it is imperative that they be restored, as well as the characteristics and nature of stormwater runoff.

1.1 – A Closer Look at Forest Canopy and Stormwater Runoff

The Pacific Northwest's native coniferous forests play a critical role in dealing with the region's wet environment. Conifers are evergreens which typically are conically shaped with needle-like leaves. The canopies of large trees are believed to intercept approximately 40 percent of the annual precipitation and the aerodynamic shape of those canopies are believed to greatly aid in evaporation.[3] The conical's needles hold more water than leaves because the needles tend to keep the water as droplets whereas leaves tend to push the droplets together to roll off the leaves.[4]

This is apparent when hiking in the forest during a rain storm; the ground is usually dryer closest to the trunk than away from it. This can be explained by looking down at the top of the conifer; a rain drop has more difficulty penetrating the canopy closest to the trunk due to the cumulative number of leaves (surface area) presented at each respective elevation. It is also apparent when viewing aerial or satellite LiDAR data where there are fewer ground returns the closer the point cluster gets to the tree trunk.

Stormwater can originate from rainfall or snow melt. The stormwater which penetrates through the forest canopy is absorbed by the ground, where it flows to the receiving waters via shallow, sub-surface flow (interflow). The amount of absorption is largely dependent on soil composition. "Soil biota and organic matter chemically and physically bind mineral particles into stable aggregates that build soil structure, increase soil porosity, and provide 20-30 percent of active water storage by volume."[5] In forested areas, the amount of interflow is approximately 20 to 30

3 WSU Extension & PSP. 2012. page 1
4 Federal Interagency Stream Restoration Working Group. 1998. page 2-4
5 WSU Extension & PSP. 2012. page 2

percent of the overall rainfall. This process can take hours, days or weeks and is dependent on many variables (ground's composition, grade, environmental conditions, etc.).

Stormwater which flows above ground, without percolating, is called stormwater runoff. In forested areas, it accounts for less than 1 percent of overall rainfall and does not usually create significant problems (see Fig. 1).

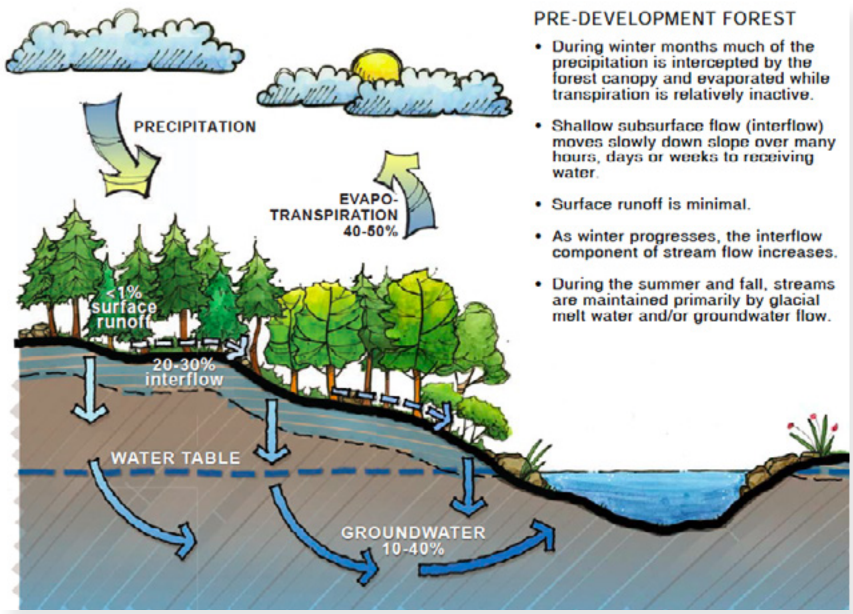


Fig. 1 - Lowland Forest Water Budget, Pre-Development[6]

Urbanization inherently alters the landscape by increasing the amount of impervious surfaces (rooftops, streets, parking lots, etc.), removal (or thinning) of native forests, compaction of biotic soil, and leveling or redirecting of catchments.

These changes affect the water budget within the hydrological cycle. As ratio of impervious surface area to forest area increases, the amount of rainfall that is intercepted by the forest canopy for evapotranspiration decreases and the amount of stormwater runoff increases. (see Fig. 2)

6 Source: WSU & PSP

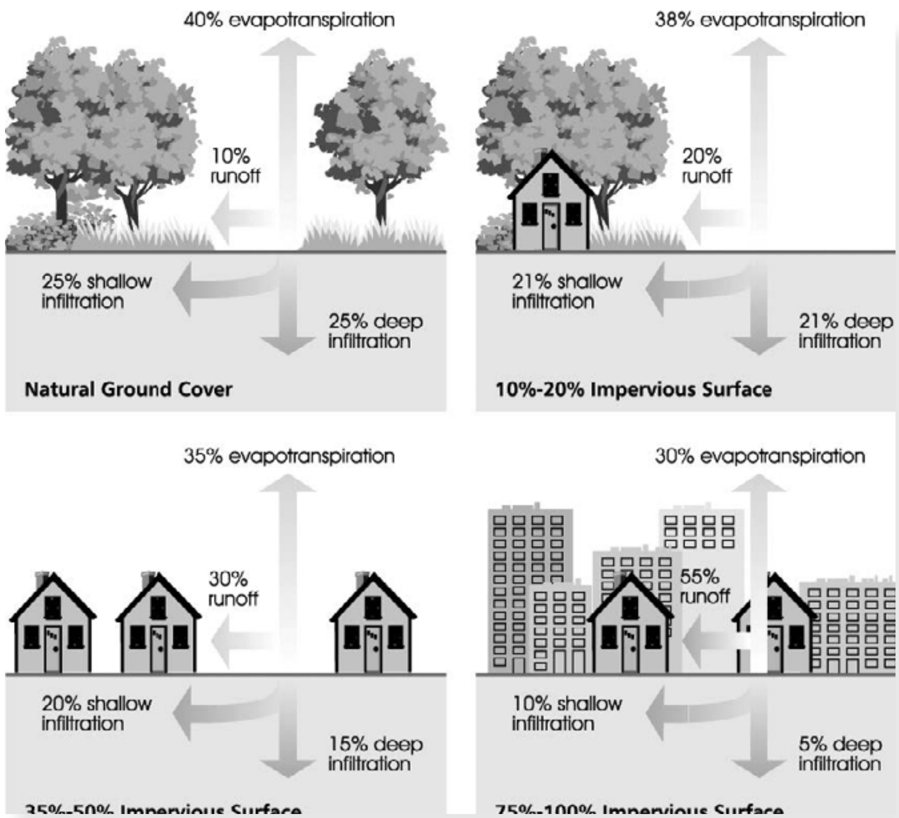


Fig. 2 - Water Budget as Impervious Surfaces Increases[7]

This increase in stormwater runoff has a negative affect on stream dynamics. Instead of the stormwater reaching the receiving waters at a more gradual rate of time, the arrival time is exponentially compressed because there is less resistance when the stormwater runoff travels above ground than when it travels sub-surface interflow. Furthermore, since the stormwater runoff traveled over heated impervious surfaces, its temperature is warmer than it would be if it flowed sub-surface. This, combined with fewer trees in the riparian zone, raises stream temperatures.

These swift waters bring with them debris, fine sediment, and trace amounts of chemicals and as they reach the receiving waters, stream flow is increased and the stream's maximum capacity is reached. This causes turbulence that distributes the fine sediment and chemicals throughout the water column. It is this presence of fine sediment, trace chemicals, and organic

7 Source: City of Seattle, SPU

debris, combined with the warmer stormwater runoff, that reduce dissolved oxygen (DO) levels.

In pre-development areas, streams would gradually fill thus allowing time for organisms to adjust to the change. However, this is not the case in places with high ratios of impervious surfaces. The thresholds of these self-organizing systems are more quickly reached and significantly altered since the frequency of the thresholds being met are increased. This alteration affects the time it takes for the adaptive cycle to transition from the back loop (reorganization phase) to the fore loop (rapid growth).

Lakes and wetlands are also negatively impacted by urbanization. Native plant species have adapted to the native slow rising and falling of water levels. However, with the fast rising waters associated with urbanization, the vegetation can die off and have a more difficult time returning because of the more frequent rises to maximum water levels.

As outlined above, the water quality in urban areas are negatively impacted and the health of fish and invertebrates are in turn negatively impacted. The trace amounts of pollutants accumulate in the fats of fish where they are introduced into the food chain. The increased amounts of organic debris increases demand on available DO to aid in its decomposition. This decomposition promotes algae growth again increasing the demand on DO inventory. The lower DO levels force the aquatic life, in search of higher DO levels, up to the shallower depths; thus becoming more vulnerable to predators.

This pollution and reduction of wildlife negatively impacts the region socially and economically. Consumers become weary of eating the tainted fish / seafood, thus affecting the fishing and restaurant industries. The stigma of tainted food can persist for long periods of time and push consumers to purchase food from other regions.

The federal Clean Water Act was passed into law in 1972 and acting under that authority the United States Environmental Protection Agency (EPA) established the National Pollutant

Discharge Elimination System (NPDES) to regulate point source pollution from discharging into waters to the United States. There are two phases outlining the municipal stormwater permit program for which the Washington State Department of Ecology uses as a guide in issuing Phase I and Phase II permits.

Seattle's stormwater code (Title 22, Sub-section 8) falls in line with "certain requirements of the city's Phase I NPDES and State Waste Discharge General Permit for Discharges from Municipal Separate Storm Sewer Systems.[8] The code requires a Drainage Control Review and application IF:

1) You are disturbing more than 750 square feet of land; or

2) You are adding or replacing more than 750 square feet of hard surface, such as pavement; or

3) You are adding or replacing more than 750 square feet of a building (as measured by the roof outline).[9]

Furthermore, a professional civil engineer is required if:

1) At least 5,000 square feet of new or replaced impervious surface require a Technical Information Report and Drainage; or

2) Less than 10,000 square feet of new or replaced hard surface with flow control requirements require the Pre-Sized Flow Control Calculator; or

3) More than 10,000 square feet of new or replaced impervious surface requiring flow control must do continuous modeling using the Western Washington Hydrology Model (WWHM) or MGS Flood.

Within the city of Seattle, stormwater runoff can reach the receiving waters in three main ways: 1) culverts or ditches; 2) storm drain; 3) combined sewers. Storm drains are intended to carry

8 The City of Seattle. 2009. page xiii
9 The City of Seattle, 2009. 22.807.020

only stormwater while combined sewers carry both sewage and stormwater. Under normal operating conditions, the combined sewers flow (mostly) to the West Point Wastewater Treatment Plant (WTP) for treatment before being discharged into the receiving waters of Puget Sound.[10] However when the combined sewers are operating under maximum capacity, during significant storms, an overflow diverts the untreated sewage directly to the receiving waters. Approximately half of the city's stormwater drains into combined sewers; this is more so in older areas.[11]

Map 1 on page 20 shows that the majority of the completely separated drainage systems exist above 85th street whereas the rest of Seattle is largely a mixture of combined and partially separated drainage systems.

Many of these combined sewers have been (and are scheduled to be) replaced, however approximately 128 locations still exist. A partially separated system typically means that street catch basins contribute runoff to the storm drain (and thus directly flow into the receiving waters), while rooftop drainage is still contributing to the sewer system. It is important to note that while several CSO locations are slated for reduction in the near future, stormwater will continue to flow into the Puget Sound and surrounding waterways, carrying with it various degrees of non-point source pollution. This is one of several reasons a call for urban afforestation is being made. While forestation projects won't be implemented overnight, plans exist to gradually restore the urban forests, with an eye towards improving the resiliency of the system, and creating a sustainable future that will accommodate both future growth and restored forestlands.

1.2 – Forterra and the Green Seattle Partnership

The Green Seattle Partnership (GSP) was formed in 2004, and is a partnership between Forterra, the city of Seattle, and the community. The GSP has a stated goal of "creating a sustainable network of healthy forested parklands throughout Seattle, supported by an aware, engaged community." The GSP put out a 20-year strategic plan in which they outlined their plan to restore 2,500 acres of forested parkland by the year 2025. The GSP state in their strategic

10 The City of Seattle. 2009. page 1-1
11 The City of Seattle. 2009. page 1-1

plan that the forests are dying and are not as self-sustaining as generally believed they would be. The main problem is that invasive species are growing in around these forests, and aren't allowing seedlings to regenerate. Thus, human intervention is required to eradicate invasive species and to reforest parklands.

Parklands are one component of the overall plan to reforest the city of Seattle. The cities' Urban Forest Management Plan (2007) is a 30-year plan to restore canopy cover to 30% within the greater Seattle region. The UFMP has 9 management units (downtown Seattle, industrial, transportation corridors, etc). The UFMP calls for 171,600 trees to be planted within the next 30 years in 2 management units (developed parks and park natural areas) for which Forterra would be considered a stakeholder. That achievement alone would result in an economic benefit of $13 million a year just in stormwater mitigation alone. Therefore, the GSP's 20-year plan coincides and acts as one component of the city of Seattle's master plan to restore canopy cover to the city.

1.3 – Site Prioritization

Phase I of the GSP's 20-year strategic plan is to evaluate and prioritize sites for restorative work. In the plan, the prioritization pertains to parklands and their associated forest health. Forterra has reached out to the University of Washington for help with this endeavor and asked that students, in the geography department's Professional Master's Program in Geographic Information Systems (PMPGIS), to perform analysis related to their prioritization goals stated in the GSP's 20-year strategic plan. Specifically, they ask for help developing criteria for identifying and categorizing basins where improvement of forested natural areas would have substantial impact on the stormwater system, with potential to impact the construction of a large-scale Green Stormwater Infrastructure.

Jeff Dong and Joel Perkins (authors of this report, referred to "the team" in this report) have agreed to take on the task of this design and analysis as part of their PMPcapstone project. Work won't be limited to prioritizing parklands as many areas within the city will be studied.

The team intends, as Forterra has asked, to scope this project at a basin level – which the team believes will also provide answers as to which parklands might be prioritized on the forest implementation phase of the plan. The conceptual model for this 9-week tasking is outlined in the next section of this report.

Map 1 - Drainage System Types for Seattle[12]

12 The City of Seattle, 2009, Fig 1.2, page 1-4

1.4 – Describing the System

In an attempt to gain additional enlightenment into the resiliency of the environment in terms of an integrated stormwater system, the Walker and Salt's (2012) assessment method was used as the vehicle by which to arrive at any conclusions.

This methodology asks the designer to define: the scale; governance structure; the "resilience of what" and the "resilience to what,"; and any drivers or trends that are known. This isn't an exhaustive list of every known component of the system – but it did seek to determine the major components and demonstrate their interconnectedness to each other.

Describing the System	
Scale	Macro scale - the setting for these analyses was the municipality of Seattle. On a meso scale, \watersheds, sewersheds, etc, were analyzed. On a micro scale, analyses were conducted at the parcel level and in public open spaces, (i.e. park lands).
People and Governance	The Green Seattle Partnership makes up the city of Seattle (which is comprised of three departments: Seattle Parks and Rec, Seattle Public Utilities, and Seattle office of sustainability) and of course Forterra. The public is a critical component as well, because they will be conducting volunteer work when it comes time to implement the rehab efforts. Also, the USDA is involved as they are the ones administering the grant (still pending). Other non-profit groups such as EarthCorps, the Student Conservation Association, and the Seattle Conservation Corps could be brought in to organize volunteers and work in restoration areas where volunteers won't be able to do the work. Landscaping crews and habitat restoration crews could be brought in as well, on an as-needed basis. Lastly, corporate sponsors could help fund the project where grant monies fall short.
Resilience of What	Sustainable urban forests are what the project would like to see become resilient (green stormwater infrastructure - GSI). These canopy covers are so beneficial to the region for a variety of reasons - but for the purposes of this analysis, resiliency of urban forests as a way to mitigate the overall effects of stormwater runoff, is discussed.
Resilience to What	The system must remain resilient to invasive species that weakens and ultimately destroys conifer forest cover. But the larger phenomenon that the system must remain resilient to is development. When forested lands are converted to impervious surfaces, stormwater, that otherwise would have seeped into the ground, will now make its way into the waterways and ultimately the Puget Sound - damaging the ecosystem in the process.
Drivers and Trends	The urban population growth that is expected to take place is definitely a driver; with population growth, the need to develop more land puts pressure on a system that is already failing as it pertains to stormwater runoff containment. Our urban forests are ending their natural life cycles - and their seedlings can't reproduce because of invasive species. By removing these healthy forests, stress is being put on the sewersheds, as it pertains to stormwater runoff, because of the lack of forests and the ubiquitous distribution of impervious developed surfaces. Other trends are that the population is expected to grow, and that it is difficult finding funding to fix the problem. It was long thought that urban forests would regenerate on its own, but this has not happened due to invasive species and development. Now, a massive restoration effort must take place in order to get parklands in to a "maintenance mode".

Table 1 - Describing the Stormwater System

1.5 – Assessing the System

After describing the system, the team moved on to the system assessment to investigate specified resilience. This assessment takes place over three different scales (parcel level, watershed level, and city/region level) and three domains (bio-physical, economic, and social). The idea of the matrix is that each box represents a threshold, and that threshold interacts with the thresholds surrounding it. Not all the threshold boxes are perfect, and some can easily fit within other categories.

Specified Resilience			
	Parcel Level	**Watershed / Sub-Watershed**	**Seattle City Limits**
Bio-Physical	Presence of forest canopy prevents stormwater runoff.	Decrease in ratio of forestation to impervious surfaces increases stormwater runoff access to waterways exponentially.	Stormwater runoff can have wide-ranging effects on the region, including erosion, wetlands contamination, adverse effects on salmon, other habitat populations.
Economic	Development on the parcel is a key driver perpetuating stormwater runoff via land use change (to impervious surfaces or even grass land for that matter).	Flooding due to landslides (many times due to upslope impervious surfaces) has cost millions and millions of dollars in damages to structures.	Population growth in the region/ city will put pressure to develop housing / infrastructure such as roadways, etc. The need for costly capital improvement projects to address this growth will require monies that are difficult to acquire.
Social	Forestation ensures healthy parklands and preservation of those parklands for use by the public.	Stormwater runoff pollution has shown in the past the ability to close beaches, waterways, reduce fishing permit sales, and halt various recreational (boating) activities.	Cultural and recreational benefits are necessary for a livable city/ region and these could be jeopardized by uncontained stormwater runoff pollution.

Table 2 - Stormwater Threshold Matrix

After assessing specified resilience an assessment of general resilience was conducted where the goal was to attempt to identify trends and look at those through the lens of what effects those might be having. Attempts to measure resiliency, from a general standpoint, were made. The purpose was to see what may have happened to cause one or more of the components of a system to lose resiliency by using several umbrella categories such as: diversity, openness, reserves, tightness of feedbacks, modularity, leadership, social networks, and trust, and levels of capital assets

General Resilience	
Diversity	There are not a lot of different (natural) components of the system that mitigate stormwater runoff flows quite like conifer canopy cover. The lack of diversity in mitigating components is without question putting the resilience of the system in question.
Openness	One one hand, it appears as if varying levels of government are very open to doing what is necessary to mitigate the effects of stormwater (Of course, acquiring funding is a separate, yet related matter). One the other hand, it appears as if the public is not quite as clued in. It's hard to say how open the citizens would be to making the changes necessary (the forestation to private property, reducing use of lawn fertilizers, etc).
Reserves	It was long thought that reserves (of forest cover) would regenerate itself in the form of seedlings from mature forests. However, invasive species have choked out what urban forests remain, and thus regeneration must happen through human intervention. The addition of forest reserves will appear via whatever efforts humans make.
Tightness of Feedbacks	The effects of stormwater runoff have been known for years. Policy creation has taken place, but it can take years to implement. Just the process of acquiring funds and putting an implementation team in place can take 3-4 years. This is a problem that does have the attention of certain agencies/organizations, but even with honest intent, corrective action takes time.
Modularity	There are a lot of modular components to the system. For example, sewersheds, watersheds, slopes, waterways, impervious surfaces, forested lands - are all part of a system that are pretty interconnected - that is to say each is a contributor to pollutants ending up in the Puget Sound. That being said, certain parts are modular in that if they were upgraded (such as forestation efforts), improved results could be expected.
Leadership, Social Networks, and Trust	There are leaders who care about the degradation of the environment due to stormwater runoff, etc. and actions are being taken to counter this trend. That being said, by and large, people in this day and age are pretty skeptical of government officials (especially, in the department of trust).
Levels of capital assets	In 2006, it was estimated that the cost to mitigate the effects of stormwater runoff would cost around 1 billion over the next decade. Generally, these stormwater capital improvement projects aren't the highest of priority, therefore don't get the use of general fund dollars. In the case of Forterra's effort, a grant is being pursued from the USDA.

Table 3 - Assessing General Resilience

1.6 – Transformability

Lastly, transformability, or the region's ability to change from a current state to a preferred one, was researched. The exciting thing about the Puget Sound region is that although stormwater runoff can have crippling effects on the ecosystem, the region does have the capacity to change - it isn't too late. A 20-year charge to implement urban forest restoration is a great example of a way the landscape can change and have a positive effect on the ecosystem. Coupled with an improvement in general overall awareness about the problem at hand - improvements to a variety of other system components could lead to change.

1.7 – Decision Situation Assessment

With the many complex elements that comprise a stormwater infrastructure system, it can be overwhelming and difficult to know where to start in regards to creating a conceptual model; especially when dealing with a major metropolitan landscape such as Seattle. For this reason, the team performed Nyerges and Jankowski's Decision Situation Assessment[13] in an attempt to gain a better understanding of the scope of the project, and how it might unfold. It was hoped that this exercise would help focus the team's efforts in on what matters the most about this particular project.

This assessment was performed by exploring the relationships of twenty-five aspects of the the eight constructs of the DSA. This process was based on the theoretical framework EAST[14] and is a general assessment. Below are the eight constructs along with our key learnings.

Social-Institutional Influence: The ability for this project to be carried out as scoped is largely dependent on grant monies from the United States Department of Agriculture. It is understood that this is a 1-year process to secure funds and a 2-3 year process afterwards, to carry out implementation. However, once funding is secured, Forterra won't have an issue carrying out its implementation in terms of bureaucracy, since they are partnered with the city of Seattle on this project and plan on carrying out the project on the city's lands. The purpose of this task is to identify "drainage basins of interest" that would be good candidates for forestation improvements, based on the idea that forestation would help improve the resiliency of the region by mitigating the effects of stormwater runoff. Per the Green Seattle Partnership, the goal of that document is to prioritize parklands. These analyses inherently did such, although they were not limited to the parklands. The roles were limited to performing this Phase I analysis and consultation with Weston Brinkley (project manager at Forterra) and Lisa Cieko (Forterra forest data expert) were conducted on an as-needed basis. Analyses were conducted utilizing mostly public data, with some private forest data being supplied by Forterra. Clearly, Forterra is the client in this scenario, and the team was motivated to satisfy Forterra's desire to further

13 Regional and Urban GIS, A Decision Support Approach. 2010
14 Enhanced Adaptive Structuration Theory, Nyerges and Jankowski 1997

advance the sequencing of this project; therefore, findings will be presented in the style of an independent type analysis.

Group Participant Influence: Analyses were performed in a way that the team thought would best forward Forterra's efforts. It was believed that Forterra would act in their own best interest as well, after taking delivery of the final analysis. The team detailed Forterra's concerns and moved forward on this analysis with an eye on delivering the best information, based upon the team's knowledge and current skill sets. The relationship was such that the team felt as if it could go to Forterra with questions about data and process on an as-needed basis; Likewise Forterra could approach the team with concerns about the proposed workflow. Both parties were familiar with and were willing to work with GIS as a means to transfer information.

Participatory GIS Influence: The plan was to work out of a shared ESRI file geodatabase on Dropbox (cloud computing). One of the known deliverables was a file geodatabase that Forterra could choose to use as stand-alone, or that they can integrate into their own GIS. Additionally, the team planned on creating maps, tables, charts, etc to use as visual information transfer. For information that couldn't be packaged into a file geodatabase, that information would be placed into a folder, compressed, and transferred to Forterra at the conclusion of the project. There may be deliverables beyond the aforementioned.

Appropriation: The group worked from the understanding that it would be supporting Forterra's desire to find the "best location" candidates for forestation improvement. It was the team's responsibility to be forthcoming in the analysis, while at the same time understanding Forterra's perspective on the matter. The team did not have an agenda of its own that would influence the determination of a "best location". Technologically speaking, Forterra possesses an internal GIS; therefore, any analysis that was generated by the team could easily be ingested into their system.

Group Process: The team planned to keep Forterra updated, with regards to the design and testing plans, to avoid surprise when it came time to take delivery of the final analysis. Furthermore, the team expected feedback in return, especially if the workflow plans didn't align with Forterra's goals for the project phasing. Therefore, a workflow would be agreed upon between the two parties. However, certain analytic discoveries may have taken place that caused the team to change course or adjust the workflow. In this event, a dialogues would have taken place between the parties so that a shift in methodologies could be agreed upon.

Emergent Influence: The group may have had the need to investigate GIS methodologies beyond our current knowledge base, provided that the situation called for it. Additionally, as the project moved along, Forterra may have intervened and asked to go down a different path based on findings that were provided. The team was prepared to be flexible in its workflow. In regards to the approval of workflows – Forterra had the final approval (and took on the role of project manager in that vein), however the team certainly asked for input from its advisors as well to ensure it went down a path that would help accomplish the mission at hand.

Task Outcomes: This process was intended to ultimately give Forterra a recommendation of formidable sites to which forestation enhancements would best benefit. As a next step, Forterra will need to study these recommendations more throughly. A report will be forwarded to Forterra; their next steps will be to further qualify these sites, and then take next steps as they see fit in their scoping schedule.

Social Outcomes: Forterra will decide if they will act on the recommendations that the team presented to them. The team's work as analysts was unique in that it performed this analysis for period of roughly eight weeks, delivered it, and then its involvement won't evolve past that point. However, the work that was performed could continue on to be the basis for future work that Forterra pursues.

2 – Design

2.1 – Conceptual Model Overview

After learning more about stormwater and its impact in the bio-physical, ecological, and social realms, this information was used to construct a conceptual model. This concept was also designed knowing what datasets were readily available, or likely to be available (to authorized organizations / personnel), and they were selected based on information gathered from the reference material (see Appendix A on page 103).

Fig. 3 below outlines the nine week workflow the team planned on using to ensure a timely completion. It outlines persons involved with the project and their roles. Team members are represented with red symbols, course facilitators / advisors are represented with gray symbols and project sponsors are represented with tan symbols. The weeks are categorized into three sections: Design, Test, and Implementation.

In the conceptual design phase: the team identified what products Forterra wished to have upon project completion (deliverables); identified likely feature classes needed; determined the relationships between those feature classes; and developed a strategy on how meet the project's objectives.

It should be noted that the objectives were frequently re-addressed during the testing phase, as some of the data failed to yield significant results or the concepts did not pass the verification and validation (V&V) process.

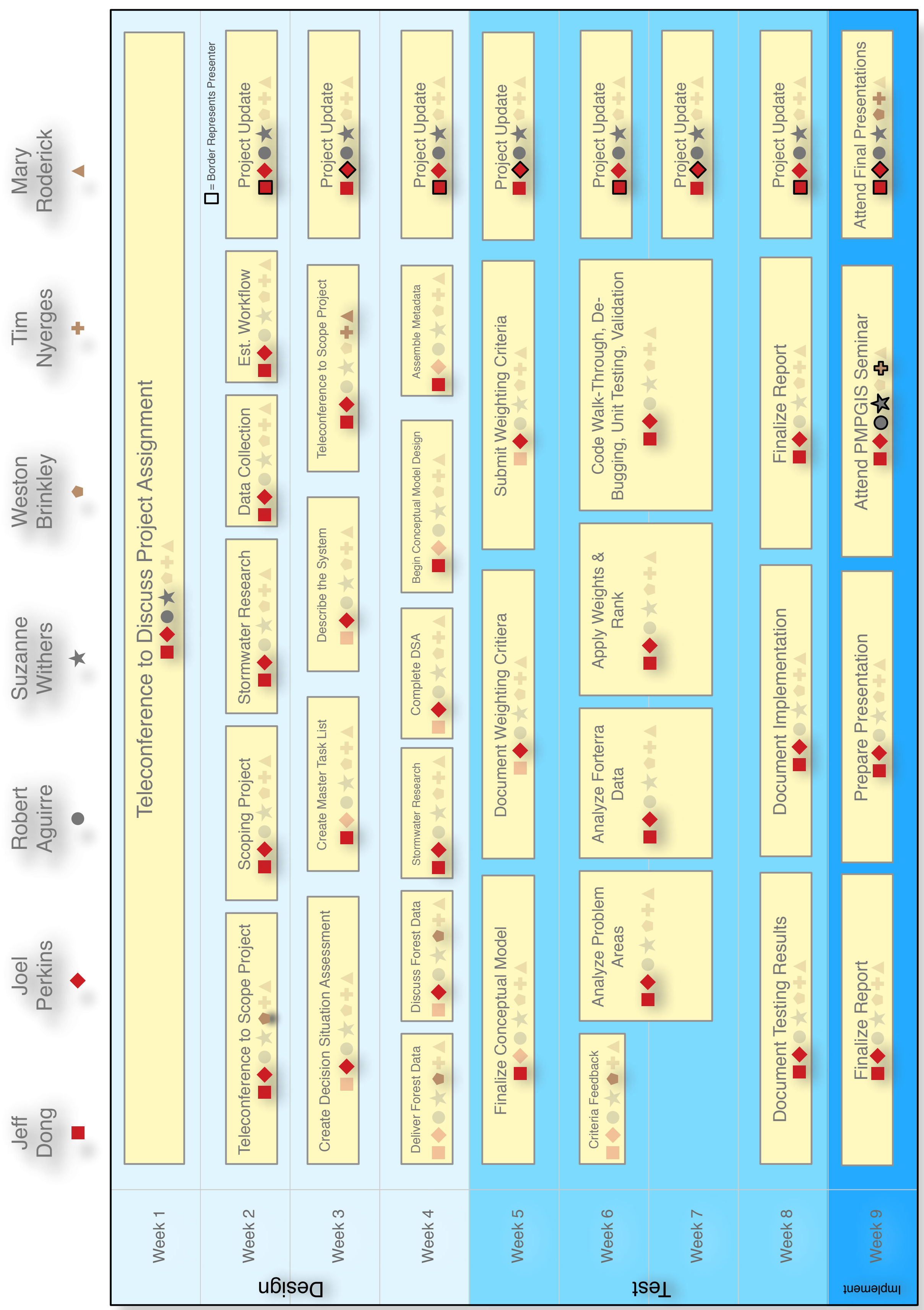


Fig. 3 - 9 week Swimlane Diagram

2.2 – Identifying Project Deliverables

The first step was to determine what products would be needed to assist Forterra in identifying suitable areas for future implementation of Green Stormwater Infrastructure (GSI). The project's sponsor (Weston Brinkley) requested documentation on datasets used to identify the locations, map products, and a list of criteria that can aid in identifying where GSI Best Management Practices (BMPs) could be implemented. He would in turn use this information for further, in depth, investigation (ground truthing) and as supporting documentation for grant applications. A Simplified Value Structure[15] was created to assist in better understanding the project's values, goals, and objectives (see Appendix B on page 105). An extract from the document is as follows:

Value:
- Low lying areas pose a flood risk

Goal / Target:
- Ensure proper drainage in those areas
- Create stormwater harvesting areas

Objectives:
- Identify stormwater inflows
- Identify feasible harvesting sites upstream from low lying areas

Criteria:
- Within low lying areas
- City owned property

2.3 – Identify Feature Classes

The next step was to identify feature classes that were needed (conceptually) to build the model and classify them according to key themes. Documentation recorded possible sources of needed data, the intended use of the data and how the data was to be generally structured. (see "Appendix C - Data Needs" on page 106).

Then, the particulars of the feature classes were documented which was an extensive process; but provided much needed insight into the availability of data, geographic extent, coordinate

15 Nyerges and Jankowski, 2010, page 106 (table 5.5)

system / projection used, accuracy and when the dataset was last updated. This document is expected to be contained within a separate document due to its length.

2.4 – Determine Relationships Between Feature Classes

In the logical database design phase, the data that was to be obtained in the physical database design phase, was analyzed. Conceptual relationships to expedite the physical design phase. For example, census block polygons would be connected with population data that was also tabulated by census block; or Combined Sewer Overflow volumes may have a relationship with impervious surfaces and therefore feature datasets would be created to investigate that aspect.

2.5 – Concept Strategy

The model's strategy was to follow the stormwaters' paths upstream, from problem areas, to their general points of origin in order to identify areas that would likely benefit from future implementation of GSI BMPs. Once these likely areas are identified, then they can be weighted, classified and ranked for further investigation.

In order to accomplish this goal, the model used the following methodology:

- Identify attributes likely to be affected by or promote stormwater runoff (Landslides, unregulated overflows, complaints, impervious surfaces, population density, etc.)
- Identify avenues in which stormwater can reach / affect, or originate / be affected by those areas.
- Identify the sub-watersheds (basins) in which those stormwaters are likely to originate from
- Identify prospective GSI implementation areas within those sub-watersheds
- Apply weighted criteria to the prospective GSI areas
- Rank the weighted prospective GSI areas
- Classify prospective GSI areas

2.5.1 - Identify Problem Areas

In order to provide a solution, a problem must first be identified and understood. The following are major problems resulting from (directly or indirectly) stormwater:

- Known and potential landslide areas
- Combined Sewer Overflow (CSO) events & volumes
- Sewers and/or drain systems receiving complaints
- Polluted / contaminated waters
- Population density
- Impervious surfaces

The feature classes *slide* and *potslide* were selected to represent known and potential landslide areas, respectively. Landslides are hazardous in urban environments due to the close proximity to residential areas and areas frequented by humans. They threaten life and property and are disruptive to available resources by diverting costs from other high priority projects. The model will use the polygons to map the landslide areas, for spatial analyses and to create thematic products.

Combined sewer systems are designed to carry both sewage and stormwaters to a Wastewater Treatment Plant (WTP), for processing, before delivery to the receiving waters. Large storms can fill the combined sewer system to maximum capacity. To prevent damage to the system, an overflow allows the excess water to flow, untreated, to the receiving waters. These events of untreated outflows are documented and can aid in better management of and future design of combined stormwater sewer systems. The model will use the dataset's points to map these events, for spatial analyses and to create thematic products.

Urbanization inherently alters landscape by increasing the ratio of impervious surfaces to forested areas; the removal / compaction of native soils; and / or the leveling of altering of natural drainage or retention ponds.[16] This can negatively impact the community if the stormwater is not adequately managed. Mis-managed waters may be inadvertently directed towards more

16 WSU Extension & PSP. 2012. page 2

established areas, initiating citizen complaints regarding flooding or backed up sewers. These complaints are valuable in identifying problems before they turn into a crisis. The model will use the drainage complaint dataset by joining it with a parcel layer to map specific complaints involving stormwater, and for spatial analysis.

Stormwater that enters the receiving waters by traveling overland (stormwater runoff) or through combined sewer systems introduces contaminates to those receiving waters. This can be in the form of organic material (fine sediment, leaves, human/animal waste, etc.) or chemicals (roadway de-icer, antifreeze, solvents, etc.). Organics increase the demand on available Dissolved Oxygen (DO) to aid in its decomposition and chemicals can be absorbed by organisms, thus entering the food chain.

Since all the datasets originated from various sources, they will need to have a common projection and coordinate system. This will be accomplished in ArcMap's ModelBuilder resulting in the projection / coordinate system of: NAD 1983 StatePlane Washington North (US Feet). An intersect calculation will be performed on all the problem area dataset to reduce size and "weight" of the geodatabase. The feature classes will be explored to determine there are any common problem areas. For example, a high number of drainage complaints adjacent to landslide areas.

Stormwater is a common factor in the above mentioned problems and it can negatively impact the bio-physical, economic and social structures of the study area; thus posing a challenge to its resilience. By understanding these problems the most appropriate GSI Best Management Practice (BMP) can be selected to mitigate the impacts.

2.5.2 - Identify Originating Sub-Watersheds & Paths to Them

After analyzing the problem areas, the model will attempt to locate the generalized source of the respective problems. This will be accomplished by identifying and analyzing the movement of stormwater with respect to the problematic areas. The model plans to use the following information to better understanding this complex system:

- Natural drainage basins
- Manufactured drainage basins
- Catch basin
- Stormwater drains / outfalls
- Combined Sewer Systems / overflows
- Sewer sheds

Stormwater runoff travels across the surface until it finds the lowest point. This can be sub-surface or above ground. Natural and manufactured basins provide a container for the water to rest. Natural basins are a valuable tool in identifying the historical movement of water. However, the urbanization of areas typically level out these depressions to provide a level surface to build on. The identification of the basins' (natural and man-made) respective locations is important for this model because it may highlight the cause of the above mentioned problems and provide information on which BMP to implement. For example, if a problematic area was located within a basin, water would naturally want to flow into it. Possible solution may involve the re-introduction of native vegetation, installation of bioretention swales, and/or installation of dispersed smaller drainage basins. This dataset can be used in conjunction with the LiDAR DEM (+/- 30 cm accuracy)[17] to more accurately determine natural basins.

However, in the above example, the stormwater may require removal by way of a stormwater drain or Combined Sewer System. The stormwater must first enter the catch basin, which is typically covered by a stormwater grate so that large debris are restricted from entering. Understanding where these catch basins are located is helpful in understanding where engineers anticipated water to accumulate. Impervious surfaces are typically used to guide stormwater runoff to the catch basin. If a catch basin is frequently experiencing difficulty effectively drain-

17 Retrieved from the Puget Sound Lidar Consortium (PSLC)

ing stormwater (backing up), due to high volumes, then it may be possible to implement GSI BMPs upstream in an attempt to reduce flow volumes. The concept is to join (via attribute) this dataset with that of the combined sewer system and/or the stormwater drain. The expectation is to track the path of flow from the point of origin to the receiving waters.

Once the stormwaters flow through the catch basins, they enter either a stormwater drain or combined sewer system to be transported to WTP[18] or directly to the receiving waters. The NPDES[19] regulates all point source pollutant discharges into waters of the United States. Pollutants can be in the form of chemicals or organic matter. During storms where heavy rainfall is observed, stormwaters traveling in Combined Sewer Systems can bypass the WTP and flow directly into the receiving waters from the Combined Sewer Overflow. Since these systems are inherently a pathway for pollutants to be introduced into the receiving waters, it is important to understand their respective locations to help isolate the source of the pollution. Focus will be placed on the overflow and outfall points however its path in addition with the catch basin layer is helpful in understanding the complete system.

The model will intersect the aforementioned basins and systems to the municipal boundaries of the city of Seattle. This is expected to show those basins that feed into the study area. A base map will be added, to help the viewer better understand the spatial layout, and a DEM, will be used to analyze for any discrepancies or to identify if any significant/relevant geographic phenomenon exist.

The inclusion of the above listed systems / features allow for a better understanding of how stormwater is collected, conveyed, and discharged. This information will be used to analyze the possibility of these systems / features contributing to any of the problems identified in the previous section[20] by following the system from a problematic area up to a likely sub-watershed.

18 Wastewater Treatment Plant (WTP)
19 National Pollution Discharge Elimination System (NPDES)
20 See “2.5.1 - Identify Problem Areas” on page 31

Map 2 (below) outlines the Sub-watersheds within the city of Seattle. Those that lie on the border of the city's boundaries, were clipped as it was felt that Forterra (and the Green Seattle Partnership) would not be as interested in those areas. Also, there were two sub-watersheds (Boeing Creek and Water - Lake Washington) that were later removed from the model due to their small sizes and the insignificant they yielded.

2.5.3 - Identify Prospective GSI Areas

Once a sub-watershed was identified as possibly being the source of the problematic stormwater or the promotion of stormwater runoff, the model attempted to identify areas within the sub-watershed where the implementation of GSI BMPs may be beneficial. The concept was for the model to use the following datasets as part of its analyses:

- Parklands & green spaces
- Rights-of-Ways (ROW)
- Canopy coverage
- Impervious surfaces
- Wetlands

The Seattle Parks are likely candidates for GSI projects due to their open areas and lower percentage of impervious surfaces. The organization has over 400 parks and open areas consisting of over 6000 acres.[21] However not all parks are the best candidates for the afforestation of native vegetation. Some are designed specifically as open areas for recreational activities while others contain protected environmental areas that prohibit/restrict disturbances. The model will use the parksland & green spaces feature class to identify the larger areas as suitable GSI implementation sites. It too can be used with the LiDAR DEM to determine the presence of any sub-basins. The forest inventory data provided by Forterra (to be later discussed) can be analyzed in conjunction with the this parks data to help classify / prioritize the areas.

Right of ways (ROWs) are areas that allow for the legal access for person(s) and / or entities. For example sidewalks are designed for the general public's use, but can be contained with-

21 http://www.seattle.gov/parks/parkspaces/index.htm

in a resident's parcel. Planting strips adjacent to a roadways are another example and their maintenance falls under the property owner's responsibility.[22] These areas may potentially be viable candidates for GSI implementation. This dataset will be analyzed in with the Impervious surface raster to determine if it would be beneficial to the area to implement GSI BMPs.

The canopy coverage datasets documents existing forested areas that may be owned / managed by someone other than the Seattle Parks Department. This feature class will be used as above, but also can be used to weight and classify selected areas. Calculations can be performed to identify the amount of canopy coverage of a given area.

Although wetlands are heavily regulated and may be restrictive on what GSI BMPs to implement, they are still an important component towards GSI site selection. Since the thresholds associated with the wetlands may be fragile depending on what phase of the adaptive cycle[23] it is in, the location of these may prohibit or benefit from the redirection of stormwaters.

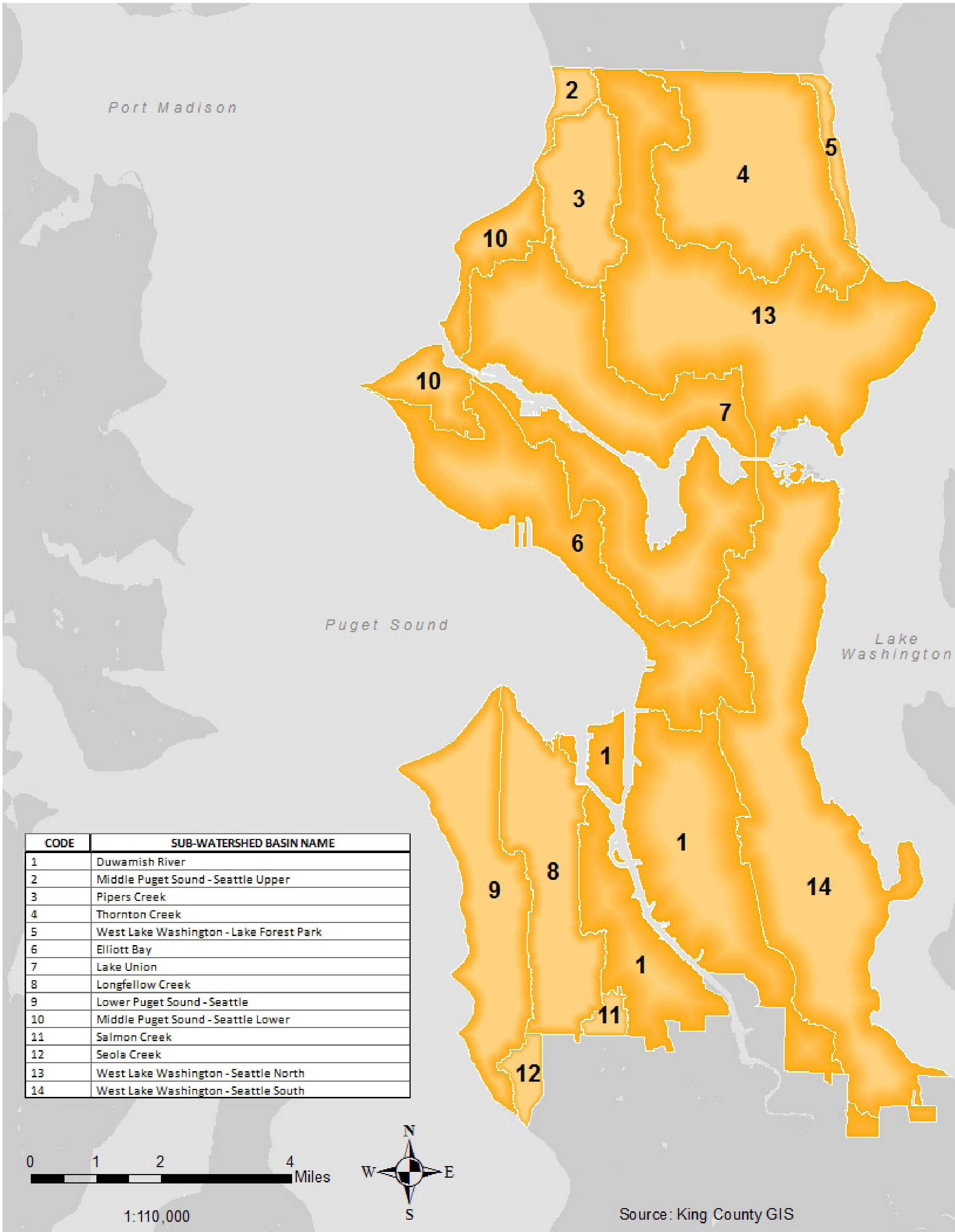
A wetland area may benefit from the introduction of plant species that are more tolerant to the high surges of stormwaters. Wetlands play an important role in the regions resilience thus justifying its inclusion in the model. The intent was to identify larger areas upstream from the problematic areas, however there is not a quantifiable number associated with this selection process.

Although this approach appears valid, during the analysis phase, team members wanted to provided Forterra with two options. One prong was identifying potential locations using the weighted scorecard and the other was to present them with a recommendation for a specific attribute outside of the Forested areas - Rights-of-Way.

22 http://www.seattle.gov/transportation/publicrow.htm
23 Rapid growth, conservation, release, and reorganization, (Walker & Salt, 2012, page 14)

This approach relies on the multiple criteria in selecting the potential locations and is dependent on the person assigning the criteria weights. This approach may be a powerful prediction tool if that person is a Subject Matter Expert (SME).

The other approach identifies one criteria (Rights-of-Way) and attempts to narrow down areas within that attribute to focus on.



Map 2 - Seattle Sub-Watersheds

2.5.4 - Apply Weighted Criteria

To this point, the model has identified problems likely caused by stormwater, identified likely avenues the stormwaters arrived at the problem, followed those avenues to likely areas (sub-watersheds) of origin and identified areas most likely to benefit from GSI BMPs.

It then proceeds to weight those respective areas to aid their subsequent ranking. The following criteria were selected to populate the weighted scorecard:

#	Inputs
1	Least amount of conifer canopy coverage
2	Least amount of overall canopy coverage
3	Highest acreage of unforested, undeveloped parkland
4	Most acreage of impervious surfaces within the basin.
5	Most acreage of impervious surfaces directly adjacent (up to 100 feet) of a waterway
6	Highest volume (gallons) of combined sewer overflow discharge in a year
7	Runoff amounts per year (using a simple runoff method)
8	Highest acreage of pre-1990 tracts in relation to impervious surfaces.
9	Highest amount of unforested, public right of ways
10	Acreage of public / vacant lands
11	Highest amount of mean slope in drainage basin
12	Pervious Soils - percentage of area with least amount of pervious soils.
13	Least amount of scheduled CSO/ GSI projects
14	Highest acreage of landslide areas
15	Monitoring gauges per basin

Table 4 - Initial Conceptual Scorecard Criteria

The presence of canopy coverage was included because the Green Seattle Partnership uses it as a means in determining which areas will be classified as “forested” and receive subsequent funding for reforestation. They defined forest parklands as those parks with 25% or greater tree canopy coverage.[24] By better understanding the spatial distribution of the canopy throughout Seattle, it allows forest / park managers to better direct resources.

24 Green Seattle Partnership, page 23

The same can be said for the distribution of impervious surfaces. The model was designed to analyze the ratio of impervious surfaces to that of forested areas. As discussed in section 1.1, the flow of stormwater runoff is accelerated as it moves across these surfaces. Understanding this ratio is important to Subject Matter Experts when performing calculations involving stormwater runoff (stormwater runoff curve calculator[25]).

Understanding when Combined Stormwater Overflow Events occur are helpful since they knowingly introduce pollutants into the receiving waters. Understanding the frequency and volumes helps in identifying if a particular CSO is experiencing more events than others. Based on the figures gathered from a Seattle Public Utilities report on Combined Sewer Overflow reduction[26] the model will use this information to highlight those overflow location with higher discharge volumes and their proximity to problem areas.

Knowing where there are current Combined Sewer Overflow project is useful. There may be projects involving Combined Sewer Overflow events or projects to mitigate these events. This dataset can be inserted in the earlier phase of the model provided that there is relevant information that indicates a project is as a result of the negative impacts of storm water.

Parcel vacancy was selected because they may be areas with less barriers/costs associated in order to initiate GIS BMPs.

Forterra's Forest "Tree-iage" dataset ranks areas, from "1" through "9", based on the composition of the land cover. Based on this score, the forest characteristics can be more easily understood. The Forterra dataset also includes an inventory of project areas which can be helpful in further narrowing down prospective GSI areas. The model uses this dataset to generate thematic maps, conduct analyses, and as a weighting criteria.

25 http://www.lmnoeng.com/Hydrology/hydrology.htm
26 2012 Annual Report Combined Sewer Overflow (CSO) Reduction Program

The type of soil is important in that it plays a large part in determining whether or not the stormwater will percolate or remain above ground as stormwater runoff. Compacted soils promote runoff and sandy soils allow for the fast penetration of water; whereas soils with high organic material content retains a higher volume of water. This dataset will be used to make thematic maps, conduct analyses and provide insight as to which GSI BMP should be implemented.

The presence of right of ways may make an area more attractive to GSI projects due to their proximity to impervious surfaces, vacancy and lower expected costs. It is important that prospective GSI project areas be located in areas already classified as public lands. The purchasing of land can be a costly process especially if eminent domain is enforced in order to acquire the property. If that is the case, then the public outcry can sway their views on the overall program.

Tracts that were developed prior to 1990 did not have to obtain a Phase I NPDES permit to discharge pollutants into receiving waters. It is important in identifying those tracts so that educational programs and/or policies can be appropriately directed. This dataset will be used to create thematic maps, spatial analyses, and weighting criteria.

Slopes may not the best candidates for GSI projects, however, understanding their locations will benefit GSI planners so that GSI BMPs can be implemented before waters reach them. Slopes promote the acceleration of stormwaters and therefore, this dataset is included for analysis purposes.

The results of the analyses conducted on the above criteria was placed into the weighted scorecard to then receive its weighting. The weighting of the above categories allows for stakeholder to express what areas are of most importance to them and their respective organizations. For the purposes of this project, the weights for the scorecard were selected by the Team Members. This is the benefit of this system as it is easily changed by the user.

2.5.5 - Rank the Sub-Watersheds

Once the sub-watersheds receive a weighting, then the sub-watersheds can be ranked. This allows viewers to better understand the geographic phenomenon presented and therefore more easily justify the selection of a prospective area to implement GSI BMPs.

2.5.6 - Further Analysis / Weighting / Ranking

Up to this point, the Forterra dataset (*Tree-iage*) was not used in the model due to data's coverage representing large scale areas. However, it is here in the model can use that data to further classify, weight, and rank a respective sub-watershed. The model takes advantage of the wealth of information contained within the Tree-iage data to identify areas on a census tract, or block, level needing GSI implementation.

2.5.7 - Conceptual Model Adjustments

As discussed at the opening of this section, the conceptual model was revisited and adjusted several times during the testing phase. It was during one of these iterations in which the weighted scorecard was reduced from having fifteen (15) criteria to eight (8). This process is outlined in the next section. The resulting scorecard criteria is outlined in

#	Final Inputs
1	Annual runoff amount in inches per sub-watershed (using the Simple Method)
2	Forest to impervious surface ratio
3	Acres of impervious surface within 30 yards of a waterway
4	Highest volume (gallons) of combined sewer overflow discharge in 2012
5	Mean slope
6	Precipitation
7	Landslide potential
8	Population

Table 5 - Final Scorecard Criteria

With the conceptual model complete, team members independently created their respective physical database models to enter the testing phase. Thus was done due to the difficulties of sharing the large datasets.

3 – Test

With the physical databases assembled, team members agreed to compartmentalize the testing process. Joel Perkins would head the testing of the ranking and weighting while Jeff Dong would analyze the testing of the Rights-of-Way model. This was done to maintain integrity of the Verification and Validation process and to overcome the previously mentioned difficulties of sharing the large datasets.

3.1 – Weighted Scorecard Overview

The goal of the testing phase was to examine which inputs would be best suitable for the multi-criteria weighted scorecard. The intent was to determine the overall characterization of each sub-watershed by: analyzing various attributes and real-world phenomena within them; normalizing their raw values; weighting them; and then ultimately ranking them using a simple scorecard method. The plan was to then use this scorecard to determine which forestation / forest rehabilitation opportunities might be explored first, or at least determine which sub-watersheds might theoretically benefit from those forestation implementations.

The testing period lasted a little over two weeks, during which time the team truly tested out different datasets and methods for feasibility. The initial goal was to obtain the following inputs to the scorecard (see Table 4 on page 39) by first acquiring the raw data, and then analyzing it within ArcGIS.

The process began by methodically working through the Table 4 criteria, in an iterative fashion. The steps involved searching for the supposed data set, examining the metadata for goodness of fit, and then performing any GIS operations, as necessary (joins, clips, conversions, etc). A determination was then made on whether or not an input should be used as a final input into the weighted scorecard. As an example, criterion #8 in Table 4 (Highest acreage of pre-1990 tracts in relation to impervious surfaces) - the purpose behind pursuing this input was that through research it was learned that in 1990, stricter stormwater regulations were put in place. Therefore, in theory, structures built before 1990 would theoretically have more drainage problems and might contribute to a combined sewer overflow more so than a grouping of newer structures. Census tract data was located on King County's GIS data site[27], as well as the census tracts shapefiles themselves. The data tables were joined to the actual tract feature class, and the data were examined. What resulted was a situation where tract-level data wasn't going to work very well, primarily because the tract boundaries extend over sub-watershed boundaries; this made it difficult to ascertain which data belonged to which location within the tract. Additionally, we found that the data was rather homogenous (the same percentages of older structures tend to blanket the city in large proportions, regardless of sub-location). Consequently, the team decided to jettison that input as one that wouldn't add a lot of value to the characterization scorecard.

There were other situations where the data couldn't be found which the team thought was needed to perform the analysis or even situations where the course was completely reversed, contrary to what was initially conceptualized. Conversely, situations were encountered where the team found itself adding inputs along the way that weren't initially thought of; as in the case with the population input. It came to light near the end of the testing period, when the team decided to add a "human" element into the multi-criteria evaluation. The thought was that highly populated locations might potentially add to the stormwater runoff problem of a particular sub-watershed, largely the same way that existence of pre-1990 built structures would, by simply existing in large numbers - and in the case of population, existing in large numbers in mostly older homes.

At the end of our testing period, the eight inputs shown in Table 5 (page 42) were identified as to populate the final weighted scorecard.

27 http://www5.kingcounty.gov/gisdataportal/Default.aspx

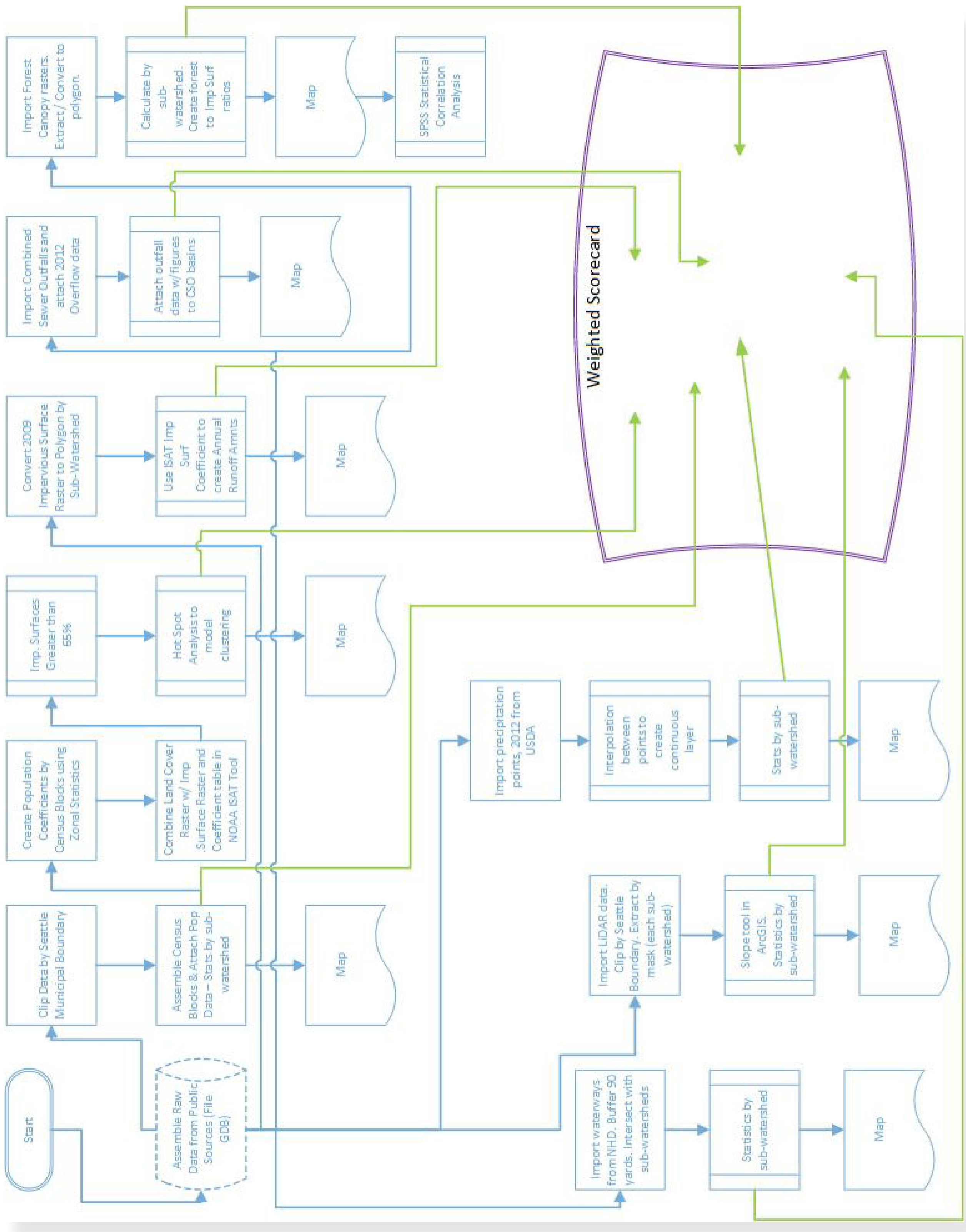


Fig. 4 - Weighted Scorecard Workflow Diagram

3.1.1 - Annual Runoff Amounts (Simple Method)

For this input, the team really wanted to be able tell (in theory) how much runoff a sub-watershed would yield given a set of inputs. For this, the Simple Method[28] was referenced to help determine what those values might be. The requirements / inputs needed for the Simple Method are outlined below.

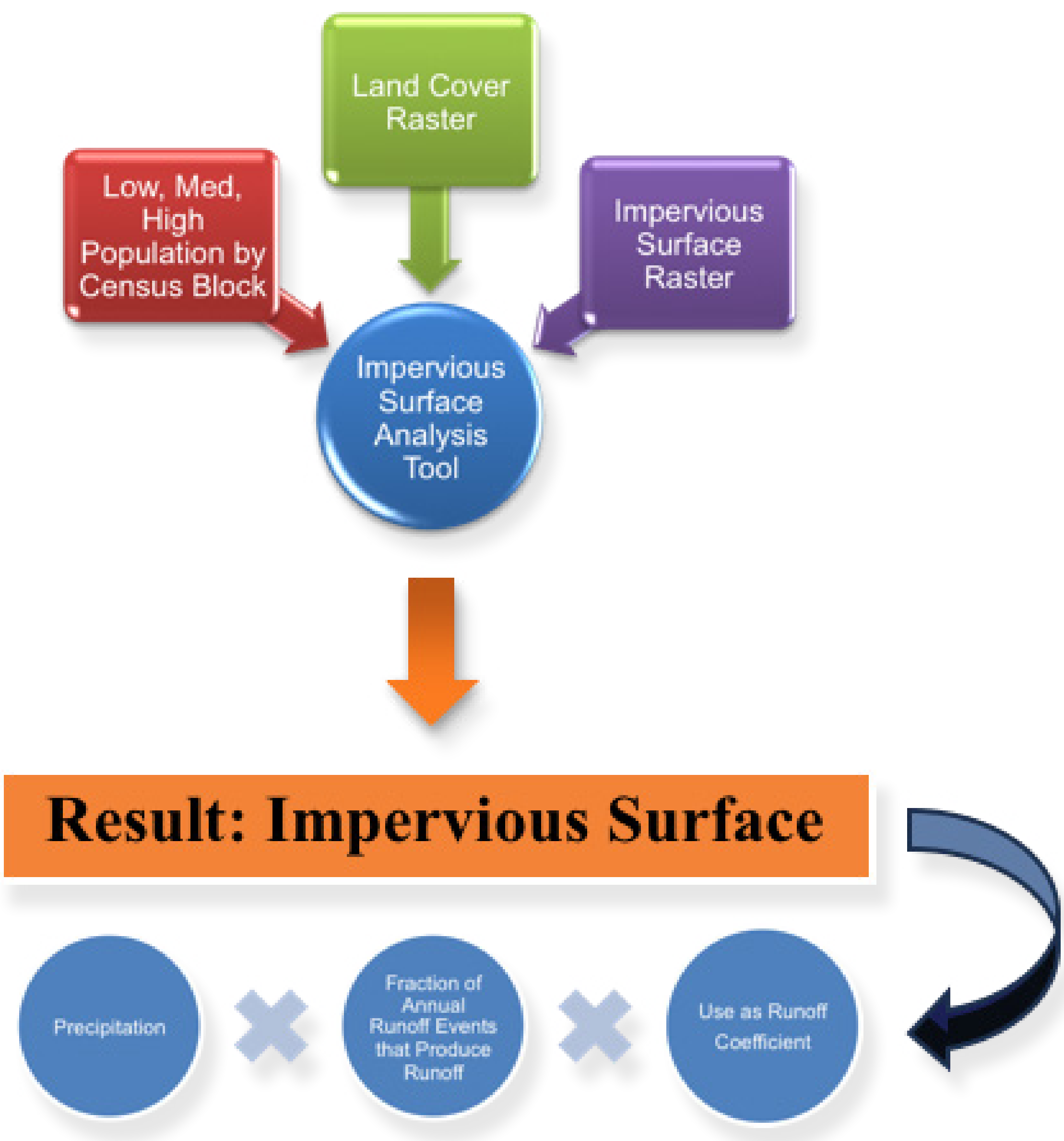


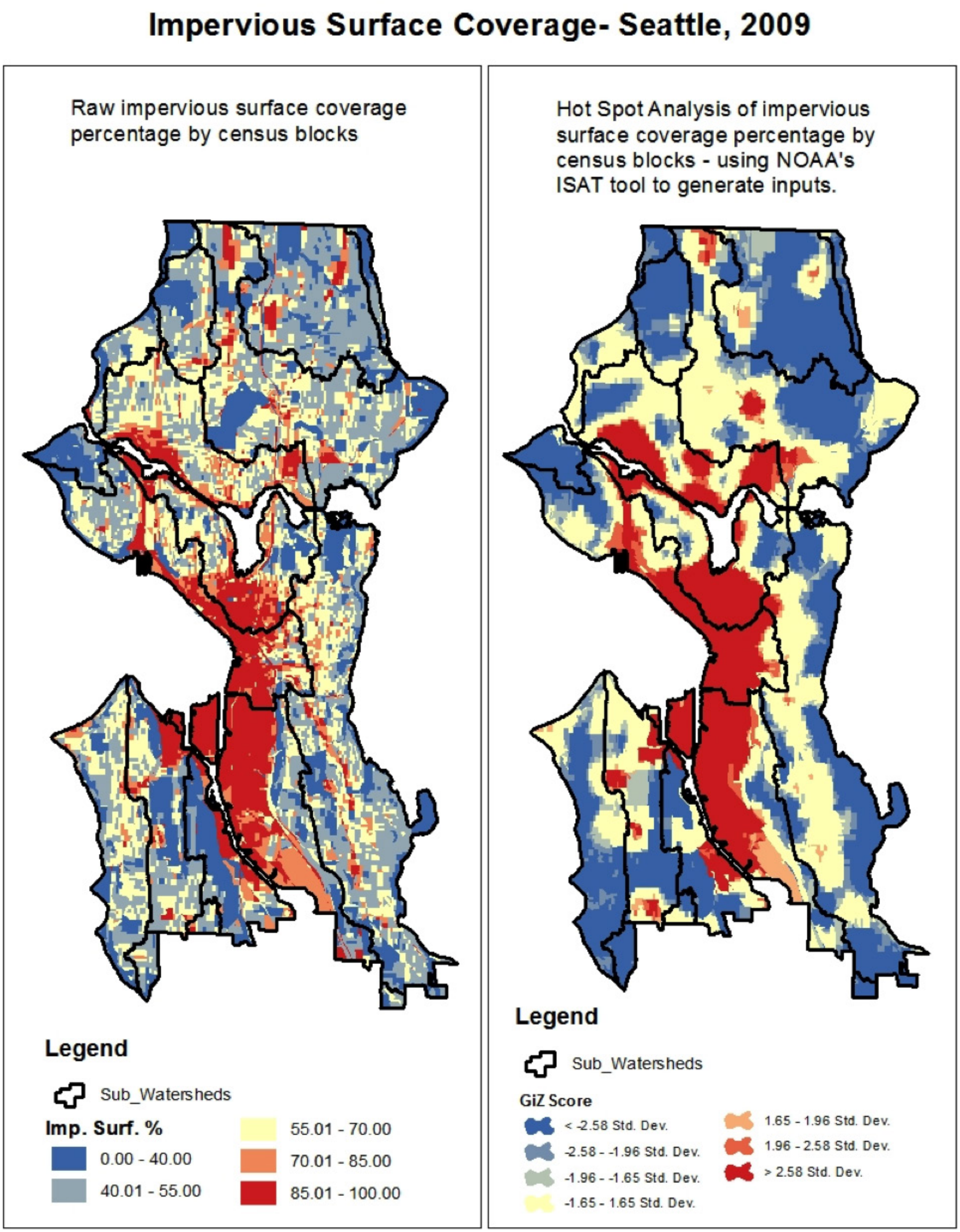
Table 6 - The Simple Method for Calculating Stormwater Runoff

28 http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple.htm

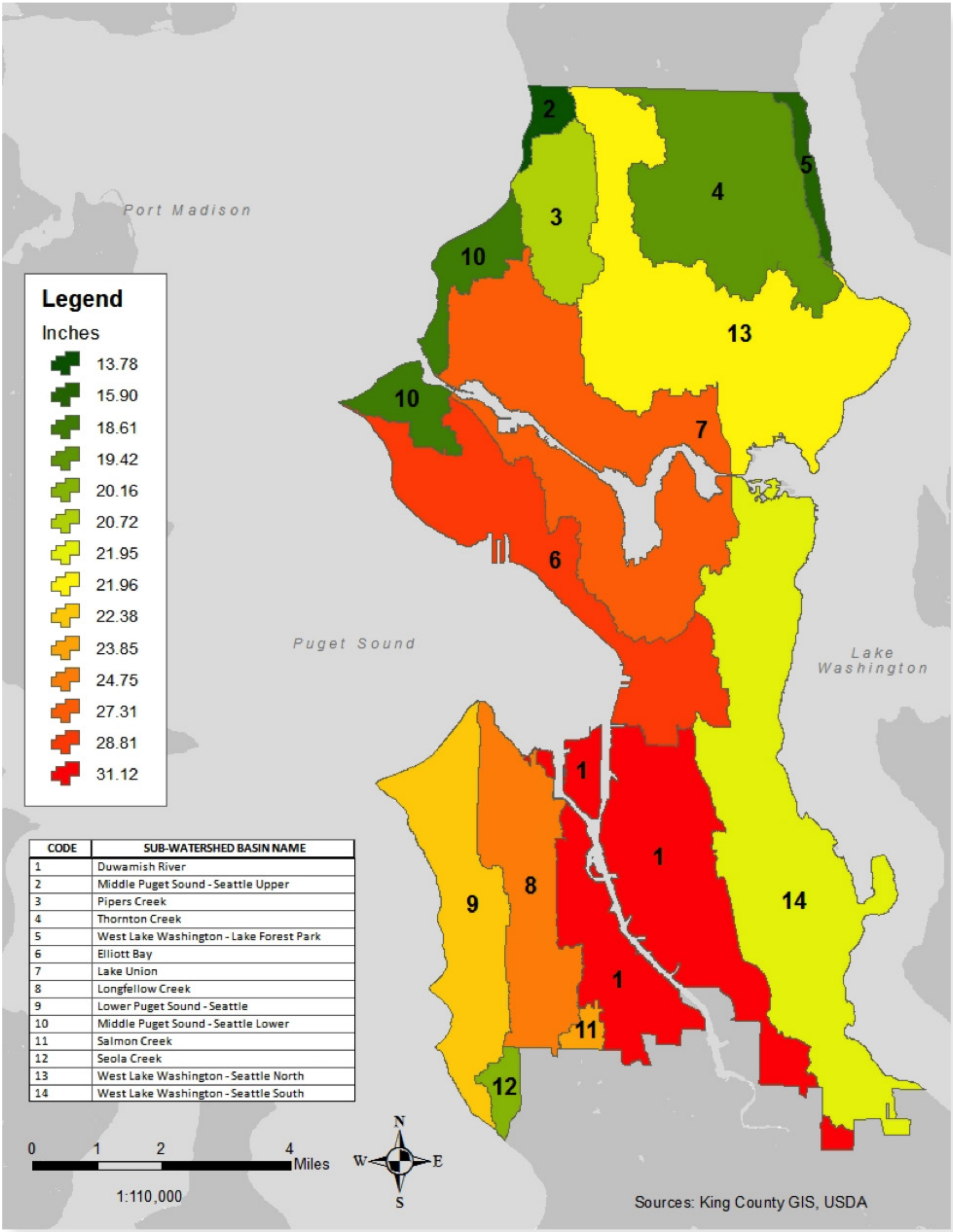
The Simple Method is an equation that requires a runoff coefficient to be plugged in as one of the inputs, in the form of an impervious surface coefficient. To create that coefficient in a more sophisticated fashion than simply calculating gross impervious surface raster cells, it was decide to use NOAA's Impervious Surface Analysis Tool[29] (ISAT). ISAT takes into account land use type, population density coefficients, and of course, impervious surface. What results is a impervious surface coefficient for all areas, not just in the actual impervious surface raster layer locations. Map 3 below shows the results of an operation that was performed, where the raw impervious surface values, by census block, were compared to the same analysis performed by ISAT (and then smoothed using the hot spot analysis in ArcGIS). The coverage's mimic each other closely; although it was felt that the underlying coefficient number in the ISAT layer is more representative of real life runoff conditions, since it involves land use type.

After the ISAT coefficients were obtained, an iterative process was used to calculate the theoretical runoff amounts for each of the 14 sub-watersheds, using 2012 precipitation data. Map 4 below shows that the highest runoff amount belonged to the Duwamish River sub-watershed with (31.12”), whereas the lowest runoff amount belonged to the Middle Puget Sound – Seattle North sub-watershed (13.78”). These figures were then joined to a master table in the team's database, for placement into the weighted scorecard after conducting the remaining input analysis.

29 http://www.csc.noaa.gov/digitalcoast/tools/isat



Map 3 - Impervious Surface Calculations (Raw data vs ISAT)



CODE	SUB-WATERSHED BASIN NAME
1	Duwamish River
2	Middle Puget Sound - Seattle Upper
3	Pipers Creek
4	Thornton Creek
5	West Lake Washington - Lake Forest Park
6	Elliott Bay
7	Lake Union
8	Longfellow Creek
9	Lower Puget Sound - Seattle
10	Middle Puget Sound - Seattle Lower
11	Salmon Creek
12	Seola Creek
13	West Lake Washington - Seattle North
14	West Lake Washington - Seattle South

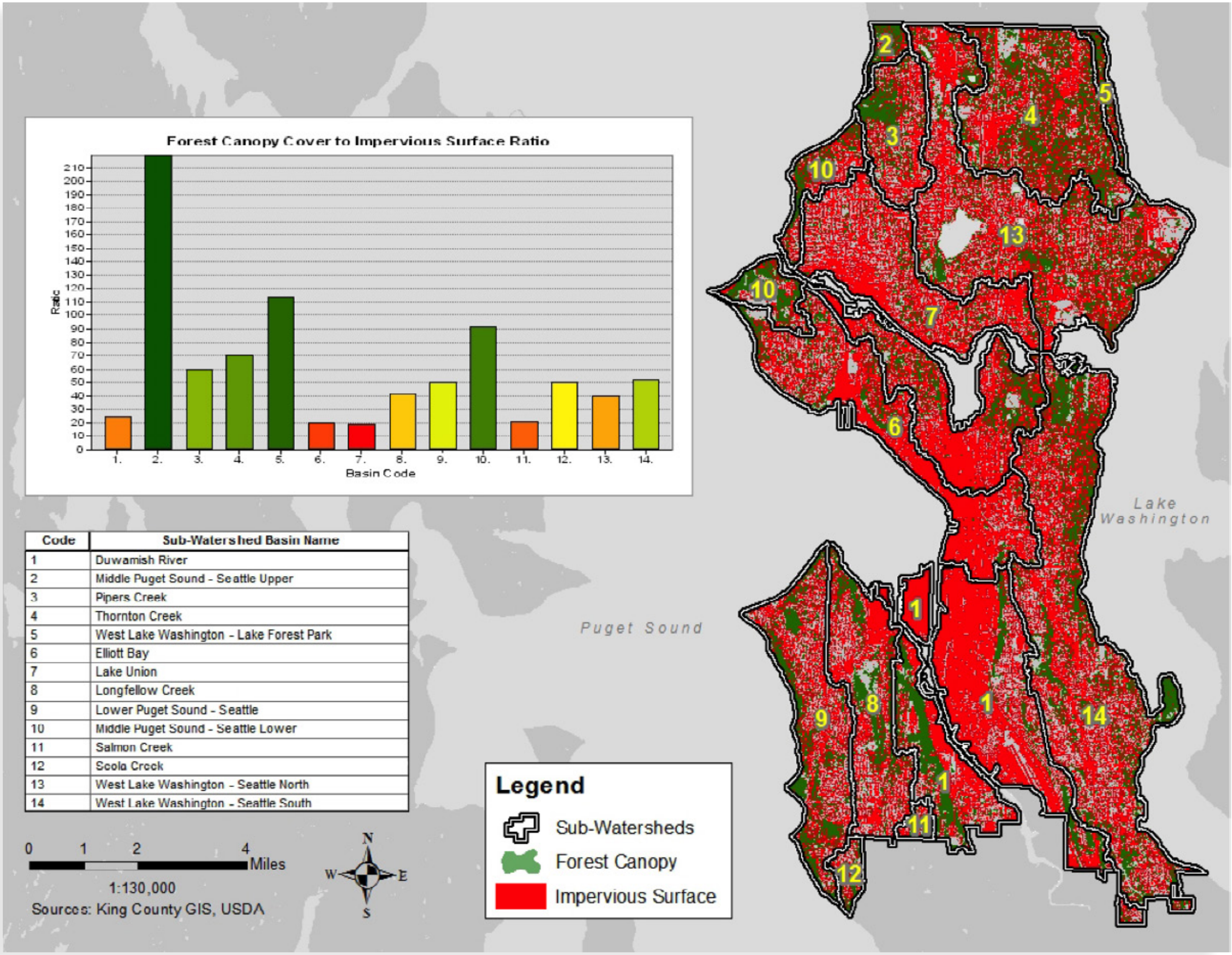
Map 4 - Annual Runoff Amounts (inches), by Sub-Watershed

3.1.2 - Forest to Impervious Surface Ratio

The next analysis involved obtaining forest canopy cover from the US Geological Survey's (USGS) Gap Analysis Program (GAP). Unfortunately, the latest update to this dataset was back in 2006, so that was all that was available for this analysis.

Operations for the canopy layer were pretty simple and straightforward. The area of the raster was calculated in acres and compared that number to the overall acreage of the sub-watershed. The model didn't delineate between the different types of forests, as the 30m raster didn't align very well with actual imagery when they were compared. For that reason, a general approach was taken and the amount of evergreen and deciduous forest, collectively, were calculated. Due to time constraints, a supervised re-classification of the land-use raster was not performed, however it may be an operation worth pursuing for future analysis. This might have yielded more accurate canopy results, because one can granularly decide based on orthophotography which pixels belong to which land use type.

The processes was conducted on the forest canopy cover, the results were stored in the main database table and the results were mapped. (see Map 5 on page 51). It was noticed that the areas having high forest canopy to impervious surface ratios seemed to coincide with low runoff totals (see Table 7). Those ratios vs the runoff amounts were uploaded to the IBM SPSS Statistics program to see if there was in fact a statistical correlation between the two phenomena. What was discovered was that there was an inverse correlation (-.823) between forest canopy to impervious surface ratios and annual runoff rate (see Map 5). The disclaimer to that method is that the sample size was very low (only 14 sub-watersheds). The results were not surprising given the present research, that low forest canopy cover yields higher runoff rates, even more so than by simply reducing impervious surfaces.



Map 5 - Forest Canopy Cover to Impervious Surface Ratio

Watershed	Runoff Rate	Forest to Impervious Surface Ratio
Middle Puget Sound - Seattle Upper	13.78	**219.91**
West Lake Washington - Lake Forest Park	15.91	113.81
Middle Puget Sound - Seattle Lower	18.61	92.05
Thornton Creek	19.42	70.81
Seola Creek	20.16	49.87
Pipers Creek	20.72	60.21
West Lake Washington - Seattle South	21.96	51.80
West Lake Washington - Seattle North	21.97	40.38
Lower Puget Sound - Seattle	22.38	51.02
Salmon Creek	23.85	21.52
Longfellow Creek	24.76	41.58
Lake Union	27.31	19.34
Elliott Bay	28.82	19.82
Duwamish River	**31.13**	24.37

Table 7 - Correlation between Canopy cover to runoff amounts

		Simple_Method	Ratio_For_to_Impsur
Pearson Correlation	Simple_Method	1.000	-.823
	Ratio_For_to_Impsur	-.823	1.000
Sig. (1-tailed)	Simple_Method	.	.000
	Ratio_For_to_Impsur	.000	.
N	Simple_Method	14	14
	Ratio_For_to_Impsur	14	14

Table 8 - Correlation Figures as Performed by SPSS

3.1.3 - Acres of Impervious Surface within 30 Yards Waterways

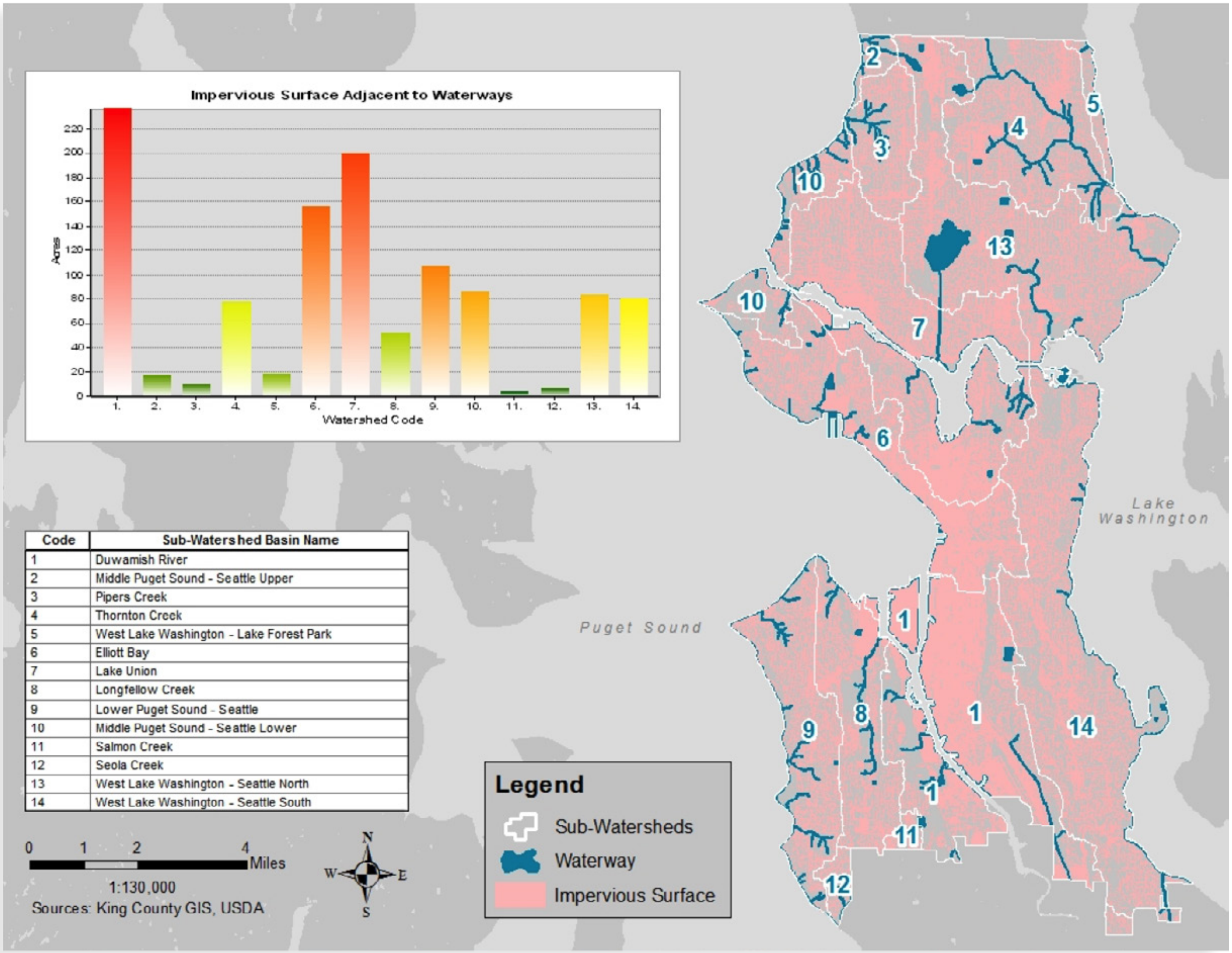
The next analysis was investigate how much impervious surface was in direct proximity to a waterway. For purposes of this exercise, the Puget Sound was counted as a waterway, even if it was separated by beach. Also, all water layers (streams, rivers, lakes) that the USGS supplies in the national hydrography dataset were included. The measurement of 30 yards was chosen to capture all impervious surfaces within a close proximity to the water way, without eliminating surfaces that might directly contribute runoff to that waterway. It was revealed (see Map 6 on page 54) that the Duwamish River sub-watershed had the greatest acres of impervious surfaces within proximity to a waterway (236 ac), followed by Lake Union (200 ac) and Elliott Bay (156 ac). That makes for a difficult runoff problem to solve when you have such a high proportion of impervious surface within such close proximity to waterways, especially in a large urban center like Seattle.

3.1.4 - Highest Volume (gal.) of CSO Discharge - 2012

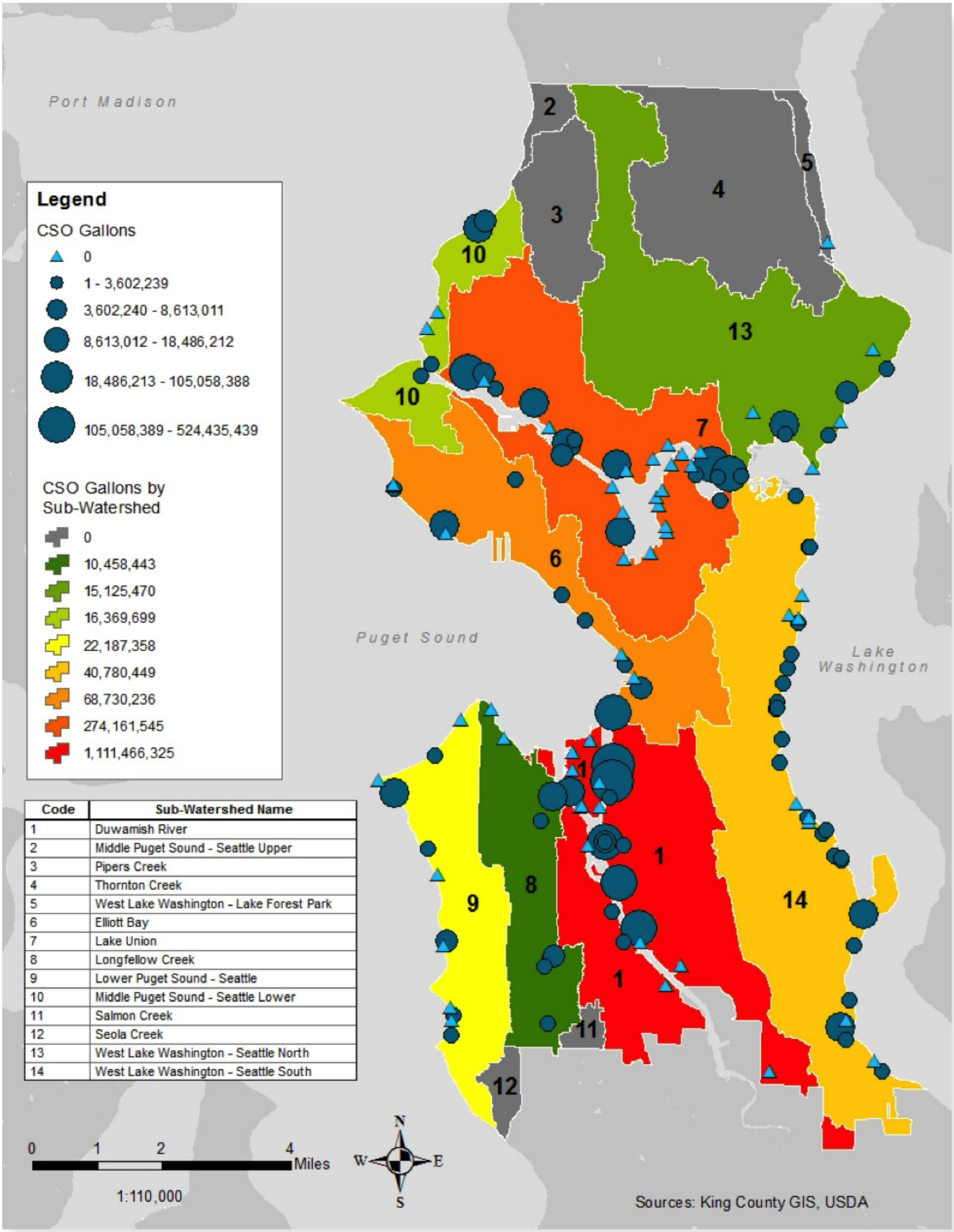
The next analysis looked into how runoff totals were directly affecting the waterways. Combined Sewer Overflow (CSO) data was obtained for the outfalls controlled by the city of Seattle and King County. This data (2012) consisted of the number of CSO gallons that went untreated, directly into a waterway. This overflow, because it was conveyed through a combined overflow system, means that overflow consisted of stormwater runoff as well as raw sewage. This data gives a good picture of how many CSO gallons flowed into a waterway in 2012, but there are a couple of caveats. Without subject matter experts, it was difficult to determine which specific catch basins were contributing to which outfall. Despite being supplied with data that outlined the means of conveyance, it was difficult to say with confidence, where stormwater is conveyed from. Where an outfall resided within a CSO basin, the assumption was made that all overflow originated from that basin and was contained to that basin. Several outfalls were not associated with a basin. For this reason, it is recommended that follow up analysis be performed, preferably with a subject matter expert from the city or county, to see which catch basins are contributing to which outfalls.

The other caveat is that some of these overflows events were due (at least in some cases, and to some degree) to mechanical failures at the outfall. Subsequently, some of these outfalls are the subject of upgrades in 2013 and in the near future.

This analysis concluded with the Duwamish River sub-watershed once again leading the others in a category - gallons of combined sewer overflow discharged into a receiving water body in 2012 (see Map 7 on page 55).



Map 6 - Impervious Surfaces in Relation to Waterways



Map 7 - CSO Discharges by Outfall - 2012

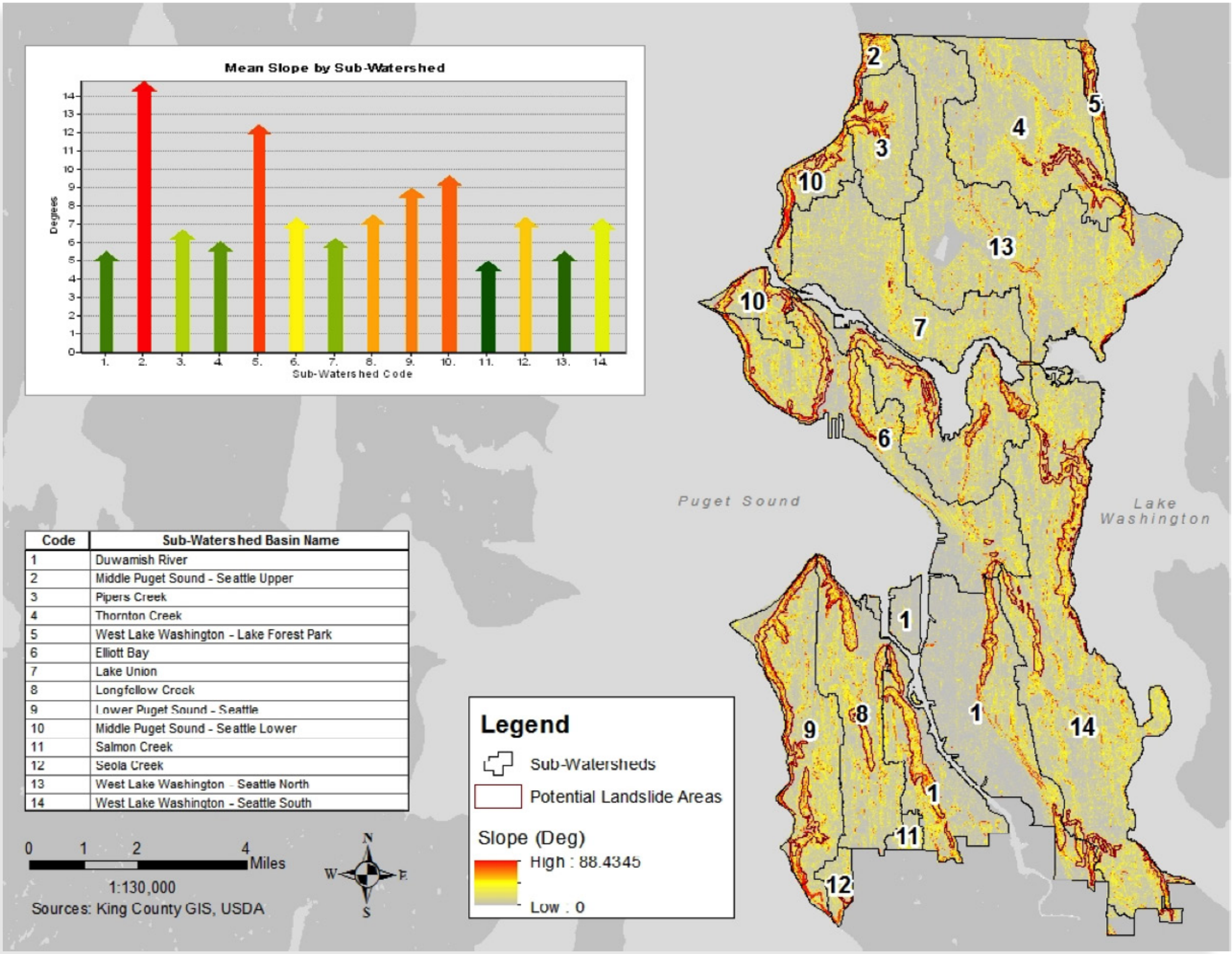
3.1.5 - Mean slope and Potential Landslide Acreage

The next analysis, for the weighted scorecard, consisted of simply calculating the mean slope of each sub-watershed. This was to get an idea of what part (if any) the respective slope plays into a sub-watershed's runoff yield amounts. Obviously, runoff will travel faster and farther in areas with greater degrees of slope. Areas with large slope numbers would be good candidates for forestation upgrades, as it would help control stormwater flow. To calculate the slope, the ArcGIS *Slope Tool* was used.

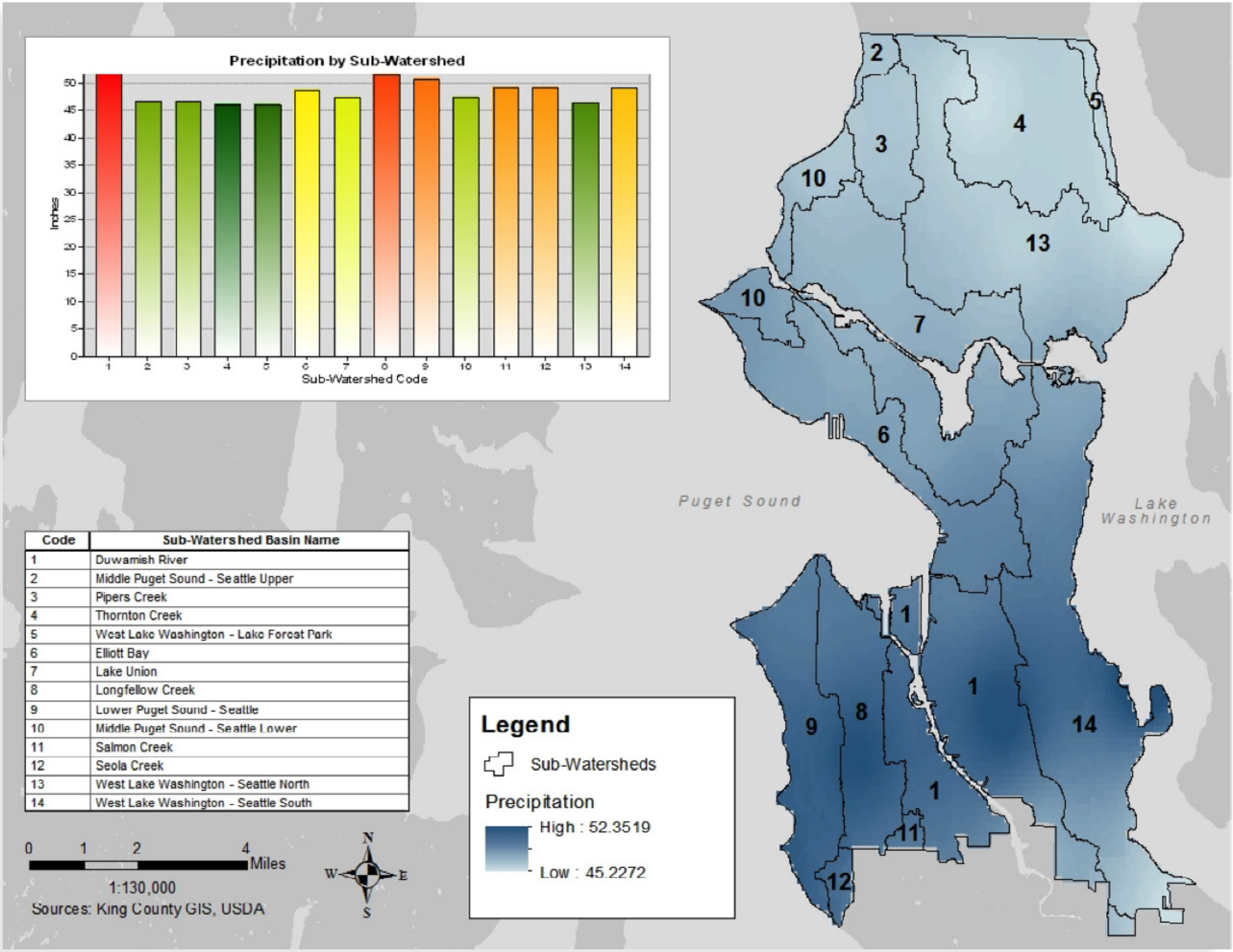
We also analyzed the locations and acreage of potential landslide areas. We wanted to see which sub-watersheds might be affected by runoff as it pertained to hazards. The goal within a sub-watershed with many potential landslide acres would be to limit the flow of stormwater in those locations, so as not to potentially contribute to the hazard itself. We ran those calculations using potential landslide data from King County GIS, and clipped them to each sub-watershed, and then inputted that information in our master table in the database (see results in Map 8 below).

3.1.6 - Precipitation

One would think that precipitation wouldn't play a large part in an analysis for this relatively small of an area, but there are differences in precipitation counts (2012) amongst the sub-watersheds. For example, the Duwamish River sub-watershed registered 51 inches in 2012, whereas on the northeast part of the city, Thornton Creek sub-watershed only registered 46 inches. That isn't a vast difference, but when the highest amount of rainfall in the city is also in the area of the city that also has the most amount of impervious surface and least amount of canopy cover, those attributes have a compounding affect (see Map 9 on page 58).



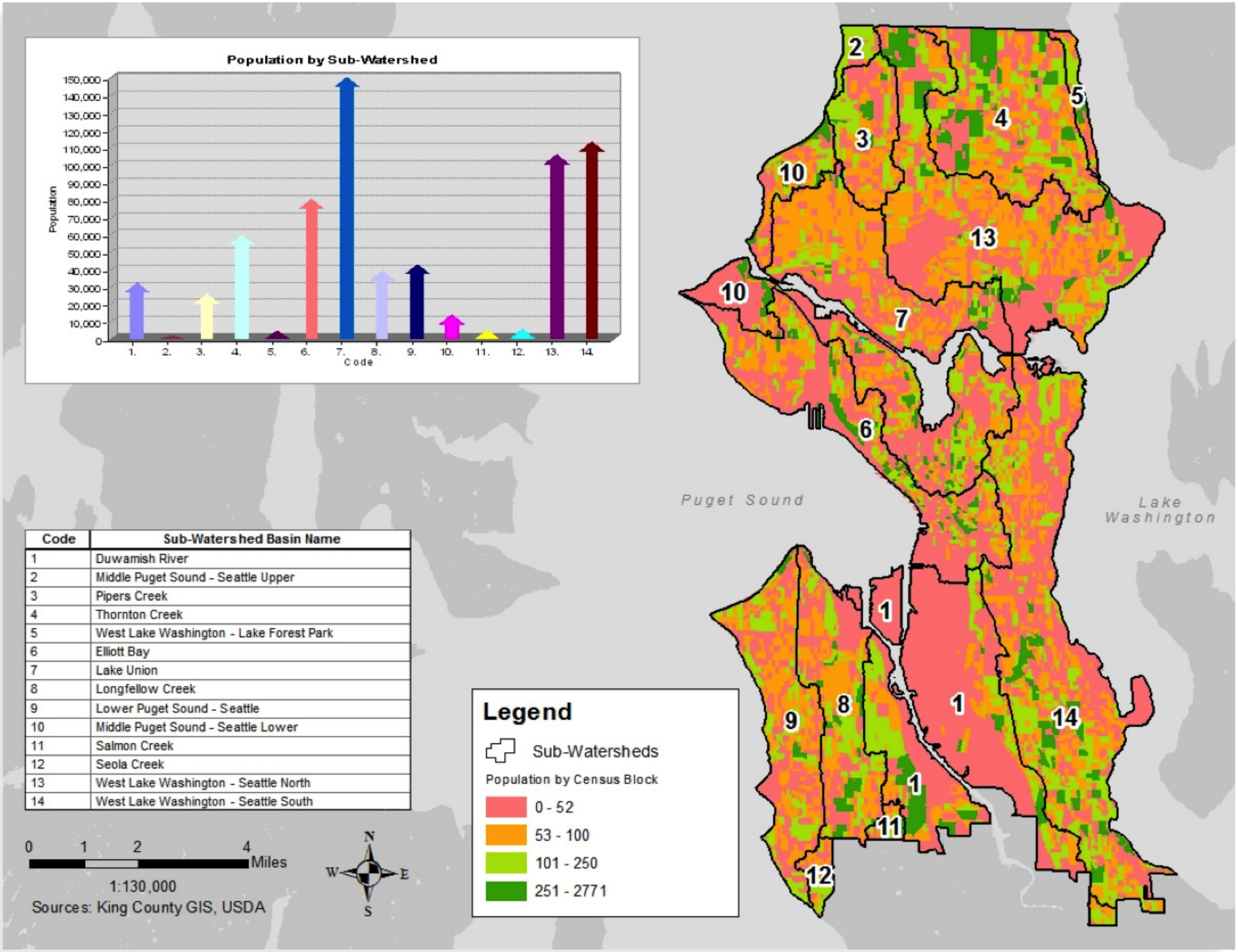
Map 8 - Mean Slope by Watershed with Landslide Areas



Map 9 - 2012 Precipitation by Sub-Watershed

3.1.7 - Population

The final analysis, for the weighted scorecard, looked at population by sub-watershed and the results were not surprising. For example, the Duwamish River sub-watershed is largely industrial and for its large area, has a low population count. In comparison, Lake Union, which has plenty of residential units, comes in at a population over 150,000. The population data would plug into the weighted scorecard in a way that shows population as a negative phenomenon. Population breeds development, and development generally means a conversion of land use type from a favorable condition (such as forest canopy) to an unfavorable one (impervious surface). Additionally, where there are large amounts of population, we would assume there are houses there. As mentioned earlier, most of the houses in Seattle are older, meaning they don’t have updated stormwater facilities as a requirement. The results of our population analysis are below (see Map 10).



Code	Sub-Watershed Basin Name
1	Duwamish River
2	Middle Puget Sound - Seattle Upper
3	Pipers Creek
4	Thornton Creek
5	West Lake Washington - Lake Forest Park
6	Elliott Bay
7	Lake Union
8	Longfellow Creek
9	Lower Puget Sound - Seattle
10	Middle Puget Sound - Seattle Lower
11	Salmon Creek
12	Seola Creek
13	West Lake Washington - Seattle North
14	West Lake Washington - Seattle South

Map 10 - Population by Sub-Watershed

3.2 – Rights-of-Way

The purpose of the Rights-of-Way (ROW) analysis was to determine the potential for the implementation of GSI BMPs within those public spaces and to calculate the potential benefits. This study was selected as an alternative approach in identifying potential GSI sites and to focus on the Urban Forest Management Plan's goal to increase tree cover with the ROW by 24 percent (see Table 9)[30]. Yet these two approaches can benefit from each other. Once the weighted scorecard identifies prospective sites, this model can further identify ROW within that respective area. The inverse could also be true in that the ROW model identifies the general area, then the weighted scorecard can be used for detailed analyses.

Land Use Category	UFMP Goal Tree Cover
Single- Family	33%
Multi-Family	20%
Commercial/Mixed Use	15%
Downtown Seattle	12%
Industrial	10%
Institutional	20%
Parks: Developed Sites	25%
Parks: Natural Areas	80%
Citywide	**30%**
Transportation Corridors/Street ROW	24%

Table 9 - UFMP's Tree Canopy Cover Goals by Land Use

3.2.1 - Available Datasets

The city of Seattle maintains an inventory of trees (*sttree*) that occupy space within the Rights-of-Way (ROW). The inventory contains 98,716 point files, that represent the trees, and extensive information regarding a specific tree's environment (i.e. - genius, species, planting strip, dieback, root_prob, dead, interfere, cond, topped, etc.) Despite this wealth of information, it was difficult to decipher the classification system. The city

30 http://www.seattle.gov/trees/management.htm

's metadata database[31] provided little meaningful help while attempts to contact the data's steward had negative results. It should be noted that the use of this dataset was performed at a layman's level and with limited understanding of the attribute classification system.

While conducting research on stormwater runoff, a city of Seattle document (*2011 Master Tree List*[32]) was located (see Fig. 5). It provided further insight into various species': mature height, canopy spread, if they should be planted under a wire, minimum planting strip width, if they were classified as a native tree and/or a "street tree", and whether they were moisture tolerant.

City of Seattle – Master Tree List

Large Columnar Trees

Scientific & Common Name	Mature Height	Spread	Under Wires?	Min Strip Width	Flower Color	Fall Color	Comments	Native Tree	Street Tree	Moisture Tolerance
Acer nigrum 'Green Column' Green Column Black Sugar Maple	50	10	No	6	N/A		Good close to buildings	No	Yes	
Fraxinus americana 'Empire' Empire Ash	50	25	No	6	N/A		Use for areas adjacent to taller buildings when ash tree is desired species	No	Yes	
Ginko biloba 'Princeton Sentry' Princeton Sentry Ginkgo	40	15	No	6	N/A		Very narrow growth.	No	Yes	

Fig. 5 - Extract from the 2011 Master Tree List

The above tree species data was used in conjunction with ROW and impervious surface data to help in identify available spaces within the ROWs where new trees could be planted; to help mitigate the amounts of stormwater runoff.

3.2.2 - Methodology

(see Fig. 6 below)

1) Identify Planting Strips
2) Identify Canopy Coverage (of existing inventory)
3) Identify Available Planting Strips
4) Estimate Potential Tree Numbers
5) Summarize Data by Sub-Watershed

31 https://wagda.lib.washington.edu/data/geography/wa_cities/seattle/metadata/cd_1/Metadata/geoguide2.htm
32 www.seattle.gov/trees/docs/2011-Master_Tree_List.pdf

3.2.3 - Identify Planting Strips

In order to identify likely planting strip areas, impervious surface areas were subtracted from the ROW areas. This was a roundabout process due to the Raster to Polygon tool not functioning correctly when applied to the Impervious Surface layer (a “background error” was received on numerous iterations). First, the ROW polygons were converted to a raster image (polygon to raster). Then the raster calculator was used to produce a new raster that subtracted the impervious surface raster from the ROW raster. Finally, this new raster was converted back to a polygon for future analyses.

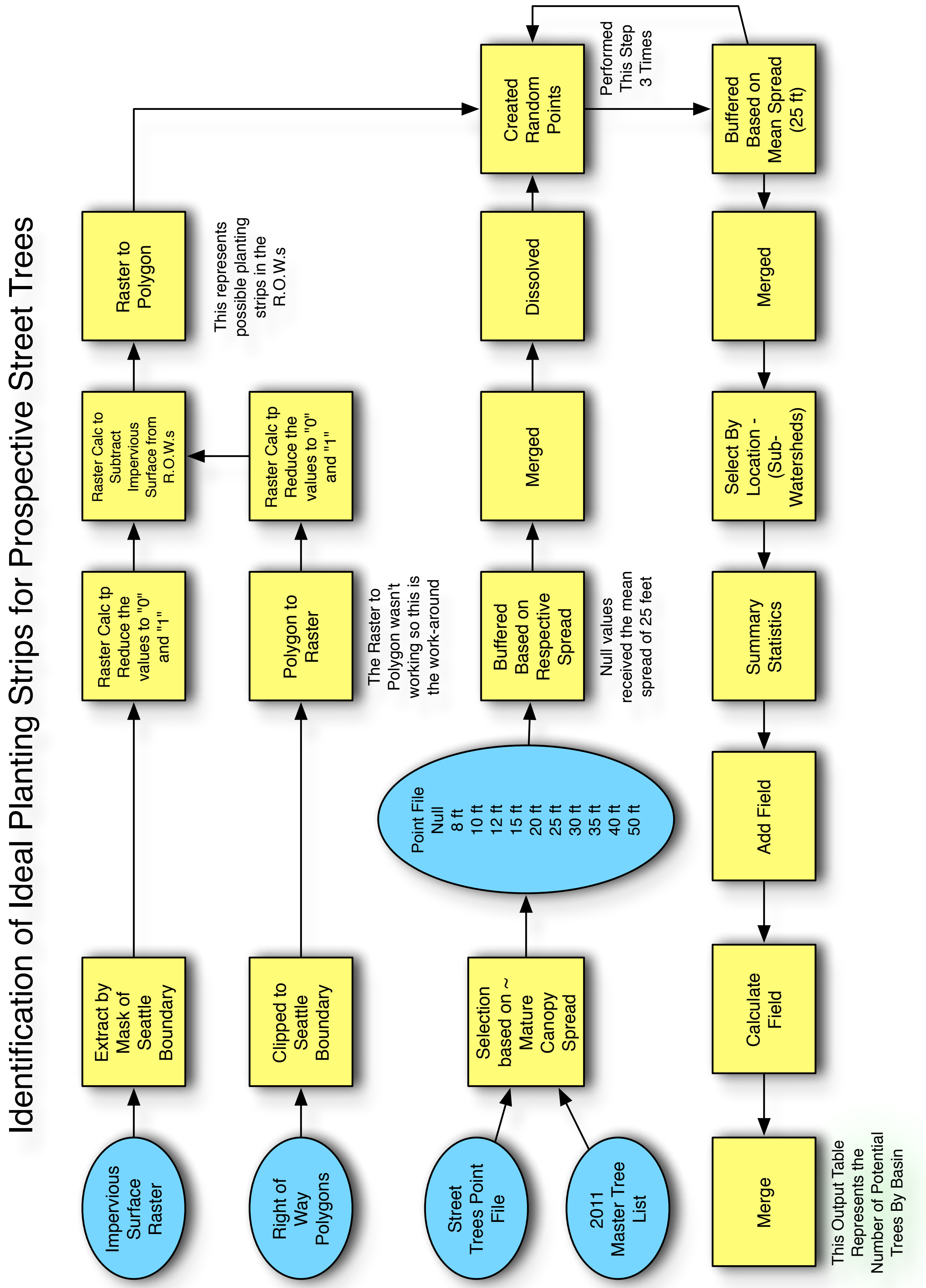


Fig. 6 - Rights-of-Way Workflow

The process was reasonably accurate when imagery was used to verify the results and results were dependent on the accuracy of the impervious surface and ROW data (see Map 11 and Map 12 on page 66). When the layer was compared with the street tree data, most trees were collocated with the extracted polygons. Table 10 on page 65 documents the approximate acreage of: The city of Seattle; ROW; and calculated planting strips.

Feature Class	Acres
City of Seattle	53534.8854
Rights-of-Ways (ROW)	14394.2833 (26.89% of Seattle)
Planting Strip	3479.0701 (24.17% of Seattle
Planting Strip (>= 28.27 sq. ft.)	3405.723 (23.66% of Seattle)

Table 10 - Approximate Acreage of Calculated Planting Strips

The maps below (Map 11 & Map 12) are of a random Seattle neighborhood. On the left: the city's Rights-of-Way are represented by transparent green with a red border; the trees of the imagery beneath are visible within that border. On the right: the result of the impervious surface layer being subtracted from the ROW layer. Note how the remaining polygons are not consistent with what you normally associate with the more symmetrical shape of actual planting strips. This can be attributed to the pixelation from the impervious surface layer.

For the purpose of this study, the results will suffice since the primary objective of this step is to identify general areas.

Seattle Rights-of-Way and Planting Strip Comparison

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community; City of Seattle; King County GIS Center

Map 11 - (Left) - Seattle ROW in Random Neighborhood

Map 12 - (Right) - Result of Planting Strips Calculation

3.2.4 - Identify Canopy Coverage

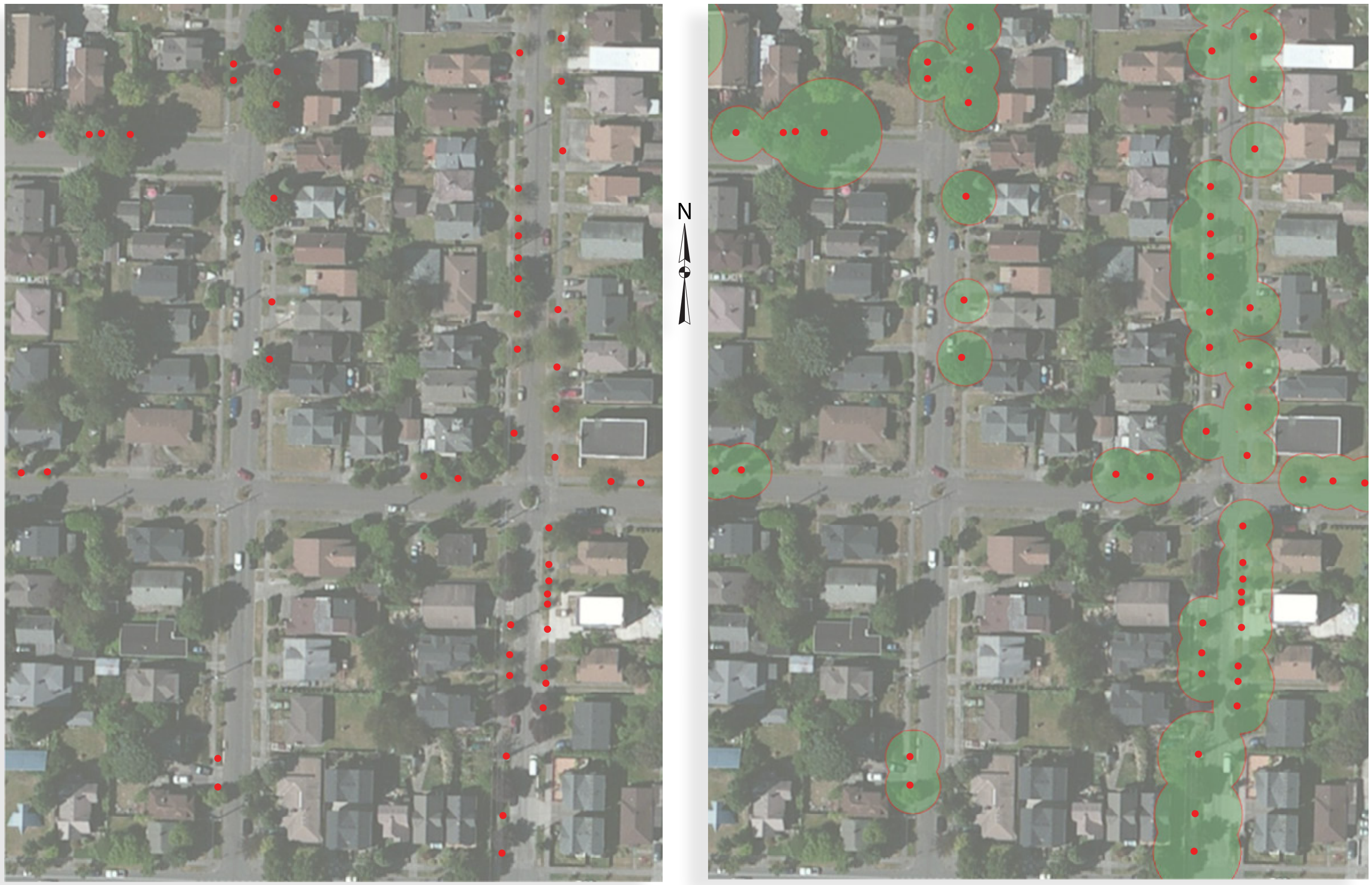
The street tree inventory (*sttree*) was joined with the 2011 Master Tree List data. However, before this join could be performed, the data within 2011MasterTreeList was prepared for import. This process was not scientific as the trees' taxonomy was not completely understood and the ultimate goal was to attempt to identify generalized information in which to apply to the *sttree* feature class.

During this preparation phase, the amount of records was reduced from 174 entries to 134 as a result of multiple entries. For example, *acer platanoides* had four entries due to the different types of that species; each having a canopy spread of 15 to 40 feet, dependent on type. In these cases, the maximum value was used so the model did not overestimate.

Also, it appeared as if there were several spelling errors and upon further research, the scientific name contained in the *sttree* feature class appeared to be correct instead of the name contained within the *2011 Master Tree List* document. In these cases (3 instances), the name was corrected to match that contained in the *sttree* feature class.

Finally, there appeared to be a difference between the classifications with the annotation "*sp.*" and without it. For example, *malus* and *malus sp.* appeared to be independent classifications. The attributes for those with the annotation were notably different from those without.

Once these tasks were accomplished, then the genus and species attributes were concatenated under a new attribute ("*scientific*"). It was this field in which the feature class *sttree* and table *2011MasterTreeList* were joined. Of the 379 tree types listed in *sttree*, only 22% (or 84 records) matched the types listed in *2011MasterTreeList*. However, this accounted for 60% of the overall records (or 60,244 of the 98,716 records).



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community; City of Seattle; King County GIS Center

• Street Trees

Street Trees Buffers

02 12.5 55 0 Meters

Map 13- (Left) - Street Tree Inventory in Random Neighborhood

Map 14 - (Right) - Buffers Representing Tree Canopies

Of those 60,244 records that did match, a buffer was created based on the maximum canopy spread documented in the "*2011 Master Tree List*". The remaining 38,472 records, whose maximum canopy spread were undocumented, were assigned the median canopy spread of 25 feet. Once all the inventoried trees were assigned buffers the merge and dissolve tools were used to generalize the data. The resulting feature class (*InventoriedTreesBuffers_Merged_Dissolved)* represents the estimated canopy coverage of the current inventory and the shadow (or footprint) it would cast on the underlying ground cover (where it may be less than ideal to plant another tree).

In Map 13 and Map 14 above, the red dots represents trees, in the Seattle tree inventory, in the same random neighborhood (as Map 11 and Map 12). Notice how it is reasonably accurate when placed on top of imagery. However, it is evident that the inventory is not complete and appears to be inaccurate in some cases. For example, the inventory may indicate the presence of a tree, whereas the imagery does not reflect such. This may be attributed to the temporal differences between the two products or the dying or movement of a tree.

The projected maximum canopy spreads of the trees are represented in Map 14, with transparent green with red border. For the ease of future calculations, these buffers were dissolved. Notice how, in some areas, the buffers cover the roadway. It is recognized that in reality, this may not occur due to the topping of treetops and the conical shape of certain native species.

3.2.5 - Identify Available Planting Strips

Having the projected canopy spread identified, the model then identified ideal planting strips for future trees. This was accomplished by erasing the buffered tree canopies from the *PlantingStrip* layer, resulting in 3479.1 acres. However, not all of the polygons identified are viewed as ideal for tree growth. Based on the 2011 Master Tree List, the average recommended width required for tree growth was six (6) feet. Therefore, polygons that were greater than 28.27 square feet (28.27 sq. ft. = $\pi (3)^2$) were classified as ideal planting strips (*IdealPlantingStrip*) which totaled 3405.7 acres.

Although less accurate, this method was much faster than the painstaking work of hand drawing the polygons; which was done for a small study area (see Map 15 below). It should be remembered that the calculation involving the Impervious Surface raster created irregular polygons and that greater accuracy can be obtained with data based on hyperspatial / spectral products.

Map 15 - Hand Drawn Polygons of Rights-of-Ways

3.2.6 - <u>Estimate Potential Tree Numbers</u>

In order to calculate the number of prospective trees that could be planted in the “ideal” planting strips, the model used the “*Create Random Points*” tool. The tool used the *IdealPlantingStrip* feature class as the foundation for the points to be generated. Furthermore, it selected the location with a minimum distance of 50 feet from another random point. This distance was selected to reflect the median canopy spread of 25 feet.

The calculation resulted in the creation of 98,463 random points that represented future trees. However upon further analysis, there were many gaps left in the coverage of the “ideal” planting strips; leaving 3283.3 acres without trees - there were 3479 acres before the calculation. The buffer tool was applied to these newly generated points with a buffer value of 25 feet and subtracted from the *IdealPlantingStrip* layer to highlight areas left without coverage.

A second iteration of the Create Random Points tool was run and it produced an additional 73,958 points (potential trees). Upon buffering this second iteration of points with the median canopy spread of 25 feet, it still revealed uncovered areas amounting to 2997.9 acres.

A third iteration was run and produced 44,019 “trees” with the remaining Ideal Planting Strip space of 2750.1 acres. This brought the total number of potential “trees” to 216,440. The Green Seattle Partnership’s *20 Year Strategic Plan* states that one large tree adjacent to a roadway has a realized benefit of $149[33]. Using this number, the potential benefit to the city would be $32,249,560 each year.

Iteration #	ROW “Tree” Potential	Acres Remaining After Calculation
1st	98,463	3283.3
2nd	73,958	2997.9
3rd	44,019	2750.1
Total Potential	> 216,440	

Table 11 - Potential Tree Estimates

Map 16 below show the distribution of the newly create points, represented by yellow dots, within in the same random neighborhood, as shown in the previous maps. Take note on how some of the points are well within the 25 foot range as specified in the calculation. This can be attributed to the running of several iterations of the tool which does not account for spatial awareness of other layers; only the points it generates. This does not negate the misplaced point since a small tree can be planted closer to a larger tree.

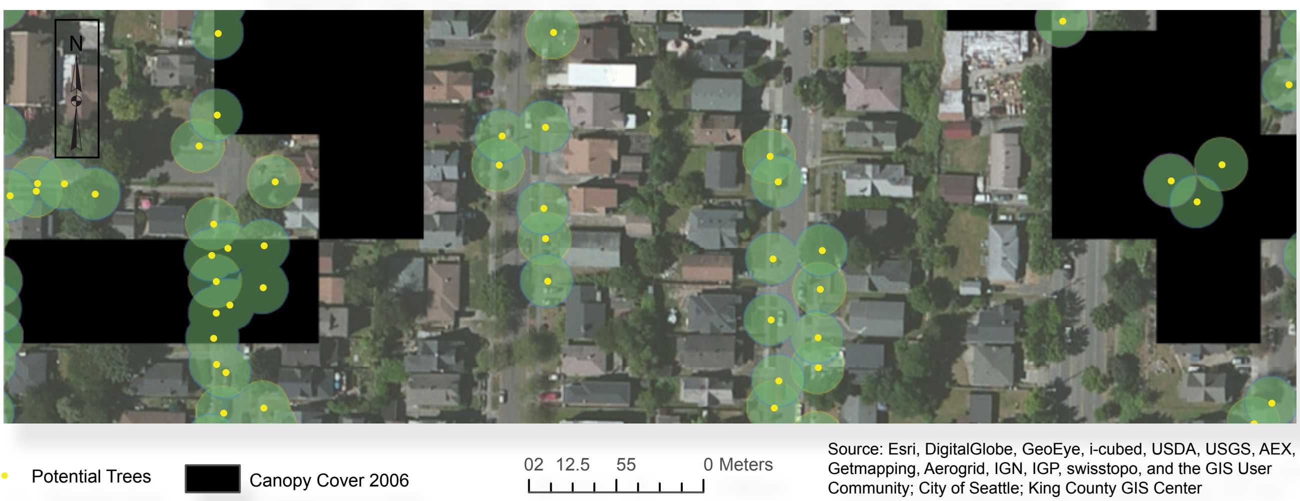
33 Green Seattle Partnership, page 10

Map 16- Estimated Trees

It should be noted that the model failed to account for the incomplete tree inventory. Future analyses should use the most current Canopy Cover information to further erase (isolate) the ideal planting strip layer. This will ensure that existing trees are accounted for and so the model does not overestimate the number of potential trees.

Map 17 shows the potential tree coverage in relationship with the *wa_canopy_2006* data. The canopy coverage (as of 2006) is displayed in black and in the left portion of the map, it is clear where the model overestimated; the yellow dots are on top of the black areas. Although the *wa_canopy_2006* data is not that accurate, it will provide a more realistic output than what achieved in these analyses.

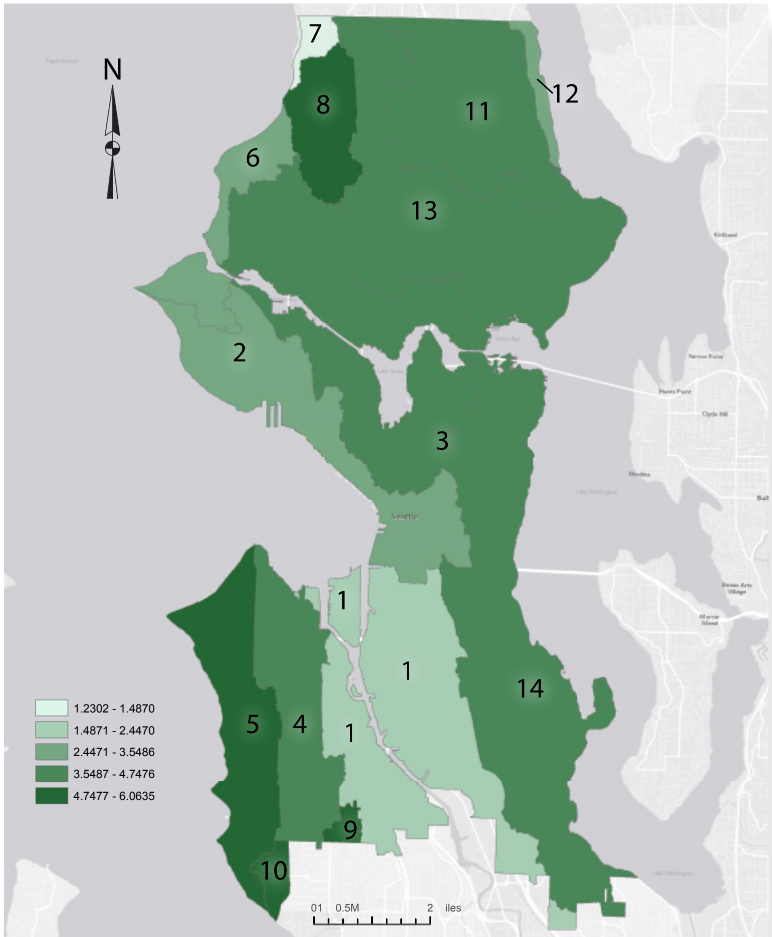
Potential Tree Population Fails to Account for Current Canopy Coverage



Map 17 - Over Estimating of Trees

The goal wasn't to provide coverage to every square foot of "ideal" planting strip space. It was to identify capacity in contrast to the urban forests. The believed benefits of GSI implementation within the Rights-of-Way will be discussed in the next section (Section 4 – Implementation).

Map 18 below shows the how many potential trees were generated by the above process.



Map 18 - Potential Trees Per Sub-Watershed Acre

Code	Sub-Watershed Name	Acres	Ideal ROW Acres	Pct Ideal ROW Acres / Basin Acres	Trees Per Acre	Tree Potential
1	Duwamish River	7,550.81	**635.9141**	**8.42**	2.3489	17,736
2	Elliott Bay	4,650.21	333.9292	7.18	3.2338	15,038
3	Lake Union	7,663.85	447.0102	5.83	4.3004	32,958
4	Longfellow Creek	3225.7	252.6579	7.83	4.524	14,593
5	Lower Puget Sound - Seattle	3,645.12	235.1809	6.45	5.526	20,143
6	Middle Puget Sound - Seattle Lower	1,791.17	97.3141	5.43	3.3286	5,962
7	Middle Puget Sound - Seattle Upper	348.34	7.3609	2.11	1.487	518
8	Pipers Creek	1,790.97	118.675	6.63	5.3312	9,548
9	Salmon Creek	219.42	17.038	7.77	5.3733	1,179
10	Seola Creek	371.24	26.8222	7.23	**6.0635**	2,251
11	Thornton Creek	4,867.55	317.8554	6.53	4.0515	19,721
12	West Lake Washington - Lake Forest Park	395.65	31.3047	7.91	3.5486	1,404
13	West Lake Washington - Seattle North	8,004	386.4947	4.83	4.1012	32,826
14	West Lake Washington - Seattle South	**8,957**	636.093	7.1	4.7476	**42,524**

Table 12 - Tree Potential Statistics Per Sub-Watershed

The tree counts were normalized by the sub-watersheds' respective acreage (tree count per sub-watershed / sub-watershed acres) and the information was placed into the project's weighted spreadsheet. Map 18 displays the spatial distribution of Table 12; the statistical results of the above calculation.

The model was able to reasonably identify areas of the ROW potentially capable of being converted into more beneficial green space. The weighted scorecard can then be used for a more granular selection.

3.2.7 - Recommendations

As identified in this section, the accuracy of the potential tree estimation is dependent on the underlying datasets. In order to better achieve better results hyper-spatial / spectral products should be used for the identification of impervious surfaces and canopy coverage. The combination of LiDAR and hyper-spectral datasets can greatly aid in the supervised classifications.

The model could also use a parcel layer to identify residential & commercial parcels from publicly held parcels so that financial costs can be more accurately estimated. As previously discussed, property owners are responsible for the maintenance of the Rights-of-Way.

The *sttree* feature class has a wealth of information that can be used, in conjunction with other feature classes, to identify ideal locations for prospective GSI BMPs.

3.3 – Analyses Not In the Scorecard

The following are analyses were conducted but not included in the final weighted scorecard either due to insignificant results or lack of data. However, their failure to make the cut shouldn't be mistaken for their lack of importance:

- Forterra Tree-iage Data
- US Census Statistics
  - Home Quantities by Sub-Watershed
  - Home Values by Sub-Watershed

Mean Home Income

3.3.1 - Forterra Tree-iage Data

Although we didn't use Forterra's forest Tree-iage data to help characterize the sub-watershed, is expected to be used within in the Implementation phase. Therefore, it was separated by Tree-iage score, clipped by sub-watershed, and accumulation totals calculated in order to determine how much work (potential and actual) that Forterra might have in upgrading forested areas within each sub-watershed.

The datasets were also analyzed in Tableau data analytic software. Since the data represented a geographically large scale, it was difficult to view the presence of any geographic phenomenon (if any) at the small scale of the city. The large volumes of data were more easily viewed and the results will be discussed in the section on Implementation.

3.3.2 - US Census Statistics

As discussed in "Assessing the System" (Table 3 on page 23), stormwater runoff can negatively impact the social and economical systems. Humans are large contributors to its effects on the environment which is why US Census home and population data were investigated for potential use in the scorecard.

3.3.2.1 - Home Quantities by Sub-Watershed

The quantity of homes increases the amount of impervious surfaces (Roofs, sidewalks, driveways, etc.) and therefore promotes stormwater runoff. Therefore, this was the basis for the investigation into identifying the density of homes per census block. The data used for this study was obtained from the U.S. Census Bureau's American Fact Finder database - American Community Survey 2011, 5 year estimate. That table was joined with 2012 census block polygons using information in the *GEO.id2* field. Once the join was made, the attribute "*HC01_V03*" (or "Estimate; Housing Occupancy - Total Housing Units") was used in the analysis.

Census tracts whose centroids were within the boundaries of the respective sub-watersheds were selected. From that selection, a field titled "*BasinName*" was added and given the value was equal to the name of the respective sub-watershed. Finally, the summary statistics tool was applied that summed the "*HC01_03*" values for the respective sub-watershed.

Within Seattle, and under the *HC01_V03* classification, there are a total of 320,072 occupied homes accounted for. Table 13 displays the statistical composition of the sub-watershed.

Lake Union stands out as it has the largest number of census tracts, occupied homes and proportion of homes per acres within a sub-watershed. This is not surprising since the area has many apartments and condominiums. However, this alone does not necessarily indicate unusually higher levels of stormwater runoff, as these types of structures take advantage of vertical living space versus residential homes.

Sub-Watershed	# of Tracts	Sub-Water-shed Acres	# of Occupied Homes	% of Total	Homes / Sub-Watershed Acre
Duwamish River	11	7550.817	18339	5.73	2.43
Elliott Bay	16	4650.2162	39895	12.46	8.58
Lake Union	**29**	7663.8499	**84074**	**26.27**	**10.97**
Longfellow Creek	6	3225.6969	12134	3.79	3.76
Lower Puget Sound - Seattle	8	3645.1166	22037	6.89	6.05
Middle Puget Sound - Seattle Lower	3	1791.1684	5983	1.87	3.34
Middle Puget Sound - Seattle Upper	1	348.3427	1504	0.47	4.32
Pipers Creek	5	1790.9696	9994	3.12	5.58
Seola Creek	2	371.2351	3814	1.19	10.27
Thornton Creek	14	4867.5458	28656	8.95	5.89
West Lake Washington - Lake Forest Park	2	395.648	2675	0.84	6.76
West Lake Washington - Seattle North	22	8003.9987	44275	13.83	5.53
West Lake Washington - Seattle South	21	**8956.9995**	46692	14.59	5.21
Total	140	53261.6044	320072		

Table 13 - Home Quantity Statistics by Sub-Watershed

3.3.2.2 - Home Values by Sub-Watershed

With the distribution of homes identified, analyses into their values were conducted. Home values in landslide areas or floodplains observe a decrease in value and homeowners must pay higher insurance premiums. Understanding this, buyers tend to shy away from purchasing these homes resulting in the decline in the neighborhood's value.

For this analyses, the same dataset (*ACS_11_5YR_DP04*) and the same join field were used as outlined above. Also, the extraction method was similar in determining the home values by sub-watershed. The attribute *HC01_V125* was used to determine the estimated median home value (in dollars). The model calculated the mean of the median home values for the respective sub-watershed (see Table 14).

Sub-Watershed	Sub-Watershed Acres	Mean Home Value (USD)	Value Per Acre
Duwamish River	7550.817	327781.82	43.41
Elliott Bay	4650.2162	464737.5	99.94
Lake Union	7663.8499	482303.45	62.93
Longfellow Creek	3225.6969	357983.33	110.98
Lower Puget Sound - Seattle	3645.1166	482362.5	132.33
Middle Puget Sound - Seattle Lower	1791.1684	**597766.67**	333.73
Middle Puget Sound - Seattle Upper	348.3427	394000	**1131.07**
Pipers Creek	1790.9696	417920	233.35
Seola Creek	371.2351	372000	1002.06
Thornton Creek	4867.5458	397164.29	81.59
West Lake Washington - Lake Forest Park	395.648	544450	1376.1
West Lake Washington - Seattle North	8003.9987	487118.18	60.86
West Lake Washington - Seattle South	8956.9995	464323.81	51.84

Table 14 - Home Value Statistics by Sub-Watershed

Although the Middle Puget Sound - Seattle Lower sub-watershed has the highest mean home values across all census tracts, it is its neighbor (Middle Puget Sound - Seattle Upper) that has the highest value per sub-watershed acre. The Duwamish River sub-watershed has the lowest value per acre and happens to be a fairly industrial neighborhood with areas in flood zones and landslide areas.

3.3.2.3 - Mean Home Income

Stormwater runoff can result in expensive mitigation efforts and in repairs. Stormwater management may require long and costly environment impact assessments and best management practices may be disruptive and time consuming. Recovering from flooding is also expensive in which the homeowner can be responsible for all costs if they do not have flood insurance. This can be devastating to those in the lower income bracket and why this attribute is being included in the model. It can also push out those who can afford to move, thus altering the economic composition of a neighborhood.

The data (*ACS_11_5YR_S1903*) was also obtained from the U.S. Census Bureau. The attribute *HC02_EST_VC02* defined the Median Income (in dollars) and the data was normalized by the attribute *HC0_EST_VC02* (number of homes) to obtain the following statistics (see Table 15).

Sub-Watershed	Number of Homes	Mean Household Income	Mean Income / Household
Duwamish River	17061	52878.18	3.10
Elliott Bay	35917	54210.88	1.51
Lake Union	**77746**	64518.59	0.83
Longfellow Creek	11340	58181.50	5.13
Lower Puget Sound - Seattle	20623	80274.88	3.89
Middle Puget Sound - Seattle Lower	5846	**86172.33**	14.74
Middle Puget Sound - Seattle Upper	1318	77784.00	**59.02**
Pipers Creek	9491	68748.80	7.24
Seola Creek	3693	68316.00	18.50
Thornton Creek	27090	66699.36	2.46
West Lake Washington - Lake Forest Park	2487	75543.50	30.38
West Lake Washington - Seattle North	41280	72597.41	1.76
West Lake Washington - Seattle South	43469	68587.43	1.58

Table 15 - Mean Household Income by Sub-Watershed

There is a discrepancy between the number of homes in this section than in the “Home Quantity” section. This may be attributed to the numbers of people willing to participate in the survey or because this is estimated data. Despite the differences, the importance is the general composition of the study area (city of Seattle) and the proportions amongst the sub-watersheds. The analyses revealed that lowest income was the Duwamish River sub-watershed. This coincides with it having the lowest mean home value amongst the other Seattle sub-watersheds.

The above census analyses attempted to identify indicators with regards to how humans interact with their environment. The following analyses were focused on those environmental areas

3.4 – Testing Conclusions

The testing phase allowed for a better feel for how the different sub-watersheds were characterized as they related to criteria that they were judged by. It was pleasing to make certain correlations (such as forest to impervious ratios compared with runoff amounts), even if some of the analyses were not as sophisticated as the team would have liked. This phase serves as an example of what could be done, but is not considered complete. A more thorough testing would involve more sophisticated hydrological runoff models, additional detailed forest data, a better understanding of the combined sewer overflow network, etc. However, the team feels as if there is enough to move to the implementation phase of the project, which involves inputting the criteria into a weighted scorecard, ranking the sub-watersheds “worst to best”, and then offering options for forestation prioritization.

4 – Implementation

4.1 – Overview

The implementation design was based upon providing options to Forterra for ways that they may prioritize a green stormwater infrastructure plan. The goal was never to come up with “the answer” for implementation, but rather a “possible answer” for implementation. It is understood that Forterra has a focus on forestation within parks. Therefore, a method was designed, based on the characterization of the watershed, for how those parks might be prioritized. In the name of sustainability, a plan was also designed that would go beyond the immediate scope of forested parkland that Forterra has stewardship over. Although this design may be outside of Forterra’s present scope, the team thought that it should be included as part of an overall sustainability approach.

In short, the team believes that there are other locations in the city that might be targeted for tree planting / GSI improvements. This model offers possible locations for those area which of course would require further exploration. The team does not profess to have a perfect solution, nor a complex one, however the team does offer the framework for a possible prioritization plan, or rather the beginnings of a plan, should this one be improved upon.

4.2 – Weighted Scorecard

This implementation plan hinges on the results of the multi-criteria analysis performed during the testing phase. With the analysis portion completed, it is time to score the raw data results from our GIS operations (see Section 3 – Test).

Step one in that process was taking the raw scores (see Table 16, below) from our GIS database and exporting them to a Microsoft Excel spreadsheet (see Table 17 on page 83). The problem with comparing data from one analysis to another is that often the results manifest in different measurement units. That is to say, acres cannot be compared to inches or degrees to gallons. The data was normalized using a linear maximum score procedure[34], which takes all

34 Regional and Urban GIS: A Decision Support Approach (Nygerges, Jankowski 2010)

the criterion and divides it by the maximum criterion value in the set. For example, if there were three values (3,6,9), the “9” value would be the maximum criterion value in that set. All other values in that set would be divided by 9, which would effectively normalize the data.

OBJE	Watershed_Name *	Ratio_Imp	Sub_Water	Imperv_Acr	Forest_Cano	Per_For_to	Mean_Slope	Pot_Landslide	Precip_2012	ISAT_Coeff
1	Thornton Creek	48.35%	4867.54	2353.51	1666.430614	0.70806183	6.06977128982	177.347072321	46.06	46.848672847
2	West Lake Washington - Lake Forest Park	42.18%	395.64	166.9	189.9468785	1.13808794	12.4201412200	119.881585024	46.08	38.362670276
3	Middle Puget Sound - Seattle Upper	29.20%	348.34	101.71	223.6707394	2.19910273	14.8150548934	98.6374847928	46.68	32.800296681
4	Pipers Creek	48.48%	1790.97	868.32	522.8508680	0.60214076	6.74238061904	124.766484537	46.68	49.324035979
5	Duwamish River	65.29%	7550.82	4929.99	1201.565305	0.24372570	5.55562067031	709.209924623	51.74	66.842885078
6	West Lake Washington - Seattle South	50.01%	8957	4479.73	2320.302300	0.51795583	7.28924703598	856.160252452	49.065	49.729915429
7	West Lake Washington - Seattle North	51.18%	8004	4096.52	1653.981956	0.40375293	5.52930068969	82.4956511859	46.29	52.728135985
8	Seola Creek	48.61%	370.63	180.18	89.85614778	0.49870211	7.40294837951	13.6198219056	49.26	45.480085012
9	Salmon Creek	53.44%	219.42	117.25	25.23794460	0.21524899	5.01059341430		49.26	53.803997006
10	Middle Puget Sound - Seattle Lower	41.05%	1791.17	735.29	676.8130249	0.92047086	9.68162155151	396.676262889	47.525	43.511502452
11	Lower Puget Sound - Seattle	50.68%	3645.12	1847.26	942.5089628	0.51021998	9.02027416229	604.750045785	50.87	48.891607573
12	Longfellow Creek	52.42%	3225.7	1690.88	703.1400044	0.41584264	7.50894832611	375.484648449	51.53	53.384505414
13	Lake Union	66.22%	7663.85	5074.92	981.4789441	0.19339791	6.23867750167	391.707041019	47.665	63.672377432
14	Elliott Bay	67.09%	4650.22	3119.95	618.3828380	0.19820280	7.35747337341	513.761447759	48.775	65.652322659

Table 16 - Raw Data from GIS Analyses

In the first analysis, “runoff amounts per year”, the maximum raw value for the Duwamish River sub-watershed was 31.13 inches. Therefore, the normalized value for the Duwamish River sub-watershed was 1.00. In contrast, Salmon Creek sub-watershed had a runoff amount of 23.85 inches: 23.85 divided by the max criterion (31.13) is 0.77, which resulted in Salmon Creek’s normalized value.

All data was subsequently normalized which left the task of weighting the normalized numbers to place an unequal importance on each analysis. The weighting in this analysis was very subjective, and the team encourages the end user to manipulate the weights to fall in line with their organizational goals. For instance, if an organization mostly characterized a sub-watershed by precipitation volume or how much slope it has, then those weights would be much higher than the remaining criteria. The weights developed for this analysis are a reflection of a combination of factors:

1. Importance of criteria as it relates to causal effects of stormwater runoff
2. How well the data represented the criterion we attempted to test, or how well the GIS tested process outputted a result that represented the real-world phenomena
3. Perceived importance of the criteria to Forterra’s organization goals

Criterion	Runoff amounts per year (using a simple run-off method)	Forest to Impervious Surface Ratio within Sub-Water-shed	Highest number of untreated combined sewer overflow gallons (2012)	Most acreage of impervious surfaces directly adjacent (up to 100 feet) of a waterway	Highest amount of mean slope in drainage basin	Highest amount of precipita-tion within Sub-Water-shed	Highest acres of landslide potential	Highest amount of popu-lation	Scoring	Rank-ing	Criterion
Planning Weight	0.26	0.24	0.2	0.13	0.06	0.04	0.04	0.03			Planning Weight
Measurement	Inches	Ratio	Gallons	Acres	Degrees	Inches	Acres	Count			Measure-ment
Max Raw Value	31.13	2.2	1,111,466,325	236.82	14.82	51.74	856.16				Max Raw Value
Duwamish River	31.13	0.24	1,111,466,325	236.82	5.56	51.74	709.21	32,341			Duwamish River
Duwamish River -Std	1.00	0.89	1.00	1.00	0.37	1.00	0.83	0.21	6.31	1	Duwamish River -Std
Duwamish River -Wt	0.2600	0.2134	0.2000	0.1300	0.0225	0.0400	0.0331	0.0064	90.55	1	Duwamish River -Wt

Table 17 - Weighted Score Card

With those general rules, and using a weighting method where all the weights had to add up to 1.00, the following weights were assigned:

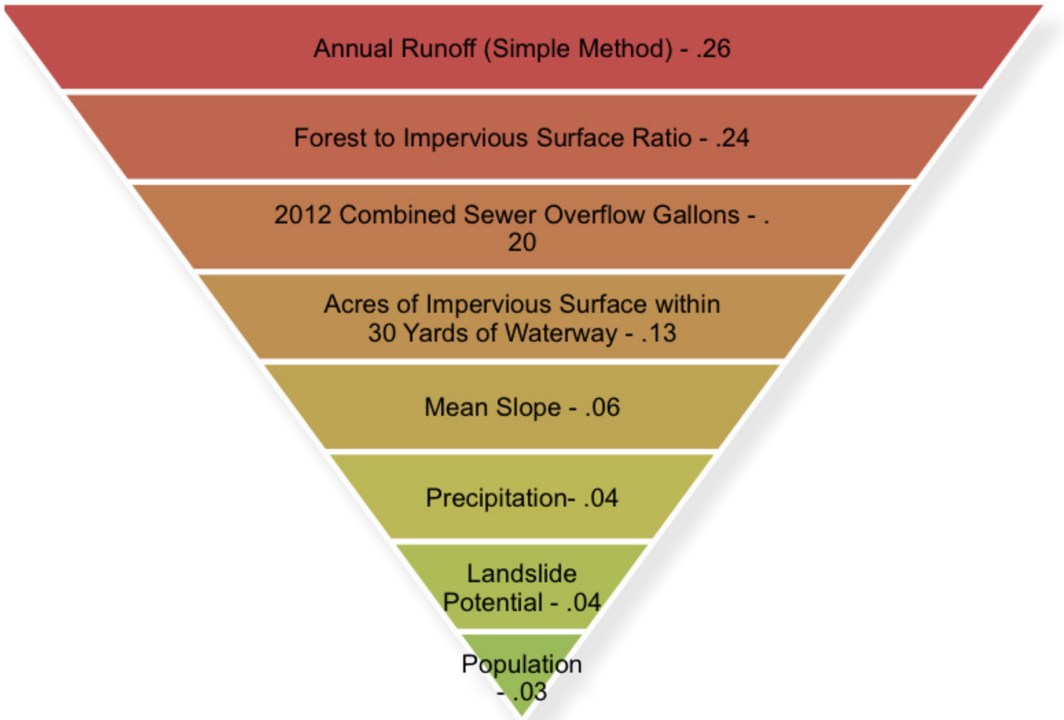


Fig. 7 - Criteria Weights

Heavier weight were assigned to analysis inputs that dealt with curtailing stormwater flow, such as impervious surface, forest, and actual CSO amount analysis. Lesser weights were assigned to those inputs that were a little more homogeneous, such as slope and precipitation. That being said, if this exercise were conducted at a more granular level, the slope input might be weighted much higher. Hazard and population analysis received the lowest weights, because although they are important factors, for this particular analysis we couldn't justify placing their importance above any of the other criterion.

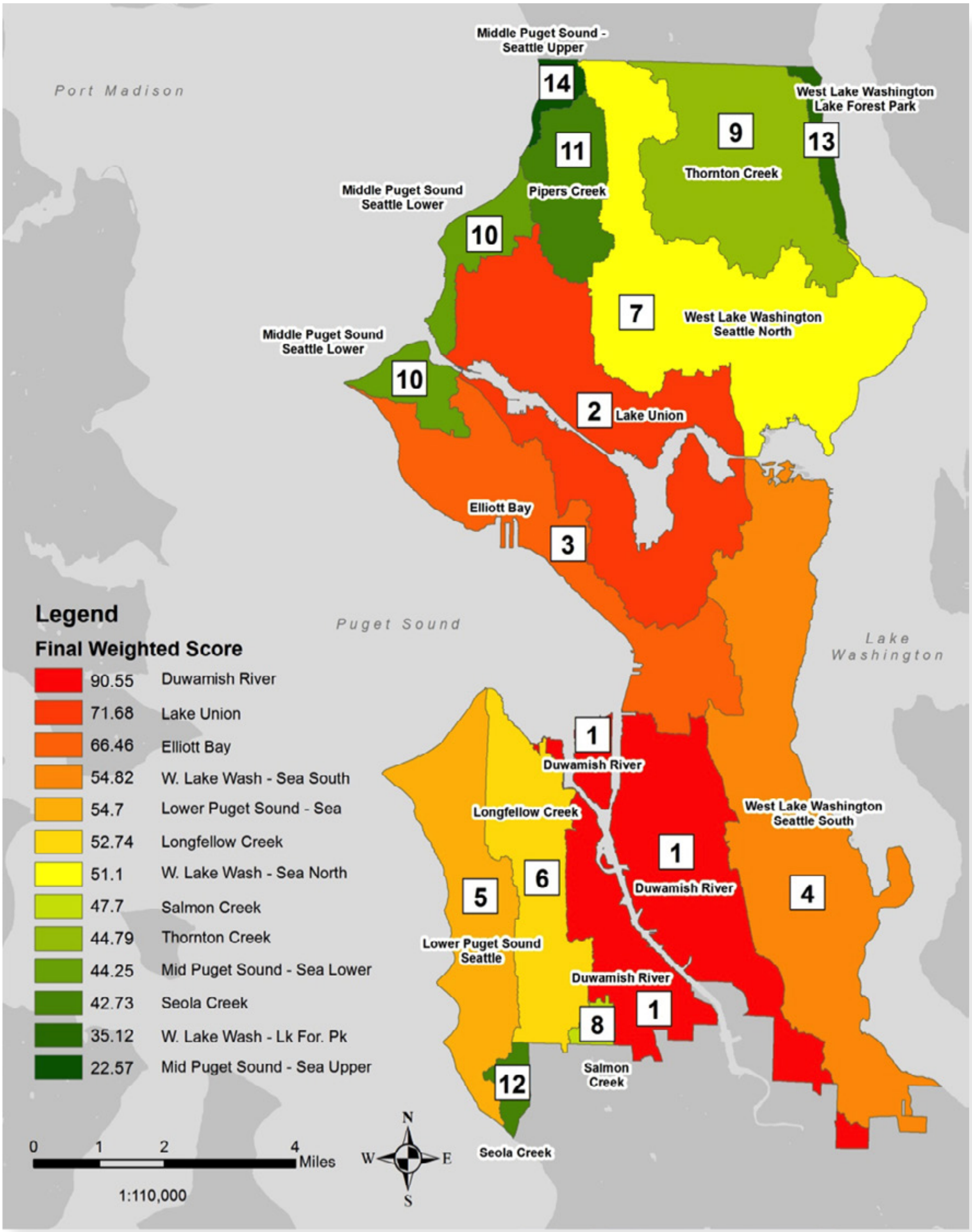
With the weights assigned, the last major step was to input and multiply those weights against the normalized values, resulting in the overall sub-watershed basin score.

	C	D	E	F	G	H	I	J	K	L
1	Forest to Impervious Surface Ratio within Sub-Watershed	Highest number of untreated combined sewer overflow gallons (2012)	Most acreage of impervious surfaces directly adjacent (up to 100 feet) of a waterway	Highest amount of mean slope in drainage basin	Highest amount of precipitation within Sub-Watershed	Highest acres of landslide potential	Highest amount of population	Scoring	Ranking	Criterion
2	0.24	0.2	0.13	0.06	0.04	0.04	0.03			Planning Weight
3	Ratio	Gallons	Acres	Degrees	Inches	Acres	Count			Measurement
4	2.2	1,111,466,325	236.82	14.82	51.74	856.16	150,589			Max Raw Value
5	0.24	1,111,466,325	236.82	5.56	51.74	709.21	32,341			Duwamish River
6	0.89	1.00	1.00	0.37	1.00	0.83	0.21	6.31		Duwamish River -Std
7	0.2134	0.2000	0.1300	0.0225	0.0400	0.0331	0.0064	90.55	1	Duwamish River -Wt
8	0.20	68,730,236	156.04	7.36	48.78	513.76	80,396			Elliott Bay
9	0.91	0.06	0.66	0.50	0.94	0.60	0.53	5.13		Elliott Bay - Std
10	0.22	0.01	0.09	0.03	0.04	0.02	0.02	66.46	3	Elliott Bay - Wt
11	0.19	274,161,545	200.40	6.24	47.67	391.71	150,589			Lake Union
12	0.91	0.25	0.85	0.42	0.92	0.46	1.00	5.68		Lake Union - Std
13	0.22	0.05	0.11	0.03	0.04	0.02	0.03	71.68	2	Lake Union - Wt
14	0.42	10,458,443	51.96	7.51	51.53	375.48	38,974			Longfellow Creek
15	0.81	0.01	0.22	0.51	1.00	0.44	0.26	4.04		Longfellow Creek - Std
16	0.19	0.00	0.03	0.03	0.04	0.02	0.01	52.74	6	Longfellow Creek - Wt
17	0.51	22,187,358	107.62	9.02	50.87	604.75	42,895			Lower Puget Sound - Seattle
18	0.77	0.02	0.45	0.61	0.98	0.71	0.28	4.54		Lower Puget Sound - Seattle - Std
19	0.18	0.00	0.06	0.04	0.04	0.03	0.01	54.70	5	Lower Puget Sound - Seattle - Wt
20	0.92	16,369,699	86.21	9.68	47.53	396.68	13,719			Middle Puget Sound - Seattle Lower
21	0.58	0.01	0.36	0.65	0.92	0.46	0.09	3.68		Middle Puget Sound - Seattle Lower - Std
22	0.14	0.00	0.05	0.04	0.04	0.02	0.00	44.25	10	Middle Puget Sound - Seattle Lower - Wt

Table 18 - Weighted Scorecard - Weights Assigned

Fig. 8 - Sub-Watersheds Ranked by Scorecard

The result of multiplying the weights and the normalized values resulted in a small decimal figure, so it was decided to multiply that final number by 100 for ease of comprehension. The results of the scoring are shown above (Fig. 8). Note: a higher number represents a sub-watershed that is characterized by a higher inability to control stormwater flow (i.e. 1 = “worst”) - see Map 19.



Map 19 - Final Weighted Scorecard by Sub-Watershed

4.3 – Green Seattle Partnership 20-Year Plan

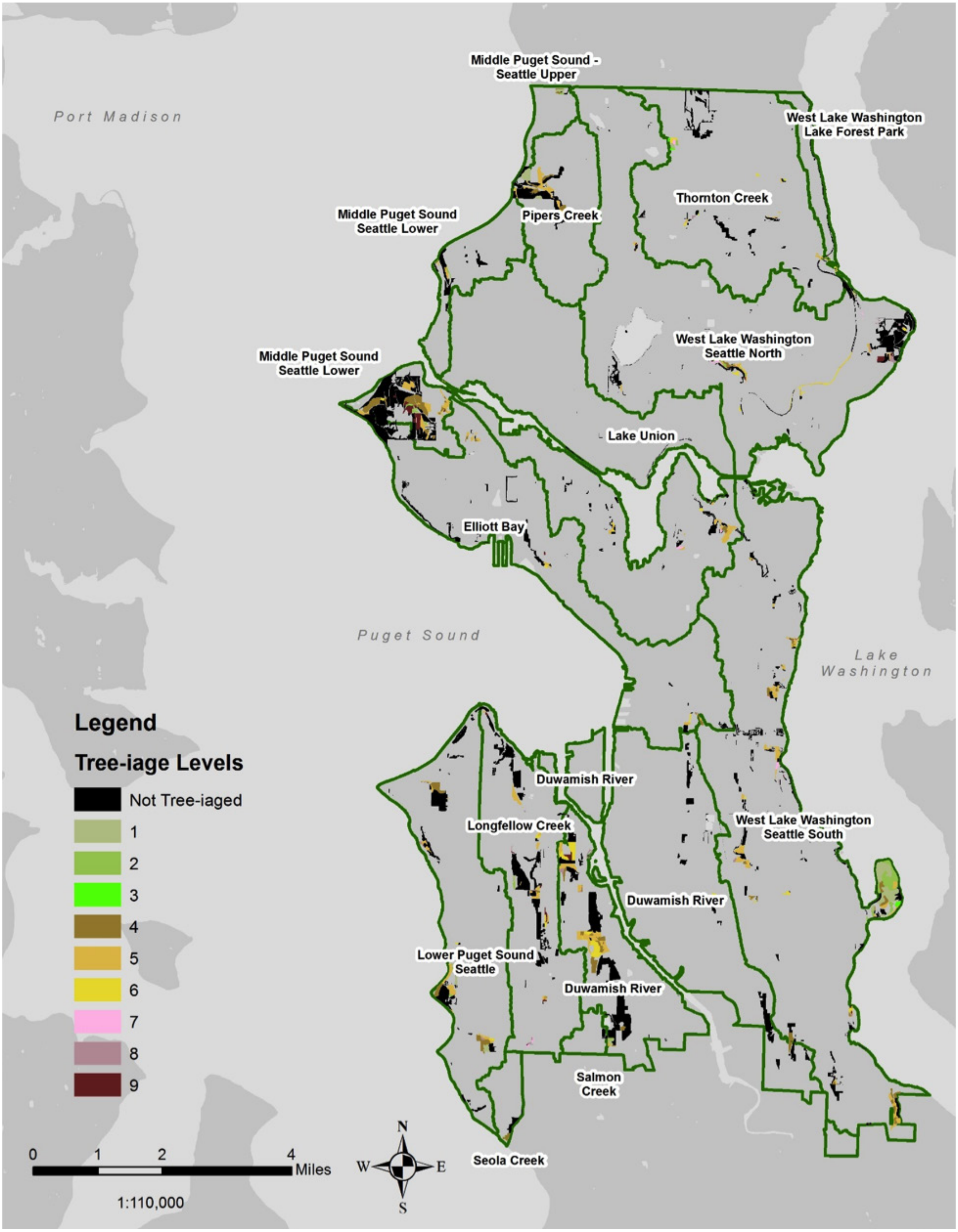
Forterra has a plan, as part of the Green Seattle Partnership, to restore 2,500 acres of forest within 20 years. In order to restore those forests, a classification process (Tree-iage) must first take place. This is a process by which the forest must be surveyed and assigned a value (1-9) based on the value and the health of the forest. Below are the 9 Tree-iage categories:

1 – High Value / Low Threat	2 – High Value / Med Threat	3 – High Value / High Threat
4 – Med Value / Low Threat	5 – Med Value / Med Threat	6 – Med Value / High Threat
7 – Low Value / Low Threat	8 – Low Value / Med Threat	9 – Low Value /High Threat

According to GIS calculations, Forterra has classified about 35% of their total acreage (955 to 2,750) that they plan to restore. According to the Green Seattle Partnership plan, a priority has been placed on the Tree-iage levels (2,3,4,7) due either to need (a high value conifer forest surrounded by invasive species is a top priority), or simply because it is more cost-effective to do so. Below is Map 20 of the Tree-iaged data that Forterra has, the data yet to be Tree-iaged, and the acreage associated with both of those categories.

Basin Name	Priority Acres (2,3,4,7)	Lesser Priority (1,5,6,8,9)	Yet to be Tree-iaged
Duwamish River	39.813115	124.879234	349.210077
Middle Puget Sound - Seattle Upper	3.365368	18.024799	4.876538
Pipers Creek	15.535273	50.975615	87.241818
Thornton Creek	7.162748	21.584613	104.028352
West Lake Washington - Lake Forest Park	0	0.696664	13.219651
Elliott Bay	3.660107	16.108121	148.142588
Lake Union	7.36375	30.709704	60.179934
Longfellow Creek	5.895787	45.169019	216.678598
Lower Puget Sound - Seattle	39.146707	48.449454	135.817784
Middle Puget Sound - Seattle Lower	69.042686	78.260894	269.797556
Salmon Creek	0	0.138153	5.421647
Seola Creek	5.077992	0	9.340325
West Lake Washington - Seattle North	16.012265	52.86095	190.881207
West Lake Washington - Seattle South	104.734832	169.376479	195.860003

Table 19 - Tree-iage Statistics by Sub-Watershed



Map 20 - Tree-iage Statistics by Sub-Watershed

4.4 – Implementation Option #1

Forterra already has a plan to restore 2,500 acres of forested areas (mostly in parks) within the next twenty years. Our first option that we would offer is that Forterra might locate their "priority forests" (Tree-iage 2,3,4,7) and choose to restore those first within the "worst" watersheds according to the weighted scorecard. However, instead of just restoring forests anywhere within the sub-watershed, an option could be to first locate those priority forests within combined sewer overflow basins that have had major overflow problems as recently as 2012, and have no current plans to make repairs or upgrades to the conveyance structure in those basins.

Fig. 9 - Option 1 - Forest Iteration within each Sub-Watershed

After targeting forested rehabilitation in those areas, Forterra could move on to other offending CSO basins within that same sub-watershed. Once all priority forest Tree-iage levels were worked in those CSO areas, Forterra could move on to the next sub-watershed and iterate in the same fashion. Then, after all the priority forests were upgraded in those CSO's throughout the city, Forterra could come back to the beginning, to the very worst sub-watershed, and do the rehab work on all the remaining "priority forests" within the sub-watershed, but outside any problem CSOs (see Fig. 9).

After all the priority forest areas have been rehabilitated for all the sub-watersheds, Forterra can look at their non-priority forested areas and reassess what priority they would place on those going forward. At that point, they could plug those forests back into the same iterative loop as outlined above.

4.4.1 - Option 1 Example

The following example, looks to the sub-watershed that had the highest "opportunity score" using our multi-criteria analysis. In this case, the Duwamish River sub-watershed has a score of 90.55, that is shown in Map 21, and contains Forterra's Tree-iage data that is broken down by Tree-iage level. For the results of the remaining sub-watersheds, see Appendix D on page 111.

Displayed are CSO basins that are scheduled for improvements, and those that aren't. There are 39.81 acres of forested areas within those CSO basins. This sub-watershed happens to have a CSO that has scheduled improvements. There are no priority forests within other CSO areas. In this case, Forterra could move on to the next sub-watershed to work the priority forests in those sub-watersheds. Data sheets like the one seen in Map 21 have been created for each sub-watershed.

Map 21 - Option 1: Example Scenario Analysis

Duwamish Sub-Watershed / Score 90.55

It was understood that 65% of forested areas have yet to be classified. For example, the Duwamish River sub-watershed has a total of 349.21 unclassified acres; with 13 of those acres in a CSO that has overflow problems - but is scheduled for repairs. Therefore, it is recommended that those forests be assessed as soon as possible and in the same iterative fashion (areas within problem CSO's with no repairs scheduled, areas within problem CSO's with repairs scheduled, and then the rest of the sub-watershed).

4.4.2 - Potential Areas for Planting / Tree-iage

This team believes there are potentially other areas that Forterra could look into further as far as both additional Tree-iage locations and/or areas where new plantings could take place. Staying with the same map of Duwamish River, the team targeted areas in purple as sites that need further exploration. These are areas of public lands that were verified by our team (via imagery) that appeared as if they could either be forested, or they were an area of public forested land that wasn't included in the data that Forterra already had. As an example, 127 acres were classified as "potential areas" in the Duwamish River sub-watershed, with 4 acres inside a CSO that has flow problems (but is scheduled for repairs). It is recognized that Forterra has enough to do with their own forested areas, but there may be a further opportunity here in the name of overall sustainability of the region, even if it isn't Forterra that handles that aspect.

4.5 – Implementation Option #2 (Rights-of-Way)

The team would like to present Forterra with a second option for this project - the Rights-of-Way methodology, as outline in the Test section. The benefits are even greater when used in conjunction with the above weighted scorecard. The ROW approach appears to save money, time and has the potential to yield greater benefit in combating stormwater runoff than in established forested areas.

It should be noted that while conducting research for the implementation phase, a study titled "Urban Tree Canopy Analysis" was located.[35] That project used remote sensing to identify

35 http://www.seattle.gov/trees/docs/NCDC_Final_Project_Report.pdf

areas within Seattle identify likely planting areas and also estimate tree potential within all areas of the city to include the ROW. This used similar estimation techniques and validated the importance of the focus on ROW and several of the estimation techniques.

4.5.1 - Cost Savings

The Green Seattle Partnership estimated the costs for restoring and maintaining 2500 acres of urban forest (over 20 years) to be $52 million, or $20,800 per acre[36]. However, this costs include the removal of invasive species, staff salaries, and maintenance cost. Table 20 was extracted from the Green Seattle Partnership's *20-Year Plan* and documents the number of hours estimated for each phase of their forest management plan.

Phase	Tasks	Range of labor investment (hours/acre)	Average labor investment (hours/acre)
1	Invasive plant removal	50 to 800	400
2	Planting and secondary invasive removal	50 to 200	100
3	Plant establishment	25 to 100/year for up to 3 years	40/year for up to 3 years
4	Long-term monitoring and maintenance	0 to 20 annually	5 annually

Table 20 - GSP's Labor Hour Estimate by Phase

It is here where the benefits for initiating projects withing the ROW become even more evident. A large benefit to focusing on the Rights-of-Way is that the city mandates that the property owner perform the maintenance (for the purposes of this study, the landcover) within them; in many cases, within residential areas, this area is lawn cover. Therefore, they are less likely to have invasive species (i.e. - vines, blackberries, etc.) or require many man-hours to maintain.

Current city programs such as ReLeaf[37], can be exploited to take advantage of the public's involvement. ReLeaf offers residents: up to four free trees; watering bags; training; and work-shops. It is unknown if current projects use seeds to re-introduce native species to an area or

36 Green Seattle Partnership, page 27
37 http://www.seattle.gov/trees/treesforneighborhoods.htm

if saplings are planted. It is reasonable that saplings are used to ensure a higher success rate. If this is the case, then this incurs higher costs since it requires someone to grow and maintain the saplings until they're ready for transplant.

To drastically reduce these costs, a program within the Seattle schools can be initiated (if not already in place) where students grow the saplings from seeds to saplings. Once they reach the age for transplant the students can plant them at their homes, at approved city locations, or donate them to the city / state.

There are some foreseeable downsides to this approach as students in low income households may be burdened by the increased costs of initiating the project (pot, soil, and routine watering). However, as a possible solution educators and program administrators can capitalize on the city's current recycling, food waste and Wastewater Treatment Plant programs by using them as a resource (pots and compost, gray water).

There is no need for curriculum development,as the city already hosts classes, provides workshops and posts curriculum Online[38]. Since the program would be instructed / managed in an academic environment, educators already possess this elementary knowledge of biology. The primary responsibility for administrators is to ensure that information is easily accessible and understandable to most. This would include multi-lingual and ADA compliant versions (if cost / benefit allows).

4.5.2 - Civic Duty / Crowd Sourcing

The above approach capitalizes on civic involvement (labor & resources) and education of biology and GSI BMPs at an early age. The students may have more of an interest in the growth and preservation of “their” tree and may be less likely to cut it down (or allow their children to) for the sake of urbanization. By utilizing other established city programs (recycling, food waste, WTP, rain harvesting, etc.), the students would be able to witness how they are all integrated and learn why their participation is important. The resiliency of this approach is in the fact that

38 http://greenseattle.org/education/urban-forestry-project

each year brings new students and therefore a new crop to bear. This approach is also viewed as a cost saving measure since the city's most major costs would be the purchasing of seeds and the salaries of employees / contractors to manage the program.

The program can be promoted through competitions between schools for the most amount of saplings grown.

The downside with this approach is that it may take some years to determine the success rate of plants that survive the transplant, provided that they even reach that stage. Therefore at the initial stages of the program, the inventory may need to be backfilled through the existing supply chain.

The U.S. Census Bureau[39] estimates the number of children to be 27,134 (ages 5 to 9) and 21,478 (ages 10 to 14), respectively to provide an idea for potential volume. Initially, the program would require a test bed until a more consistent system can be replicated across all participating schools / organizations.

Since the success of this conceptual program relies on the actual number of plants that transfer from the students to the final transplant site, the age of the student and the plant species should be appropriately chosen. For example, a slow growing species should be selected for teenagers that have more patience and a fast growing species for younger children.

Homeowners who participate in the ReLeaf program are viewed as more likely to ensure the successful maintenance of the trees because they are the ones who requested assistance, versus being mandated to do so. Also, planting trees in proximity to their homes versus a remote location (park or hard to reach forest) is a factor. By planting in forested areas, it makes it more difficult for the public to participate. They must first find time in their schedule, to fight traffic as they drive to the location, find parking, and walk to the location(s) with their tools and

39 2011 ACS 3-year Estimate (http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_11_3YR_DP05&prodType=table)

water. Focusing the implementation of GSI BMPs in the ROW helps to reduce (if not eliminate) these perceived barriers.

4.5.2.1 - Competitions

Another approach to garner public participation is to hold a “Design a ROW” competition. Competitors can access online curriculum about GSI BMPs and be judged based on the self-sustainability of their entry, number and types of BMPs involved, and visual appeal. Of course the city would need to approve contestants’ projects and all costs would be paid for by the contestants. Awards issued could be for “Best in Show”, “Cost Effectiveness”, or “Best Neighborhood”.

4.5.2.2 - Technology

Technology can take advantage of the publics willingness to help. A website that allows people to help classify the forests or ROW can be created. Of course it would have to be properly designed to ensure the validity and accuracy of the information being uploaded. To help combat inaccuracies, the database could allow (or require) the upload of pictures, so that someone with more training could validate the entry (i.e.- confirm type of species). The uploaded photo’s metadata could be mined for data point’s GPS coordinates, date, and time.

4.5.3 - Financing

The implementation of the discussed ROW approach will incur financial costs, however they are estimated to be a fraction of those estimated for existing programs (city park’s forests), if the above conceptual examples above are implemented.

Furthermore, if the above conceptual program involving students is implemented, the city may find itself with a surplus of saplings / vegetation if urban afforestation goals have been met or if maintenance costs outweigh the benefits of their storage. It can then take advantage of this opportunity by selling them to other government / private foresters, to help offset operating costs. Wildfires create an undesirable ecological state and re-forestation may be required to prevent ecological thresholds changing to that state. In this example, the city could be the source of these restoration efforts.

Another potential revenue stream may be in the form of advertising. In commercially zoned ROW, trees could have tree rings (or saplings with supports) with advertising on them. There could be a set of approved styles (that are customizable) approved by the city and all costs associated with this program would be paid for by the advertiser. The approved styles must be reasonably subtle and functional. For example: a circular design; less than 12 inches above ground; designed to keep the root zone safe, allows stormwater to percolate; and is visually appealing. The required permit would include an RFID tag, that contains permit information, to be affixed to the tree ring. The RFID tag is to more easily inventory valid “advertisements”. All costs would be passed on to the advertiser.

Additional revenue streams could be more traditional and in the form of grants - however, non-traditional sectors can also be sources. GSI BMPs include converting impervious surfaces to pervious surfaces with functional foliage - these species can be edible. For example, the ROW planting strips could be converted to bio-swales that cleanse waters before being stored in a basin which supplies water for a raised bed garden.

Federal grant monies may be obtained to fund these types of GSI projects as it would enable communities to become more self-sustaining which the Federal Emergency Management Agency is trying to promote.

Unfortunately, cost estimates could not be generated due to the lack of time to properly investigate current city resources or interview program managers.

Further investigation should be conducted into the ReLeaf program as it appears to best mimic the above concepts. According to the city’s 2013 Adopted budget[40], ReLeaf operating budget

40 http://www.seattle.gov/financedepartment/13adoptedbudget/default.htm

increased from 2012 to 2013 by 60% and is forecasted to increase approximately 2.5% thereafter (see Table 21).

	2012	2013	2014	2015	2016
SCL for ReLeaf	80,000	133,000	136,000	141,000	144,000

Table 21 - ReLeaf Operating Budget

	2008	2009	2010	2011	2012
# of Trees Planted	2990	3465	3572	2634	3759

Table 22 - Number of Trees Planted by ReLeaf

Table 22 documents the number of trees planted by ReLeaf and was compiled from their annual progress reports[41]. Taking 2012 as an example, because prior years did not have financial information, the amount of operating revenue per tree planted was $21.28. It should be noted that it is unknown if another program purchased the trees or any other particulars about the program's operation. Using the GSP's maximum distribution of 110 trees per acre, this would translate to $2,341 per acre.

41 http://www.seattle.gov/trees/progressreports.htm

Tree-iage category	Average restoration cost/acre	Acres	Total Cost/ category
1	$2,800	41	$114,800
2	$9,500	330	$3,135,000
3	$15,400	95	$1,463,000
4	$9,500	39	$370,500
5	$16,100	422	$6,794,200
6	$22,000	608	$13,376,000
7	$15,400	44	$677,600
8	$22,000	380	$8,360,000
9	$27,900	633	$17,660,700
	Total	**2,592**	**$51,951,800**

Table 23 - GSP's Cost Estimate for Restoration

This still is cheaper than the GSP's estimate for the 20 year least costly restoration site, Tree-iage category 1 (see Table 23). However, according to the U.S. Tree Planting for Carbon Sequestration report[42], the average cost of establishing forest vegetation is $523 per acre and $200 per acre for afforestation. These figures are drastically different from the Oregon Department of Natural Resources document regarding the cost per seedling observed during the reforestation project.[43] The report covered the years 1998 to 2008 and lists the price per seed ranging from $0.08 to $0.23, respectively.

Further research should be conducted to find the true costs so that sound decisions could be made.

42 http://www.fas.org/sgp/crs/misc/R40562.pdf
43 http://www.dnr.state.oh.us/Portals/11/aml/pdf/reforestation_costs.pdf

4.5.4 - Forterra's Involvement

Forterra's involvement in these areas could be: identifying / preparing key ROW / transplant areas that would provide the most benefits, managing the distribution of plant species, monitoring the health of the transplants, overseeing the conceptual school program, working with corporations in commercial areas, or providing public outreach / workshops.

4.5.5 - Benefits

The emplacement of native vegetation adjacent to impervious surfaces is viewed as being more beneficial in that it is more likely to control stormwater runoff. If stormwater reaches the grounds of a forest, it requires a greater amount to accumulate for it to turn into stormwater runoff, than in an urban environment with impervious surfaces. Areas with impervious surfaces have greater access to storm drains / combined sewers, thus providing an expedited route for pollution to reach the receiving waters.

Furthermore, by being collocated with those impervious surfaces, they will aid in filtering the air by trapping airborne particulates (dust) within the canopy - thus improving the health conditions within the city.

The city of Seattle is home to many technology companies having young and educated employees. Visitors flock to the area for business meetings, conventions, outdoor recreation, to attend the many festivals or to witness the serene landscapes. The city is one of the top cities in the nation for LEED certified facilities and billed as the center for industry-leading innovation and sustainable businesses.[44] Planting in the ROW (specifically areas of high visibility), helps to maintain the resilience of the region, give residents and visitors what they are expecting, and works towards achieving the Urban Forest Management Plan's goal of increasing the tree cover in ROW by 24%.

44 http://www.seattlechamber.com/AboutSeattle/RegionalInformation.aspx

5 – Conclusion

Two options have been put forth in which Forterra can use to prioritize their efforts in establishing a green stormwater infrastructure in the city of Seattle. Introduced was a way to prioritize their forest rehab work through a sub-watershed prioritization method. This is a framework that Forterra could either use now as is, or they could use it as a jumping off point to improve upon with more robust analysis/data sets. It is a highly flexible framework and the team simply offered one way in which it could be implemented. Within that framework, the team also presented additional locations that might be further examined as places of additional Tree-iage and planting opportunities. A methodology presented for finding planting opportunities in planting strips within neighborhood right of ways. The team feels that there is a large opportunity there to increase canopy cover and decrease stormwater flow amounts.

Implementing green stormwater infrastructure - which will effectively increase forest canopy cover at the same time, is no easy task. The team feels that these options will help to organize Forterra's efforts in a way that will maximize their effectiveness, and to more quickly contribute to a sustainable future in the city of Seattle.

Appendix A - References

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Appendix B - Simplified Value Structure

Values	Goals / Target	Objectives	Criteria for site sustainability
Seattle owns property that needs to be managed	Open area or low growing vegetation	Identify city owned parcels.	Greater than 4000 sq. ft.
Stormwater Runoff can clog stormwater drains	reduce the amount of stormwater runoff entering the Stormwater drains	Identify Stormwater inflows	within 500 feet of open area
Low lying areas pose a flood risk	Ensure proper drainage in those those areas create stormwater harvesting areas	identify stormwater inflows identify feasible harvesting sites upstream from low lying areas	within lowlying areas city owned property
landslide areas lower home values and pose a danger to the community	reduce stormwater from reaching the soil	identify areas upstream from landslide areas that would benefit from the re-introduction of native species	must be able to support large-growth trees
residents complain of sewer back-ups during heavy storms	reduce the amount of stormwater from entering the CS system	“identify complaint locations and inflows in the vicinity. Identify vacant parcels upstream meeting GSI suitability requirements	More than one complaint, repeated complaints (if possible), on the same Stormwater drain, or CS sewer
Construction Prior to 1990 were not required to adhere to GSI BMP	implement sub-basin educational programs and policies	Identify parcels	
Outfalls should be better regulated	reduce the number of “events” (i.e- low DO level, flooding, erosion, pollution) after outfalls	identify historical “events” proximity to outfalls	site selection should be based on reasonable cost benefit ratio
Unhealthy / ineffective / non-native forests could be better managed	reforest problem areas w/ native species	identify areas that would benefit from reforestation	capable of accomodating large canopy trees

Appendix C - Data Needs

Basemap

Coordinate Reference System

Environmental Characteristics

Soil Characteristics

Layer: Soil Composition
Source: Possibly USGS, NRCS (http://soils.usda.gov)?
Map Use: Display and analysis

Topography

Layer: DEM (Digital Elevation Model)v
Source: City of Seattle, Seattle Public Utilities, GIS & Puget Sound LiDAR Consortium
Map Use: Display and analysis

Layer: contours (2-foot)
Source: City of Seattle, Seattle Public Utilities, GIS
Map Use: Display and analysis

Water Courses

Layer: Groundwater Sources (gwsource)
Source: King County GIS
Map Use: Display and analysis of Groundwater Sources

Layer: wtrbody (water bodies)
Source: King County GIS
Map Use: Display and analysis of open Waters"

Land Cover / Use

Layer: canopy cover (canopy2006)
Source: Department of Ecology
Map Use: Display and analysis of canopy

Layer: Impervious surface layer (2006impervious)
Source: Department of Ecology
Map Use: Display and analysis of impervious surfaces

Layer: Land cover (2006landcover)
Source: Department of Ecology
Map Use: Display and analysis of National Land Cover Database

Layer: 2009impervious (impervious surfaces)
Source: King County GIS
Map Use: Display and analysis of impervious surfaces

Layer: rip_dclu (Riparian areas)
Source: City of Seattle, DPD
Map Use: Display and analysis of riparian areas

Layer: geology
Source: City of Seattle, SPU
Map Use: Display and analysis of geology

Layer: land use
Source: Possibly City of Seattle or King County

Map Use: Display and analysis of geology

Layer: Forest Management Data (FMT Plots, Treeiage, and Zones)
Source: Forterra
Map Use: Display and analysis of forest health and categorization

Layer: Natural Drainage Systems
Source: City of Seattle, SPU
Map Use: Display and analysis of the natural drainage systems

Natural Hazards

Layer: slide (known landslide areas)
Source: City of Seattle, DPD
Map Use: Display and analysis of Landslides

Layer: potslide (Potential Landslide Areas)
Source: City of Seattle, DPD
Map Use: Display and analysis of Landslides

Layer: fldplain (Floodplain areas)
Source: King County, Dept. of Natural Resources and Parks, Water and Lands Resources Division
Map Use: Display and analysis of Floodplains"

Ecologically Sensitive Areas

Layer: basin_condition
Source: King County, King County Dept. of Environmental Services
Map Use: Display and analysis of Basin Condition

Layer: drainage_complaints
Source: King County Dept. of Natural Resources and Parks, Water and Lands Resources Division
Map Use: Display and analysis of Drainage Complaint areas

Layer: wetland
Source: City of Seattle, DPD
Map Use: Display and analysis of wetlands

Infrastructure Characteristics

Buildings

Layer: Building footprints
Source: Possibly the City of Seattle
Map Use: Display and analysis of Roadways

Transportation

Layer: paveedge (Street Pavement Edges)
Source: City of Seattle, SPU / GIS
Map Use: Display and analysis of Roadways

Utilities

Layer: stormreg (Stormwater Regional Facilities)
Source: King County Dept. of Natural Resources and Parks, Water and Lands Resources Division
Map Use: Display and analysis of Regional Stormwater Facilities"

Layer: storm_fac (Residential and Commercial Stormwater Facilities)
Source: King County Dept. of Natural Resources and Parks, Water and Lands Resources Division

Map Use: Display and analysis of stormwater facilities

Layer: catch basins (catchbasin)
Source: City of Seattle
Map Use: Display and analysis of stormwater facilities

Layer: metrocso (metro combined Sewer Overflows)
Source: City of Seattle SPU/resource planning
Map Use: Display and analysis of combined sewer overflows

Layer: ditches
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of ditches

Layer: dts (Drainage and Wastewater Detention Systems)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of drainage and wastewater detention systems

Layer: outfall (City-owned drainage outfalls: storm water only)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of Drainage and wastewater outfalls.

Layer: npdes (Drainage and Regulated Outfalls)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of City NPDES Overflows.

Layer: dwupoly (Drainage and Wastewater Structures)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of drainage and wastewater structures.

Layer: dwulat (Sewer & drainage lateral connections including side sewers)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of Drainage & Wastewater Side Sewers/Laterals.

Layer: dwulatpt (Sewer Lateral Point Features)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of sewer lateral point features.

Layer: dwumnl (Sewer & drainage mainline pipes)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of sewer mainlines

Layer: dwumnlpt (Sewer Mainline Point Features)
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of sewer mainline points

Layer: green_stormwater_infrastructure
Source: City of Seattle SPU/DWU
Map Use: Display and analysis of sewer mainline points

Land Designations

Zoning

Layer: zoning
Source: City of Seattle
Map Use: Display and analysis of Restricted Use Areas”

Land Administration

Boundaries

Layer: mun_wshd (municipal watershed)

Source: King County GIS Center
Map Use: Display and analysis of municipal watersheds

Layer: topo_basin_kc (water basin in King County)
Source: King County Dept. of Natural Resources and Parks, Water and Lands Resources Division
Map Use: Display and analysis of basins

Layer: topo_watershed_kc (watershed in King County
Source: King County Dept. of Natural Resources and Parks, Water and Lands Resources Division
Map Use: Display and analysis of watersheds

Layer: kingsh (King County political boundaries)
Source: King County GIS Center
Map Use: Display and analysis of and within King County"

Layer: wbd_wa (watershed Boundaries)
Source: Dept. of Ecology
Map Use: Display and analysis of watersheds boundaries

Layer: munibond (City of Seattle Municipal boundaries)
Source: City of Seattle, SPU / GIS
Map Use: Display and analysis of and within City of Seattle

Land Ownership

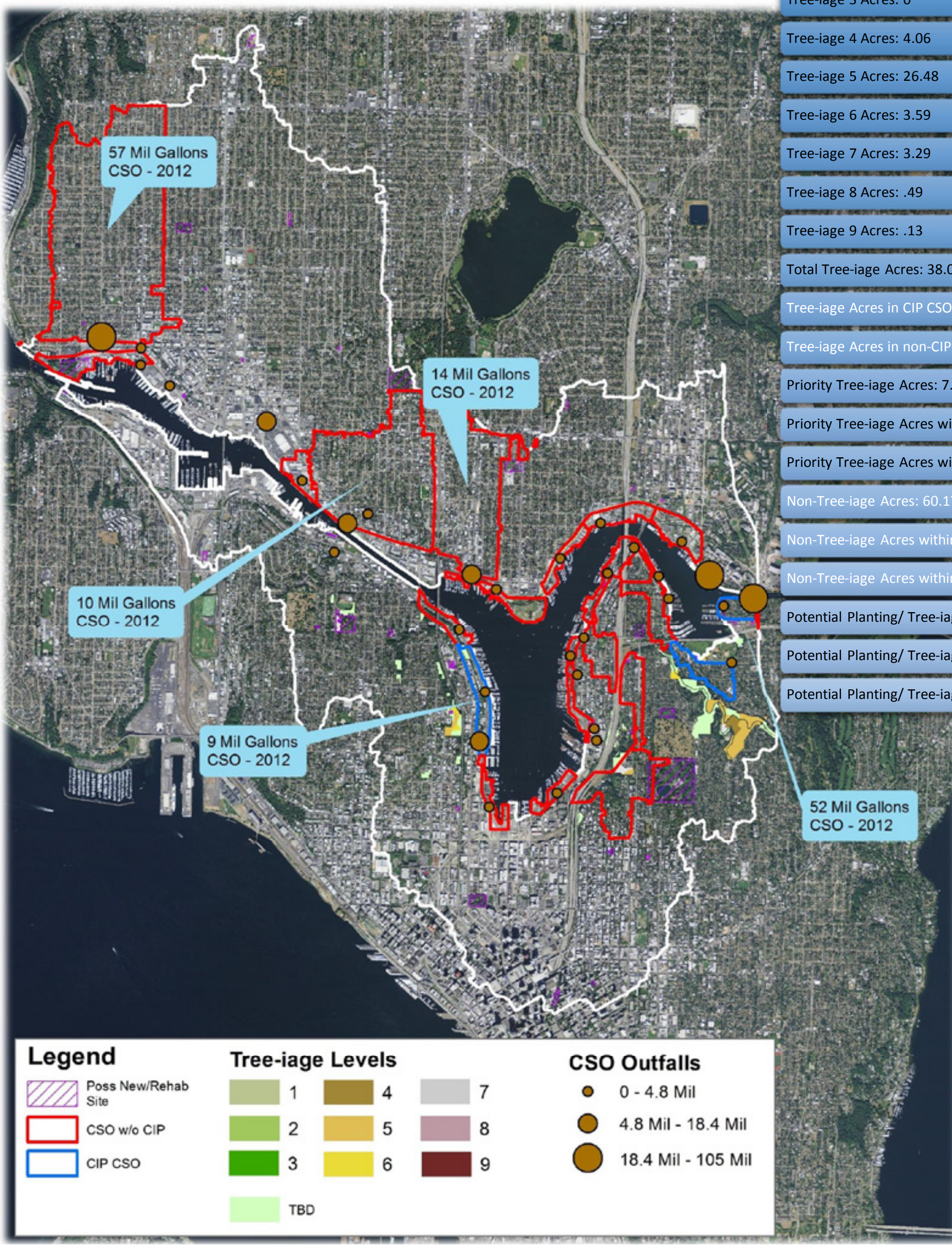
Boundaries

Layer: parcel (parcels of King County)
Source: King County GIS, King County Assessor
Map Use: Display and analysis of parcels

Appendix D - Weighted Scorecards by Sub-Watershed

Sub-Watershed: Lake Union / Score: 71.6

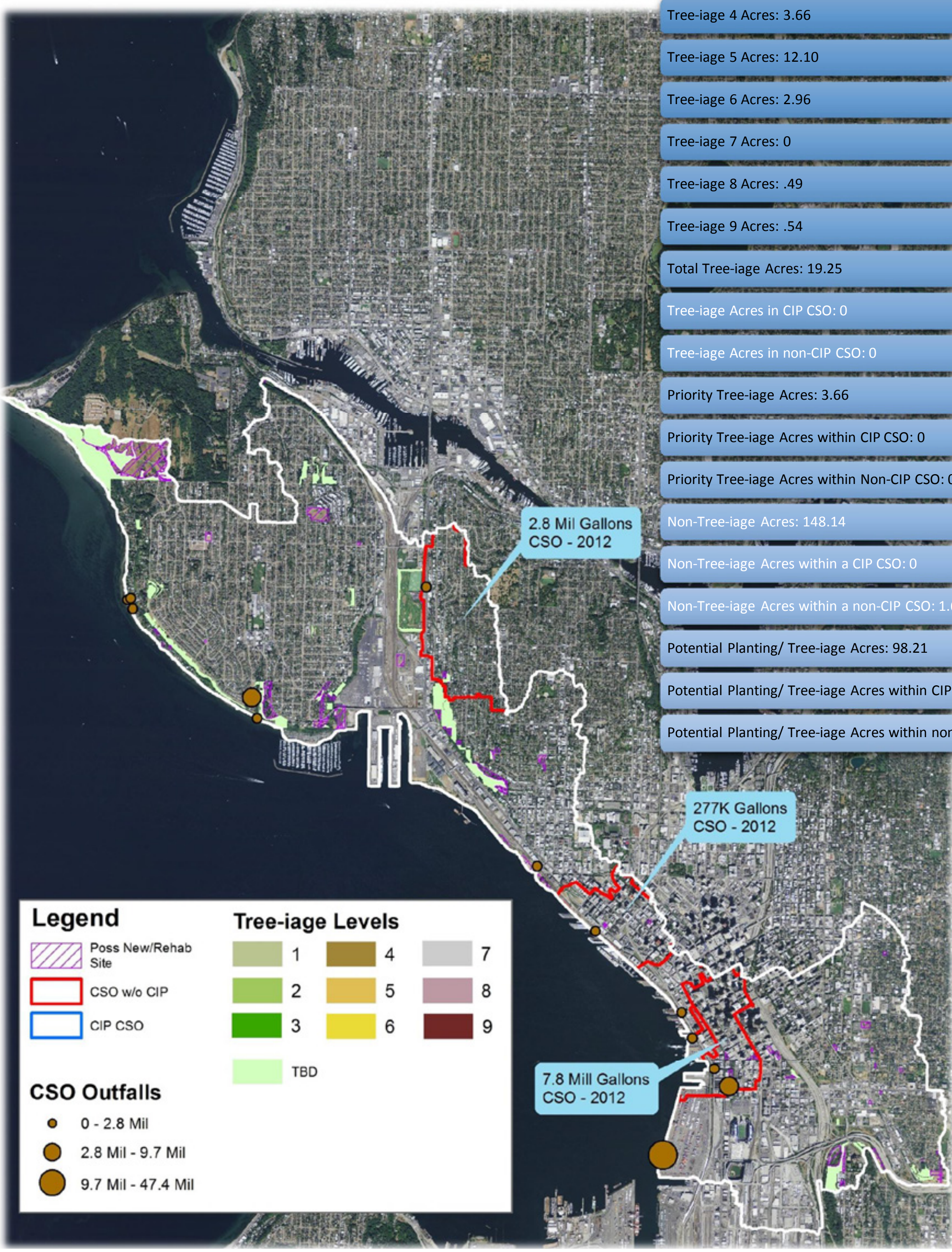
- CSO 2012: 274,161,545
- Sub-Watershed Acres: 7,663.85
- Tree-iage 1 Acres: 0
- Tree-iage 2 Acres: 0
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 4.06
- Tree-iage 5 Acres: 26.48
- Tree-iage 6 Acres: 3.59
- Tree-iage 7 Acres: 3.29
- Tree-iage 8 Acres: .49
- Tree-iage 9 Acres: .13
- Total Tree-iage Acres: 38.07
- Tree-iage Acres in CIP CSO: .29
- Tree-iage Acres in non-CIP CSO: 3.61
- Priority Tree-iage Acres: 7.3
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 2.6
- Non-Tree-iage Acres: 60.17
- Non-Tree-iage Acres within a CIP CSO: 1.39
- Non-Tree-iage Acres within a non-CIP CSO: 6.11
- Potential Planting/ Tree-iage Acres: 113.33
- Potential Planting/ Tree-iage Acres within CIP CSO: 1.91
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 19.51



Map 22 - Lake Union Sub-Watershed Score

Sub-Watershed: Elliott Bay / Score: 66.46

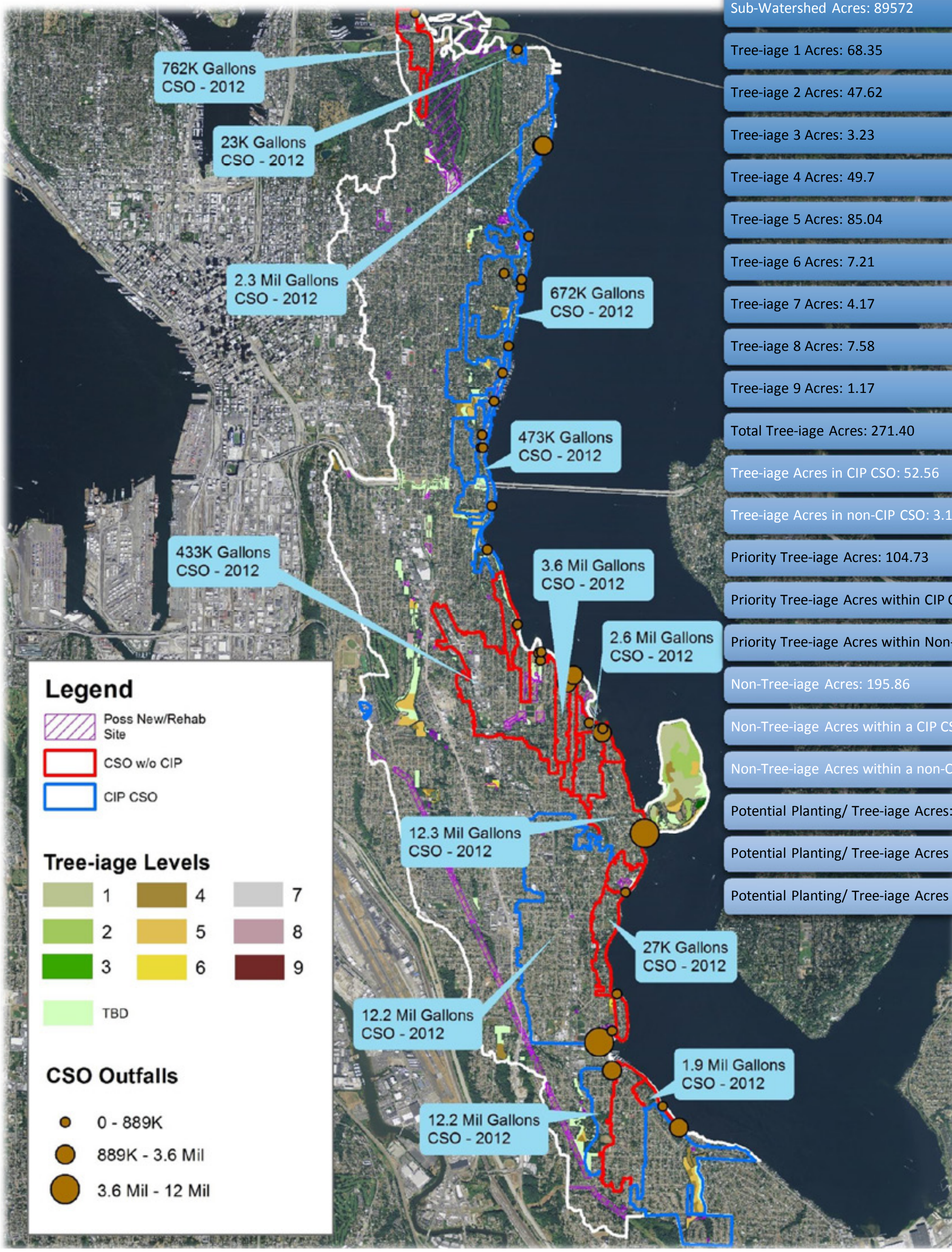
- Sub-Watershed Acres: 4650.22
- Tree-iage 1 Acres: 0
- Tree-iage 2 Acres: 0
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 3.66
- Tree-iage 5 Acres: 12.10
- Tree-iage 6 Acres: 2.96
- Tree-iage 7 Acres: 0
- Tree-iage 8 Acres: .49
- Tree-iage 9 Acres: .54
- Total Tree-iage Acres: 19.25
- Tree-iage Acres in CIP CSO: 0
- Tree-iage Acres in non-CIP CSO: 0
- Priority Tree-iage Acres: 3.66
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 148.14
- Non-Tree-iage Acres within a CIP CSO: 0
- Non-Tree-iage Acres within a non-CIP CSO: 1.69
- Potential Planting/ Tree-iage Acres: 98.21
- Potential Planting/ Tree-iage Acres within CIP CSO: 0
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 2.76



Map 23 - Elliot Bay Sub-Watershed Score

Sub-Watershed: West Lake Washington – Sea South / Score: 54.82

- CSO 2012: 40,780,449
- Sub-Watershed Acres: 89572
- Tree-iage 1 Acres: 68.35
- Tree-iage 2 Acres: 47.62
- Tree-iage 3 Acres: 3.23
- Tree-iage 4 Acres: 49.7
- Tree-iage 5 Acres: 85.04
- Tree-iage 6 Acres: 7.21
- Tree-iage 7 Acres: 4.17
- Tree-iage 8 Acres: 7.58
- Tree-iage 9 Acres: 1.17
- Total Tree-iage Acres: 271.40
- Tree-iage Acres in CIP CSO: 52.56
- Tree-iage Acres in non-CIP CSO: 3.19
- Priority Tree-iage Acres: 104.73
- Priority Tree-iage Acres within CIP CSO: 25.63
- Priority Tree-iage Acres within Non-CIP CSO: .87
- Non-Tree-iage Acres: 195.86
- Non-Tree-iage Acres within a CIP CSO: 32.25
- Non-Tree-iage Acres within a non-CIP CSO: 21.42
- Potential Planting/ Tree-iage Acres: 323.60
- Potential Planting/ Tree-iage Acres within CIP CSO: 9.01
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 26.18



Sub-Watershed: Lower Puget Sound – Seattle / Score: 54.7

- CSO 2012: 22,187,358
- Sub-Watershed Acres: 3645.12
- Tree-iage 1 Acres: 9.19
- Tree-iage 2 Acres: 2.92
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 35.74
- Tree-iage 5 Acres: 33.18
- Tree-iage 6 Acres: 51.28
- Tree-iage 7 Acres: 0
- Tree-iage 8 Acres: .42
- Tree-iage 9 Acres: 24.99
- Total Tree-iage Acres: 87.59
- Tree-iage Acres in CIP CSO: 3.25
- Tree-iage Acres in non-CIP CSO: 1.17
- Priority Tree-iage Acres: 39.14
- Priority Tree-iage Acres within CIP CSO: 1.26
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 135.81
- Non-Tree-iage Acres within a CIP CSO: 6.06
- Non-Tree-iage Acres within a non-CIP CSO: 2.98
- Potential Planting/ Tree-iage Acres: 59.34
- Potential Planting/ Tree-iage Acres within CIP CSO: 7.72
- Potential Planting/ Tree-iage Acres within non-CIP CSO: .47

Map 24 - Lower Puget Sound - Seattle Sub-Watershed Score

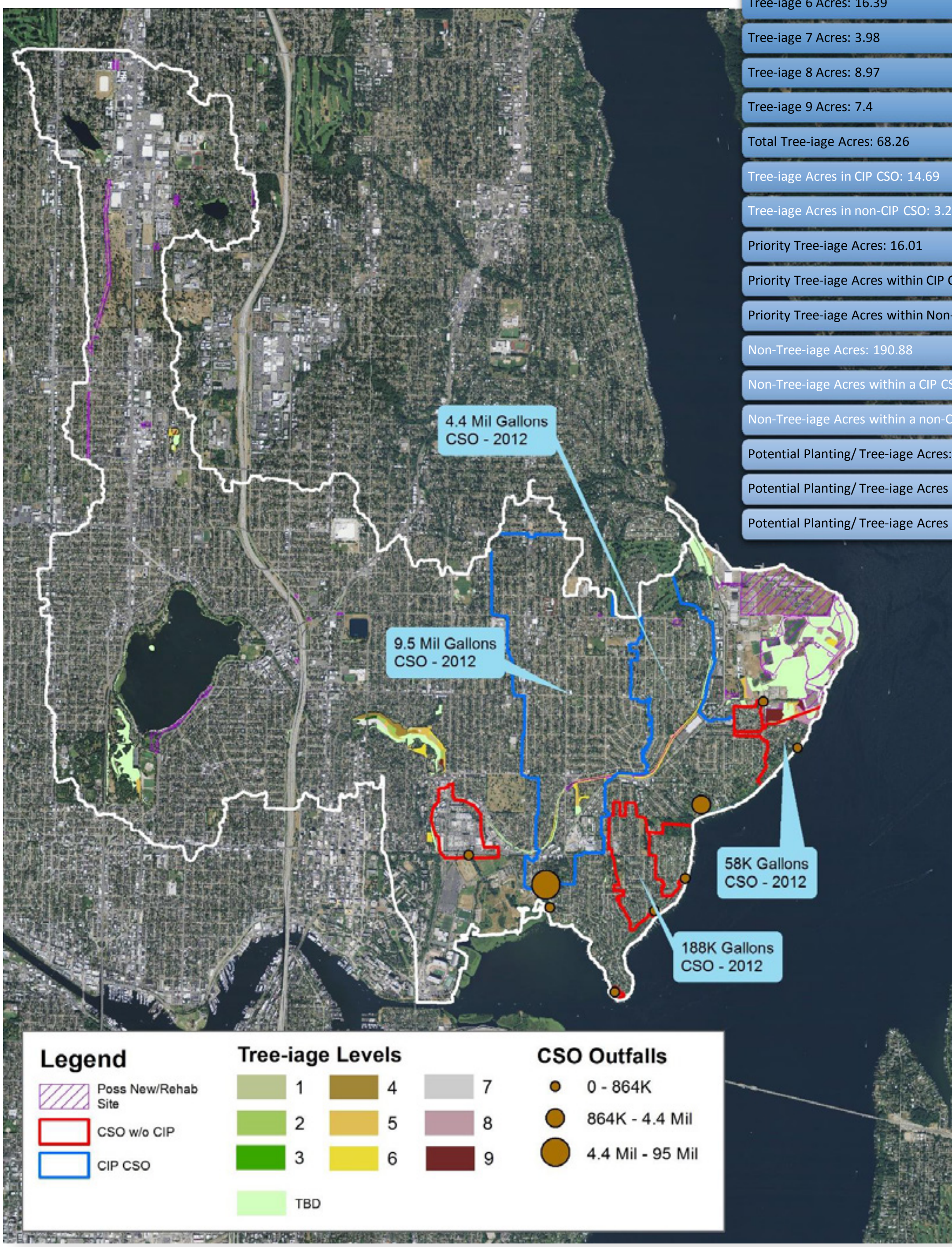
Sub-Watershed: Longfellow Creek / Score: 52.74

- CSO 2012: 10,458,443
- Sub-Watershed Acres: 3225.7
- Tree-iage 1 Acres: 3.54
- Tree-iage 2 Acres: 2.15
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 1.34
- Tree-iage 5 Acres: 27.87
- Tree-iage 6 Acres: 5.52
- Tree-iage 7 Acres: 2.39
- Tree-iage 8 Acres: 2.2
- Tree-iage 9 Acres: 6.01
- Total Tree-iage Acres: 51.06
- Tree-iage Acres in CIP CSO: 0
- Tree-iage Acres in non-CIP CSO: 4.54
- Priority Tree-iage Acres: 5.89
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 216.67
- Non-Tree-iage Acres within a CIP CSO: 0
- Non-Tree-iage Acres within a non-CIP CSO: 41.38
- Potential Planting/ Tree-iage Acres: 38.11
- Potential Planting/ Tree-iage Acres within CIP CSO: 2.48
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 12.06

Map 25 - Longfellow Creek Sub-Watershed Score

Sub-Watershed: W. Lk. Wash – Sea North / Score: 51.10

- CSO 2012: 15,125,470
- Sub-Watershed Acres: 8,004
- Tree-iage 1 Acres: .74
- Tree-iage 2 Acres: 3.5
- Tree-iage 3 Acres: 1.57
- Tree-iage 4 Acres: 6.94
- Tree-iage 5 Acres: 19.33
- Tree-iage 6 Acres: 16.39
- Tree-iage 7 Acres: 3.98
- Tree-iage 8 Acres: 8.97
- Tree-iage 9 Acres: 7.4
- Total Tree-iage Acres: 68.26
- Tree-iage Acres in CIP CSO: 14.69
- Tree-iage Acres in non-CIP CSO: 3.2
- Priority Tree-iage Acres: 16.01
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 190.88
- Non-Tree-iage Acres within a CIP CSO: 6.10
- Non-Tree-iage Acres within a non-CIP CSO: 3.85
- Potential Planting/ Tree-iage Acres: 192.04
- Potential Planting/ Tree-iage Acres within CIP CSO: 4.75
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 1.68



Map 26 - West Lake Washington - Seattle North Sub-Watershed Score

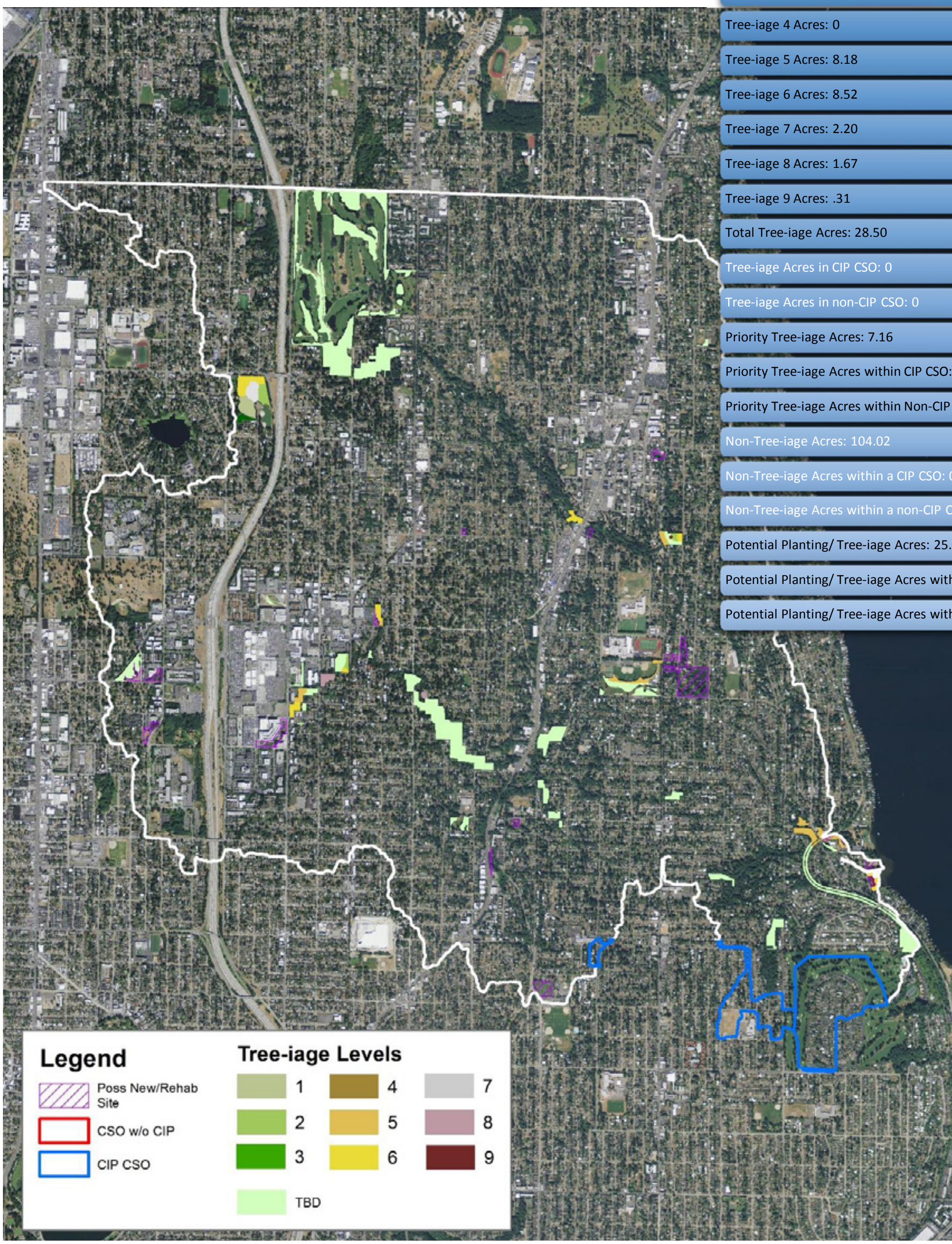
Sub-Watershed: Salmon Creek / Score: 47.70

- CSO 2012: 0
- Sub-Watershed Acres: 219.42
- Tree-iage 1 Acres: 0
- Tree-iage 2 Acres: 0
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 0
- Tree-iage 5 Acres: .13
- Tree-iage 6 Acres: 0
- Tree-iage 7 Acres: 0
- Tree-iage 8 Acres: 0
- Tree-iage 9 Acres: 0
- Total Tree-iage Acres: .13
- Tree-iage Acres in CIP CSO: 0
- Tree-iage Acres in non-CIP CSO: 0
- Priority Tree-iage Acres: 0
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 5.42
- Non-Tree-iage Acres within a CIP CSO: 0
- Non-Tree-iage Acres within a non-CIP CSO: 0
- Potential Planting/ Tree-iage Acres: 12.67
- Potential Planting/ Tree-iage Acres within CIP CSO: 0
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 0

Map 27 - Salmon Creek Sub-Watershed Score

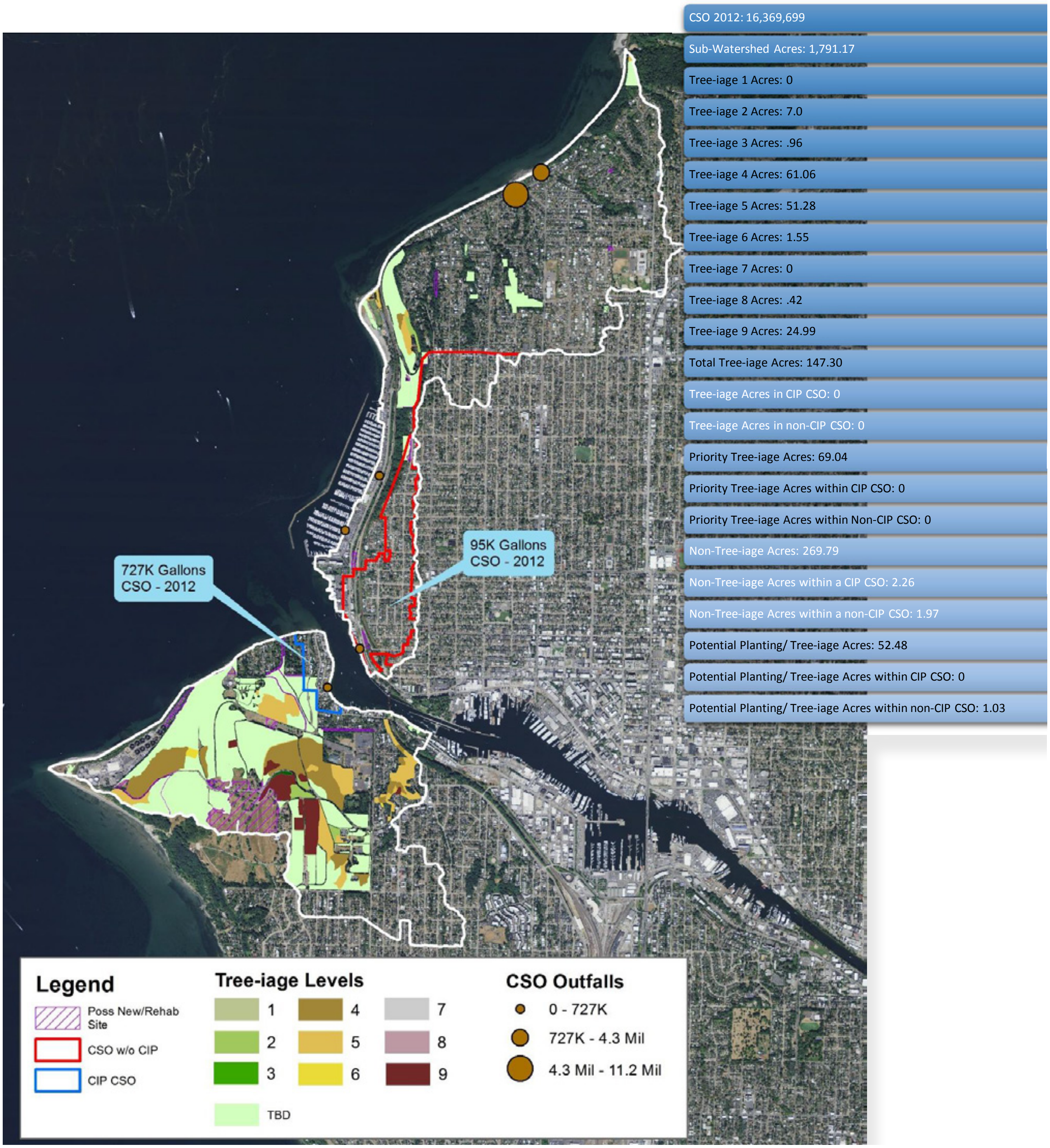
Sub-Watershed: Thornton Creek / Score: 44.79

CSO 2012: 0
Sub-Watershed Acres: 4867.54
Tree-iage 1 Acres: 2.88
Tree-iage 2 Acres: 2.86
Tree-iage 3 Acres: 2.1
Tree-iage 4 Acres: 0
Tree-iage 5 Acres: 8.18
Tree-iage 6 Acres: 8.52
Tree-iage 7 Acres: 2.20
Tree-iage 8 Acres: 1.67
Tree-iage 9 Acres: .31
Total Tree-iage Acres: 28.50
Tree-iage Acres in CIP CSO: 0
Tree-iage Acres in non-CIP CSO: 0
Priority Tree-iage Acres: 7.16
Priority Tree-iage Acres within CIP CSO: 0
Priority Tree-iage Acres within Non-CIP CSO: 0
Non-Tree-iage Acres: 104.02
Non-Tree-iage Acres within a CIP CSO: 0
Non-Tree-iage Acres within a non-CIP CSO: 0
Potential Planting/ Tree-iage Acres: 25.73
Potential Planting/ Tree-iage Acres within CIP CSO: 0
Potential Planting/ Tree-iage Acres within non-CIP CSO: 0



Map 28 - Thornton Creek Sub-Watershed Score

Sub-Watershed: Middle Puget Sound – Seattle Lower / Score: 44.25



Map 29 - Middle Puget Sound - Seattle Lower Sub-Watershed Score

Sub-Watershed: Piper's Creek / Score: 42.73

- CSO 2012: 0
- Sub-Watershed Acres: 1790.97
- Tree-iage 1 Acres: 17.44
- Tree-iage 2 Acres: 0
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 15.53
- Tree-iage 5 Acres: 33.35
- Tree-iage 6 Acres: 0
- Tree-iage 7 Acres: 0
- Tree-iage 8 Acres: .18
- Tree-iage 9 Acres: 0
- Total Tree-iage Acres: 65.92
- Tree-iage Acres in CIP CSO: 0
- Tree-iage Acres in non-CIP CSO: 0
- Priority Tree-iage Acres: 15.53
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 87.24
- Non-Tree-iage Acres within a CIP CSO: 0
- Non-Tree-iage Acres within a non-CIP CSO: 0
- Potential Planting/ Tree-iage Acres: 4.13
- Potential Planting/ Tree-iage Acres within CIP CSO: 0
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 0

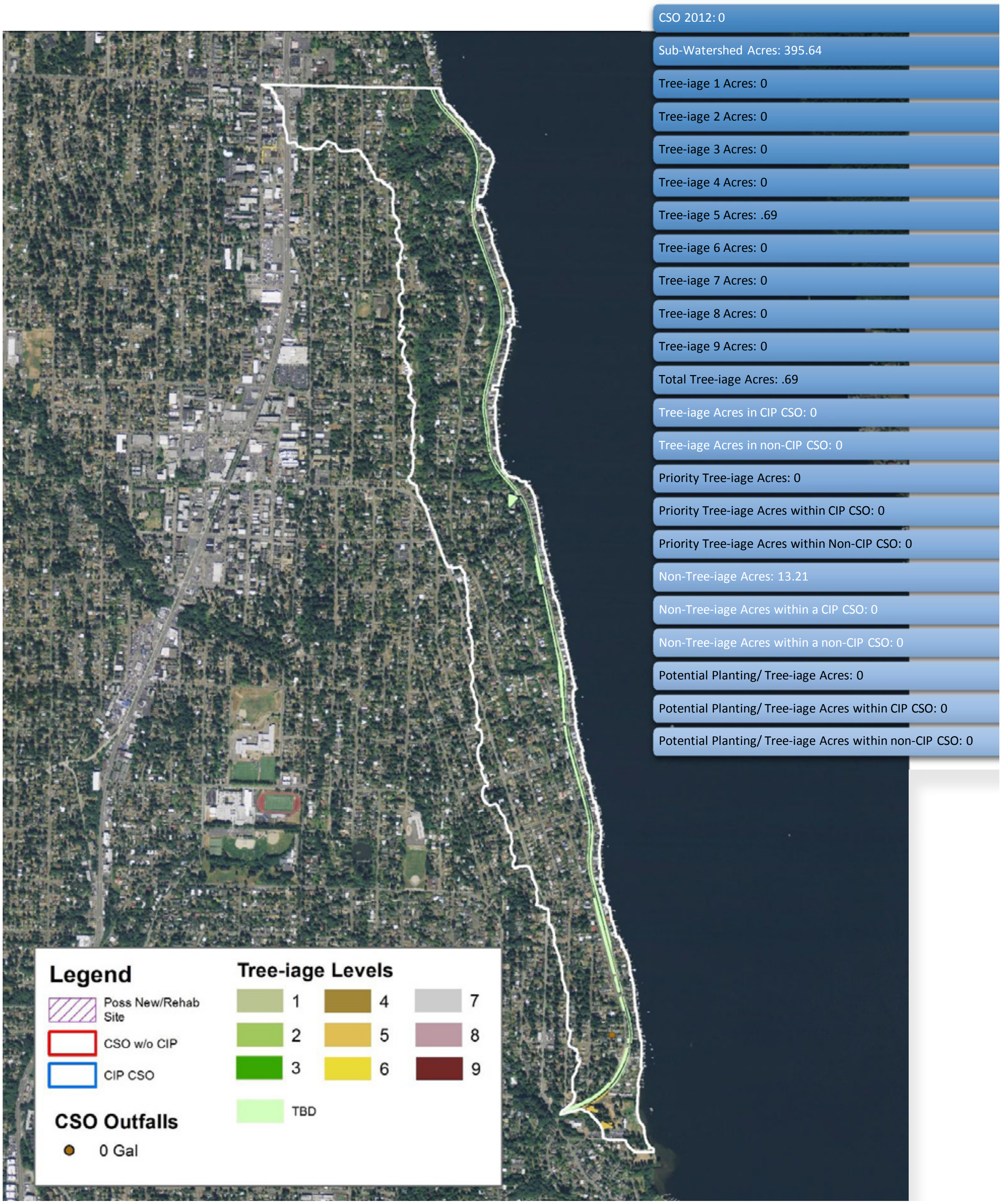
Map 30 - Piper's Creek Sub-Watershed Score

Sub-Watershed: Seola Creek / Score: 42.73

- CSO 2012: 0
- Sub-Watershed Acres: 370.63
- Tree-iage 1 Acres: 0
- Tree-iage 2 Acres: .41
- Tree-iage 3 Acres: 0
- Tree-iage 4 Acres: 4.66
- Tree-iage 5 Acres: 0
- Tree-iage 6 Acres: 0
- Tree-iage 7 Acres: 0
- Tree-iage 8 Acres: 0
- Tree-iage 9 Acres: 0
- Total Tree-iage Acres: 5.07
- Tree-iage Acres in CIP CSO: 0
- Tree-iage Acres in non-CIP CSO: 0
- Priority Tree-iage Acres: 5.07
- Priority Tree-iage Acres within CIP CSO: 0
- Priority Tree-iage Acres within Non-CIP CSO: 0
- Non-Tree-iage Acres: 9.34
- Non-Tree-iage Acres within a CIP CSO: 0
- Non-Tree-iage Acres within a non-CIP CSO: 0
- Potential Planting/ Tree-iage Acres: .34
- Potential Planting/ Tree-iage Acres within CIP CSO: 0
- Potential Planting/ Tree-iage Acres within non-CIP CSO: 0

Map 31 - Seola Creek Sub-Watershed Score

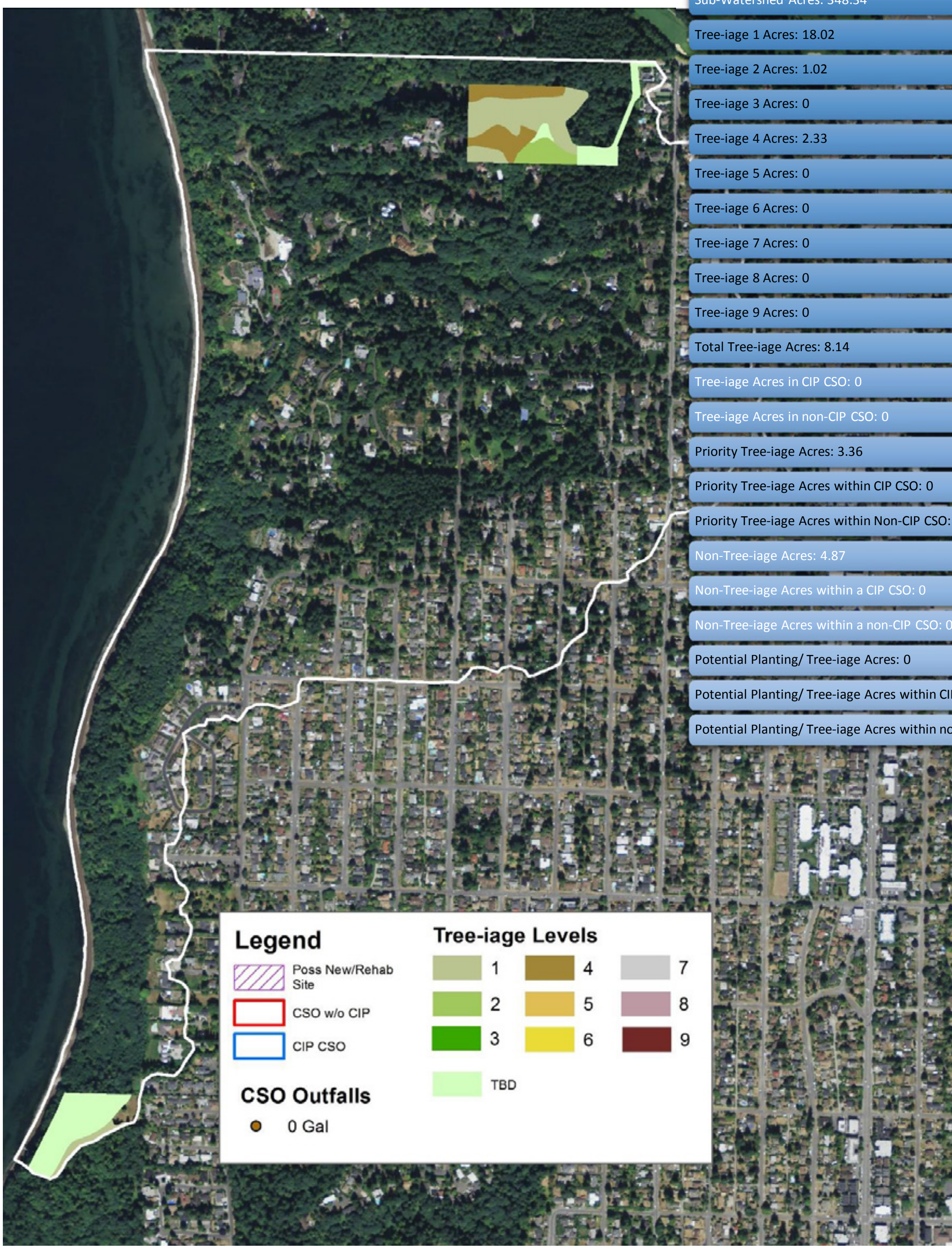
Sub-Watershed: W. Lk. Wash – Lake Forest Park / Score: 35.12



Map 32 - West Lake Washington - Lake Forest Park Sub-Watershed Score

Sub-Watershed: Middle Puget Sound – Seattle Upper / Score: 22.57

CSO 2012: 0
Sub-Watershed Acres: 348.34
Tree-iage 1 Acres: 18.02
Tree-iage 2 Acres: 1.02
Tree-iage 3 Acres: 0
Tree-iage 4 Acres: 2.33
Tree-iage 5 Acres: 0
Tree-iage 6 Acres: 0
Tree-iage 7 Acres: 0
Tree-iage 8 Acres: 0
Tree-iage 9 Acres: 0
Total Tree-iage Acres: 8.14
Tree-iage Acres in CIP CSO: 0
Tree-iage Acres in non-CIP CSO: 0
Priority Tree-iage Acres: 3.36
Priority Tree-iage Acres within CIP CSO: 0
Priority Tree-iage Acres within Non-CIP CSO: 0
Non-Tree-iage Acres: 4.87
Non-Tree-iage Acres within a CIP CSO: 0
Non-Tree-iage Acres within a non-CIP CSO: 0
Potential Planting/ Tree-iage Acres: 0
Potential Planting/ Tree-iage Acres within CIP CSO: 0
Potential Planting/ Tree-iage Acres within non-CIP CSO: 0



Map 33 - Middle Puget Sound Seattle Upper Sub-Watershed Score