



**PROFESSIONAL MASTER'S PROGRAM
IN GIS FOR SUSTAINABILITY
MANAGEMENT (PMP-GIS)**

**GEOG 569 | GIS WORKSHOP
SUMMER 2012**

“[I]t may take some real work to find out what the real business is and thereby what the real needs are. But even a relatively detailed business plan tells only part of the story. You need to uncover the organization's secrets, its objectives, how its workflows really operate, what makes it tick. You need to know all of this to plan for an effective GIS.”

R. Tomlinson (2011), Thinking About GIS

INTRODUCTION

It is with considerable pleasure that we present the Summer Quarter 2012 GIS Workshop reports from our inaugural class of the Professional Master's Program in GIS (PMP-GIS) for Sustainability Management at the University of Washington. The successes of the 2012 PMP-GIS Workshop were due entirely to the efforts of a very unique and memorable group that we grew to learn possessed a remarkable depth of professional experience and as well as genuine intellectual curiosity about how to use sustainability information science for sustainability management. The results of 2012 GIS Workshop are presented in their entirety at the end of this document.

A CAPSTONE EXPERIENCE

The GEOG 569 graduate workshop was designed as a capstone field experience in the improvement, redesign, or reengineering of workflows involving the use of GIS for sustainability management. Each group scoped out an organization's existing workflows and core processes; identified best practices; and finally, prepared a business case for an improvement, redesign, or reengineering of an existing workflow for sustainability management.

Workshop project groups adopted a systems thinking perspective on problem-solving and used various geospatial competencies mastered during the program. However, GIS workshop participants also recognized the value of their existing professional experience, particularly their personal effectiveness competencies like time management. It can be difficult to scope out a geospatial information product. It can be even more difficult to redesign a component of an organization's core business process. In fact, one of the major challenges our workshop project groups had to confront was that an organization's geospatial business process can be fragmented into activities carried out by operational managers from different functional units or departments, with no one being responsible for the performance of the entire process, e.g., a matrix or process manager. Yet organizations, with their resources and authority, are tremendous levers of change *if* the proper business case for sustainability management can be made. This is not an easy thing to do. It takes a special level of mastery, which we hope that the Professional Master's Program in GIS for Sustainability Management at the University of Washington can provide to current and future generations of sustainability management practitioners working in the field.

Seattle, WA

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Sustainable Coastal Communities: Washington State Outer Coast

for

West Coast Governance Alliance on Ocean Health
Sustainable Coastal Community Action Coordination Team
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Professional Master Program in GIS
Geography 569 GIS Workshop
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I. Background and Problem Statement

Background

On September 18, 2006, the Governors of California, Oregon and Washington formed the West Coast Governors' Alliance on Ocean Health (WCGA). The agreement was intended to “launch a coordinated West Coast ocean and coastal collaboration to address critical ocean and coastal protection and management issues facing all three states.” To that end, the Alliance promotes the following goals (West Coast Governors Alliance on Ocean Health 2011):

- Clean coastal waters and beaches
- Healthy ocean and coastal habitats
- Effective ecosystem-based management
- Reduced impacts of offshore development
- Increased ocean awareness and literacy among the region’s citizens
- Expanded ocean and coastal scientific information, research, and monitoring
- Sustainable economic development of coastal communities

In 2008, the three Governors released an Action Plan that includes 26 actions for the WCGA to improve and sustain the health of the coastal and ocean resources and the coastal communities within California, Oregon, and Washington States (West Coast Governors Alliance on Ocean Health 2010). The Action Plan requires experts to give advice and implement the Plan; therefore, the WCGA formed 11 Action Coordination Teams (ACTs) represented in Figure 1. The ACTs developed work plans on ten priority issues to help realize the tri-state “... vision of clean, healthy, and sustainable natural resources and communities along the entire West Coast.” (West Coast Governors Alliance on Ocean Health 2010).

One of the ACTs focuses is on Sustainable Coastal Communities (SCC). The SCC ACT consists of representative from the Department of Ecology (ECY), Sea Grant, NOAA, non-profits, other federal, state, and local agencies. As part of the sustainable fisheries and aquaculture sections of their work plan, this ACT outlines the need to assess fisheries related infrastructure and facilities in coastal communities and determine whether ports are viable to support aquaculture and seafood industries in general. To assist in the effort to satisfy geo-spatial goals of the WSGA SSC ACT, the SCC ACT partnered with University of Washington graduate students¹ from the Department of Geography under the guidance of Dr. Robert Aguirre.

¹ The University of Washington Graduate Program consists of working professionals from the Professional Masters Program in Geographic Information Systems (PMPGIS).

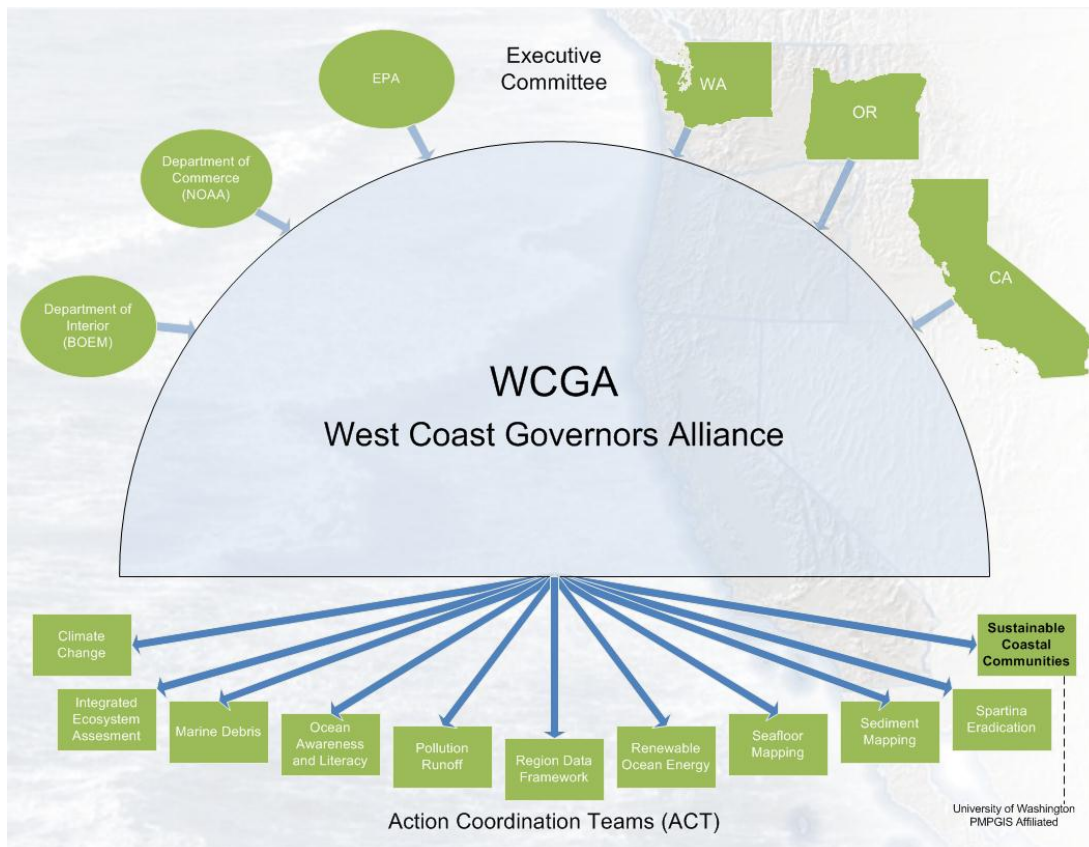


Figure 1: Organizational structure of the West Coast Governance Alliance and the Action Coordination Teams including the partnership with the University of Washington.

Project Goal

The overall goal of the West Coast Governors Alliance (WCGA) is to “protect and manage the health of West Coast Ocean and coastal resources, support ocean-dependent economies, and honor societal values of these resources through coordinated policies and actions as well as cost-effective leveraging of resources to effectively address these issues.” (West Coast Governors Alliance on Ocean Health 2011). One important action of the Sustainable Coastal Communities Action Coordination Team (SCC ACT), consisting of representatives from the Department of Ecology (ECY), Sea Grant, NOAA, non-profits, other federal, state, and local agencies, is to compile an inventory assessment of both coastal fisheries and aquaculture related infrastructure for the coastal communities on the outer coast of Washington State. Pacific County WA will be used as the pilot county to assess the critical infrastructure.

Objectives

The SCC ACT created a **three-phase**² approach in an effort to better understand coastal fisheries and aquaculture related critical infrastructure along Washington State’s outer coast. The objective

² The three phase approach was developed by the SCC ACT and the University of Washington graduate student project team in June of 2012. The three phases were created to facilitate the limited time the graduate students had to work on the project (between June 18th to August 17th) and to provide a workflow model to future project work teams.

of this report is **phase-one** of the three-phase approach which identifies data sources and potential data collection of four major broad scale attributes pertaining to the inventory assessment of critical infrastructure that supports marine resource based economies of coastal communities. The phase-one objectives³ are:

1. Amount of commercial vessel fish landings at coastal ports and harbors.
2. Number of fish receiving facilities at ports and harbors.
3. Department of Natural Resources (DNR) licensed aquaculture facilities at or near ports and harbors.
4. Number of recreational or charter fishing boat permits that could be associated to ports and harbors.

The identification of data sources and potential data collection will focus on the four coastal counties of Pacific, Grays Harbor, Jefferson, and Clallam County, WA. Collection of phase-one information will assist in creating an inventory that identifies critical infrastructure in communities and ports located on the coast and potential socio-ecological conditions that affect the presence of critical infrastructure of the associated coastal communities.

Phase-One

The phase-one goal is to assess the current situation and conditions of critical infrastructure through the acquisition of data sources and initiation of data collection for the outer coastal Counties. Starting in the most southern coastal county (Pacific), the collection of data sources and associated critical infrastructure data will proceed north to Grays Harbor, Jefferson, and finishing with Clallam County, WA. Due to project timeframe constraints, phase-one will use Pacific County as a pilot project for assessing data source identification and data acquisition of critical infrastructure, and can inform the continuation of this project into the other three counties.

Phase-Two

In an effort to expand on and identify the socio-ecological impacts on coastal communities, phase-two of this project will focus on and develop a set of status indicators for critical infrastructure (waiting list for slips, renovation or removal of ports or harbors, processing facilities, access to cold storage, etc.). The indicators then can be utilized by local coastal communities to measure their socio-ecological condition and assist the community in designing a sustainable development plan.

Phase-Three

Phase-three of SCC ACT three-phase approach will primarily focus on expanding the SCC ACT three-phase model to the entire Puget Sound coastal counties of Washington State and the data integration into the Washington State Coastal Atlas for data access and distribution. If phase-three project scope permits, a business case should be developed to improve or redesign how the SCC ACT as an organization uses geospatial information technology to support their work and meet their strategic goals. This effort should be coordinated largely with the Regional Data Framework

³ Objectives were created during the working session between the SCC ACT and the UW project team.

ACT (RDF ACT)⁴ and address concerns such as warehousing the data (how, who, cloud, what organization), data access (Coastal Atlas, Geo-portals, access privileges), data use (public, private, free), and database maintenance (updates and moderated). Unfortunately, due to project scope, timeframe, and resources, phase-two and phase-three will not be discussed in detail in this report.

Existing Process Workflow

The major themes that connect the SCC ACT work plan are economic development, sustainable fisheries, sustainable aquaculture, non-consumptive recreation and tourism, green ports, and clean marinas. The SCC ACT process workflow strategies to implement the themes are to stimulate expertise, capacity, and infrastructure support for coastal communities. However, participating entities assisting the SCC ACT work plan implementation seek funding from diverse sources and leverage strategic collaboration to support the themes listed in the plan (West Coast Governors Alliance on Ocean Health. 2011).

Since 2006, when the WCGA was signed and ACTs were formed, the west coast states have suffered notable economic declines. According to the SCC ACT final work plan from December of 2011, the PEW⁵ center rated California and Oregon as two of ten states in fiscal distress. Washington specifically will have a 21.6%⁶ budget shortfall.

Due to the economic decline of the western states, implementation of the WCGA action plans for the associated ACTs has been difficult. In turn, the existing process workflow of the SCC has been slow to enact and as a result, the SCC ACT created a high-level overview of the existing process.

⁴ RDF ACT improve access to regional scientific and geospatial data needed for coastal and marine resource management and coordinates a West Coast regional network of data producers, data users, tool developers, and GIS experts (West Coast Governors Alliance on Ocean Health 2012).

⁵ PEW Center on the States. November 2009. *Beyond California: States in Fiscal Peril*.
http://www.pewcenteronthestates.org/report_detail.aspx?id=56044.

⁶ Center on Budget and Policy Priorities, "States Continue to Feel Recession's Impact":
<http://www.cbpp.org/cms/?fa=view&id=711>

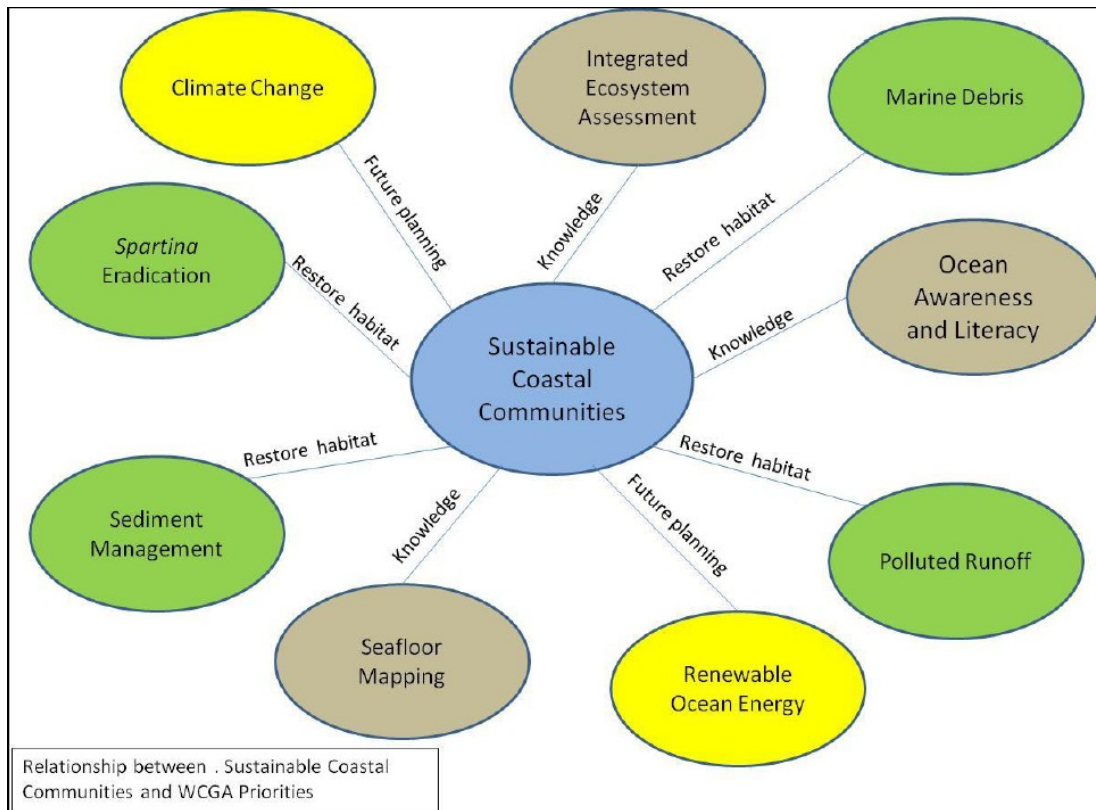


Figure 2: High level perspective of the WCGA and SCC ACT relationship.

Existing Activity Workflow

The collaborative nature of the WCGA and its interrelationship between the ACTs makes the workflow complex, as displayed in Figure 2. The SCC ACT considers the needs of the coastal communities within the larger region (California, Oregon, and Washington) when coordinating among the states for future efforts that benefit a more sustainable coastal communities. In the spirit of collaboration and focusing on the SCC ACT three-phase approach specific to the Washington State coastal counties, the SCC ACT and the University of Washington project working team created an activity workflow specific to the current three-phase approach. Figure 3 represents the feedback loop between federal agencies, Governors' offices, and the greater WCGA as a whole, how the SCC ACT receives guidance from the WCGA, and how the SCC ACT refines the project scope with NOAA, multiple agencies from the state of Washington, and the RDF ACT.

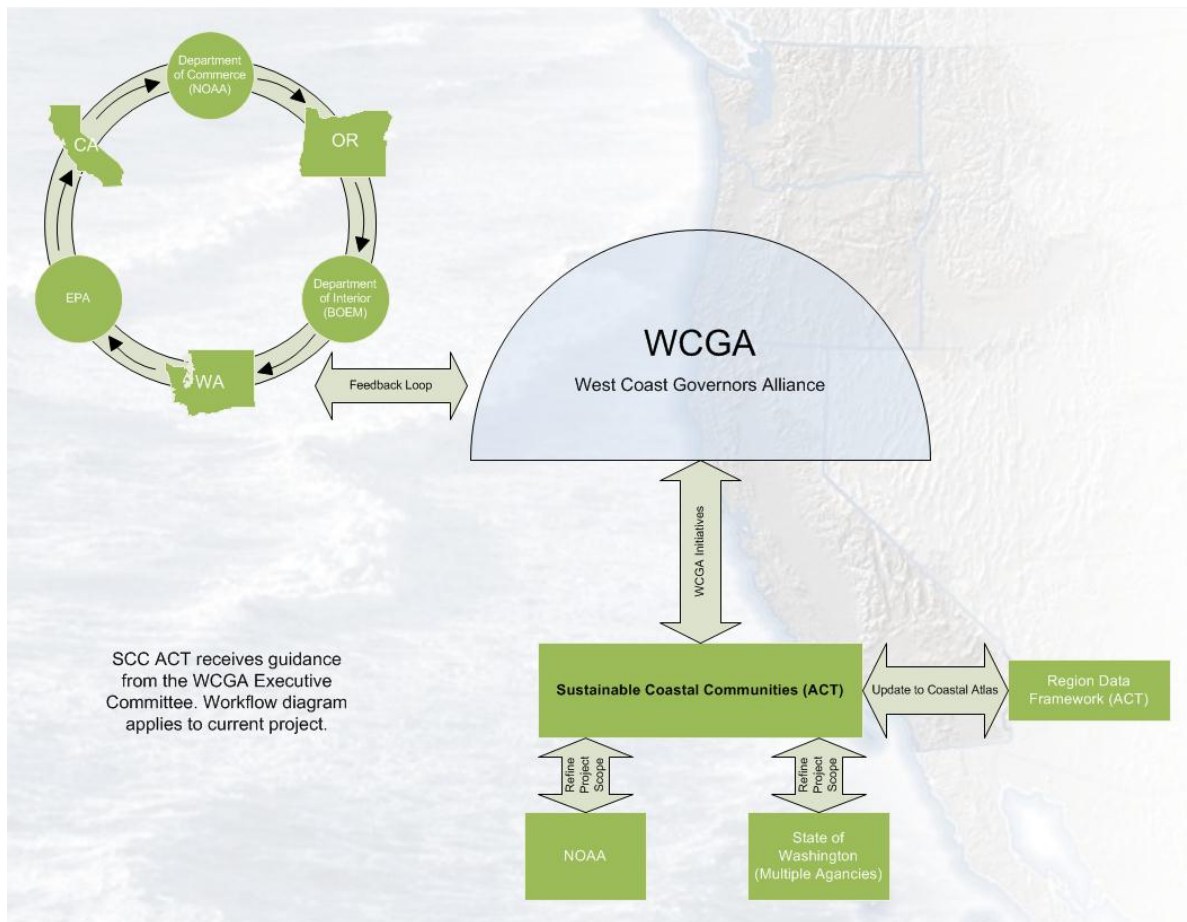


Figure 3: Existing Activity Workflow as it relates to the SCC ACT/UW project team three-phase implementation approach.

Proposed Activity Workflow

While the WCGA process and activity workflows will likely change in time as the Alliance matures, a proposed activity workflow can be currently defined to implement phase-one of the SCC ACT three-phase approach. The workflow consists of the University of Washington project team (PMPGIS Working Team), the SCC ACT, and the WCGA (executive committee) as represented in Figure 4.

The initial project scope was defined by the SCC ACT and the PMPGIS project team in late June of 2012. Once the scope of the project was defined, the SCC ACT identified data resources and contact information. The contact information was provided to the PMPGIS working team and data collection was initiated in July 2012. The appropriate agencies were contacted to obtain data regarding the four objectives in coordination with the Regional Data Framework ACT. The RDF ACT was contacted to obtain metadata standards and to understand the region wide implementation and distribution of collected data to geo-portals that would disseminate data to end users. In late July and early August of 2012, data processing occurred to deliver the required information product. Refer to section IV for a detailed explanation.

In August of 2012, data findings were reported to the SCC ACT for review. After the review of the data findings, the SCC ACT assisted the PMPGIS project team to refine and enhance the SCC ACT PMPGIS proposal that will be submitted to the WCGA executive committee for review.

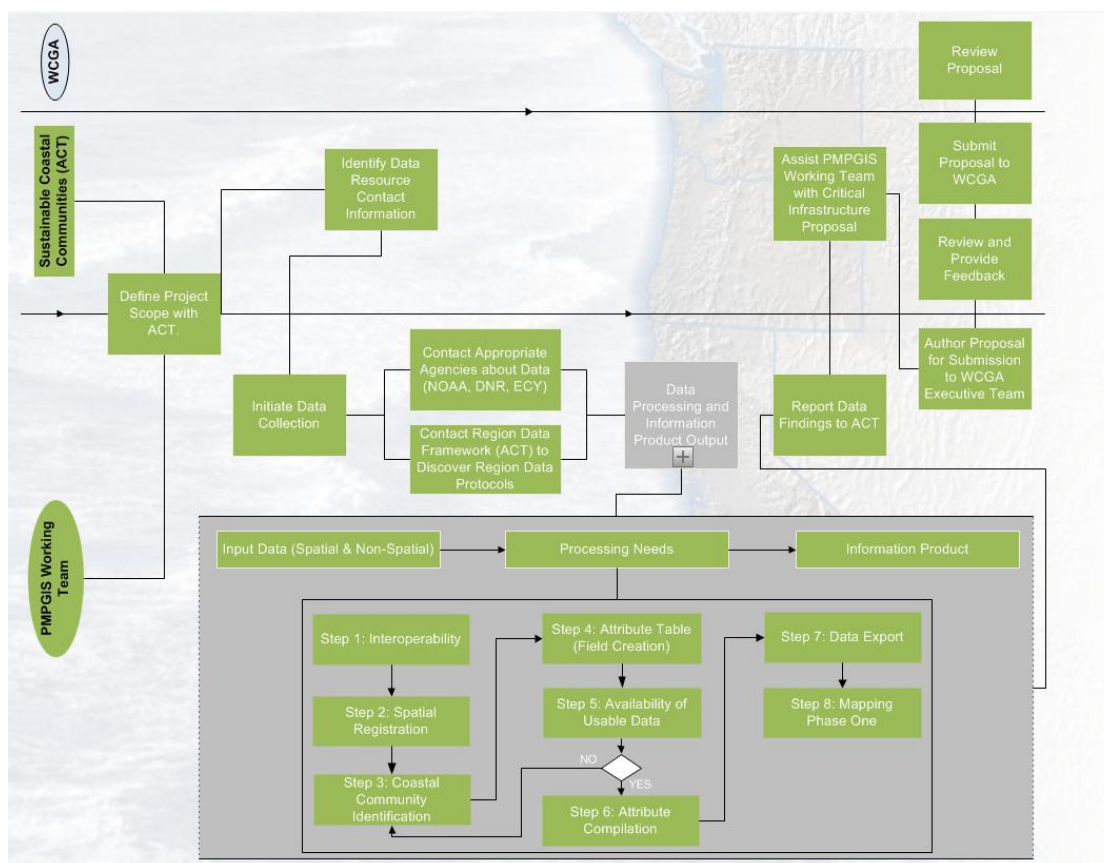


Figure 4: Proposed Activity Workflow

Information Categories Anticipated

Phase-one of the SCC ACT project will compile an inventory assessment of critical infrastructure based on the four indicators outlined by the SCC ACT and UW project team that are associated to ports and harbors along the outer coast of Washington State. Coastline data, road networks, and potential bathymetric data are needed to adequately determine ports and harbors that support critical infrastructure related to coastal communities. Ortho photos would assist in the virtual ground truth of acquired data. Non spatial harbor and port facility data that support commercial vessel landings, fish processing facilities, and aquaculture production are needed to measure the flux of seasonal capacities. Additionally, the impact of commercial and recreation or charter fishing will need to be addressed to understand other socio ecological concerns.

Information Structures/Products

The phase-one goal is to compile an inventory assessment of both coastal fisheries and aquaculture related infrastructure for coastal communities, specifically the coastal communities of Pacific County, WA. Summarizing the scoped project framework of phase-one, deliverables will include data to answer the four objectives of:

1. How many commercial vessel fish landings?
2. How many fish receiving facilities?
3. How many licensed aquaculture facilities near a port?
4. How many recreational & charter fishing boat licenses?

Along with this report, the information will be presented with a summary table answering the four objectives, supported by map figures that represent the coastal communities with critical infrastructure that impact socio-economic development in Pacific County, WA. The report will provide the specific steps and methodologies to compile an inventory assessment of both coastal fisheries and aquaculture related infrastructure and a workflow model for future project work teams to complete the remaining SCC ACT project phases.

II. System Requirements

Hardware Requirements

To successfully achieve phase-one objectives of the SCC ACT three-phase approach, basic hardware requirements consist of standard laptop or desktop configurations that are commonly accessible in today's market. There are no intensive data handling methods to complete phase-one objectives and the amount of computational power needed for phase-one is minimal. Any brand of personal computer (PC) or Mac equivalent, with a current operating system that runs Microsoft Office products (or equivalent) and a PC/Mac driven geographic information systems (GIS), is sufficient. Please refer to Appendix C for a detailed description of the basic hardware requirements for phase-one.

Phase-two and three of the SCC ACT approach will continue to utilize the basic available PC/Mac computers. Further collection of data and or ground truthing activities that occur in phase-two would benefit from the use of global positioning system (GPS) devices. The GPS will assist in verifying the data collected in phase-one and new data collected in phase-two. In phase-three, when data integration is anticipated into region wide geo-portal or the Washington State Coastal Atlas, the RDF ACT will establish the appropriate hardware requirements and protocols. The RDF ACT will account for the appropriate servers needed to house the data that supports the SCC ACT and associated WCGA action coordination teams.

Software and Networking Requirements

The utilization of basic word processing software such as Microsoft Office will be sufficient to address the SCC ACT objectives. The use of Microsoft Office products such as Word, Excel, and Access more than adequately address any word processing, spreadsheet, or databases activities that might arise during phase-one and subsequent phases. ESRI⁷ ArcGIS Desktop 10 Suite of Tools will be used to address geo-spatial needs during all phases of the SCC ACT three phase approach (See Appendix C for software requirements). Additionally, geo-portals such as the Washington

⁷ ESRI was founded by Jack and Laura Dangermond as Environmental Systems Research Institute in 1969 as a small land-use planning company. ESRI provides geographic information system (GIS) software and geo-database management application and holds the highest market share in the worldwide geo-spatial market.

State Coastal Atlas will be required. Geo-portals will be used to access and disseminate data. Access to the internet is critical to obtain data during the data collection process of all phases and to adequately communicate with team members (email, VoIP, IM). During the data integration activity of phase-three, the RDF ACT will establish the appropriate networking protocols. Currently, no established client-server architecture exists that supports the WCGA and action coordination teams because the overall WCGA program implementation has been slow to enact. Regular communication between the SCC and RDF ACTs will be required to update appropriate protocol as the project scope is implemented.

Personnel and Time Requirements

In order to accurately determine personnel and time requirements, a close look at the activities shown in the Proposed Activity Workflow in Figure 4 is highly recommended. To prepare for the first audio conference meeting with the SCC ACT to define the project scope, which is the first activity in the proposed activity workflow, the UW PMPGIS project team met twice for a total of approximately five hours to discuss the project in general. The first meeting between the SCC ACT and the UW PMPGIS project team took approximately 90 minutes. Next, the UW PMPGIS working team met on their own to discuss ACTs current needs, consider the time and personnel constraints and then determine project scope. The UW PMPGIS project team then wrote the project proposal outline and sent it to the SCC ACT for approval along with six other documents/diagrams that describe the fundamental information about the WCGA such as the organization's structure, goals, measures and strategic business plan, current and proposed activity work plans, and a redesigned project plan. Since 28 June 2012, one-hour weekly meetings have been scheduled between the SCC ACT and the UW PMPGIS project team for status updates, and questions and answers sessions. Each week, the UW PMPGIS project team met twice a week on their own to discuss the requirements of the upcoming project phase, produced required documents/diagrams and write report sections. Each of these meetings took approximately six hours. Additionally, both the SCC ACT and the UW PMPGIS project team also spent a good amount of time on email communications, as well as reviewing, commenting and updating documents.

Next, the SCC ACT helps guide and introduce the UW PMPGIS project team to the right contacts for data collection. Data collection and information finding for phase-one took several weeks to complete. Phase-two will require a lot of ground truthing work in the field to collect status indicators for critical infrastructure such as waiting list for slips, renovation or removal of ports or harbors, processing facilities, access to cold storage, etc. This phase is estimated to take approximately one year. Phase-three is estimated to take at least two more years to expand the SCC ACT three phase model to the entire Puget Sound coastal Counties of Washington State and integrate data into the Washington State Coastal Atlas for data access and distribution. This phase calls for major coordination with the RDF ACT. Certainly continuous and effective communications among the stakeholders will remain a consistent requirement throughout all the phases.

Other Considerations

There are not many other considerations for phase-one, but because in phases two and three there will be data integration with the RDF ACT and the WA Coastal Atlas, the majority of other considerations will be addressed at that time. In order to accomplish the data integration objectives, a close study of the current technical requirements to obtain specific protocols will be crucial. However, the RDF ACT is still in its early stages of technical requirements so it is hard to get specific protocols. Nevertheless, it may be helpful to keep in mind that currently the RDF ACT

plans on building a West Coast Data Registry and West Coast Data Catalog. The idea behind the West Coast Data Registry is to allow for searching and finding machine readable metadata records throughout the West Coast. Records can be manually entered, and machines are able to go and find metadata. To help facilitate this goal, one of the requirements is Catalogue Services for the Web (CSW⁸) standard for metadata has to be used when it comes to publishing collections of data.

III. Data Acquisition

Data Design

The overall scope of the WCGA and associated ACTs is to restore the health of coastal waters, resources, and the economies that depend on them on the West Coast of the continental United States. Specifically, the SCC ACT goal is to compile an inventory assessment of both coastal fisheries and aquaculture related infrastructure for the pilot project of Pacific County, WA based on the phase-one objectives outlined in this article. The data design considers how the information collected will support the information product output for phase-one objectives. The output is the first part to better understand the potential critical infrastructure locations and potential socio-ecological conditions that impact the presence of critical infrastructure of the associated coastal communities. Modeling the design characteristics of the data will determine the system architecture (Tomlinson, 4th edition 2011). The data design for phase-one objectives considers the data characteristics, data design capabilities, and data logistics.

Data Characteristics

The data characteristics that are important to phase-one objectives of the SCC ACT three phase project scope are scale, resolution, and map projection. The information product for phase-one is a summary table based on port and harbor coastal communities that depend on accurate vector data of municipal boundaries that represent a coastal community. The municipality will need to be represented from a large scale⁹ or a city wide perspective (ex: 1:24,000) and the county wide small scale perspective (ex: 1:100,000). At a large scale level, the coastal community data layer will be represented by the municipality polygon vector boundary while a vector point data layer (Lat/Long) of the polygons centroid will represent the coastal community at a small scale.

Resolution of the vector data will be important when determining a port or harbor coastal community. If the coastline vector geometry available represents the real world phenomena from a small scale perspective, there is a chance of excluding some coastal communities that are more inland or reside on a mouth of a river. Small scale vector geometry sometimes excludes subtle nuances in the geometry and represents the real world in a more generalized manner. Detailed

⁸ CSW is an Open Geo-Spatial Consortium (OGC) abstract specification for supporting the ability to publish and search collections of descriptive information (metadata) for data, services, and related information objects. CSWs allow a unified access to metadata records within a community or an organization, thus harmonizing GIS resources discovery and search. For this reason, CSWs are required for coastal atlases in order to facilitate syntactic and schematic interoperability (Nebert and Whiteside 2005).

⁹ Scale is the relationship between the distance on the a map and the corresponding distance in the real world. The larger the scale, the more detail the dataset reveals where the largest scale is 1:1.

large scale geometry is preferred when determining coastal communities by providing better clarity between physical relationships. In phase-two of the SCC ACT three-phase scope, the resolution of bathymetry might be a factor when determining indicators of ports and harbors. Detailed or high resolution bathymetry would be useful to identify ports and harbors that can support large commercial fishing vessels. A community can utilize this information for a dredging project if there is a need to expand their respective industry in an effort to adhere to their development plan.

A map projection commonly used in the United States is the North American Datum (NAD) of 1983. However, the overall scope of the WCGA is the entire west coast spanning a North/South direction from Washington to California. For this reason, the map projection that will be used (and discussed in more detail in section IV of this article) is UTM Zone 10 North. The projection is a meter based projection (1 meter = 3.28 feet) and is applicable for the scale and resolution that supports phase-one objective and information products.

Data Design Capabilities

There are a variety of data types available which are collected by numerous technologies. The technologies that derive the data deliver its output in a variety of different format by numerous methods. The data design for phase-one objectives attempts to account for the data acquisition by a variety of technologies from disparate sources. The phase-one data design attempts to account for data collected from survey instruments such as GPS devices or coordinate geometry (COGO). There is an expectation to collect temporal data in phase two that will assist in identifying indicators for coastal communities.

The primary information product is a summary table derived from the objectives based on coastal community municipal vector geometry boundaries. Map figures representing the sustainable coastal community phenomena for phase-one SCC ACT goals will support the summary table. The data design incorporates the latest cartographic and spatial analysis capabilities (for advanced geographic analysis) from ESRI ArcGIS suite of tools. The data design will also anticipate the possibility of public feedback from the community in phase-three during the integration to the Washington State Coastal Atlas. The Coastal Atlas (or whatever geo-portal will be used) could provide an opportunity for the public to interact, provide suggestions on improvement (data or technology), and conduct key research on supporting a community's sustainable development plan.

Data Logistics

The data logistics of data design for phase-one consist of digital source data, technology standards, and data conversation and interoperability. The vector, raster, and non-spatial data tables will be collected primarily from digital source data but there could be a need to utilize survey technologies in the later phases on the project. Identifying the source data that supports the overall data design is crucial for consistency and data integrity. Data identification will be supported by guidance from the SCC and RDF ACTs.

Technology standards will be fully adopted from the RDF ACT during phase-two and three of the project. The adoption of the RDF protocol will facilitate the effective sharing of application data between phase-one data collection and eventual integration into the Coastal Atlas or appropriate

WCGA regional geo-portal. During phase-one, all data will be collected and converted to a Shapefile format and related data tables will be linked to appropriate geometries. This allows for easy input into the geo-database. Additionally, the geo-database format will allow for interoperability into the Washington State Coastal Atlas or whichever geo-portal the RDF ACT chooses.

Logical Database Model

In phase-one of the SCC ACT, the ESRI supported geo-database object-relational database model will be utilized. The geo-database is quick to execute and links well with all types of databases (Oracle, SQL, AS/400) from legacy datasets to non-geospatial databases. The object-relational geo-database offers the interoperability needed when considering phase-three data integration with the Washington State Coastal Atlas or other region wide geo-portals as defined by the RDF ACT and has the capability to automate the output of the information product as new data becomes available. Additionally, since the RDF ACT strategic plan is a work in progress, the geo-database model provides the most flexibility for data integration until the RDF ACT defines a region wide logical database model protocol.

Data Sources, Fitness for Use & Metadata

Data Sources

Referencing phase-one objectives as outlined by the SCC ACT, there are two types of data that need to be collected: spatial and non-spatial data. The details of the data types are discussed under "Data Analysis, Information Products, and Findings". Table 1 in Appendix A outlines the variety of sources that are appropriate for phase-one data collection. The compiled data sources are provided by the SCC ACT project team members and therefore are assumed to be of good quality.

Fitness for use

During data collection, it is important to determine if the data is suitable to use and to implement the appropriate data integrity to assist in generating the information product. Based on the data sources and the eight basic processing steps as outlined under 'Data Analysis' of the "Data Analysis, Information Products, and Findings" section in this paper, the data meets the fitness of use metric terms of identification detail, volume, characteristics, and availability.

Metadata

The metadata standard for the WCGA will be outlined by the RDF ACT and will be adopted into SCC ACT three phase scope once the protocol is released. In short, metadata is a summary document providing content, quality, type, creation, and spatial information about a data set. It can be stored in any format such as a text file, Extensible Markup Language (XML), or database record (ESRI 2002). Hence, it is important to create metadata for all the data sets used for the project. During phase-one, new datasets are generated but not published, well-documented FDGC metadata standard¹⁰ is acceptable. Table 2 in Appendix B represents a geo-database diagram and metadata

¹⁰ The Federal Geographic Data Committee's (FGDC) Content Standard for Digital Spatial Metadata (CSDGM) is a well-known metadata standard that has been used in North America and around the world for many years (ESRI 2012).

for the SCC ACT phase-one objectives. In light of any new metadata standards outline by the RDF ACT, the metadata template is subject to change.

Future Database Development

Considering all the issues faced when transitioning from the SCC ACT's needs to the spatial-temporal database discussed above, it is anticipated that there will be numerous feedback loops. In particular, there will be a need to refer back to the reality or the project objectives for phase-one to re-evaluate findings. Next, it will be necessary to report the findings to the SCC ACT who in turn will help develop a critical infrastructure proposal to be reviewed, submitted to and approved by the WCGA. During the feedback loops, additional information may come to light about the adequacy of the data sources. Future information will help in adjusting the amount of work that will need to be completed in understanding the specific geographical and historical setting scale and domain of interest pertaining to the SCC ACT and WCGA.

The ultimate goal is to integrate data based on RDF ACT protocols into the Washington State Coastal Atlas and expand the model to the rest of the Puget Sound coastal counties. To prepare for the data integration, there will be a need to review and analyze the RDF ACT existing database protocols to understand not only how the current database systems flow but also their required input and expected output methods. The preparation work is a part of SCC ACT phase-one objectives which began on 17 July 2012.

IV. Data Analysis, Information Products, and Findings

Input Data

The input data will be a combination of spatial and non-spatial data originating from a variety of different data types. Data types could include ASCII (*.txt, *.csv, *.xyz), Adobe PDF's, MS Office formats (work, excel, access), GPS X/Y/Z, interchange files (e00), and other GIS based raster and vector data models (DWG/DXF, KMZ/KML, NetCDF, BAG, S-57, BSB).

The spatial data input represents vector geometries and raster datasets of the Washington Coast (shoreline), coastal transportation routes, coastal and harbor bathymetry, Coastal Communities (towns and city boundaries), County boundaries, satellite imagery and ortho photos (for virtual ground truthing and base map representation). Non-spatial data input represents logs and data tables of activities that support phase-one scope parameters of the SCC ACT. The scoped activities for phase-one include counts of commercial fishing vessel landings, fish receiving stations, DNR licensed aquaculture facilities, and charter and recreation fishing licenses associated to a port.

Data Analysis

The transformation from input data into an information product consists of eight basic processing steps. The steps include data interoperability, spatial registration, coastal community identification, creation of attribute table(s), determining if a coastal community has available and useable data, data attribute compilations (could contain numerous sub steps), exporting table attributes to an MS office format, and map figure representations of the SCC ACT phenomena for phase-one.

1. Interoperability

The interoperability process consists of converting input vector, raster, and non-spatial data into a compatible format that is useable with ESRI ArcGIS 10 Suite of geospatial tools. The overall project scope calls for the use of a spatial database. In phase-one of the SCC ACT implementation effort, an ESRI geo-database format will be utilized. The geo-database will contain the vector, raster, and non-spatial data (tables) that allows for data transfer to a geo-portal (ex: Washington State Coastal Atlas). Database protocols and data interoperability between the phase-one geo-database and the geo-portal will be vetted in phase-two and three of the SCC ACT implementation effort.

For phase-one, an interim data format for disparate input vector datasets will be utilized. The format is called an ESRI "Shapefile" which stores non-topological geometry and attribute information for the spatial features in the data set. The Shapefile geometry for a feature is stored as a shape comprising a set of vector coordinates that supports point, line, and polygon area features. Shapefile attributes are held in a dBASE format file (ESRI 1998). Each attribute record has a one-to-one relationship with the associated shape record. The Shapefile format is being used because it's easy to use and a manipulative format that is compatible with the ESRI geo-database format, the uncertainty of data type that will be collected during the data collection process, and the unknown design of how the data will be grouped as feature datasets in the geo-database. Once the data is collected, a geo-database can be created specifically for the SCC ACT phase-one goals.

2. Spatial Registration

The most common spatial registration or projected coordinate systems used in the United States by local, regional, state, and federal agencies is the North American Datum (NAD) State Plane coordinate system of 1983. The SCC ACT overall project scope includes the coastal communities of California, Oregon, and Washington States. California uses six State Plane zones and Oregon and Washington uses two zones each (10 zones). Additionally, the State Plane zones span a geographic area of from West to East across each state, respectively.

The SCC ACT overall project scope focuses only on coastal communities, so a North/South projected coordinated system is warranted. For this reason, NAD 1983 UTM (Universal Transverse Mercator) Zone 10 North will be utilized. NAD 1983 UTM Zone 10N covers approximately 85% of the continental West coast (including parts of the Province of British Columbia, Canada) leaving a stretch of coastline approximately 230 miles long from Santa Barbara, CA to San Diego, CA in NAD 1983 UTM Zone 11N. The small stretch of coastline in Southern California can easily be projected in Zone 10 without too much distortion. If the distortion is too great, Zone 10 and 11 will be used for the overall scope as opposed to ten different State Plane systems spanning West to East.

3. Coastal Community Identification

To identify port and harbor communities that reside on the coast, a relation between the proximity to the coastline and the municipality or port district boundary needs to be ascertained. Utilizing ESRI ArcGIS suite of geospatial tools, coastal communities will be identified where the vector boundaries of the municipalities or port districts intersect with the vector coastline geometry within a search tolerance. The search tolerance will be based on the how detailed the input coastline vector geometry is (accounting for inlets, rivers, bays, etc. or not) and potential feedback from the SCC ACT. Satellite and Ortho Photo imagery can then be utilized to virtually ground-truth spatial intersection of the two vector geometries. The result will be a port or harbor coastal community that could potentially support phase-one metrics.

4. Attribute Table (Field Creation)

As coastal communities become identified, the attribute table for the vector polygon representing the community needs to be designed to support non-spatial data for phase-one metrics. The table will have nine primary fields, not including fields that are specific to the Shapefile data model architecture. The fields are:

LongX	: Longitude of Communities Centroid in Decimal Degree Format .
LatY	: Latitude of Communities Centroid in Decimal Degree Format .
CCName	: Name of Coastal Community
CCCounty	: Name of the County the Coastal Community resided in.
CCState	: Name of the State the Coastal Community resides in.
NCVL	: Number of Commercial Vessel Landings at a port or harbor. (AvgLBsFISH) ¹¹
NFPF	: Number of Fish Processing Facilities/stations at a port of harbor. (AvgNBUYERS) ¹²
NAF	: Number of DNR Licensed Aquaculture Facilities at or near a port or harbor.
NCRFL	: Number of Charter or Recreational Fishing Licenses associated to a port or harbor.

The table field associated to the municipality boundary might include basic demographic data depending on the data source. The demographic data will be included along with the nine primary fields mentioned above. The nine fields will be added using the geospatial toolsets offered in the ESRI ArcGIS1 10.

5. Availability of Usable Data

Once input data is obtained, interpreted, and converted to the interim data format (Shapefile), a review of the non-spatial data will be conducted to determine if the data aligns with the spatial vector data of identified port and harbor coastal communities. If the non-spatial data aligns with the spatial vector data, the attributes will be compiled (refer to step six). If the data does not align, the non-spatial data and the available spatial data will be re-examined as outlined in step three.

6. Attribute Compilation

After the spatial and non-spatial data has been aligned to a coastal community, the datasets will be compiled using ESRI ArcGIS suite of geospatial tools. Depending on the types of input data obtained, there could be numerous sub steps to adequately compile and append the spatial and non-spatial data to the appropriate coastal community vector geometry. The most basic compilation method is to join the data via a unique field that is present in both data tables (relational). Another compilation method is to spatially join the tables by location. The spatial join uses spatial associations between the layers involved to append fields from one layer to another (ex: municipality inside a County).

¹¹ NCVL changed to AvgLBsFISH due to how data is reported by DFW. Refer to 'Findings' under Section IV.

¹² NFPF changed to AvgNBUYERS due how the DFW collects and reports data. Refer to 'Findings' under section IV.

7. Data Export

The output of the data export will be in an ASCII (TXT, CSV) format and can be manipulated for formatting in Microsoft Office. It is anticipated that the most common formatted output would be MS Excel where numerous post processing functionalities can be conducted in the software.

8. Mapping Phase-One

To identify the location of port and harbor coastal communities for phase-one, simple map figures will be created using ESRI ArcGIS 10 representing the coastal communities for a particular county. In phase-one, the focus is Pacific County, WA. The figures will have the appropriate map elements and represent the County, Coastal Communities, Coastline, and any other feature that is appropriate as the project scope develops.

Information Products

The final information products will be delivered in two forms and supported by this report. The primary information product will be a summary table in an MS Excel spreadsheet format. The second information product will be a map figures that support the summary table. If appropriate, the map figures can be a standalone PDF, JPG, or TIFF images or pasted within the spreadsheet itself. The map figures will be exported from the GIS at 300 dpi to allow for utilization in presentations and future reports. Refer to Appendix E for the executive summary table and map figure.

Findings

The data collection activity primarily occurred in July of 2012. Base map data in the form of vector ESRI GIS compatible data was easily accessible and obtained through Pacific County Utilities, Department of Ecology, and the Department of Natural Resources Geo-portals. Information specific to answering the four objectives stated in section one was obtained in early August from the Washington Department of Fish & Wildlife (DFW) and the Department of Natural Resources (DNR). For objectives one, two, and four, data were obtained from the DFW while objective three were obtained from DNR.

Objectives One & Two

After analyzing the data, it was determined that objectives one and two (Amount of commercial vessel fish landings and number of fish receiving facilities at ports and harbors) needed to be refined due to how the data is reported by the DFW. DFW reports fish landings by the amount of fish landed (excluding shellfish except for crab) in pounds for a port district by year. DFW requires by law that the fish receiving ticket recording the landing must be filled out at the place of landing. However, the place of landing is not necessarily the place of processing. Similarly, the processing facility does not equate to a fish buyer. DFW reports the number of fish buyers that are licensed by DFW and require the buyers to identify what port the fish was purchased from. Respectively, where the fish is landed and who buys the fish does not always mean that the fish will be processed on site. These findings would refine the initial scope and change objective one to the pounds of fish landed by port district and objective two to the number DFW licensed fish buyers reported to buy fish from a port district in a given year.

Port districts are defined by a DFW code. Of the four port districts in Pacific County, DFW reports Ilwaco and Chinook port districts as LWC and Willapa Bay as WLB. The fourth port district of Peninsula does not have any harbors and uses the harbors in LWC. As such, all data is reported through the LWC port district. Tables 3 and 4 represent fish landed and number of buyers by port between the years of 2001 to 2011. LWC landed on averaged approximately 30,000,000 lbs of fish with 51 buyers while WLB landed on averaged approximately 2,500,000 lbs of fish with 37 buyers.

Pounds landed by port code (see port code tab)												
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	average
Columbia River, WA (CLW)												
LWC	35,950,268	42,237,443	43,225,349	30,937,690	29,989,446	40,519,216	21,630,364	17,399,263	18,718,729	24,510,274	20,463,049	29,598,281
OCR	2,231,042	2,394,642	3,428,452	2,364,051	1,672,708	1,449,219	1,055,411	1,179,889	1,210,860	2,460,392	2,995,841	
Washington coast (CWA)												
CPL	1,354,287	2,942,954	1,063	0	0	0	0	0	0	0	0	
GRH	252,631	1,345,876	237,158	81,291	276,231	239,871	237,548	231,374	229,549	14,936	51,779	
LAP	1,300,618	1,249,376	1,629,969	2,069,878	2,715,543	1,731,772	1,040,383	993,184	844,212	1,070,546	1,360,782	
OWC	2,095,644	3,345,558	3,004,005	3,312,384	4,560,267	2,948,756	4,009,175	3,520,819	5,305,433	4,573,644	4,017,991	
WLB	2,928,440	3,294,205	4,273,356	1,635,220	3,429,258	2,693,236	1,535,206	1,523,393	1,863,883	2,282,254	1,881,299	2,485,432
WPT	53,418,747	57,429,830	74,278,354	90,894,571	121,552,646	140,992,906	119,690,187	110,919,862	79,310,129	108,651,753	115,912,000	

Table 3: Fish received a year by port between the years of 2001 to 2011.

Number of Buyers												
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	average
Columbia River, WA (CLW)												
LWC	51	61	72	53	50	47	49	40	48	44	48	51
OCR	43	37	40	33	34	38	36	34	35	37	40	
Washington coast (CWA)												
CPL	4	4	1	0	0	0	0	0	0	0	0	
GRH	12	19	9	7	7	7	8	9	8	5	5	
LAP	15	14	14	14	14	12	15	11	12	19	16	
OWC	9	9	12	11	10	8	10	7	7	6	7	
WLB	41	41	50	39	35	41	34	30	32	31	29	37
WPT	77	90	107	104	102	87	94	91	93	92	90	

Table 4: Number of fish buyers a year by port between the years of 2001 to 2011.

Again, DFW does not distinguish if fish are landed by commercial fishing companies or if a buyer is associated with a specific processing facility. Further investigation is needed to determine what entities are landing the fish and what processing facilities are purchasing the fish which represent critical infrastructure for the coastal communities in Pacific County.

Objective Three

DNR licensed aquaculture facilities were obtained from DNR in ESRI Shapefile format and imported into the project geo-database. The data represents the boundaries of licensed aquaculture areas being used for cultivation (refer to figure 5).



Figure 5: DNR licensed aquaculture area in Pacific County, WA.

Initially, the data table associated with the vector geometry did not associate a district to an aquaculture area. A detailed search of the internet identified which company is associated to which port district. To supplement and verify the findings, DFW supplied the addresses of the aquaculture licensees. Most if not all licensees use P.O. Boxes, so the addresses were geo-coded to zip code. When a company was not verified by either internet search or DFW supplemental licensee addresses, the closest port district was assigned to the DNR aquaculture cultivation area. There are seventeen companies with a total of sixty licenses operating in Pacific County with three licenses without names (refer to table 5). It is approximated that the Port of Ilwaco has twelve operators with forty-five DNR licensed aquaculture areas while the Port of Willapa has five operators with twelve licenses areas and three unknown licensee operators.

The data captured does not represent private cultivators. Further investigation is needed to determine overall aquaculture facilities in Pacific County, WA.

Lessee Name	Lease County	Port			
GREAT WHITE BAIT	4	Ilwaco		Total	#
HERROLD FISH & OYSTER CO	3	Ilwaco		Ilwaco =	45
JAMES J KEMMER	1	Ilwaco		Willapa =	15
JAMES L KEMMER	1	Ilwaco			
JEFF ISAKSEN	4	Ilwaco			
KEMMER OYSTER CO INC	4	Ilwaco			
LONG ISLAND OYSTER CO	3	Ilwaco			
LONG ISLAND OYSTER COMPANY	1	Ilwaco			
NORTHERN OYSTER CO INC	2	Ilwaco			
PETER HECKES	4	Ilwaco			
TAYLOR SHELLFISH CO INC	9	Ilwaco			
WIEGARDT & SONS INC	9	Ilwaco			
BAY CENTER MARICULTURE CO	2	Willapa			
COAST SEAFOODS COMPANY	4	Willapa			
JAMES COLLINS JR	4	Willapa			
NISBET OYSTER CO INC	1	Willapa			
No Name Reported	3	Willapa			
R & B OYSTER INC	1	Willapa			

Table 5: DNR licensed aquaculture companies by port district.

Objective Four

An excel spreadsheet was obtained from DFW that contains license holder name, city, and zip code of charter fishing boats. License holder address reflects where the owner lives or where the business is based but not necessarily where their boat is based. A simple review of the data revealed that fourteen licenses are in Ilwaco, two in Peninsula, and one in Willapa port districts. It will be important to conduct ground truthing of fishing boat charters in Pacific County as it will provide more insight on charter fishing actives.

Data Warehousing

Until phase-two and three where data integration with the Washington State Coastal Atlas occurs, SCC ACT geo-data could be stored at the University of Washington WAGDA (Washington State Geospatial Data Archive) geo-portal website. Check the WAGDA website for data availability.

V. Financial & Strategic Analysis

Financial Analysis

Although there are six steps in preparing the financial analysis section of a business case, the steps are primarily based on the calculation of tangible benefits (positive cash flows) and tangible costs (negative cash flows). However, not all benefits are tangible. Sometimes, it is impossible to estimate the dollar value of a particular project outcome (Lerner et al. 2007). This can be said for the SCC ACT three-phase approach. Indeed, the project is aiming to bring a modern intellectual approach or

methodology of geography to the real-world challenges faced by Washington residents living in coastal communities and employed in coastal economies. When coastal community residents and other stakeholders have spatial information on the status of the critical infrastructure that supports their major industries, they will have a powerful tool to draw attention to the need for preserving and enhancing their communities. Although the mission is extremely valuable to the whole West Coast Region, the project's information product will not result in any future revenues or cost savings that could be translated directly into dollar values. In other words, the benefits of the project are not quantifiable. In spite of not affecting the financial analysis, intangible benefits can be equally important or even more important than then tangible benefits (Lerner et al. 2007).

It is anticipated that one and a half (one full-time and one part-time) GIS analyst or a GIS contractor would be sufficient to complete the SCC ACT phases. The qualifications of the candidates would be a minimum of a Bachelor of Art degree and five year experience in the GIS field or a Master's degree in the GIS field. The estimated annual salary cost for an entry level GIS analyst in the Seattle area is \$43,535 ("Salary Wizard" 2012); however the potential candidate salary should be commensurate with their experience and education. The full-time employee or contractor would be responsible for working with the SCC ACT collecting status indicators for critical infrastructure and implementing data integration. The part-time employee or contractor would be responsible for assisting the full-time employee. In other words, the major factor of costs would be personnel and time. In phase-one, it costs the SCC ACT team several hours each week leading to fewer hours toward the end of phase-one, but utilizes the current UW PMPGIS working team's volunteer time. In phases two and three, a future UW PMPGIS team or additional SCC ACT staff members are needed to continue implementing the proposed plan and creating the appropriate contacts for the SCC ACT and RDF ACT.

Strategic Analysis

This section further defines the intangible benefits and intangible costs. Intangible benefits are comprised of strategic benefits, external benefits and project interrelationships (Lerner et al. 2007).The strategic benefits are public attention to the need for preserving and enhancing their communities, an increased certainty of fishery and aqua-cultural business continuity, a more resilient environment and a better quality of life. As for external benefits, the project's information product—the intellectual methodology—can be utilized by other northern counties along the West Coast, and potentially beyond the West Coast. Regarding the project interrelationships, this project will lay out a ground-work for other future projects. For example, once this project provides a spatial infrastructure (waiting list for slips, renovation or removal of ports or harbors, processing facilities, access to cold storage, etc.), the laid out ground work will assist national initiatives, such as coastal and marine spatial planning (CMSP).

Migration strategy and risk analysis have also been considered (Tomlinson 2011). Currently, the SCC ACT does not have an existing system or methodologies that can generate the information product that is being proposed in phase-one. In other words, there is no legacy system to be migrated over. However, there are some new considerations for implementing the proposed methodologies such as the transfer of knowledge about the proposed methodologies to the SCC ACT and other technical considerations such as data warehousing issue. It is common to find oneself

extremely dependent on the project's information product provider (Tomlinson 2011). Especially in phases two and three when data integrations and model expansion will be involved and expert knowledge will be needed. One last thing to be included in migration strategy is that phase-one of the SCC ACT three-phase approach is a pilot project. A pilot project is essentially a test run for part of—or for a small-scale version of—your planned GIS (Tomlinson 2011). With respect to phase-one, Pacific County of WA is chosen to be the only focus of the pilot project. This way, the information product will be tested out for Pacific County first before being deployed to the rest of the counties in the West Coast.

Out of all the factors used to identify risks of the project, time constraint, organizational interactions, stakeholders, overall complexity and project resources could be note-worthy. This project lasts from 18 June 2012 to 17 August 2012. In the course of two months, a complete project proposal, data collection for a summary table and a map figure, methodologies and a workflow model to be used by future project work teams need to be delivered. The organization has a unique structure which leads to geographically dispersed departments and stakeholders at multiple levels. This in turn challenges many processes during the life of the project, such as understanding the organizational structure itself, finding data, and integrating data which adds to the overall complexity of the project. However, thanks to appropriate project management, time management, planning and knowledge of the GIS field, none of the risk factors has become so severe that any aspect related to the project will need to be changed.

Recommended Course of Action

The WCGA Executive Committee formed the SCC ACT to develop an implementation plan for actions 7.1 and 7.2. (West Coast Governors Alliance on Ocean Health 2011):

- Action 7.1 – Support local planning efforts for working waterfronts to promote sustainable fisheries and prioritize coastal-dependent business and infrastructure through grant processes and federal assistance programs.
- Action 7.2 – Promote and expand environmentally responsible operations and infrastructure at ports and harbors, such as through Green Ports and Clean Marinas programs. Support revitalization efforts for struggling ports.

This proposed project directly supports both of the above actions. Phase-one of the SCC ACT three phase approach helps lay out a methodology to compile an inventory assessment of both coastal fisheries and aquaculture related infrastructure and a workflow model for use by future project work teams to complete the SCC ACT project phases. The SCC ACT will incur minimal extra costs except the few hours they spent on reviewing and providing feedback on documents and the project proposal for the current UW PMPGIS working team. The SCC ACTs current situation is that there is limited ability for coastal communities to advocate for a sustainable future with limited information. Therefore, based on all the benefits discussed in the “Financial Analysis” and “Strategic Analysis” sections, it is highly recommended to make the important investment that will lead the West Coast to a more resilient, more sustainable coast and form a clearer vision of its future and what is required to get there. To accomplish this goal, it is also recommended to hire a fulltime GIS analyst and a part-time GIS assistant. However, as a “labor cost avoidance” strategy, it

could use the UW's partnership. The result of a "labor cost avoidance" strategy is the elimination (or avoidance) of the associated labor costs, including salaries, fringe, and the costs of related office space, equipment and support services (Lerner et al 2007).

Bringing awareness to real world challenges faced by Washington residents living in coastal towns and cities that are employed in resource based coastal economies is the main goal of the overall project. When spatial data collected by the SCC ACT are made available to coastal communities, residents and key stakeholders will be able to obtain the status of critical infrastructure that supports their major industries. The information gleaned will be a powerful tool that will draw attention to preserve and enhance their communities. With communities empowered by spatial data and tools to access the information critical to their needs, communities can create a more sustainable coastal environment with a clearer vision of their future endeavors and what is required to achieve it.

VI. Future Directions

To better understand critical infrastructure for Pacific County coastal communities, additional detailed GIS analysis is encouraged in phase-two to understand critical indicators such as commercial fishing companies that are landing fish and what port are based at, what entity is buying the fish and where the fish are processed (on site or out of the county), further quantifying what aquaculture facility is associated to licensee by port district, and where charter fishing companies moor their boats. Recommendations include of creating an aquaculture spider diagram¹³, thematically mapping aquaculture facilities by licensee name, ground truthing processing facilities and their associated names with GPS devices, and further outreach with local experts at the ports districts about commercial fish landings and charter boats.

The coastal counties along the West Coast are a complex social ecological society (SES). SESs are composed of multiple subsystems and internal variables within these subsystems at multiple levels (Ostrom 2009). Figure 6 below represents the core subsystems for analyzing SESs. The West Coast itself is a complex SES, in which the subsystems are resource systems (e.g., a coastal fishery), resource units (fish, vessel fish landings, fish receiving facilities at ports and harbors), resource users (recreational and commercial fishers), and governance systems (WGCA and rules that govern fishing on that coast). A general framework is used to identify ten subsystem variables that affect the likelihood of self-organization in efforts to achieve a sustainable SES (Ostrom 2009). Table 6 in Appendix D depicts the ten subsystem variables and their corresponding scores which denote the likelihood of self-organization. According to Table 6, there is a sixty percent of probability that the resource users will make efforts to self-organize to manage resources. An example is the Pacific County Marine Resource Committee (PCMRC). The PCMRC serves as a steward for the marine and estuarine resources in our county by facilitating science based policies, research, and education that

¹³ Spider diagrams can be created from points contained in one or two feature classes. If using two feature classes, one feature class must contain the origins and the other must contain the destinations. The tool can be downloaded here: <http://resources.arcgis.com/gallery/file/Geoprocessing-Model-and-Script-Tool-Gallery/details?entryID=1C1927D6-1422-2418-8809-3BA43CBD435C>

enhance the sustainability of the economy and ecology of our communities (Pacific County Marine Resource Committee 2012).

In the long term, knowledge of sustainability science, sustainability information science is needed to enhance efforts to sustain the West Coast SES. Using human cognitive abilities such as systems thinking and spatial thinking, sustainability science helps identify important elements and relations in sustainable systems (Ostrom 2007, 2009). Systems thinking and spatial thinking frameworks, theories, and models of SES's with information technology, specifically GIS are in turn supported by sustainability information science. In the future, the endeavor to apply sustainability science and sustainability information science will help achieve a better sustainability management, and therefore a more resilient SES for the West Coast.

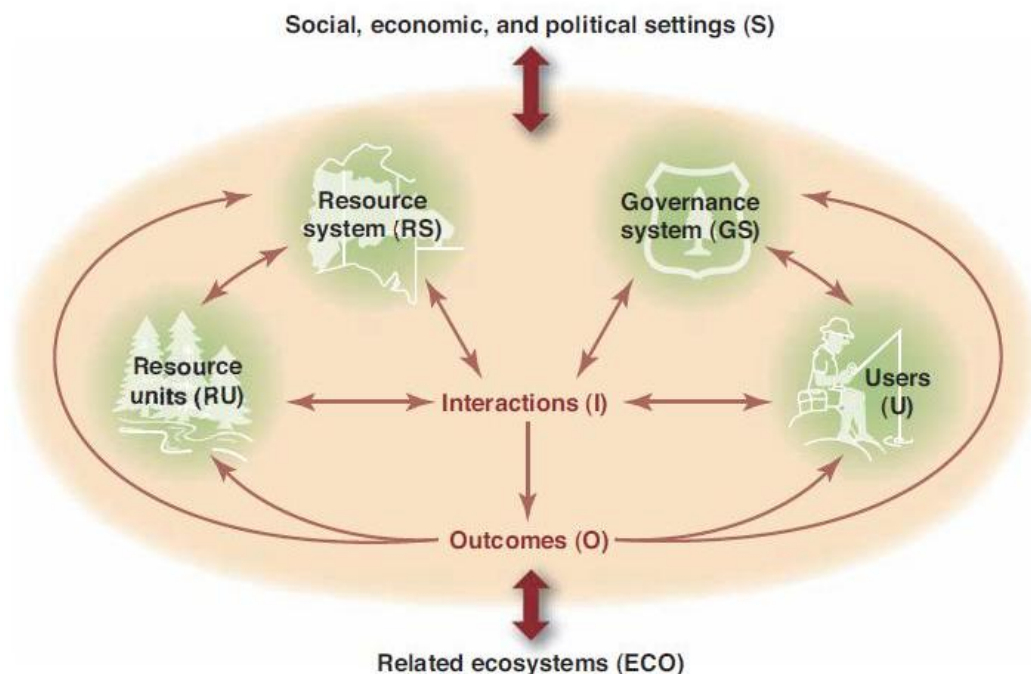


Figure 6: Core subsystems in a framework for analyzing social ecological systems (Ostrom 2009).

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Appendix A - Data Sources

Source	Data Type that Can Be Potentially Collected	Contact
Ecotrust	Spatial data for the coast	Charles Steinback
WA Department of Fish and Wildlife (WDFW)	GIS data pertaining to a wide variety of habitats and locations of fish and wildlife species	Michelle Wainstein
National Marine Fisheries Service's Northwest Region (Washington, Oregon, and Idaho)	Data layers of use/interest	Barb Seekins (Lead Geographer)
Northwest Fisheries Science Center (NWFSC) – Fishery Resource Analysis and Monitoring (FRAM) Division	High-resolution bathymetry data (West Coast, Oregon, California), marine managed data, National Marine Sanctuary Boundary polygons, Yelloweye Rockfish/ Cowcod conservation areas data, etc.	No need for a contact. Data available online (http://pacoos.coas.oregonstate.edu/datasets.html)
Department of Natural Resources	DNR licensed Aquaculture area in ESRI shapefile format (polygon geometries)	Michal Rechner, Tim Strickler, Dolores Sare
Pacific County Marine Resource Committee	Data/knowledge on the facilities and infrastructure existing in Pacific County	Mike Nordin
Port of Ilwaco	Data/information on the Port of Ilwaco and surrounding ports	Jim Neva
WA Department of Fish and Wildlife	Data/information on fisheries permitting for both commercial and recreational fisheries	Corey Niles
Department of Ecology	Ecological data/information	Jennifer Hennessey, Bridget Trosin
Pacific States Marine Fisheries Commission	Recreational fisheries landings and commercial landings data	Ed Hibsich, Brad Stenberg

Table 1: Data Sources and Contact Information

Appendix B – Metadata

Geo-database schema diagram of SCCACT

This diagram was auto-generated by the Geodatabase Diagrammer application. The application is available from the ArcScripts site on www.esri.com . You can find examples of finished data model diagrams at the data model section of arconline.esri.com .	Geodatabase \SCCACT_PacificCountyPilotProject\Data\SCCACT.gdb
Date generated Tuesday, August 14, 2012	
Author Jason Karr and Vu Vo on the Behalf of Suzanna Stoiike, Sustainable Coastal Community Action Coordination Team (SCC ACT) of the West Coat Governance Alliance (WCGA).	

Geodatabase Summary Feature Dataset Graphics

JurisdictionBoundaries

 Polygon feature class PacificCountyCityLimits	To delineate the extent of incorporated areas within Pacific County, WA.
 Polygon feature class PacificCountyPortDistricts2010	For political boundary reference purposes of Port Districts in Pacific County, WA.
 Polygon feature class PacificCountyOutline	For political boundary reference purposes of Pacific County, WA.

Fisheries

 Polygon feature class PacificCountyAquacultureDNR	This dataset is being developed in order to provide an accurate, complete, and up-to-date representation of all State Owned Aquatic Lands use authorizations/encumbrances.
 Point feature class PacificCountyAquacultureDFW	The purpose of this data is to represent the spatial location of DFW licenses of Aquatic farming production from 2009 on.

Geodatabase Detail Graphics

Simple feature class PacificCountyCityLimits		Geometry Polygon Contains M values: No Contains Z values: No					
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
CITY	String	Yes					25
SqFeet	Float	Yes			0	0	
Acres	Long integer	Yes			0		
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	
City2	String	Yes					25

City limits created with boundary descriptions provided by the Pacific County Auditor's office.

	Simple feature class PacificCountyPortDistricts2010				Geometry Polygon Contains M values: No Contains Z values: No			
	Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID							
Shape	Geometry	Yes						
PORT	String	Yes						16
Shape_Length	Double	Yes				0	0	
Shape_Area	Double	Yes				0	0	
CCName	String	Yes						25
CCCounty	String	Yes						25
CCState	String	Yes						25
AvgLBuFish	Long integer	Yes				0		
AvgHumbuyers	Short integer	Yes				0		
NAF	Short integer	Yes				0		
NCRFL	Short integer	Yes				0		

Pacific County Political boundaries include; County Commissioner, Hospital, School, Port, Fire, Precinct, Water and Sewer Districts in separate shapefiles. These delineations were based on legal descriptions obtained from the Auditor's office. Port Districts were extracted and used for this project.



Simple feature class

PacificCountyOutline

Geometry Polygon

Contains M values: No

Contains Z values: No

Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
AREA	Double	Yes			0	0	
ACRES	Double	Yes			0	0	
SQ_MILE	Double	Yes			0	0	
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

Pacific County Political boundaries include; County Commissioner, Hospital, School, Port, Fire, Precinct, Water and Sewer, County Districts in separate shapefiles. These delineations were based on legal descriptions obtained from the Auditor's office. County was extracted and used for this data set.

Simple feature class PacificCountyAquacultureDNR					Geometry: Polygon Contains M values: No Contains Z values: No		
Field name	Data type	Allow nulls	Default value	Domain	Precision (short)	Scale	Length
OBJECTID_1	Object ID	Yes					
Shape	Geometry	Yes					
OBJECTID	Double	Yes			0	0	
CONTRACT_N	String	Yes					11
LESSEE_NAM	String	Yes					100
CONTRACT_2	Double	Yes			0	0	
UNITS	String	Yes					4
GIS_ACRES	Double	Yes			0	0	
BOOK_PAGE	String	Yes					25
AUDITOR_FI	String	Yes					25
NOTES_1_TX	String	Yes					254
NOTES_2_TX	String	Yes					254
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

Washington State Department of Natural Resources (DNR) is responsible for the management of an estimated 2.6 million acres of aquatic lands. DNR's management responsibility includes leasing aquatic lands for a wide range of uses. The Encumbrance 2011 Project is an on-going effort to develop and maintain an up-to-date GIS dataset including points, lines, and polygons. The polygon footprints of these encumbrances are presented here. These footprints represent the true shape and area of the encumbrance with an estimated accuracy of +/- 50 ft. This polygon dataset is a work-in-progress. It is refreshed weekly.

Simple feature class PacificCountyAquacultureDFW				Geometry Point Contains M values: No Contains Z values: No			
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
Loc_name	String	Yes					14
Status	String	Yes					1
Score	Double	Yes			0	0	
Match_type	String	Yes					2
Match_addr	String	Yes					120
Side	String	Yes					1
X	Double	Yes			0	0	
Y	Double	Yes			0	0	
Disp_Lon	Double	Yes			0	0	
Disp_Lat	Double	Yes			0	0	
Addr_type	String	Yes					20
House	String	Yes					12
PreDir	String	Yes					6
PreType	String	Yes					20
StreetName	String	Yes					32
SufType	String	Yes					6
SufDir	String	Yes					6
City	String	Yes					20
Province	String	Yes					2
Postal	String	Yes					5
ZIP	String	Yes					5
ZIP4	String	Yes					4
ZIP4_TYPE	String	Yes					120
User_fld	String	Yes					120
State	String	Yes					120
Lab	String	Yes					5
xmin	Double	Yes			0	0	
xmax	Double	Yes			0	0	
ymin	Double	Yes			0	0	
ymax	Double	Yes			0	0	
ARC_Address	String	Yes					100
ARC_City	String	Yes					40
ARC_State	String	Yes					20
ARC_Zip	String	Yes					50
ARC_Zip4	String	Yes					12
ARC_Countr	String	Yes					50
license_ty	String	Yes					254
license_yr	Double	Yes			0	0	
license_id	Double	Yes			0	0	
name	String	Yes					254
addr_in1	String	Yes					254
addr_in2	String	Yes					254
city_1	String	Yes					254
state_1	String	Yes					254
zip_1	Double	Yes			0	0	
Active_St	Double	Yes			0	0	

Data obtain from Corey Niles of the DFW in August of 2012. The data was geo-coded using address first then zip code second to locate the address. Pacific County matches were extrapolated to create this data set.

Table 2: Geo-database schema, feature definition, and metadata. For a higher resolution table, refer to the SCC ACT Pacific County Pilot Project image folder. Contact Suzanna Stoiike (ECY) or the University of Washington Geography Department to obtain a copy.

Appendix C - Hardware/Software Requirements

Microsoft Office (Microsoft. 2012)

Office Standard 2010

COMPONENT	REQUIREMENT
Computer and processor	500 MHz or faster processor
Memory	256 MB RAM; 512 MB recommended for graphics features and certain advanced functionality. ¹
Hard disk	3.0 GB available disk space
Display	1024x576 or higher resolution monitor
Operating system	Windows XP (must have SP3) (32-bit), Windows 7, Windows Vista with Service Pack (SP) 1, Windows Server 2003 with SP2 and MSXML 6.0 (32-bit Office only), Windows Server 2008, or later 32- or 64-bit OS.
Graphics	Graphics hardware acceleration requires a DirectX 9.0c graphics card with 64 MB or more video memory.
Additional Requirements	Internet Explorer (IE) 6 or later, 32 bit browser only. IE7 or later required to receive broadcast presentations. Internet functionality requires an Internet connection.
	Multi-Touch features require Windows 7 and a touch enabled device.
	Certain inking features require Windows XP Tablet PC Edition or later.
	Speech recognition functionality requires a close-talk microphone and audio output device.
	Internet Fax not available on Windows Vista Starter, Windows Vista Home Basic, or Windows Vista Home Premium
	Information Rights Management features require access to a Windows 2003 Server with SP1 or later running Windows Rights Management Services.
	Certain online functionality requires a Windows Live™ ID.
Other	Product functionality and graphics may vary based on your system configuration. Some features may require additional or advanced hardware or server connectivity; www.office.com/products .

¹ 2 GHz processor or faster and 1 GB RAM or more recommended for OneNote Audio Search. Close-talking microphone required. Audio Search not available in all languages.

ESRI ArcGIS Desktop 10 (ESRI 2012)

Hardware Requirements

	ArcInfo, ArcView, ArcEditor
CPU Speed	2.2 GHz minimum or higher; Hyper-threading (HHT) or Multi-core recommended
Processor	Intel Pentium 4, Intel Core Duo, or Xeon Processors; SSE2 (or greater) Run this Microsoft utility from your Windows command prompt to check your processor. See Dual or dual-core support policy . 
Memory/RAM	2 GB or higher
Display Properties	24 bit color depth
Screen Resolution	1024 x 768 recommended or higher at Normal size (96dpi)
Swap Space	Determined by the operating system, 500 MB minimum.
Disk Space	2.4 GB In addition, up to 50 MB of disk space maybe needed in the Windows System directory (typically C:\Windows\System32). You can view the disk space requirement for each of the 10.0 components in the Setup program. If using ArcGlobe (as part of 3D Analyst), additional disk space may be required. ArcGlobe will create cache files when used.
Video/Graphics Adapter	Check your computer's ability to run ArcGIS 64 MB RAM minimum, 256 MB RAM or higher recommended. NVIDIA, ATI and INTEL chipsets supported 24 bit capable graphics accelerator OpenGL version 2.0 runtime or higher is required, and Shader Model 3.0 or higher is recommended. Be sure to use the latest available driver.
Networking Hardware	Simple TCP/IP, Network Card or Microsoft Loopback Adapter is required for the License Manager.

ESRI ArcGIS Desktop 10 (ESRI 2012)

Supported Operating Systems

Supported Operating System	Minimum Version	Maximum Version
Windows 2003 Server Standard, Enterprise & Datacenter (32-bit and 64-bit (EM64T))	SP2	SP2
Windows 2003 Server Terminal Services	SP2	SP2
Windows 2008 Server Standard, Enterprise & Datacenter (32-bit and 64-bit (EM64T))		SP2
Windows 2008 R2 Server Standard, Enterprise & Datacenter (64-bit (EM64T))		SP1*
Windows 2008 R2 Server with Citrix XenApp 6**	SP1*	SP1*
Windows 7 Ultimate, Enterprise, Professional, Home Premium (32-bit and 64-bit (EM64T))		SP1*
Windows Vista Ultimate, Enterprise, Business, Home Premium (32-bit and 64-bit (EM64T))	SP2	SP2
Windows XP Professional Edition, Home Edition (32-bit)	SP3	SP3
Windows XP Professional Edition, Home Edition (64-bit (EM64T))	SP2	SP2

*Support begins at ArcGIS 10 Service Pack 2.

**Esri has certified ArcGIS 10 SP2 as a hosted application with Citrix XenApp 6 and Windows 2008 R2 using the Citrix ICA Online Plug-in for Windows 12.1. Please note that ArcGlobe, ArcScene, and any other 3D application generally will not work over Remote Desktop or other Windows Terminal Services clients, because these clients do not support 3D graphics acceleration. Also note that Esri does not recommend running virtualized XenApp servers to host ArcGIS Desktop applications due to performance bottlenecks encountered with multiple layers of virtualization.

Appendix D – Ten West Coast Subsystem Variables Score Sheet

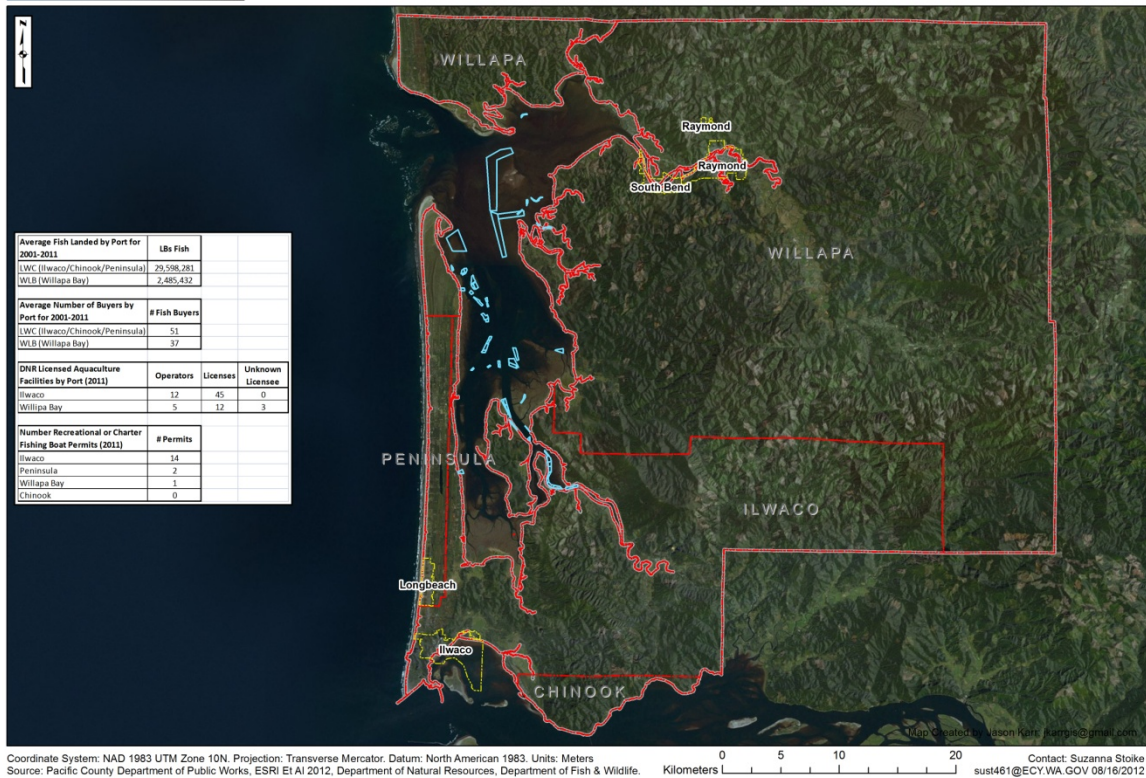
No.	Name	Score	Enter 1 in Score	Enter 0 in Score
1	Size of resource system	0	Moderately-sized territorial boundary	Very small or very large-sized territorial boundary
2	Productivity of system	0	Some apparent scarcity	Either appearing very abundant or already exhausted
3	Predictability of system dynamics	1	Predictable type of system (e.g., terrestrial)	Unpredictable type of system (e.g., fisheries)
4	Resource unit mobility	0	Stationary resource units (e.g., forests, agriculture, water in a lake)	Mobile resource units (e.g., fisheries, water in a unregulated river)
5	Number of users	0	Smaller group size	Larger group size
6	Leadership/entrepreneurship	1	Presence of resource users with entrepreneurial skills or respected as local leaders, as a result of prior organization	Absence of resource users with entrepreneurial skills or respected as local leaders, as a result of prior organization
7	Norms/social capital	1	Presence of users with entrepreneurial skills or respected as local leaders, as a result of prior organization	Absence of users with entrepreneurial skills or respected as local leaders, as a result of prior organization
8	Knowledge of the SES	1	Common knowledge of relevant SES elements and relationships	Absence of knowledge of relevant SES elements and relationships
9	Importance of resource	1	High dependence on resource system for livelihoods, or high value attached to its sustainability	Low dependence on resource system for livelihoods, or low value attached to its sustainability
10	Collective-choice rules	1	Autonomy to craft and enforce their own rules	Lack of autonomy to craft and enforce their own rules
		0.6	Likelihood of resource users self-organizing	

Table 6: Subsystem variables and corresponding scores which denote the likelihood of self-organization

Appendix E – Executive Summary Table and Map

WEST COAST GOVERNORS
ALLIANCE on OCEAN HEALTH
CALIFORNIA OREGON WASHINGTON

Sustainable Coastal Communities Action Coordination Team: Pacific County, WA



**Storm Drainage Basin and Urban Forest Analysis:
A Social-Ecological Systems
Model of Increasing Benefits and Sustainability
For the City of Bellevue, Washington**

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University of Washington
Professional Master's Program in GIS
Geography 569 GIS Workshop
August 17, 2012

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I. Introduction

Background

Large amounts of stormwater runoff are unique to developed land with impervious surfaces and compacted soils, and are urgent issues in many urban areas. Stormwater runoff is the number one source of pollution entering urban waterways and has resulted in degraded aquatic ecosystems across Washington (Washington Department of Ecology 2012). Runoff is contaminated with many noxious chemicals, pharmaceuticals, excess nutrients, and sediments which eventually make their way to the Puget Sound estuary. Traditionally, municipalities have invested heavily in the grey or hard infrastructure of waste-water treatment and detention facilities, and the associated management strategies with which to cope with this problem, but these techniques have proven to be expensive and not very effective at preventing water pollution. In addition to this traditional approach, a common theme is to increase the number of trees and vegetative cover.

A dominant proponent of urban forestry is the organization American Forests (AF). American Forests is the oldest national nonprofit conservation organization in the country and advocates for the protection and expansion of forests. American Forests has coordinated the planting of over 40 million trees since 1990 and their goal is to work with city partners to plant an additional 25 - 30 million trees for forest restoration projects over the next five years. Developed areas account for a large portion of the canopy coverage in the U.S., so expansion of trees in urban areas is critical to increasing total canopy coverage. American Forests also supports the mega-tree national register of the oldest and largest trees in the country, of which all but two reside in California, Oregon, and Washington such as the Seven Sisters (Figure 1).

Figure 1. The Seven Sisters Oak in Louisiana.



American Forests supports local urban forest initiatives through their Global ReLeaf program to make recommendations about urban forest canopy coverage. Urban trees are a vital part of healthy functioning urban systems as they can significantly reduce stormwater runoff, reduce pollutants in the air and soil, sequester carbon, and release oxygen. They also intercept airborne particulates and deaden urban noise. Shade from trees and evapotranspiration create microclimates 20 - 45°F cooler than the surrounding paved areas reducing the urban heat island effect (Environmental Protection Agency 2012). In addition, trees increase property values, reduce energy use in buildings during summer and winter, and increase local business traffic.

American Forests' recommendations are guided by peer-reviewed scientific research that documents urban forests as providers of substantial ecological services with true economic value. This organization works with federal, state, and local governments to evaluate and increase their urban canopies, and has contracted with many cities including Boston, Chicago, Los Angeles, Seattle, and New York.

In 2008, the City of Bellevue commissioned American Forests to update the City's 1998 Urban Ecosystem Analysis which utilized Landsat imagery. The report documented a loss of more than 20 percent of Bellevue's tree canopy since 1986, and evaluated the current canopy coverage at 36 percent (American Forests 2008). The organization recommends 40 percent canopy coverage in the Pacific Northwest.

The decline of Bellevue's urban forest has resulted in a loss of ecosystem services valued at \$7,291,657 (American Forests 2008). The 2008 ecosystem analysis was conducted using CITYgreen software which was developed by American Forests in conjunction with the USDA. This software utilized Landsat imagery developed by the Multi-Resolution Characteristics Consortium (MLRC), a partnership of Federal agencies led by the U.S. Geological Survey. CITYgreen software is no longer available or supported by American Forests. Additional research led the Project Team to software called i-Tree.

The USDA Forest Service, National Arbor Day Foundation, Davey Tree Expert Company, and the Society of Municipal Arborists have partnered to develop a suite of software called i-Tree that analyzes the benefits of the services provided by the urban forest. This software also utilizes MLRC imagery in one of its modules. The software is in the public domain and available through the website (www.itreetools.org). i-Trees software utilizes user input to inventory and

analyze the benefits of the urban forest which can be used to guide decision making and public policy, and education program to improve the health and welfare of the urban community. The i-Tree benefit analysis includes; inventory, energy savings, carbon sequestration, removal of air pollutants, stormwater runoff reduction, and aesthetic values.

The tree canopy, stems, and bark of urban forest trees as well as the accompanying understory and ground vegetation substantially mitigate the volume of fall through precipitation (USDA 2008). According to reports, the City has lost a substantial portion of its urban forest over the last two decades and is undergoing rapid population growth (American Forests 2008). To meet the challenge of this trend, while maintaining the high quality of life for its residents, the City has options to address these needs. Increasing the size of the urban forest is a leading method utilized by thousands of cities across the country (Dwyer and Miller 1999). Increasing urban forests and other vegetative features such as shrubs and groundcover will improve air quality, reduce ambient noise congestion, stabilize temperature extremes, save energy, improve neighborhood aesthetics and property values, and increase wildlife habitat. Concurrent with urban forest expansion, forest planning that incorporates a wide selection of plant species and structural complexity will increase the long-term benefits by improving forest health. A healthy forest is more resistant to disease and pest infestation and is a self-sustaining (in wild sections) and resilient ecosystem requiring less maintenance and less replacement costs (Coalition 2007).

The City expects its population to grow from the current population of over 122,000 to 138,500 by 2020 and to 148,400 by 2030 (Bellevue City Council 2010). With this population growth, there will be significant land use changes (American Forests 2008). The urban forest is a

multi-tasking green infrastructure that not only provides substantial economic return on investment, but also, offers many other intangible benefits. In order to receive credit and be included in budget calculations for this economic return, urban forest services must be quantified. In the United States, the value of the services performed by urban forests is based on what it would take a technology to perform the identical tasks.

For the City of Bellevue it is the responsibility of the Storm Drainage Engineer to assist in stormwater management by conducting basin analyses. A basin analysis provides insight to precipitation events that may damage the infrastructure, lead to excessive peak flow events, and/or flow rate and flow duration of storm events. For example, this information assists the decision maker in determining the correct pipe size, control structures, or replacement of pipes that have reached the end of their functional capabilities. The basin analysis method is a very time consuming and manual process as the Engineer reviews aerial imagery, impervious surfaces, pervious surfaces, streams, and other datasets. Determining which side of the building structure the precipitation is most likely to fall takes considerable time to evaluate, especially coupled with the placement of the waterbodies, storm drainage pipes and structures. Designing a model to streamline the data processing would go a long way towards reducing the amount of time and effort necessary to conduct basin analyses and as a result, produce a future cost savings.

An integrated model of traditional storm water management and enhanced urban forestry infrastructure initiative could provide the city with a maximum return on expenditure while increasing service efficiencies, reliabilities, and minimizing hazards from storm events which

have not previously been utilized by the City. In addition, conducting a cost-benefit analysis for the urban forest will encourage integration between City Departments.

Problem Statement

Currently, the City of Bellevue Utilities Department conducts basin analyses as an ad hoc request utilizing both ArcGIS and the storm drainage modeling software PC Stormwater Management Modeling (PCSWMM) to perform the analyses (Computational Hydraulics International (CHI) 2012). Developing a model for each of these analyses is a very manual and time consuming process and depending on the size of the subcatchment, model development can take anywhere from 10 to 22 hours (Ward, Weber and Klock 2012). As a result, the need for a scalable, repeatable, and measurable process in the form of ArcGIS models is essential to reducing the amount of time and effort required to conduct a basin analysis.

Project Goals

The goals of this project are two-fold: pragmatic and theoretical. The first goal is to streamline the existing ArcGIS processes for developing subcatchments and accompanying data. By automating the data processing and calculations for stormwater modeling; including creating the subcatchment boundary and applicable data overlays, and making calculations, it is proposed that the processing time will be reduced for the entire basin analysis.

The second goal of the project will evaluate the canopy cover of the storm drainage basins that contain the subcatchment. This process will quantify the mitigation from the current green infrastructure and calculate alternative scenarios if plantings are undertaken for long-term planning. This evaluation could offer savings in time and costs of repairing expensive grey

infrastructure by negating hazards that arise from severe storm events, and by mitigating the first “flush” that results from the small and short-duration, but frequent precipitation events in the City of Bellevue.

The first few millimeters of precipitation dissolve and carry substantial pollutants from the air and surfaces. If this precipitation is not intercepted by plants or retained by soil, it enters the water cycle. The first few millimeters of rain are also the most effectively intercepted by vegetation before leaf areas become saturated and precipitation fall-through begins. Although larger rain events or sustained precipitation result in fall-through, they also offer the benefit of diluting pollutants as they enter the water cycle. Therefore the most obtainable goal for urban forestry planning in regards to stormwater pollution should be the interception of small rain events.

Objectives

To obtain the goals listed above, the project team will address “increasing population and pollution trends” and will facilitate the design of stormwater facilities (e.g. the sizing of pipes, detention ponds, and water quality treatment facilities) in a more efficient manner through tools and models. “Computer simulations of rainfall-runoff events are essential for sizing stormwater facilities that are designed to achieve management goals. For example, pipe sizes are based on the goal of keeping a certain size storm from flooding the streets. In Bellevue, pipes are sized to convey the 100-year, 24-hour storm recurrence interval. Existing land cover, soil infiltration properties, vegetative cover, and topographic slope are the types of information required to get accurate computer model results when simulating rain events. The GIS tools are essential for helping to characterize the many and varied factors that affect the rate and

volume of stormwater generated by storm events.” (Ward, Weber and Klock 2012) This generates several questions necessary to design a comprehensive model.

- a. What data is needed for the basin analysis?
- b. What tools are needed to create the subcatchment layer?
- c. What tools are needed to perform the calculations?
- d. What are the soil infiltration categories?
- e. What file formats are needed to utilize in PCSWMM?
- f. How much of the process can be automated?
- g. What training is needed by the Customer to run the models?
- h. What are the storage needs?
- i. What are the naming conventions – is specific terminology needed?

There are many structural Best Management Practices including detention ponds, buffer requirements, and zoning regulations utilized to manage stormwater runoff, but the progressive decline of water quality demonstrates the pervasive failure of these techniques. This necessitates an integrated approach to stormwater mitigation efforts. Across the country green infrastructure is becoming the standard for these efforts and the most prudent approach (Booth, Hartley and Jackson 2002).

There are many success stories of the benefits from investing in green infrastructure for stormwater management practices that utilize trees including regenerative stormwater conveyance systems, foresting stormwater ponds, green street and street edge projects, vacant land stabilization, public school greening, and green roofs (Center for Watershed Protection 2011).

This project will calculate the benefits of increasing forest coverage throughout the City, and develop a model and GIS tools for running several calculations to determine the potential mitigation value within basins where storm drainage problems occur. This green infrastructure

component will add value to the storm drainage basin analysis by providing alternatives to remediation which the City may consider. These alternatives offer long-term economic and maintenance solutions for the community. The restoration or creation of green infrastructure that naturally direct, retain, and purify runoff as it makes its way to streams and lakes of the City of Bellevue will reduce not only grey infrastructure costs, but also perform other vital services such as pollution removal, carbon sequestration, and aesthetic enhancement.

While many urban forest plans have already accomplished the basics of this concept and have reduced stormwater runoff; there have been issues with a lack of biodiversity in plantings which has led to epidemics of disease and pests such as Dutch elm disease. In addition, urban forest structure has received little attention in favor of mass plantings of similar aged and sized components. A more holistic approach is to plan for forest communities that are biologically and structurally diverse. Research has shown that forests with diverse species components function more efficiently and provide more natural resource services than monoculture stands (Dwyer and Miller 1999). In addition, biologically diverse forests are more resistant to disease and insect infestation, and provide a variety of habitat and food sources for wildlife. Nationwide, trees in urban counties account for 25% of the canopy coverage over the entire contiguous United States (Alvey 2006). Therefore, the need-to-know questions are:

- a. What are the current urban forest characteristics for the City of Bellevue?
- b. What are the dominant tree species?
- c. How much precipitation is intercepted by the urban forest?
- d. What quantities of pollutants are removed by the forest?
- e. Where and how much area is available for forestry expansion?
- f. What basins are most deficient in canopy coverage?
- g. What are the economic benefits of expanding the urban forest?

Scope

The section below further explains the goals and objectives, by outlining what is considered in-scope and out-of-scope for this project.

In-Scope

Part 1: Storm Drainage Basin Analysis

- Develop a model to create a feature class polygon for the subcatchment
- Develop a model to automate the ArcGIS process of clipping, data overlay, add fields and perform calculations such as Total Area, Total Acres, etc.
- Design a User Reference Guide outlining how the models were created, calculations performed and step-by-step instructions on using the models
- Provide training to the Engineer on setting up the Toolbox, accessing the models, and running the new process from start to finish
- Submit a Standard Operating Procedure (SOP) document which instructs the GIS Team when and how to update the data as updates are available
- Convert raster layers to vector layers and map data appropriately
- Data output will be in the following formats: shapefile (*.shp) and/or (*.csv) file formats

Part 2: Urban Forestry Analysis & Benefits Assessments

- Utilize i-Tree Urban Forest Modeling Software
 - Develop baseline data for the city
 - Calculate current land cover percentages
 - Calculate urban forest ecosystem service values (\$)
 - Stormwater runoff
 - Air quality
 - Carbon sequestration indices
 - Replacement values
 - Benefit/Cost Analysis
- Develop GIS Model & Tools to:
 - Select areal coverage (parcel to basin)
 - Generate reports for each basin analysis

Out-of-Scope

Other Software (PCSWMM and WWHM)

- Using the PCSWMM software, except to understand what file types are required by PCSWMM and that the data created in ArcGIS works in PCSWMM

- Using the Western Washington Hydrology Model (WWHM) software, except to understand how the data needs to be formatted to feed into this model.
- Developing land cover analysis at the parcel level
- Using other software such as ArcHydro to replace PCSWMM and WWHM

Information Structures & Products

As mentioned previously, this project will create data in a format such that a repeatable, measurable, and scalable model has been created. ArcGIS ModelBuilder will be used to iterate through layers and records, add additional attribute fields, perform specific calculations such as total area, and output data resulting in file formats the Storm Drainage Engineer can import into the storm drainage software thereby, finishing the analysis using PCSWMM and WWHM software, specific storm drainage engineering software. The analysis results will be explained within the narrative, as well as, reference data provided in tables, charts, and graphs with an overview in maps.

To provide additional holistic benefits to the Bellevue urban area, a comparison will be made between the historic value as derived from the 2008 ecosystem analysis, the present urban forest, and the benefits that could be realized from a re-designed urban forest; emphasizing expanding canopy coverage, improving forest health, and building in long-term resilience.

A spatial analysis of the City limit will detail the city-wide forest canopy coverage classified by deciduous and evergreen trees; the City street trees will be evaluated by species dominance and size/age; total area available for forest enhancement determined; and the economic value of the forest ecosystem services will be calculated. These metrics provide a more inclusive hydrologic, ecologic, economic, and social benefit analysis long term.

Project Benefits

This project proposes several benefits for the City of Bellevue. First, a GIS model to automate the manual portion of the basin analysis which will reduce the amount of time and resources required to conduct the analysis while standardizing and documenting the workflow process.

Secondly, a preliminary survey of the city-wide urban forest that utilizes new modeling software for evaluating urban forest extent, composition and economic benefits.

As an added value, the project suggests a manner in which integration may occur between these models. To date, this integration has not been utilized by the City of Bellevue and will result in additional detailed land cover information and economic information to enhance the basin analysis results.

Regional Case Studies

In order to evaluate contemporaneous methods of quantifying ecosystem service values and goals for increasing urban forest coverage, comparisons were made with similarly situated cities. Each of these cities has similar goals of increasing urban forest canopy coverage based on American Forest recommendations, but each have utilized a slightly different approach. These comparisons serve to inform the future study, model development, and implementation of a program to increase urban forestry in Bellevue.

Corvallis, Oregon

The City of Corvallis utilized i-Tree models to assess the ecosystem services provided by publicly owned trees in the Corvallis urban area. The ecosystem service assessments from two street tree data sets were run with i-Tree Streets and randomly selected plots

from public parks and other areas were run with i-Tree Eco. These two models estimate ecosystem services so the output data was summed.

Kirkland, Washington

The City of Kirkland received funding from the USDA Forest Service and the Washington Department of Natural Resources Urban and Community Forestry Program to assess their urban forest with GIS. AMEC Environment & Infrastructure, Inc. was commissioned to map the City urban canopy change over various spatial scales including parcels, basins and by zoning type. These values were computed both before and after annexation which nearly doubled the city limits. Six categories were derived and quantified from 2001 and 2010 Landsat NLCD imagery. Results: City wide canopy coverage (36 percent).

Issaquah, Washington

The City of Issaquah utilized 2006 aerial photographs to calculate areas of 100 percent and 90 percent forest canopy coverage in their parks and other public areas. The city also developed a guide for planting native trees, shrubs and ground cover. Results: City wide canopy coverage (51 percent).

Seattle, Washington

The City of Seattle is in the process of developing their 2012 Urban Forest Management Plan. The plan outlines the process of moving from 23 percent canopy coverage to 30 percent by 2037. The plan addresses environmental, economic, and social values, and will approach the management of the entire urban forest by dividing areas into nine management units. These units are classifications of developed areas such as single or multi-family residences, and right of ways. Areas of pervious surface without tree cover will

be analyzed with an algorithm to determine suitability. The report discounts previous surveys that utilized Landsat due to low accuracy and used i-Tree Eco for ground surveys which ran summer 2010 to summer 2011. The management plan focuses on interdepartmental teams who manage different aspects of the green infrastructure. Results: City wide canopy coverage (23 percent).

Bellevue Urban Forest Studies

The City of Bellevue has commissioned several projects over the years to evaluate their urban forests which utilized a variety of methods. Table 1 displays some of those methods.

Table 1. Bellevue Urban Forest Studies.

Contractor	Date	Focus	Model	Methods
American Forests	1998	Change in canopy coverage	Urban Ecosystem Analysis (UEA)	Landsat imagery
Major findings: Between 1986-1996 a loss of 12% of the urban forest canopy coverage; loss of stormwater runoff services valued at [(\$2/cubic foot); \$5,614,162].				
EarthCorps	May 2008	Forest Health; City Parks and Open Spaces	Forest Condition Assessment Model (FCAM)	Visual ground sampling.
Major findings: Class 1 forests=29%				
American Forests	2008	Canopy coverage; calculating urban forest service values	Urban Forest Effects Model (UFORE)	1985-2006 Landsat (USGS); 2007 2-ft pixel resolution digital imagery by land use category; true-color aerial photography
Major findings: Between 1996-2006 a loss of 9% of the urban forest canopy coverage; loss of stormwater runoff services valued at [(\$2/cubic foot); \$1,509,650].				
EarthCorps	2010-11	Forest Health; Public Parks and Open Spaces	UFORE	Plot based 100, 0.1 acre samples
Major findings: Class I forests = 34%. Invasive species list (Norway maple). Forest classes with the highest scores for health are a mix of conifer, wetland, mixed conifer/deciduous and pure deciduous trees, with considerable overstory tree density, substantial coarse woody debris, a dense native shrub layer and a healthy native herbaceous layer. Very low levels of invasive shrubs and herbs.				

II. System Requirements

The Project Sponsor utilizes PCSWMM, WWHM, ArcGIS (ArcMap, ArcCatalog), MS Access and/or MS Excel to conduct the basin analysis. The goal of this project is to create a model(s) to replace the manual processes performed in ArcGIS.

Hardware Requirements

Currently, the Project Sponsor uses a desktop computer that does not contain the standard “GIS specifications” that the GIS Team uses. Although the existing hardware the Project Sponsor uses will suffice for now, it is recommended during the next scheduled computer replacement, that the Engineer request the GIS Workstation which will provide more processing power for graphic and engineering applications. As a result, the Project Sponsor will need a GIS Workstation that includes a Windows 7 operating system (Appendix A – Technical Specifications).

Software and Networking Requirements

As mentioned above, the Engineer uses PCSWMM, WWHM, ArcGIS, MS Access and/or MS Excel for his analysis. However, to operate the storm drainage models, the Project Sponsor will need:

- ArcGIS 10x
 - ArcMap and ArcCatalog
 - ModelBuilder
- MS Excel or MS Access

The following software is required in order to run the urban forest model.

- ArcGIS 10x
 - ArcMap and ArcCatalog
 - ModelBuilder
- i-Tree <Modules>

Access to the City of Bellevue network and enterprise data is required for this project. The Project Sponsor currently has this access; therefore, no change is necessary for network requirements.

Personnel and Time Requirements

There are several personnel required to implement this project, however, it is the intent that once the models have been implemented, the resources and time requirements are reduced.

Project Sponsor: Uses the model to conduct basin analysis; answers questions regarding data and sign off on deliverables

GIS Analyst: Setup and install toolbox/model; train Project Sponsor; demonstrate model

GIS Team: Provide updates and/or troubleshoot any issues that may arise

Parks Department: For the integration piece, it will require

After implementing the storm drainage models, the time and personnel required to operate the models are reduced to just the Project Sponsor.

Other Considerations

Per the standards set by the City of Bellevue GIS Team, there are certain documents that are required for each project in which a Project Overview Statement (POS) has been submitted. The POS is submitted when a project will take over 40 hours of resources to complete. Since there were two graduate students working on the project and it would take over 40 hours to complete the project, a POS was completed. Other documents required are a Standard Operating Procedure (SOP) which states how the tools created are supported and the data maintained based on a specific schedule. A Project Plan which includes items such as Technical Requirements, Implementation Plan, and a Training Plan are also required and is the minimum information required for projects. All these documents should be factored into the time and

resources spent on the project and exclusive of the homework documentation required for the Capstone class.

III. Data Acquisition

The data for this project already exists therefore; no data is needed to be purchased.

However, some of the data does need to be converted, re-classified and clipped to meet the needs of the Project Sponsor and work for the basin analysis model.

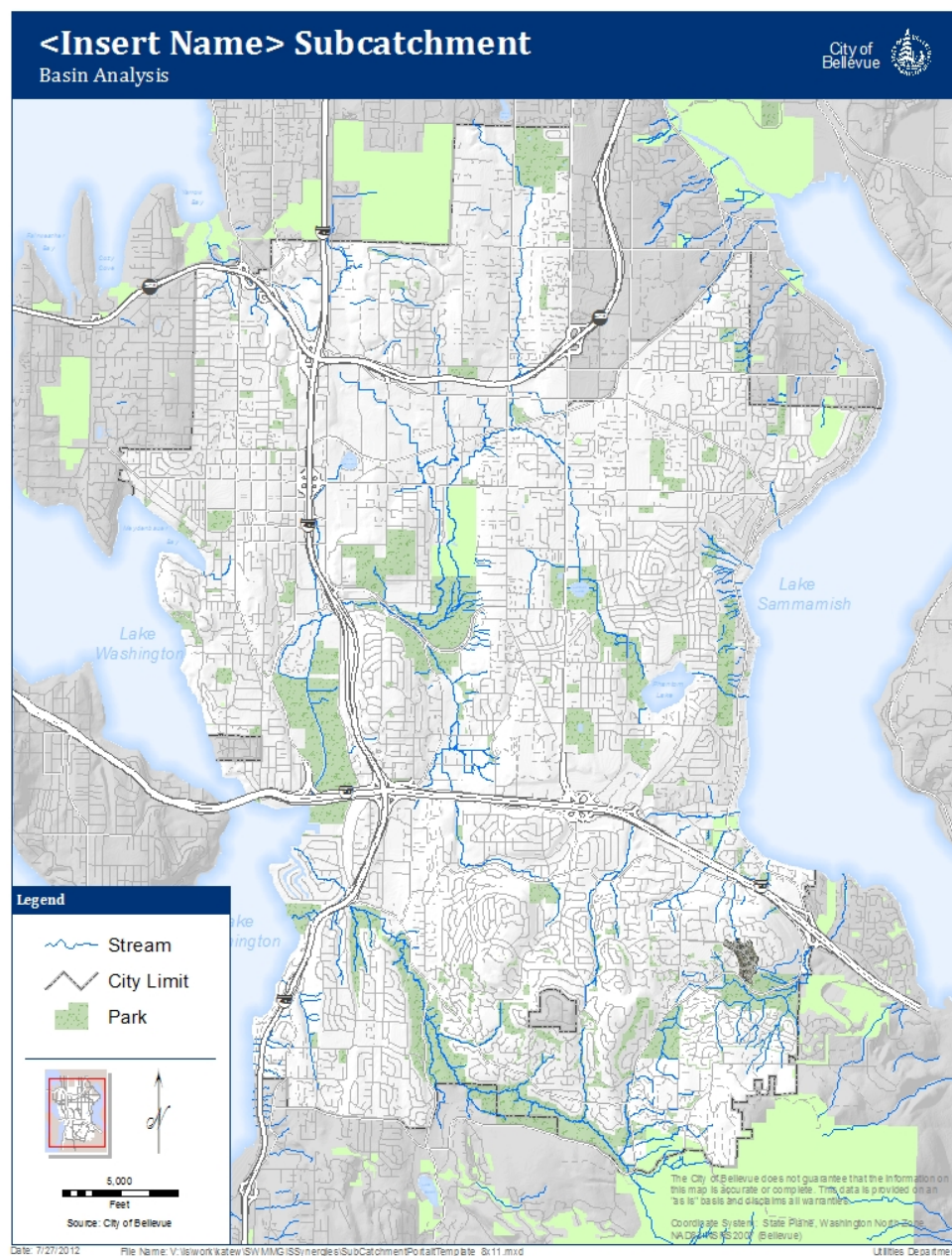
Data Design

The sections below outline the types of data design required to meet the needs of the Storm Drainage Engineer.

Storm Drainage Data Design

A template *.mxd (Figure 2) will be created and setup with the data the Engineer will need to perform the basin analysis, run the models as well as extra layers have been added to the template should he want to create a map of the subcatchment area. Once the models are finished running, the Engineer will be able to finish the basin analysis using PCSWMM and WWHM.

Figure 2. Storm Drainage Subcatchment Map Template.



Conducting basin analyses is increasingly performed by consultants; however, the Project Sponsor is currently the only Storm Drainage Engineer that conducts the basin analysis for Bellevue therefore a model that reduces the amount of time spent conducting the analysis will be well received. The basin analysis is conducted using methodologies

learned in college, certification courses and seminars, and Western Washington standards by using WWHM.

All data will be in the Bellevue NAD83, NSRS 2007 Lambert Conformal Conic projection. This projection was specifically created for the City of Bellevue GIS Team.

Urban Forest Data Design

The urban forest analysis will utilize three datasets; an existing completed survey of the city street trees, point data collected from aerial imagery from 2012, and a land cover evaluation with Landsat imagery using the National Land Cover Set (NLCD). These data sets will be processed by three i-Tree modules; i-Tree Street, i-Tree Canopy, and i-Tree Vue. These modules calculate land cover and urban forest benefits. i-Tree species was used as a stand-alone program for species suitability.

The complete inventory of the trees growing and maintained in the city public right-of-ways (ROW trees), were collected by the City of Bellevue. In addition to the common and scientific name of each tree species, the data set includes tree trunk diameter (90.6 percent) and canopy spread (83 percent) of the inventoried trees. The street tree survey was formatted for input into i-Tree Streets and ecosystem service values were calculated.

The city-wide land cover analysis was collected by classifying 1,700 points into 22 classes (Table 2). The i-Tree Canopy software randomly selects aerial imagery within the boundary of the shapefile provided (city limits) with a marker that designates the center of the image as the specific sampling site. The results are saved as *.dat files containing a feature ID, cover class, description, and latitude and longitude coordinates. This file can be re-loaded

for collecting additional sample sites or downloaded as a *.csv file formatted and loaded into ArcMap.

The aerial imagery taken during early 2012 during leaf-on conditions is approximately a 1:500 - 1:2,000 map scale. Accuracy limitation of the analysis depends upon the user's ability to correctly classify points into classes; therefore sample sizes should be large to decrease the standard error of the estimate. Another limitation is that imagery may be difficult to interpret areas due to image clarity from atmospheric conditions or poor image quality. The program does allow users to reposition the perspective of the image, for example, by moving from a north to south view. In a sample of 600 sites, there were only a few unclear images which limited ability to distinguish between deciduous and evergreen canopies, but this is not relevant to determining total canopy coverage.

These land cover values were then extracted for each of the 28 storm drainage basins. From this classification of points, a statistical estimate of percent cover of each cover class was calculated with the associated ecosystem services provided.

Table 2. Classification of Land Cover (2012).

Cover Class		Description	Abbr.
1)	Trees Broadleaf (deciduous)	Seasonal canopy	T-D
2)	Trees Needleleaf (evergreen)	Conifers	T-E
3)	Shrubs (woody, non-woody)	All shrub vegetation	S
4)	Grass (natural)	Wildtype areas	G-N
5)	Grass (lawns)	Grass manicured	G-Cul
6)	Ground Cover	Non-grass	GC
7)	Tree (ROW)	Trees in public right-of-way	T-ROW
8)	Building Residential	Residential areas	B-R
9)	Building Commercial	All commercial	B-C
10)	Roads Paved	All impervious roadways	R-P

Cover Class		Description	Abbr.
11)	Roads Unpaved	All pervious roadways	R-U
12)	Driveways Paved	Impervious driveways	D-P
13)	Driveways Unpaved	Pervious driveways	D-U
14)	Sidewalks paved	Impervious walkways	S-P
15)	Sidewalks unpaved	Pervious walkways	S-U
16)	Ponds	All open standing water	P
17)	Streams	All moving water	S
18)	Crops row	All planted row crops	C
19)	Crops fields	All open grown crops	C-F
20)	Riparian Vegetation	All plants in riparian zone	R-Veg
21)	Open Area (dirt)	All undeveloped disturbed areas	O-D
22)	Parking Lot	All parking lots	P

No real-time modeling will occur, but the analysis reports will be driven by queries that are developed by the City Engineer as he manually creates the landscape-level polygon for his analysis. This subcatchment polygon defines the initial spatial extent for the urban forest analysis model which in turn will be extended to the basin that contains the polygon.

This process will generate information products at various scales in which the Engineer and City Planners can use to quantify the benefits possible by urban forest development or enhancement in conjunction with the hard infrastructure remediation. The urban forestry aspect is more of an insurance policy against future hazards and is a longer-term view of remediation. The options delivered will be available for further analysis if that is deemed to be appropriate for the particular storm drainage basin analysis.

The third module utilizes the NLCD produced by the Multi-Resolution Land Characteristics Consortium (MRLC). The MRLC is a collaborative effort by several federal agencies in a collegial environment to provide digital land-cover and ancillary data to the nation. Many Federal institutions participate, including the U.S. Geological Survey (USGS),

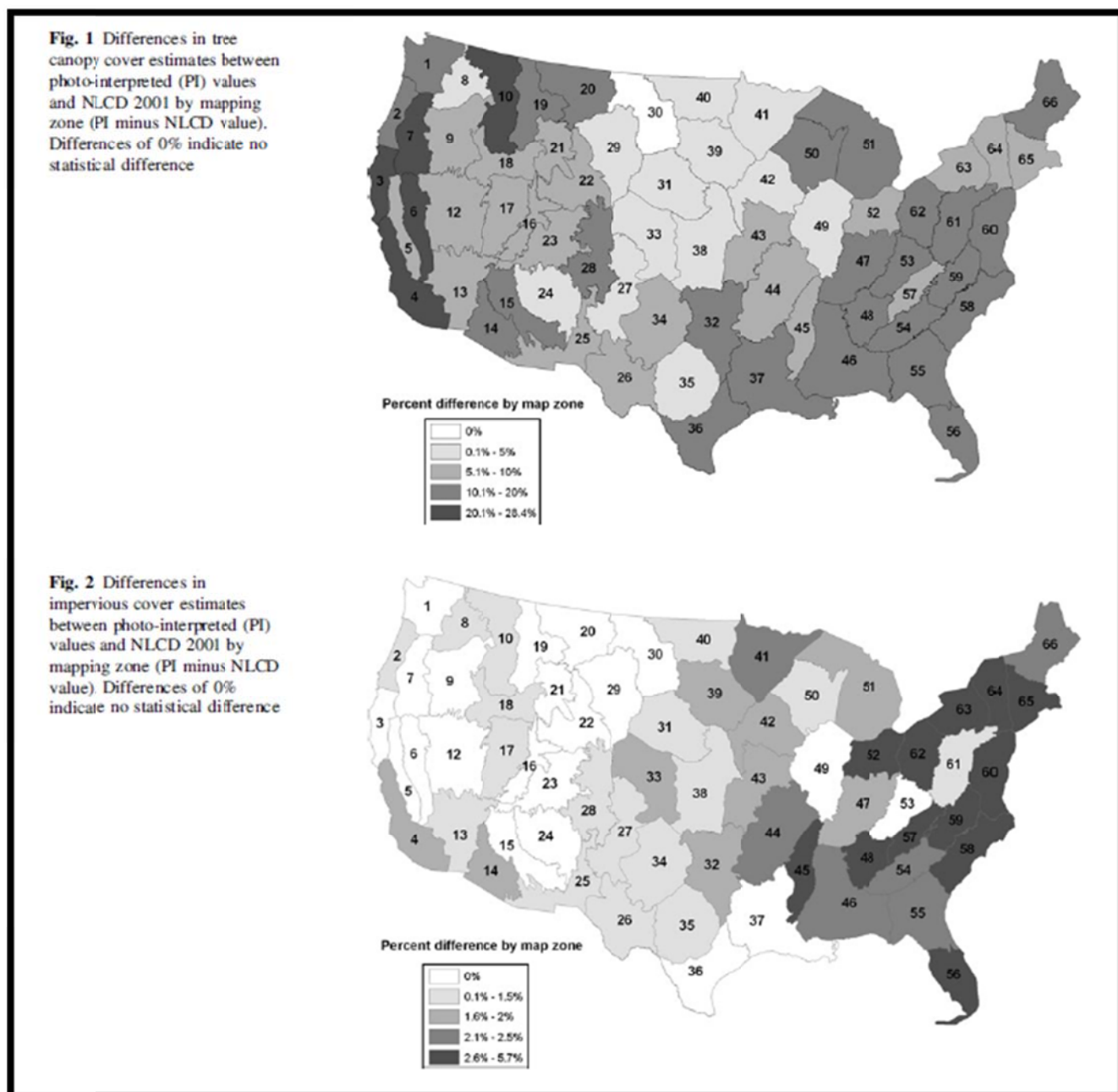
Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA) and the U.S. Forest Service (USFS). More recently the National Atmospheric and Space Administration (NASA) and the Bureau of Land Management (BLM), National Park Service, U.S. Fish and Wildlife Service (USFWS), National Aeronautics and Space Administration (NASA), Office of Surface Mining (OSM), and the Natural Resource Conservation Service (NRCS) have joined the consortium.

Three different land-cover databases are generated; land cover, impervious surface, and canopy density. Each relies on the same Landsat data collected from 65 NLCD mapping zones. These images were produced for 1992, 2001, and most recently 2006. Historically, NLCD has been a land-cover mapping program, but NLCD 2006 is being undertaken for making NLCD a land-cover monitoring program for spectral comparison of data sets and areas identified as land cover change. The classified change areas will be integrated into the NLCD 2001 to produce NLCD 2006. In short, NLCD 2001 will serve as the base map for NLCD 2006.

Dr. David Nowak is a member of the Science Board of Directors for American Forests and developed the formulas utilized in the UFORE (Urban Forest Effects) model. This model estimated the amount of ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide, and particulate matter that are less than 10 microns, are absorbed and filtered by tree canopies based on data collected in 55 U.S. cities. In 2010, David Nowak and Eric Greenfield published a paper that evaluated the accuracy of the NLCD (Nowak and Greenfield 2010). The results of this research showed that the NLCD significantly underestimates tree canopy coverage and impervious surface area with a national average underestimation of 9.7

percent and a maximum underestimation of 28.4 percent. The largest errors for canopy coverage occur along the west coast mapping zones and the highest for impervious surface occur along the east coast of the US (Figure 3). Impervious cover was underestimated an average of 1.4 percent and a maximum underestimation of 5.7 percent. As a result of his research, i-Tree utilizes a correction measure into their calculations. For Region 1 (Pacific Northwest) this adjustment is 11.6 percent for tree canopy which is a significant difference to the 99 percent confidence percentile, and 0.8 percent for impervious surface which is not statistically significant. Incorporating these corrections into the i-Tree Vue model produces better estimates of tree canopy, impervious cover and urban forest benefits. This represents a previous under estimation of the canopy coverage for the City of Bellevue.

Figure 3. Correction Across 65 NLCD Mapping.



Reprinted with permission of the author (Nowalk and Greenfield 2010).

Data Source

The data source for the storm drainage model will be the City of Bellevue Enterprise Data.

The data source for the urban forest analysis will be the City of Bellevue Enterprise Data, USGS

(including NHD), King County GIS Data Portal, i-Tree (USDA Forest Service, NE Division), and Department of Ecology.

Future Database Development

The storm drainage aspect of the project does not require a geodatabase; however, to keep all the files organized, a geodatabase has been created. The output from the model will be shapefiles and comma delimited files and saved in the specific basin analysis folder the Engineer created. The urban forest analysis will require a derived propriety geodatabase from analysis of the models.

IV. Data Analysis, Information Products, and Findings

This project is driven by the current basin analysis methodology of the City Engineer as he addresses ad hoc requests from inter-departments and the public. The existing process is a very manual and laborious process. Upon request from the City Engineer, the Project Team is designing a model that will streamline the ArcGIS basin analysis process thereby, reducing the number of hours and resources required to complete a request.

Storm Drainage Data Analysis

The Storm Drainage Engineer utilizes the following layers when creating the subcatchment layer: orthophotography, 2ft contours, impervious surface, pervious surface which combines the soils layer to the vegetative layer (Table 3), storm drainage pipes and structures, and streams. The proposed storm drainage workflow (Figure 4) provides a high-level overview of the process. In comparison, the existing storm drainage workflow (Figure 13 and Figure 14) has more steps to complete the ArcGIS processes for the basin analysis.

Figure 4. Proposed Storm Drainage Workflow Process.

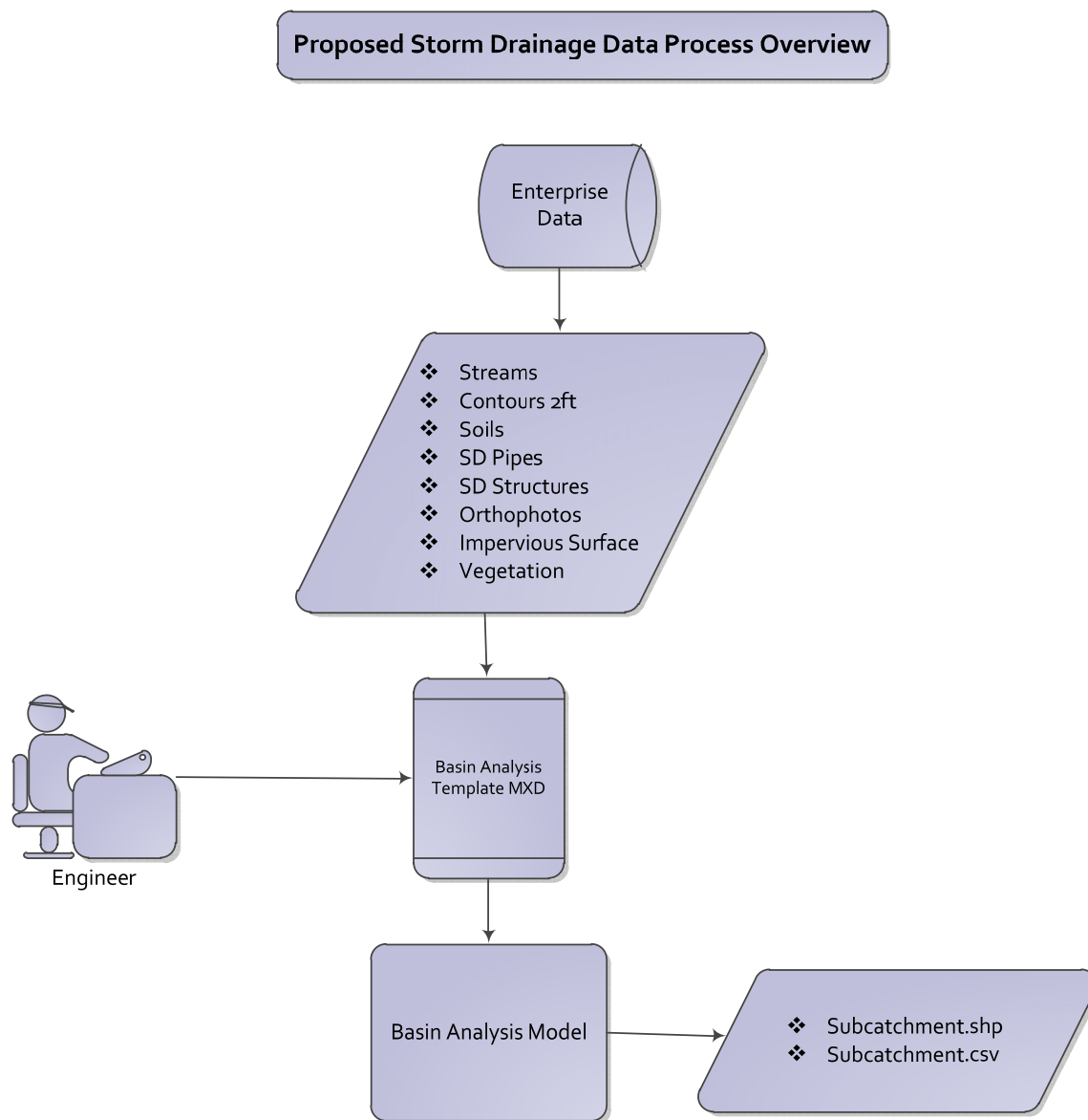
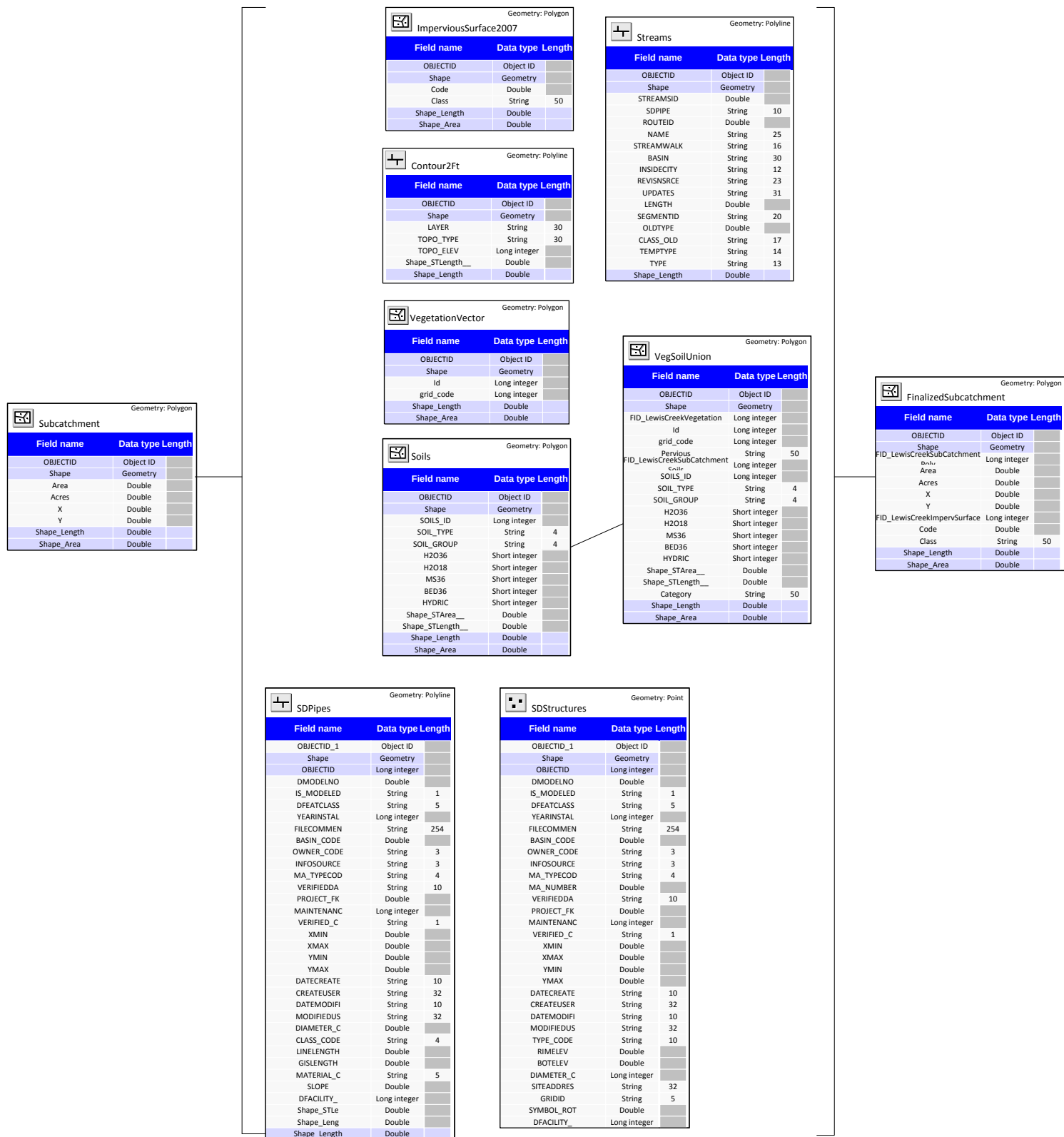


Figure 5. Storm Drainage Subcatchment Data Model.



The pervious surface data is obtained by overlaying the vegetation layer with the soils layer.

Table 3. Vegetation Data Mapping.

Vegetation Layer Mapping		
ExistingValue	Existing Class_Name	New Class_Name
0	unclassified	skip
1	non-woody	Landscaped Area
2	shrub	Pasture
3	deciduous	Forest
4	evergreen	Forest
5	blank	skip
6	impervious	Skip
7	water	Pond
8	bare	Impervious

Urban Forest Data Analysis

The City Engineer's analysis will mostly take place at the parcel level so the urban forest analysis will be expanded out to the watershed basin that contains the Engineer's entry polygon.

Modeling software, i-Tree, is a software suite developed by the USDA Forest Service and collaborators that provide urban forestry analysis and benefit assessment tools. These tools calculate the tangible ecosystem services that the urban forest provides based on peer-reviewed research and data based on the literature.

Electricity: The economic values are calculated from the energy savings for cooling due to shading of buildings based on energy costs. For monetary values, the electricity rate used was [\$0.1157] per kilowatt-hour [KWH], based on the average Washington residential rate for March 2012 (U.S. Energy Information Administration 2012).

Carbon Sequestration: The monetary value used for CO₂ carbon was \$0.0033 per pound (\$20.30 per metric ton or megagram [Mg]), based on the estimated social costs for CO₂ emission for 2001-2010 (Fankhauser 1994; Nowak et al. 2008).

Removal of Air Pollutants: The monetary value of pollution removal by trees is based on the median externality values for the United States for each pollutant, updated to 2007 values based on the Producer's Price Index. Total CO₂ sequestered (\$/lb.) 0.0033; NO₂ (\$/lb.) 0.94; PM₁₀ (\$/lb.) 1.67; SO₂ (\$/lb.) 1.88; and VOC (\$/lb.) 0.35.

Stormwater Runoff Reduction: The models take into account the seasonal variation in leaf area for evergreen versus deciduous trees, and calculate precipitation interception on an hourly basis from local weather records. The monetary value used was \$0.02779 per gallon based on cost studies in western Washington (McPherson et al. 2002). The construction costs for stormwater infrastructure are estimated to be \$10 per cubic foot for retention facilities in the Bellevue area (American Forests 2008).

Aesthetics: Determined by annual increase in private real estate values based on tree presence, size, and growth. The median home sales price of \$499,500 for Bellevue for April - June 2012 was used as the basis for this monetary value calculation (http://www.trulia.com/real_estate/Bellevue-Washington). In addition to these annual benefits, the models also estimate one-time asset values of replacement value (full cost to replace a tree with a tree of similar species, size, and condition; based on Council of Tree & Landscape Appraisers Guide for Plant Appraisal).

The i-Tree Streets module was designed for assessment of ecosystem services provided by street trees without using GIS. The module works with basic inventory data on tree species and

diameter at breast height (DBH) based on geographic location and worked performed in an intensively studied reference city within the same climate zone.¹ This also quantifies other aspects of tree structure including height, crown diameter, tree condition and relationships of the tree data to ecosystem services and their economic values. The climate zone for Bellevue is the Pacific Northwest, and the reference city is Longview, Washington (McPherson 2010), but electricity and real estate values were specific to Bellevue.

The assumptions are that the same proportion of buildings are air-conditioned as in the reference city for the energy savings calculations for cooling due to shading were appropriately scaled. The model is described in more detail in Maco and McPherson (2003) and the i-Tree Streets User's Manual (USDA Forest Service 2011). This baseline data can demonstrate a dollar value and allow for assigning priorities in city planning and effective decision-making.

The i-Tree Suite version 4.0 software is available free from the public domain at (www.itreetools.org), and includes analysis tools and utility programs of which the following will be used:

i-Tree Species is a free-standing utility designed to select the most appropriate tree species based on environmental function and geographic area.

i-Tree Streets centers on the ecosystem services and structure of a municipality's street tree population from a total inventory of street trees within the city limits to quantify the dollar value of the annual tree benefits.

¹ (http://www.itreetools.org/streets/resources/Streets_Reference_Cities_Science_Update_Nov2011.pdf)

i-Tree Canopy offers a quick and easy way to produce a statistically valid estimate of land cover types using aerial imagery available in Google Maps to estimate tree canopy cover and feeds other models that require land cover data.

i-Tree Vue utilizes national land cover data maps to assess a city's land cover, tree canopy, and some of the ecosystem services provided by the urban forest.

i-Tree Canopy Analysis Verification: Within the city boundaries six hundred sampling points were classified into twenty-two classifications from imagery. All coordinates were mapped and a Moran's-I test run to evaluate auto correlation; z-score = -0.86, variance of 0.0006, and p = 0.388. These score values indicate random sampling.

Table 4. Land Cover Classification; Initial Procedural Testing Results.

Cover Class	Description	Abbr.	% Cover
Trees Broadleaf (deciduous)	Seasonal canopy	T-D	11.2 ±1.29
Trees Needleleaf (evergreen)	Conifers	T-E	23.7 ±1.74
Shrubs (woody, non-woody)	All shrub vegetation	S	8.17 ±1.12
Grass (natural)	Wildtype areas	G-N	0.67 ±0.33
Grass (lawns)	Grass manicured	G-Cul	8.17 ±1.12
Ground Cover	Non-grass	GC	0.83 ±0.37
Tree (ROW)	public right-of-way	T-ROW	2.83 ±0.68
Building Residential	Residential areas	B-R	12.0 ±1.33
Building Commercial	All commercial	B-C	3.17 ±0.71
Roads Paved	All impervious roadways	R-P	7.83 ±1.10
Roads Unpaved	All pervious roadways	R-U	0.50 ±0.29
Driveways Paved	Impervious driveways	D-P	4.67 ±0.86
Driveways Unpaved	Pervious driveways	D-U	0.33 ±0.24
Sidewalks paved	Impervious walkways	S-P	0.33 ±0.24
Sidewalks unpaved	Pervious walkways	S-U	0.33 ±0.24
Ponds	All open water	P	7.67 ±1.09
Streams	All moving water	S	0.00 ±0.00

Cover Class	Description	Abbr.	% Cover
Crops row	All planted row crops	C	0.33 ±0.24
Crops fields	All open grown crops	C-F	0.00 ±0.00
Riparian Vegetation	All riparian plants	R-Veg	0.17 ±0.17
Open Area (dirt)	All open areas	O-D	2.50 ±0.64
Parking Lot	All parking lots	P	4.67 ±0.86

N=600

Figure 6. Proposed i-Tree Module Workflow for Baseline Data.

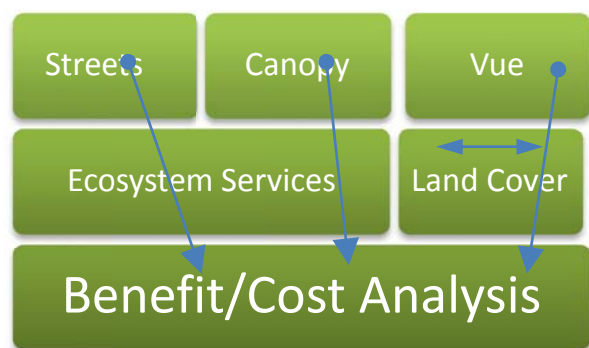
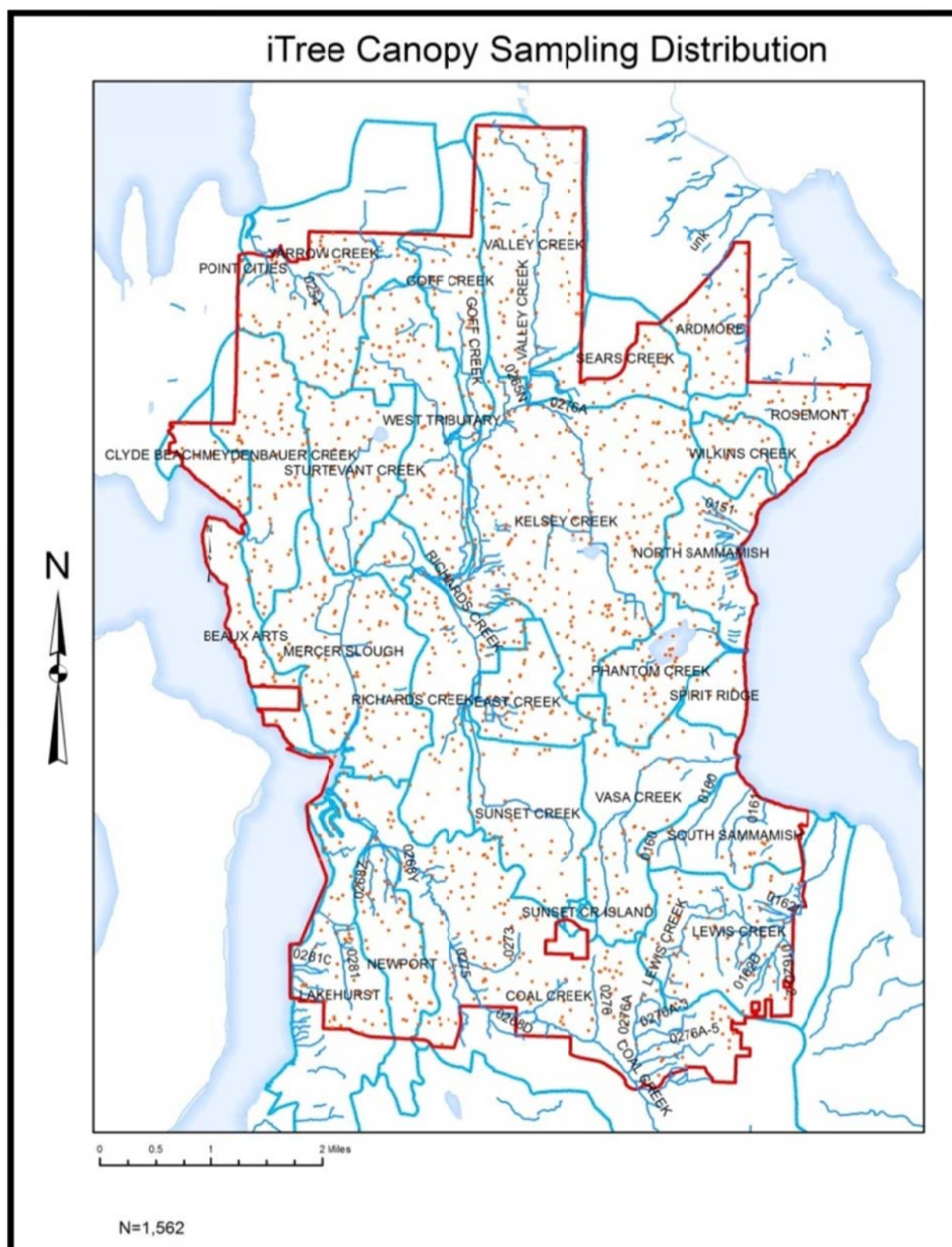


Figure 7. Phase II i-Tree Canopy Data Collection.



Urban Forest Input Data – Step 1

One of the products of the Engineer's normal process is an output polygon of the area of interest encompassing the total extent of his analysis. The Engineer develops polygons at the parcel level (1 - 20 acres), but also at much larger scales of over a thousand acres. This polygon will be the initiation entry point for the urban forestry analysis model. Due to the variance of storm water analysis, the urban forestry analysis will have two alternative paths. One will query at the parcel level to 10 magnitudes of size out of the Engineer's parcel and export this as a new layer (Figure 8 & Figure 9).

Figure 8. Phase II Site Selection Model Tool; Parcel or Basin.

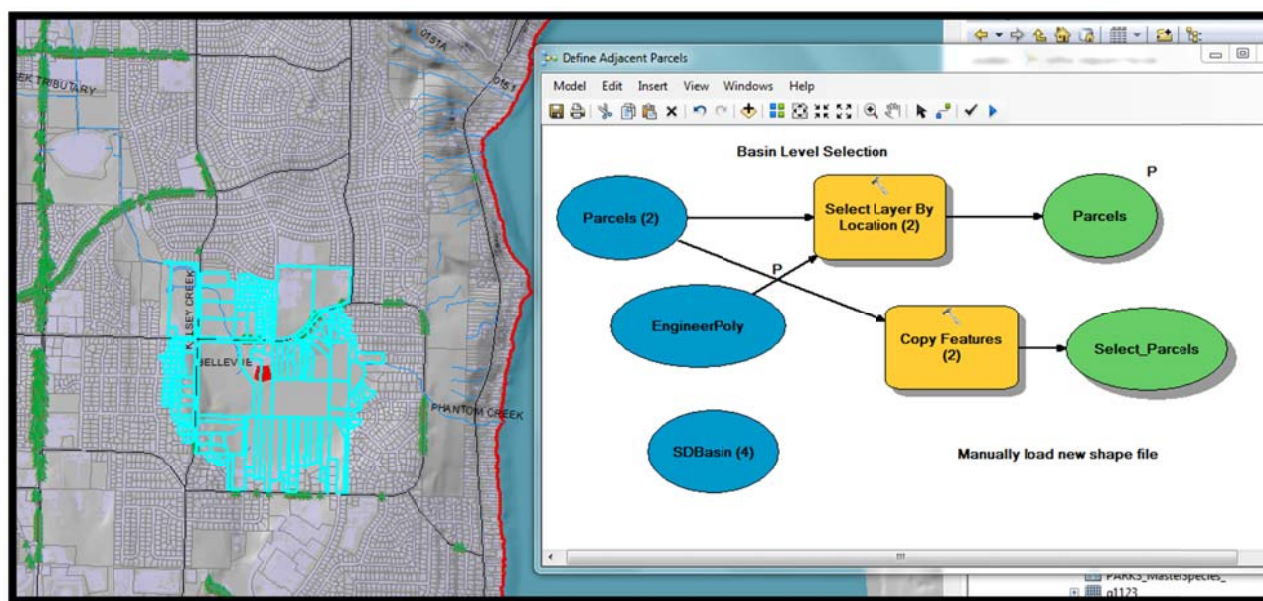
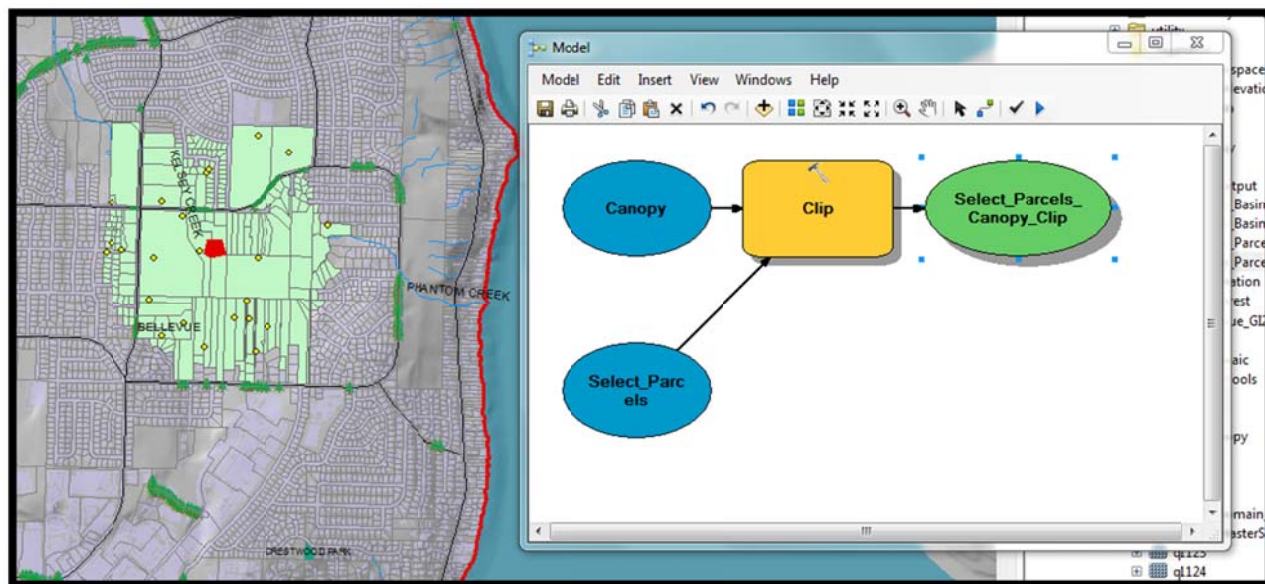


Figure 9. Phase II Canopy Clipping to Site Selection Model Tool.



The second alternate scenario will be to query out to the scale of the watershed basin that encloses the Engineers parcel. Rules will have to be applied when the parcel overlays more than one basin.

Figure 10. Phase II Canopy Clipping to Site Selection Model Tool.

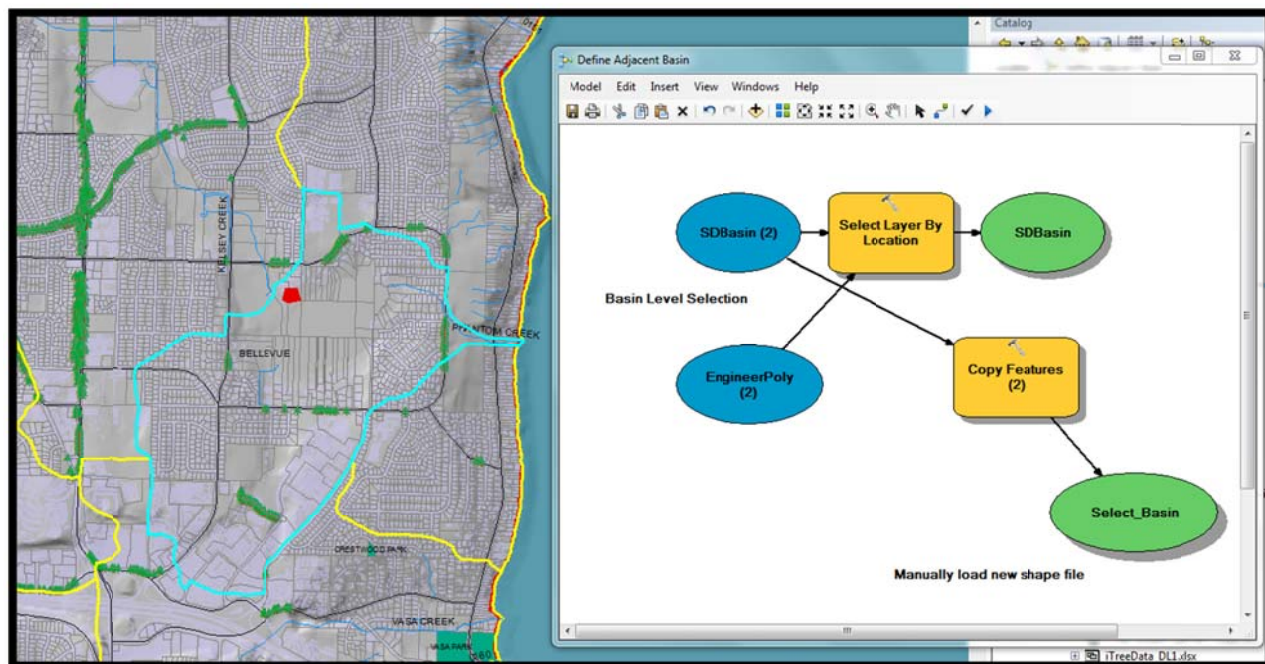
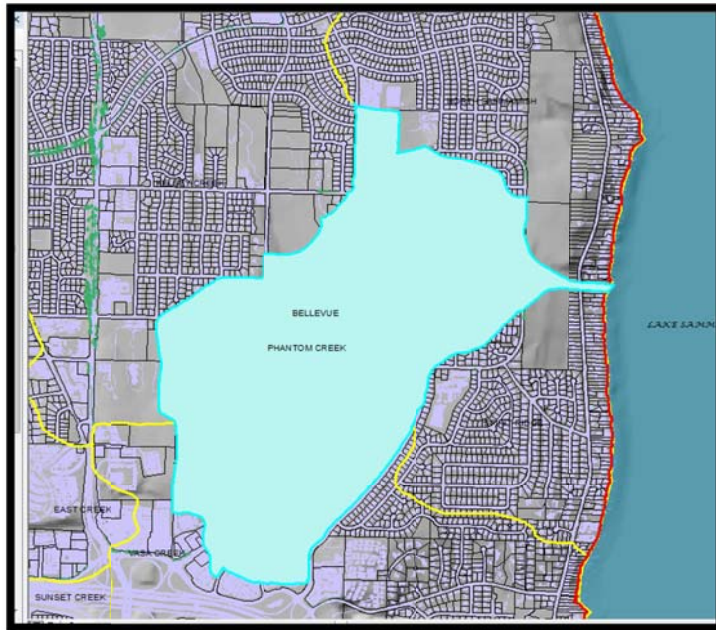
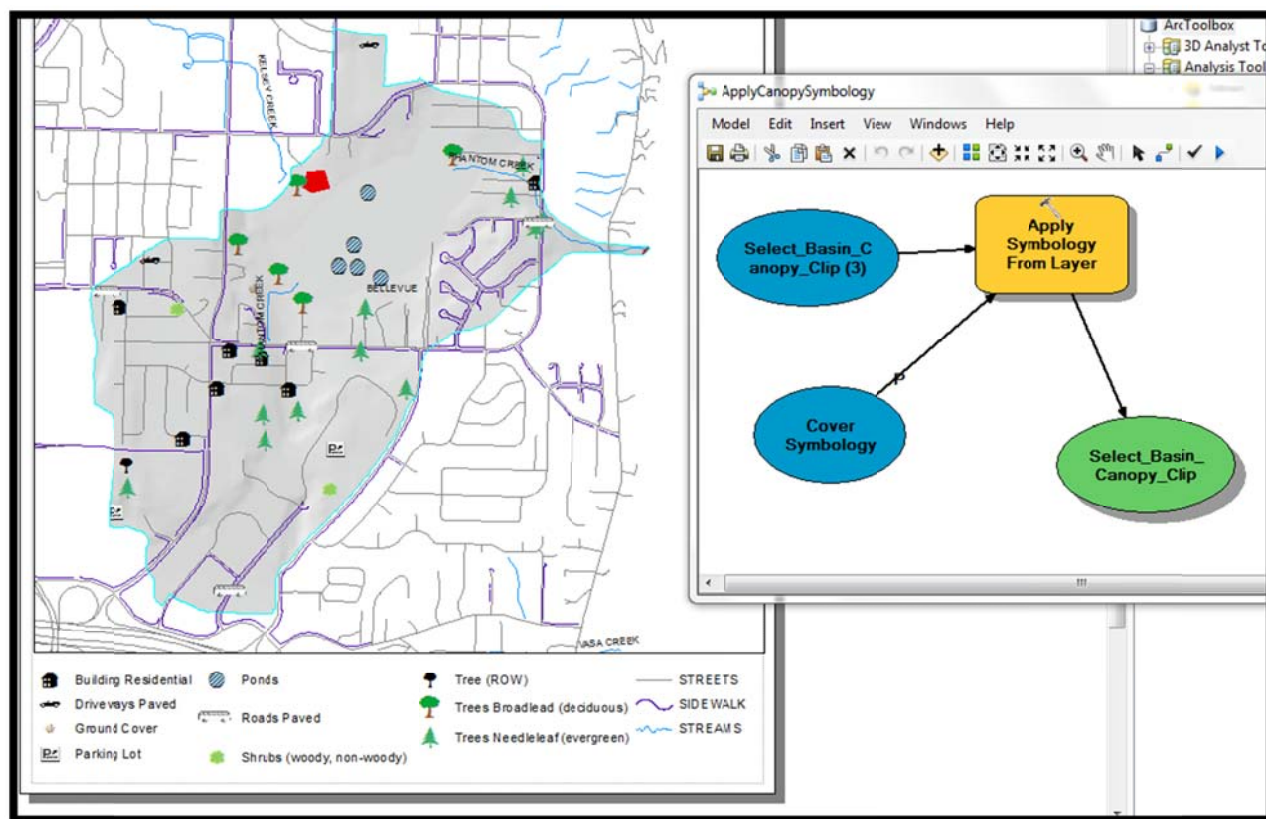


Figure 11. Phase II Site Selection Model Tool: Parcel or Basin.



Application of symbology will locate specific features on the landscape in conjunction with the existing city layers of impervious surfaces and vegetation.

Figure 12. Phase II Define Symbology of the Site.



Information Products

Storm Drainage

For the storm drainage component, the deliverables will consist of at least two models to facilitate the creation of the subcatchment layer: the subcatchment layer itself with the remaining data overlaid including calculations, and the resultant shapefile and tables of results for the Engineer to import into PCSWMM and WWHM.

The data from the ArcGIS model provides re-classified data that will be used in the WWHM. Table 5 depicts the categories necessary to feed the data into the Western Washington Hydrology Model.

Table 5. Western Washington Hydrology Data Categories.

Land Use / Vegetative Cover	Soil Type		
	A/B	C/D	Saturated
	Outwash	Till	Saturated
Impervious Area (Roof)	0	0	0
Streets/Sidewalks/Parking	0	0	0
Landscaped Area	0	0	0
Forest	0	0	0
Pasture	0	0	0
Pond	0	0	0

Western Washington Hydrology Model Basin Information

Figure 13. Existing Storm Drainage Geoprocessing Process Workflow.

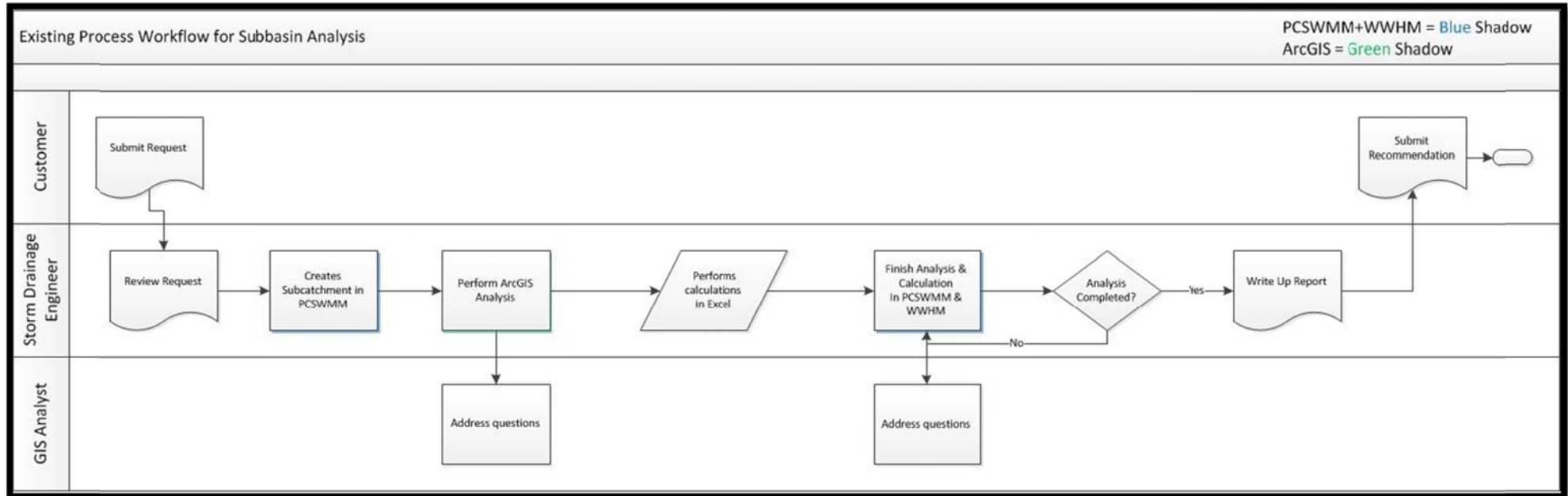
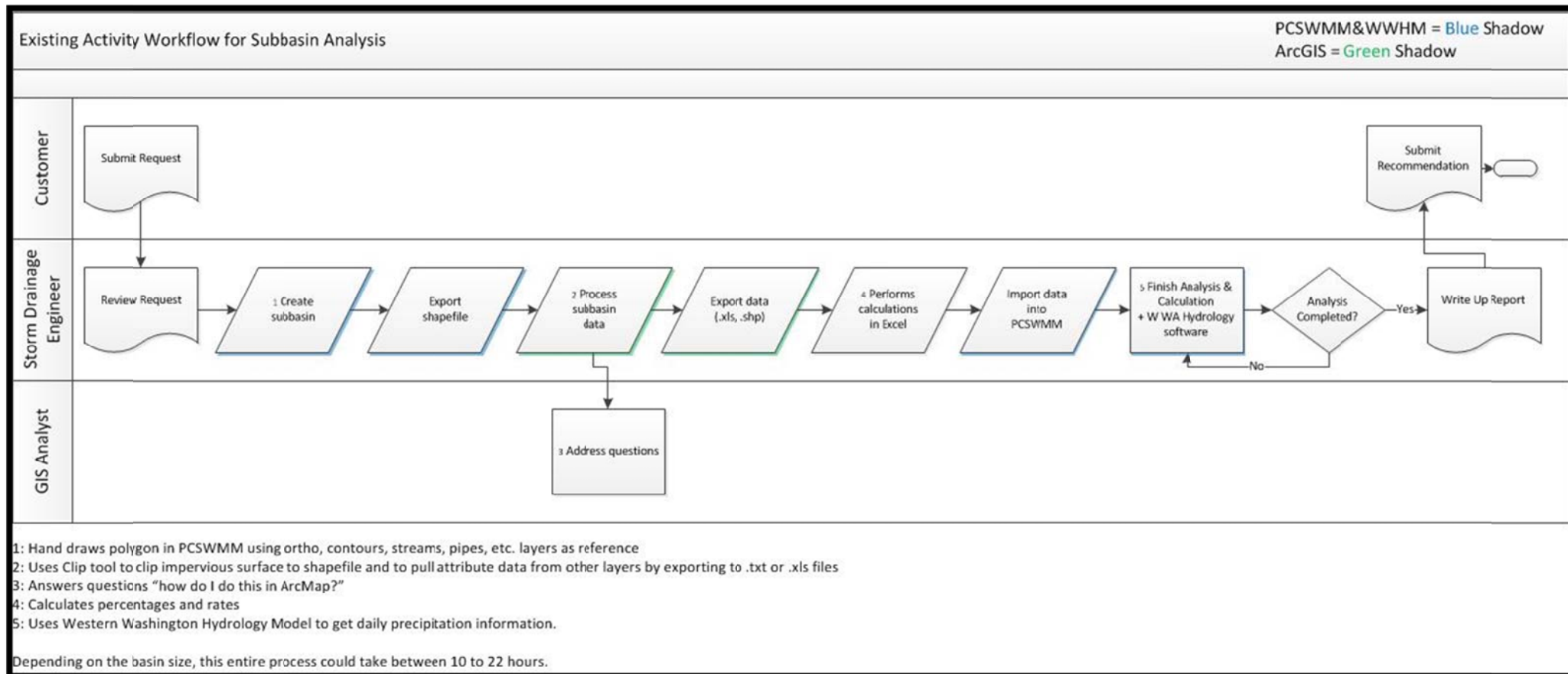


Figure 14. Existing Storm Drainage Geoprocessing Activity Workflow.



The urban forest workflow has not been included as it does not currently exist. This is new process that will be proposed as part of a long term goal for the Project Sponsors to work towards. Figure 16 depicts the proposed integration of the storm drainage model with the urban forest model.

Figure 15. Proposed Storm Drainage Geoprocessing Overview.

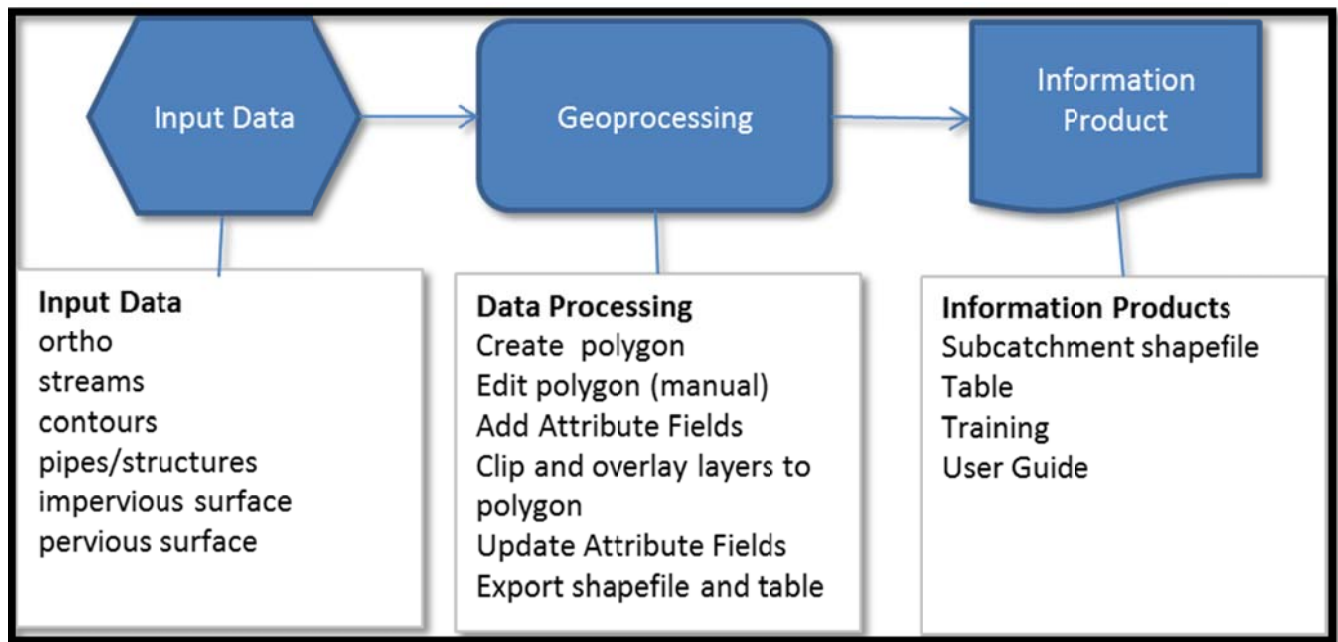
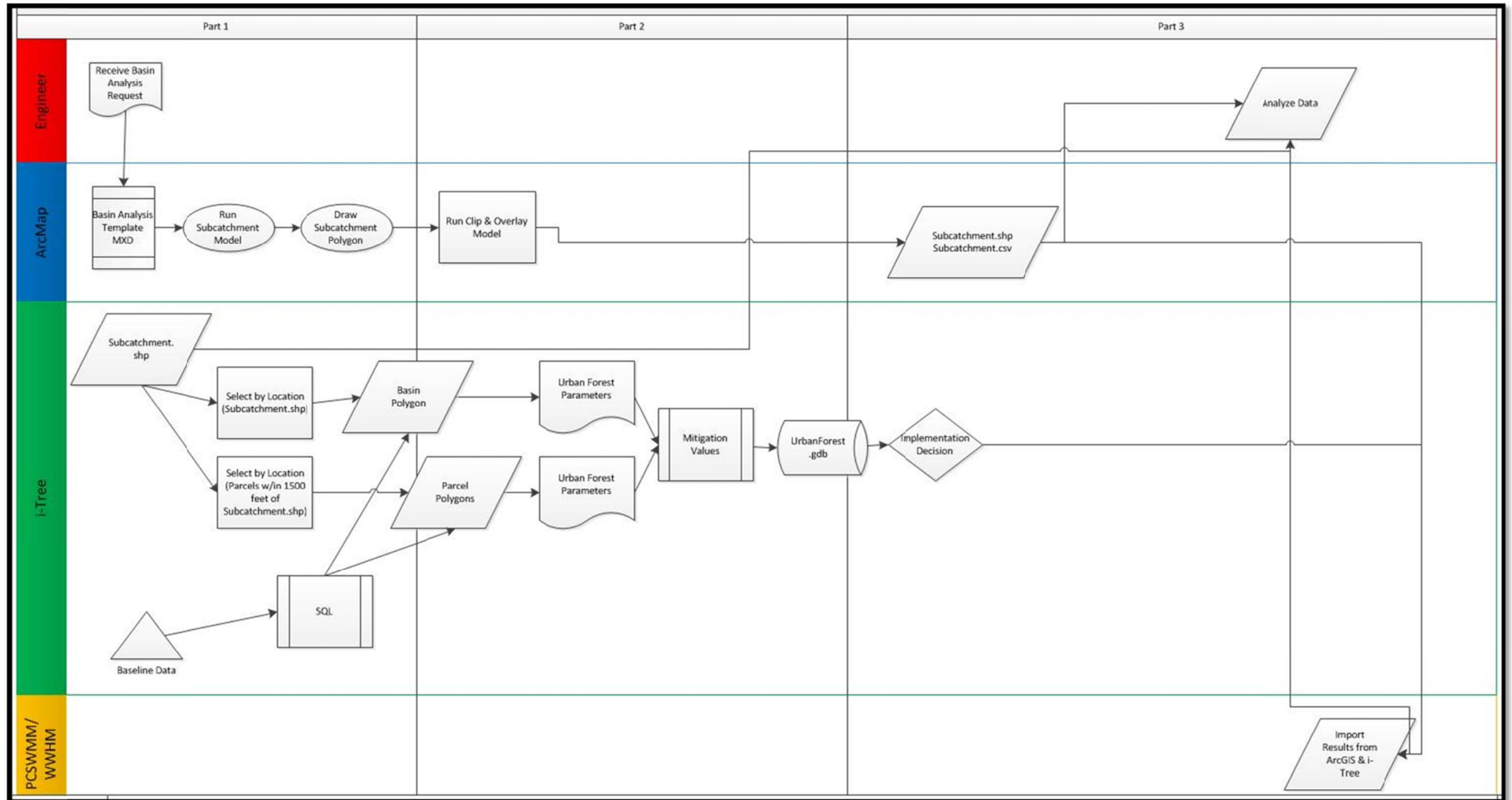


Figure 16. Proposed Integrated Process Workflow.

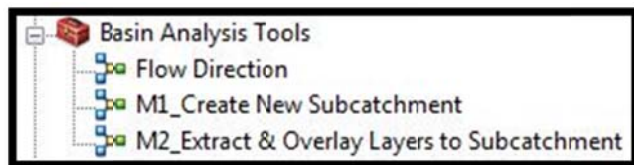


Findings

Storm Drainage Results

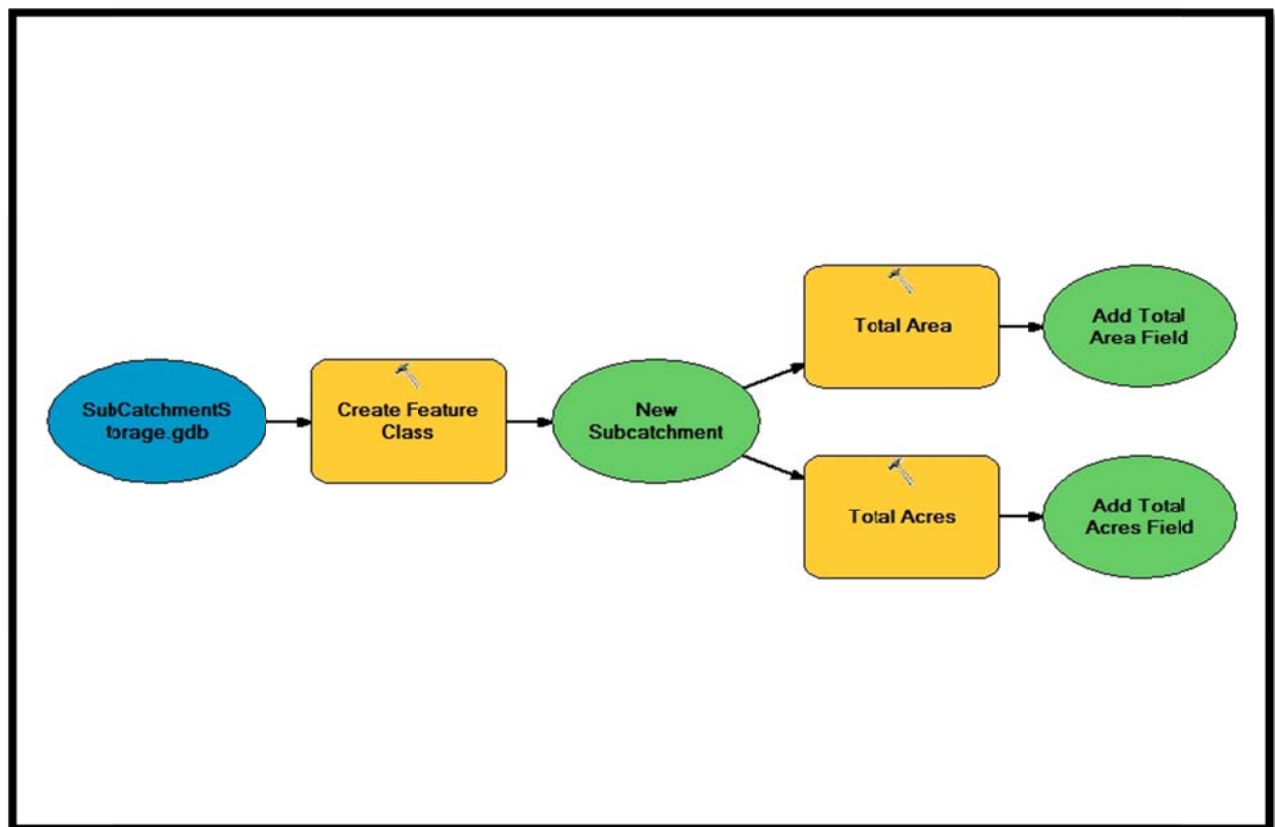
It is proposed to replace the existing ArcGIS process with two models that were created in ArcGIS ModelBuilder (Figure 17).

Figure 17. Basin Analysis Tools Using ModelBuilder.



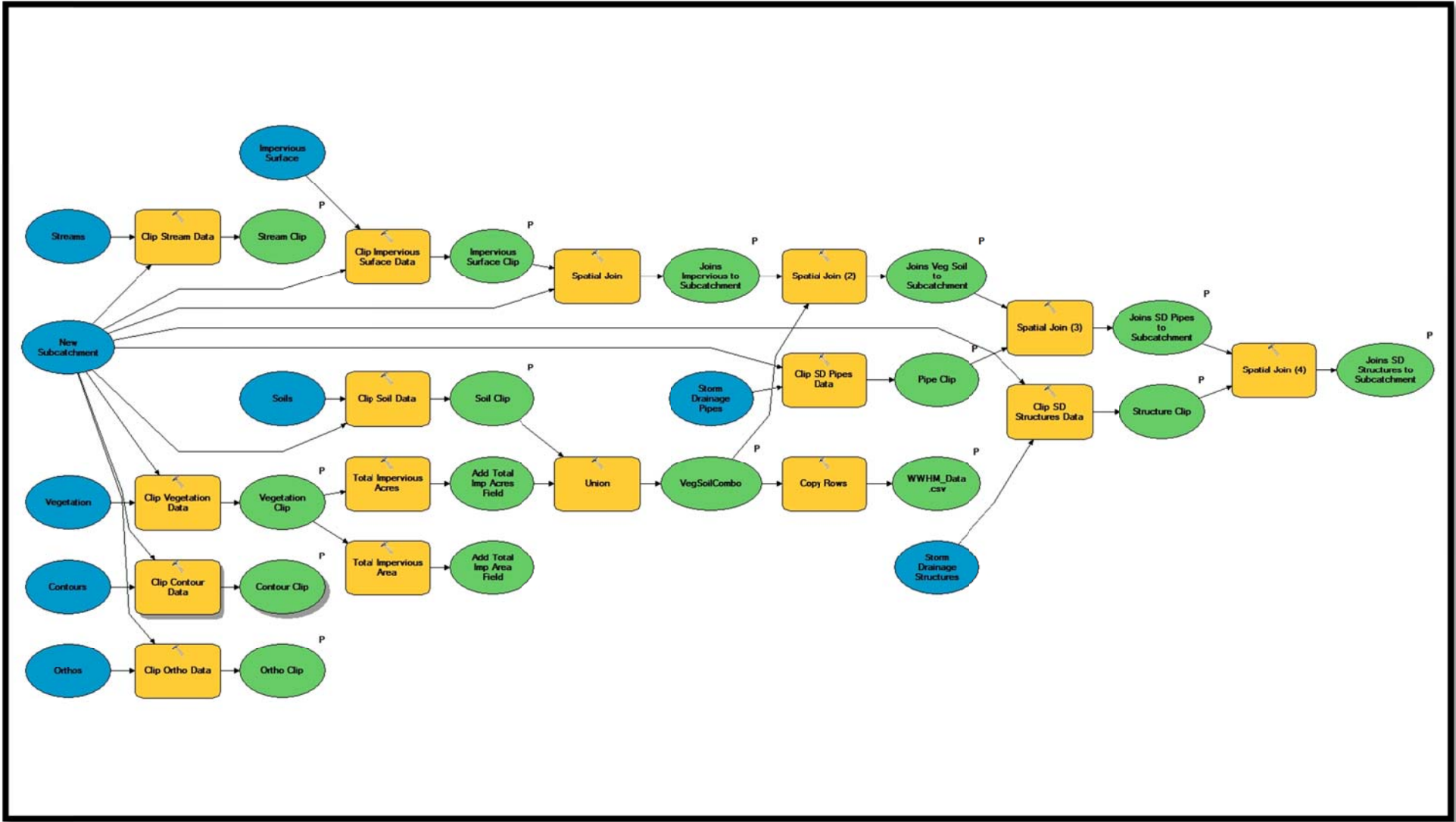
The first model (Figure 18) creates a feature class polygon, adds the Total Area and Total Acres to the attribute table, and adds the empty polygon to the .mxd.

Figure 18. Model 1: Create a New Subcatchment Model.



Next, the Engineer will be able to zoom into the applicable area, turn on the layers he needs to visually create the subcatchment and using the Editor Tool, start drawing the subcatchment. Once he finishes the new subcatchment layer, the second model (Figure 19) will be executed. The second model takes the newly created subcatchment, clips the required data to it, performs an overlay analysis using the Union Tool for the soil and vegetation layer; exports these combined data as *.csv and then spatially joins the remaining layers to the subcatchment layer and then the entire layer is exported as a shapefile.

Figure 19. Model 2: Clip & Overlay Data Processing Model.



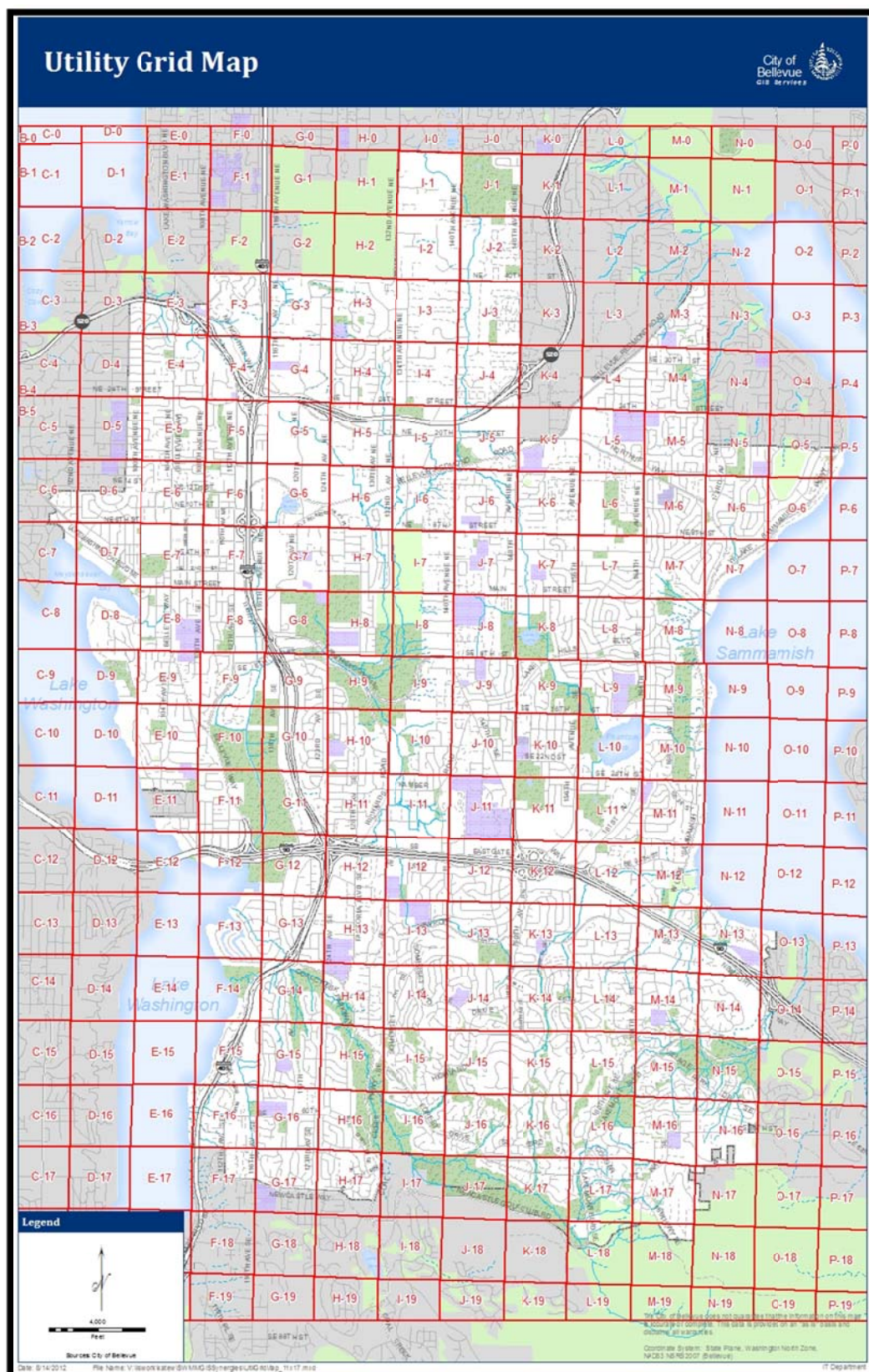
After running the models, it is estimated that by using these models to replace the existing ArcGIS processes, the models will save approximately four hours of the Engineer's time and effort per small basin analysis and approximately six hours of time for a large basin analysis. Additional immeasurable benefits arise out of this proposed project such as adding to the credibility of the analysis through model and process documentation, ability to pick up and use ArcGIS if he hasn't used it in a while, and decreases the amount of time he relies on GIS Analysts to address his questions.

Additional Information Products

In addition to the requested deliverable of a basin analysis model, the Project Team created a few extra products for the Engineer. A map template with all the required data plus, extra data layers to display on the map. The map template is formatted using the City of Bellevue standards and is setup such that the Engineer can quickly produce a map with the results of the basin analysis.

Next, a hardcopy of a utility grid map was created for the Engineer to post at his desk as a quick reference to narrow down the area he is looking to create the subcatchment (Figure 20).

Figure 20. Utility Grid Map.



Lastly, a flow direction layer is in the process of being created with the intent of replacing the use or in addition to the contour lines currently being used. This point layer with arrow symbology will allow the Engineer to identify more easily the path the water flows. This is an important piece of information that Storm Drainage Engineers use in their job. This last product has not yet been completed as the raster processing for the City of Bellevue is time intensive, but the product will be delivered to the Engineer upon completion.

Urban Forest Results

Table 6. Urban Forest Canopy Cover and Associated Benefits.

Urban Forest Canopy Cover:			
i-Tree Canopy (<i>photo interpretation = 44.5%</i>)			
i-Tree Vue (<i>Landsat classification = 48.4%</i>)			
Street Tree Total Societal Benefits			
	<u>Benefits(\$)</u>	<u>\$/tree</u>	<u>\$/capita</u>
Annual Benefits:	\$1,172,865	\$122.59	\$9.57
Costs:	\$224,800	\$23.50	\$1.84
<i>Net Benefits:</i>	<i>\$948,065</i>	<i>\$99.10</i>	<i>\$7.74</i>
Regional Canopy Air Pollution Removal Benefits			
	<u>Current</u>	<u>Proposed (+3%)</u>	<u>Grand Total</u>
Annual Benefits:	\$11,603,790	\$731,011	\$12,334,801

V. Cost-Benefit Analysis

The costs associated with this project are low as a result of utilizing existing hardware and software, open source software, and free resources in the form of two University of Washington Professional Master's in GIS students to conduct the research, design models, implement the streamlined processes, and provide training on utilizing the models and new processes. The expected proposed benefits of this project far outweigh the costs due to the free resources listed above as well as the intangible benefits listed below in the Strategic Analysis section. The information included in the Benefit-Cost Summary is based on the information typically gathered for this type and scope of project at the City of Bellevue IT Department. Resource salary amount is depicted using an IT blended rate that already includes costs for hardware/software replacement, troubleshooting issues, data maintenance, and data acquisition. Data acquisition is considered covered under the blended rate as the project is utilizing existing data and is already maintained by the appropriate personnel. Not covered under the blended rate is training.

Financial Analysis

It is anticipated that by providing a model to replace the existing manual process of creating a subcatchment, clipping, overlaying data, and performing calculations that the costs and benefits associated with the proposed process are of low cost and high benefits. It is estimated that approximately four hours will be saved on small basin analysis and six hours on large basin analysis using the new models with approximately four basin analysis conducted per year. As a result, the benefits to cost ratio within the first year are small, but positive at \$1.89 for every one dollar of costs spent using the scenarios of three small basin requests and one large basin

request are conducted. Extrapolating out to five years, the benefits to cost ratio increases exponentially as the costs drop to zero since any data maintenance or GIS Analyst assistance is covered under the IT blended rate. Net Present Value is \$527 per year using the formula $NPV = NVB - PVC$.

Non-capital costs considered for the financial analysis are: hardware, software, user training, data maintenance, data acquisition and (human) resources. For resources, the same amount of people will be performing the basin analysis and the GIS Team will continue to support the model and tools as part of the existing support contract. This does not change the dollar or time amount as the IT blended rate was used for calculations. The hardware amount does not change as it is part of the recommendation that when the Engineer is due for a new computer, the old computer will be replaced with a GIS Workstation (Appendix A – Technical Specifications) instead of a Desktop computer. Even the urban forest analysis utilizes open source software (i-Tree) as well as MS Excel and ArcGIS resulting in zero software costs. In addition, this meets the City of Bellevue's IT goals by utilizing existing software to meet the needs of the job.

Training: For user training on the storm drainage model, it has been estimated for five hours of each the Engineer's time and a GIS Analyst's time. The training will include setting up the toolbox the models are stored in, setting up the workspaces, showing the Engineer how to run the models, edit the data, and export the data for further analysis. In addition to the training, the Engineer has requested detailed documentation with diagrams be provided. The GIS Team Lead has requested that a Project Overview Statement (POS), essentially, an executive summary, and the Standard Operating Procedure (SOP) documentation be completed

for the project, be submitted for ongoing data maintenance. The POS and the SOP are part of the standard documentation, among other documents, required for every project.

Data Maintenance & Data Acquisition: The cost for data acquisition is zero as existing enterprise data is being used for the storm drainage model and for the i-Tree model. Data maintenance will be minimal as the majority of the data used is connected to the SDE Server where the enterprise data is housed. As a result, the data is updated on a regular basis as part of the standard operating procedure. Some layers such as the Vegetation vector layer and the orthophotos will need to be replaced during the next regularly scheduled data update which occurs every two years. Once the data is updated, the vegetation layer will need to be converted from a raster to a vector and the data reclassified to match the WWHM categories for further processing. A model has been designed to perform the conversion and reclassification to the vegetation layer and the information is provided in the SOP, documenting this business need and will become part of the biennial process for data maintenance.

Table 7. Storm Drainage & Urban Forest Non-Capital Costs Summary.

Storm Drainage & Urban Forest Non-Capital Costs		
Non-Capital Costs*	Current	Proposed
Resources	N/C	\$239
Hardware	\$0	\$0
Software	\$0	\$0
User Training	N/A	\$350
Data Maintenance	\$0	\$0
Data Acquisition	\$0	\$0
Total Costs:	\$0	\$589

Table 8. Storm Drainage Benefits Summary.

Storm Drainage Benefits	
Benefits	Cost Saves/Year
Engineer	\$738
GIS Analyst 1	\$377
Total Benefits:	\$1,115
Net Present Value:	\$527
Benefit-Cost Ratio:	1.89

Unique Urban Forest Cost-Benefit Calculations

A quantitative comparison of the urban forest cost-benefits will be available between the historic, current conditions, and enhanced conditions. The historic state of the City's urban forest is based upon the report "Calculating the Value of Nature" completed in 2008 by American Forests. This report quantified the loss of the ecosystem services (Table 10).

Table 9. Street Trees Cost-Benefit Summary.

Street Trees Benefit-Cost			
Benefits	Total (\$)	Per Tree	Per Capita
Energy	\$28,045	\$2.93	\$0.23
CO2	\$4,204	\$0.44	\$0.03
Air Quality	\$8,232	\$0.86	\$0.07
Stormwater	\$106,839	\$11.17	\$0.87
Aesthetic/Other	\$1,025,545	\$107.20	\$8.37
Total Benefits:	\$1,172,865	\$122.60	\$9.57
Cost**	Total (\$) Cost	Per Tree	Per Capita
Planting	\$30,000	\$3.14	\$0.24
Contract Pruning	\$70,000	\$7.32	\$0.57
Other Costs***	\$124,800	\$13.04	\$1.02
Total Costs:	\$224,800	\$23.50	\$1.83
Net Benefits:	\$948,065	\$99.10	\$7.74
Benefit:Cost Ratio:	5.22		

Net Annual Benefits: Citywide benefits and costs are presented according to category and summed. Net benefits are calculated as benefits minus costs, and the benefit-cost ratio (benefits divided by costs) is shown.

****Not accounting for pest management, irrigation, removal, administration, inspection/service, infrastructure repairs, litter clean-up, liability/claims, and other costs.**

*****Hand watering 120 street trees at (\$20/tree/week).**

Table 10. Bellevue's Loss of Urban Forest and Ecosystem Services (American Forests 2008).

	Tree Canopy Change (acres)	Tree Canopy Change %	Loss in Stormwater Value (cu. ft.)	Loss In Stormwater Value (\$2/cu. ft.)	Loss of Air Pollution Removal (lbs/yr)	Loss of Air Pollution Removal Value (\$)	Loss of Air Carbon Stored (tons)	Loss of Carbon Sequestered (tons/yr)
1985-1996	(499)	(12%)	(2,807,081)	(\$5,614,162)	(44,548)	(\$100,176)	(21,505)	(167)
1996-2006	(338)	(9%)	(754,825)	(\$1,509,650)	(30,093)	(\$67,669)	(14,527)	(113)
Total Loss		(21%)	(3,561,906)	(\$7,123,812)	(74,641)	(\$167,845)	(36,032)	(280)
Total Economic Impact				(\$7,291,657)				

Strategic Analysis

According to Lerner et al. (2007), the strategic analysis encompasses intangible benefits such as external benefits and interdepartmental benefits. Both the storm drainage and the urban forest aspects of the project propose several external and interdepartmental benefits such allowing engineers and GIS professionals to collaborate together by working on the same data. Most importantly, they meet several of the City of Bellevue's "One City" goals (City of Bellevue n.d.). They are:

- **Empowered work force:** By providing tools and training to employees so that they are empowered to seek innovative solutions to challenges.
- **Collaborative effort:** Working across departments towards a common goal.
- **Healthy and sustainable environment:** Contributing towards a green city, clean, reliable resources such as storm water management, and supports a healthy environment for current and future generations.

Other intangible benefits listed below speak to the GIS Team goals.

- Value added to existing business process through geospatial solutions
- Standardization of GIS to a mainstream technology within the company
- Development of models to re-engineer spatial solutions for new and existing business processes

As mentioned previously, other immeasurable benefits also arise out of creating a scalable, repeatable, and measurable model such as adding credibility to the analysis being

conducted through model documentation and model reproducibility, reduces the amount of time the Engineer needs to engage the GIS Team for support, and provides him the opportunity to use ArcGIS without having to remember all the processes since they are contained in the model which leads back to empowering the workforce by providing tools and training.

VI. Migration Strategy

This project is unique in that it does not require a migration strategy. The storm drainage aspect of the project is about streamlining existing business processes thereby reducing time, effort, and resources required to conduct a basin analysis. For this part of the project, the focus is on the implementation of the new toolbox and models that are rolled out during the training provided to the Engineer. The data used for the project is pulled from the enterprise data location.

The urban forest aspect of the project is new and is a proposed long term goal, looking ahead to see where the two departments can assist one another and at the same time mitigate stormwater runoff and its effects. The Parks Department is currently gathering data to be used in i-Tree and this is where the urban forest analysis provided in this report will assist in future endeavors of these two Departments. This analysis produces substantial information product that could be utilized for other yet unforeseen activities as well.

VII. Risk Analysis & Challenges

The risks associated with this project are minimal and typical of most projects such as resource availability, data availability, tools/technology performing as they should, etc.

ID	Risk / Challenges	Score	Mitigation
1	Resource availability: Summertime is a popular time to take vacation, other projects	High	Reviewed Project Sponsors calendar and scheduled meetings at the start of the project.
2	Data availability	Low	Reviewed Enterprise Data and requirements of analysis/processes to

ID	Risk / Challenges	Score	Mitigation
			see what was needed
3	Tools/Technology: Servers could go down, maintenance windows could interrupt work.	High	Try to work around known maintenance windows and troubleshoot issues quickly
4	Scope creep: too much to do for timeframe of project	Med	Defined what is in scope and out of scope for the project
5	Challenge of incorporating urban forest analysis into storm drainage aspect of project	High	Engaged the Parks Dept to provide insight on their data collection and analyses

VIII. Discussion and Recommendations

Storm Drainage

In order to meet the demands of the processing required for the models to run and loading the data, it is recommended that when the Project Sponsor is due for a new computer, he receive the “GIS Workstation” computer which has a higher processing speed and more RAM. This will address the slowness issues he is currently experiencing when loading the orthophotography, contour and impervious surface layers both in ArcGIS and PCSWMM.

Urban Forestry

The City of Bellevue residents (79 percent) agreed that the city should place a priority on improving the health and ecological function of forests, wetlands, lakes, and streams (Bellevue City Council 2010). In response to this large consensus, the city has a unique opportunity to expand and enhance its urban forest in several areas.

The street tree program managed by the Parks Department currently manages an inventory of over 10,000 trees in the public right-of-ways. Urban trees face a variety of stressors in the

urban environment. They are exposed to ground disturbances, increased root temperatures and physical damage which negatively affect their health, decrease their growth rates and also decrease the level of physiological functions that are the basis of the ecological services they provide. Trees under stress are less able to ward off pests and diseases routinely introduced in urban areas. This vulnerability will ultimately impose increased risks to wild forest in adjacent areas of the city.

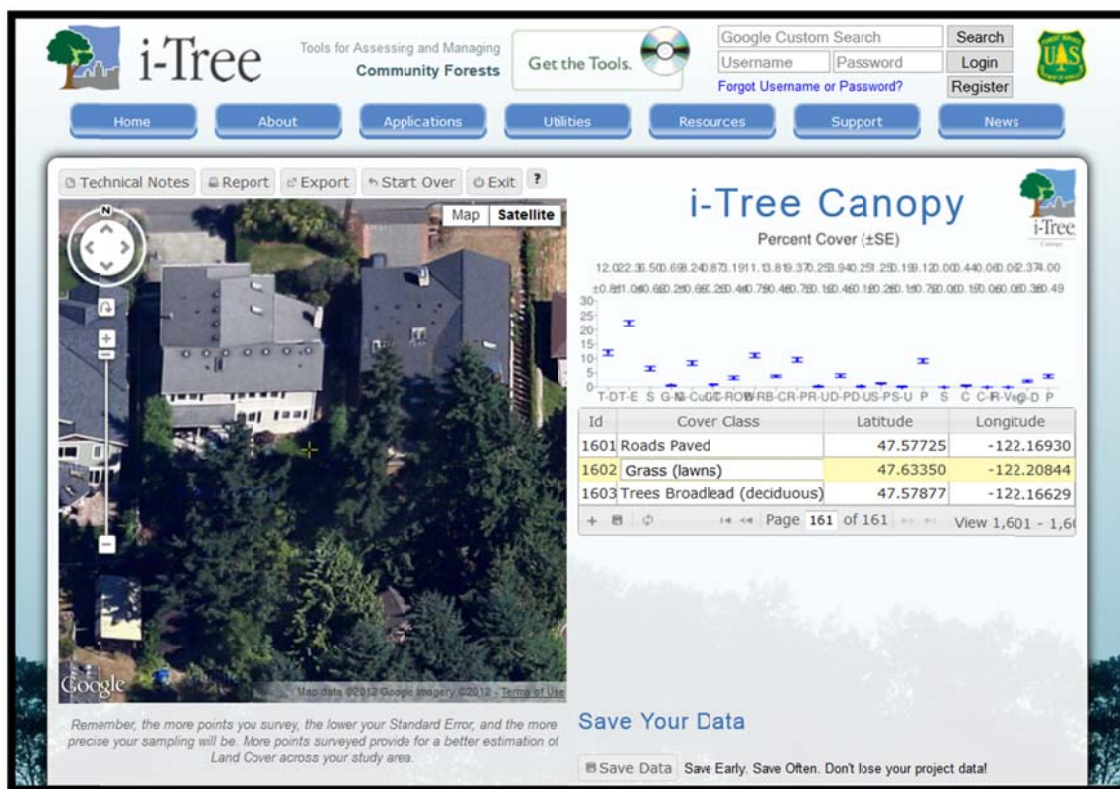
A collection of trees and shrubs in the urban setting is not an ecosystem and trees perform more ecological functions as a natural community of species. Planting more native species in their naturally occurring community structures will improve tree health and increase the delivery and amount of urban forest benefits. In Washington forests are classified by the dominant over-story and one or two predominant under-story species. These communities have evolved together for thousands of years in our region and complement each other in many ways beyond the scope of this analysis. As urbanization occurred over the last two hundred years the coniferous forests have been logged and what remains is fragmented. Ecosystem fragmentation results in declines in forest health and declines in biodiversity. The urban forest can provide continuity in process and contiguity in extent for our remaining wild forests if plantings are designed that build upon the wild forests just beyond their borders. A city has the ability to enhance our native communities which will ultimately lessen the threat from pests and disease agents while also providing a wild genetic influence in areas where natural recruitment is possible. In areas that offer sufficient space new tree plantings should be clustered with the appropriate community structure of species where they share root area. Root sharing also offers the benefit of consolidating manual water efforts where they are

required. In areas where trees cannot be planted in groups efforts should be made to foster soil microbial health with ground cover, natural leaf litter from leaf drop or other organic mulch to keep soils cool and moist.

Careful consideration should be given to planting introduced tree plantings that may negatively impact the regions' forests. The dominant tree in the street tree inventory is the Norway maple which was identified as an invasive species in unmaintained areas and which readily escapes into other areas. The city should not rely heavily on introduced species even if they offer substantial short-term benefits such as minimal costs for acquisition or maintenance as the long-term costs could be substantial when introduced organisms adapt to their new conditions and exploit their new territory.

In Bellevue as in most urban areas private land contains the majority of the urban forest. The city should actively engage private land owners to manage their trees in ways that serve to enhance natural settings and system function. A common occurrence that has been documented is that most private residences concentrate their tree plantings in the back yard. This practice has the added benefit of providing denser clusters of trees and shrubs which mimic small contiguous forested areas. If these clusters include large numbers of native trees, shrubs and ground cover the benefits are enhanced for local wildlife (Figure 20).

Figure 21. Example of Back Yard Tree Clusters.



IX. Future Directions

Sustainability science is the tool by which we measure social-ecological system resilience and techniques in this field are based on research, but rooted in delivering services. The science of sustainability seeks to inform the problems of stormwater runoff which is unique to modern industrial societies, but at its core, the issue of fresh water is universal in human scope. Fresh water resource management is bound by the acquisition and distribution of pure fresh water, and stormwater management is concerned with the channeling, detention, and purification of runoff. Water is a critical resource that is just beginning to establish an economic market on the scale of energy and agriculture. Developing strategies that will ensure, or at least improve, the sustainability of our fresh water resources requires consensus across multi-disciplinary fields

and through inter-departmental jurisdictions. This broad audience must view the resource from a perspective of shared commonality less one succumbs to the “tragedy of the commons.”

A primary objective of municipalities in King County is to improve stream health, reduce stormwater runoff, and decrease pollution delivery to the Puget Sound. Trees provide all of these services for free. The challenge is developing strategies that transition how our social-ecological systems have historically operated toward a mode of operation that is ecological sound, socially equitable, and economically viable (i.e., sustainable).

Utilizing natural resources in a manner that preserves their integrity, permits other organisms to thrive (not just exist), and instills confidence in the resources’ persistence over long time scales without pushing the ecological system beyond its carrying capacity is a tall order. This goal is particularly crucial to areas such as Bellevue that will undergo population growth. The City residents are motivated, informed and active participants in management of the cities natural spaces, parks, and trees. This represents a wealth of opportunity for moving the City towards sustainability. The implementation of urban forest initiatives that increase canopy coverage is expected to decrease the amount of runoff as development continues and more demands are placed upon the ecological services the city residents depend upon. The City has room for urban forest expansion which will reduce stormwater runoff, and the authority to control how the existing trees are managed. The City has many local rules that protect the urban forest, but must also comply with county, state, and federal rules in regards to water quality. Given these opportunities and constraints, there remains room for implementations that incorporate public participation at minimal costs.

Private property remains the largest source of the cities trees. Policies, practices, and public outreach that encourage urban forest expansion will provide long term benefits to residents and lessen the demands on the City's stormwater infrastructure. As trees grow, the services they provide compound providing increasing return on investment over time. The City can offer guidance in urban forest structure to guard against pest management issues, exotic plant establishment, preserving native plant associations, and wildlife habitats.

There is no doubt that the benefits of expanding the urban forest far outweigh the costs. Although benefits vary considerably by community and tree species, a five-city study found that the average tree returns \$1.50–\$3.00 for every dollar invested (Environmental Protection Agency 2012). For Bellevue, this value was calculated to be \$7.74.

However, these are complex issues and require thoughtful, comprehensive, and multi-tiered solutions. Shared responsibility, developing urban forest management zones by natural hydrology, soils and landscape, and rewarding desired practices will offer a variety of approaches to remedy the issue of storm water pollution. The old adage “variety is the spice of life” is especially true for sustainability in ecological systems.

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Appendix A – Technical Specifications

The GIS Workstation consists of the following specifications.

Product: HP Z420 Workstation

Operating Systems: Windows® 7 Professional 64

Processor: Intel® Xeon® E5-1603 2.80ghz 10MB 1066 4C CPU

Thermal Kit: HP Processor Air Cooling Kit

Graphics: NVIDIA Quadro 2000 1GB Graphics

Memory: 16GB DDR3-1600 ECC (4x4GB) RAM

1st Hard Drive: 500GB 7200 RPM SATA

Appendix B – i-Tree Methodology & Limitations

i. i-Tree Species Method

i-Tree Species is a free-standing utility designed to identify the proper species given the tree functions they desire. By providing a relative rating for environmental benefits of each tree species at maturity, this program is designed to complement existing tree selection programs that rank species for esthetics and/or other features. i-Tree Species rates the following tree functions, based on a user's ranking (0-10 scale):

- Air pollution removal
- Air temperature reduction
- Ultraviolet radiation reduction
- Carbon storage
- Pollen allergenicity
- Building energy conservation
- Wind reduction
- Stream flow reduction

ii. i-Tree Streets Method

Precipitation interception by leaves is the factor considered for mitigation of storm water in the i-Tree models. Water intercepted by stems, branches, and bark is not considered indicating a conservative model output. The amount of interception is also directly related to the leaf area index which is unique to the age, health, community structure, growing conditions, and species of tree. These factors determine leaf area and foliage depth. In addition the leaf area indices are only calculated for the upper surface of the leaves, again building a more conservative estimate of values.

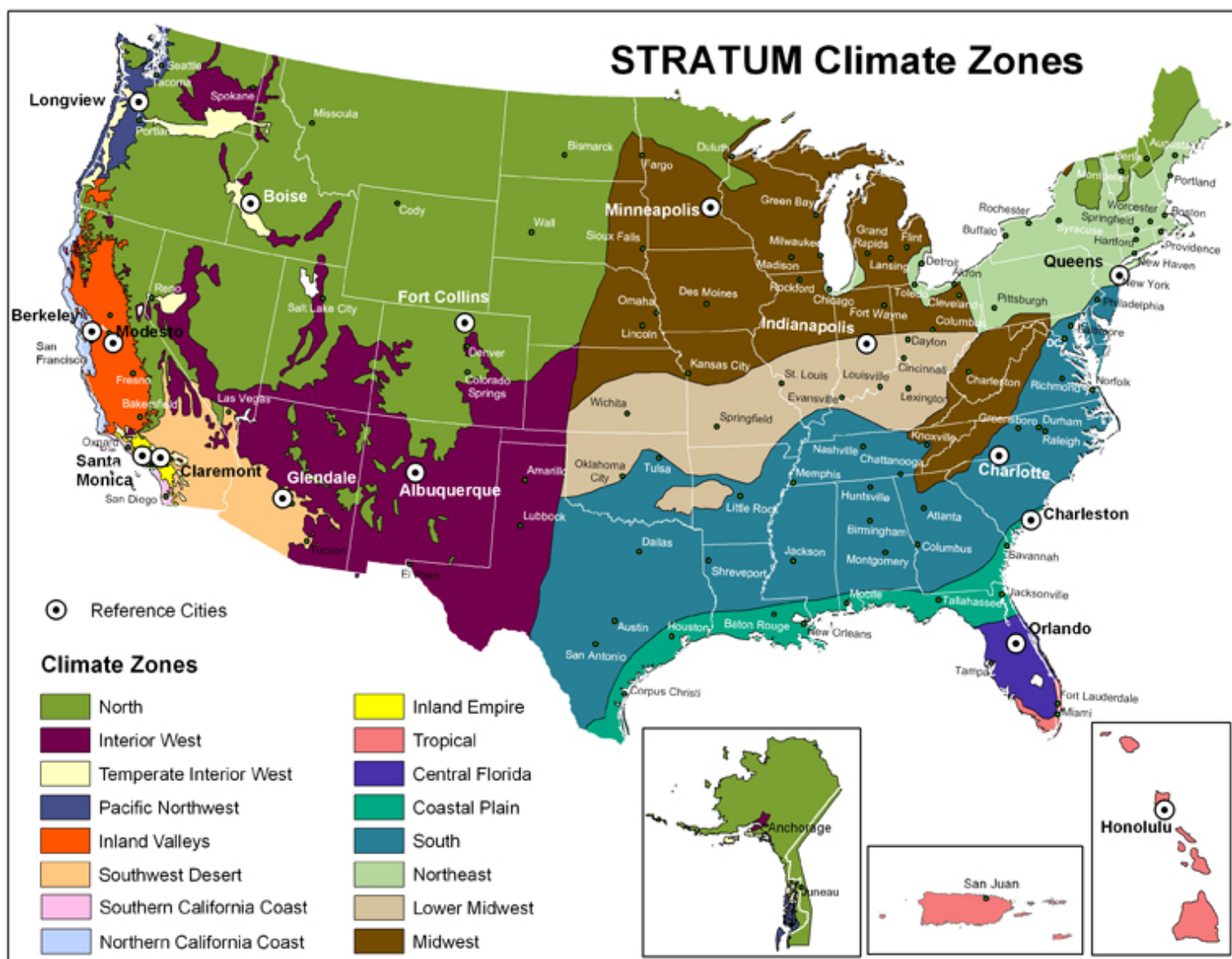
STRATUM is a legacy feature in i-Tree Streets requiring the STRATUM naming convention for database loading. The STRATUM Climate zones are utilized when you import a project into i-Trees Streets and choose the climate zone. Data specific to each zone is used to model the costs and benefits of trees. When you import a project into STRATUM you are asked to choose your climate zone (STRATUM Climate Zones Map, Figure 22). The STRATUM program uses data

specific to each zone to model the costs and benefits of tree species most likely to be found in your region, their size, rate of growth, how quickly they reach maturity, and leaf area.

Nineteen regional tree-growth zones, based on aggregation of climate zones from Sunset's National Garden Book (Eyre 1997), have been identified for the nation. Cities within zones are assumed to have similar species of trees with similar growth and size traits. The regional tree data are based on measurements from a Reference City (STRATUM Climate Zones Map).

Approximately 800 trees are randomly sampled—40 trees of each of the 20 most common species. For each species, five to ten trees from each diameter at breast height (DBH) size class are measured for DBH, tree height, crown diameter, crown shape, and tree condition. Planting dates are determined from city records and other local sources. Crown volume and leaf area are estimated from computer processing of tree-crown images taken with a digital camera. This method has shown greater accuracy for open-grown trees than other techniques (± 20 percent of actual leaf area). Regression analyses are used to determine regionally specific growth curves, so that the tree-related benefits can be estimated for each year of a tree's life.

Figure 22. STRATUM Climate Zones for Economic Value Calculation.



iii. i-Tree Canopy Method

The Canopy tool is designed to easily and accurately estimate tree and other land cover classes as set by the user within a set extent. The tool randomly lays points onto Google Earth imagery for the user to classify. Any class cover can set and the data is exported as point features with coordinates. The Bellevue city boundary was utilized for this analysis.

iv. i-Tree Vue Method

i-Tree Vue is a new program that provides coarse estimates of tree cover and some urban forest ecosystem services without collected field data resulting in estimates considered to be very coarse approximations with some significant limitations to the data and estimates. This method should be considered in conjunction with other data sets.

i-Tree Vue has several advantages, but also has some serious limitations:

Advantages:

- 1) Can provide coarse estimates of tree cover and air pollution removal and carbon storage and annual carbon removal (sequestration) for anywhere in the United States
- 2) No field data are required
- 3) Needed data can be derived from available data sets
- 4) User can visualize variations in urban tree cover and ecosystem services for their area
- 5) Allows users to simulate effects of changes in tree cover on ecosystem services
- 6) Ability to generate output datasets for use in GIS

Disadvantages and Limitations:

- 1) Generalized estimates – the basic approach to i-Tree Vue is to use spatial tree cover maps developed by the National Land Cover Database (NLCD) (<http://www.mrlc.gov/>) and apply average ecosystem service values per unit of canopy cover to estimate services of the local area. This generalized approach using national or state averages has significant limitations at the local scale.
- 2) NLCD tree cover estimates – NLCD provides tree cover estimates within 30 meter pixels for entire lower 48 states. This national database provides important information on our national tree resources, but has limitations, particularly at the local scale. Tree cover estimates from the NLCD cover maps underestimate tree cover in the PNW by an average of 11.6 percent so better estimates of tree cover can be obtain through aerial photo interpretation or LIDAR technology.

- 3) Air pollution removal estimates – to more accurately estimate pollution removal in a city, local pollution and weather data are needed, as well as local estimates of the leaf area index (depth of canopy) and canopy cover. As local data are unknown in i-Tree Vue (except for the estimate of tree cover), i-Tree Vue uses state average estimates of annual pollution removal per square meter of tree cover (g/m²/yr) to estimate local pollution removal assuming a local leaf area index of 6 (i.e., 6 m² of leaves (one-sided) per m² of canopy cover). As pollution concentrations, weather and urban forest leaf area indices can vary significantly at the local level, i-Tree Vue estimates are coarse at best. The closer your area conditions are to the state average and a leaf area index of 6, the closer the i-Tree Vue estimate will be for your area.
- 4) Carbon storage and sequestration estimates – to more accurately estimate carbon storage (amount of carbon currently in trees) and annual carbon sequestration (amount of carbon removed in one year) in a city, local environmental conditions (e.g., tree competition, length of growing season) and tree density, species, and diameter distribution information are required. Local tree data are unknown in i-Tree Vue (except for the estimate of tree cover), i-Tree Vue uses national average estimates to approximate local carbon effects. Carbon sequestration and storage values are estimated from tree cover (m²) multiplied by average carbon storage (9.1 kg C/m²), and sequestration (0.3 kg C/m²) density values derived from several U.S. communities (e.g., Nowak and Crane 2002, Nowak and Greenfield, 2008). As tree population and environmental variables can vary significantly at the local level, i-Tree Vue estimates are coarse at best. The closer your area conditions are to the group average, the closer the i-Tree Vue estimate will be for your area.
- 5) Dollar value estimates – monetary estimates of ecosystem services are based on literature estimates of values per ton of pollution or carbon. Monetary values associated with urban tree carbon storage and sequestration are based on the 2001-2010 projected marginal social cost of carbon dioxide emissions, \$22.8/t C (Fankhauser 1994). Pollution removal dollar value estimates were calculated using 1994 national median externality values used in energy decision making (Murray et al. 1994, Ottinger et al. 1990). The 1994 values were adjusted to 2007 dollars based on the producer price index (U.S. Dept. of Labor 2008). These values, in dollars/metric ton (t) are: Nitrogen dioxide (NO₂) = \$9,906/t, Particulate matter less than 10 microns (PM₁₀) = \$6,614/t, Sulfur dioxide (SO₂) = \$2,425/t, Carbon monoxide (CO) = \$1,407/t. Externality values for ozone (O₃) were set to equal the value for NO₂. Externality values can be considered the estimated cost of pollution to society that is not accounted for in the market price of the goods or services that produced the pollution.

- 6) Although there are limitations to the estimates, the i-Tree Vue is designed to provide easy first-order estimates of ecosystem services for urban areas. These data can be used to view variations in existing cover and services, potential changes in services with changes in tree cover, and provide a stepping stone to provide more accurate estimates of services through i-Tree Eco. Data can be used to illustrate the types and general magnitude of service to aid in advocacy for better management and assessments. These data should not be considered as final or accurate estimates of urban tree cover or environmental services.

Air Pollution Removal Methods

Air pollution removal estimates are derived from the Urban Forest Effects (UFORE) model (Nowak and Crane 2000) and 2000 weather and pollution data (National Climatic Data Center 2000, U.S. EPA 2008). The UFORE model was used to integrate hourly pollution and weather data with urban or community tree cover data to estimate annual pollution removal in each state (Nowak and Crane 2000, Nowak et al. 2006).

To estimate pollution by urban trees in each state, state pollutant flux rates (grams of pollution removal per square meter of canopy per year) were derived from a study of national pollution removal by urban trees for the year 1994 (Nowak et al. 2006). As pollution concentrations vary through time, the 1994 flux rates were adjusted to 2000 values based on average regional pollution concentration changes between 1994 and 2000 (U.S. EPA 2003). As flux rate = deposition velocity * pollution concentration, the ratio of the pollution concentration between years was used to update the flux rate.

Arithmetic mean concentration values were used for nitrogen dioxide, particulate matter less than 10 microns, and sulfur dioxide, 2nd Max. 8-hr average for carbon dioxide, and 4th Max. 8-hr average for ozone, to determine the ratio of change between 1994 and 2000 (U.S. EPA 2003). The new 2000 flux rates are multiplied by urban or community tree cover to estimate total pollution removal by trees.

NLCD Imagery Technical Notes

NLCD image data are stored as values from 0 to 100 in each image pixel. As such, results of the New Tree Canopy estimates are necessarily rounded. This rounding has the potential to skew user-defined tree cover estimates in the output tree canopy dataset by up to one percent. Errors increase with decreasing spatial scales. In addition, Carbon and Pollution values are not actually stored in the image pixels as rounding them would reduce their usefulness. Instead, tree canopy - existing or new estimates - is stored in the image pixels. Within i-Tree Vue, the Carbon and Pollution values are then computed on the fly for display in the Pixel Information windows. After export of Carbon or Pollution images, the user can multiply the stored tree canopy values by their chosen carbon and pollution values in their GIS system of choice.

Projection System (see <http://www.mrlc.gov> for more information):

Projection ALBERS; Datum NAD83; Units METERS

Leaf Area Index Notes

The leaf area index (LAI) of trees, shrubs and ground cover is calculated measurement of a one-sided green leaf per unit ground area. The global range of coverage values are 0.1-0.18 (minimum; desert and tundra) to 47.0 (maximum; a peculiarity of one allometric method for estimating all-sided LAI in coniferous tree stands). The mean LAI ($\pm$ standard deviation), distributed between 15 land cover classes (biomes), range from 1.31 ($\pm$ 0.85) for deserts to 8.72 ($\pm$ 4.32) for tree plantations. Evergreen forests (needleleaf and broadleaf) have the highest LAI among the natural terrestrial vegetation classes. Units are m^2/m^2 or dimensionless.

Only 14% of the global records have LAI greater than 8.0 (a typical maximum value for one-sided or projected LAI, unlikely to be exceeded except with peculiar conditions or methodology.) Many variables are associated with LAI including latitude, longitude, time of measurement, methodology, biome / land cover, dominant species, leaf type/ leaf angle, year of measurement, elevation, and stand age.

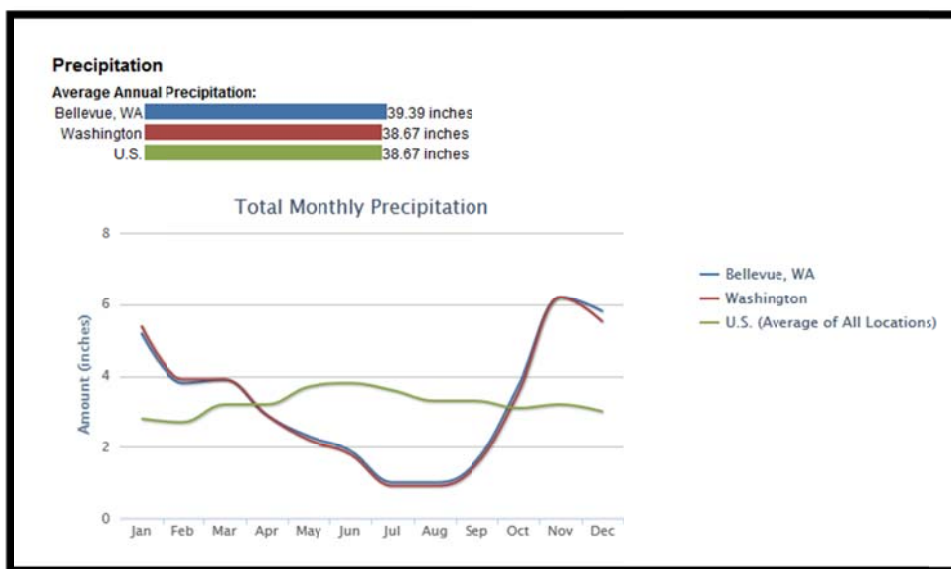
Methodologies differ for determining LAI and have changed over time, but the maximum values reported in the scientific literature are for coniferous forests which are also the most commonly measured biome/land cover types in the Global Leaf Area Indices (<http://daac.ornl.gov/index.shtml>) compilation, with 22% of the measurements from temperate evergreen needleleaf forests, and boreal evergreen needleleaf forests and crops being the next most common (~9% each).

Additional ancillary variables have been suggested by a number of sources, including time course (phenology) of LAI, fPAR (fraction of photosynthetically active radiation intercepted by the canopy), and leaf area density distribution within the canopy. Strictly speaking, LAI alone is a rather broad descriptor of a study site and assumes random distribution of foliage within the canopy - this may not be adequate for modeling of photosynthesis/radiation absorption at the stand level, although a general LAI is more useful for regional/global scale modeling.

[The leaf area index (LAI) used for the Seattle/Bellevue zone (47.17, -121.83) was taken from the Global Leaf Area Index Data (Scurlock 2001, Revised June 2002). This value was an average from the compilation of 1,000 published estimates and 400 unique field records from 1932-2000. The average for the area was [3.52].

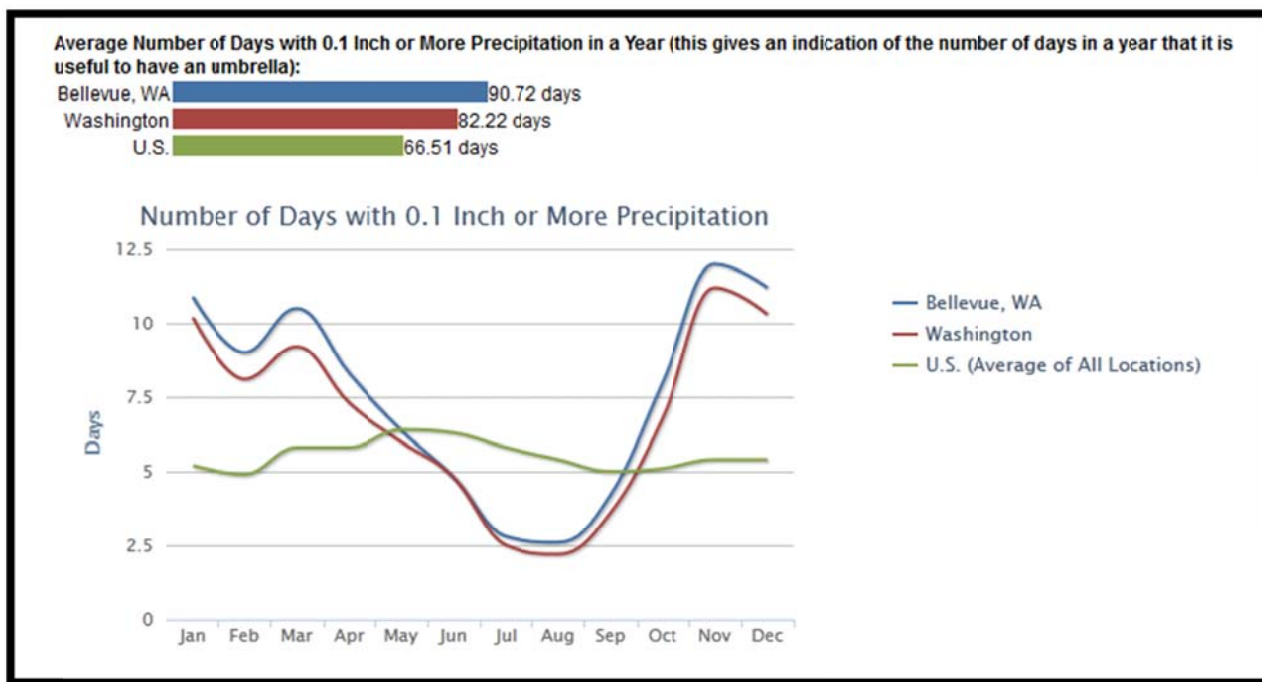
The average annual precipitation in Bellevue is 39.39 inches which is slightly higher than the average for Washington State (38.67 inches) and the United States (38.67 inches). The months of lowest rainfall occur from June through September with most precipitation occurring between October through March (<http://www.usa.com/bellevue-wa-weather.htm>).

Figure 23. Total Monthly Precipitation.



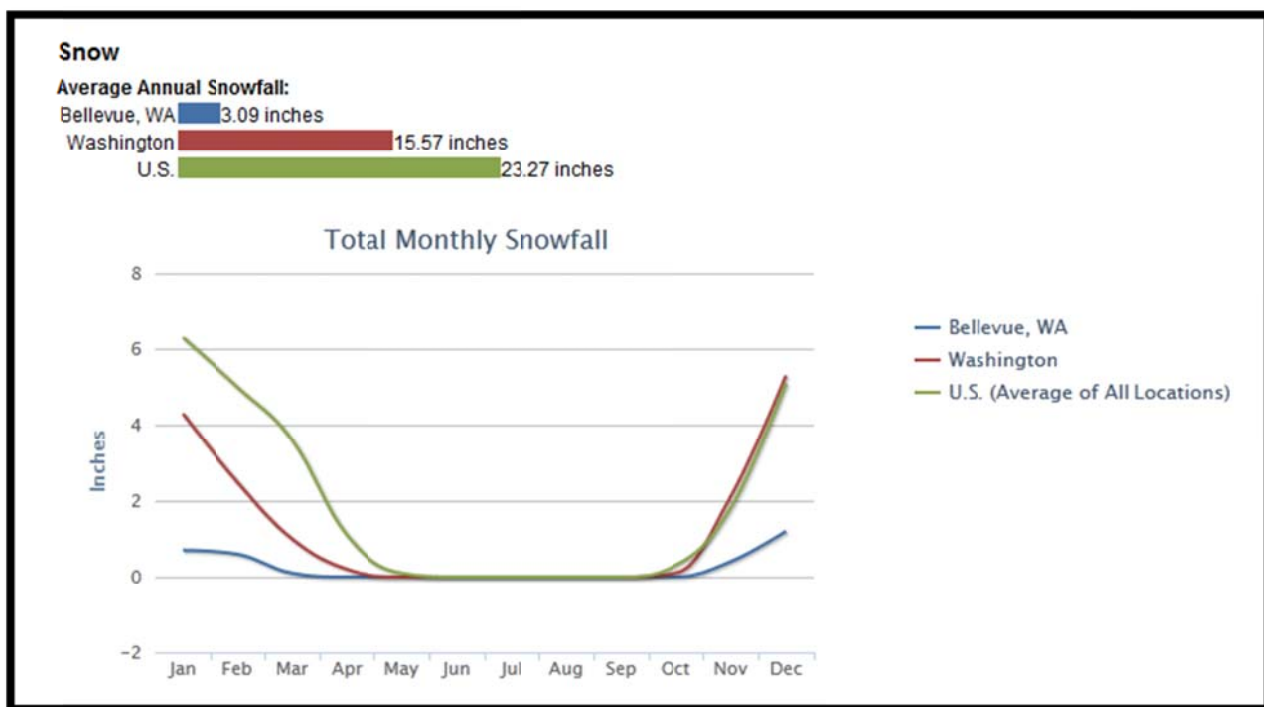
The average number of days with 0.1 inch or more in a year. Bellevue 90.72; Washington State 82.22; and the United States is 66.51 days (<http://www.usa.com/bellevue-wa-weather.htm>).

Figure 24. Annual Precipitation with One Inch or More.



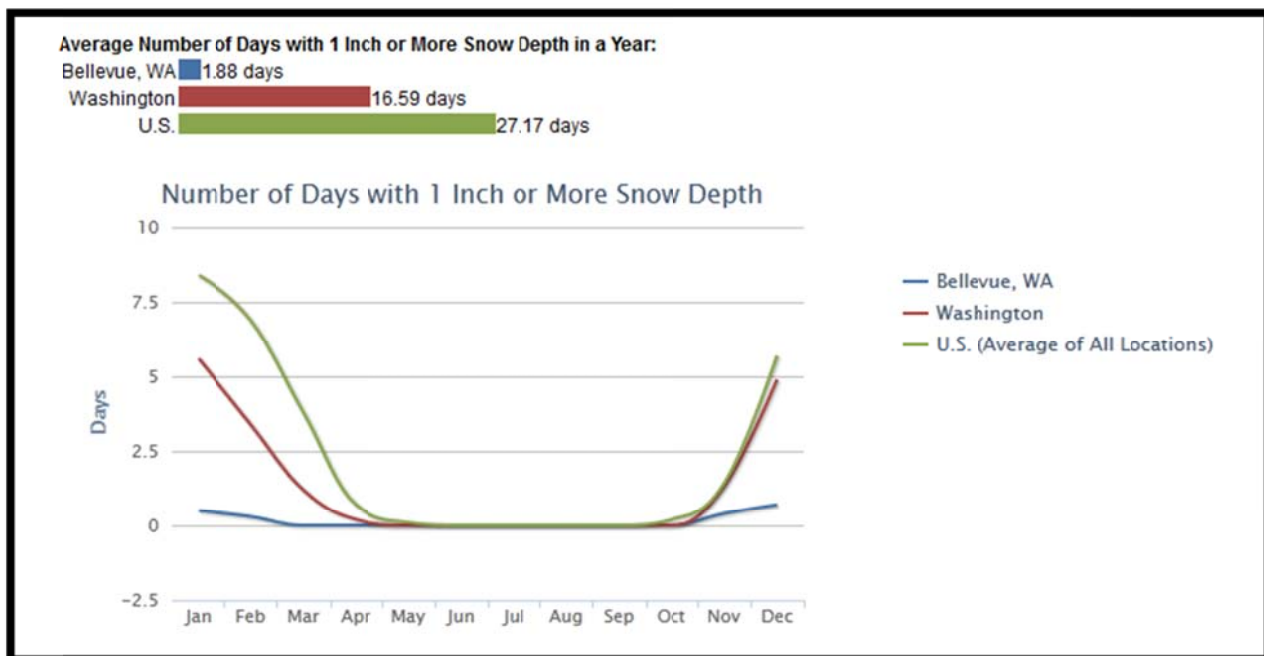
The average annual snowfall in Bellevue is 3.09 inches; Washington State 15.57; and the United States is 23.27 inches (<http://www.usa.com/bellevue-wa-weather.htm>).

Figure 25. Total Monthly Snowfall.



The average annual snowfall in Bellevue is 3.09 inches; Washington State 15.57; and the United States is 23.27 inches (<http://www.usa.com/bellevue-wa-weather.htm>).

Figure 26. Annual Precipitation with One Inch or More Snow.



v. i-Tree: What's New?

i-Tree version 5.0 is planned for release in late summer 2012. Module testing and final revisions are happening now. Version 5 will feature data collection web form for the i-Tree Streets and Eco applications for mobile devices through a browser. The iPhone, Android or tablet devices can be used to collect and enter field data. Additional analysis tools will include the ability to survey historical Google images in i-Tree Canopy, model multiple trees in a landscape using i-Tree Design and other enhancements are also planned for i-Tree Hydro, Vue, Eco & Streets.

People and governments around the world continue to plan, measure and inventory their trees and tree values, the i-Tree user base continues to grow internationally. Last November the nation of Hungary was the 100th country to join the i-Tree community of users, with Nigeria and Sri Lanka joining soon afterward. The London Tree Officers Association used i-Tree Canopy to calculate tree canopy cover at 21% in the Greater London area.

Tree Species Results

ME	COMMON NAME	SCIENTIFIC NAME	COMMON NAME
		CARYA PALLIDA**	SAND HICKORY
	BIGLEAF MAPLE	CARYA PUMILIA**	CARYA HICKORY
	RED MAPLE	CARYA TEXANA**	BLACK HICKORY
	SILVER MAPLE	CARYA X BROWNII**	BROWN'S HICKORY
	SUGAR MAPLE	CARYA X COLLINA**	COLLIN HICKORY
	FREEMAN MAPLE	CARYA X DEMAREEII**	DEMAREE HICKORY
	YELLOW BUCKEYE	CARYA X DUNBARII**	DUNBAR'S HICKORY
	WHITE ALDER	CARYA X LANEYI**	LANEY'S HICKORY
	MOCKERNUT HICKORY	CARYA X LECONTEI**	LECONTE'S HICKORY
	WATER HICKORY	CARYA X LUDOVICIANA**	HICKORY
	SOUTHERN SHAGBARK HICKORY	CARYA X NUSSBAUMERI**	NUSSBAUMER'S HICKORY
		CARYA X SCHNECKII**	SCHNECK'S HICKORY
	BITTERNUT HICKORY	CEDRUS DEODARA	DEODAR CEDAR
	PECAN	CEDRUS LIBANI	CEDAR OF LEBANON
	NUTMEG HICKORY	CELTIS LAEVIGATA	SUGARBERRY
	RED HICKORY	CELTIS OCCIDENTALIS	NORTHERN HACKBERRY
	SHAGBARK HICKORY	CUNNINGHAMIA LANCEOLATA	BLUE CHINESE FIR

SCIENTIFIC NAME	COMMON NAME	SCIENTIFIC NAME	COMMON NAME
<i>FAGUS GRANDIFOLIA</i>	AMERICAN BEECH	<i>METASEQUOIA GLYPTOSTROBOIDES</i> *	DAWN REDWOOD
<i>FRAXINUS AMERICANA</i>	WHITE ASH	<i>MORUS RUBRA</i>	RED MULBERRY
<i>FRAXINUS EXCELSIOR</i>	EUROPEAN ASH	<i>NOTHOFAGUS ALPINA</i> **	RAULÍ
<i>FRAXINUS PENNSYLVANICA</i>	GREEN ASH	<i>NOTHOFAGUS OBLIQUA</i>	ROBLE
<i>FRAXINUS UHDEI</i>	EVERGREEN ASH	<i>NYSSA AQUATICA</i>	WATER TUPELO
<i>GINKGO BILOBA</i>	GINKGO	<i>NYSSA BIFLORA</i> **	SWAMP TUPELO
<i>JUGLANS AILANTHIFOLIA</i> **	JAPANESE WALNUT	<i>NYSSA URSINA</i> **	BEAR TUPELO
<i>JUGLANS JAMAICENSIS</i> **	WEST INDIAN WALNUT	<i>OSTRYA CARPINIFOLIA</i>	HOP HORNBEAM
<i>JUGLANS MAJOR</i>	ARIZONA WALNUT	<i>OSTRYA KNOWLTONII</i> **	KNOWLTON HOPHORNBEAM
<i>JUGLANS MICROCARPA</i> **	LITTLE WALNUT	<i>PERSEA HUMILIS</i> **	SILK BAY
<i>JUGLANS NIGRA</i>	BLACK WALNUT	<i>PERSEA KRUGII</i> **	CANELA
<i>JUGLANS X BIXBYI</i> **	BIXBY WALNUT	<i>PERSEA LINGUE</i> **	LINGUE
<i>JUGLANS X INTERMEDIA</i> **	INTERMEDIATE WALNUT	<i>PERSEA PALUSTRIS</i>	SWAMP BAY
<i>J. X QUADRANGULATA</i> **	NCN - WALNUT	<i>PERSEA URBANIANA</i> **	AQUACATILLO
<i>LIRIODENDRON CHINENSE</i> **	CHINESE TULIP TREE	<i>PINUS ELLIOTTII</i>	SLASH PINE
<i>LIRIODENDRON TULIPIFERA</i>	TULIP TREE	<i>PINUS PALUSTRIS</i>	LONGLEAF PINE
<i>MAGNOLIA ACUMINATA</i>	CUCUMBER TREE	<i>PLATANUS HYBRIDA</i> *	LONDON PLANETREE
<i>MAGNOLIA GRANDIFLORA</i>	SOUTHERN MAGNOLIA	<i>PLATANUS OCCIDENTALIS</i>	AMERICAN SYCAMORE
<i>MAGNOLIA MACROPHYLLA</i>	BIGLEAF MAGNOLIA	<i>PLATANUS ORIENTALIS</i>	ORIENTAL PLANETREE
<i>MAGNOLIA OFFICINALIS</i>	MAGNOLIA OFFICINALIS	<i>PLATANUS RACEMOSA</i>	CALIFORNIA SYCAMORE

SCIENTIFIC NAME	COMMON NAME	SCIENTIFIC NAME	COMMON NAME
<i>PLATANUS WRIGHTII</i>	ARIZONA SYCAMORE	<i>TAXODIUM MUCRONATUM</i> **	MONTEZUMA CYPRESS
<i>POPULUS DELTOIDES</i>	EASTERN COTTONWOOD	<i>TILIA AMERICANA</i>	AMERICAN BASSWOOD
<i>PRUNUS SEROTINA</i>	BLACK CHERRY	<i>ULMUS AMERICANA</i>	AMERICAN ELM
<i>QUERCUS PETRAEA</i>	DURMAST OAK	<i>ULMUS CRASSIFOLIA</i>	CEDAR ELM
<i>QUERCUS SHUMARDII</i>	SHUMARD OAK	<i>ULMUS PARVIFOLIA</i>	CHINESE ELM
<i>QUERCUS SUBER</i>	CORK OAK	<i>ULMUS SEROTINA</i>	SEPTEMBER ELM
<i>SEQUOIA DENDRON GIGANTEUM</i>	GIANT SEQUOIA	<i>ZELKOVA CARPINIFOLIA</i>	CAUCASIAN ZELKOVA
<i>TAXODIUM ASCENDENS</i>	POND CYPRESS	<i>ZELKOVA SERRATA</i>	JAPANESE ZELKOVA
<i>TAXODIUM DISTICHUM</i>	BALDCYPRESS		

Hardiness zone derived from Horticipia database based on USDA Hardiness zones. For hardiness zones with decimal (e.g., 4.5) values were rounded down for maximum hardiness (e.g., 4) and up for minimum hardiness zone (e.g., 5)

* Some uncertainty to hardiness zone - hardiness zone estimates derived from Dirr (M.A. Dirr, 1975, Manual of Woody Landscape Plants. Stipes Publ. Co. Champaign IL. 1007 p.) and Sunset (1985, New Western Garden Book, Lane Publ. Co. Menlo Park, CA. 512 p.). As hardiness estimates or maps did not always exactly match USDA Hardiness zone ranges, some extrapolations were made to the closest hardiness zone.

** Moderate uncertainty to hardiness zone - hardiness zone estimate based on genera average of minimum and maximum hardiness zone based on Horticipia database and

information from Dirr (1997) and Sunset (1985). Average value was rounded to nearest hardiness zone class (1 -11).

*** High uncertainty to hardiness zone - hardiness zone estimate based on family average of minimum and maximum hardiness zone based on Horticipia database and information from Dirr (1997) and Sunset (1985). Average value was rounded to nearest hardiness zone class (1 -11).

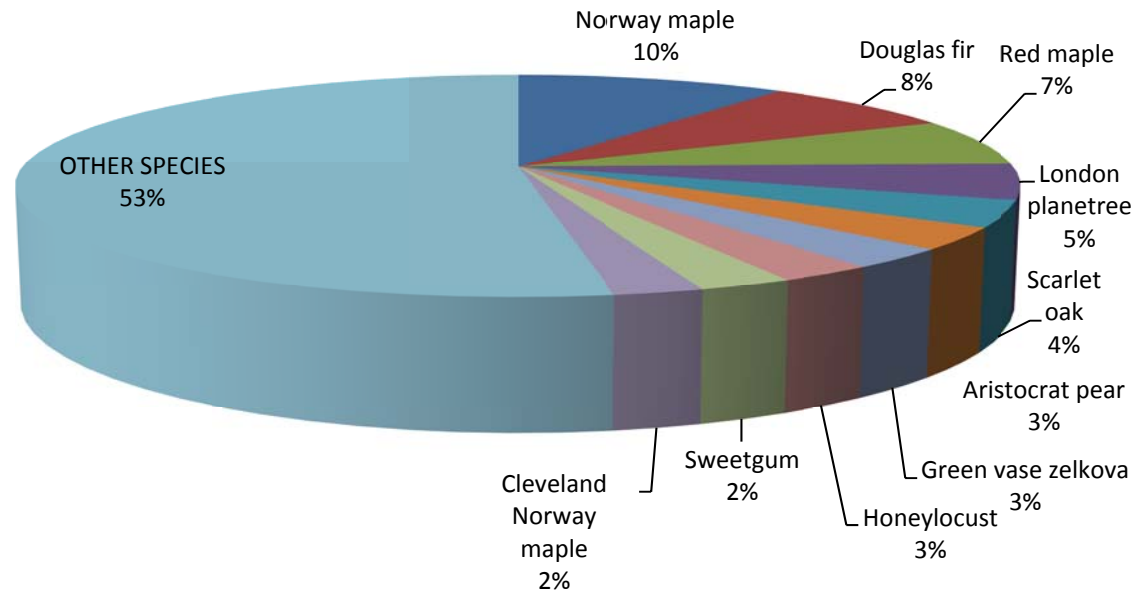
Sensitivity - "S" indicates sensitive to pollutant; "I" indicates intermediate rating between sensitive and tolerant to pollutant; and "S/I" indicates a mix of sensitive and intermediate ratings in the literature.

Appendix D – i-Tree Streets Results

i. Resource Structural Analysis: Diversity

Species Distribution: The Species Distribution reports present data on species composition in the form of pie charts and tables for the 10 most common species, displayed in percentage of total numbers. These reports are helpful for understanding species dominance.

Species Distribution	
Species	Percent
Norway maple	10.22
Douglas fir	7.59
Red maple	6.77
London planetree	5.21
Scarlet oak	3.80
Aristocrat pear	3.20
Green vase zelkova	2.92
Honeylocust	2.69
Sweetgum	2.56
Cleveland Norway maple	2.46
OTHER SPECIES	52.59
Total	100.00

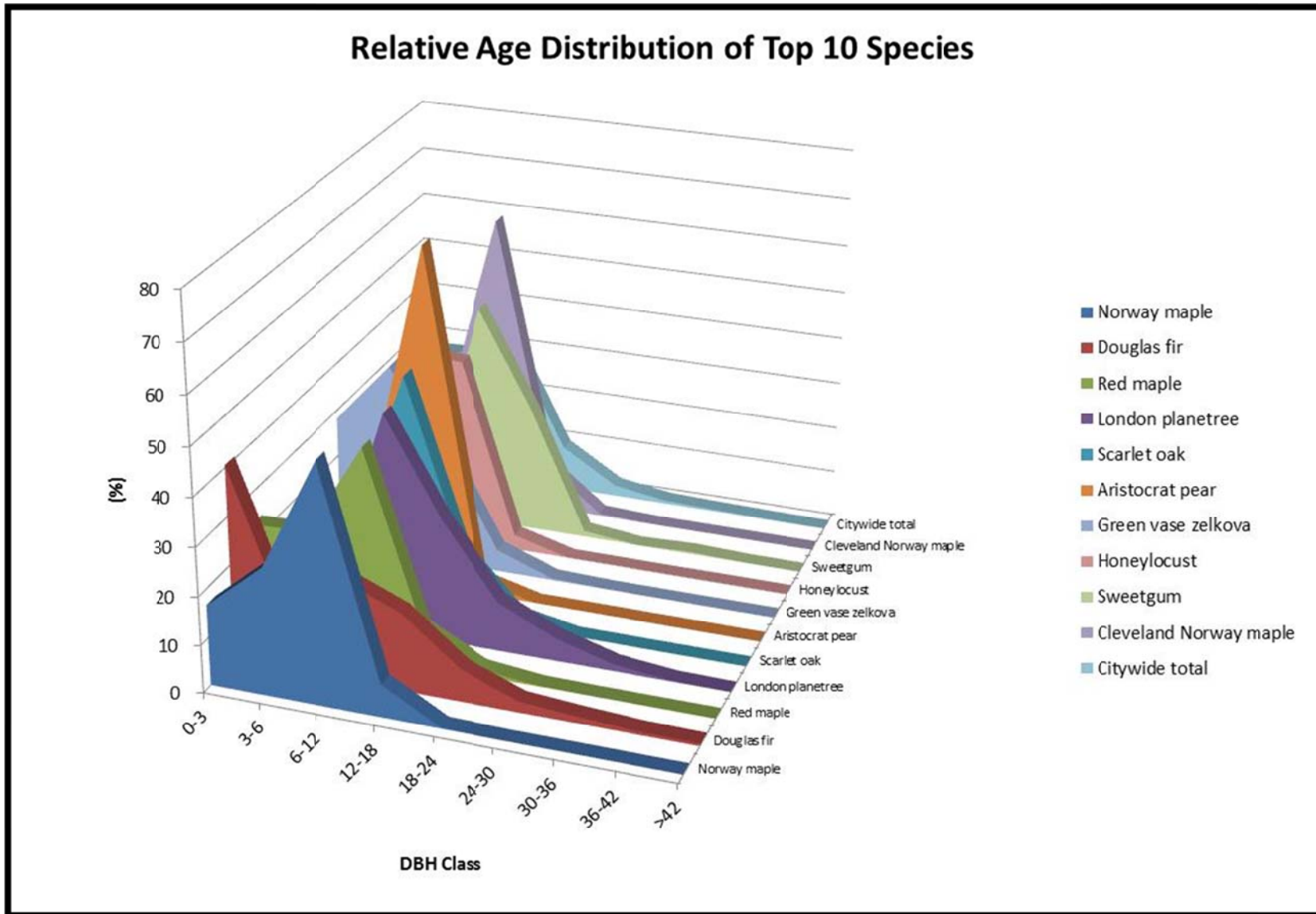


ii. Resource Structural Analysis: Age Distribution

Relative Age Distribution: Tree age data, presented in terms of DBH size class, is given in chart and table form for the 10 most common species, displayed in percentage of total numbers. These reports are important for determining current management needs as well as anticipating how needs will change based on total numbers and aging of individual species. The distribution of ages within a tree population influences present and future costs as well as the flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assure continuity in overall tree canopy cover. An ideal distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age.

Relative Age Distribution of Top 10 Species (%)									
Species	Diameter Breast Height (4.5 ft.), Class (in)								
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42
Norway maple	16.77	26.48	49.69	6.85	0.20	0.00	0.00	0.00	0.00
Douglas fir	40.50	10.33	21.07	16.25	6.89	2.34	1.38	0.69	0.55
Red maple	23.61	24.07	43.21	7.56	1.39	0.15	0.00	0.00	0.00
London planetree	2.81	9.04	45.78	25.70	10.24	4.82	1.41	0.20	0.00
Scarlet oak	18.96	15.38	49.18	14.29	2.20	0.00	0.00	0.00	0.00
Aristocrat pear	4.25	20.92	71.90	2.94	0.00	0.00	0.00	0.00	0.00
Green vase zelkova	28.32	41.22	25.45	4.66	0.36	0.00	0.00	0.00	0.00
Honeylocust	16.34	40.86	39.69	3.11	0.00	0.00	0.00	0.00	0.00
Sweetgum	17.96	6.53	47.35	26.53	1.22	0.00	0.41	0.00	0.00
Cleveland Norway maple	8.09	19.57	62.55	9.36	0.43	0.00	0.00	0.00	0.00
Citywide total	27.54	28.05	31.41	9.42	2.36	0.67	0.34	0.10	0.09

Figure 27. City Street Trees Graphic: Age Distribution.



iii. Resource Structural Analysis: Importance Value

Importance values (IV) are displayed in table form for all species that make up more than 1% of the population. The Streets IV is the mean of three relative values (percentage of total trees, percentage of total leaf area, and percentage of canopy cover) and can range from 0 to 100 with an IV of 100 suggesting total reliance on one species. IVs offer valuable information about a community's reliance on certain species to provide functional benefits. For example, a species might represent 10% of a population, but have an IV of 25% because of its great size, indicating that the loss of those trees due to pests or disease would be more significant than their numbers suggest.

Species	Number of Trees	% of Total Trees	Leaf Area (ft2)	% of Total Leaf Area	Canopy Cover (ft2)	% of Total Canopy Cover	Importance Value
Norway maple	978	10.22	1,661,308.87	12.91	284,313.36	11.11	11.41
Douglas fir	726	7.59	1,438,389.05	11.17	251,155.71	9.81	9.53
Red maple	648	6.77	933,835.55	7.25	213,613.73	8.35	7.46
London planetree	498	5.21	1,383,302.49	10.75	254,449.66	9.94	8.63
Scarlet oak	364	3.80	757,191.15	5.88	167,775.09	6.56	5.41
Aristocrat pear	306	3.20	313,158.89	2.43	113,804.61	4.45	3.36
Green vase zelkova	279	2.92	244,157.28	1.90	45,576.15	1.78	2.20
Honeylocust	257	2.69	186,528.78	1.45	41,552.18	1.62	1.92
Sweetgum	245	2.56	525,760.18	4.08	96,737.40	3.78	3.48
Cleveland Norway maple	235	2.46	279,412.38	2.17	58,418.96	2.28	2.30
Pin oak	221	2.31	843,017.74	6.55	176,455.76	6.89	5.25
Western red cedar	221	2.31	185,403.01	1.44	34,473.19	1.35	1.70
Marshal green ash	213	2.23	175,994.45	1.37	30,766.39	1.20	1.60
Eddie's white wonder	189	1.98	28,783.82	0.22	5,729.56	0.22	0.81

Species	Number of Trees	% of Total Trees	Leaf Area (ft2)	% of Total Leaf Area	Canopy Cover (ft2)	% of Total Canopy Cover	Importance Value
Littleleaf linden	184	1.92	173,480.07	1.35	32,288.73	1.26	1.51
Kwanzan cherry "K"	161	1.68	82,525.64	0.64	33,398.97	1.31	1.21
Katsura tree	152	1.59	49,464.31	0.38	9,595.21	0.37	0.78
Callery pear	150	1.57	68,496.64	0.53	13,093.62	0.51	0.87
Emerald queen Norway maple	149	1.56	68,832.94	0.53	16,454.86	0.64	0.91
Northern red oak	146	1.53	513,565.62	3.99	106,890.31	4.18	3.23
Caucasian ash	125	1.31	170,029.20	1.32	27,991.98	1.09	1.24
Green ash 'Sherwood Glen'	124	1.30	144,153.42	1.12	24,128.13	0.94	1.12
European white birch	121	1.26	275,211.44	2.14	44,885.66	1.75	1.72
Pacific sunset maple	121	1.26	11,337.65	0.09	4,076.24	0.16	0.50
Hornbeam 'Fastigiata'	115	1.20	117,378.29	0.91	15,461.91	0.60	0.91
Deodar cedar	101	1.06	367,542.15	2.86	63,827.28	2.49	2.14
Jacquemontii birch	100	1.05	82,233.36	0.64	16,155.46	0.63	0.77
Hedge maple	97	1.01	33,682.80	0.26	8,661.72	0.34	0.54
OTHER TREES	2,341	24.47	1,757,937.78	13.66	367,516.74	14.36	17.50
Total	9,567	100.00	12,872,114.95	100.00	2,559,248.57	100.00	100.0

iv. Resource Structural Analysis: Canopy Cover

Canopy Cover of Street Trees (Acres)					
	Total City Land Area	Total Street and Sidewalk Area	Total Canopy Cover	Canopy Cover as % of Total Land Area	Canopy Cover as % of Total Streets and Sidewalks
Citywide total	21,439.91	663.27	58.75	0.27	8.86

v. Population Summary: Fine Detail

The Population Summary reports include summary tables and complete lists of inventoried species, their total numbers, numbers by tree type, and numbers by default DBH size classes. These reports provide a basic understanding of species frequencies citywide, by management zone and by DBH size class.

Population Complete of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Broadleaf Deciduous Large (BDL)										
London planetree	14	45	228	128	51	24	7	1	0	498
Scarlet oak	69	56	179	52	8	0	0	0	0	364
Honeylocust	42	105	102	8	0	0	0	0	0	257
Cleveland Norway maple	19	46	147	22	1	0	0	0	0	235
Pin oak	7	22	84	92	16	0	0	0	0	221
Emerald queen Norway maple	44	66	39	0	0	0	0	0	0	149
Northern red oak	4	17	78	32	11	4	0	0	0	146
Pacific sunset maple	86	35	0	0	0	0	0	0	0	121
Hedge maple	22	63	12	0	0	0	0	0	0	97
Quaking aspen "WA"	6	15	57	7	0	1	0	0	0	86
Tulip tree	32	15	3	3	2	0	0	0	0	55
Ginkgo	4	30	8	1	0	0	0	0	0	43
Oregon ash	22	4	7	1	0	0	0	0	0	34
Allee elm	29	0	0	0	0	0	0	0	0	29
European beech	2	14	9	1	1	0	0	0	0	27
Black cottonwood 'black'	2	1	3	5	5	6	1	0	0	23
Bloodgood maple	2	20	0	0	0	0	0	0	0	22

Population Complete of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Sitka mountain ash	6	7	3	0	0	0	0	0	0	16
Swedish columnar aspen	15	0	0	0	0	0	0	0	0	15
Bigleaf linden	0	4	8	2	0	0	0	0	0	14
Bigleaf maple	2	0	3	3	1	1	0	1	1	12
Reddish alder	5	1	3	1	0	0	1	0	0	11
Fernleaf Full-moon maple	10	0	0	0	0	0	0	0	0	10
White oak	0	7	1	0	0	1	0	0	0	9
Cascara	8	0	0	0	0	0	0	0	0	8
Paperbark maple	4	2	0	0	0	0	0	0	0	6
European ash	0	0	5	0	0	0	0	0	0	5
California hazel	2	0	2	0	0	0	0	0	0	4
Pacific madrone	1	1	1	0	0	0	0	0	0	3
Sugar maple	0	0	0	0	0	0	0	0	1	1
American chestnut	0	0	0	1	0	0	0	0	0	1
Bloodgood planetree	1	0	0	0	0	0	0	0	0	1
Bowhall silver maple	1	0	0	0	0	0	0	0	0	1
Hedge maple 'small'	0	1	0	0	0	0	0	0	0	1
Total	461	577	982	359	96	37	9	2	2	2,525
<i>Broadleaf Deciduous Medium (BDM)</i>										
Norway maple	164	259	486	67	2	0	0	0	0	978
Red maple	153	156	280	49	9	1	0	0	0	648

Population Complete of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Green vase zelkova	79	115	71	13	1	0	0	0	0	279
Sweetgum	44	16	116	65	3	0	1	0	0	245
Marshal green ash	16	139	52	6	0	0	0	0	0	213
Eddie's white wonder	147	40	2	0	0	0	0	0	0	189
Littleleaf linden	59	63	49	13	0	0	0	0	0	184
Katsura tree	53	98	1	0	0	0	0	0	0	152
Callery pear	39	101	9	1	0	0	0	0	0	150
Caucasian ash	11	46	55	13	0	0	0	0	0	125
Green ash 'Sherwood Glen'	12	41	69	2	0	0	0	0	0	124
European white birch	42	10	19	42	8	0	0	0	0	121
Hornbeam 'Fastigiata'	28	37	48	2	0	0	0	0	0	115
Jacquemontii birch	33	34	30	3	0	0	0	0	0	100
Crimean linden	29	52	10	0	0	0	0	0	0	91
Armstrong maple	10	4	36	19	4	0	0	0	0	73
Robin Hill Serviceberry	26	36	1	0	0	0	0	0	0	63
Autumn brilliance serviceberry	52	7	0	0	0	0	0	0	0	59
American basswood	9	43	4	0	0	0	0	0	0	56
Sourgum	51	1	0	0	0	0	0	0	0	52
Persian ironwood	0	43	5	0	0	0	0	0	0	48
White ash	11	27	4	0	0	0	0	0	0	42
Amur maple	1	35	1	0	0	0	0	0	0	37

Population Complete of All Trees										
Species	DBH Class (in)									
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Bowhall red maple	32	4	1	0	0	0	0	0	0	37
Sourwood	22	0	1	0	0	0	0	0	0	23
Willow	0	1	13	5	1	0	0	0	0	20
Sweet cherry	7	1	3	1	1	0	0	0	0	13
Cornelian cherry dogwood	12	0	0	0	0	0	0	0	0	12
Three flowered maple	11	1	0	0	0	0	0	0	0	12
Americans linden	0	6	3	0	0	0	0	0	0	9
Scouler willow	9	0	0	0	0	0	0	0	0	9
Pacific dogwood 'Pacific'	4	1	2	0	0	0	0	0	0	7
Siberian elm	0	0	0	0	5	1	1	0	0	7
Sycamore maple	1	2	3	0	0	0	0	0	0	6
River birch	0	3	1	0	0	0	0	0	0	4
Japanses stewartia	3	0	0	0	0	0	0	0	0	3
Thundercloud plum 'Thunder'	1	0	0	0	0	0	0	0	0	1
Total	1,171	1,422	1,375	301	34	2	2	0	0	4,307
<i>Broadleaf Deciduous Small (BDS)</i>										
Kwanzan cherry "K"	14	55	58	33	1	0	0	0	0	161
Vine maple	73	16	1	0	0	0	0	0	0	90
Kousa dogwood	79	2	6	0	0	0	0	0	0	87
Eastern redbud	7	66	8	0	0	0	0	0	0	81
Centurion crabapple	42	29	1	1	0	0	1	0	0	74

Population Complete of All Trees										
Species	DBH Class (in)									
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Total	489	258	99	37	2	0	1	0	0	886
<i>Broadleaf Evergreen Large (BEL)</i>										
English oak	3	31	42	6	0	0	0	0	1	83
Pine tree	9	3	0	1	0	0	0	0	0	13
Upright English white oak	0	3	1	3	3	0	0	0	0	10
Port Orford cedar	0	2	2	0	0	0	0	0	0	4
Leyland cypress	4	0	0	0	0	0	0	0	0	4
Pacific silver fir	1	0	2	0	0	0	0	0	0	3
Dawn redwood	1	0	0	0	0	0	0	0	0	1
Total	18	39	47	10	3	0	0	0	1	118
<i>Broadleaf Evergreen Small (BES)</i>										
Aristocrat pear	13	64	220	9	0	0	0	0	0	306
Bradford pear 'bradford'	16	38	16	0	0	0	0	0	0	70
Southern magnolia	2	52	2	0	0	0	0	0	0	56
Bradford pear	1	2	12	0	0	0	0	0	0	15
Domestic apple	0	2	1	0	0	0	0	0	0	3
Columnar pear	2	0	0	0	0	0	0	0	0	2
Total	34	158	251	9	0	0	0	0	0	452
<i>Conifer Evergreen Large (CEL)</i>										
Douglas fir	294	75	153	118	50	17	10	5	4	726
Western red cedar	105	58	47	4	3	1	2	1	0	221

Population Complete of All Trees										
Species	DBH Class (in)						30-36	36-42	>42	Total
	0-3	3-6	6-12	12-18	18-24	24-30				
Deodar cedar	1	34	3	28	28	4	3	0	0	101
Giant sequoia	17	23	4	3	1	0	0	0	1	49
Scotch pine	0	0	10	7	1	1	0	0	0	19
Alaska cedar	0	0	9	7	0	0	0	0	0	16
Ponderosa pine	1	0	1	3	3	0	1	1	0	10
Western hemlock	0	0	2	7	0	0	0	0	0	9
Norway spruce	7	0	0	0	0	0	0	0	0	7
Sitka spruce	4	0	0	0	0	0	0	0	0	4
Coast redwood	0	0	0	0	1	0	2	0	1	4
Blue spruce	0	0	0	1	1	0	0	0	0	2
Atlas cedar	0	0	0	0	1	0	0	0	0	1
Japanese black pine	0	1	0	0	0	0	0	0	0	1
Total	429	191	229	178	89	23	18	7	6	1,170
Conifer Evergreen Medium (CEM)										
California Incense Cedar	15	17	13	0	1	2	3	1	0	52
Total	15	17	13	0	1	2	3	1	0	52
Conifer Evergreen Small										
Lodgepole pine	12	19	9	5	1	0	0	0	0	46
Western white pine	6	0	0	2	0	0	0	0	0	8
Nigerian pine	0	3	0	0	0	0	0	0	0	3
Total	18	22	9	7	1	0	0	0	0	57

Population Complete of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Grand Total	2,635	2,684	3,005	901	226	64	33	10	9	9,567

vi. Population Summary: Course Detail

Population Summary of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
<i>Broadleaf Deciduous Large (BDL)</i>										
London planetree	14	45	228	128	51	24	7	1	0	498
Scarlet oak	69	56	179	52	8	0	0	0	0	364
Honeylocust	42	105	102	8	0	0	0	0	0	257
Cleveland Norway maple	19	46	147	22	1	0	0	0	0	235
Pin oak	7	22	84	92	16	0	0	0	0	221
Emerald queen Norway maple	44	66	39	0	0	0	0	0	0	149
Northern red oak	4	17	78	32	11	4	0	0	0	146
Pacific sunset maple	86	35	0	0	0	0	0	0	0	121
Hedge maple	22	63	12	0	0	0	0	0	0	97
BDL OTHER	154	122	113	25	9	9	2	1	2	437

Population Summary of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Total	461	577	982	359	96	37	9	2	2	2,525
<i>Broadleaf Deciduous Medium (BDM)</i>										
Norway maple	164	259	486	67	2	0	0	0	0	978
Red maple	153	156	280	49	9	1	0	0	0	648
Green vase zelkova	79	115	71	13	1	0	0	0	0	279
Sweetgum	44	16	116	65	3	0	1	0	0	245
Marshall green ash	16	139	52	6	0	0	0	0	0	213
Eddie's white wonder	147	40	2	0	0	0	0	0	0	189
Littleleaf linden	59	63	49	13	0	0	0	0	0	184
Katsura tree	53	98	1	0	0	0	0	0	0	152
Callery pear	39	101	9	1	0	0	0	0	0	150
Caucasian ash	11	46	55	13	0	0	0	0	0	125
Green ash 'Sherwood Glen'	12	41	69	2	0	0	0	0	0	124
European white birch	42	10	19	42	8	0	0	0	0	121
Hornbeam 'Fastigiata'	28	37	48	2	0	0	0	0	0	115
Jacquemontii birch	33	34	30	3	0	0	0	0	0	100
BDM OTHER	291	267	88	25	11	1	1	0	0	684
Total	1,171	1,422	1,375	301	34	2	2	0	0	4,307

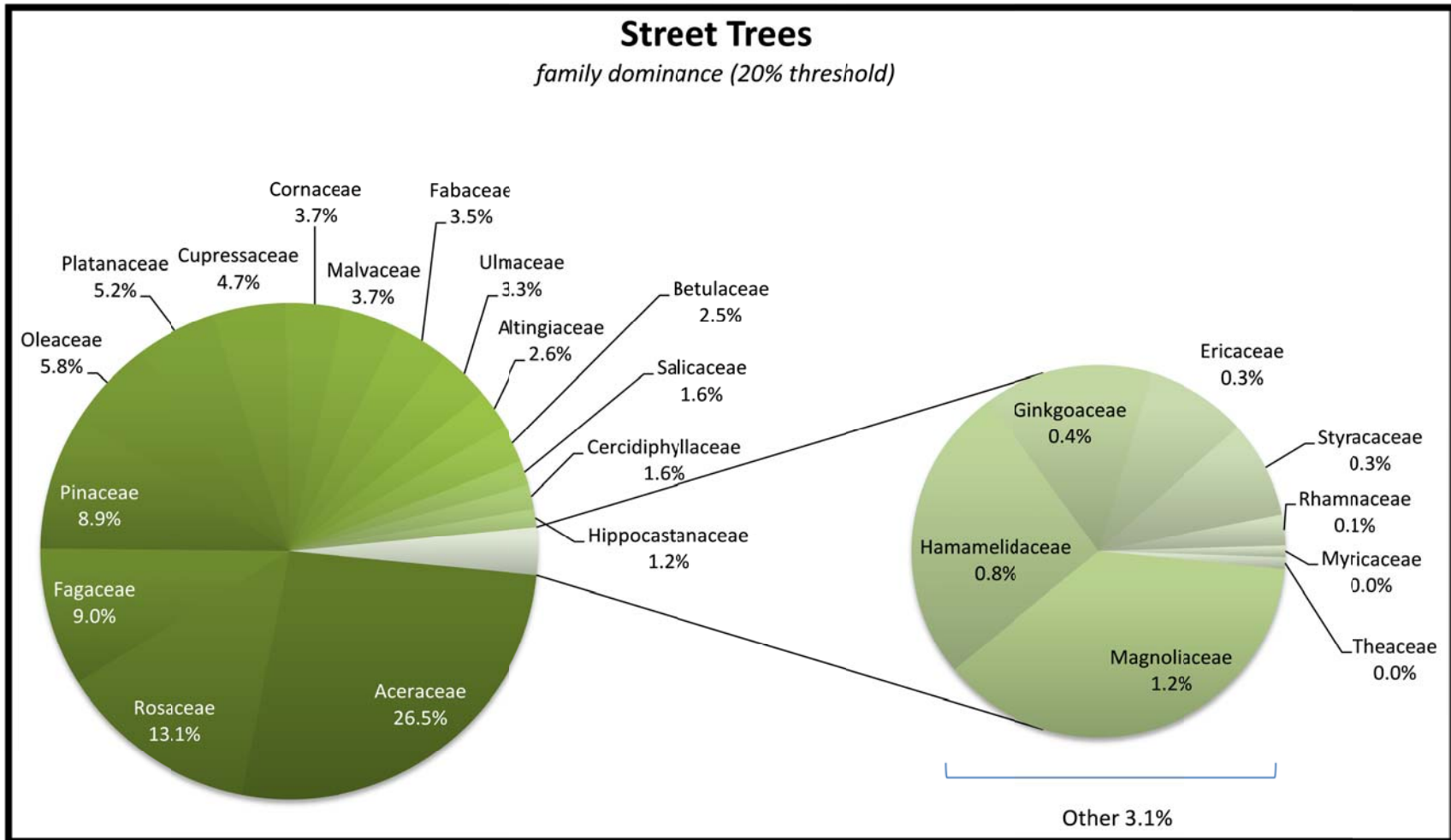
Population Summary of All Trees										
Species	DBH Class (in)									
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
<i>Broadleaf Deciduous Small (BDS)</i>										
Kwanzan cherry "K"	14	55	58	33	1	0	0	0	0	161
BDS OTHER	475	203	41	4	1	0	1	0	0	725
Total	489	258	99	37	2	0	1	0	0	886
<i>Broadleaf Evergreen Large (BEL)</i>										
BEL OTHER	18	39	47	10	3	0	0	0	1	118
Total	18	39	47	10	3	0	0	0	1	118
<i>Broadleaf Evergreen Small (BES)</i>										
Aristocrat pear	13	64	220	9	0	0	0	0	0	306
BES OTHER	21	94	31	0	0	0	0	0	0	146
Total	34	158	251	9	0	0	0	0	0	452
<i>Conifer Evergreen Large (CEL)</i>										
Douglas fir	294	75	153	118	50	17	10	5	4	726
Western red cedar	105	58	47	4	3	1	2	1	0	221
Deodar cedar	1	34	3	28	28	4	3	0	0	101
CEL OTHER	29	24	26	28	8	1	3	1	2	122
Total	429	191	229	178	89	23	18	7	6	1,170

Population Summary of All Trees										
Species	DBH Class (in)									Total
	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	
Conifer Evergreen Medium (CEM)										
CEM OTHER	15	17	13	0	1	2	3	1	0	52
Total	15	17	13	0	1	2	3	1	0	52
Conifer Evergreen Small (CES)										
CES OTHER	18	22	9	7	1	0	0	0	0	57
Total	18	22	9	7	1	0	0	0	0	57
Total	2,635	2,684	3,005	901	226	64	33	10	9	9,567

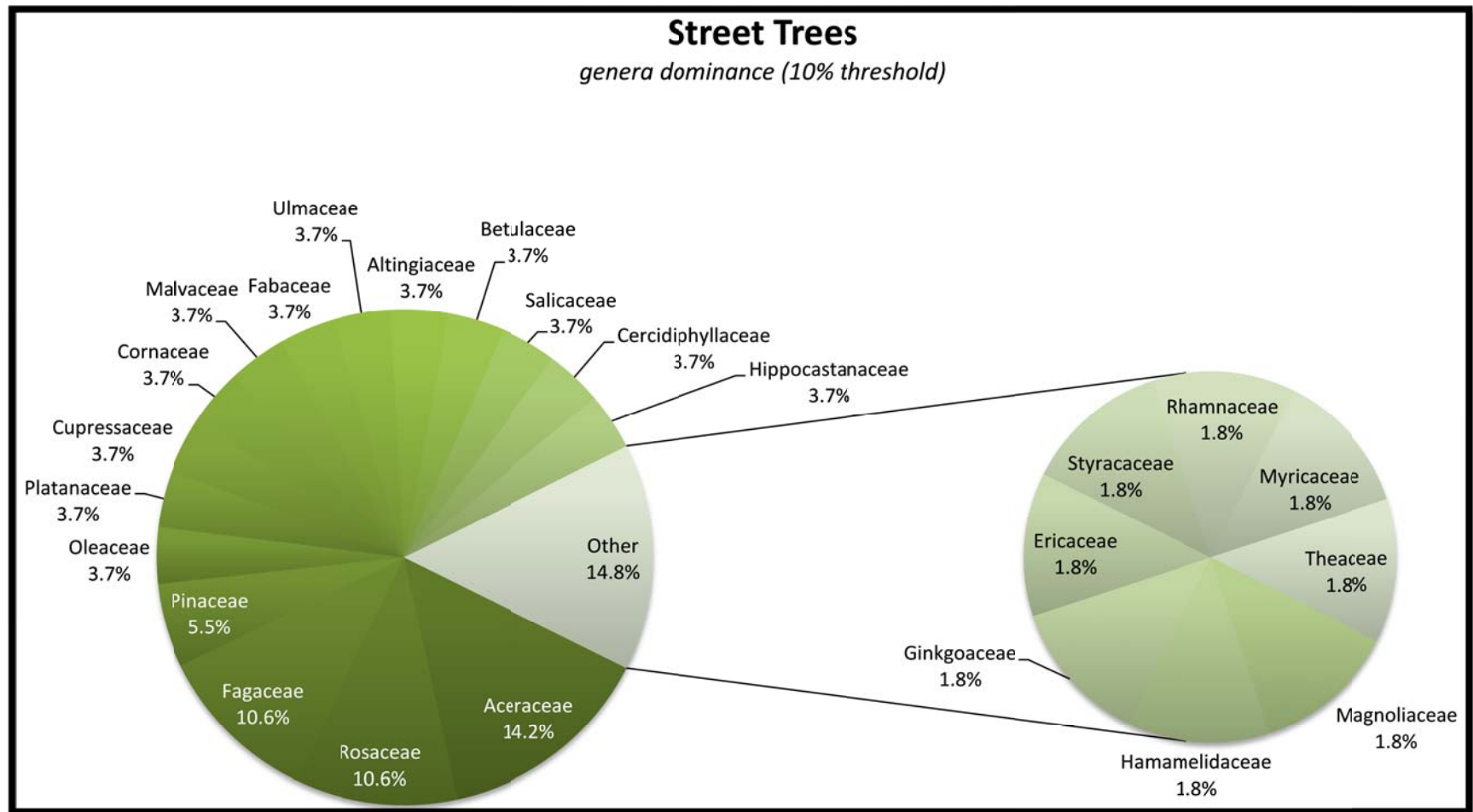
vii. Population Summary by Type (%)

	BDL	BDM	BDS	BEL	BES	CEL	CEM	CES	Percent
Street Tree Total	26.39	45.02	9.26	1.23	4.72	12.23	0.54	0.60	100.00

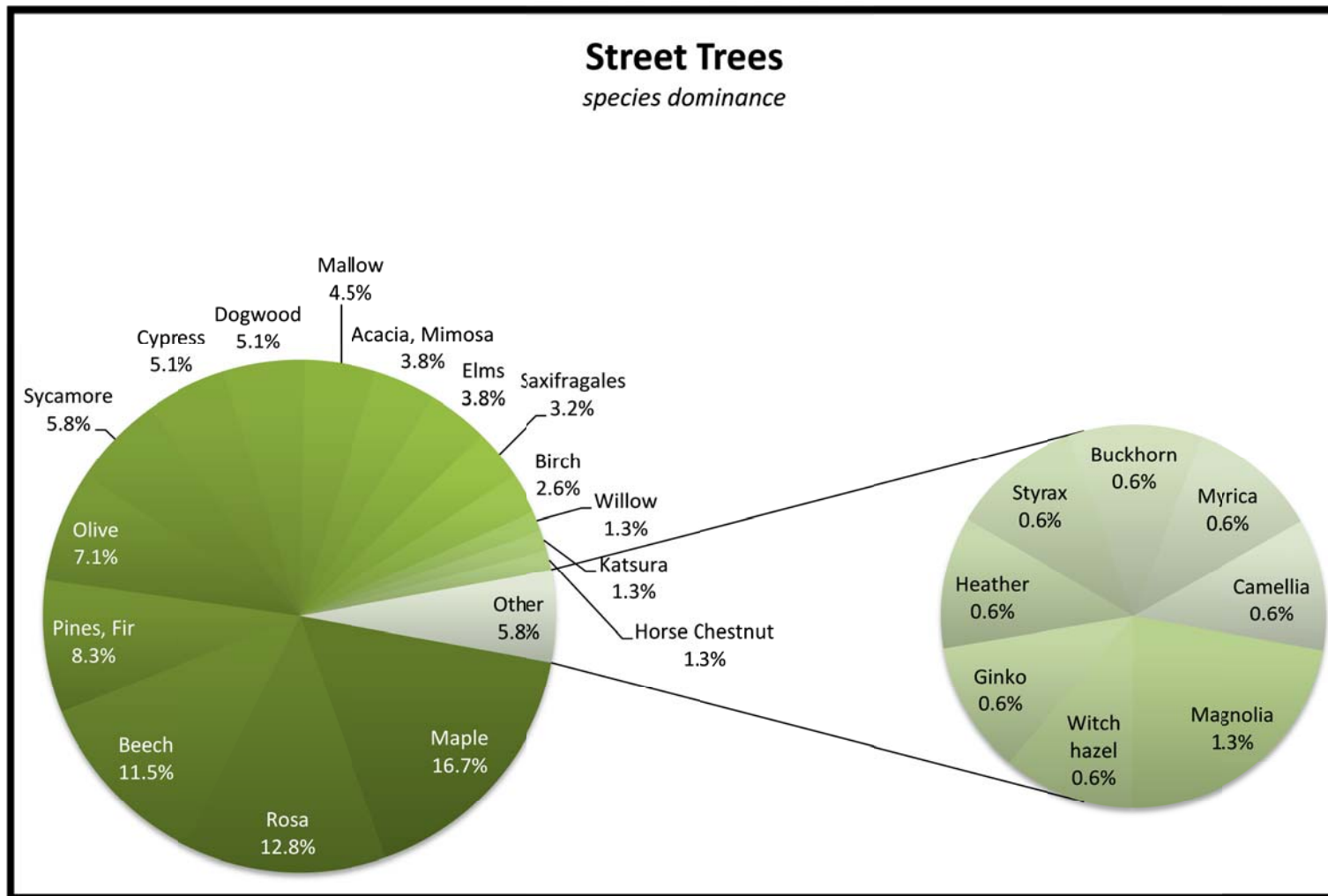
viii. Street Trees Family Dominance (20% Threshold)



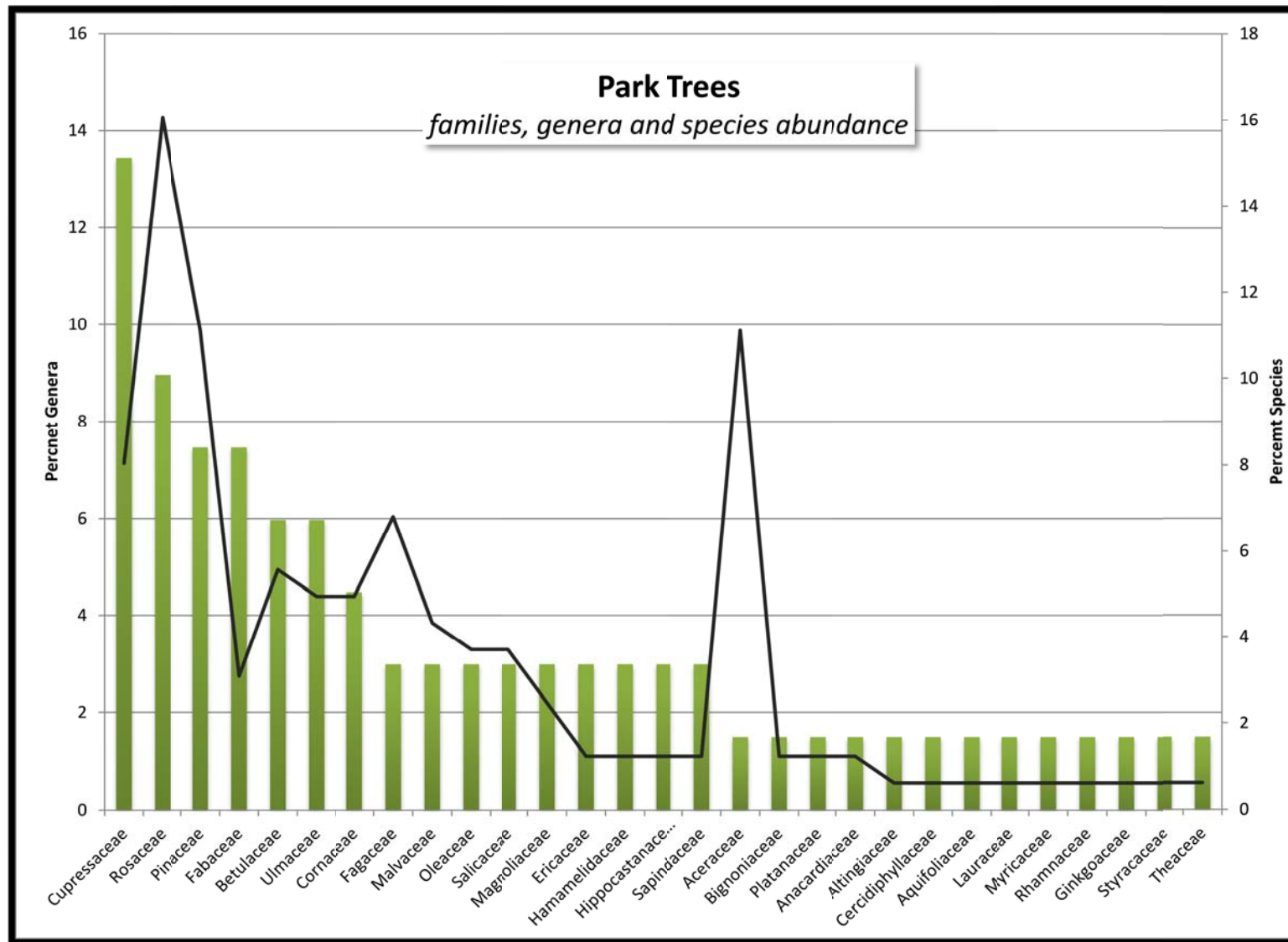
ix. Street Trees Genera Dominance (10% Threshold)



x. Street Trees Species Dominance



xi. Park Trees Families, Genera and Species Abundance



Appendix E – Streets Cost/Benefits Analysis

i. Reports

Streets calculates the environmental and other benefits provided by the urban forest. It is not intended to account to the penny for every benefit that trees produce. Reported benefits and costs are initial approximations as some benefits and costs are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Also, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable, and benefits and costs depend on the specific conditions at the site (e.g., tree species, growing conditions, maintenance practices). Therefore, Streets provides a general accounting of the benefits street trees produce given limited knowledge of site-specific conditions—an accounting with an accepted degree of uncertainty that can nonetheless provide a foundation on which decisions can be made. Methods used to quantify and price these benefits are described in the published series of Tree Guides (available at www.itreetools.org under Resources), which correspond to the Streets climate regions. There are three kinds of Benefit-Cost Reports: Annual Benefits, Management Costs, and Net Annual Benefits.

ii. Annual Energy Benefits

Energy: The Energy report presents the contribution of the urban forest toward conserving energy in terms of reduced natural gas use in winter (measured in therms or gigajoules) and reduced electricity use for air conditioning in summer (measured in kilowatt-hours or gigajoules).

Annual Energy Benefits of All Trees by Species

Species	Elec (MWh)	Electric (\$)	Natural Gas (Therms)	Natural Gas (\$)	Total (\$)	% of Total Trees	% of Total \$	Avg. \$/tree
Norway maple	19.55	2,261.90	839.91	962.54	3,224.44	10.22	11.50	3.30
Douglas fir	18.61	2,153.09	339.27	388.81	2,541.89	7.59	9.06	3.50
Red maple	14.65	1,695.21	657.03	752.95	2,448.16	6.77	8.73	3.78
London planetree	18.55	2,146.04	674.13	772.56	2,918.59	5.21	10.41	5.86
Scarlet oak	11.29	1,305.85	467.60	535.87	1,841.72	3.80	6.57	5.06
Aristocrat pear	7.28	842.02	280.37	321.31	1,163.33	3.20	4.15	3.80
Green vase zelvova	3.30	381.44	119.30	136.72	518.16	2.92	1.85	1.86
Honeylocust	3.23	374.25	120.34	137.91	512.15	2.69	1.83	1.99
Sweetgum	6.90	798.71	249.12	285.49	1,084.21	2.56	3.87	4.43
Cleveland Norway maple	4.54	524.96	164.37	188.36	713.32	2.46	2.54	3.04
Pin oak	11.78	1,362.86	456.58	523.24	1,886.10	2.31	6.73	8.53
Western red cedar	2.56	296.03	40.62	46.55	342.58	2.31	1.22	1.55
Marshal green ash	2.39	276.42	28.92	33.14	309.56	2.23	1.10	1.45
Eddie's white wonder	0.40	46.51	15.26	17.49	64.00	1.98	0.23	0.34
Littleleaf linden	2.34	270.16	84.77	97.15	367.31	1.92	1.31	2.00
Kwanzan cherry "K"	2.25	260.11	75.95	87.04	347.15	1.68	1.24	2.16
Katsura tree	0.72	83.50	24.16	27.68	111.18	1.59	0.40	0.73
Callery pear	0.98	112.94	33.42	38.30	151.24	1.57	0.54	1.01
Emerald queen Norway maple	1.28	147.67	48.88	56.01	203.68	1.56	0.73	1.37
Northern red oak	6.99	808.60	272.12	311.84	1,120.45	1.53	4.00	7.67
Caucasian ash	2.19	253.35	27.48	31.49	284.84	1.31	1.02	2.28
Green ash 'Sherwood Glen'	1.90	219.70	18.45	21.14	240.83	1.30	0.86	1.94
European white birch	3.22	373.13	119.83	137.32	510.45	1.26	1.82	4.22
Pacific sunset maple	0.30	34.22	13.68	15.68	49.90	1.26	0.18	0.41

Hornbeam 'Fastigiata'	1.25	144.16	39.46	45.22	189.38	1.20	0.68	1.65
Deodar cedar	4.73	547.01	96.63	110.74	657.75	1.06	2.35	6.51
Jacquemontii birch	1.27	147.40	39.63	45.42	192.81	1.05	0.69	1.93
Hedge maple	0.67	77.65	26.90	30.82	108.47	1.01	0.39	1.12
OTHER STREET TREES	25.53	2,954.18	861.43	987.20	3,941.38	24.47	14.05	1.68
CITYWIDE TOTAL	180.63	20,899.06	6,235.59	7,145.98	28,045.05	100.00	100.00	2.93

iii. Annual Stormwater Benefits

Stormwater: The Stormwater report presents the reductions in annual stormwater runoff due to rainfall interception by trees (measured in gallons or cubic meters).

Annual Stormwater Benefits of All Trees by Species					
Species	Total Gallons Intercepted	Total (\$)	% of Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	436,656.46	12,096.22	10.22	11.32	11.32
Douglas fir	550,343.00	15,245.56	7.59	14.27	20.00
Red maple	271,541.88	7,522.23	6.77	7.04	10.90
London planetree	373,757.44	10,353.80	5.21	9.69	20.00
Scarlet oak	208,766.12	5,783.22	3.80	5.41	14.45
Aristocrat pear	155,069.76	4,295.73	3.20	4.02	12.80
Green vase zelkova	63,597.89	1,761.78	2.92	1.65	5.99
Honeylocust	53,942.96	1,494.32	2.69	1.40	5.55
Sweetgum	136,454.91	3,780.06	2.56	3.54	14.38
Cleveland Norway maple	78,946.58	2,186.97	2.46	2.05	8.48
Pin oak	227,952.97	6,314.74	2.31	5.91	25.58
Western red cedar	71,878.19	1,991.16	2.31	1.86	8.19
Marshal green ash	43,855.48	1,214.88	2.23	1.14	5.45
Eddie's white wonder	7,666.25	212.37	1.98	0.20	10.73
Littleleaf linden	45,147.93	1,250.68	1.92	1.17	6.51
Kwanzan cherry "K"	29,227.09	809.65	1.68	0.76	4.82
Katsura tree	13,044.11	361.35	1.59	0.34	2.27
Callery pear	17,974.17	497.92	1.57	0.47	3.17
Emerald queen Norway maple	20,442.58	566.30	1.56	0.53	3.63
Northern red oak	138,560.87	3,838.40	1.53	3.59	23.52
Caucasian ash	41,530.98	1,150.49	1.31	1.08	8.78
Green ash 'Sherwood Glen'	35,395.05	980.51	1.30	0.92	7.54
European white birch	71,083.45	1,969.15	1.26	1.84	14.84

Pacific sunset maple	3,997.68	110.74	1.26	0.10	0.92
Hornbeam 'Fastigiata'	26,657.19	738.46	1.20	0.69	6.42
Deodar cedar	140,727.90	3,898.43	1.06	3.65	38.60
Jacquemontii birch	22,643.36	627.26	1.05	0.59	6.27
Hedge maple	10,302.72	285.41	1.01	0.27	2.94
OTHER STREET TREES	559,584.76	15,501.58	24.47	14.51	6.62
Citywide total	3,856,749.70	106,839.39	100.00	100.00	11.17

iv. Annual Carbon Storage

Carbon stored: Whereas the above report quantifies *annual* CO₂ reductions, the Carbon Stored report tallies all of the carbon dioxide stored in the urban forest *over the life of the trees* as a result of sequestration (in pounds or kilograms). It should not be added to the Carbon Dioxide value or double-counting will occur.

Stored CO2 Benefits of all Trees by Species					
Species	CO2 Stored (lbs)	Total (\$)	% of Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	852,965.05	2,814.78	10.22	9.95	2.88
Douglas fir	733,109.52	2,419.26	7.59	8.55	3.33
Red maple	419,393.32	1,384.00	6.77	4.89	2.14
London planetree	1,666,133.66	5,498.24	5.21	19.43	11.04
Scarlet oak	447,402.63	1,476.43	3.80	5.22	4.06
Aristocrat pear	238,631.74	787.48	3.20	2.78	2.57
Green vase zelkova	104,670.76	345.41	2.92	1.22	1.24
Honeylocust	164,905.03	544.19	2.69	1.92	2.12
Sweetgum	289,745.32	956.16	2.56	3.38	3.90
Cleveland Norway maple	259,840.38	857.47	2.46	3.03	3.65
Pin oak	552,482.08	1,823.19	2.31	6.44	8.25
Western red cedar	76,707.06	253.13	2.31	0.89	1.15
Marshal green ash	101,798.35	335.93	2.23	1.19	1.58
Eddie's white wonder	7,430.96	24.52	1.98	0.09	0.13
Littleleaf linden	76,495.92	252.44	1.92	0.89	1.37

Kwanzan cherry "K"	216,437.23	714.24	1.68	2.52	4.44
Katsura tree	13,113.65	43.28	1.59	0.15	0.28
Callery pear	21,630.06	71.38	1.57	0.25	0.48
Emerald queen Norway maple	58,084.81	191.68	1.56	0.68	1.29
Northern red oak	349,532.51	1,153.46	1.53	4.08	7.90
Caucasian ash	113,296.06	373.88	1.31	1.32	2.99
Green ash 'Sherwood Glen'	86,474.58	285.37	1.30	1.01	2.30
European white birch	129,543.49	427.49	1.26	1.51	3.53
Pacific sunset maple	9,094.29	30.01	1.26	0.11	0.25
Hornbeam 'Fastigiata'	40,629.19	134.08	1.20	0.47	1.17
Deodar cedar	189,662.18	625.89	1.06	2.21	6.20
Jacquemontii birch	33,085.01	109.18	1.05	0.39	1.09
Hedge maple	27,341.39	90.23	1.01	0.32	0.93
OTHER STREET TREES	587,930.14	4,277.34	24.47	15.11	1.83
CITYWIDE TOTAL	8,575,798.77	28,300.14	100.00	100.00	2.96

v. Annual CO2 Benefits

Carbon dioxide: The Carbon Dioxide report presents annual reductions in atmospheric CO2 due to sequestration by trees and reduced emissions from power plants due to reduced energy use (in pounds or kilograms). The model accounts for CO2 released as trees die and decompose and CO2 released during the care and maintenance of trees.

Species	Sequestered (lb)	Sequestered (\$)	Decomposition Release (lb)	Maintenance Release (lb)	Total Release (\$)	Avoided (lb)	Avoided (\$)	Net Total (lb)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/ tree
Norway maple	125,647.83	414.64	- 3,592.95	- 5,329.34	- 29.44	39,466.68	130.24	156,192.22	515.43	10.22	12.26	0.53
Douglas fir	55,716.99	183.87	- 3,094.20	- 4,779.76	- 25.98	37,568.08	123.97	85,411.12	281.86	7.59	6.70	0.39
Red maple	54,452.14	179.69	- 1,770.39	- 3,433.95	- 17.17	29,578.78	97.61	78,826.59	260.13	6.77	6.19	0.40
London planetree	129,985.54	428.95	- 6,998.66	- 4,823.90	- 39.01	37,445.12	123.57	155,608.09	513.51	5.21	12.22	1.03
Scarlet oak	69,969.22	230.90	- 1,882.38	- 2,273.31	- 13.71	22,785.03	75.19	88,598.56	292.38	3.80	6.96	0.80
Aristocrat pear	30,804.15	101.65	- 1,002.25	- 358.02	- 4.49	14,691.97	48.48	44,135.84	145.65	3.20	3.46	0.48
Green vase zelkova	13,408.48	44.25	- 441.89	- 1,162.98	- 5.30	6,655.48	21.96	18,459.09	60.91	2.92	1.45	0.22
Honeylocust	28,142.84	92.87	- 695.29	- 1,227.33	- 6.34	6,530.03	21.55	32,750.25	108.08	2.69	2.57	0.42
Sweetgum	27,362.66	90.30	- 1,218.20	- 1,757.34	- 9.82	13,936.36	45.99	38,323.49	126.47	2.56	3.01	0.52
Cleveland Norway maple	36,589.90	120.75	- 1,092.55	- 1,489.41	- 8.52	9,159.74	30.23	43,167.69	142.45	2.46	3.39	0.61
Pin oak	66,617.74	219.84	- 2,320.76	- 2,013.57	- 14.30	23,779.83	78.47	86,063.24	284.01	2.31	6.76	1.29
Western red cedar	7,736.26	25.53	- 332.94	- 855.27	- 3.92	5,165.30	17.05	11,713.35	38.65	2.31	0.92	0.17
Marshal green ash	17,412.23	57.46	- 428.29	- 941.85	- 4.52	4,823.19	15.92	20,865.27	68.86	2.23	1.64	0.32

Species	Sequestered (lb)	Sequestered (\$)	Decomposition Release (lb)	Maintenance Release (lb)	Total Release (\$)	Avoided (lb)	Avoided (\$)	Net Total (lb)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/ tree
Eddie's white wonder	2,211.65	7.30	- 35.44	- 326.43	- 1.19	811.47	2.68	2,661.25	8.78	1.98	0.21	0.05
Littleleaf linden	9,418.29	31.08	- 322.98	- 786.24	- 3.66	4,713.93	15.56	13,023.00	42.98	1.92	1.02	0.23
Kwanzan cherry "K"	34,709.66	114.54	- 909.56	- 1,019.07	- 6.36	4,538.52	14.98	37,319.55	123.15	1.68	2.93	0.76
Katsura tree	3,273.66	10.80	- 56.60	- 413.01	- 1.55	1,456.90	4.81	4,260.95	14.06	1.59	0.33	0.09
Callery pear	4,213.66	13.91	- 91.97	- 475.02	- 1.87	1,970.70	6.50	5,617.36	18.54	1.57	0.44	0.12
Emerald queen Norway maple	12,070.49	39.83	- 246.77	- 556.92	- 2.65	2,576.58	8.50	13,843.37	45.68	1.56	1.09	0.31
Northern red oak	40,476.68	133.57	- 1,468.23	- 1,250.73	- 8.97	14,108.92	46.56	51,866.65	171.16	1.53	4.07	1.17
Caucasian ash	14,719.47	48.57	- 476.35	- 712.53	- 3.92	4,420.59	14.59	17,951.18	59.24	1.31	1.41	0.47
Green ash 'Sherwood Glen'	13,316.79	43.95	- 363.75	- 665.73	- 3.40	3,833.36	12.65	16,120.68	53.20	1.30	1.27	0.43
European white birch	8,070.89	26.63	- 544.08	- 141.57	- 2.26	6,510.48	21.48	13,895.71	45.86	1.26	1.09	0.38
Pacific sunset maple	4,120.77	13.60	- 43.70	- 223.47	- 0.88	597.11	1.97	4,450.71	14.69	1.26	0.35	0.12
Hornbeam 'Fastigiata'	9,054.01	29.88	- 170.64	- 134.55	- 1.01	2,515.43	8.30	11,264.25	37.17	1.20	0.88	0.32
Deodar cedar	14,451.15	47.69	- 802.43	- 1,089.27	- 6.24	9,544.48	31.50	22,103.93	72.94	1.06	1.74	0.72
Jacquemontii	4,501.67	14.86	- 138.96	- 117.00	- 0.84	2,571.88	8.49	6,817.59	22.50	1.05	0.54	0.22

Species	Sequestered (lb)	Sequestered (\$)	Decomposition Release (lb)	Maintenance Release (lb)	Total Release (\$)	Avoided (lb)	Avoided (\$)	Net Total (lb)	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/ tree
birch												
Hedge maple	6,704.15	22.12	- 116.24	- 331.11	- 1.48	1,354.91	4.47	7,611.71	25.12	1.01	0.60	0.26
OTHER STREET TREES	146,632.82	483.89	- 5,480.26	- 7,758.65	- 43.69	51,545.97	170.10	184,939.88	610.30	24.47	14.52	0.26
<i>CITYWIDE TOTAL</i>	<i>991,791.78</i>	<i>3,272.91</i>	<i>- 36,138.70</i>	<i>- 46,447.31</i>	<i>272.53</i>	<i>364,656.83</i>	<i>1,203.37</i>	<i>1,273,862.60</i>	<i>4,204.75</i>	<i>100</i>	<i>100</i>	<i>0.44</i>

vi. Annual Air Quality Benefits

Air quality: The Air Quality report quantifies the air pollutants (O3, NO2, SO2, PM10) deposited on tree surfaces and reduced emissions from power plants (NO2, PM10, VOCs, SO2) due to reduced electricity use (measured in pounds or kilograms). Also reported are the potential negative effects of trees on air quality due to BVOC emissions. *Depo. = Deposition

Species	Depo. O3 (lb)	Depo. NO2 (lb)	Depo. PM10 (lb)	Depo. SO2 (lb)	Total Depo. (\$)	Avoided NO2 (lb)	Avoided PM10 (lb)	Avoided VOC (lb)	Avoided SO2 (lb)	Total Avoided (\$)	BVOC Emissions (lb)	BVOC Emissions (\$)	Total (lb)	Total (\$)	% of Tree Number	Avg. \$ per tree
Norway maple	109.42	36.05	49.61	8.44	235.46	559.97	14.74	13.79	86.98	719.32	- 89.84	- 31.44	789.16	923.34	10.22	0.94
Douglas fir	137.35	43.62	89.35	12.86	343.51	528.34	13.68	12.88	82.76	679.60	- 580.24	- 203.08	340.61	820.02	7.59	1.13
Red maple	82.21	27.08	37.28	6.34	176.91	419.96	11.06	10.35	65.19	539.41	- 56.00	- 19.60	603.47	696.72	6.77	1.08
London planetree	97.92	32.26	44.40	7.56	210.73	530.04	13.89	13.02	82.51	681.11	- 82.95	- 29.03	738.65	862.81	5.21	1.73
Scarlet oak	65.81	20.93	34.91	5.29	149.78	323.11	8.49	7.95	50.21	415.09	- 117.38	- 41.08	399.32	523.79	3.80	1.44
Aristocrat pear	62.24	19.77	40.49	5.83	155.65	208.13	5.46	5.12	32.38	267.42	0.00	0.00	379.40	423.07	3.20	1.38
Green vase zelkova	17.21	5.67	7.72	1.30	36.85	94.20	2.47	2.31	14.67	121.05	- 137.57	- 48.15	7.99	109.75	2.92	0.39
Honeylocust	15.99	5.27	7.25	1.23	34.41	92.46	2.42	2.27	14.39	118.81	- 11.19	- 3.91	130.11	149.31	2.69	0.58
Sweetgum	36.54	12.03	16.40	2.75	78.21	197.25	5.17	4.84	30.71	253.48	- 296.23	- 103.68	9.45	228.00	2.56	0.93
Cleveland Norway maple	22.48	7.41	10.19	1.73	48.38	129.65	3.40	3.18	20.18	166.61	- 16.75	- 5.86	181.48	209.12	2.46	0.89
Pin oak	69.21	22.01	36.72	5.57	157.53	336.89	8.84	8.28	52.40	432.86	- 130.69	- 45.74	409.24	544.65	2.31	2.46
Western red cedar	18.85	5.99	12.26	1.77	47.15	72.58	1.88	1.77	11.38	93.37	- 74.79	- 26.18	51.68	114.34	2.31	0.52
Marshal green ash	11.62	3.82	5.21	0.88	24.87	67.68	1.75	1.65	10.62	87.09	0.00	0.00	103.23	111.96	2.23	0.53
Eddie's white wonder	2.16	0.71	0.97	0.16	4.63	11.49	0.30	0.28	1.79	14.77	- 16.22	- 5.68	1.66	13.72	1.98	0.07
Littleleaf linden	12.19	4.01	5.47	0.92	26.10	66.72	1.75	1.64	10.39	85.74	- 97.74	- 34.21	5.36	77.64	1.92	0.42
Kwanzan cherry "K"	12.61	4.15	5.66	0.95	27.00	64.18	1.68	1.57	10.00	82.49	- 0.23	- 0.08	100.58	109.41	1.68	0.68
Katsura tree	3.62	1.19	1.63	0.27	7.76	20.60	0.54	0.51	3.21	26.48	- 27.87	- 9.75	3.70	24.48	1.59	0.16

Species	Depo. O3 (lb)	Depo. NO2 (lb)	Depo. PM10 (lb)	Depo. SO2 (lb)	Total Depo. (\$)	Avoided NO2 (lb)	Avoided PM10 (lb)	Avoided VOC (lb)	Avoided SO2 (lb)	Total Avoided (\$)	BVOC Emissions (lb)	BVOC Emissions (\$)	Total (lb)	Total (\$)	% of Tree Number	Avg. \$ per tree
Callery pear	4.95	1.63	2.22	0.37	10.59	27.87	0.73	0.68	4.34	35.82	- 38.59	- 13.51	4.20	32.90	1.57	0.22
Emerald queen Norway maple	6.33	2.09	2.87	0.49	13.63	36.50	0.96	0.90	5.68	46.89	- 4.13	- 1.44	51.68	59.08	1.56	0.40
Northern red oak	41.92	13.33	22.24	3.37	95.43	199.90	5.25	4.92	31.09	256.84	- 79.62	- 27.87	242.41	324.40	1.53	2.22
Caucasian ash	10.57	3.48	4.74	0.80	22.63	62.04	1.60	1.51	9.74	79.83	0.00	0.00	94.48	102.46	1.31	0.82
Green ash 'Sherwood Glen'	9.11	3.00	4.09	0.69	19.51	53.75	1.38	1.31	8.44	69.16	0.00	0.00	81.77	88.67	1.30	0.72
European white birch	17.27	5.69	7.83	1.33	37.17	92.18	2.42	2.26	14.35	118.45	- 1.65	- 0.58	141.69	155.05	1.26	1.28
Pacific sunset maple	1.57	0.52	0.71	0.12	3.38	8.48	0.22	0.21	1.32	10.89	- 0.68	- 0.24	12.47	14.03	1.26	0.12
Hornbeam 'Fastigiata'	5.84	1.92	2.62	0.44	12.50	35.55	0.93	0.87	5.54	45.69	- 10.52	- 3.68	43.19	54.51	1.20	0.47
Deodar cedar	34.90	11.09	22.71	3.27	87.30	134.34	3.48	3.28	21.03	172.77	- 148.26	- 51.89	85.83	208.18	1.06	2.06
Jacquemontii birch	6.22	2.05	2.82	0.48	13.38	36.34	0.95	0.89	5.67	46.71	- 0.49	- 0.17	54.92	59.91	1.05	0.60
Hedge maple	3.33	1.10	1.51	0.26	7.17	19.20	0.50	0.47	2.99	24.67	- 2.02	- 0.71	27.35	31.14	1.01	0.32
OTHER STREET TREES	161.05	52.18	86.69	13.50	370.59	728.95	19.07	17.89	113.58	936.86	- 421.69	- 147.59	771.22	1,159.85	24.47	0.50
CITYWIDE TOTAL	1,080.51	350.03	566.60	88.98	2,458.20	5,158.36	135.01	126.61	803.53	6,629.28	- 2,443.34	- 855.17	5,866.28	8,232.31	100.00	0.86

vii. Annual Aesthetic Benefits

Aesthetic/other: The Aesthetic/Other report presents the tangible and intangible benefits of trees reflected in increases in property values (in dollars).

Species	Total (\$)	% of Total Tree Numbers	% of Total \$	Avg. \$/tree
Norway maple	142,173.53	10.22	13.86	145.37
Douglas fir	84,259.20	7.59	8.22	116.06
Red maple	76,854.43	6.77	7.49	118.60
London planetree	74,982.85	5.21	7.31	150.57
Scarlet oak	81,051.78	3.80	7.90	222.67
Aristocrat pear	16,545.06	3.20	1.61	54.07
Green vase zelkova	21,029.57	2.92	2.05	75.37
Honeylocust	22,847.75	2.69	2.23	88.90
Sweetgum	29,265.92	2.56	2.85	119.45
Cleveland Norway maple	27,167.14	2.46	2.65	115.60
Pin oak	65,706.50	2.31	6.41	297.31
Western red cedar	19,030.29	2.31	1.86	86.11
Marshal green ash	20,156.86	2.23	1.97	94.63
Eddie's white wonder	6,361.16	1.98	0.62	33.66
Littleleaf linden	14,121.18	1.92	1.38	76.75
Kwanzan cherry "K"	7,985.70	1.68	0.78	49.60
Katsura tree	7,922.28	1.59	0.77	52.12
Callery pear	8,982.37	1.57	0.88	59.88
Emerald queen Norway maple	10,536.53	1.56	1.03	70.71
Northern red oak	40,918.17	1.53	3.99	280.26
Caucasian ash	14,245.07	1.31	1.39	113.96
Green ash 'Sherwood Glen'	13,786.90	1.30	1.34	111.18
European white birch	12,386.90	1.26	1.21	102.37
Pacific sunset maple	4,359.83	1.26	0.43	36.03
Hornbeam 'Fastigiata'	17,379.33	1.20	1.69	151.12
Deodar cedar	16,869.66	1.06	1.64	167.03

Jacquemontii birch	8,194.10	1.05	0.80	81.94
Hedge maple	6,252.43	1.01	0.61	64.46
OTHER STREET TREES	154,172.31	24.47	15.03	65.86
<i>CITYWIDE TOTAL</i>	<i>1,025,544.80</i>	<i>100.00</i>	<i>100.00</i>	<i>107.20</i>

viii. Average Annual Benefits All Trees by Species

Species	Energy	CO2	Air Quality	Stormwater	Aesthetic/Other	Total
Norway maple	3.30	0.53	0.94	12.37	145.37	162.51
Douglas fir	3.50	0.39	1.13	21.00	116.06	142.08
Red maple	3.78	0.40	1.08	11.61	118.60	135.47
London planetree	5.86	1.03	1.73	20.79	150.57	179.98
Scarlet oak	5.06	0.80	1.44	15.89	222.67	245.86
Aristocrat pear	3.80	0.48	1.38	14.04	54.07	73.77
Green vase zelkova	1.86	0.22	0.39	6.31	75.37	84.16
Honeylocust	1.99	0.42	0.58	5.81	88.90	97.71
Sweetgum	4.43	0.52	0.93	15.43	119.45	140.75
Cleveland Norway maple	3.04	0.61	0.89	9.31	115.60	129.44
Pin oak	8.53	1.29	2.46	28.57	297.31	338.17
Western red cedar	1.55	0.17	0.52	9.01	86.11	97.36
Marshal green ash	1.45	0.32	0.53	5.70	94.63	102.64
Eddie's white wonder	0.34	0.05	0.07	1.12	33.66	35.24
Littleleaf linden	2.00	0.23	0.42	6.80	76.75	86.19
Kwanzan cherry "K"	2.16	0.76	0.68	5.03	49.60	58.23
Katsura tree	0.73	0.09	0.16	2.38	52.12	55.48
Callery pear	1.01	0.12	0.22	3.32	59.88	64.55
Emerald queen Norway maple	1.37	0.31	0.40	3.80	70.71	76.59
Northern red oak	7.67	1.17	2.22	26.29	280.26	317.62
Caucasian ash	2.28	0.47	0.82	9.20	113.96	126.74

Green ash 'Sherwood Glen'	1.94	0.43	0.72	7.91	111.18	122.18
European white birch	4.22	0.38	1.28	16.27	102.37	124.52
Pacific sunset maple	0.41	0.12	0.12	0.92	36.03	37.60
Hornbeam 'Fastigiata'	1.65	0.32	0.47	6.42	151.12	159.99
Deodar cedar	6.51	0.72	2.06	38.60	167.03	214.92
Jacquemontii birch	1.93	0.22	0.60	6.27	81.94	90.97
Hedge maple	1.12	0.26	0.32	2.94	64.46	69.10
OTHER STREET TREES	1.68	0.26	0.50	6.62	65.86	74.92

ix. Average Annual Benefits by Inventory of Species

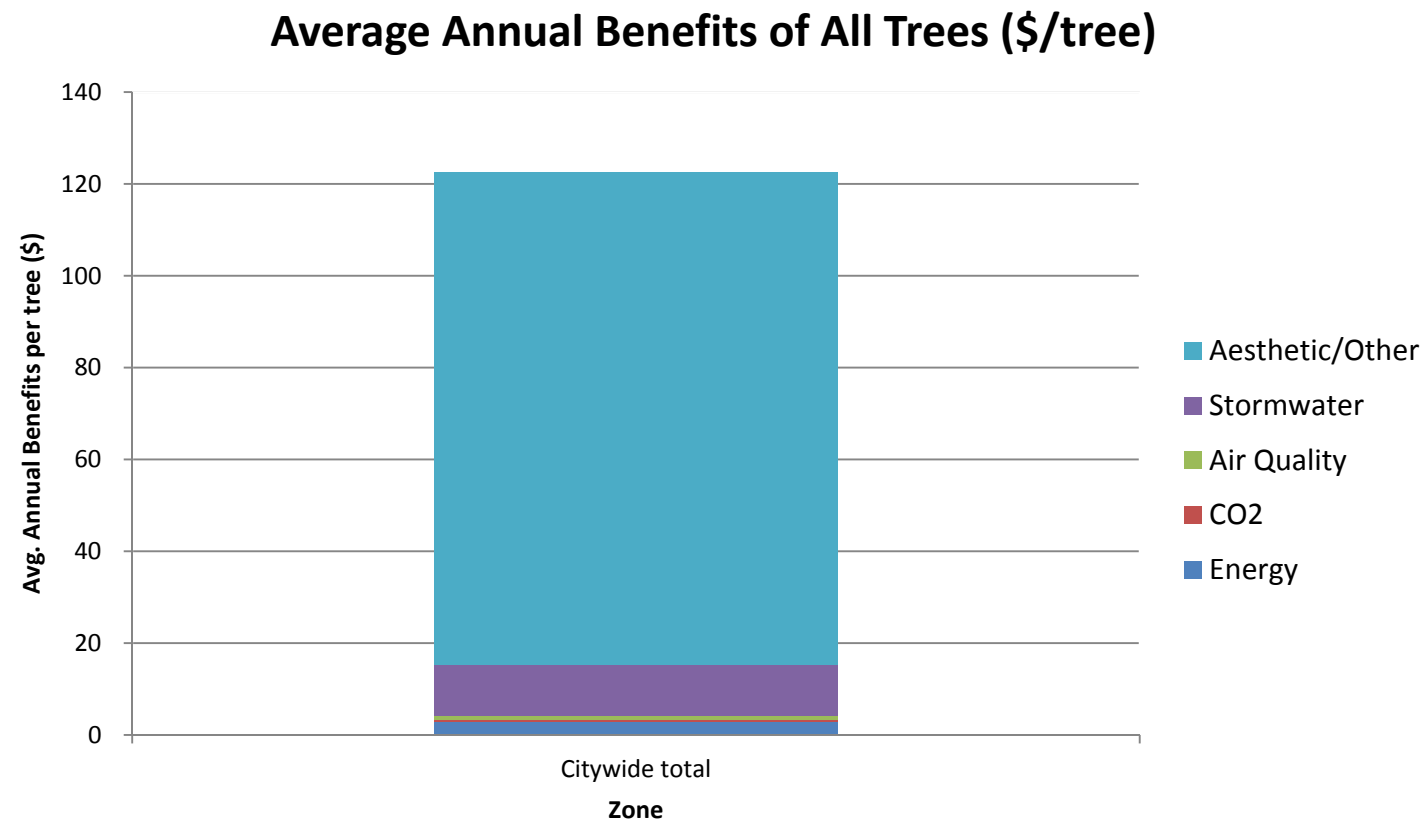
Species	Energy	CO2	Air Quality	Stormwater	Aesthetic/Other	Total (\$)	% of Total \$
Norway maple	3,224.44	515.43	923.34	12,096.22	142,173.53	158,932.97	13.55
Douglas fir	2,541.89	281.86	820.02	15,245.56	84,259.20	103,148.53	8.79
Red maple	2,448.16	260.13	696.72	7,522.23	76,854.43	87,781.67	7.48
London planetree	2,918.59	513.51	862.81	10,353.80	74,982.85	89,631.56	7.64
Scarlet oak	1,841.72	292.38	523.79	5,783.22	81,051.78	89,492.89	7.63
Aristocrat pear	1,163.33	145.65	423.07	4,295.73	16,545.06	22,572.83	1.92
Green vase zelkova	518.16	60.91	109.75	1,761.78	21,029.57	23,480.18	2.00
Honeylocust	512.15	108.08	149.31	1,494.32	22,847.75	25,111.61	2.14
Sweetgum	1,084.21	126.47	228.00	3,780.06	29,265.92	34,484.65	2.94
Cleveland Norway maple	713.32	142.45	209.12	2,186.97	27,167.14	30,419.01	2.59
Pin oak	1,886.10	284.01	544.65	6,314.74	65,706.50	74,735.99	6.37
Western red cedar	342.58	38.65	114.34	1,991.16	19,030.29	21,517.04	1.83

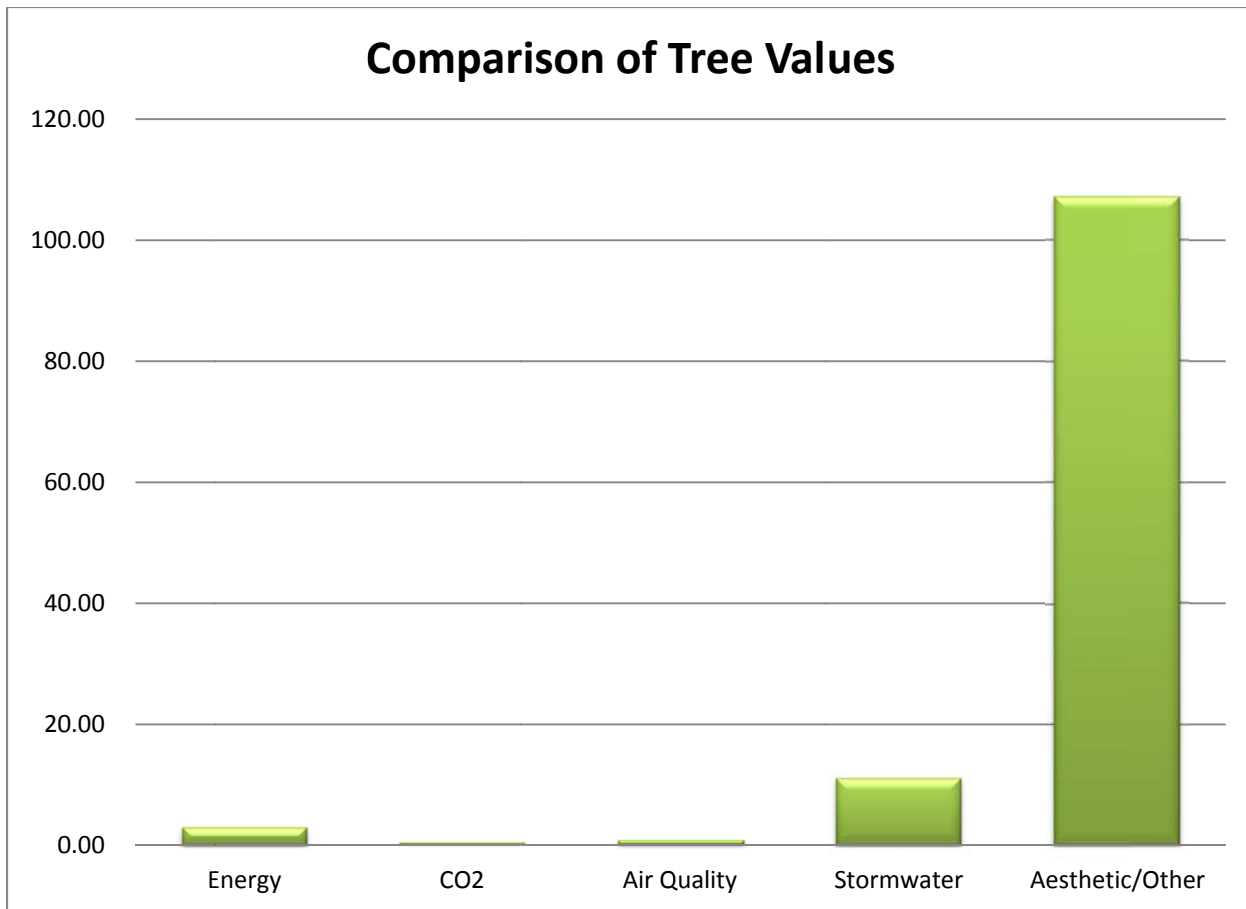
Marshal green ash	309.56	68.86	111.96	1,214.88	20,156.86	21,862.12	1.86
Eddie's white wonder	64.00	8.78	13.72	212.37	6,361.16	6,660.03	0.57
Littleleaf linden	367.31	42.98	77.64	1,250.68	14,121.18	15,859.79	1.35
Kwanzan cherry "K"	347.15	123.15	109.41	809.65	7,985.70	9,375.06	0.80
Katsura tree	111.18	14.06	24.48	361.35	7,922.28	8,433.34	0.72
Callery pear	151.24	18.54	32.90	497.92	8,982.37	9,682.96	0.83
Emerald queen Norway maple	203.68	45.68	59.08	566.30	10,536.53	11,411.27	0.97
Northern red oak	1,120.45	171.16	324.40	3,838.40	40,918.17	46,372.58	3.95
Caucasian ash	284.84	59.24	102.46	1,150.49	14,245.07	15,842.10	1.35
Green ash 'Sherwood Glen'	240.83	53.20	88.67	980.51	13,786.90	15,150.11	1.29
European white birch	510.45	45.86	155.05	1,969.15	12,386.90	15,067.40	1.28
Pacific sunset maple	49.90	14.69	14.03	110.74	4,359.83	4,549.19	0.39
Hornbeam 'Fastigiata'	189.38	37.17	54.51	738.46	17,379.33	18,398.85	1.57
Deodar cedar	657.75	72.94	208.18	3,898.43	16,869.66	21,706.97	1.85
Jacquemontii birch	192.81	22.50	59.91	627.26	8,194.10	9,096.60	0.78
Hedge maple	108.47	25.12	31.14	285.41	6,252.43	6,702.57	0.57
OTHER STREET TREES	3,941.38	610.30	1,159.85	15,501.58	154,172.31	175,385.43	14.95
CITYWIDE TOTAL	28,045.05	4,203.75	8,232.31	106,839.39	1,025,544.80	1,172,865.30	100.00

x. Average Annual Benefits of All Trees

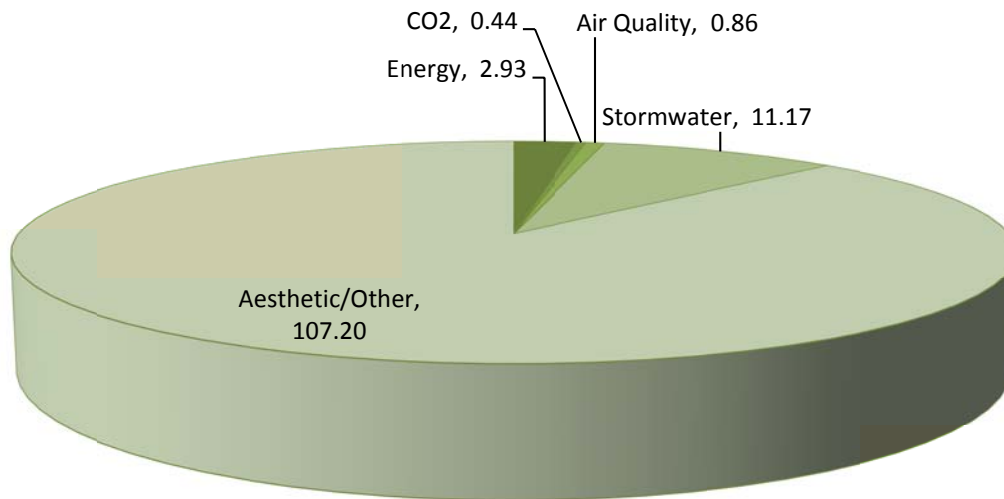
Average Annual Benefits of All Trees (\$/tree)						
	Energy	CO2	Air Quality	Stormwater	Aesthetic/Other	Total
City	2.93	0.44	0.86	11.17	107.20	122.59

xi. Average Annual Benefits of All Trees Chart I



xii. Average Annual Benefits of All Trees Chart II

xiii. Average Annual Benefits of All Trees Pie Chart



xiv. Annual Management Costs of Trees

Management Costs: Expenditures associated with street tree management are presented according to category and summed. Results are presented in total dollars, dollars per tree, and dollars per capita.

Expenditures Per Year	Total (\$)	\$ / Tree	\$ / Capita
Purchasing Trees and Planting	30,000.00	3.14	0.24
Contract Pruning	70,000.00	7.32	0.57
Pest Management	0.00	0.00	0.00
Irrigation	0.00	0.00	0.00
Removal	0.00	0.00	0.00
Administration	0.00	0.00	0.00
Inspection/Service	0.00	0.00	0.00
Infrastructure Repairs	0.00	0.00	0.00
Litter Clean-up	0.00	0.00	0.00
Liability/Claim	0.00	0.00	0.00
Other Cost	124,800.00	13.04	1.02
Total Expenditures	224,800.00	23.50	1.84

xv. Total Net Annual Benefits/Costs

Net Annual Benefits: Citywide benefits and costs are presented according to category and summed. Net benefits are calculated as benefits minus costs, and the benefit-cost ratio (benefits divided by costs) is shown. *Not accounting for pest management, irrigation, removal, administration, inspection/service, infrastructure repairs, litter clean-up, liability/claims, and other costs. **Hand watering 120 street trees at (\$20/tree/week).

Benefits Per Year	Total Benefits (\$)	\$/tree	\$/capita
Energy	28,045	2.93	0.23
CO2	4,204	0.44	0.03
Air Quality	8,232	0.86	0.07
Stormwater	106,839	11.17	0.87
Aesthetic/Other	1,025,545	107.20	8.37
Total Benefits	1,172,865	122.59	9.57
Cost*			

Planting	30,000	3.14	0.24
Contract Pruning	70,000	7.32	0.57
Other Costs** (hand watering)	124,800	13.04	1.02
Total Costs	224,800	23.50	1.84
Net Benefits	948,065	99.10	7.74
<i>Benefit-cost ratio</i>	5.217371		

xvi. Replacement Value of All Trees by Species

Replacement values are estimates of the full cost of replacing trees in their current condition, should they be removed for some reason. Replacement values are based on the Council of Tree and Landscape Appraisers (CTLA) Guide for Plant Appraisal, which uses a trunk formula methodology. The CTLA is a widely accepted methodology used by arborists for determining landscape tree replacement value based on regional species ratings, condition, location in the landscape, cross-sectional area of the trunk and regional replacement costs. Species ratings, replacement costs, and basic prices were obtained for each species in each reference city from regional appraisal guides. Because of the approximations used in these calculations, replacement values are first-order estimates for the population and are not intended to be definitive on a tree-by-tree basis.

Species/DBH (in)	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% Total
Norway maple	20,670.23	124,959.74	819,118.16	303,971.29	17,628.14	0.00	0.00	0.00	0.00	1,286,347.55	8.41
Douglas fir	33,528.54	37,684.67	277,446.88	580,646.71	479,088.48	268,540.21		152,364.30	136,252.53	2,197,394.94	14.37
										231,842.62	
Red maple	16,661.98	79,720.73	523,099.92	249,176.86	89,197.06	16,344.84	0.00	0.00	0.00	974,201.37	6.37
London planetree	1,332.70	24,024.53	459,292.90	707,062.73	550,195.91	427,371.01		34,382.80	0.00	2,386,043.86	15.61
										182,381.28	
Scarlet oak	10,233.73	24,939.14	259,157.44	198,849.08	59,106.73	0.00	0.00	0.00	0.00	552,286.12	3.61
Aristocrat pear	1,816.71	29,415.80	338,623.95	36,883.79	0.00	0.00	0.00	0.00	0.00	406,740.25	2.66
Green vase zelkova	9,280.12	57,126.27	126,154.30	62,543.82	9,362.43	0.00	0.00	0.00	0.00	264,466.94	1.73
Honeylocust	5,869.37	48,260.29	156,998.38	32,785.59	0.00	0.00	0.00	0.00	0.00	243,913.63	1.60
Sweetgum	6,299.66	7,262.56	174,306.54	259,254.31	23,152.07	0.00	18,468.85	0.00	0.00	488,743.99	3.20
Cleveland Norway maple	2,492.40	21,799.49	239,697.11	96,192.31	8,485.06	0.00	0.00	0.00	0.00	368,666.37	2.41
Pin oak	858.28	10,740.01	144,646.78	427,483.18	144,534.60	0.00	0.00	0.00	0.00	728,262.84	4.76

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[illegible]

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Species/DBH (in)	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% Total
dogwood											
Three flowered	1,292.17	496.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,788.92	0.01
maple											
Reddish alder	655.89	473.90	4,891.78	4,372.38	0.00	0.00	20,823.09	0.00	0.00	31,217.04	0.20
Pacific crabapple	1,348.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,348.72	0.01
Fernleaf Full-moon	1,311.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,311.79	0.01
maple											
Upright English	0.00	1,378.87	1,539.20	12,294.60	23,810.10	0.00	0.00	0.00	0.00	39,022.76	0.26
white oak											
Ponderosa pine	108.90	0.00	1,868.21	15,255.73	29,732.35	0.00	23,824.49	31,539.21	0.00	102,328.89	0.67
Japanese tree lilac	1,226.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,226.11	0.01
Americans linden	0.00	2,757.73	4,617.60	0.00	0.00	0.00	0.00	0.00	0.00	7,375.33	0.05
White oak	0.00	3,217.35	1,539.20	0.00	0.00	13,054.70	0.00	0.00	0.00	17,811.25	0.12
Scouler willow	1,643.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,643.29	0.01
Western hemlock	0.00	0.00	2,822.50	26,000.45	0.00	0.00	0.00	0.00	0.00	28,822.95	0.19
Cascara	1,049.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,049.43	0.01
Flowering	1,186.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,186.52	0.01
dogwood											
Western white	838.48	0.00	0.00	8,196.40	0.00	0.00	0.00	0.00	0.00	9,034.88	0.06
pine											
Pacific dogwood	469.88	496.75	3,553.64	0.00	0.00	0.00	0.00	0.00	0.00	4,520.27	0.03
'Pacific'											

[illegible]

[illegible]

Species/DBH (in)	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% Total
plum 'Thunder'											
Citywide total	334,682.19	1,286,635.72	5,053,818.03	4,148,929.95	2,120,185.66	1,011,523.26	748,444.95	307,216.74	275,150.89	15,286,587.38	100.00

Appendix F - i-Tree Canopy Results

Table 11. i-Tree Canopy Results Web Window - City Wide.

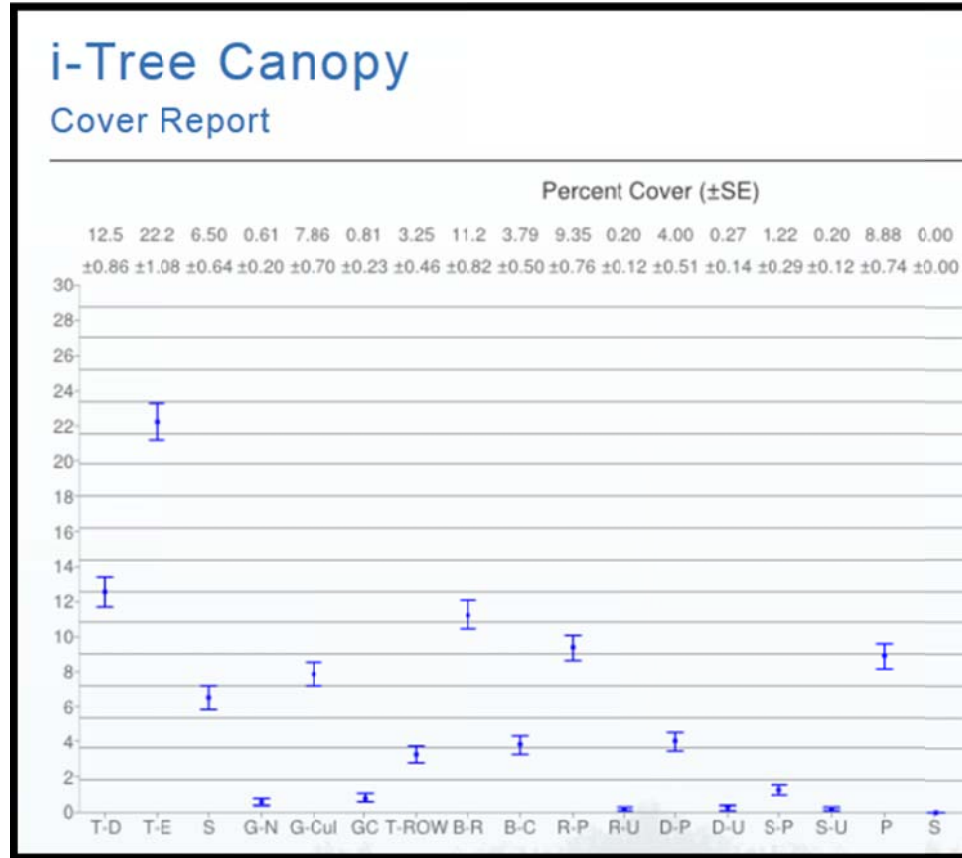


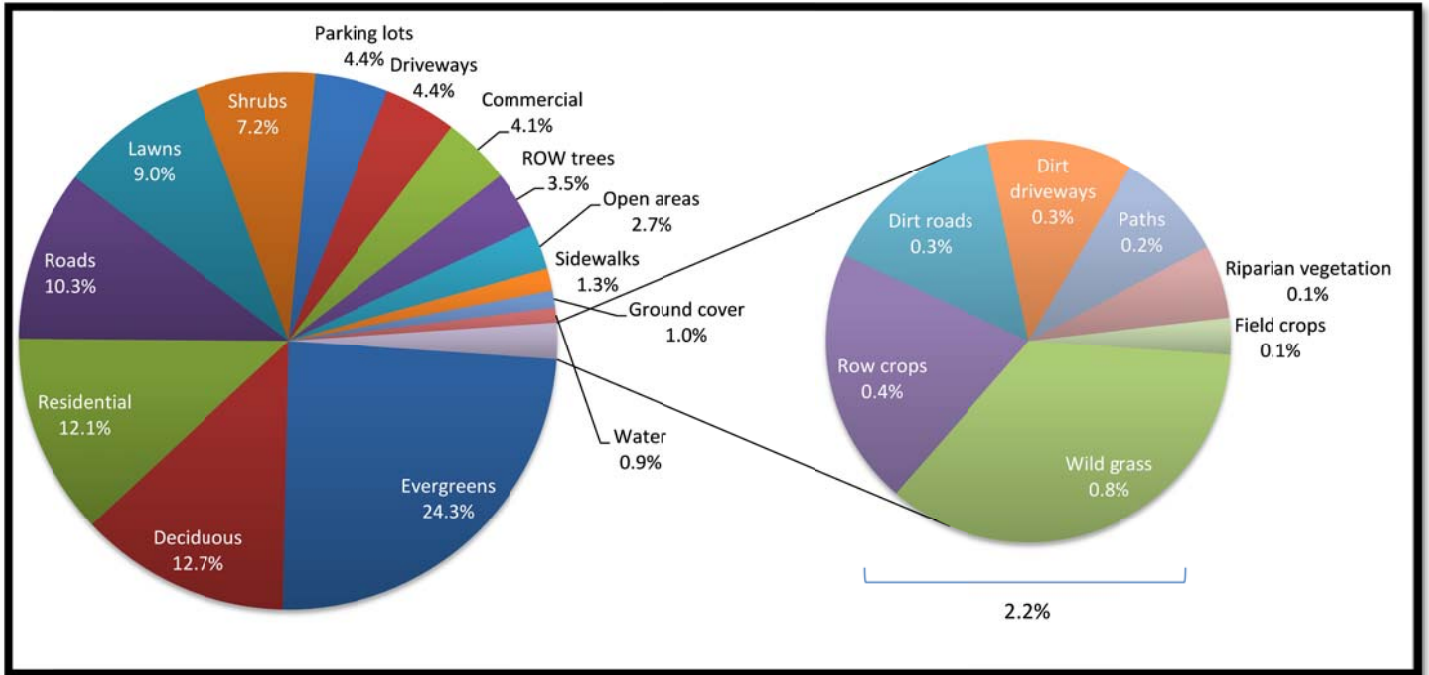
Table 12. i-Tree Canopy Results with Standard Error - City Wide.

Cover Class	Description
Trees Broadleaf (deciduous)	Seasonal canopy
Trees Needleleaf (evergreen)	Conifers
Shrubs (woody, non-woody)	All shrub vegetation
Grass (natural)	Wildtype areas
Grass (lawns)	Grass manicured
Ground Cover	Non-grass
Tree (ROW)	Trees in public ROW
Building Residential	Residential areas
Building Commercial	All commercial
Roads Paved	All impervious roadways
Roads Unpaved	All pervious roadways
Driveways Paved	Impervious driveways
Driveways Unpaved	Pervious driveways
Sidewalks paved	Impervious walkways
Sidewalks unpaved	Pervious walkways
Ponds	All open standing water
Streams	All moving water
Crops row	All planted row crops
Crops fields	All open grown crops
Riparian Vegetation	All plants in riparian zone
Open Area (dirt)	All undeveloped disturbed areas
Parking Lot	All parking lots

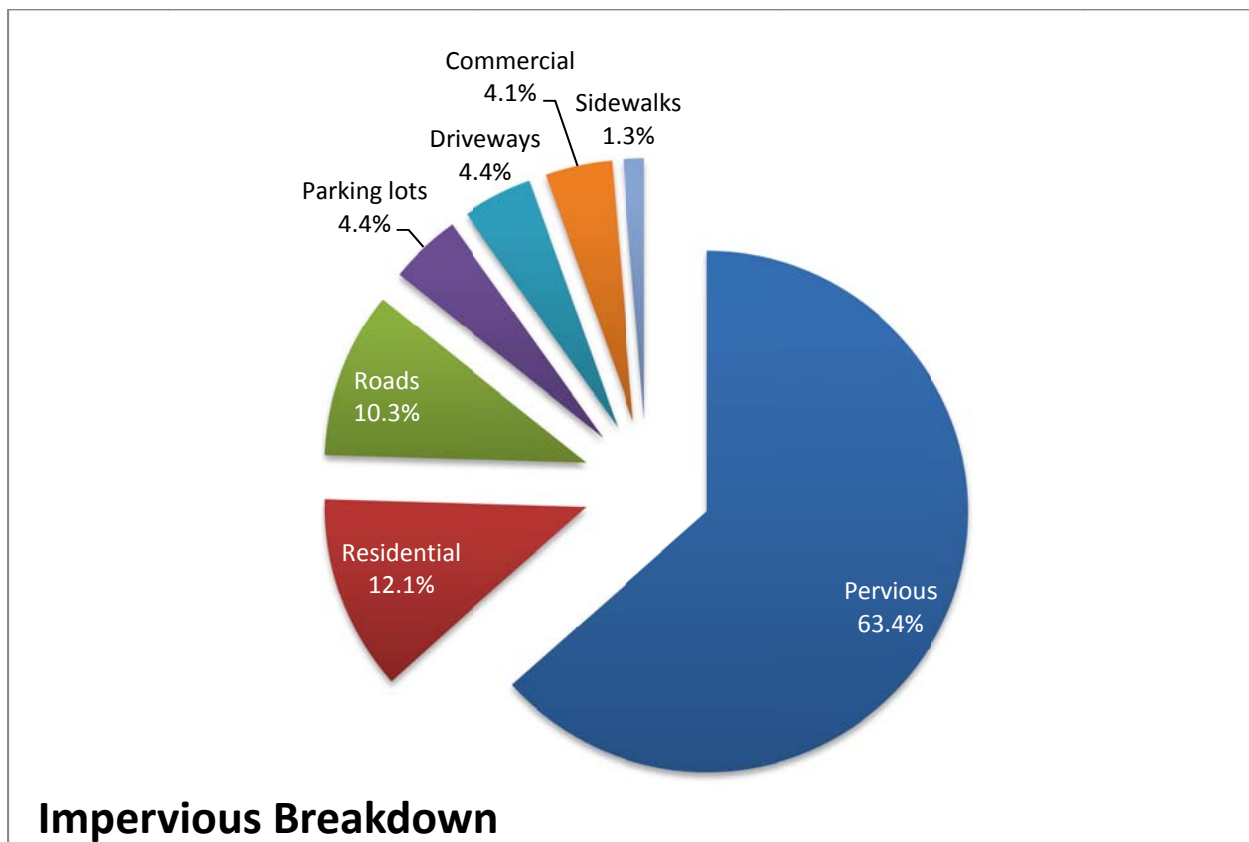
Table 13. Land Cover and Canopy Coverage - City Wide.

Class	Percentage		
Evergreen	24.24		
Deciduous	13.67	Pervious	63.12 %
Residential RE	12.27		
Paved Roads	10.42	Impervious	36.88 %
Lawns	8.57		
Shrubs	7.10	Forest Canopy	38.43 %
Paved Driveways	4.36		
Parking Lot	4.36		
Commercial RE	4.14		
Row Trees	3.55		
Dirt	2.66		
Sidewalks	1.33		
Ground Cover	0.89		
Grass	0.67		
Row Crops	0.52		
Lakes	0.37		
Unpaved Driveways	0.30		
Unpaved Roads	0.22		
Paths	0.22		
Field Crops	0.07		
Riparian Veg	0.07		

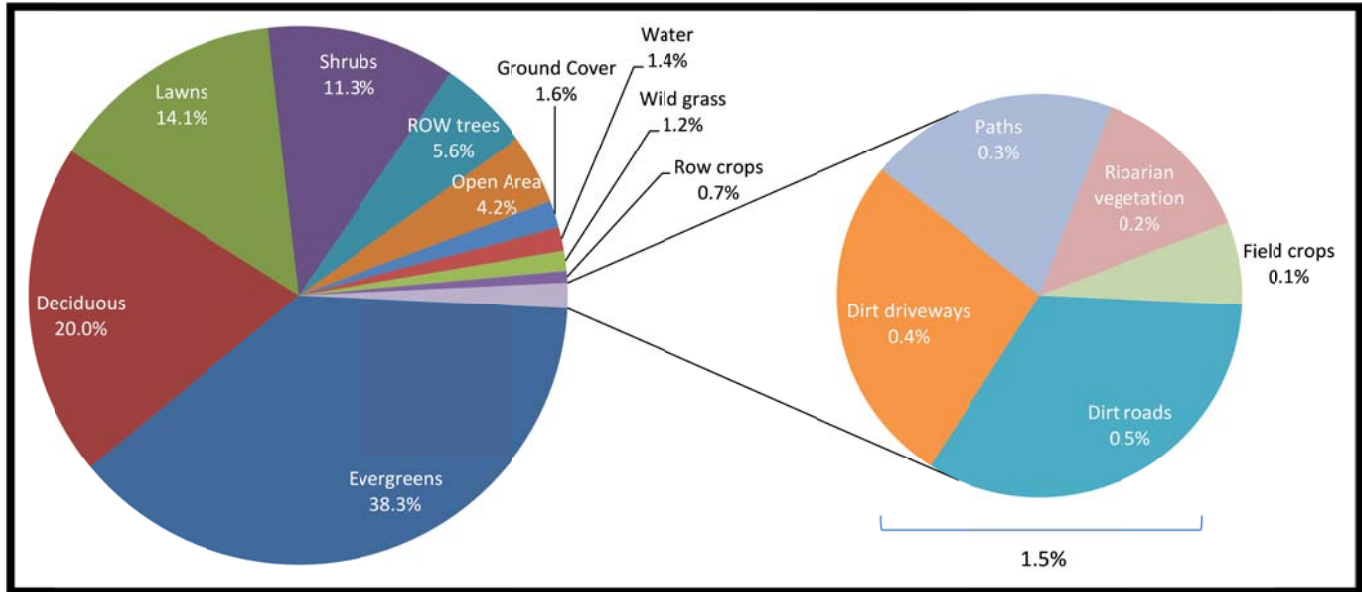
i. Total Land Cover Breakdown



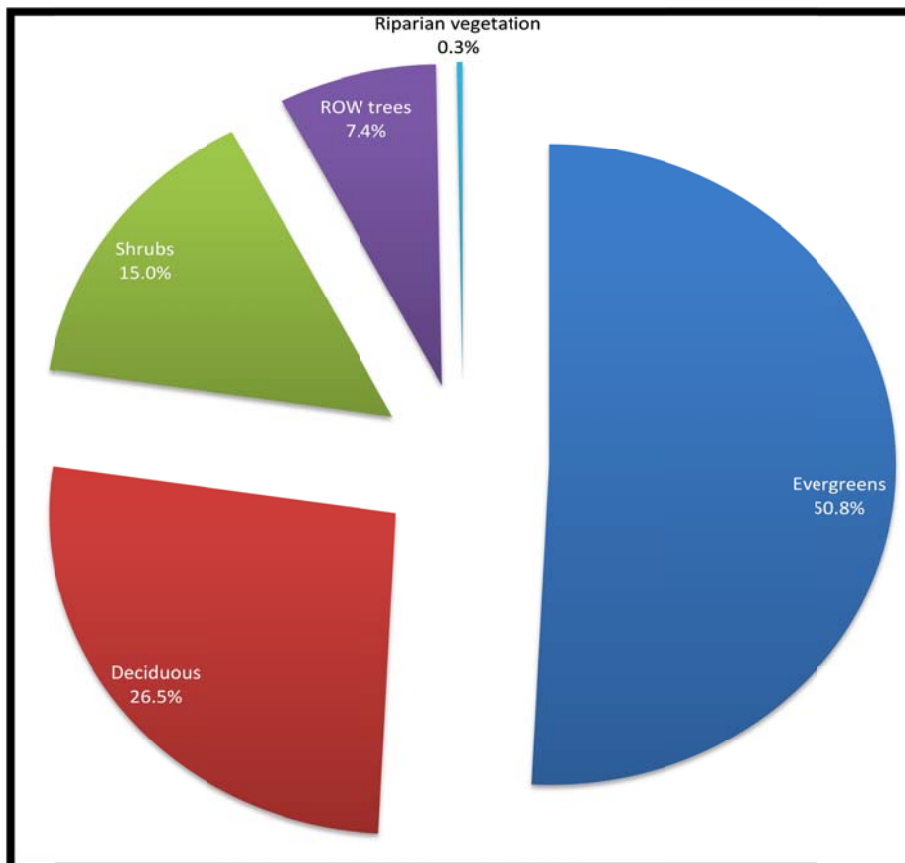
ii. Impervious Breakdown



iii. Pervious Land Cover Breakdown



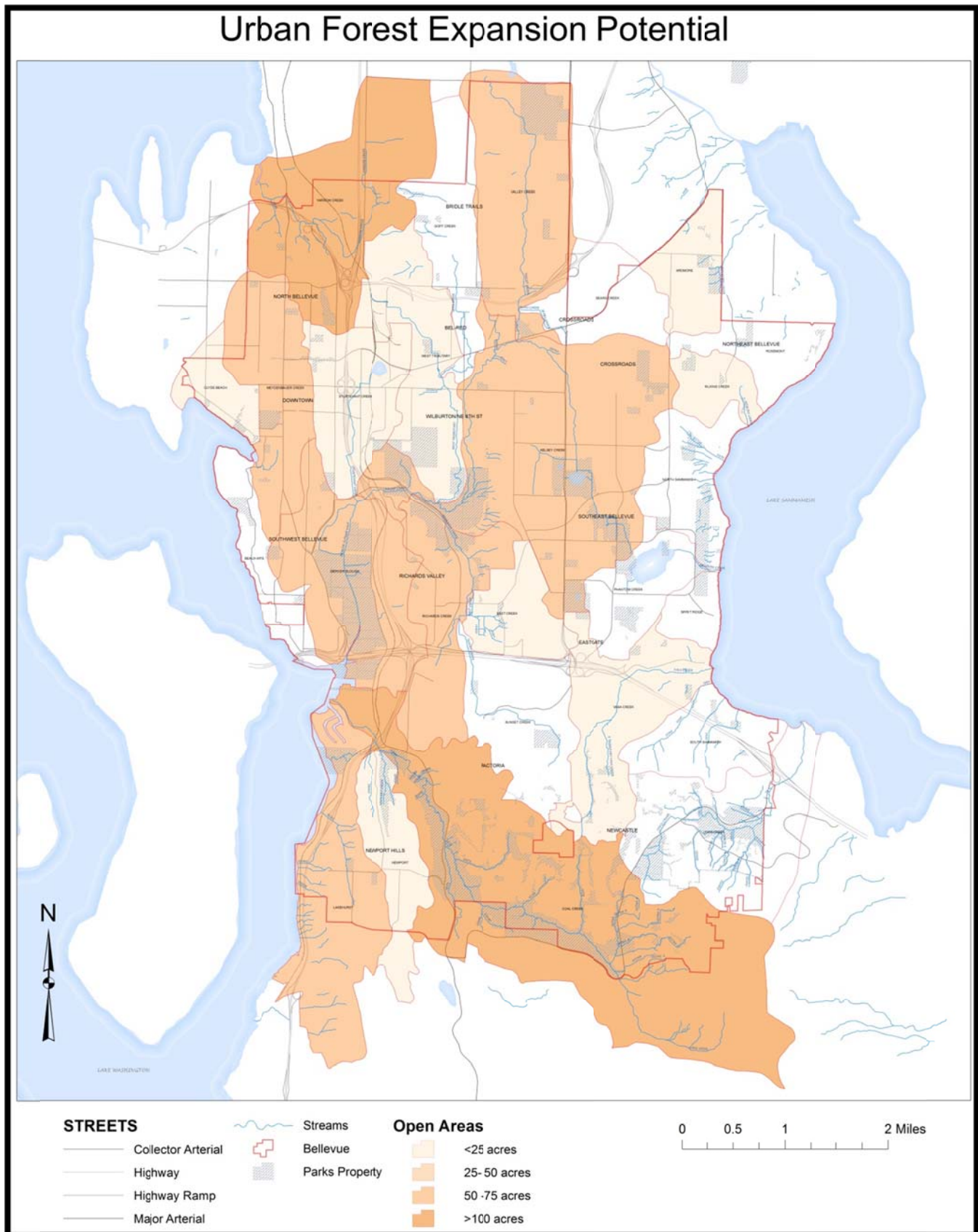
iv. Urban Forest Breakdown



Land Cover and Forest Canopy

Pervious Acres	% Pervious	Impervious Acres	% Impervious	% Canopy	% Evergreen	% Deciduous	Total Canopy Acres	Total Open Acres
317.2	70.3	134.3	29.7	34.5	31.0	3.5	155.8	15.4
318.2	75.6	102.7	24.4	57.1	33.3	23.8	240.5	-
195.8	66.9	96.7	33.1	33.3	20.0	13.3	97.5	19.5
3,437.8	86.2	552.0	13.8	53.8	31.7	15.2	2,146.5	75.8
317.2	66.9	157.0	33.1	43.6	23.1	15.4	206.7	12.1
575.4	82.3	124.1	17.7	56.0	42.2	6.7	391.7	-
1,986.5	70.5	832.3	29.5	40.0	19.6	17.1	1,127.5	73.3
1,011.1	78.8	272.6	21.2	46.9	24.5	18.4	602.6	26.2
1,144.7	79.7	291.5	20.3	46.0	28.6	15.9	661.1	-
1,088.0	81.6	246.1	18.4	35.6	15.8	15.8	475.5	66.0
523.7	57.1	393.9	42.9	18.8	8.7	7.3	172.9	39.9
419.7	73.2	153.4	26.8	32.0	20.0	12.0	183.4	22.9
490.9	78.4	134.9	21.6	32.6	25.6	7.0	203.8	-
409.3	76.3	127.3	23.7	43.1	27.5	9.8	231.5	-
624.6	69.3	276.8	30.7	41.0	16.7	24.2	369.6	27.3
315.9	72.8	117.7	27.2	46.7	33.3	13.3	202.4	-
321.2	55.6	256.2	44.4	33.3	29.6	3.7	192.5	-
478.3	80.5	116.1	19.5	43.8	18.8	25.0	260.0	-
153.4	71.2	62.1	28.8	50.0	50.0	0.0	107.8	-
409.6	53.0	363.4	47.0	21.2	5.8	11.5	163.5	14.8
648.6	76.0	205.0	24.0	36.0	28.6	3.6	307.3	-
1,033.6	74.3	357.2	25.7	42.7	34.2	6.1	593.6	50.9
835.8	76.7	253.3	23.3	41.7	29.2	8.3	453.8	22.7
680.9	68.0	320.0	32.0	39.0	25.8	10.1	390.4	20.0
222.5	72.8	83.3	27.2	25.0	0.0	10.7	76.5	21.8

vi. Urban Forest Expansion Potential



Appendix G – i-Tree Vue Results

Figure 28. i-Tree Vue Correction Dialog Box.

NLCD Adjustment Factor - Tree Canopy (beta)

NLCD Tree Canopy Image

Enter an NLCD adjustment factor for the entire region:

Help for this Form:

Studies have shown NLCD to underestimate Tree Canopy to varying degrees. If desired, use this form to enter an adjustment factor to be applied UNIFORMLY across the NLCD Tree Canopy imagery.

A COPY of the adjusted Tree Canopy image will be saved to the same folder as the original image. The adjusted Tree Canopy image will be loaded into Vue and used for the remainder of this session. Upon restarting Vue, the ORIGINAL Tree Canopy image can be reloaded OR the ADJUSTED Tree Canopy image can be loaded. The original Tree Canopy will NOT be overwritten or deleted.

Use the map at left to identify the NLCD Zone (1-66) that the Area of Interest lies within. Once the Zone is identified, scroll to the appropriate zone in the table at left to review the research results for that Zone. CLICK the value from the Difference column to set as the adjustment factor for the entire region. More information via the Adjustment Factor Information button below.

As an ALTERNATIVE method, i-Tree Canopy can be used to statistically estimate the percent Tree Canopy of a specific Area of Interest. Visit www.itreetools.org > applications > i-Tree Canopy for more information.

- » Cancel returns to the images.
- » OK starts the adjustment processing.
- » Reset restores default values.

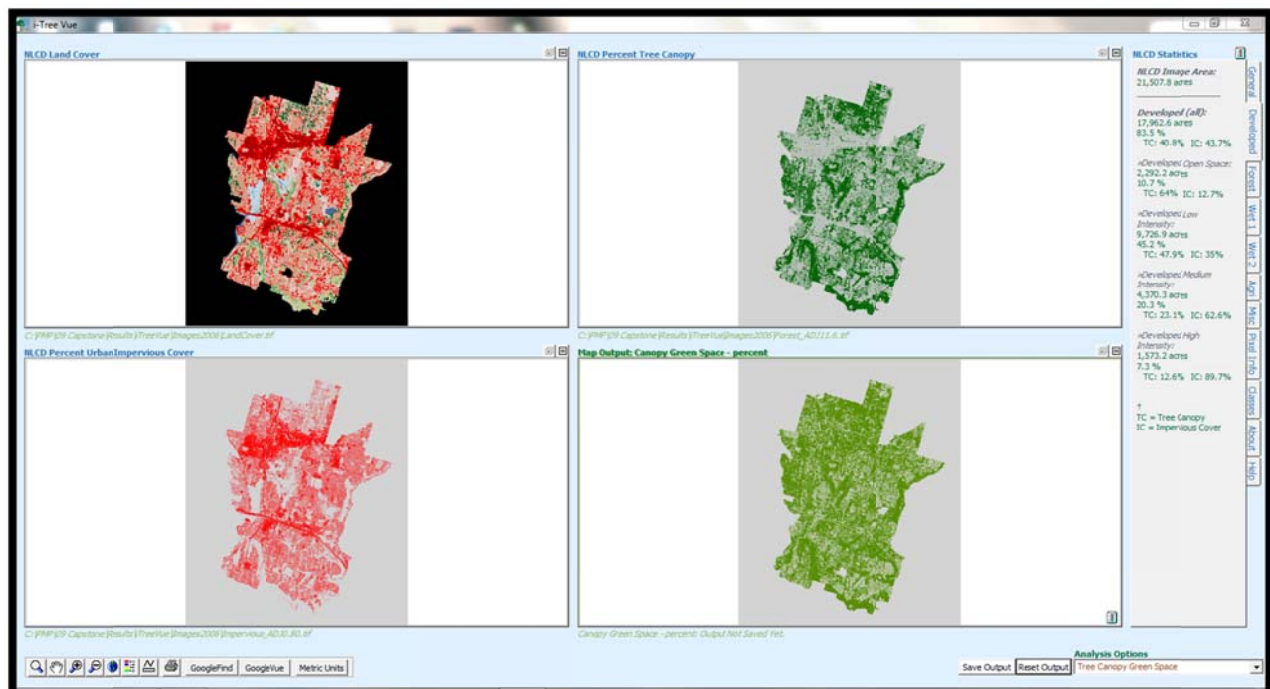
Adjustment Factor Information

Zone	n	Photo	SE	NLCD	Difference	Notes
1	992	69.7	1.3	58.1	11.6 **	
2	996	69.7	1.1	53	16.7 **	
3	1017	72.3	1.2	43.9	28.4 **	
4	1000	37.4	1.3	11.5	25.9 **	
5	1000	11	1	5.5	5.5 **	
6	995	59	1.4	35.6	23.4 **	
7	999	62	1.4	40.7	21.3 **	
8	998	3.6	0.6	1.3	2.3 **	
9	930	19	1.3	12.6	6.4 **	

n = number of photo interpreted points
Photo = photo-interpreted value
SE = standard error of photo-interpretation estimate
NLCD = NLCD derived cover value
Difference = Photo value minus NLCD value

** Significant difference at 95% confidence level
*** Significant difference at 99% confidence level
Source: Nowak, D.J., Greenfield, E.J., Environmental Management (2010) 46: 379-390

Figure 29. i-Tree Vue Interface.



i. i-Tree Vue Uncorrected and Corrected Land Cover Results

NLCD Raw Image Statistics (without Nowak Correction)

Image Area	21,507.8 acres	
Impervious Cover	7,667.9 acres	35.8%
Tree Canopy	10,344.8 acres	36.6%
Developed (All)	17,962.6 acres	83.5% (TC 28.9; IC 42.7)
Forest (ALL)	2,851.5 acres	13.3 (TC 81.1; IC 0.1%)

NLCD Corrected Image Statistics Correction - Current Benefits

Impervious Cover:	7,667.9 acres	35.8%
Tree Canopy	10,344.8 acres	48.4%
Developed (All)	17,962.6 acres	83.5% (TC 40.8; IC 42.7)
Forest (ALL)	2,851.5 acres	13.3 (TC 92.1; IC 0.1%)

ii. i-Tree Vue Current Canopy Benefits

Carbon Sequestration: 13,844.2 short tons per year
 \$286,350.5 @ \$20.68 per short tons per year
 CO₂ Equivalent Sequestration: 50,752.8 short tons
 per year; \$286,350.5 @ \$5.64 per short ton/year
 2,676.53 pounds per acre/year

Carbon Storage: 419,940.2 short tons; \$8,685,964.1 @ \$20.68 per
 short tons
 CO₂ Equivalent Storage: 1,539,500.8 short tons;
 \$8,685,964.1 @ \$5.64 per short ton

81,188 tons per acre of tree canopy:

Pollution Removal - CO: 20.1 short tons per year
 \$25,647.2 @ \$1276.41 per short tons per year

3.88468 pounds per acre/year of canopy

Pollution Removal - NO₂: 58.7 short tons per year
 \$527,114.3 @ \$8,986.57 per short tons per year

11.3400 pounds per acre/year of canopy

Pollution Removal - O₃: 157.2 short tons per year
 \$1,412,898.3 @ \$8,986.57 per short tons per year

30.3964 pounds per acre/year of canopy

Pollution Removal - PM₁₀:	92.6 short tons per year
	\$555,830.4 @ \$6,000.12 per short tons per year

17.9097 pounds per acre/year of canopy

Pollution Removal - SO₂:	50.0 short tons per year
	\$109,985.4 @ \$2,199.92 per short tons per year

9.66570 pounds per acre/year of canopy

iii. i-Tree Vue Conservative Canopy Expansion 51.4 %(+3%)

Move to 10,997.0 acres adding 652.2 acres

Carbon Storage: \$547,599	446,415.0 short tons; \$9,233,563.2 @ \$20.68 per short tons
----------------------------------	--

Difference: 26,474.8 short tons

CO₂ Equivalent Storage: 1,636,557.2 short tons;
\$9,233,563.2 @ \$5.64 per short ton

Difference: 97,056.5 short tons

Carbon Sequestration: \$18,053	14,717.0 short tons per year
	\$304,403.2 @ \$20.68 per short tons per year
	CO ₂ Equivalent Sequestration: 53,952.4 short tons per year; \$304,403.2 @ \$5.64 per short ton/year

Difference: 3,199.7 short tons

Pollution Removal CO: \$1,617	21.4 short tons per year
	\$27,264.1 @ \$1,276.41 per short tons per year

Difference: 1.3 short tons

Pollution Removal NO₂: \$33,231	62.4 short tons per year
	\$560,345.8 @ \$8,986.57 per short tons per year

Difference: 3.7 short tons

Pollution Removal O₃: 89,075	167.1 short tons per year
	\$1,501,973.3 @ \$8,986.57 per short tons per year

Difference: 9.9 short tons

Pollution Removal PM₁₀: \$35,042 98.5 short tons per year
 \$590,872.3 @ \$6,000.12 per short tons per year
 Difference: 5.8 short tons

NLCD Technical Notes:

Main Components Independent DEM ancillary data layers of slope, aspect, elevation and topographic position. Classified Land Cover data derived from imagery and ancillary data using a Decision Tree.

- 1) Identification of optimal early, peak and late Landsat TM scene acquisitions for each path/row based on AVHRR seasonal averages. (Yang et al)
- 2) Development of Landsat 7 radiometric and at-sensor reflectance calibrations for imagery to reduce mosaicking difficulty. (Huang et al)
- 3) Development of Tasseled Cap coefficients for Landsat 7 at-sensor reflectance (Huang et al)
- 4) Justification of Tasseled Cap as an optimal way of distilling 6 bands into 3 (Wylie et al)
- 5) Regional mapping using land cover friendly mapping zones (Homer et al)
- 6) Development of imperviousness estimates from TM imagery. (Yang et al)
- 7) Development of tree canopy estimates from TM imagery. (Huang et al)
- 8) Development of image processing rules coupled with ancillary data as needed to classify Landsat data into land cover.
- 9) Comprehensive accuracy assessments of the land cover data and related components.

For More Information: Website: <http://www.mrlc.gov/index.php>. The above text taken from:

<http://www.mrlc.gov/about.php> and Complete References: <http://www.mrlc.gov/publications.php>.

National Land Cover Dataset:

2006: Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

2001: Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J.N., and Wickham, J. 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States. *Photogrammetric Engineering and Remote Sensing*, Vol. 73, No. 4, pp 337-341.

Appendix H - Going Forward: Resources

i. Storm Drainage

ArchHydro& Other GIS Software: http://www.esri.com/industries/water_resources/index.html

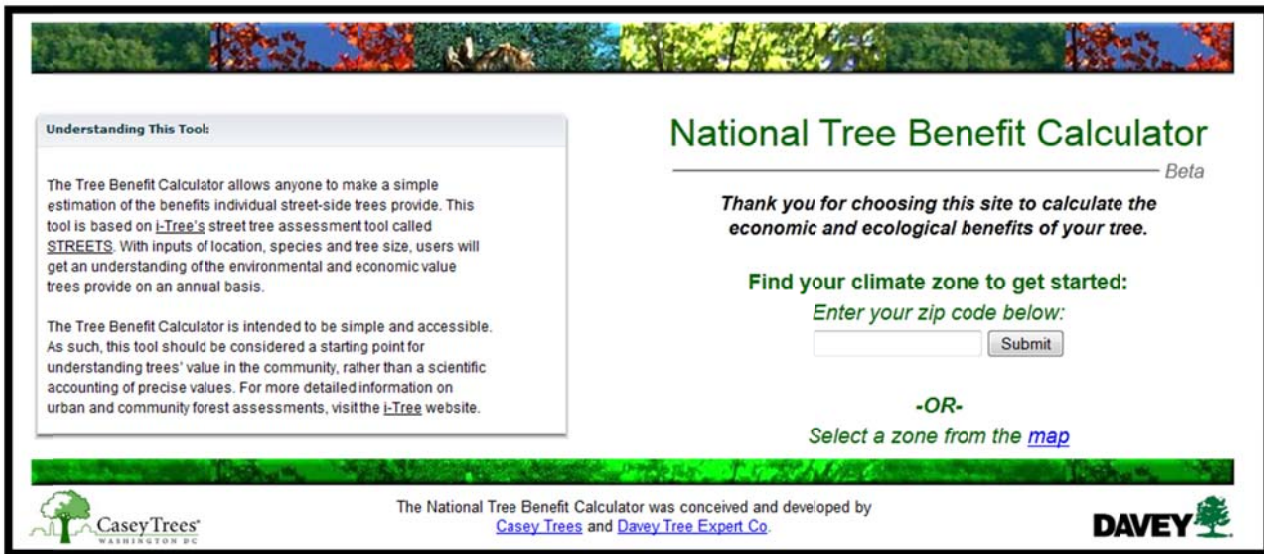
Surface Water: <http://resources.arcgis.com/en/communities/hydro/01vn00000010000000.htm>

National Hydrography Dataset New Applications Site:

<http://blogs.esri.com/esri/arcgis/2012/07/17/national-hydrography-dataset-new-applications-page/>

StreamStats: <http://streamstats.usgs.gov/>

ii. Urban Forest



National Tree Benefit Calculator Beta

Thank you for choosing this site to calculate the economic and ecological benefits of your tree.

Find your climate zone to get started:
 Enter your zip code below:

-OR-
 Select a zone from the [map](#)

Understanding This Tool:

The Tree Benefit Calculator allows anyone to make a simple estimation of the benefits individual street-side trees provide. This tool is based on i-Tree's street tree assessment tool called **STREETs**. With inputs of location, species and tree size, users will get an understanding of the environmental and economic value trees provide on an annual basis.

The Tree Benefit Calculator is intended to be simple and accessible. As such, this tool should be considered a starting point for understanding trees' value in the community, rather than a scientific accounting of precise values. For more detailed information on urban and community forest assessments, visit the [i-Tree](#) website.

The National Tree Benefit Calculator was conceived and developed by [Casey Trees](#) and [Davey Tree Expert Co.](#)

Casey Trees WASHINGTON DC **DAVEY**

Source: http://www.fs.fed.us/psw/programs/uesd/uep/tree_guides.php

Examples of Urban Forest Management Plans: http://phytosphere.com/caufc/links_manageplans.html

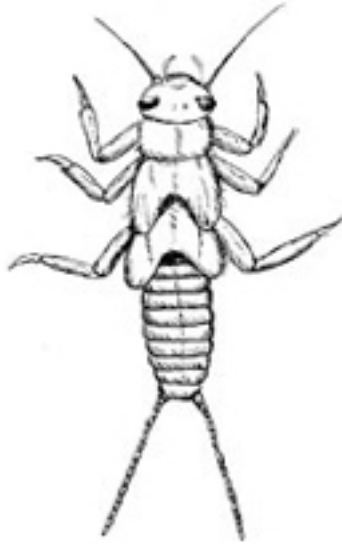
Benefits Calculator: <http://www.treebenefits.com/calculator/index.cfm>

i-Tree Canopy Link: <http://www.itreetools.org/canopy/index.php>

Appendix I – Project Cost-Benefit Summary

Storm Drainage and Urban Forest Analysis Project Benefit-Cost Summary																					
Hours Per Resource Per Week	Initiate Gateway Start Date: 6/18/2012 End Date: 7/1/2012			Plan Gateway Start Date: 6/25/2012 End Date: 7/15/2012			Implementation Gateway Total: 5 weeks									Execute 8/17/2012			Close Gateway Start Date: 8/13/2012 End Date: 8/19/2012		
	2		Week Duration	2		Week Duration	Development Start Date: 7/9/2012 End Date: 7/29/2012			SIT Start Date: 7/30/2012 End Date: 8/5/2012			UAT Start Date: 8/6/2012 End Date: 8/12/2012			1		Day Duration	1		Week Duration
	Weekly Hours	Aggregate Hours	\$ per Resource	Weekly Hours	Aggregate Hours	\$ per Resource	Weekly Hours	Aggregate Hours	\$ per Resource	Weekly Hours	Aggregate Hours	\$ per Resource	Weekly Hours	Aggregate Hours	\$ per Resource	Daily Hours	Aggregate Hours	\$ per Resource	Weekly Hours	Aggregate Hours	\$ per Resource
GIS Resources																					
GIS Analyst 1	15	30	\$870	12.5	41	\$363	12.5	49	\$1,421	12.5	12.5	\$363	12.5	12.5	\$363	1.5	1.5	\$44	0	0	\$0
GIS Analyst 1	15	30	\$870	12.5	41	\$363	12.5	49	\$1,421	12.5	12.5	\$363	12.5	12.5	\$363	1.5	1.5	\$44	6	6	\$174
Totals: Hours/\$	30	60	\$1,740	25	82	\$725	25	98	\$2,842	25	25	\$725	25	25	\$725	3	3	87	6	6	\$174
Project Sponsors																					
Engineer	2	2.5	\$103	3	4	\$164	1.5	2	\$82			\$0	2	2	\$82	1.5	1.5	\$62	5	5	\$205
GIS Team Lead	1	1	\$136	1.5	1.5	\$204	1	1	\$136			\$0	2	1	\$136	1.5	1	\$136	0	0	\$0
Totals: Hours/\$	3	3.5	\$239	4.5	5.5	\$368	2.5	3	\$218	0	0	\$0	4	3	\$218	3	2.5	\$198	5	5	\$205
Summary Project Estimates				Hours	\$ Totals	Storm Drainage Benefits				Street Trees Benefit-Cost											
Initial Gateway				63.5	\$1,979	Benefits		Cost Saves/Year		Benefits		Total (\$)		Per Tree		Per Capita					
Plan Gateway				87.5	\$1,093	Engineer		\$738		Energy		\$28,045		\$2.93		\$0.23					
Implementation Gateway (Dev, SIT, UAT)				154	\$4,728	GIS Analyst 1		\$377		CO2		\$4,204		\$0.44		\$0.03					
Execute + Close Gateway				16.5	\$664	Total Benefits:		\$1,115		Air Quality		\$8,232		\$0.86		\$0.07					
				321.5	\$8,463	Net Present Value:		\$527		Stormwater		\$106,839		\$11.17		\$0.87					
						Benefit-Cost Ratio:		1.89		Aesthetic/Other		\$1,025,545		\$107.20		\$8.37					
										Total Benefits:		\$1,172,865		\$122.60		\$9.57					
										Cost**		Total (\$)		Cost		Per Tree		Per Capita			
										Planting		\$30,000		\$3.14		\$0.24					
										Contract Pruning		\$70,000		\$7.32		\$0.57					
										Other Costs***		\$124,800		\$13.04		\$1.02					
										Total Costs:		\$224,800		\$23.50		\$1.83					
										Net Benefits:		\$948,065		\$99.10		\$7.74					
										Benefit:Cost Ratio:		5.22									
Storm Drainage & Urban Forest Non-Capital Costs																					
Non-Capital Costs*	Current	Proposed																			
Resources	N/C	\$239																			
Hardware	\$0	\$0																			
Software	\$0	\$0																			
User Training	N/A	\$350																			
Data Maintenance	\$0	\$0																			
Data Acquisition	\$0	\$0																			
Total Costs:	\$0	\$589																			

Analysis of Stream Benthic Macroinvertebrate Data Project



**Project Sponsor: King County Department of Natural Resources
Water and Land Resources
Science and Technology Section**

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Geography 569 – GIS Workshop – Summer 2012

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I. Background and Problem Statement

Background

Streams perform a variety of ecological functions for humans and a diversity of other species ranging from sustenance to recreation as well as absorbing wastes. The health of a stream is impacted by instream and out of stream habitat degradation, invasive species, altered river flows, and other factors (Allan 2012). Federal, state, and local agencies monitor stream health, but given the extensive miles of streams, a cost-effective methodology for monitoring and assessing stream health is needed as well as one that measures the direct biological conditions in a stream (J. R. Karr 1990). In the mid-1980's the Environmental Protection Agency developed the Rapid Bioassessment Protocols (RBPs), consolidating procedures used by various State water quality agencies resulting in benthic macroinvertebrate protocols.

There are two important terms related to stream health: biological integrity and ecological health. Karr & Dudley (1981) define biological integrity as, "The capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition and functional organization comparable to that of natural of the region." Ecological health means, "A biological system – whether it is a human system or a stream ecosystem – can be considered healthy when its inherent potential is realized, its condition is [relatively] stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed" (Karr, Fausch, et al. 1986).

Benthic macroinvertebrates, also known as "stream bugs", represent a cost-effective and localized manor with which to assess stream health. Barbour et al. (1999) detail out a number

of reasons they are so effective. They have limited migration patterns, thus making them ideal for assessing site-specific impacts and they are abundant and diverse in most streams, including small streams. In addition, sampling is relatively easy and an experienced biologist can quickly detect degraded conditions with a cursory examination. They also serve as an important food source for many fish species, linking them to recreational and commercial interests that may not be immediately apparent when discussing “stream bugs.” Benthos can be used to assess local conditions or an entire basin through multiple samples as well as being used for monitoring trends over time (J. R. Karr 1990). Furthermore the Benthic Index of Biotic Integrity (BIBI) scores and other environmental attributes, such as land cover, can be analyzed for correlations to identify areas with excellent conditions for conservation and areas to target restoration efforts (Morley and Karr 2002).

The Science and Technical Support Section (Science Section) of the Water and Land Resources Division of the King County Department of Natural Resources and Parks (DNRP), is responsible for collecting, analyzing, modeling, and interpreting the information that informs land use, habitat management, sewage treatment, water resource, and surface water management decisions. The section is also responsible for providing objective scientific knowledge to inform and guide important policy and management decisions that protect the overall quality of life for King County residents, visitors, and decision makers (King County 2008). The Science Section conducts extensive collection of stream bugs every summer at designated locations following defined standard operating procedures using the Puget Sound Lowlands BIBI.

The King County DNRP Water and Land Resources Division received the *Enhancement and Standardization of Benthic Macroinvertebrate Monitoring and Analysis Tools for the Puget Sound Region* grant from the U.S. Environmental Protection Agency (EPA) to start the process of developing standardized benthic macroinvertebrate monitoring methods and enhance

monitoring tools, regional collaboration, and partnerships throughout the Puget Sound region. The grant runs from January 2011 to December 2013 with a budget of \$699,877. The project outcomes include (King County 2011):

- An updated list of sensitive and tolerant taxa specific to the Puget Sound lowlands;
- Recalibration of a regional multimetric index, the BIBI;
- A numeric cross-walk to reconcile index scores derived from different field collection protocols that allow agencies to switch to a standard without orphaning previous data;
- Application of EPA's Biological Condition Gradient framework to define thresholds of impairment; and
- Expansion of the existing Puget Sound Stream Benthos (PSSB) database, which includes data for >3,000 macroinvertebrate samples: <http://www.pugetsoundstreambenthos.org/>

The project has engaged with over 100 individuals from almost 50 organizations including cities, tribes, counties, state or regional entities, non-for-profit organizations, and federal agencies.

Below, in Figure 1, is an organizational diagram representing the King County organizational structure and the individuals from the Science Section involved in implementing the EPA grant. This serves as an example of where individuals from other jurisdictions around the Puget Sound involved in the collaboration may be found in their respective organizational structures in different jurisdictions. As a loose knit collaboration with the coordination being led by King County, the human resources from other jurisdictions are individual people moving the work forward based on the perceived benefits of the collaboration as well as through leveraging of other projects with goals that intersect with the goal of this grant.

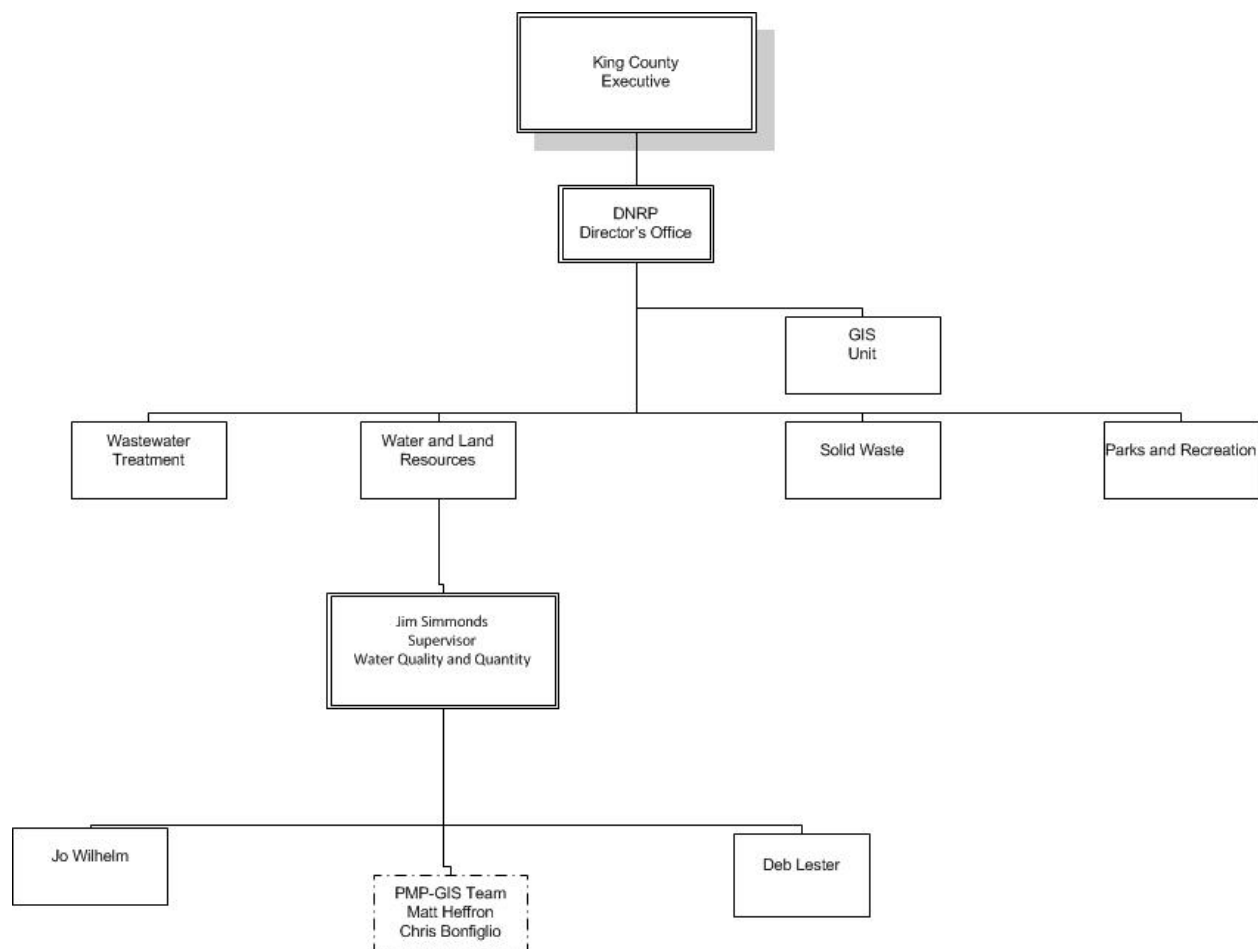


Figure 1 - King County Organizational Structure related to the EPA grant

The Puget Sound Stream Benthos database webpage manages, analyzes, and shares data from participating agency stream monitoring programs illustrated in a work flow diagram in Appendix A. In the future the site will be used to chart trends as well as calculate scores using alternate scoring systems. One such use is calculating relationships between benthos scores and environmental attributes of streams in Puget Sound streams (Puget Sound Stream Benthos 2012).

Project Goal

Within the context of the King County EPA-funded project the goal of this report is to propose steps that lead to the visualization of statistical relationships between Puget Sound region stream benthos and environmental attribute data. The benefit of having a model for analysis of correlations will be to 1) apply it to other areas within the region where benthos sampling is not conducted and 2) to inform the allocation of precious financial and human resources where they will have the most impact through remediation of modifiable environmental attributes.

Objectives

Specifically this project will assess the relationship between stream benthos scores and different environmental attributes, such as geology, streamside forest cover, elevation, orientation (north, south, east, west), percent of upstream land that is forested, percent of upstream land that is paved or otherwise impervious to rain infiltration (such as roofs), road crossings across the stream, and urban vs. rural designation according to the urban growth boundary. These associations will also inform what habitat data should be standardized across the Puget Sound region for collection by the different collaborating organizations.

Existing Process Workflow

Benthic data collection is conducted extensively throughout the United States (J. R. Karr 1990) and the overall process is very straight forward. This process is illustrated below in Figure 2 with a linear flow from site selection, to data collection, to data entry, and ending with data analysis.

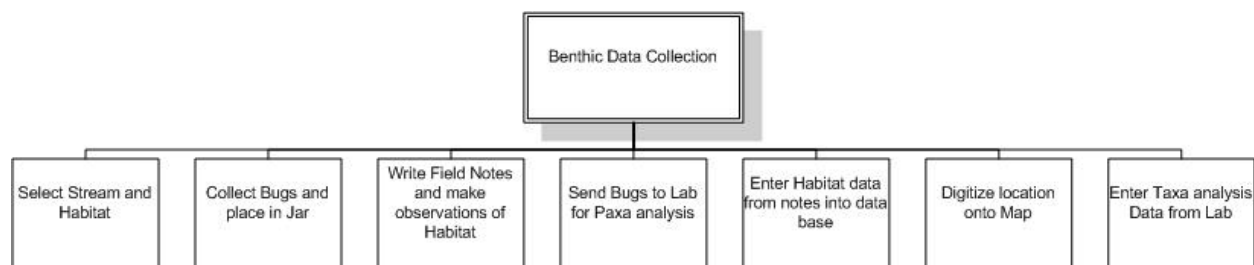


Figure 2 - Current high-level model of the benthic data collection (McKibben and Pacatte 2003)

This process is implemented annually in the Puget Sound with data collection taking place in mid to late summer. Each jurisdiction follows the same general process, with variations in the activities dependent on jurisdictional and/or entity needs and resources determined annually or as needed. We look more closely at the common activity workflow in the next section drawing on what we know about King County.

Existing Activity Workflow

At present the process of collecting biotic integrity data in the Puget Sound region has elements that are standardized and elements that are not standardized. The collection and taxonomic analysis of benthic macroinvertebrate samples for determining BIBI scores is an established method followed by the majority of partners in the Puget Sound region. The analysis is done in a laboratory and the results are provided in an XML file that is uploaded to the PSSB database for representation and visualization on the webpage as point data.

The elements not standardized are the habitat data collected at the benthos data collection sites, which supplement the BIBI scores with data on the environmental attributes. These attributes include the in stream features, nearest road crossing, riffle data, land use/ land cover, riparian buffer, and Wolman pebble count, using the King County data collection form as an example shown in Appendix B. Each jurisdiction or entity determines the data elements to be

collected each year and the data collected is often a subjective interpretation by the individual(s) conducting the data collection. Currently data collection is done on rite-in-the-rain paper forms and at the end of the collection season the forms are entered into a Microsoft Access database by seasonal field employees, again citing the process in King County. The process differs across jurisdictions and entities.

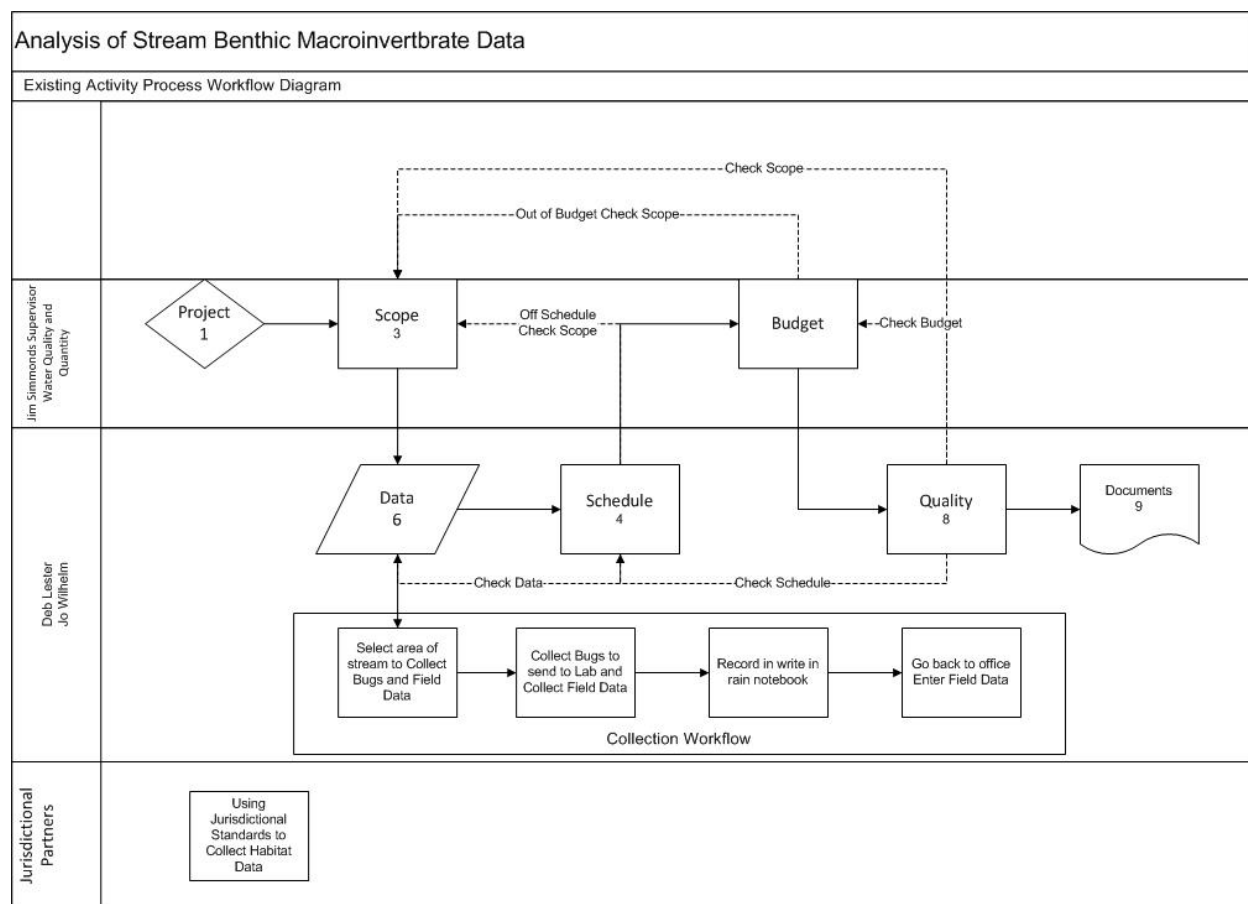


Figure 3 - The current workflow used by partners in the Puget Sound region

Therefore, the existing activity process shown above contains some standardized activities that support benthic macroinvertebrate monitoring for the Puget Sound region, but only for the BIBI scores output data, not the habitat data collected. The habitat data is crucial for any spatial analysis of local, within a 100 meter buffer, environmental attributes impacting the BIBI scores.

Proposed Activity Workflow

To standardize in habitat data collection Figure 4 below proposes revised activities for data collection and analysis that would conserve resources by expanding the database of habitat data related to benthic macroinvertebrate sampling sites. This will greatly increase the ability to conduct regional statistical analysis of correlations between BIBI scores and environmental attributes.

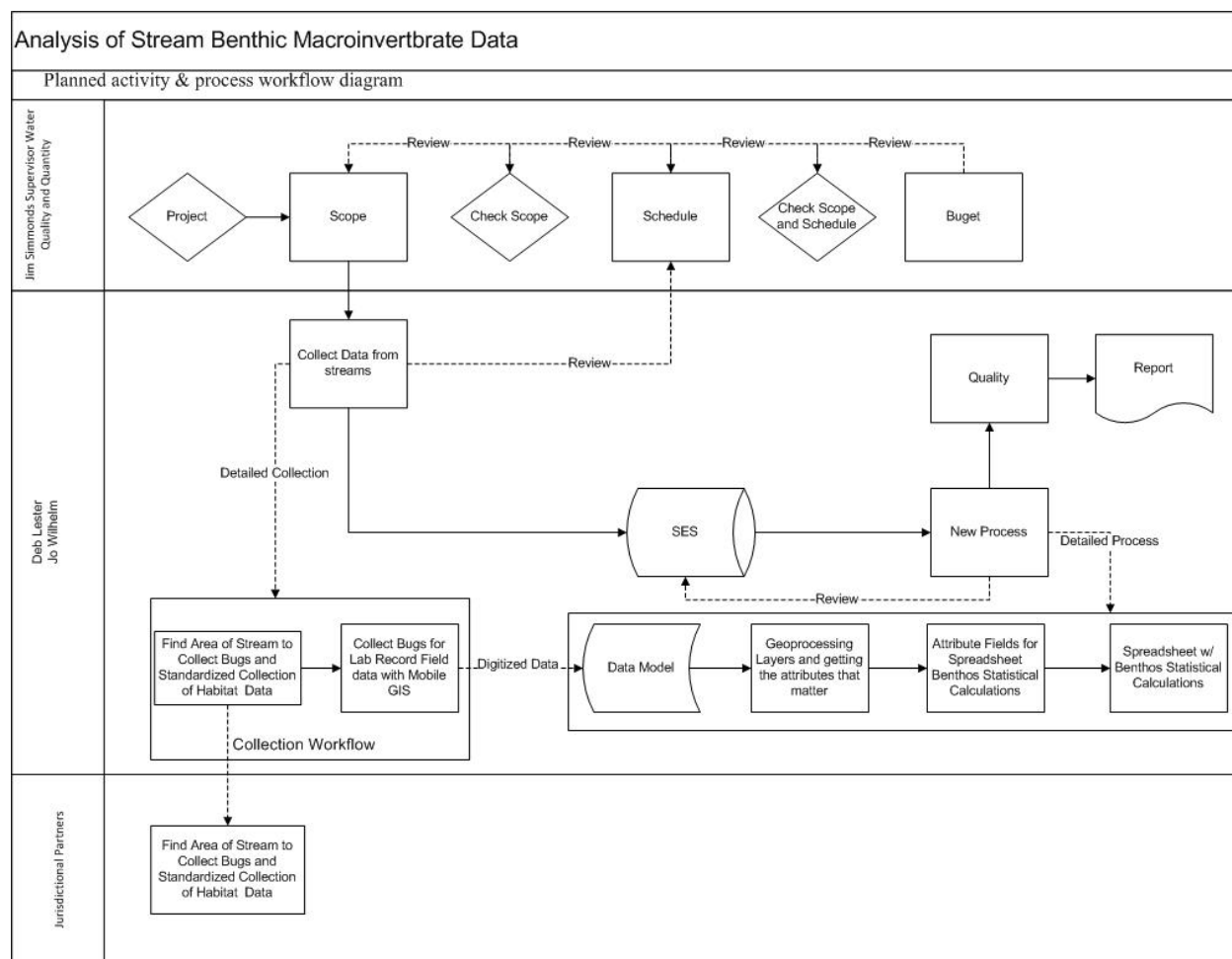


Figure 4 - The proposed workflow for use by partners in the Puget Sound region

First, we propose that through statistical analysis or literature review a standardized set of habitat data be proposed and then collected by all jurisdictions and entities in the Puget Sound region. The statistical analysis would need to be conducted on a scale where habitat and BIBI scores can be compared, such as across King County. All, or a subset of the jurisdictions would need to agree on use of the standardized habitat variables. Standardized habitat variables

enable regional monitoring of habitat data impacting BIBI scores. We also propose the use of rugged, handheld devices that streamline the process of data entry by immediately uploading habitat data to organizational databases, rather than waiting until the end of the season for manual data entry from paper forms.

Second, we propose expanding the PSSB website to include habitat data visualization just as it currently does with BIBI scores. This will allow for analysis conducted on habitat data and BIBI scores to be shared through a common and already recognized resource while saving a lot of jurisdictional resources. We discuss this more specifically in the System Requirements section.

Proposed Information Structures & Products

The information products resulting from our work include a database developed for use in conducting analysis of BIBI scores and environmental attributes. A second information product is a brief literature review of variables influencing biotic integrity at various scales as well as methods for future analysis at the catchment level. Future development of the Puget Sound Stream Benthos website is also suggested. In addition, considerations for the use of national data in spatial analysis are outline and shown in a workflow.

II. System Requirements

Hardware Requirements

With the EPA grant focused on developing standardized benthic macroinvertebrate monitoring methods and enhance monitoring tools, regional collaboration, and partnerships across the Puget Sound region the PSSB website is the central point of collaboration. It provides a known and trusted portal for the warehousing and visualization of the data. Therefore, the hardware

needed for this project is already in place across the region with simple access to the World Wide Web from a laptop, desktop or mobile device being all the hardware required for accessing the system. The live site is hosted on a server at an independent service provider with a mirror copy of the system maintained at King County for development and testing purposes.

For the collection of benthic habitat data includes a rugged, handheld electronic personal computer with Wi-Fi, multi-carrier broadband, Bluetooth® wireless, and integrated GPS. A tablet style handheld with a touch screen is recommended for readability and ease of data entry.

Software and Networking Requirements

With the PSSB website as the hub for information storage and visualization, this is where any additional software or networking requirement would be focused. This system allows the partners to share, analyze and store their benthic macroinvertebrate data. The architecture includes a Microsoft® SQL Server database and a web interface built using the Microsoft®.NET Framework and Google® Maps Application Programming Interface (King County 2009). The database and web servers are hosted and managed by a third party service provider. If the project were to decide to enhance visualization to represent environmental attributes along with the benthos scores, online GIS software would be required such as Esri® ArcOnline or MapBox®. These software packages would support more compelling representation of land cover, geology, soil, precipitation, storm water, and other environmental attributes to complement the existing BIBI score data. An agreed upon set of analysis will be pre-analyzed and placed in a data warehouse to speed up the map visualization on the website of standardized environmental attribute variables and relationships with BIBI scores. A part of the

site to build would be availing Puget Sound region shapefiles for the various partners to download and use in their own jurisdictions for more advanced analysis.

The rugged, handheld devices will run using Windows operating systems for compatibility with the website operating system.

Personnel and Time Requirements

By keeping the focus on enhancing the website we minimize the need for multiple servers hosting the data throughout the region. To support the addition of GIS visualization the resources currently in place will need to be assessed for the ability to support backend running analysis and pre running operations for faster map visualization on the website. This could require support from existing GIS Analyst staff at King County, but that would depend on the software used for analysis and visualization. The longer term issue of site maintenance, upgrades and general ongoing support for the functioning of the site are under discussion among the jurisdictions and entities with the possibility of funding coming from Washington State (King County 2009).

Other Considerations

Server capacity will be one consideration to take into account as the amount of data increases and the processing needs increase. Also, discussions will need to take place with the partners on how data is accessed and if it is all publicly available or if it would require a user name and password to access data for download. Thinking through how shapefiles would be developed, stored and made available for download is another consideration including metadata, which will be important for analysis purposes as described in section IV.

III. Data Acquisition

Data Design

The data design of this project reflects the needs of the collaborating partners in the Puget Sound region working towards the enhancement and standardization of benthic macroinvertebrate monitoring and analysis tools. The overall area of interest for this project is Puget Sound streams and thus the contributing watersheds of those streams. While we are looking at the Puget Sound in its entirety we are actually interested in a watershed level representation of the phenomena of correlations between BIBI scores and environmental attributes. In most cases stream analysis will look at watershed level data and it is important that the granularity of the data appropriately represent the geographic phenomena of interest.

The raster data for this project is drawn from 30m, Puget Sound wide Landsat satellite imagery, as this is what is available for multiple temporal samples starting in 1992 to the present. In those constituencies where higher resolution data is available it can be substituted to provide better detail. At the same time the scope of the area of interest needs to be kept in mind when thinking about the computing power available by those who will make use of the data.

The map projection, or more accurately coordinate system, used by King County is the State Plane Coordinate System 1983 (Washington State Plane North; FIPS Zone 4601, HARN) and all data will be projected following this standard. However much of the hydrologic data is taken from National Hydrological Data (NHD) and is in the Projected Coordinate System: NAD 1983 Albers projection Albers, which results in certain challenges detailed in section IV.

Given the number of organizations collaborating on this project a concerted effort to limit referential, topological, relative, and absolute errors in the data will be the responsibility of the

individual organizations (counties, cities, tribes, state or regional entities, not-for-profit organizations, and federal agencies) following standardized approaches determined outside the scope of this article.

Logical Database Model

A relational database model, illustrated in Figure 5 below, was selected for this project.

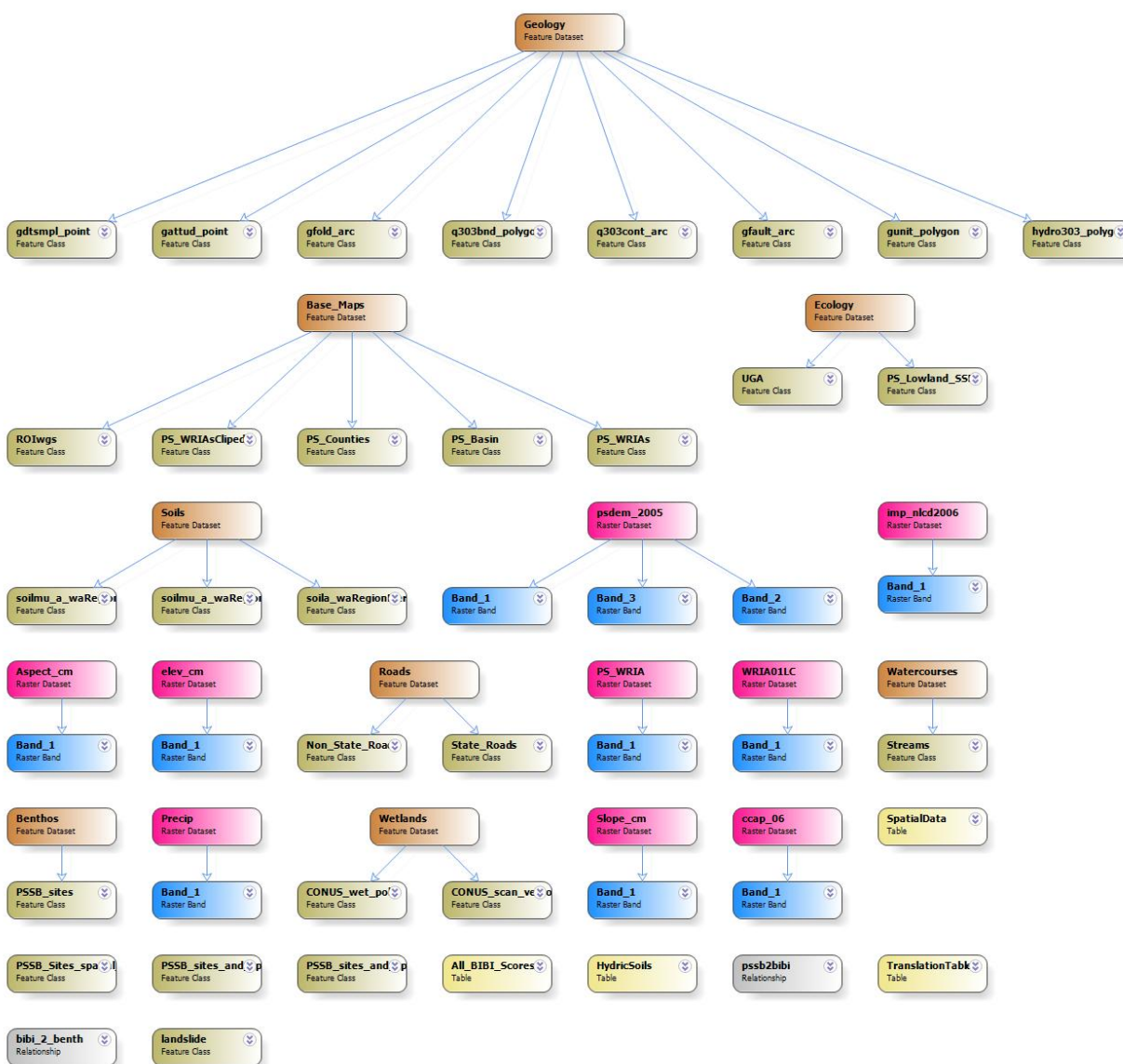


Figure 5 - Geodatabase Schema developed using ArcGIS Diagrammer

Data Source, Fitness for Use & Metadata

Data used for this project is provided by the Science Section, with some coming from King County GIS and other data from the EPA, NOAA, and other sources. The data sources are very reliable and the data fit for use in this project. King County, the EPA, and NOAA all have robust metadata available with explanations of assumptions made and data sources used.

One limitation on the data is that there for the Puget Sound region data is being derived from data developed for different scales, either county scale or national scale in some cases, so the metadata for Puget Sound specific shapefiles is only being developed as the data is joined and clipped to focus on the region.

Future Database Development

The current stream benthos database housed on the PSSB website represents the locations and BIBI scores for each of the sites where collection takes place. Not shown are the environmental attributes, such as land cover, of the immediate area that contribute to BIBI scores. In the future land cover data could be incorporated into the PSSB website to enable the representation of environmental attributes impacting the stream health of streams where data collection takes place as well as where it doesn't.

Statistical analysis of relationships between select environmental attributes and BIBI scores could be conducted at the same time as previous season data is uploaded for an annualized view of any trends or correlations. Using a select or standardized set of environmental attributes would allow for the statistical analysis process to be conducted at the time of upload to dramatically speed the visualization on the website as users browse the data.

IV. Data Analysis, Information Products and Findings

Input Data

INFORMATION INCLUDED	SOURCE	PURPOSE/USE	Data Type	FEATURE CLASS/FILE NAME
Base Data				
Puget Sound Region	U.S. Environmental Protection Agency	For reference in mapping	Polygon	Puget_Sound.shp
Puget Sound Counties	U.S. Environmental Protection Agency	For reference in mapping	Polygon	County_Areas_in_PS
Puget Sound Water Inventory Resource Areas	U.S. Environmental Protection Agency	For reference in mapping	Polygon	PS_WRIAs.shp
Benthos Data				
Puget Sound Benthic Sampling Sites	Puget Sound Stream Benthos website	Location of benthos sampling sites	Point	PS_PSSBsites_20120629.shp
Puget Sound BIBI Scores	Puget Sound Stream Benthos website	BIBI Scores associated with Puget Sound Sites	Table	AllScores_STE3_SpFam_98att.xlsx
Land Cover Data				
Puget Sound Coastal Change Analysis Program Regional Land Cover (1992, 1996, 2001, 2006)	National Oceanic and Atmospheric Administration	Provides Land Cover data represented by a classification scheme	Raster	ccap_92.rrd; ccap_96.rrd ccap_01.rrd; ccap_06.rrd
Watercourses				
Puget Sound Streams	U.S. Environmental Protection Agency	For reference mapping of stream locations, both where benthos are collected and not	Polyline	strm100_usalb.shp
Wetlands				
Puget Sound Wetlands	U.S. Fish and Wildlife Service	For analysis of hydric soils related to benthic scores	Polygon	CONUS_scan_vectors.shp
Soils				
Puget Sound Hydric Soils	USDA Natural Resources Conservation Service	For analysis of hydric soils related to benthic scores	Polygon	Soila_waRegionMerge.shp
Puget Sound Hydric Soils	USDA Natural Resources Conservation Service	For analysis of hydric soils related to benthic scores	Table	HydricSoils.xlsx

Geology				
Geology of Washington State	Washington State Department of Natural Resources Division of Geology and Earth Resources	For analysis of geology related to benthic scores	Polygon	Hydro303_polygon
Ecology				
Puget Sound Urban Growth Areas	Washington State Office of Financial Management	For reference and analysis of benthic scores related to urban growth areas	Polygon	UGS.shp

Data Analysis

Correlations

The data assembled is in a single file joined to the Puget Sound Benthic Sampling Sites shapefile. However, this was not accomplished with sufficient time to conduct reliable statistical analysis. We ran some basic analysis using tools in ArcMap as well as SPSS. Two options in ArcMap are to develop some basic scatterplots of the variables using the Graph tool under View

on the menu bar. Screen shots are included in Appendix XX.

Figure XX below, illustrates the output of using the Graph tool.

After gaining a good understanding of the data, the Ordinary Least Squares tool in the Spatial Analyst tool can be

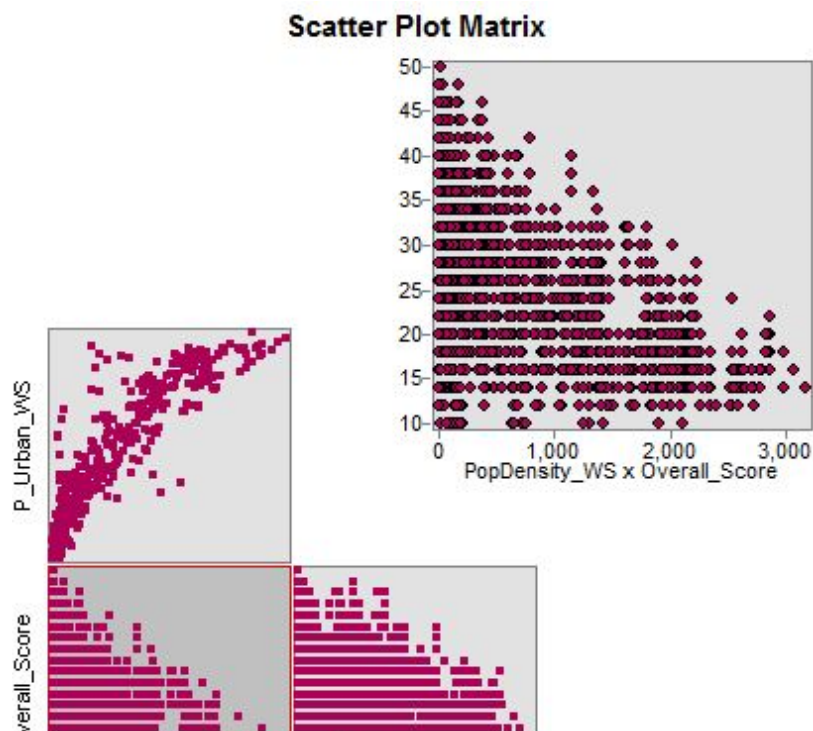


Figure 6 - Scatterplot tool output in ArcMap with Overall_Scores as dependent and PopDensity_WS and P_Urban_WS as the independent variables

used for additional analysis looking at multiple variables.

Projections for Spatial Analysis

One of the original instructions given was to re-project data into the coordinate system commonly used by King County and local jurisdictions of the Puget Sound region. However, not all of the data should be re-projected due to an issue that creates with the reliability of subsequent data analysis due.

Information Products

The information products resulting from our work include the assembly of a database including new and existing data for use in the spatial analysis of BIBI scores and environmental attributes. A second information product is a brief literature review of variables influencing biotic integrity at various scales as well as methods for future analysis at the catchment level. In addition, considerations for the use of national data in spatial analysis are outline and shown in a work flow.

Findings

Future Analysis – Literature Review

We conducted a literature review on biotic integrity and associated habitat variables, which provided a wide range of results and potential future directions for analysis. The literature compared analysis at multiple scales, such as reach, riparian, local, watershed, and catchment (Arya 2000; Lammert and Allan 1999; Weigel, et al. 2003) as well as looking at methods for predicting the effects of land cover on stream biotic integrity at the catchment level (McNair 2009).

The literature we reviewed indicated that local habitat variables were superior to land use in predicting biotic integrity (Arya 2000; Lammert and Allan 1999) with the exception of one, which found that environmental variables at multiple scales had similar influence on macroinvertebrates, meaning they were strongly related across spatial scales (Weigel, et al. 2003). In this case the authors point out that their randomly selected stream sites were located in areas “least-influenced” by agriculture or urban development, so their results may be more applicable for stream restoration efforts.

The studies indicating the strength of local habitat variables pointed to variables used based on existing methodology, such as the Qualitative Habitat Evaluation Index (QHEI) (Ecological Assessment Section 2006), which focuses on six principle metrics: 1) substrate, 2) instream cover, 3) channel morphology, 4) bank erosion and riparian zone, 5) pool/glide and riffle/run quality, and 6) gradient. The importance of substrate as a predictor of biotic measures is demonstrated, with flow stability also contributing (Lammert and Allan 1999).

James N. McNair (2009) presents two methods for predicting effects of land cover-related stressors on stream biotic integrity at the catchment scale. Both methods focus on using fitted stressor-response functions (SRFs) (U.S. Environmental Protection Agency 1998) to predict stressor levels on metrics of stream biotic integrity. The first modeling approach uses a GIS-based version of generalized watershed loading functions (GWLF) called AVGWFL (ArcView GWLF) developed by Evans et al. (2002, 2003). The second modeling approach focuses on sediment as the stressor predicting levels of erosion-derived sediment in streams using a GIS-based version of the Revised Universal Soil Loss Equation called RUSLE3D and the hydrologically based spatial regression technique of Johnson et al. (2007). The article presents the results of using the two modeling approaches, with neither consistently outperforming the

other. McNair leans toward preferring the second model because it employs a hydrologically based spatial routing of stressors making it an attractive tool for land use planning.

Future Analysis – Raster

Our opinion is to use raster overlay to do the analysis. In a raster overlay, the cells in each of the layers reference the same geographic location. So in operations such as the Benthic score analysis, where we were looking at climate, land use, soil, habitat, and geology. A raster overlay is well suited to combine these many characteristics into a single layer.

In a raster overlay, numeric values are usually assigned to each characteristic, this allows the

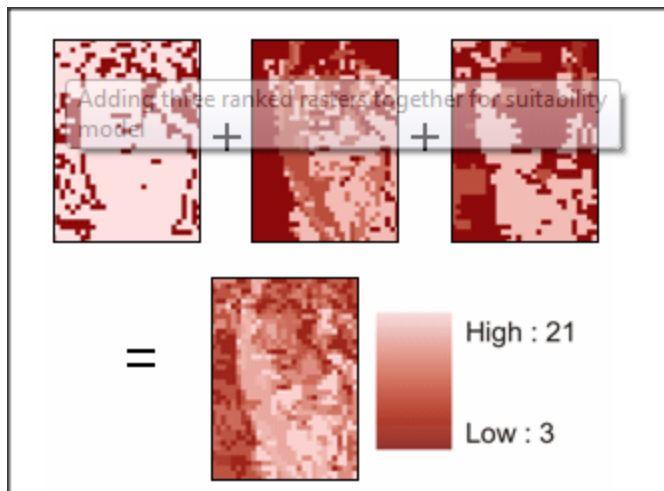


Figure 7 - Raster overlay example (Esri 2012)

Above is an example of raster overlay by addition for suitability modeling. Three raster layers (steep slopes, soils, and vegetation) are ranked for development suitability on a scale of 1 to 7. When the layers are added (bottom), each cell is ranked on a scale of 3 to 21.

Projection Considerations

In the process of re-projecting all of the data in to NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet Projection: Lambert Conformal Conic, per the standard of King County data we stumbled across the fact that doing this for any hydrological data would cause issues that would impact the quality of analysis. National Hydrological Data (NHD) is in the Projected

Coordinate System: NAD 1983 Albers projection Albers. The Digital Elevation Model (DEM) comes from NHD data and is in the Projected Coordinate System: NAD 1983 Albers projection Albers. Many of the current and future analysis rely on the DEM upslope, downstream, and delineation to name a few. A DEM re-projection introduces abnormalities that will cause the analysis functions not to work.

When you look at re –sampling a 30 m DEM to a coarser resolution of 100 m features that will be lost are flow accumulation, flow direction with the original river reaches and catchment boundaries. This will require a re-definition of surface hydrographic features. There are many other problems that result with a DEM re-projection, catchments can change shape along with the possibility that the associated basin outlets or pour points will also change locations. In addition, the fact that reprocessing of raster data, along with the re-specification of hydrographic features to coarser grids is time consuming (David, et al. 2009).

For reports and/or visualization the data will be re-projected to NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet Projection: Lambert Conformal Conic, but no analysis should be done using the re-projected data. The metadata should read that the NAD 1983 HARN StatePlane projection is not to be used for analysis citing the above reasons. Any follow-up analysis is to be in the Albers projection. This is represented in the work flow diagram below.

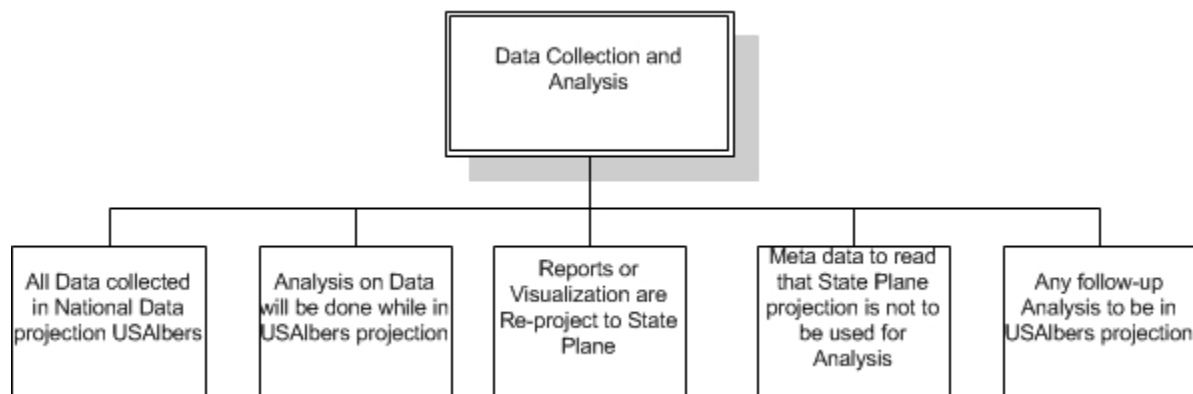


Figure 8 - Workflow for projection considerations in spatial analysis

V. Financial & Strategic Analysis

Financial Analysis

While conducting benthic sampling is more holistic and less expensive than the assessment of physical and chemical properties of water (J. R. Karr 1990) it still comes with a cost and limitations on the extent to which it can be reasonably implemented. These costs are multiplied when applied to a region the size of Puget Sound, which covers many jurisdictions, tribes, and includes many independent stakeholders all collecting stream benthos data.

Using the original budget for the *Enhancement and Standardization of Benthic Macroinvertebrate Monitoring and Analysis Tools for the Puget Sound Region* grant we looked at the habitat data collection and data entry process to investigate efficiencies that could be implemented and scaled to the Puget Sound partners. In addition, we modeled potential saving resulting from predictive analysis of BIBI scores resulting from environmental attributes.

The current practice for habitat data collection and data entry is to hire seasonal Field Sampling Technicians who support the benthos and habitat data collection, which is done using printed, two page rite-in-the-rain forms. At the conclusion of data collection the Field Sampling Technician enters the data from the sheets in to an Access database manually and each form is scanned to a PDF file. The forms include text fields for measurements and counts, tick boxes, and a notes section. With data collection at 100 sites there are an equal number of forms requiring data entry and scanning.

We explored the potential benefits of combining the data collection and data entry steps into one through the use of rugged, handheld personal computing devices in the place of rite-in-the-

rain forms. The devices would be used in the field and synchronized with the database at the end of each day so data entry would be instant. Costing approximately \$1,600 for a tablet unit we compared this cost against savings on seasonal staff salary and benefits, which was budgeted at \$29,952 for 78 days of work. The cost of the unit will be recovered with a reduction of five days from the seasonal staff time that would otherwise be spent doing data entry. Taking inflation into account the seasonal staff time will increase by four percent each year while the cost of rugged, handheld devices will continue to drop as is seen with most electronic devices over time. The use of these devices has shown cost savings in its use by the Honolulu Board Water Supply (Learner 2007) as well as in applications specific to stream assessment (Tedrow 2010).

The second part of our financial analysis focused on the benefits of predicting stream health through statistical modeling of BIBI scores and environmental attributes. By taking what we know about associations between the current sites where data collection is conducted and applying them to streams based on what we know to be their environmental attributes, the savings on taxonomic laboratory analysis would be substantial.

Currently the PSSB website has 1,197 sample scores and assuming a cost of \$250 per sample that is \$299,250 spent just on the taxonomic laboratory analysis, not including any staff time spent in the field. In the Puget Sound region there are approximately 10,000 rivers and streams (Puget Sound Partnership 2012), so the cost of sampling each stream in the region would be in the millions of dollars with multiple samples required to be collected in some streams.

Strategic Analysis

Benefits

Using rugged, handheld personal computing devices would cut the time for data entry by maximizing the field collection time and enabling the data to be uploaded to a database immediately upon returning from the field. In addition this would assist in the standardization of data entry at the county and potentially across the Puget Sound, which would dramatically enhance the quality of the data in comparison with the already standardized benthos data collection.

Another financial savings would come from developing the ability to predict stream health based on the prevailing environmental attributes impacting a stream. There are far too many streams in the Puget Sound area to hope to have the time and resources to conduct benthos sampling at each and every one. However, with a statistical model and standardized environmental attribute data the health of streams could be modeled based purely on the environmental attributes meaning that significant savings on expanded benthos sampling would be made.

Although not quantified financially, there are significant benefits in continuing to build the PSSB website to provide more visualization of habitat data to complement the existing BIBI score data. The use of a common website for the whole Puget Sound region consolidates data and its maintenance into one location on a single server for everyone to access. So, there is no need for each jurisdiction or entity to spend time and resources on maintaining the data on a server or figuring out how to represent their data on a map, among other things.

Risks

The proposed directions do not come without risks related to the introduction of new technology, inter-organizational dynamics, complex systems, and project resources, to name a few (Tomlinson 2011). The introduction of rugged, handheld personal computing devices introduces

the potential for technology issues around their adoption by staff, usability, reliability, and their cost when looking at if such a device could be scaled for use by all jurisdictions and entities. The prediction of BIBI scores based on habitat and environmental data through statistical modeling requires good, clean data as an input and high quality analysis processes in order for a reliable and repeatable output to be produced, which is a complex process requiring skilled analysis. Lastly, the expansion of the website to include more data has technological and financial as well as organizational risks between the collaborating partners. Issues of server backups, updates and bugs can impact user confidence in the system and require ongoing financial support. Also, the issue of accessibility of data would need to be addressed. Do all partners want all data to be public or do access rights need to be developed? Ideas on mitigating these risks are addressed in the future directions section below.

Recommended Course of Action

Our recommendation is to start with a pilot use of the rugged, handheld personal computing devices by purchasing one for use in data collection from a certain number of sites. By piloting first, the Science Section will minimize investment cost and allow for testing of the reliability, usability and staff acceptance of this type of device. Develop some basic metrics for objectively evaluating the technology for comparison with the existing practice of using printed rite-in-the-rain forms. From a data standpoint, if the devices meet the data collection needs they will support the standardization of habitat data across the Puget Sound with direct upload to the PSSB website database.

In order to validate the proposed predictive model we recommend developing a protocol to collect benthic macroinvertebrate data at a select number of streams across the region that are not currently sampled to validate the projections of the model. This protocol would need to look

at the different scales of environmental attributes used to predict scores ranging from watershed scale to localized scale to compare and contrast the predictive capacity of the model given the available data.

Expanding the website will require a commitment of resources and clear communications about new functionality being added. There is already an existing infrastructure that meets part of the need, so a systematic approach to determine what further functionality would be beneficial and how that process will be implemented needs partner input. A development and testing environment already exists with King County, so following their existing processes is the recommended course of action. Models of the existing and proposed use of the website are included in Appendix H.

VI. Future Directions

At the beginning of this article we defined biological integrity and ecological health. They provide the framework that guides why the collection of benthic macroinvertebrates in the Puget Sound is so important. The goals of the *Enhancement and Standardization of Benthic Macroinvertebrate Monitoring and Analysis Tools for the Puget Sound Region* grant focus on synergizing the efforts of numerous individuals and organizations across the region to create a regional social-ecological system (SES) focused on the sustainability of the biological integrity and ecological health of streams.

That the grant exists and there is so much existing collaboration among jurisdictions and different entities positions this SES well for the future. To assess where the goals of the grant stand a present and where they should focus in the future for enhanced sustainability we'll apply ten variables presented by Elinor Ostrom in her article *A General Framework for Analyzing*

Sustainability of Social-Ecological Systems (2009). These variables are used to assess the likelihood of stakeholders to “engage in collective action to self-organize” to achieve a sustainable SES.

Variable	Current Status	Future Direction
Size of resource system	The Puget Sound region as the focus territory is appropriate exhibited by the voluntary participation of organizations in the use of the PSSB website and interest in expanded collaboration and standardization.	The resource system is well defined already and self-organization is apparent.
Productivity of system	The Puget Sound exhibits some scarcity and impaired ecological health, but that is countered by extensive regenerative efforts to maintain the productivity of the Puget Sound regions streams.	The extent of regenerative efforts and planned efforts in the Puget Sound region is apparent and long term.
Predictability of system dynamics	The predictability of the stream system dynamics is currently fragmented with only BIBI scores being reported collaboratively.	Continue to enhance the predictability of the stream dynamics by standardizing habitat data collection for the sampling sites to provide for larger scale assessment
Resource unit mobility	Benthic macroinvertebrates are localized and have limited migration patterns.	Continue standardization of collection and analysis protocols, recalibration of multimetric index and other areas where standardization can be applied.
Number of users	There are currently 100 individuals and almost 50 organizations engaged in the project from cities, tribes, counties, state/regional, not-for-profit, and federal entities.	Continue to engage new users, but be cautious of the costs of all-inclusiveness. Build in levels of coordination, management, decision making, all supported by joint financial resources if possible.
Leadership	The leadership of this project is with the King County DNRP WLRD Science Section based on the grant.	Make sure to make the most of the funded opportunity the grant provides to organize for the future functioning of the collaboration.
Norms/social capital	Project timelines and outcomes have been defined that standardize	Be sure to build in ongoing strategies for updating and

	collaboration through monitoring and assessment tools.	enhancing the outcomes of the grant.
Knowledge of SES	The knowledge of the SES is strong within the existing collaboration, but outside of it the knowledge needs to be clearer.	Strategize methods for reaching out to the general public to communicate on the importance of stream health and be sure to use the political process to strengthen laws and policies around stream health, including increased funding for restoration.
Importance of resource to users	Many users know the importance of the resources of the Puget Sound, but more could be done to illustrate the importance and engage more of the public.	If more of the general public doesn't acknowledge the importance progress won't be sustainable. Engage them and put information in their hands that will empower them to make a difference on stream health no matter how small it might seem.
Collective-choice rules	The collective-choice rules are built into the system of the different collaborating jurisdictional partners.	Understand that standardization needs to be balanced with the individual needs and resources of each of the partners.

Overall the grant objectives and associated Puget Sound Stream Benthos website represent strong examples of sustainability management related to the Puget Sound region that incorporates sustainability information science. The foundation the grant is building should serve as a platform for building more sustainable systems across the region resulting from the existing collaborations and those yet to come. Drawing on the analysis using the Ostrom framework (included in Appendix F) some areas to expand on include promoting the importance of the Puget Sound region as a resource to users is one of the critical elements. One strategy for supporting this is to continue the development of the functionality of the website to include environmental attribute analysis and visualization. The more data is available for public consumption the better for providing people the information they need to recognize the importance and act accordingly.

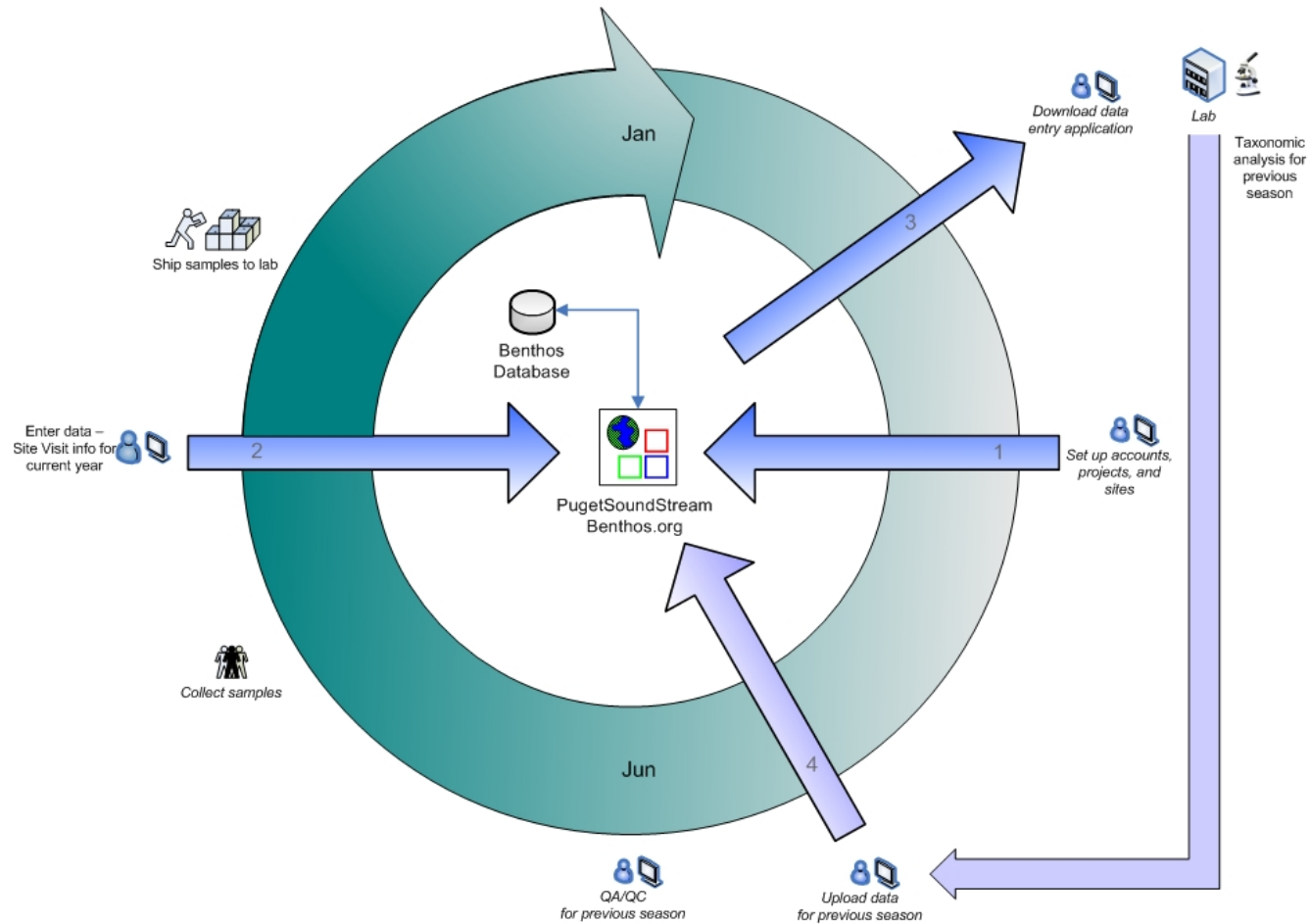
From a sustainability management perspective it is critical to plan for and build the infrastructure for continued management of the collaboration that is already underway. Maintaining the website and expanding upon it will take resources, but by keeping it in a central, accessible location the overall cost will be lower and the collaborative benefit higher, resulting in continued progress towards the sustainable management of Puget Sound regional water and land resources.

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Appendix A: Work Flow – Provided by King County WLRD Science Section



Appendix B: King County Benthic Habitat & Data Sheet

2012

☐ NO SAMPLE TAKEN ☐ Ambient ☐ EPA grant ☐ CAO ☐ Other

Site Name/Number:	Replicate site? Y N	Data Entry-check when complete	
Date & Time:	Personnel:	☐ Habitat	☐ Database
Location:	Changed location? Y N <i>If yes, explain:</i>	Date: _____	Date: _____
		Initials: _____	Initials: _____

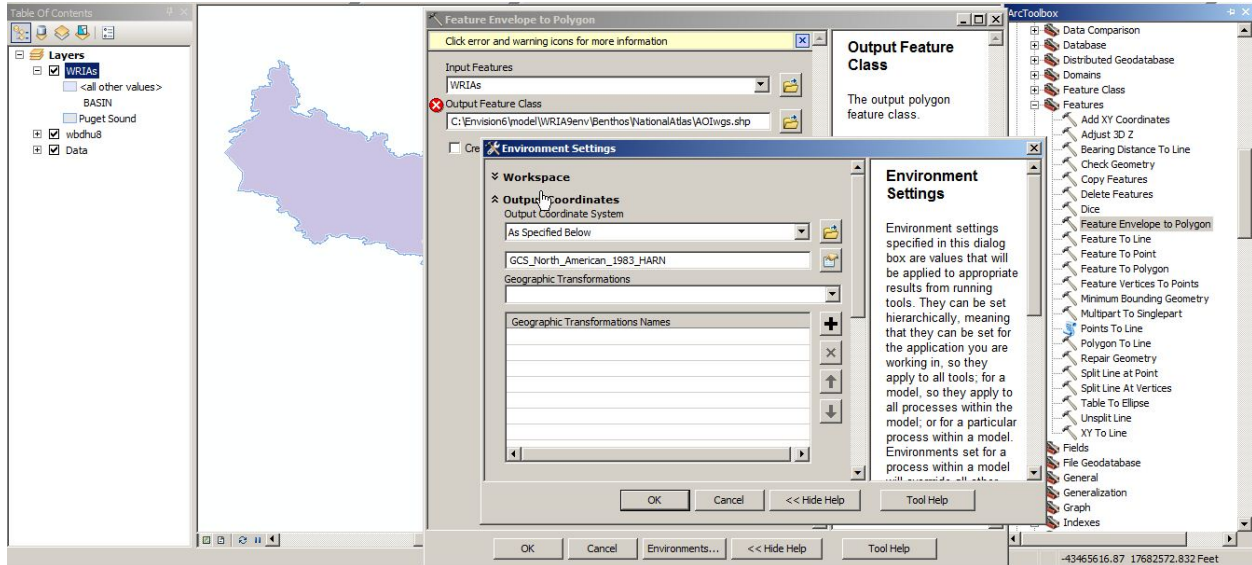
NEAREST ROAD X-ING	Within 50ft of reach: ☐ Upstream ☐ Downstream ☐ None within 50'		
WEATHER AND WATER CONDITIONS			
Currently: ☐ rain ☐ mostly cloudy (> 50%) ☐ partly cloudy (10 – 50%) ☐ sunny	Has there been a heavy rain event in the last 7 days? Y N <i>(Greater than 0.5" in 24 hrs)</i> Air Temperature: _____ °C Water Temperature: _____ °C Water Clarity: Clear Turbid		
INSTREAM FEATURES	<i>*Record in decimals!</i> 1" = 0.08ft 2" = 0.17 3" = 0.25 4" = 0.33 5" = 0.42 6" = 0.5 7" = 0.58 8" = 0.66 9" = 0.75 10" = 0.83 11" = 0.92		
Reach length: _____ ft. # Pools _____	<u>Streambank Stability:</u> 4 – Stable <i>Veg. to waterline, no undercutting or erosion</i> 3 – Slightly unstable <i>Most veg. to waterline, some minor erosion</i> 2 – Moderately unstable <i>Sparse veg. to waterline, erosion and undercutting</i> 1 – Completely unstable <i>No veg. to waterline, severe erosion & undercutting</i>		
Sampled from 1 2 3 4 riffles			
Riffle 1		Riffle 2	
Wetted Width: _____ ft. Bankfull Width: _____ ft. Bankfull Depth: _____ ft. ☐ <1 ft. ☐ 1-3 ft. ☐ >3 ft. Riffle Length: _____ ft. Riffle Depth: _____ in.	<u>Riffle Flow</u> Distance: _____ ft. Time (sec., 3 reps): _____ _____ _____	Wetted Width: _____ ft. Bankfull Width: _____ ft. Bankfull Depth: _____ ft. ☐ <1 ft. ☐ 1-3 ft. ☐ >3 ft. Riffle Length: _____ ft. Riffle Depth: _____ in.	<u>Riffle Flow</u> Distance: _____ ft. Time (sec., 3 reps): _____ _____ _____
Riffle 3		Riffle 4	
Wetted Width: _____ ft. Bankfull Width: _____ ft. Bankfull Depth: _____ ft. ☐ <1 ft. ☐ 1-3 ft. ☐ >3 ft. Riffle Length: _____ ft. Riffle Depth: _____ in.	<u>Riffle Flow</u> Distance: _____ ft. Time (sec., 3 reps): _____ _____ _____	Wetted Width: _____ ft. Bankfull Width: _____ ft. Bankfull Depth: _____ ft. ☐ <1 ft. ☐ 1-3 ft. ☐ >3 ft. Riffle Length: _____ ft. Riffle Depth: _____ in.	<u>Riffle Flow</u> Distance: _____ ft. Time (sec., 3 reps): _____ _____ _____
LARGE WOODY DEBRIS	# LWD (>6 ft. long & >4 in. dia.) within bankfull width: _____ ☐ no LWD in reach		
	# rootwads: _____ ☐ no rootwads in reach		
OTHER ORGANISMS	☐ Crayfish _____ ☐ Mussels _____ ☐ Other _____		
Notes:			

Site:	Date:	Personnel:
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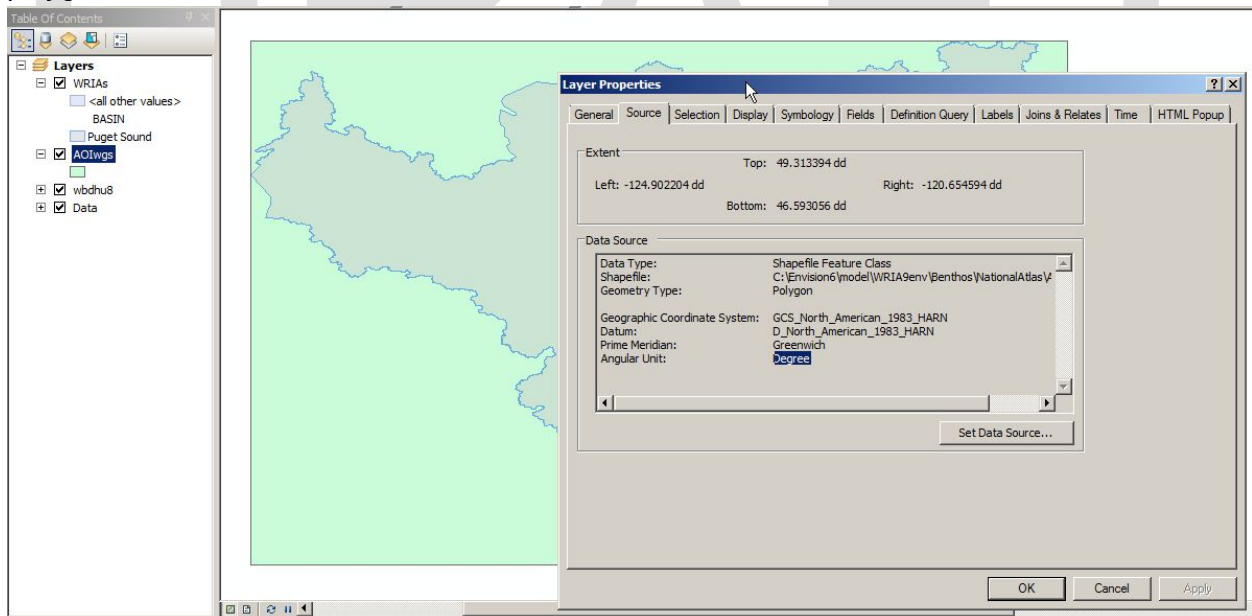
LAND USE/LAND COVER: Consider for 100 ft out, perpendicular to the stream on each side, <i>facing downstream</i> . Check each land-use/land-cover present.	
Left Bank: ☐ Forested (specify) ☐ Hardwood/deciduous ☐ Conifer/evergreen ☐ Mixed ☐ Agriculture (specify) ☐ Crop ☐ Pasture ☐ Shrub/Herbaceous vegetation ☐ Urban/Impervious surfaces ☐ Residential (low-impervious) ☐ Commercial/Industrial (high impervious) ☐ Roads Only ☐ Grass & Lawn	Right Bank: ☐ Forested (specify) ☐ Hardwood/deciduous ☐ Conifer/evergreen ☐ Mixed ☐ Agriculture (specify) ☐ Crop ☐ Pasture ☐ Shrub/Herbaceous vegetation ☐ Urban/Impervious surfaces ☐ Residential (low-impervious) ☐ Commercial/Industrial (high impervious) ☐ Roads Only ☐ Grass & Lawn
RIPARIAN BUFFER (<i>facing downstream</i>)	
Left Bank: ☐ < 10 ft ☐ 10 – 50 ft ☐ > 50 ft. <i>If forested, dominant canopy forming size:</i> ☐ Small: DBH < 12" ☐ Large 20" ≤ DBH ☐ Medium: 12" ≤ DBH < 20 ☐ Not applicable	Right Bank: ☐ < 10 ft ☐ 10 – 50 ft ☐ > 50 ft. <i>If forested, dominant canopy forming size:</i> ☐ Small: DBH < 12" ☐ Large 20" ≤ DBH ☐ Medium: 12" ≤ DBH < 20 ☐ Not applicable
Does the buffer shade the stream? (> 50% shade if sun was overhead) Y N	Noxious weeds observed at site
Signs of recent (within 1-2 years) landscape change? (If yes, describe in notes) Y N	☐ bedstraw ☐ bindweed, hedge (morning glory) ☐ bird's foot trefoil ☐ bittersweet nightshade ☐ blackberry, cutleaf (evergreen) ☐ blackberry, Himalayan ☐ buttercup, creeping ☐ butterfly bush ☐ comfrey ☐ garlic mustard* ☐ giant hogweed* ☐ herb Robert ☐ holly, English ☐ ivy, English ☐ jewelweed, spotted ☐ knapweed, spotted*
Buffer composed predominately of native vegetation? Y N	☐ knotweed, Bohemian/Japanese ☐ laurel, cherry (English) ☐ loosestrife, garden* ☐ loosestrife, purple* ☐ multiflora rose ☐ old man's beard ☐ poison-hemlock ☐ policeman's helmet* ☐ reed canarygrass ☐ Scotch broom ☐ tansy, common ☐ tansy, ragwort* ☐ thistle, bull ☐ thistle, Canada ☐ yellow archangel ☐ yellow flag iris
Photos (<i>US, DS, RB, LB, noxious weeds</i>):	* Regulated noxious weeds in King County

WOLMAN PEBBLE COUNT: Count at least 100 total. Collect from bankfull to bankfull. Complete the full transect even after 100 is reached. Middle Riffle unless otherwise noted.	Substrate Class (Wentworth Scale)	Size Class (mm)		Pebble Count	Total
	Sand	0-2	A		
	Very Fine Gravel	>2-4	B		
	Fine Gravel	>4-8	C		
	Medium Gravel	>8-16	D		
	Coarse Gravel	>16-32	E		
	Very Coarse Gravel	>32-64	F		
	Small Cobble	>64-128	G		
	Large Cobble	>128 - 256	H		
	Small Boulder	>256 - 512	I		
	Medium Boulder	>512 - 1024	J		
	Large Boulder	>1024 - 2048	K		
	Very Large Boulder	>2048 - 4096	L		

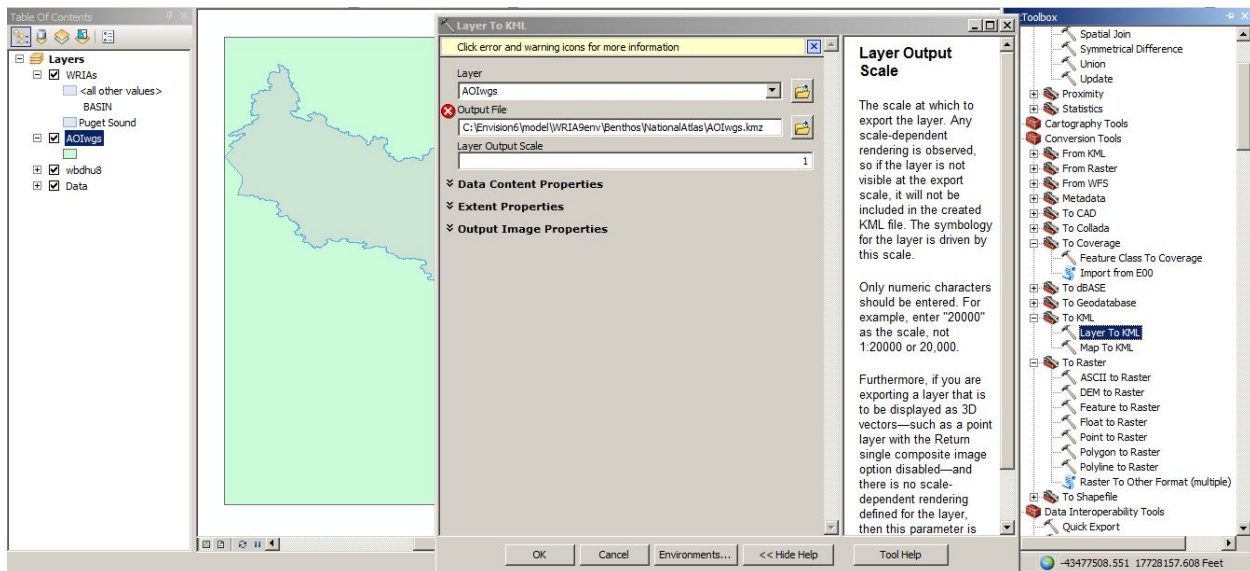
Appendix C: Landcover Data Download



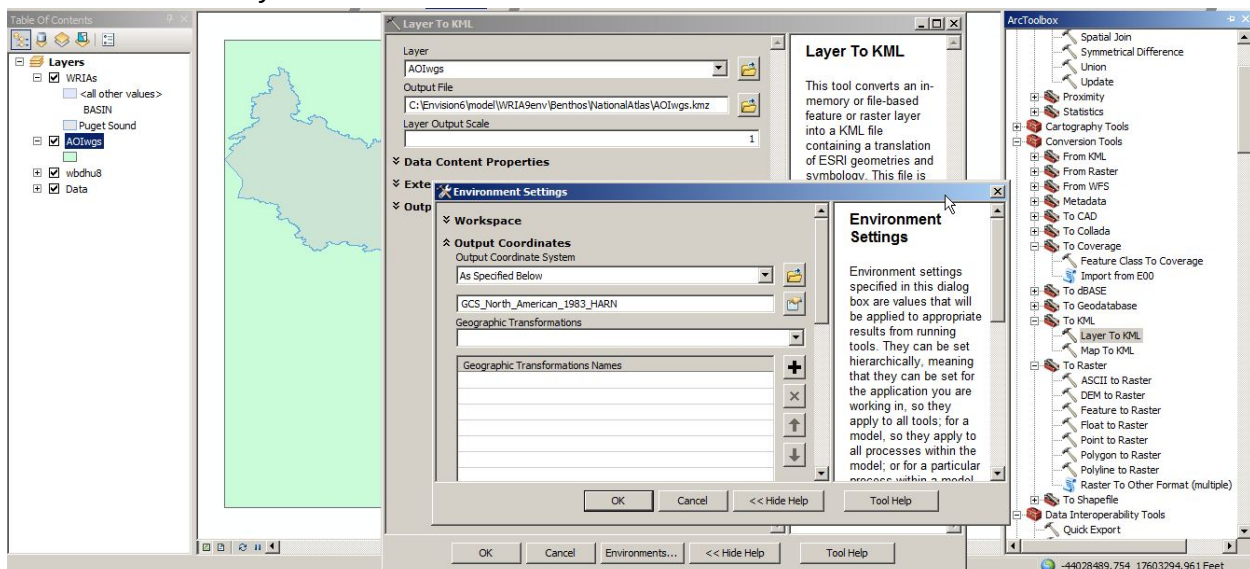
Take the ROI which is the Puget Sound watersheds and use the tool feature envelope to polygon.



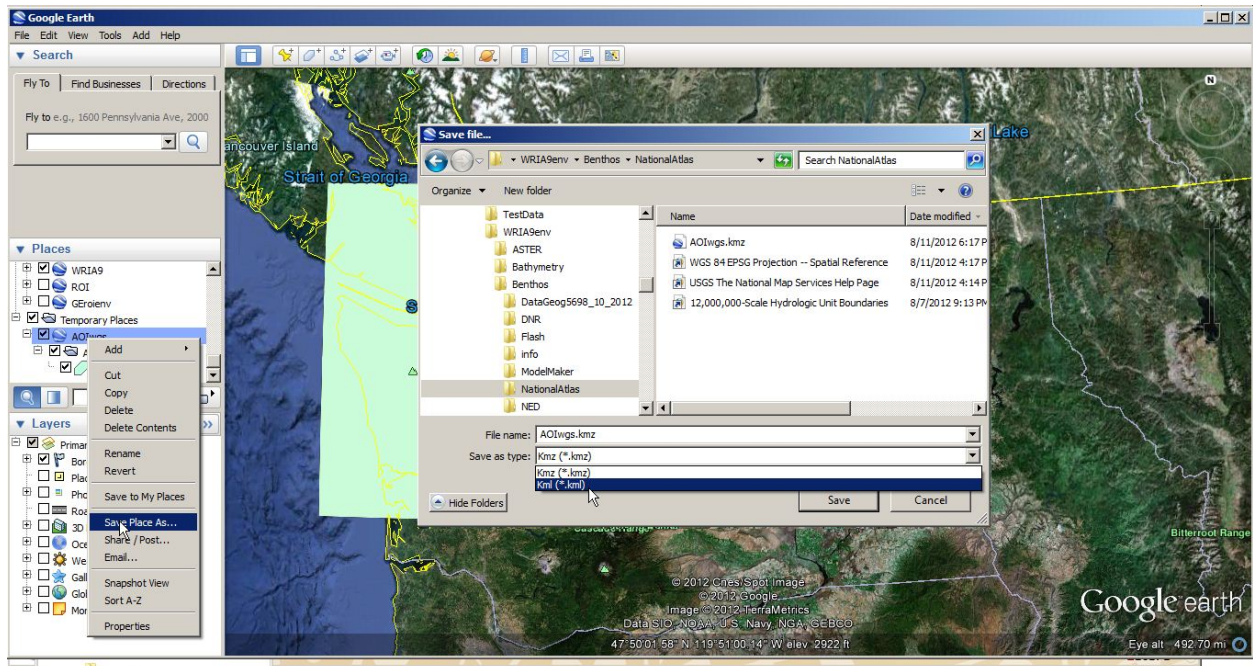
Check to see that it is in the proper coordinate system.



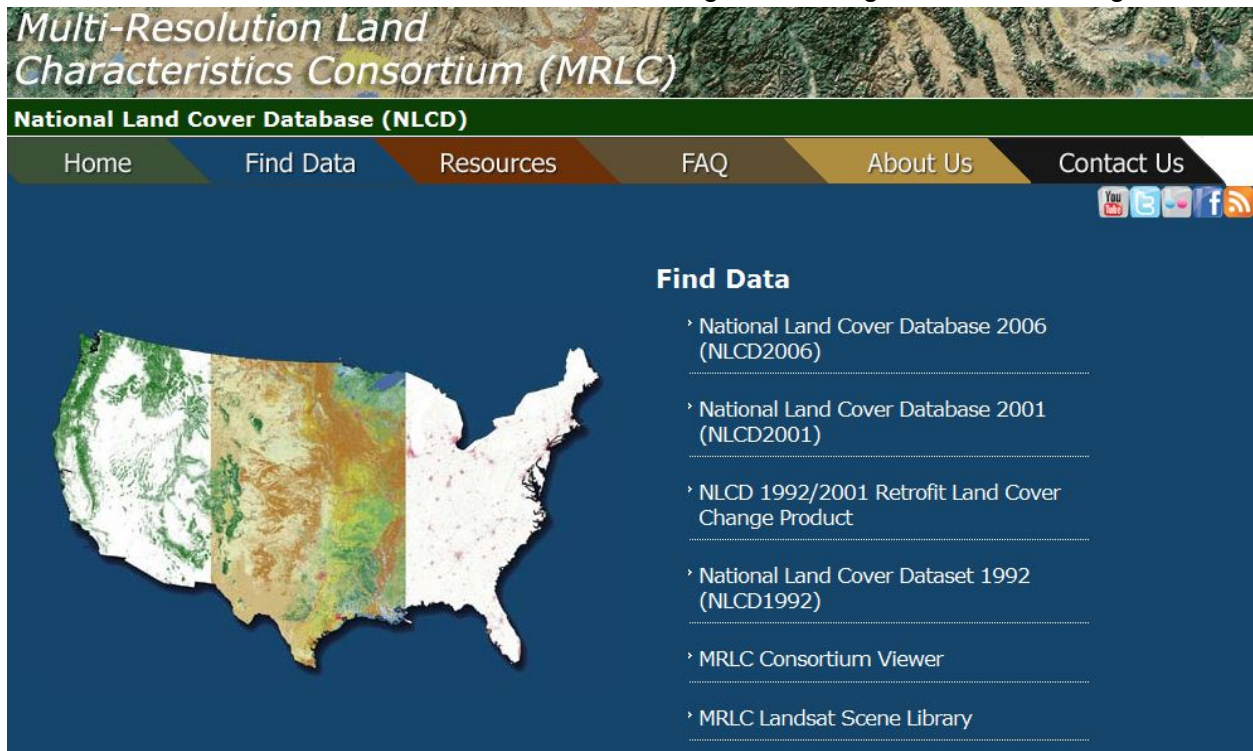
Next use the tool layer to KML on the ROI feature.



Go into the environment settings and set output coordinates to as specified below then give the coordinate system that is proper.



The feature ROI is now a kmz and it needs to be brought into Google Earth and changed to kml.



Go to the national land cover database

Multi-Resolution Land Characteristics Consortium (MRLC)
National Land Cover Database (NLCD)
HomeFind DataResourcesFAQAbout UsContact Us

NLCD 2006
Product Description
Data Downloads
Legend
Statistics
References
NLCD 2001
Product Description
Data Downloads
Legend
Statistics
References
Retrofit Land Cover Change
Product Description

National Land Cover Database 2006 (NLCD2006)

Product Data Downloads

NOTE: NLCD2001 Version 2.0 products must be used in any comparison of NLCD2001 and NLCD2006 products.

Conterminous United States

[NLCD2006 Land Cover](#) (1.1Gb)
The 2006 land cover layer for the conterminous United States for all pixels.

[NLCD2006 Land Cover Change](#) (99.5MB)
Land cover layer containing only those pixels identified as changed between NLCD2001 Land Cover Version 2.0 and NLCD2006 Land Cover products for the conterminous United States.

nationalmap.gov/viewer.html

The National Map

The National Geospatial Program
The National Map Home
The National Map Viewer & Download Platform
US Topo
Historical Topographic Map Collection
The National Atlas of the United States
Products and Services

The National Map Viewer

Managed by the National Geospatial Program (NGP), *The National Map* provides visualization and download of all eight primary themes of data sets to include US Topo and historical topographic map products. The platform is extended upon the National Geospatial Intelligence Agency Palantira x3 Viewer.

[Click Here to Open Viewer](#)

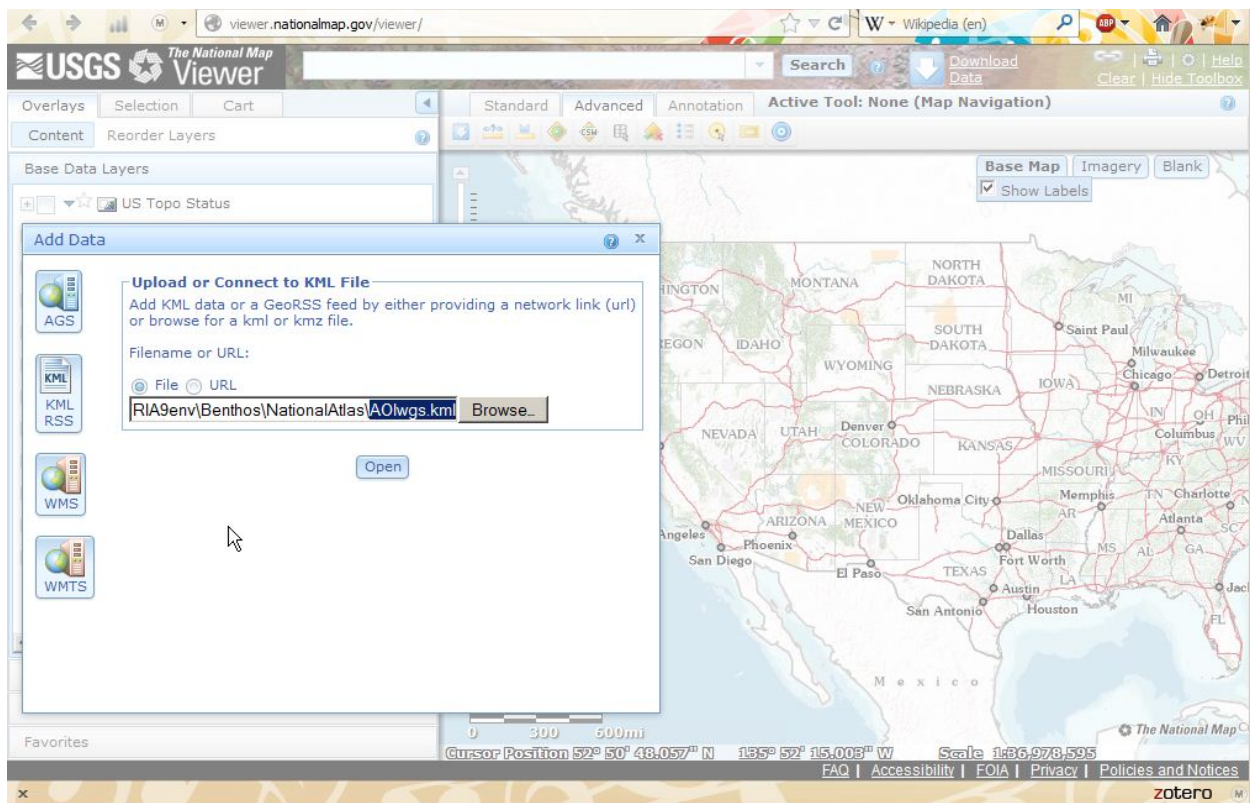
[Help](#) - Updates, Quick Start, User Guides, FAQs, Contact Us

[Services List](#) - Service Endpoints used in *The National Map Viewer*

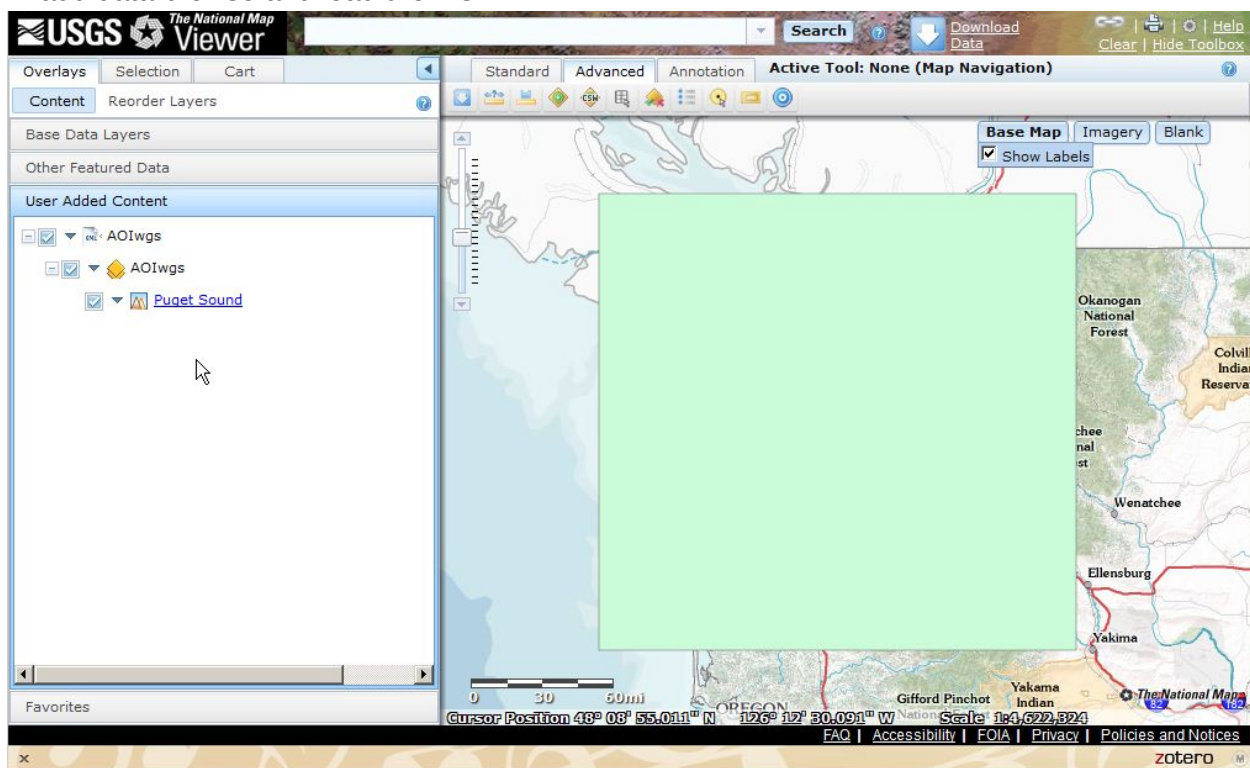
Recommended Browsers: [Firefox](#) - [Chrome](#) - [Internet Explorer 7 or higher](#)

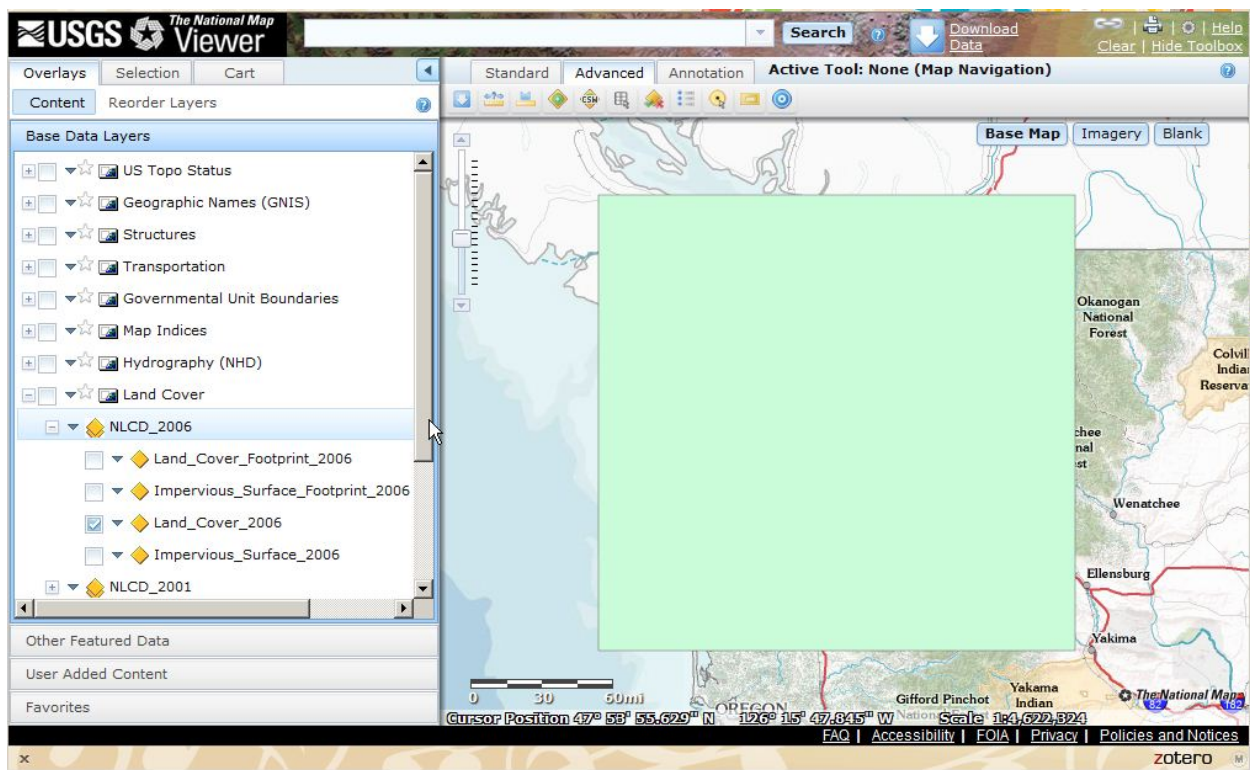
Can't see Flash? Install [Flash Player](#) or view [text version](#).

Open map viewer

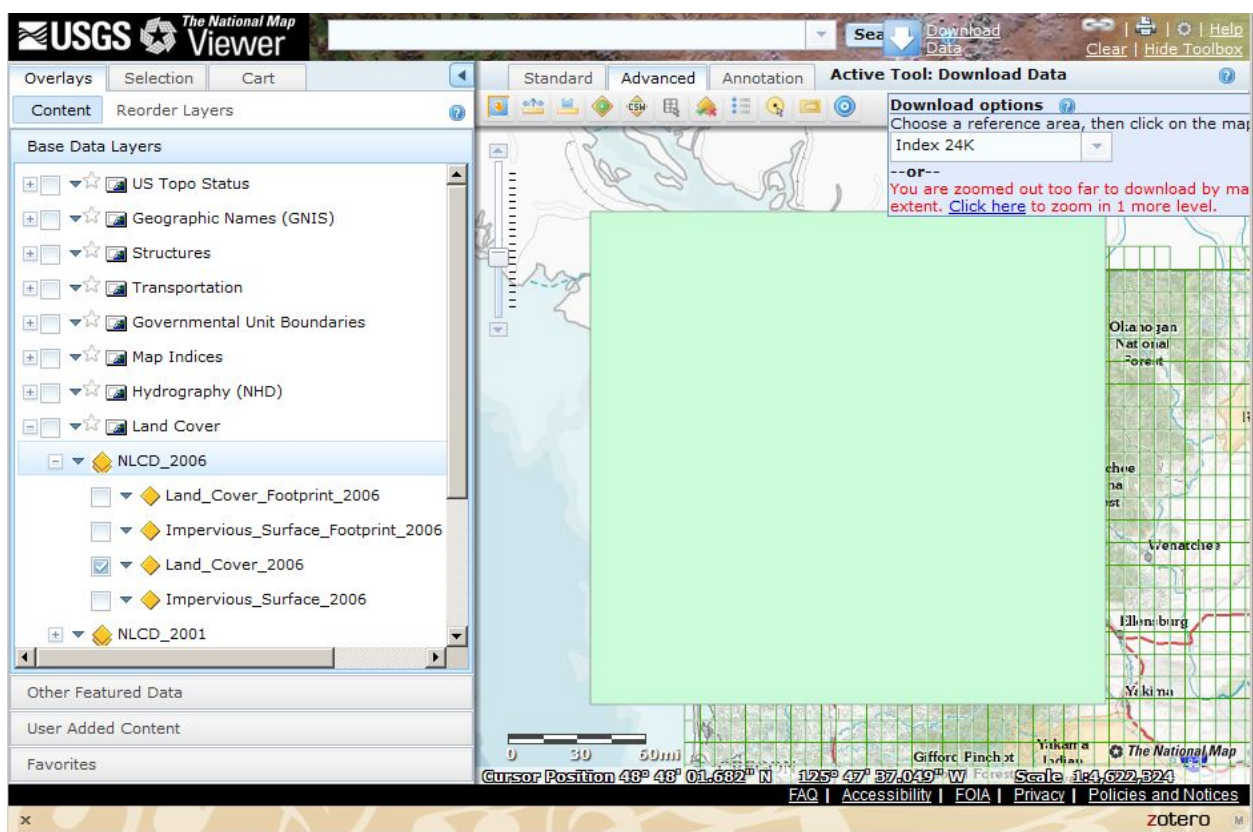


In add data browse and load the ROI kml.





The ROI kml is then used to select the landcover area to download.



Appendix D: Hydric Soils Data Acquisition

United States Department of Agriculture
NRCS Natural Resources Conservation Service

Home Select State State Contacts Template Databases SSURGO Metadata Status Map US General Soil Map

Soil Data Mart
 Logon/Register Help

Please select a state or territory with at least one survey area:

State or Territory Code	State or Territory Name	Available Survey Areas
NV	Nevada	45
NH	New Hampshire	10
NJ	New Jersey	20
NM	New Mexico	41
NY	New York	64
NC	North Carolina	101
ND	North Dakota	53
OH	Ohio	88
OK	Oklahoma	77
OR	Oregon	50
PA	Pennsylvania	61
RI	Rhode Island	1
SC	South Carolina	48
SD	South Dakota	67
TN	Tennessee	94
TX	Texas	233
UT	Utah	37
VT	Vermont	14
VA	Virginia	108
WA	Washington	54

Select County Select Survey Area

In the NRCS soil data mart select State.

United States Department of Agriculture
NRCS Natural Resources Conservation Service

Home Select State State Contacts Template Databases SSURGO Metadata Status Map US General Soil Map

Washington **Soil Data Mart**
 Logon/Register Help

Please select a county or parish with at least one survey area:

County Code	County Name	Available Survey Areas
WA001	Adams	1
WA003	Asotin	1
WA005	Benton	2
WA007	Chelan	4
WA009	Clallam	2
WA011	Clark	1
WA013	Columbia	1
WA015	Cowlitz	1
WA017	Douglas	1
WA019	Ferry	2
WA021	Franklin	1
WA023	Garfield	2
WA025	Grant	1
WA027	Grays Harbor	2
WA029	Island	1
WA031	Jefferson	3
WA033	King	3
WA035	Kitsap	2
WA037	Kittitas	4

Select State Select Survey Area

Next select a county that is in the ROI.

Please select a soil survey area:

Survey Area Symbol	Survey Area Name	Available Data
WA607	Chelan County Area, Washington (Parts of Chelan and Kittitas Counties)	Tabular and Spatial, complete
WA608	Cashmere Mountain Area, Washington, Parts of Chelan and Okanogan Counties	Tabular and Spatial, complete
WA749	Okanogan National Forest Area, Washington	Tabular and Spatial, complete
WA774	North Cascades National Park Complex, Washington	Tabular and Spatial, complete

Data Availability	Description
Tabular and Spatial, complete	Mapping for this survey area is finished, and complete tabular and spatial data are available.
Tabular and Spatial, incomplete	Mapping for this survey area is still in progress. Tabular and spatial data for the completed portion(s) are available.
Tabular only	Mapping for this survey area is still in progress. Tabular data are available but may not be complete. Soil map unit spatial data is not available. Spatial data for the survey area boundary is available.
Survey Area Boundary only	Mapping for this survey area is still in progress or has not yet been started. There is no tabular or spatial data. Spatial data for the survey area boundary is available.

View Metadata Download Data Generate Reports Subscribe

Select State Select County

Next a Survey area is selected and then click on download data. Take note of the survey area symbol it will be used to join with an Excel spreadsheet.

Please select the class of data you wish to download: (Survey Area Version 8 , Tabular Version 6 , Spatial Version 3)

☐ Tabular Data Only
 ☒ Tabular and Spatial Data
 ☐ Spatial Data Only
 ☐ Template Database Only

Please select a spatial format: ArcView Shapefile

Please select a coordinate system: State Plane Washington North (NAD83, meters)

Reset Default

Please select a template database (optional):

State	MS Access Version	Template DB Version	Template DB Name	Size
US	Access 2002	35	soildb_US_2002	1.7M
US	Access 2002	34	soildb_US_2002	1.7M
US	Access 2000	34	soildb_US_2000	1.6M
US	Access 2002	33.2	soildb_NPS_2002	2.4M
AK	Access 2002	32.15	soildb_AK_2002	2.5M
CA	Access 2002	33.2	soildb_CA_2003	1.8M
CA	Access 2000	33.2	soildb_CA_2000	1.8M
CA	Access 2002	32.1	soildb_CA_2002	1.8M
CT	Access 2002	32.1	soildb_CT_2002	1.8M
DC	Access 2002	31	soildb_DC_2002	1.7M
GA	Access 2002	32	soildb_GA_2002	1.8M
GA	Access 2002	31	soildb_GA_2002	1.5M
GA	Access 97	31	soildb_GA_97	1.3M
ID	Access 2002	33.4	soildb_ID_2003	1.9M
ID	Access 2000	33.4	soildb_ID_2000	2.3M
ID	Access 2002	33.3	soildb_ID_2003	1.9M
ID	Access 2000	33.3	soildb_ID_2000	1.9M
IN	Access 2002	33	soildb_IN_2002	1.7M
IN	Access 2000	33	soildb_IN_2000	1.7M
IN	Access 97	33	soildb_IN_97	1.4M
IN	Access 2002	33	soildb_IN_2002	1.7M

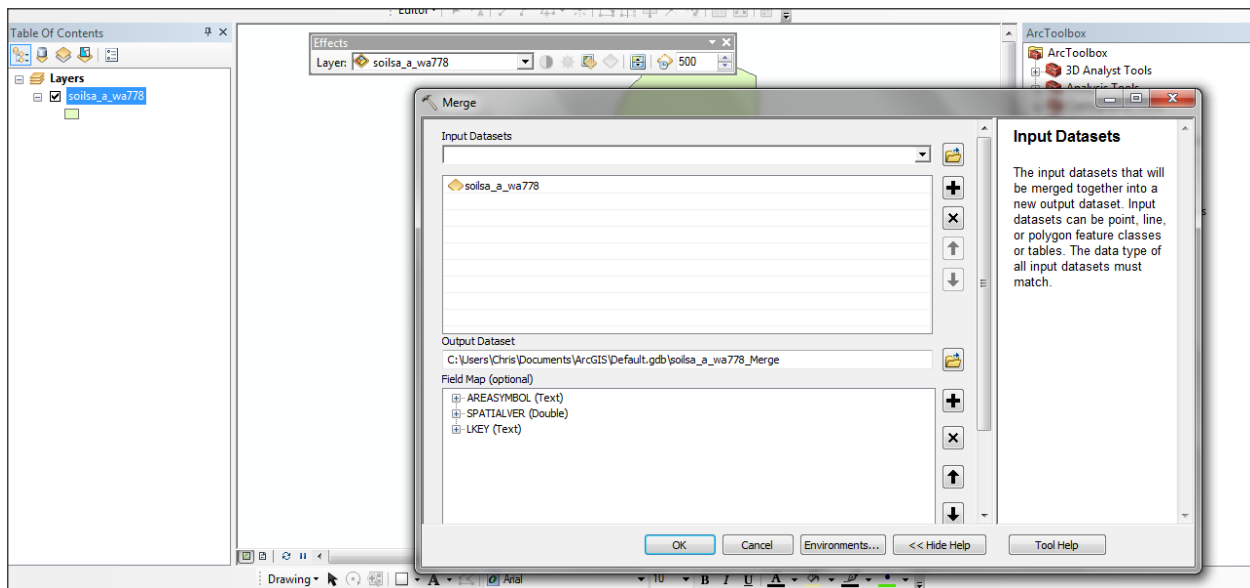
Clear Selection

Description:

Next the type of data tabular and spatial data is selected along with selecting a coordinate system.

Name	Date modified	Type	Size
soil_wa029	8/6/2012 6:47 PM	File folder	
soil_wa055	8/6/2012 7:23 PM	File folder	
soil_wa609	8/6/2012 6:47 PM	File folder	
soil_wa631	8/6/2012 6:48 PM	File folder	
soil_wa632	8/6/2012 6:53 PM	File folder	
soil_wa633	8/6/2012 6:53 PM	File folder	
soil_wa634	8/6/2012 6:54 PM	File folder	
soil_wa635	8/6/2012 6:54 PM	File folder	
soil_wa641	8/6/2012 7:24 PM	File folder	
soil_wa645	8/6/2012 6:54 PM	File folder	
soil_wa653	8/6/2012 8:15 PM	File folder	
soil_wa657	8/6/2012 7:24 PM	File folder	
soil_wa661	8/6/2012 6:54 PM	File folder	
soil_wa667	8/6/2012 6:55 PM	File folder	
soil_wa673	8/6/2012 6:55 PM	File folder	
soil_wa730	8/6/2012 6:55 PM	File folder	
soil_wa749	8/6/2012 6:55 PM	File folder	
soil_wa762	8/6/2012 6:56 PM	File folder	
soil_wa774	8/6/2012 6:57 PM	File folder	
soil_wa775	8/6/2012 6:57 PM	File folder	
soil_wa776	8/6/2012 7:23 PM	File folder	
soil_wa777	8/6/2012 6:57 PM	File folder	

After all of the soil survey areas are downloaded and unzipped they will need to be brought into ArcMap. Some more work needs to be done on the shapefiles before they can be used. In ArcCatalog create a file geodatabase to save the soil files in.



All of the soil survey area files are brought into ArcMap and merged into one file and saved to the file geodatabase.

	A	B	C	D	E
1	area symbol	area name	mapunit sequence	mapunit symbol	mapunit name
2	WA015	Cowlitz County, Washington	0	1	Andaquepts, 0 to 3 percent slopes
3	WA043	Lincoln County, Washington	0	1	Anders silt loam, 0 to 5 percent slopes
4	WA043	Lincoln County, Washington	0	1	Anders silt loam, 0 to 5 percent slopes
5	WA067	Thurston County, Washington	0	1	Alderwood gravelly sandy loam, 0 to 3 percent slopes
6	WA067	Thurston County, Washington	0	1	Alderwood gravelly sandy loam, 0 to 3 percent slopes
7	WA067	Thurston County, Washington	0	1	Alderwood gravelly sandy loam, 0 to 3 percent slopes
8	WA609	Clallam County Area, Washington	0	1	Agnew silt loam, 0 to 8 percent slopes
9	WA609	Clallam County Area, Washington	0	1	Agnew silt loam, 0 to 8 percent slopes
10	WA627	Grays Harbor County Area, Pacific and Wahkiakum Counties, Washington	0	1	Aabab silt loam
11	WA633	King County Area, Washington	0	AgB	Alderwood gravelly sandy loam, 0 to 6 percent slopes
12	WA633	King County Area, Washington	0	AgB	Alderwood gravelly sandy loam, 0 to 6 percent slopes
13	WA633	King County Area, Washington	0	AgB	Alderwood gravelly sandy loam, 0 to 6 percent slopes
14	WA633	King County Area, Washington	0	AgB	Alderwood gravelly sandy loam, 0 to 6 percent slopes
15	WA633	King County Area, Washington	0	AgB	Alderwood gravelly sandy loam, 0 to 6 percent slopes
16	WA634	Snoqualmie Pass Area, Washington (Parts of King and Pierce Counties)	0	1	Alderwood gravelly loam, 6 to 15 percent slopes
17	WA635	Kitsap County Area, Washington	0	1	Alderwood very gravelly sandy loam, 0 to 6 percent slopes
18	WA635	Kitsap County Area, Washington	0	1	Alderwood very gravelly sandy loam, 0 to 6 percent slopes
19	WA635	Kitsap County Area, Washington	0	1	Alderwood very gravelly sandy loam, 0 to 6 percent slopes
20	WA641	Lewis County Area, Washington	0	1	Alvor silty clay loam
21	WA641	Lewis County Area, Washington	0	1	Alvor silty clay loam
22	WA645	Mason County, Washington	0	Aa	Alderwood gravelly loam, 5 to 15 percent slopes
23	WA653	Pierce County Area, Washington	0	1B	Alderwood gravelly sandy loam, 0 to 6 percent slopes
24	WA653	Pierce County Area, Washington	0	1B	Alderwood gravelly sandy loam, 0 to 6 percent slopes

The next step should be to save the Washington hydric soils spreadsheet to the file geodatabase.

In the file geodatabase the Washington hydric soils field area symbol can be calculated to a new field that matches the properties with the area symbol field in the feature class that was created and saved. These two fields have to have the same properties so they will be able to join if it is one record in the spreadsheet to one record in the feature class. Or create a relate if it is many records to one record.

Table

soilsa_a_wa778

FID	Shape *	AREASYMBOL	SPATIALVER	LKEY
0	Polygon	WA778	1	10513

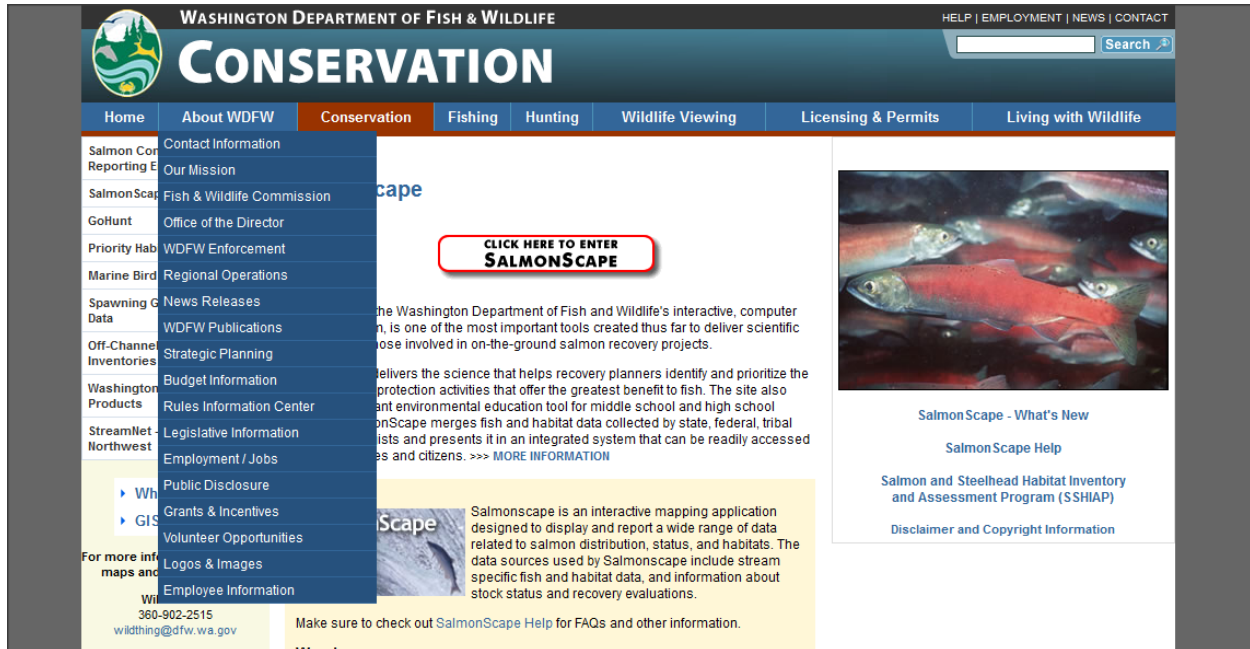
Effects

Layer: soilsa_a_wa778

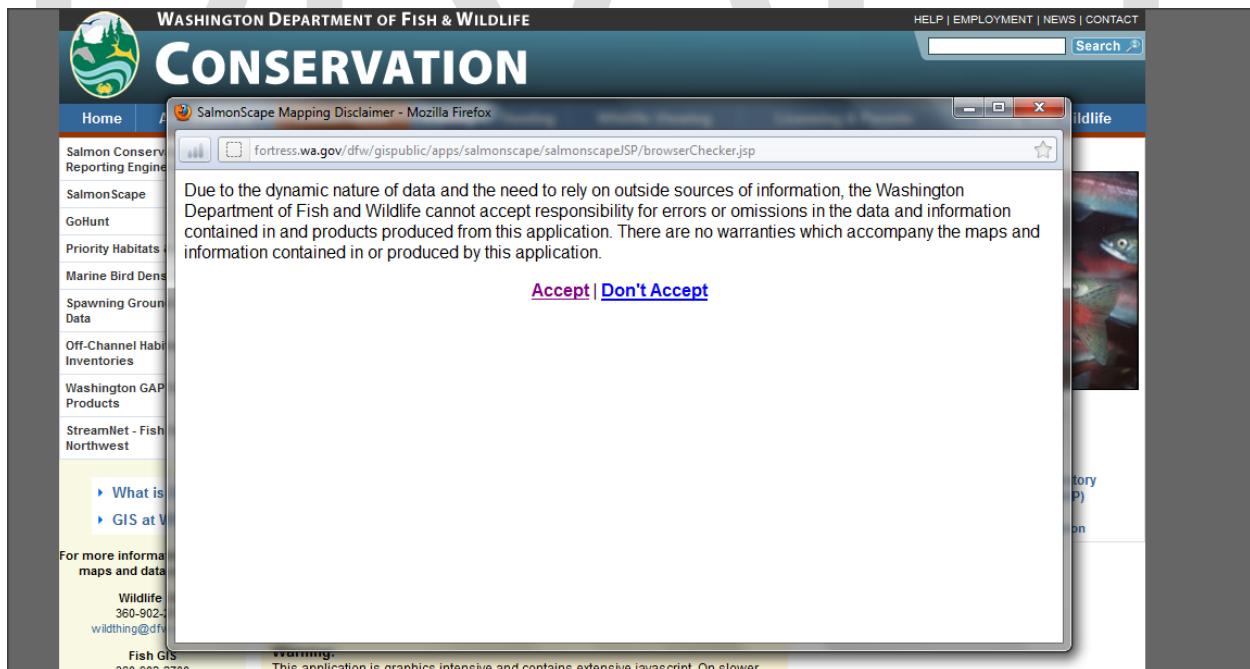
500

Appendix E: SalmonScape Data Acquisition

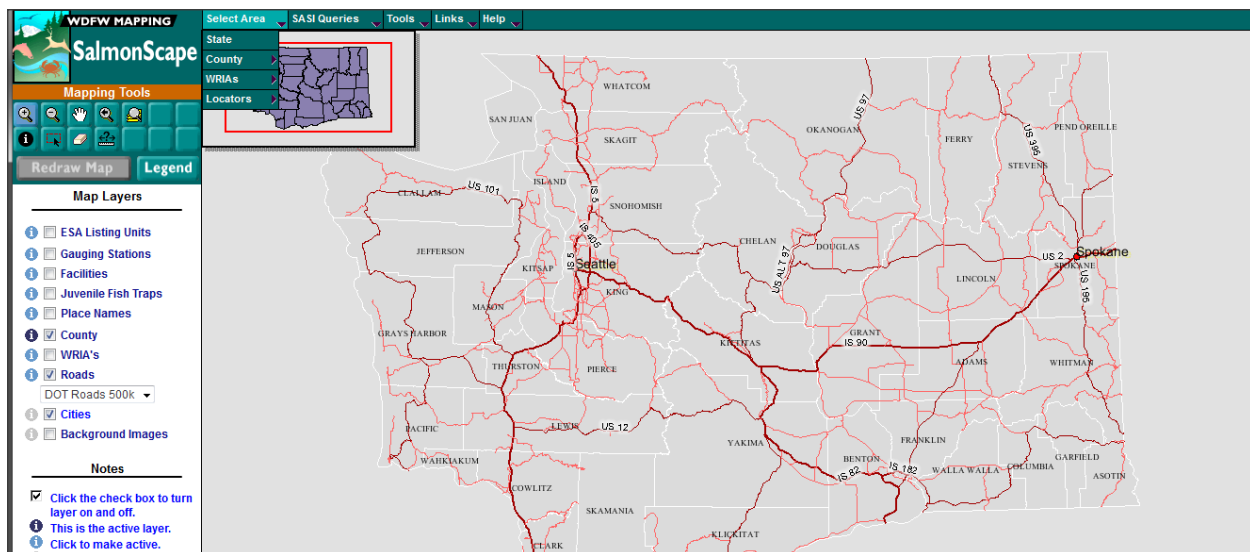
Salmon Scape - <http://wdfw.wa.gov/mapping/salmonscape/>



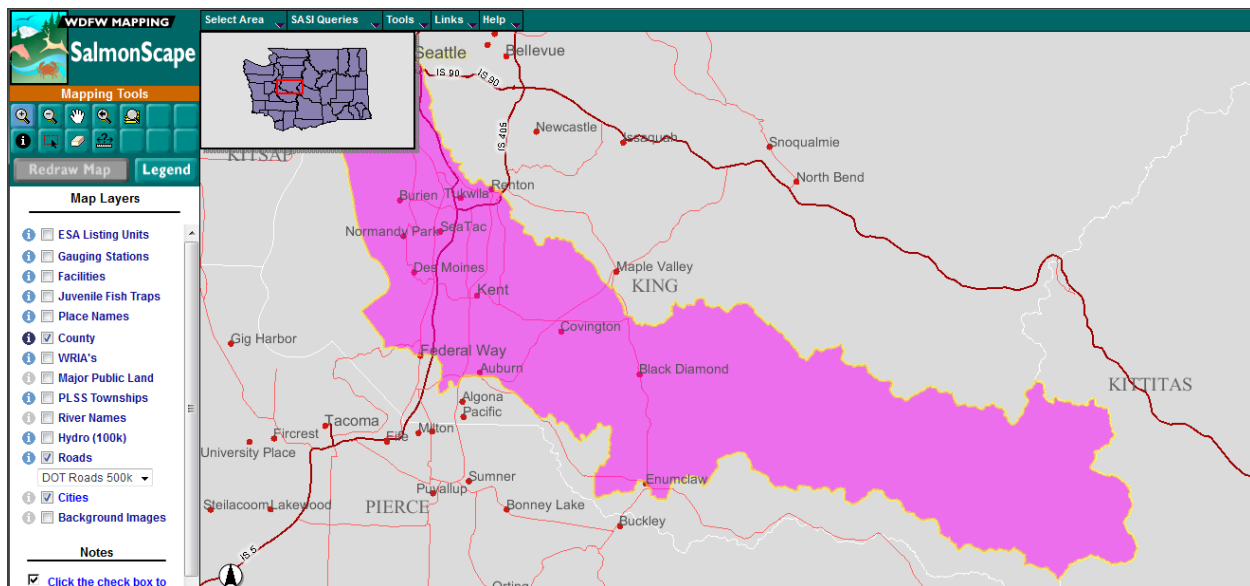
Go to the Washington Department of Fish and Wildlife and go to Salmon Scape

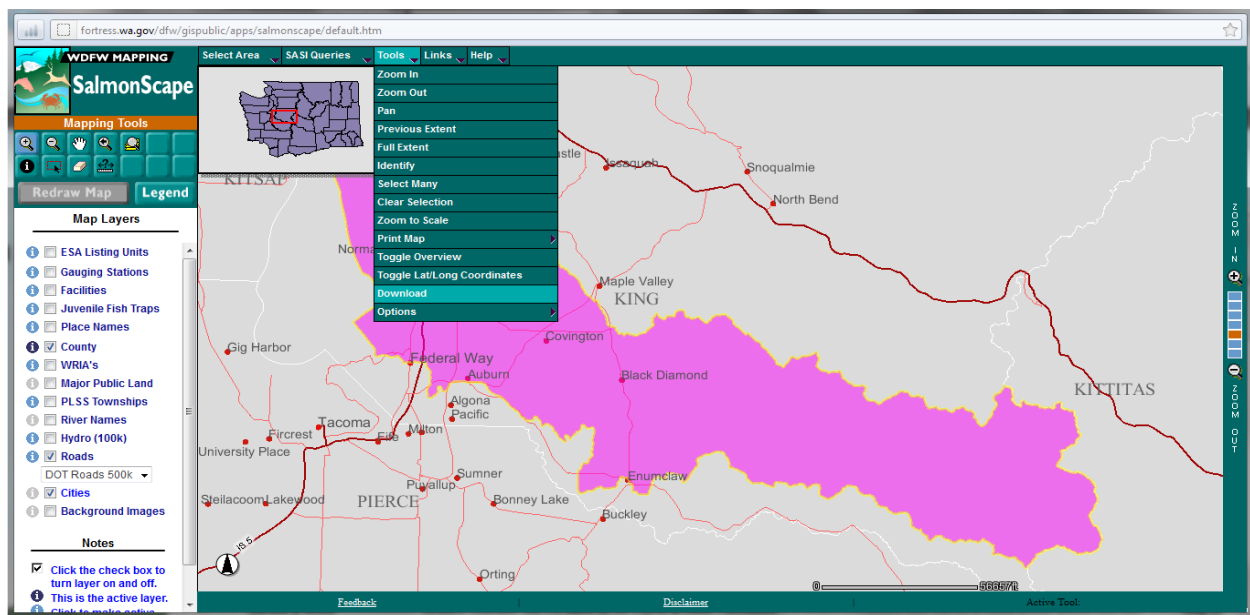


When window comes up accept it.

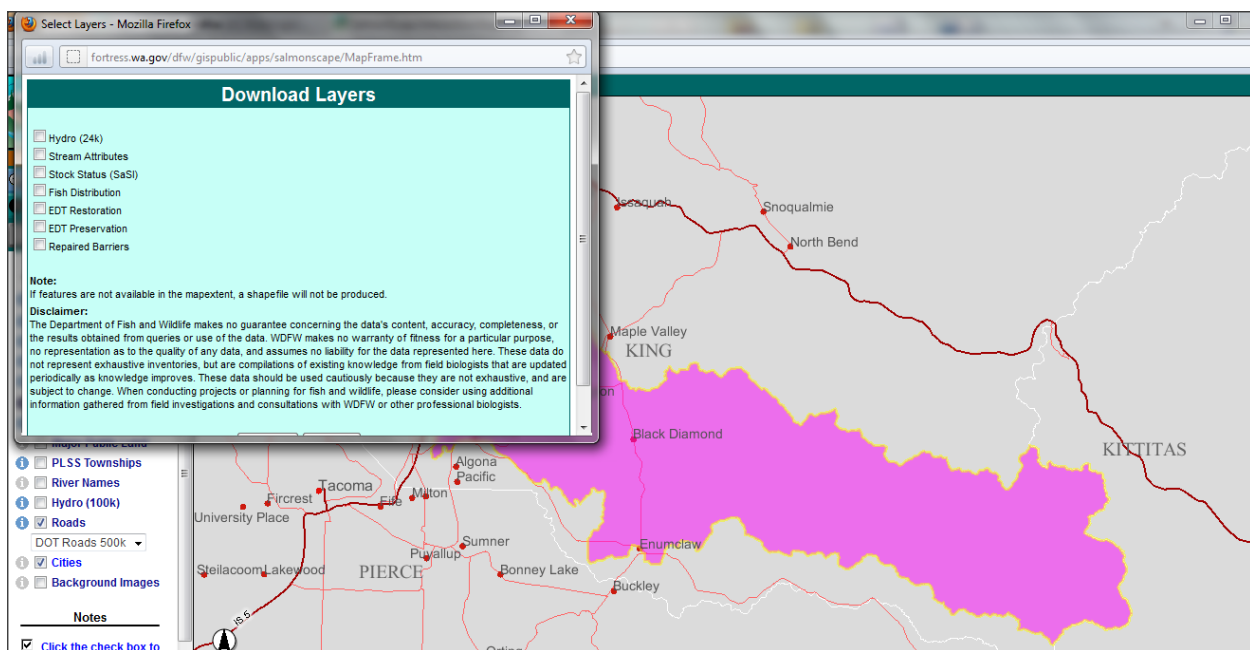


Select area WRIAs

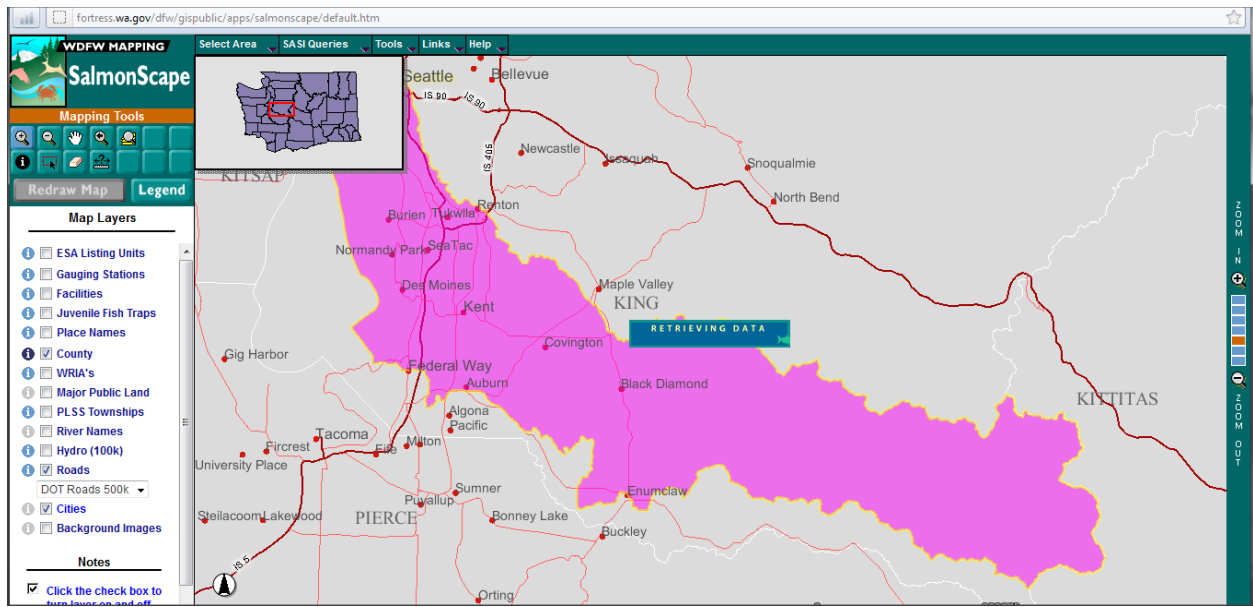




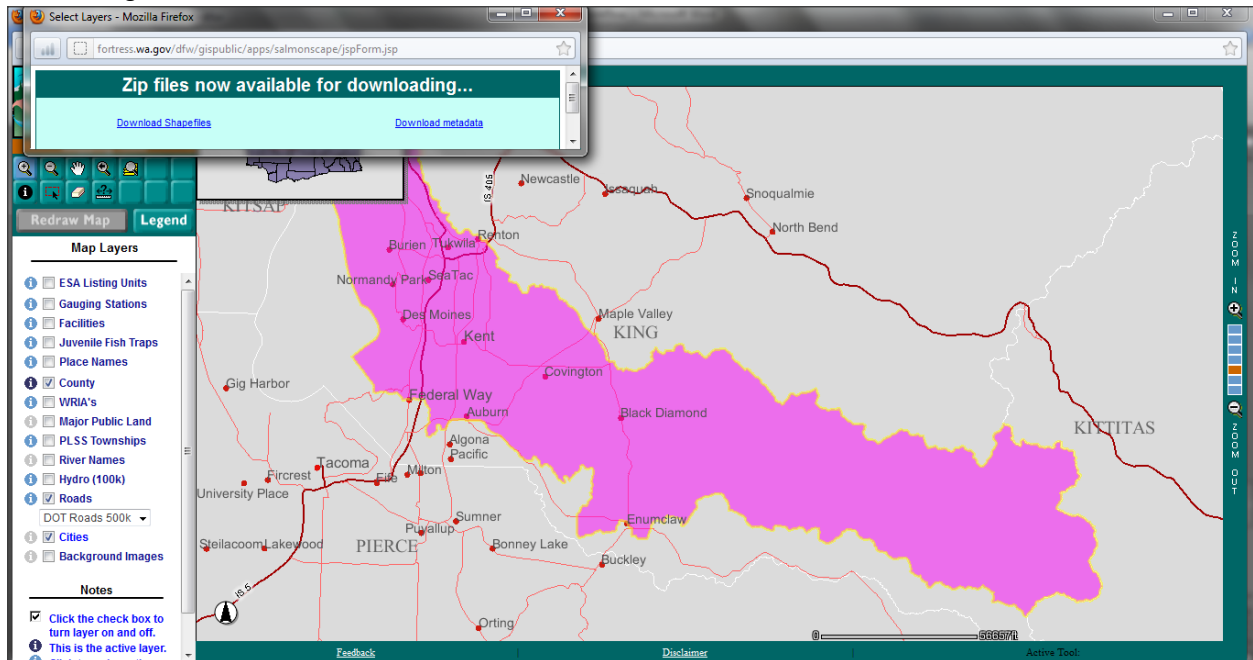
Select download



Select layers to download



Retrieving data



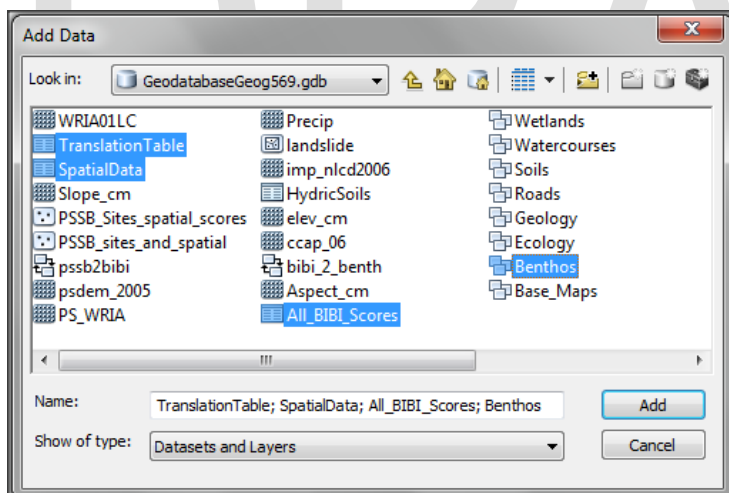
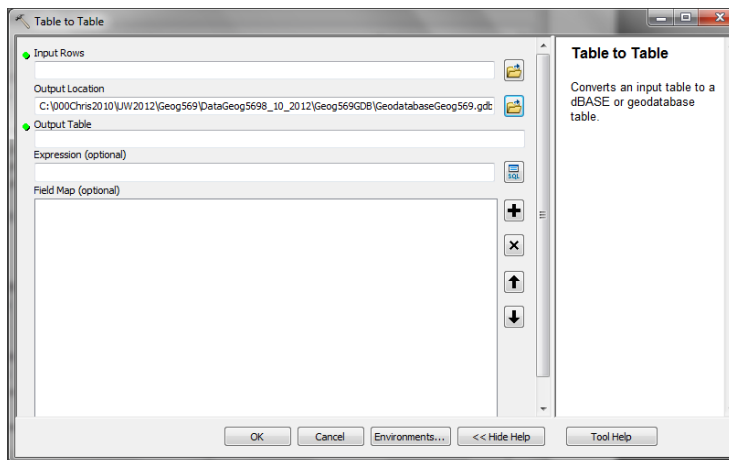
Download zipped shapefile

Bring into ArcMap and merge to create a single feature class.

Appendix F: Joining the tables to the Benthic Sites

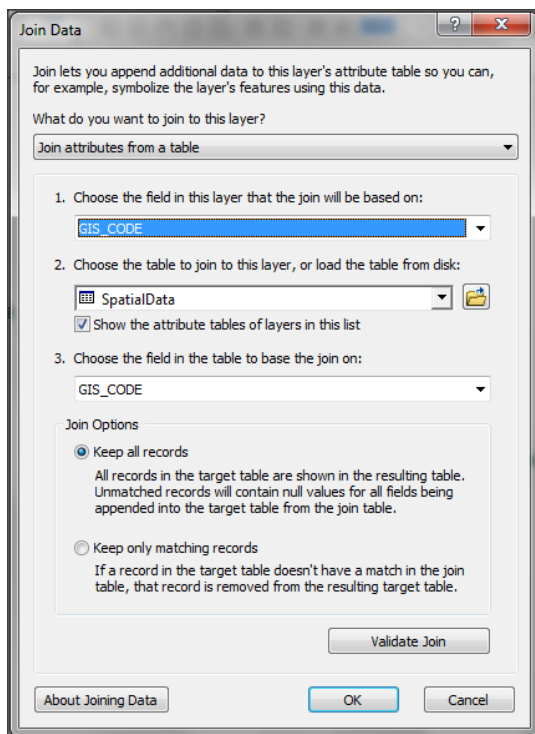
How to create the joins using the habitat data table, BIBI locations feature class, Translation table and BI BI scores table.

All of the Excel spreadsheets or data bases need to be imported into a filegeodatabase. There will be three spatial joins to complete this operation.

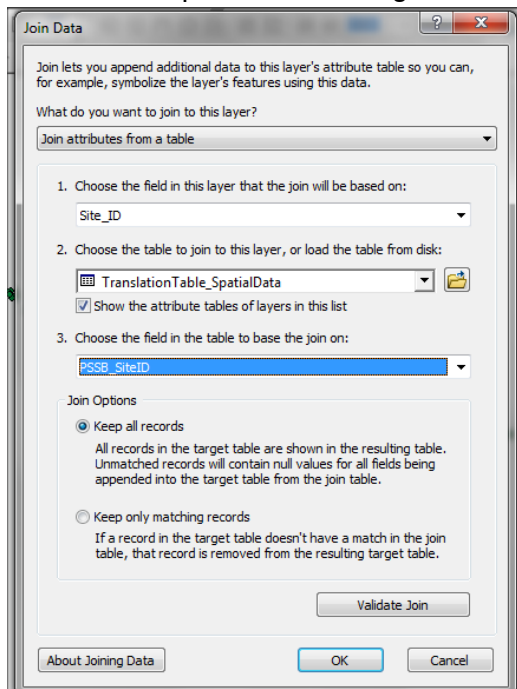


Before any of the joins are started the fields which will be used to join the tables and the feature class will need to have the same properties. All of the join fields will either need to be doubles, integers, or text. The properties in the text fields will need to have the same number of characters.

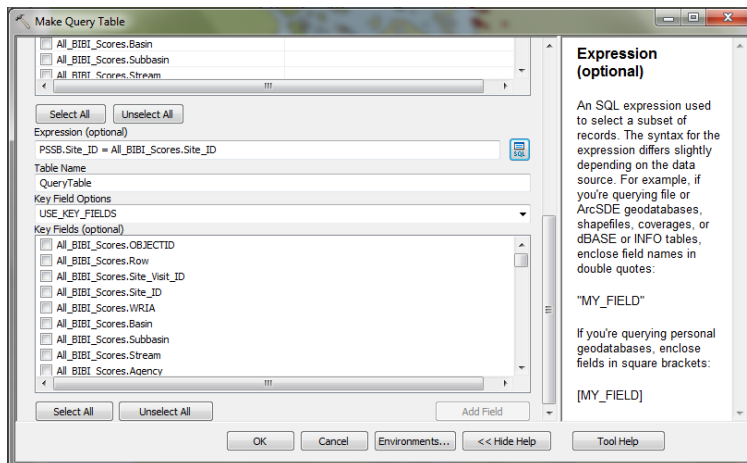
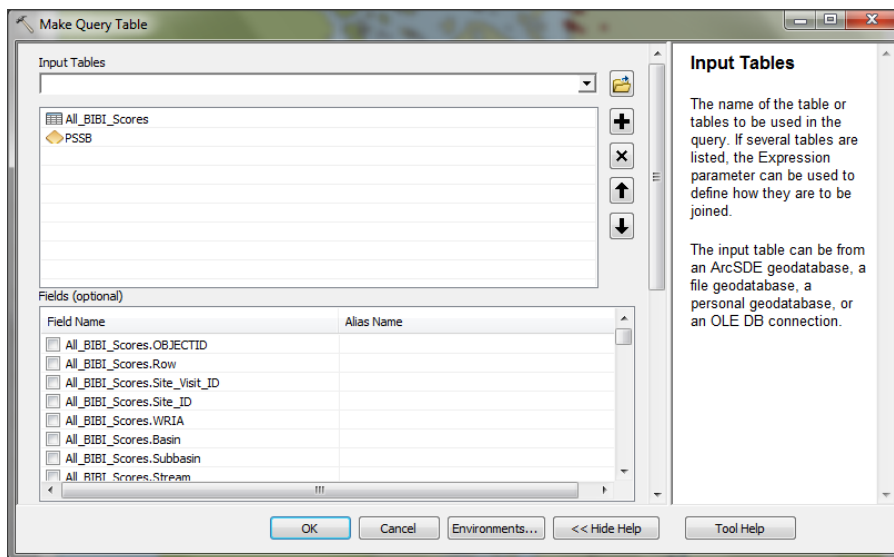
The first spatial join will be with the SpitalData table and the Translation table. In these two tables the GIS_CODE FIELD will be used for the join and is a one to one spatial join.



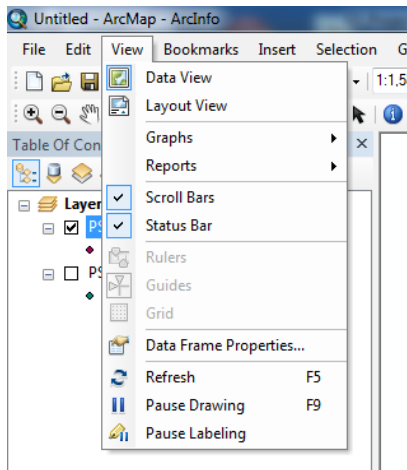
The next join will be between the joined Translation Table_SpatialData table and the Benthos location points and is a one to one spatial join. After this join a feature class will need to be saved and imported to the filegeodatabase and brought into the mxd for the next step.



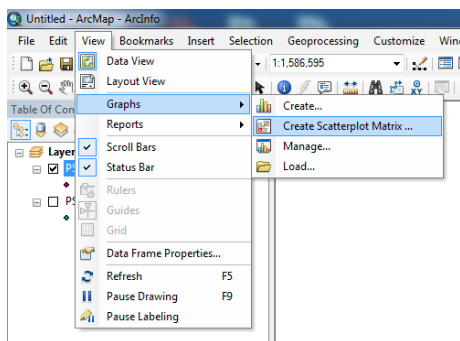
Data Management Tools, Layers and Table Views, Make Query Table



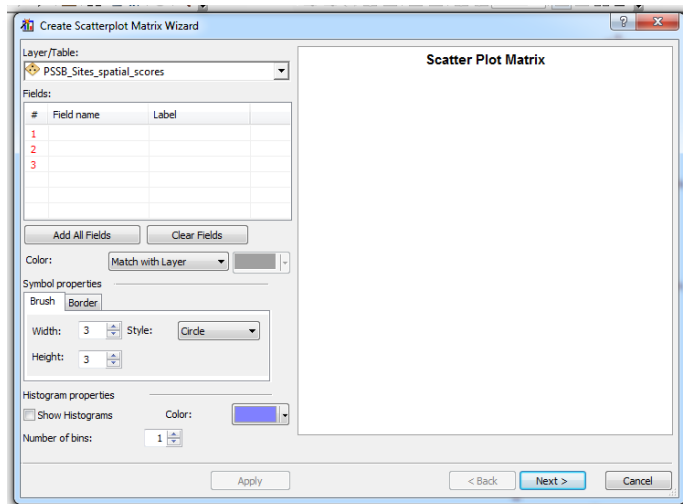
Appendix G: Producing Scatterplots in ArcMap



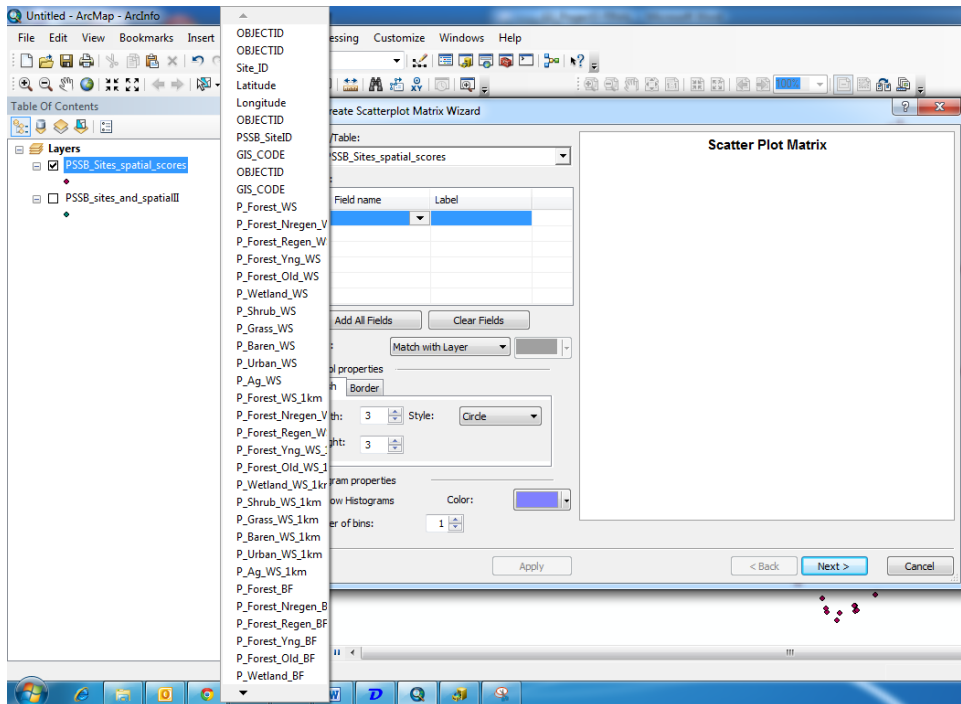
First select Graphs from the View menu



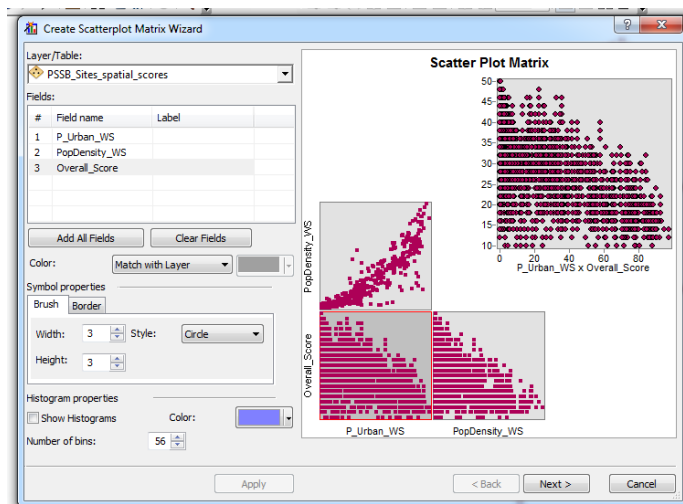
Second select Create Scatterplot Matrix



The Create Scatterplot Matrix Wizard will appear



Select the independent and dependent variables of interest. In order to place the dependent variable on the y-axis, select it last.



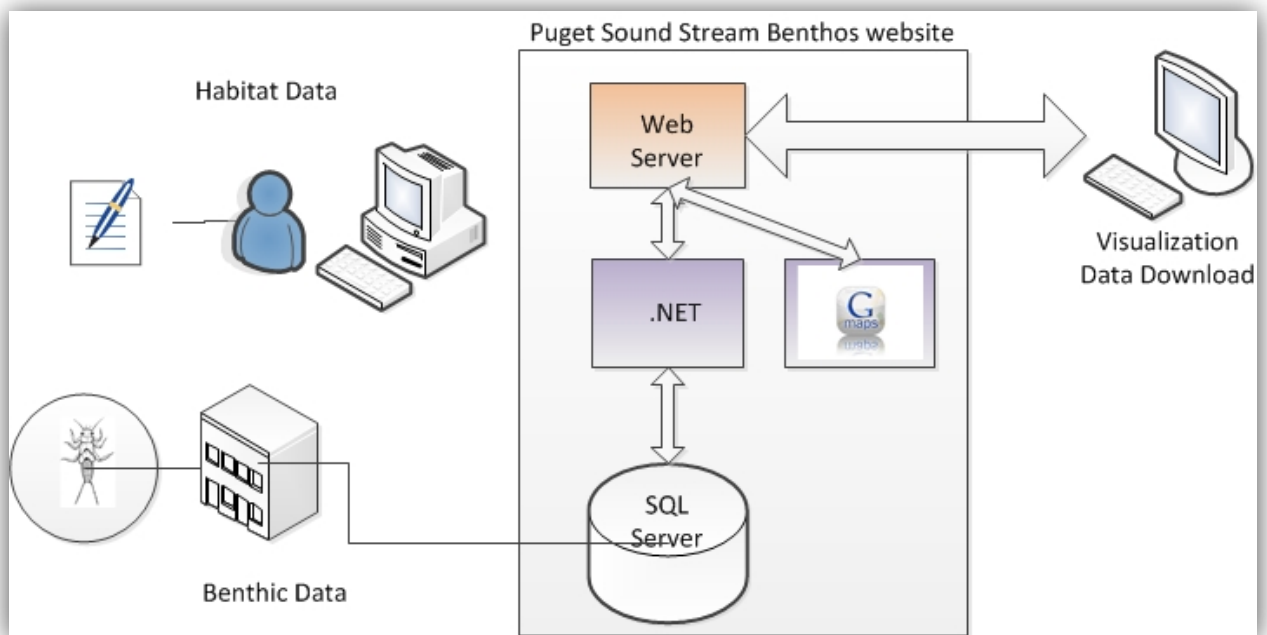
Hit Apply and these will be your outputs. You can select from the three graphs in the lower left to display in the upper right.

Appendix H: Framework Definitions Extracted from Ostrom 2009

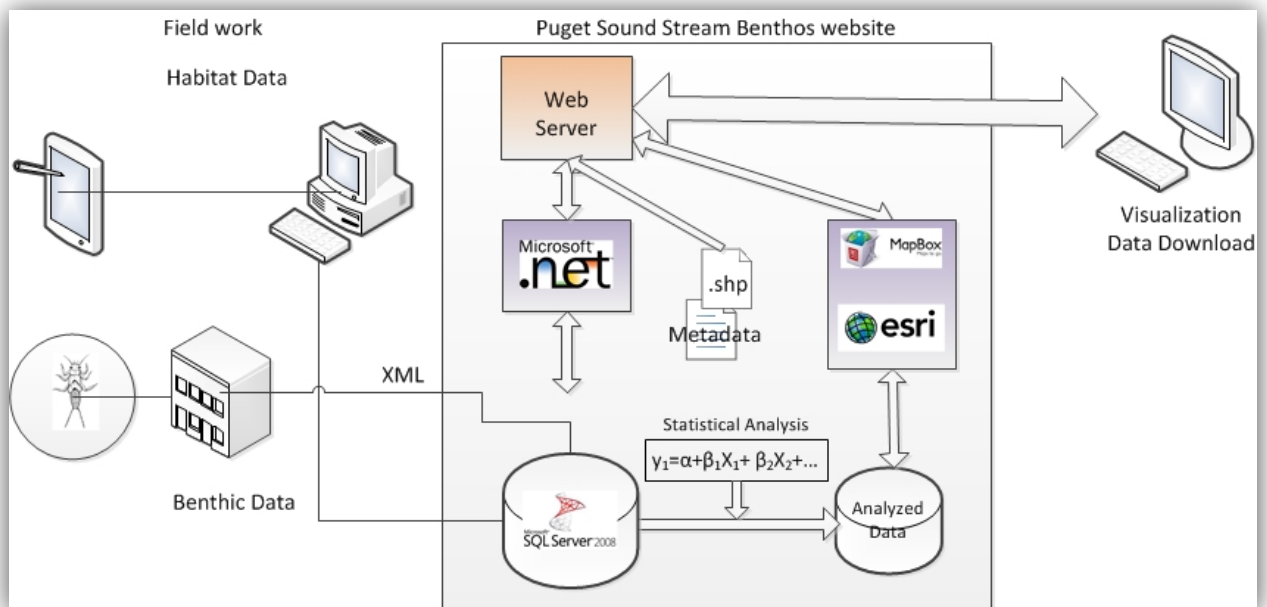
Variable	Definitions/Examples
Size of resource system	For land-related resource systems, such as forests, very large territories are unlikely to be self-organized given the high costs of defining boundaries (e.g., surrounding with markers or fences), monitoring use patterns, and gaining ecological knowledge. Very small territories do not generate substantial flows of valuable products. Thus, moderate territorial size is most conducive to self-organization. Fishers who consistently harvest from moderately sized coastal zones, lakes, or rivers are also more likely to organize than fishers who travel the ocean in search of valuable fish.
Productivity of system	A resource system's current productivity has a curvilinear effect on self-organization across all sectors. If a water source or a fishery is already exhausted or apparently very abundant, users will not see a need to manage for the future. Users need to observe some scarcity before they invest in self-organization.
Predictability of system dynamics	System dynamics need to be sufficiently predictable that users can estimate what would happen if they were to establish particular harvesting rules or no-entry territories. Forests tend to be more predictable than water systems. Some fishery systems approach mathematical chaos and are particularly challenging for users or government officials. Unpredictability at a small scale may lead users of pastoral systems to organize at larger scales to increase overall predictability.
Resource unit mobility	Due to the costs of observing and managing a system, self-organization is less likely with mobile resource units, such as wildlife or water in an unregulated river, than with stationary units such as trees and plants or water in a lake.
Number of users	The impact of group size on the transaction costs of self-organizing tends to be negative given the higher costs of getting users together and agreeing on changes. If the tasks of managing a resource, however, such as monitoring extensive community forests in India, are very costly, larger groups are more able to mobilize necessary labor and other resources. Thus, group size is always relevant, but its effect on self-organization depends on other SES variables and the types of management tasks envisioned.
Leadership	When some users of any type of resource system have entrepreneurial skills and are respected as local leaders as a result of prior organization for other purposes, self-organization is more likely. The presence of college graduates and influential elders, for example, had a strong positive effect on the establishment of irrigation organization in a stratified sample of 48 irrigation systems in Karnataka and Rajasthan, India.
Norms/social capital	Users of all types of resource systems who share moral and ethical standards regarding how to behave in groups they form, and thus the norms of reciprocity, and have sufficient trust in one another to keep agreements will face lower transaction costs in reaching agreements and lower costs of monitoring.
Knowledge of SES	When users share common knowledge of relevant SES attributes, how their actions affect each other, and rules used in other SESs, they will perceive lower costs of organizing (7). If the resource system regenerates slowly while the population grows rapidly, such as on Easter Island, users may not understand the carrying capacity of the resource, fail to organize, and destroy the resource.
Importance of resource to users	In successful cases of self-organization, users are either dependent on the RS for a substantial portion of their livelihoods or attach high value to the sustainability of the resource. Otherwise, the costs of organizing and maintaining a self-governing system may not be worth the effort.
Collective-choice rules	When users, such as the Seri fishers in Mexico (29) and forest user groups in Nepal (30), have full autonomy at the collective-choice level to craft and enforce some of their own rules, they face lower transaction costs as well as lower costs in defending a resource against invasion by others.

Appendix I: Puget Sound Stream Benthos website

Current use of the website:



Proposed use of the website:



New Strategies for Impervious Surface Data Development

for the King County Water Quality and Water Quantity Groups Unit

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Geography 569: GIS Workshop

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LIST OF ACRONYMS USED IN THIS DOCUMENT

BHT	Building Height
BMP	Best Management Practice
CIR	Color Infra-Red
DEM	Digital Elevation Model
DNRP	Department of Natural Resources and Parks
EPA	Environmental Protection Agency
Esri	Environmental Systems Research Institute
GIS	Geographic Information Systems
HSP-F	Hydrologic Simulation Program-Fortran
KC	King County
LC/LU	Land Cover/Land Use
LID	Low Impact Development
LiDAR	Light Detection And Ranging
NPDES	National Pollutant Discharge Elimination System
NVI	National Vegetation Index
RAM	Random Access Memory
SSWM	Storm and Surface Water Management
STSS	Science and Technical Support Section
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
VHT	Vegetation Height
WLRD	Water and Land Resources Division
WRIA	Water Resource Inventory Area
WWTP	Waste Water Treatment Plant

New Strategies for Impervious Surface Data Development

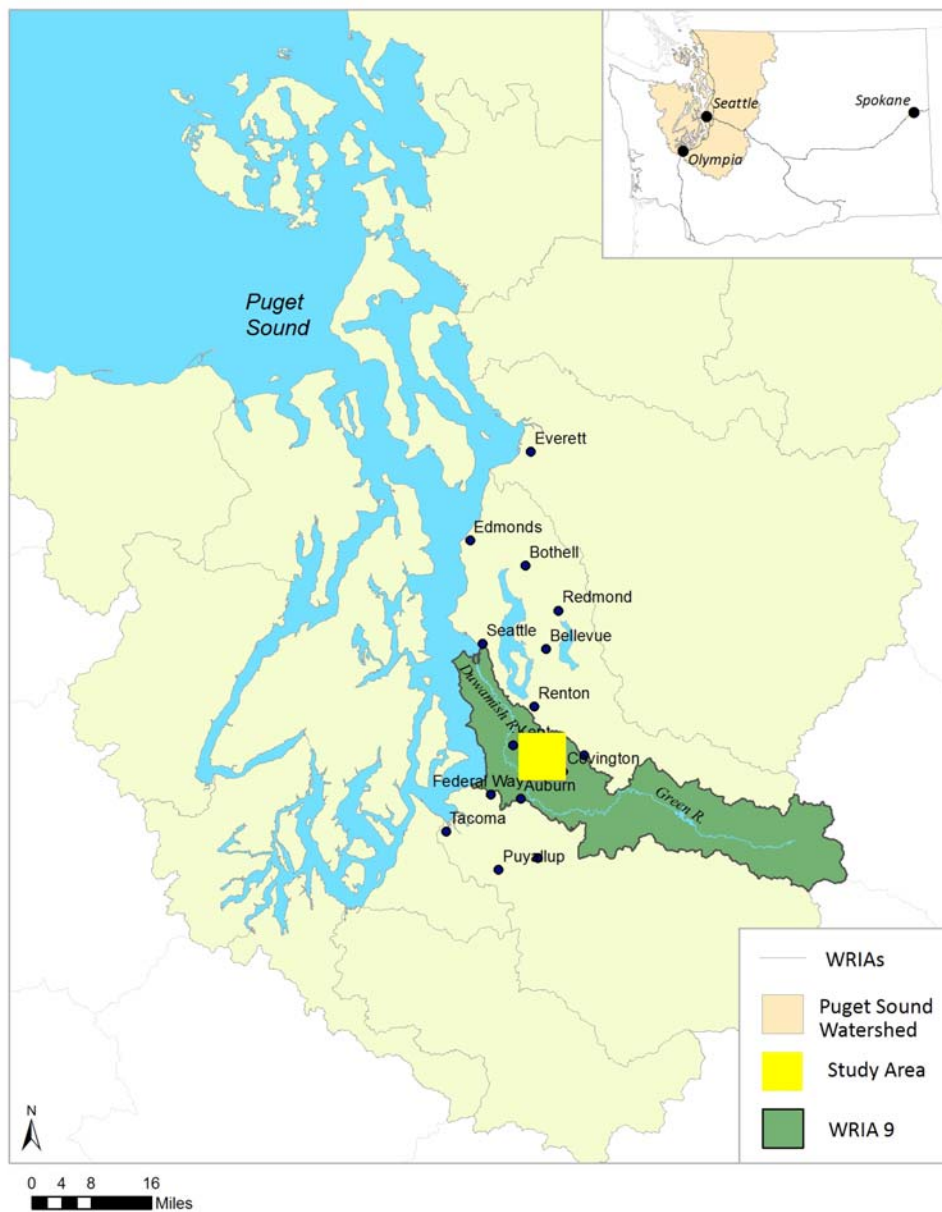
I. BACKGROUND AND PROBLEM STATEMENT

BACKGROUND

Water quality and water resource management within the Puget Sound watershed are essential for the ecological restoration, management, and maintenance of the waters of Puget Sound. The Puget Sound watershed includes lands in Clallam Island, Jefferson, King, Kitsap, Mason, Pierce, San Juan, Skagit, Snohomish, Thurston, and Whatcom counties, Washington (U.S. Environmental Protection Agency [EPA], 2012; Jim Simmonds, Science and Technical Services Section Supervisor, King County Department of Parks and Natural Resources Water and Land Resources Division, email communication 3 July 2012). Water Resource Inventory Area (WRIA) 9, the Green/Duwamish and Central Puget Sound watershed, is the second most populated watershed in the state. It is a source of drinking water, food, and forest products, and is host to several species of federally Endangered Species Act salmonids, including Chinook, Coho, chum, and steelhead and has been identified as a conservation priority. As described in the King County (KC) Science and Technical Support Section (STSS) Business plan, stormwater is a significant stressor affecting the health of the Puget Sound Ecosystem. Efficiently and effectively managing stormwater to reduce harm to the ecosystem is a common goal of numerous local agencies and actors, ranging from special interest groups to citizens and government (King County Department of Natural Resources and Parks [KCDNRP], 2008). The KCDNRP Water and Land Resources Division (WLRD) STSS exercises a critical role in this effort, as WRIA 9 lies almost entirely within the county boundary (Figure 1), and the STSS is tasked with monitoring land and water resources, with developing and implementing management strategies for the benefit of the resources, as well as providing information and data for other departments to support them in their missions (Figure 2).

Historically, stormwater management efforts focused on concentrating and removing water from the landscape as quickly as possible, which contributed to sediment, thermal, and contaminant impacts to receiving waters. More recent efforts shifted to the development of regional and local systems to manage stormwater, through a stormwater conveyance and collection infrastructure that provides a measure of pretreatment before discharging to local waterbodies. King County is now looking forward to the next generation of stormwater management, with a focus on developing highly localized, site based stormwater treatment systems that provide maximum stormwater treatment benefit for the cost.

Green-Duwamish River Watershed, Water Resource Inventory Area (WRIA 9)



Data source: WA State Dept. of Ecology, <<http://www.ecy.wa.gov/services/gis/data/data.htm>>. County layer from Census 2010TIGER/Line, <<http://www.ofm.wa.gov/pop/geographic/tiger.asp>>. City data generated from Bing Maps Hybrid (c) 2010 Microsoft Corporation and its data suppliers. Road data from WA Dept of Transportation <<http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm>>
 Coordinate system: NAD_1927_UTM_Zone_10N, Transverse_Mercator.

Figure 1: Project Location

King County, Water and Land Resource Division: Science and Technical Support Section Organizational Diagram

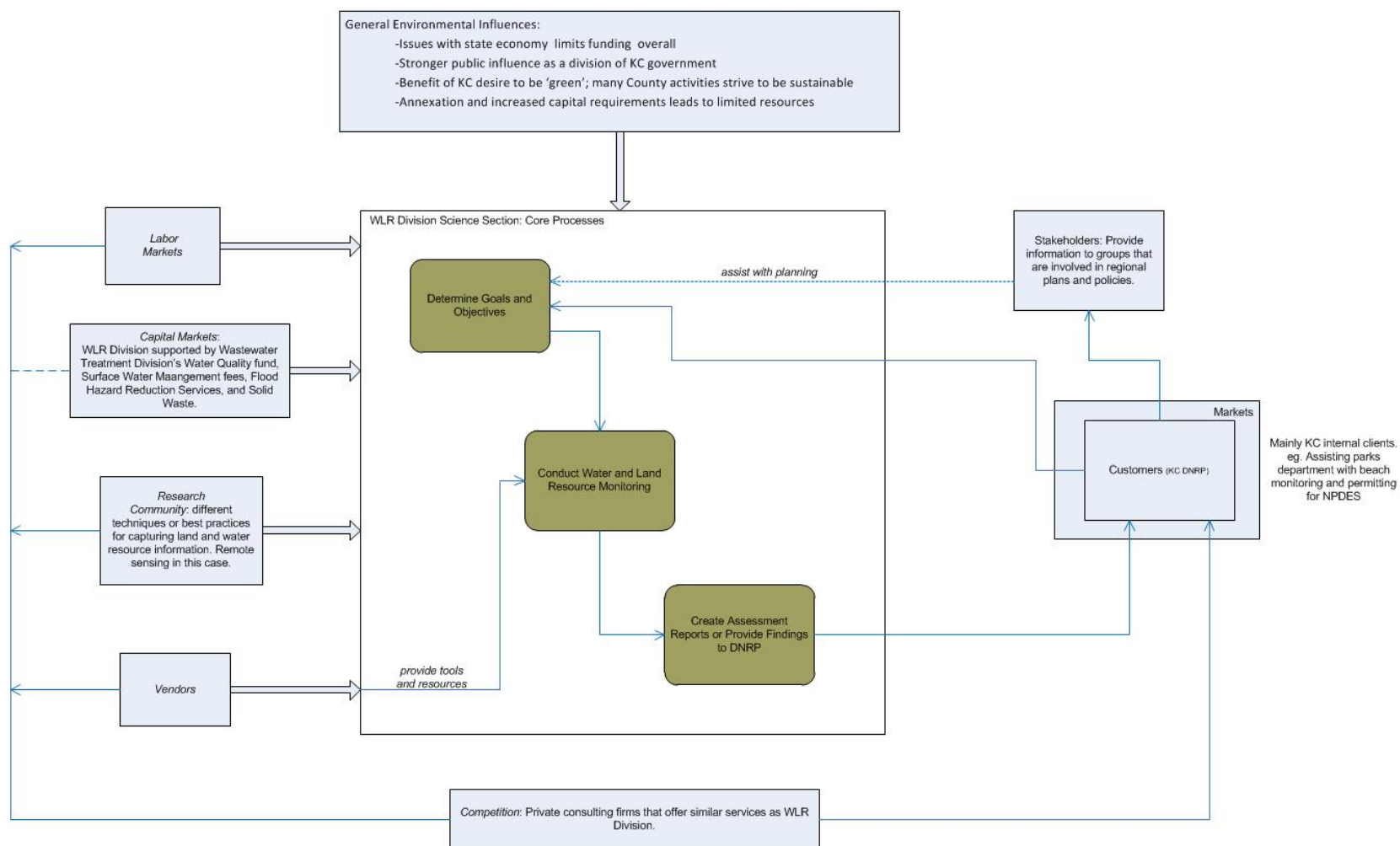


Figure 2: King County Water and Land Resources Division: Science and Technical Support Section Organizational Diagram

PROJECT GOAL

A significant area of focus for the County and the STSS is the implementation of strategies and structures to improve water quality via storm and surface water management (SSWM) (Jim Simmonds and Curtis DeGasperi, meeting notes, 27 June 2012; KCDNRP, 2008). In particular, the STSS is interested in knowing the precise locations of different types of impervious surfaces, since the type and ownership of impervious areas affects the kinds of stormwater management features that can be used to manage the associated runoff, and informs which approaches are most appropriate for funding and implementation.

OBJECTIVES

The objective for this project is to develop a tool that operates in Esri's ArcGIS and which KC GIS staff can use to automate the process of generating high resolution, fine scale, GIS-compatible vector data layers of land cover type from existing raster information. In other words, the county "needs to know" the exact location and type of impervious surface in order to plan appropriate pre-treatment strategies for a specific site. The types of impervious surface areas to be mapped automatically include:

- Commercial Parking Lots
- Commercial Roofs
- Industrial Parking Lots
- Industrial Roofs
- Multifamily Parking
- Multifamily (Buildings)
- Single Family Buildings
- Roads

An area within WRIA 9 was identified as a "sample" area to test potential methodologies. This geographic area of interest is Township 22N Range 5W--the City of Covington (Figure 1)-- which includes a mixture of developed and undeveloped land cover types.

EXISTING PROCESS WORKFLOW

DNRP executives work together to create broad strategies that address environmental health conditions of King County (Figure 3, Box 5a). (King County, 2012b) These strategies are then interpreted by the WLRD and from these strategies performance measures are established which indicate environmental health. WLRD is tasked with overseeing the STSS groups. Decisions must be made on how to delegate tasks among the STSS groups, including the Hydrology section (Figure 3, Row 2). This group conducts hydrologic monitoring and analysis to create watershed and hydrology models for KC. Hydrologic Services works with the KC GIS Center to obtain data (Figure 3, Box 1b) to assist in hydrology modeling. This information is then assessed and is used to develop specific strategies for conducting SSWM and water quality improvement projects proposed by the larger STSS (Figure 3, Box 3c). To ensure that this management is successful the STSS secure funding for projects. With the assessments made by the Hydrologic Services group and the effectiveness of SSWM improvement projects the WLRD will update their performance measures. This allows the DNRP to reevaluate their overarching strategies and goals based on these indicators. If water quality conditions in King County have not improved or are worsening then they can formulate necessary interventions (Figure 3, Box 5b).

EXISTING ACTIVITY WORKFLOW

While current regulations require that the creation of new impervious surface areas include adequate storm and surface water management treatment methods, existing or older impervious surface areas often do not have adequate existing stormwater infrastructure. Stormwater maintenance and improvements are currently funded via the stormwater management fee paid by KC property owners.

This generates \$1-2 million annually (Figure 4 Box 3b) , which is enough revenue to cover emergency repairs to infrastructure within the stormwater management "train", and to address violations that contribute to water quality degradation, such as erosion, but is not sufficient to cover the cost of routine maintenance or upgrades (Figure 4, Box 3c). While KC has investigated the possibility of increasing the fees and expanding the capital improvement program, the ten-fold or more increase that is necessary to fully fund needed improvements and maintenance is politically untenable, and the County remains limited to managing only emergencies and violations. The Science section group supervisor leads this process, with input from the lead hydrologist and data and processing support from KC GIS center (Figure 4, Boxes 1a -d, 2a-c)

PROPOSED ACTIVITY WORKFLOW

As part of the effort to further refine King County's SSWM efforts into a highly localized treatment system, members of the KCDNRP WLRD received EPA funding to develop models that will prioritize areas in WRIA 9 where stormwater infrastructure installation will provide maximum benefit to water quality (Figure 5). The modeling effort is a two-stage process, executed by the hydrologists at KC DNRP WLRD. The first phase (Figure 5, Box 2b) uses the Hydrologic Simulation Program-Fortran (HSP-F) to develop time series data of flow and water quality at catchment pour-points for subbasins within the watershed. Data input into this model includes land cover, Digital Elevation Model (DEM) information, weather, geologic information, soils, hydrologic features including stream channel morphology, incision, and depth, and the locations and types of existing stormwater facilities (Figure 5, Box 1b). Desired additional information to input into this model includes highly detailed information about the types and locations of impervious surface within the model area (Figure 5, Box 1d).

The output from the HSPF model is then input into the EPA's SUSTAIN model (System for Urban Stormwater Treatment and Analysis Integration) (Figure 5 Box 2c). SUSTAIN is a powerful, flexible, and complex modeling software with the capability of outputting very specific information about the size, types, numbers, and locations of Best Management Practices (BMPs) and Low Impact Development (LID) strategies that will provide the maximum benefit to watershed water quality for the cost (Figure 5, Box 2a) . Once this information is available, implementation and retrofitting of the new stormwater treatment infrastructure can be accomplished via several approaches (Figure 5 Box 3g). When existing sites are redeveloped, permitting under the National Pollutant Discharge Elimination System (NPDES) requires implementation of appropriate metrics and measures to eliminate discharge. For existing properties, the ability to customize existing stormwater fees based on the site contribution may serve as incentive for property owners to retrofit. Finally, government programs exist that can fund stormwater management improvements on public lands; in addition to minimizing impacts arising from these lands, stormwater treatments on these lands may be planned and designed in such a way as to treat or mitigate from adjacent private lands (personal communications, Jim Simmonds and Victor High, meeting 11 July 2012).

However, to effectively implement this strategy, the SSTS needs to know the locations of impervious surface at as fine a scale as possible, and to be able to distinguish the type and ownership of impervious, as different types require different treatment strategies, and the ownership type affects which implementation strategies are appropriate. Typically this has been accomplished via manually digitizing vector data layers from satellite imagery (Sterr and Yui Lau, 2012). However, this process was found to be extremely labor intensive and expensive given the geographic scope of the study area, often too coarse in scale, and not necessarily comparable through time (Simmonds, 2012; Harmon, 2007). (Figure 5, boxes 6a-e, Boxes 3b-c)

INFORMATION PRODUCTS

The information products include fine scale vector data layers that represent the location of specific types of impervious surface, within a 6' horizontal accuracy. Specifically, the data products include vector layers of roof tops and pavement, organized according whether the associated land use is single family homes, multiple-family dwellings, commercial, or industrial. The products also include a "blueprint" for the method for generating the data, so that KC can refine and additionally develop outputs as needed, including potential future development of a tool to map vegetative cover type. The method for creating the vector data layers will also be captured as a tool coded in Python and executable within ArcGIS vers. 10.1.

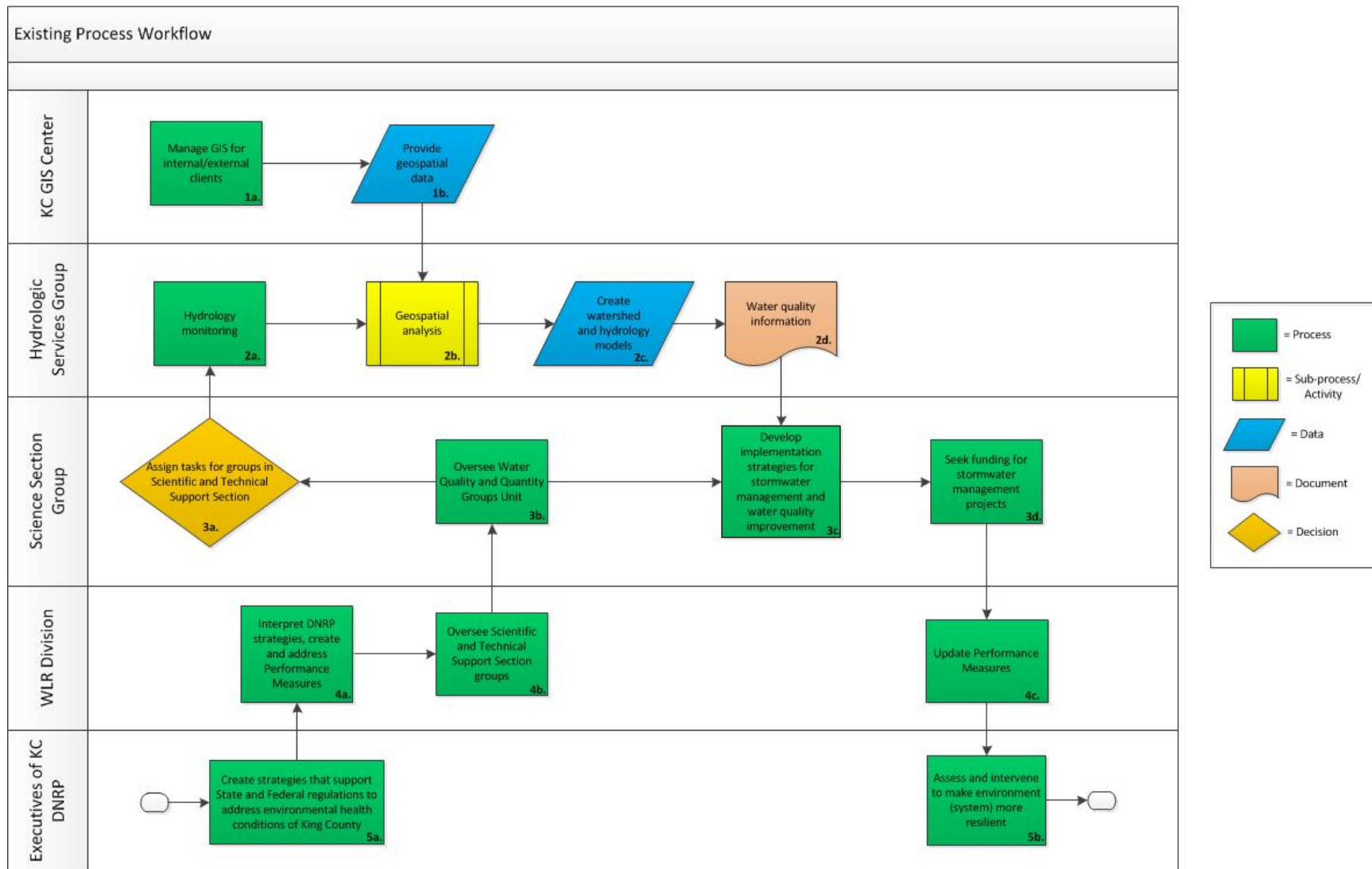


Figure 3: Existing Process Workflow

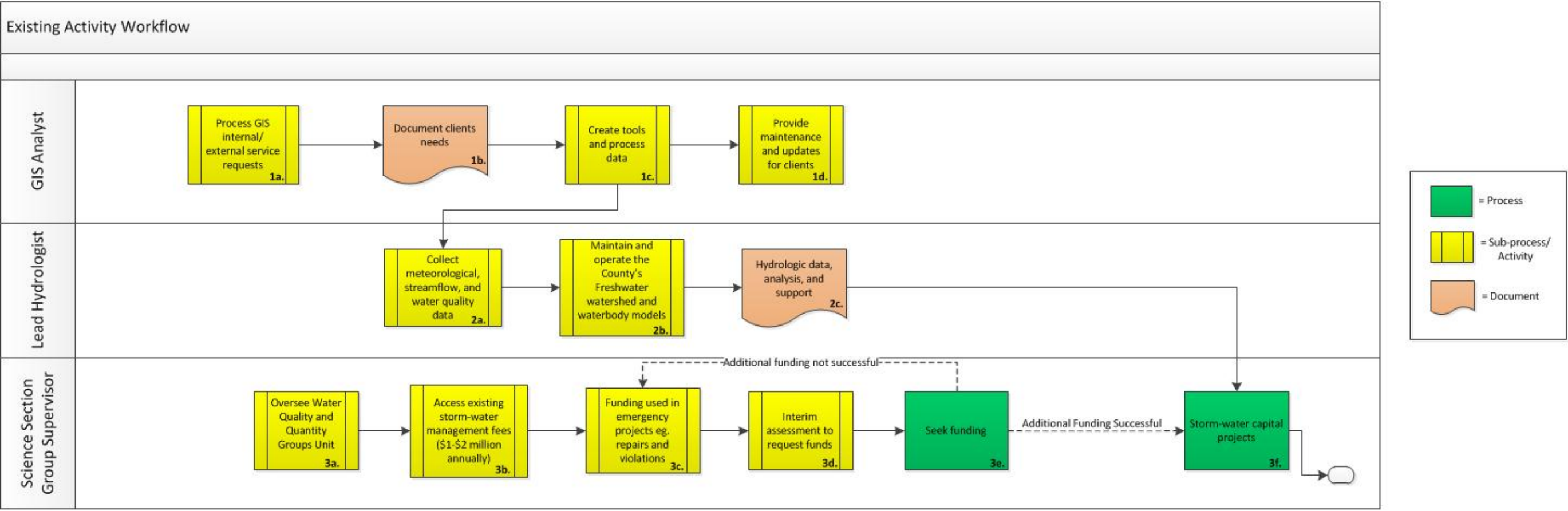


Figure 4: Existing Activity Workflow

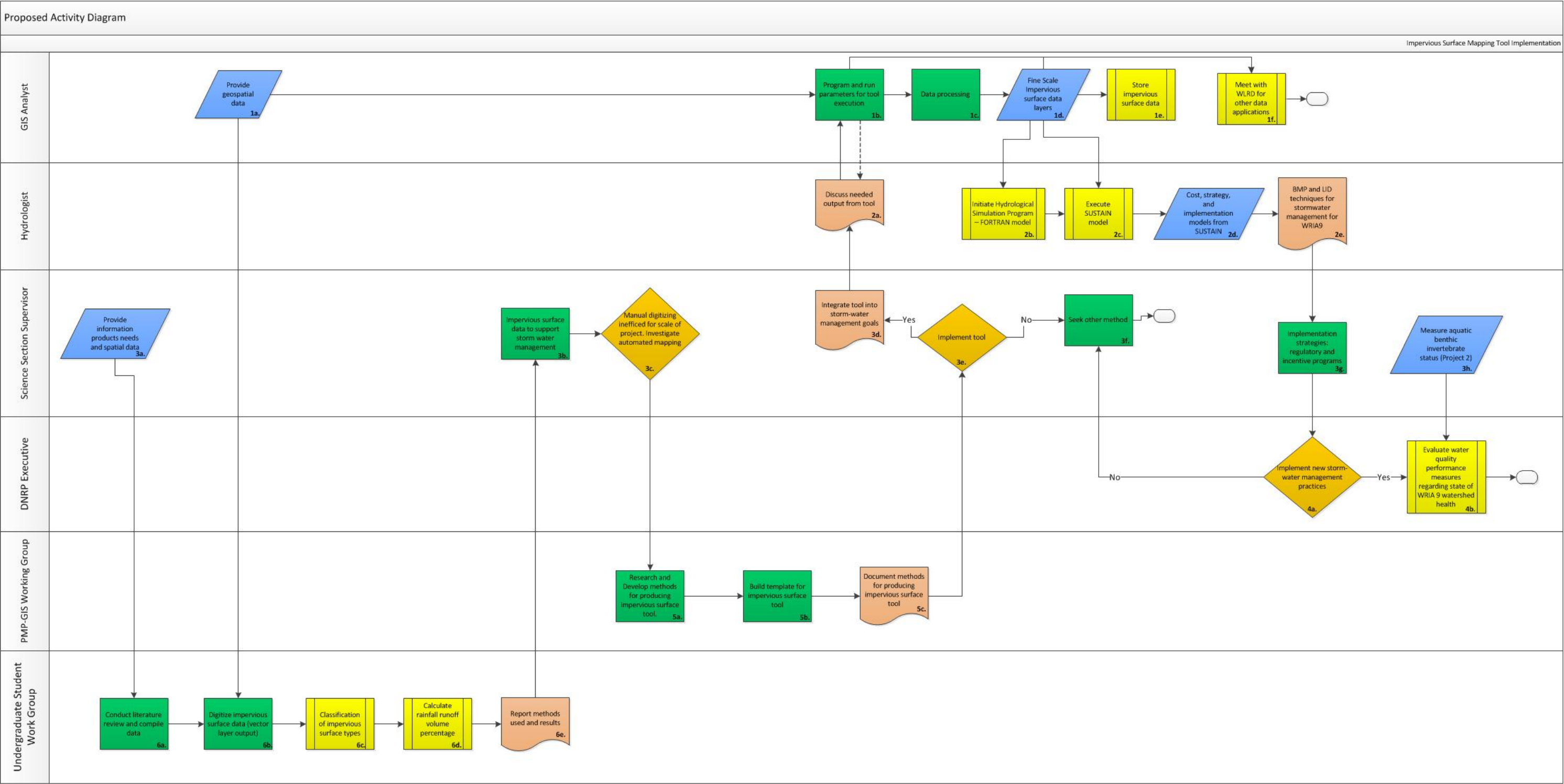


Figure 5: Proposed Activity Workflow

PROJECT BENEFITS

When developed to completion, the project will benefit water quality within WRIA 9 and Puget Sound by allowing a very focused, directed application of stormwater management strategies within the watershed. Because generating the data by hand is extremely labor intensive and thus very costly, having a tool that automates the process will present a cost savings to the SSTS and KC (see Section V) and also will make it possible to generate impervious cover data far more frequently, as well as with greater accuracy.

While the immediate benefit of the impervious surface tool is the stormwater treatment analysis that will be output from the SUSTAIN model, this fine scale mapping of impervious has various other applications that will benefit water quality within the implementation area.

In addition to the funding challenges that the county faces in stormwater management, there are practical challenges that arise naturally when working in an area with a varied and long history. One of these is the lack of adequate information about the location --or existence--of all connections between commercial, industrial, and multifamily units and the existing stormwater infrastructure. This makes planning and implementing maintenance of these connections impossible (Jim Simmonds, 26 July 2012). When overlaid with the stormwater infrastructure data in GIS, the fine scale impervious data output will facilitate the identification of locations where these connections are likely to occur.

Other challenges to water quality protection include the fact that, at the time when the City of Seattle's original stormwater conveyance system was constructed, it was standard practice to design stormwater systems such that any stormwater overflow resulting from heavy precipitation events was diverted to the sanitary sewer and ultimately to the waste water treatment plants (WWTPs). This can drive up treatment costs at the WWTP and has the potential to overwhelm the WWTP capacity, resulting in the

discharge of untreated water into receiving waterbodies. In some cases, cities with this design have been able to separate the storm water and wastewater infrastructure into two different pipe systems, however in Seattle this is both cost-prohibitive and impractical, as it would require digging up every street to make the necessary changes. Instead, King County and the City of Seattle are taking a two-pronged approach: 1. prevent stormwater from entering the system in the first place and 2. incurring significant costs to increase the capacity of the WWTP to reduce the potential for an overflow event. The SUSTAIN model process will allow SSTS to identify, with a much higher degree of accuracy, those areas within the watershed that contribute a disproportionately high level of runoff into the storm sewer system. Prioritizing these areas for stormwater rate and volume control will have significant benefit in reducing both operations costs at WWTP during runoff events and in reducing the risk of untreated discharge from the WWTP.

II. SYSTEM REQUIREMENTS

SOFTWARE AND NETWORKING REQUIREMENTS

The tool is designed to run on ArcGIS vers. 10.1, using either a standard laptop or desktop configuration. A summary of the specifications used during development, available at KCGIS, and the recommended configuration is provided in Table 1. Note that faster processing speeds and greater RAM will significantly improve data handling and processing performance during tool execution.

Table 1: System Configuration

	Tool Development	Current KCGIS	Recommended Hardware (Minimum Requirements from Esri)
Hardware	HP Pavilion dv6 Notebook PC	Unknown	2.2 GHz
Processor	Intel(R) Core(TM) i7-	Dual processors, Dell Intel	Intel Pentium 4, Intel

	3610QM CPU @ 2.30 GHz	Xeon E5640 @2.67 GHz and 2.66 GHz	Core Duo, or Xeon Processors; SSE2 (or greater)
System type	64 bit	64 bit	
RAM	16.0 GB	12 GB	2GB
Operating System	Microsoft Windows 7, Service Pack 1	Windows 7 Professional	Windows 7 Professional
Software	ArcGIS version 10.1	ArcGIS version 10.1	ArcGIS version 10.1

While the tool was developed using ArcGIS vers.10.1, it may not run on earlier versions of ArcGIS, since ArcToolbox varies among different versions of ArcGIS. However, the fundamental process outlined in the model remains accurate.

PERSONNEL AND TIME REQUIREMENTS

Running tools in ArcGIS with larger raster data inputs can be time consuming, but once the tool is operational, initiating execution will be straightforward. Processing the data and outputs for a 36 square mile area takes several minutes; the processing time will increase somewhat proportionally as the study area increases, and will be affected by variables including the complexity of land cover. In highly developed areas, the high levels of impervious cover will require more time to process. In rural areas, where there is less impervious, processing time may be shorter.

King County anticipates that this detailed land cover data would only need to be generated every few years (Simmonds, 2012); the data could be updated when new LiDAR or new Land cover/Land use (LC/LU) data becomes available, and when the county needs updated information about the detailed location of impervious cover types. The tool is designed so that it can be executed by one person and has the potential to be generated at a local desktop or workstation. However, the recommended "best practice" for management and use of the tool output data is that the tool and output be maintained by

KCGIS, and that KC STSS staff coordinate with the KCGIS for data use; this coordination will require minimal time.

OTHER CONSIDERATIONS

In the event of significant changes or upgrades to the ArcGIS software, it may be necessary to implement some changes in how the tool is programmed, although the workflow process executed by the tool will remain valid. Similarly, the impervious surface tool uses some functions and tools that are already pre-installed in the GIS "toolbox", and the impervious surface tool design assumes that those pre-installed tools are unaltered and are stored in the default location. If Esri changes where the pre-installed tools are stored in a future version of the software, the coding in the impervious surface tool will need to be updated so that the sub-processes are initiated from the correct location.

III. DATA ACQUISITION

DATA DESIGN

Several sources and types of data were used to generate the final vector layers of impervious surface types. These are summarized in Table 2. Essential data includes the "BHT" layer created by King County GIS. "BHT" is a DEM layer that represents the heights of buildings and pavement--in other words, impervious surfaces. ("VHT" is a corresponding DEM layer that represents the heights of vegetated surfaces.) These data layers were generated by KCGIS using the 2002 6 foot resolution LiDAR and 2009 Color InfraRed (CIR) aerial imagery, using the following process (Victor High, meeting, 11 July 2012) (see also Figure 6):

1. Create a DEM file of feature heights: obtained by subtracting ground elevation LiDAR from surface elevations, using 2002 6' resolution LiDAR.
2. Separate pervious and impervious cover types:

- (a) Create a "mask" of vegetated vs. non-vegetated cover, using spectral signatures in the 2009 Color InfraRed (CIR) aerial photos and calculations from the National Vegetation Index (NVI)
 - (b) Several cover types, including water, bare earth, and recent clearcuts, will read as "impervious" using this methodology. The King County water layer was used to subtract water features from the impervious layer that was output in step 2a. Then, the data was reviewed against the aerial photos and any remaining non-impervious areas were manually removed.
3. The resulting layer of impervious cover was used to clip the feature height LiDAR from step 1 into a "vegetation height" layer (VHT) and an "impervious height" layer (BHT).

Data Processing for BHT & VHT layers

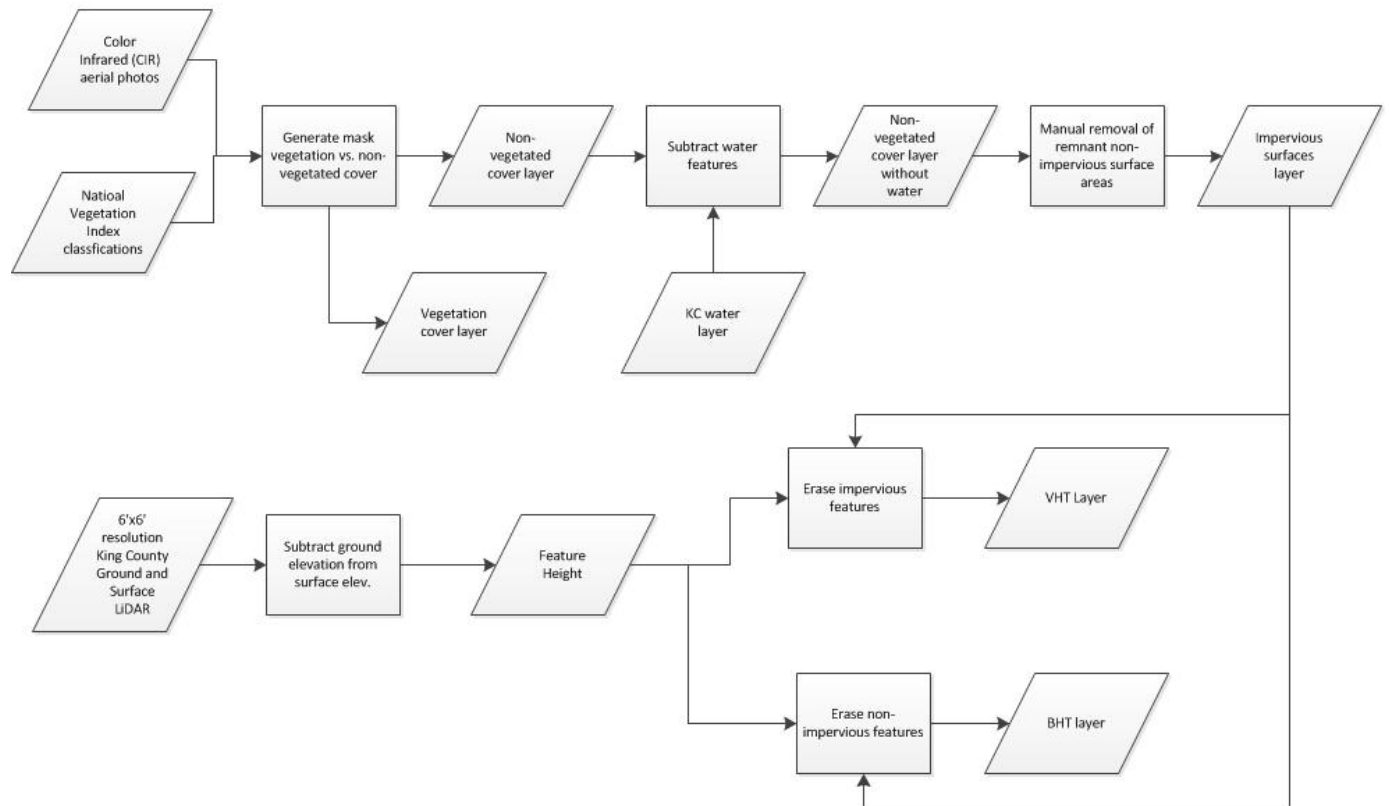


Figure 6: Process for Creating the BHT and VHT DEM files

Table 2: Input Data , Fitness for Use, Application, and Sources

Information Needed	Source ¹	Purpose/Use	Feature Class Name or Attribute Selected	Type
Building heights	KCGIS	Shows height of most impervious surface data	t22r05_bht006 ("BHT")	Raster
Vegetation heights	KCGIS	Shows height of most vegetation data	t22r05_vht006 ("VHT")	Raster
Orthophoto	KCGIS	Used as reference to determine whether the proper values are selected for each Land Cover type.	t22r05_10n050.sid	Raster
Parcel	KCGIS	Used to distinguish the roads from drive ways	parcel	Shape file
Landuse	WSGP	To help determine commercial buildings and parking lots from building height raster	Commercial	Shape file
Landuse	WSGP	To help determine industrial buildings and parking lots from building height raster	Industrial	Shape file
Landuse	WSGP	To help determine multifamily buildings, parking lots, and drive ways	MultiFamily	Shape file
Landuse	WSGP	To help determine single family buildings and driveways	SingleFamily	Shape file

¹ KCGIS: King County Geographic Information Center
WSGP: Washington State Geospatial Portal

DATA CHARACTERISTICS

Relevant data characteristics include resolution, projection, and temporal.

Resolution is important, because the finer the resolution, the more accurately the final output data can be used to model optimal location for siting stormwater treatment features. Data resolution is determined by the resolution at which the LiDAR data was processed when creating the BHT and VHT layer, which in this case was 6 feet. King County has expressed an interest in repeating the processing at

a resolution of 3 feet at a future date. (Jim Simmonds and Victor High, personal communication, 11 July 2012).

Projection: to maintain compatibility with KCGIS data standards, data were generated in the projection used by King County GIS: NAD_1983_StatePlane_Washington_North_FIPS_4601_Feet.

Temporal: currently, the base data (BHT and VHT data layers) reflect a "hybrid" point in time, because the base data used to derive these files is from different time points. The LiDAR is from 2003, whereas the Color Infrared used to separate the vegetation and impervious surfaces dates from 2009. It may be possible to generate the fine-scale impervious and fine-scale land cover mapping for a particular time point if appropriate base data becomes available.

DATABASES

The tool will operate in ArcGIS 10, running on Windows 7 Operating System, and a current version of Microsoft Word will be used to document the metadata. The eventual data output includes raster data and vector data (layer files). Metadata will follow KC GIS Center Metadata standards (FGDC-1998 standards), and will be generated by KC GIS after executing the tool and creating county-wide coverage of the data. Tool output will also conform to KC GIS center data standards.

LOGICAL DATABASE MODEL

The database model for this project is object-relational, which allows for integration with Esri's ArcGIS Object Model. This also allows for the use of relational table primary keys to provide for data interaction, coded domains for generating data attributes, and database integrity rules. This model is consistent with existing KC GIS protocol and standards.

The proposed database structure is illustrated in Figure 7. The elements of the database are not very interconnected because this database is used solely to present basic data output from the Impervious Surface Mapping tool. As a result of data table attributes not being a major component of the project's data needs there are not many parts that describe the behavior of the data. As illustrated, the database contains one dataset to hold impervious shapefiles and also includes individual datasets for the raster data. The database stores metadata and data layer information as well.

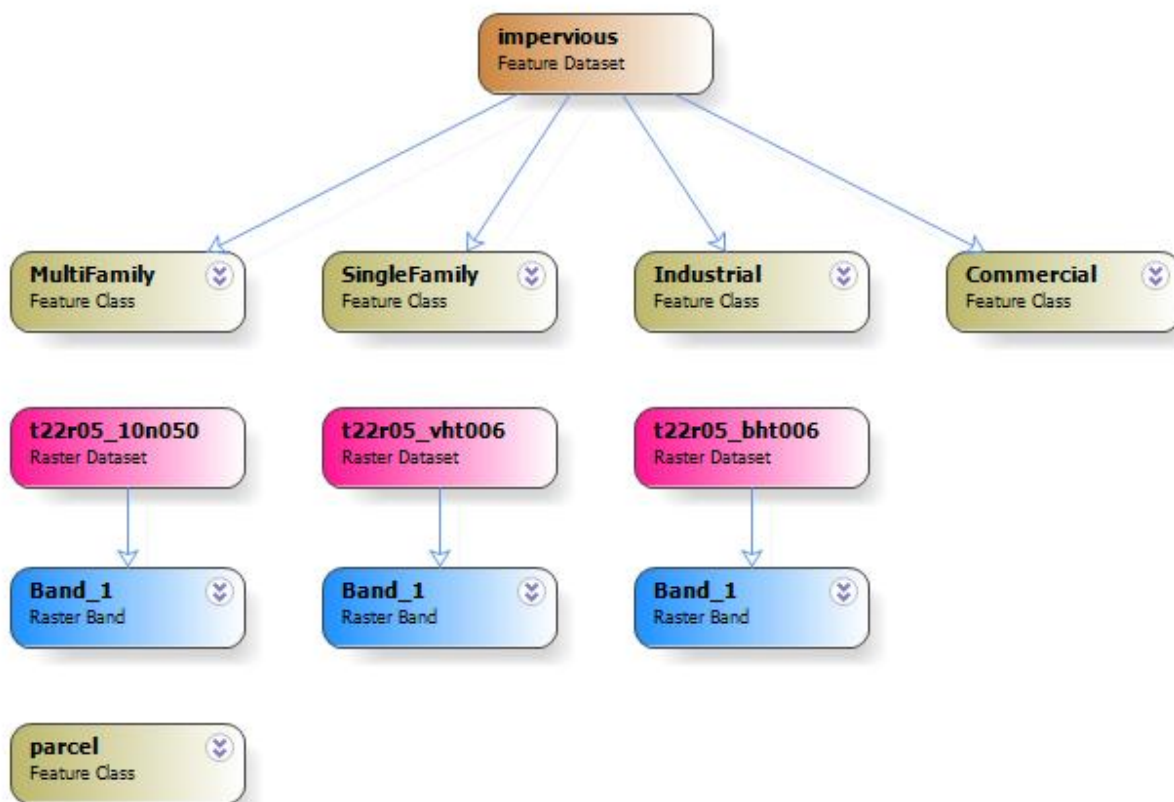


Figure 7: Proposed Database Structure

FUTURE DATABASE DEVELOPMENT

In terms of the larger project --developing the stormwater infrastructure placements--additional refinement of the existing data will be required. KC GIS will need to revisit some of the data processing

steps that were conducted outside of this immediate project to develop a more refined--and more current- layer for BHT and VHT to capture more current conditions, and at a finer resolution.

As the larger stormwater project evolves and takes form, it may make sense for the project geodatabase to hold additional information and attributes, according to the input needed for the stormwater model. This will be evaluated as the project progresses.

IV: DATA ANALYSIS, INFORMATION PRODUCTS, AND FINDINGS

INPUT DATA

There are several feature layers that were input into the data processing. The first one is the "man-made feature height", or BHT data developed by King County GIS. This is a continuous raster data set which stores a single value representing a general height of impervious features relative to ground elevation. The King County parcel data and subsets of the King County land cover data were also input (Table 2).

DATA ANALYSIS

The data analysis process involves using various layers to mask and extract different subsets of information from the BHT file. The premise behind the analysis is to first separate building from roads using the parcel data. The parcel data was used as the first mask, as it allowed the separation of roads, which are not captured in the parcel layer, and driveways and parking lots, which are included in the parcel layer. Next, the resulting output data was masked using specific subsets of the land cover data. Finally, buildings and pavement output were distinguished based on feature height. The result is a raster layer representing specific types of impervious cover. The last step is conversion of the raster output into a vector data layer.

Early during the planning process, the STSS identified a number of types of impervious surface to isolate via this tool. As part of the tool design process, these impervious surface categories were matched with corresponding LU/LC categories as defined in the LU/LC data layer provided by KC (Table 3). The result of this process has allowed the automated creation of raster and vector data for:

- Commercial Parking Lots
- Commercial Roofs
- Industrial Parking Lots
- Industrial Roofs
- Multifamily Parking
- Multifamily Roofs
- Single Family Paved areas
- Single Family Roofs
- Roads

The full workflow for each of these processes is depicted in Appendix A. Once each vector layer has been created, we recommend combining the separate layers into a single GIS file, and separating the cover types within the attribute table. Since the final GIS layer will likely be posted on the KC GIS data center, combining the layers into one file will help ensure that end-users have the full data set, rather than partial data, and reduces the potential for errors of omission by subsequent users (Jim Simmonds, meeting, 26 July 2012).

Table 3: KC DNRP WLRD Impervious Categories and Corresponding Land Use/Land Cover Attribute Values

KC Impervious Surface Category	Corresponding Land Use/Land Cover Value
Single family residential roof	Household, single family units Mobile home parks or courts
Single family residential driveways	Household, single family units Mobile home parks or courts
Multifamily parking lots	Household, 2-4 units -Household, multi-units (5 or more) Residential condominiums Automobile parking
Multifamily roofs	-Household, 2-4 units -Household, multi-units (5 or more) Residential condominiums
Industrial roofs	Food and kindred products Utilities Miscellaneous manufacturing
Industrial parking lots	Automobile parking Food and kindred products Utilities Miscellaneous manufacturing
Commercial roofs	Business services Cultural activities Cultural activities and nature exhibitions Finance, insurance, and real estate services Governmental services Hotels/motels Institutional lodging Miscellaneous services Other cultural, entertainment, recreational, church, cemetery Other retail trade Personal services Public assembly Retail trade - automotive, marine craft, aircraft, and accessories Retail trade - eating and drinking Retail trade - food Retail trade - general merchandise Wholesale trade
Commercial parking lots	Automobile parking

	Business services Cultural activities Cultural activities and nature exhibitions Finance, insurance, and real estate services Governmental services Hotels/motels Institutional lodging Miscellaneous services Other cultural, entertainment, recreational, church, cemetery Other retail trade Personal services Public assembly Retail trade - automotive, marine craft, aircraft, and accessories Retail trade - eating and drinking Retail trade - food Retail trade - general merchandise Wholesale trade
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INFORMATION PRODUCTS

There are two significant products of this project. The first is a "blueprint" for a methodology to for automating the creation of vector impervious cover type data from existing, LiDAR derived rasters. The second product is the data output itself. Samples of the data output for the City of Covington--the study area-- are available in Appendix C.

V. FINANCIAL & STRATEGIC ANALYSIS

FINANCIAL ANALYSIS

An important consideration when evaluating whether to implement a new technology or technique is cost: will the new approach provide a cost savings over the existing or conventional strategies? How does the cost savings compare to the cost of implementation? To address these questions, a detailed, step-by-step financial analysis was conducted (Lerner, 2007). The full analysis is presented in Appendix D, and summarized here.

As outlined in the proposed activity workflow diagram (Figure 5) there are only a few positions involved with implementing the impervious surface mapping tool: a GIS analyst, a hydrologist, and STSS supervisor. The GIS analyst will work to integrate the tool within the King County GIS Center, and will coordinate with the hydrologist on analysis extent and the formatting of input data prior to tool execution. The GIS analyst will also execute the tool and assume responsibility for processing the output data and maintaining the final dataset within the KCGIS data library. The hydrologist will work closely with the GIS analyst and provide specifications for the tool output. The STSS supervisor will work closely with the hydrologist and provide overall guidance and direction.

Since the WLRD has already decided to conduct new stormwater modeling using HSP-F and SUSTAIN to determine the optimal location and types of stormwater treatment methods, the financial analysis focuses on the two options considered as methods for generating the impervious surface data: hand digitizing and automated digitizing (Figure 5, boxes 6a-e, and boxes 3c, 5a-c). At current labor costs and using entry level staff, the STSS supervisor estimates that it would take 6-8 months to manually digitize, field verify, and complete a data quality check on impervious data for the approximately 570 square miles in WRIA 9. This would likely be done by entry-level analysts and technicians, with an estimated cost of \$40,000-\$60,000 for salary, benefits, and overhead, or \$70 - \$105/square mile. Once the data is finalized, the STSS supervisor estimates that it would take another 240 hours for a senior hydrologist to develop and automate a method to process the data into the format necessary for input into the hydrologic models. The estimated total cost for the senior hydrologist's effort is an additional \$15,000. This represents a total cost of \$55,000 - \$75,000 to generate the impervious data for WRIA 9, or \$97 to \$131 per square mile. While there will be some additional savings when the method is implemented in other WRIAs because some of the processes will be automated, the per mile cost will remain high. In addition, the same costs will be incurred each time the data needs to be updated. Finally, funding availability has the potential to limit the frequency with which the data is updated and the extent of

quality review, and may place the county in a position of using dated information in future analysis. (Jim Simmonds, email communication, 6 August 2012).

Automating the process of impervious surface mapping significantly reduces the cost per square mile. We estimate that it will require a GIS analyst a maximum of 40 hours to set up and integrate the impervious surface tool within the existing KC GIS system and prepare the input data for processing. In preliminary tests, the tool was able to generate the necessary vector data at a rate of 36 square miles in 3 minutes, which predicts less than an hour of effort for WRIA 9. Additional post processing will be required to combine the multiple outputs into a single layer file. In all, we estimate that generating a single vector data layer representing the impervious cover types for WRIA 9 will take less than 50 hours, and should require minimal additional time from the senior hydrologist prior to input into the hydrologic models. This reflects a total estimated cost of \$3,000, or approximately \$5 per square mile. As well, if the original tool design and the input data are accurate, the resultant output data is less susceptible to mapping error when compared to manual mapping, and costs are low enough that repeating the mapping when new input data become available is a much more affordable process.

STRATEGIC ANALYSIS

The costs included in this analysis represent tool implementation costs including labor, tool updates, and maintenance, but does not consider other costs needed for developing specialized impervious surface layers for other groups or departments within KC. One of the indirect benefits gained by KC as a result of the impervious surface tool is the ability for KC GIS to offer additional support to these other groups, and for the LWRD Water Quality /Water Quantity Groups Unit to additionally refine and prioritize expenditures to maximize benefit to the existing system, by focusing water quality management strategies in areas where connections to the existing stormwater system may be damaged or absent.

One of the most significant ancillary cost savings and environmental benefit may result from the prioritization of stormwater management projects that reduce or eliminate the potential for high volume storm events to overflow the storm water system and impact the wastewater system, including WWTPS (see Project Benefits section).

Increased support for related projects is thus an ancillary benefit of this impervious surface mapping tool. WLRD performance measures are influenced by many separate groups, but many of these groups will be able to work together on the water management projects that require information on impervious surfaces of King County. Finally, KC may also want to consider how the new impervious surface information created by this tool can benefit outside agencies and organizations in the Puget Sound region.

RECOMMENDED COURSE OF ACTION

The proposed course of action is to implement the impervious surface mapping tool within the KCs enterprise GIS using the methods outlined here. This will result in substantial benefit to KC, both in terms of cost savings and in terms of a significant increase in data accuracy, and a concomitant increase in modeling and planning accuracy.

VI. FUTURE DIRECTIONS

The effort thus far has focused on isolating different types of impervious cover. There are a variety of potential directions both for next steps, and for future efforts.

1. Implement the tool and generate the detailed impervious surface data for WRIA 9 and potentially for Bear Creek. While WRIA 9 is the current focus for KC SSWM and modeling efforts, studies in the Bear Creek watershed will begin in 2013. Eventually the goal is to generate this information for all of KC, so that it can be used more widely for a variety of stormwater

management studies and implementation projects, ranging from improving maintenance and repair of the existing system or preventing high volume runoff from impacting Seattle's WWTPs (see Project Benefits section), as well as potential uses as yet undefined. While the tool outputs individual vector data files, we recommend that KCGIS merge all of the output files into a single file, and distinguish the impervious cover type via attributes. Since the final GIS layer will likely be posted on the KCGIS data center, combining the layers into one file will help ensure that end-users have the full data set, rather than partial data, and reduces the potential for errors of omission by subsequent users (Jim Simmonds, meeting, 26 July 2012).

2. To generate a finer detail for impervious surface mapping, resample the LiDAR data that was used to create the BHT DEM files at a 3' resolution rather than 6', and re-run the tool.
3. Evaluate how a similar process could be used for mapping pervious/vegetated cover types. King County is interested in automatically generating detailed vector information about vegetation cover types, as well as impervious. The methods developed during this project may help to lay the groundwork for developing a similar tool for mapping types of vegetated cover.
4. For the most accurate and current impervious surface input into the hydrologic modeling sequence, re-create the BHT and VHT DEM files using current LiDAR and current CIR imagery.

The information created by this tool will be used by KC to support the STSS's hydrology modeling efforts. This, in turn, assists in implementing storm water management efforts that will minimize or eliminate negative water quality impacts to Puget Sound. The information generated by this tool will provide

significant support for the WLRD in their decision making efforts, for the benefit of the health of the Puget Sound aquatic ecosystem and tributary waterways.

The goal of WLRD STSS is to implement best practices for the sustainable management of the region's water resources. Using sustainability-focused science and sustainability -focused management practices is an effective strategy for moving the Puget Sound ecosystem towards a more healthy balance or trajectory. Given this, the data generated by the impervious surface tool, and more significantly, the extensive analysis and modeling conducted by the WLRD can be considered as an expression of "sustainability information science"--a detailed, data based analysis of an existing system, with the express intent of how to modify that system so that it functions within a state of resilience and equilibrium.

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APPENDICES

APPENDIX A: ENVIRONMENT SETTINGS

Setting the Environment in ArcMap

Before doing any processing, we need to set up the ArcMap environment. Establishing the environment parameters provides for consistency in coordinates, spatial extent, cell size, and file saving in the data processing output products, as illustrated in Figure A-1 and described below.

Workspace

The current workspace is where the outputs will be automatically saved. We set the current workspace to the geodatabase that was created specifically for this project.

The Scratch Workspace is where the intermediate rasters and shapefiles are stored. These are files that are not needed in the final product, but are intermediate steps in the processing analysis. The scratch workspace is within the geodatabase.

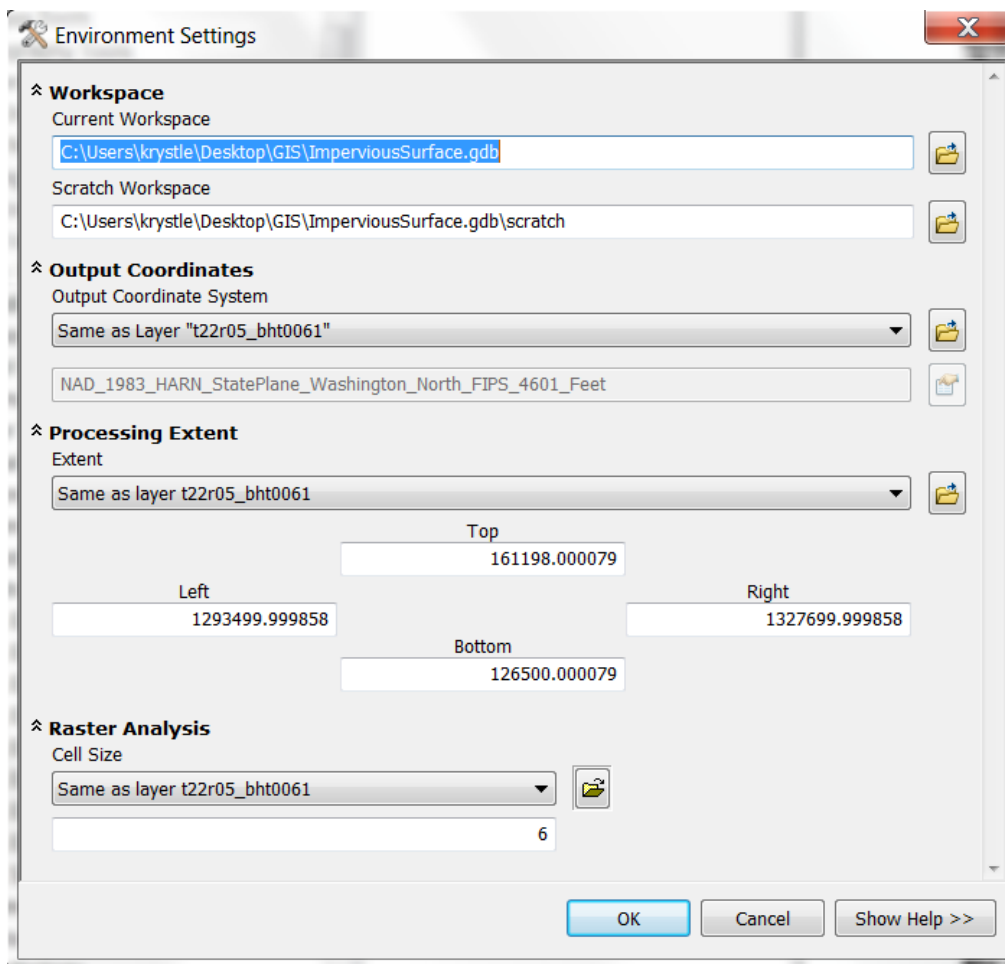


Figure A-1: ArcGIS Environment Settings Used

Output Coordinates

The Output Coordinate System is used to set the coordinate system of each output dataset. For this project, the output coordinate system was set to match the t22r05_bht006 raster, because this raster was the basis for most of the processing in this process.

Processing Extent

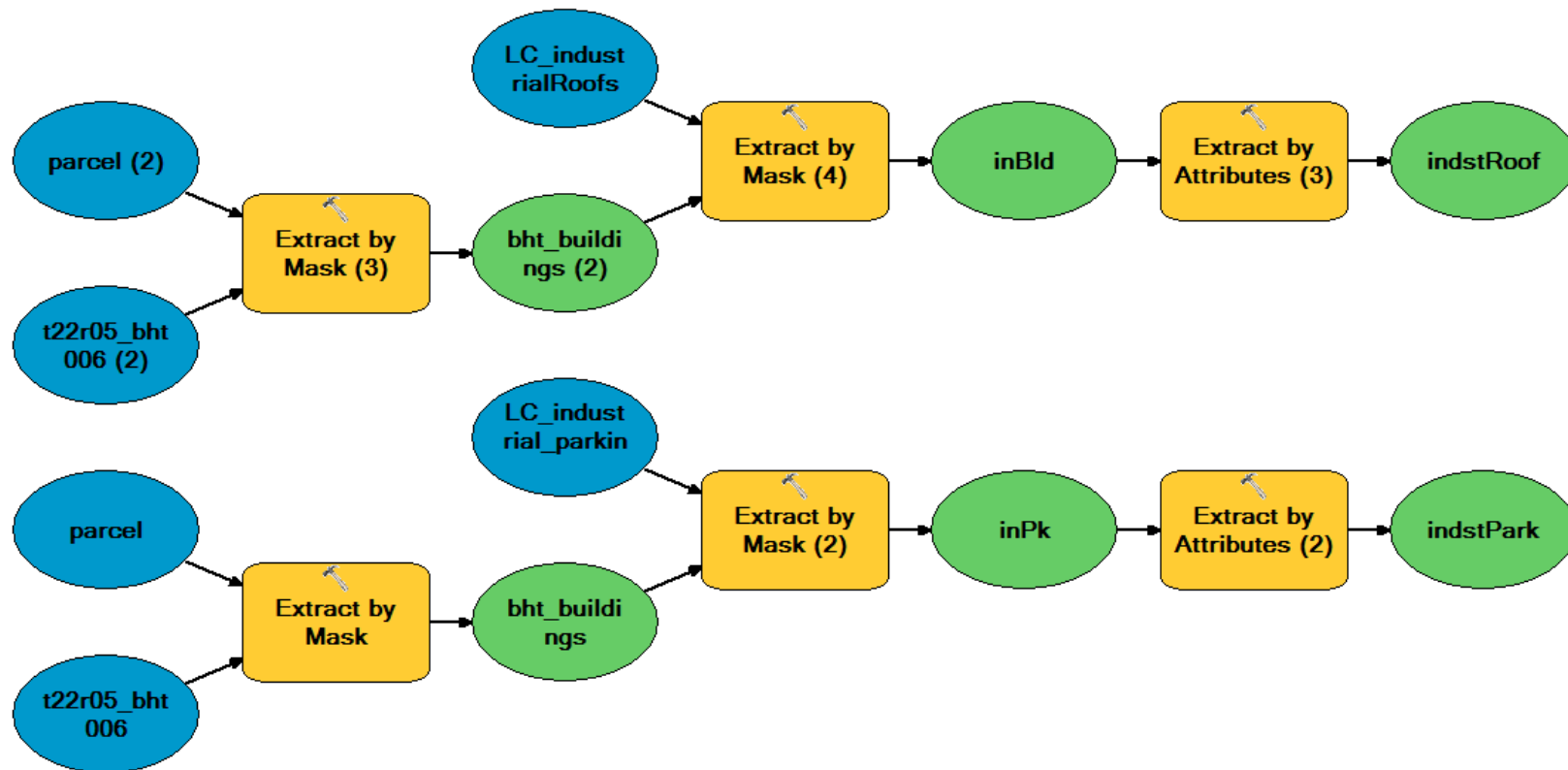
The Extent defines the geographic extent of the areas that will be processed during execution of the tool; areas outside of this extent are excluded from analysis. We set the extent to match the t22r05_bht006 raster because that defines our study area. This will need to be reset/redefined each time KCGIS chooses to run the tool for a new area.

Raster Analysis

The cell size is where we set the cell size of all of the rasters that are processed or produced. We set the cell size to the same as t22r05_bht006 because our final output is extracted from t22r05_bht006, therefore the resolution of that raster defines the finest resolution obtainable from any subsidiary raster datasets.

APPENDIX B: WORKFLOW FOR IMPERVIOUS SURFACE EXTRACTION PROCESSES

Industrial workflow



Industrial Roof

Goal: to create a new raster that only includes the buildings that are used for industrial purposes from the t22r05_bht 006 raster file. Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Use the extract by mask on bht_buildings to obtain a raster data output that represents industrial roofs.

Input: bht_building

Input Mask: LC_industrialRoofs

Output: inBld

Select the roofs of industrial buildings from inBld by using select by values tool.

Input: inBld

Where clause: "Values" > 14 (we select anything higher than 14' because the maximum height freights can be is 14')

Output: industRoof

Industrial Parking

Goal: to create a new raster that only includes the buildings from the t22r05_bht 006 raster file. Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Use the extract by mask tool on bht_buildings to a obtain a raster data output that represents the industrial parking area.

Input: bht_building

Input Mask: LC_industrial_Parking

Output: inPk

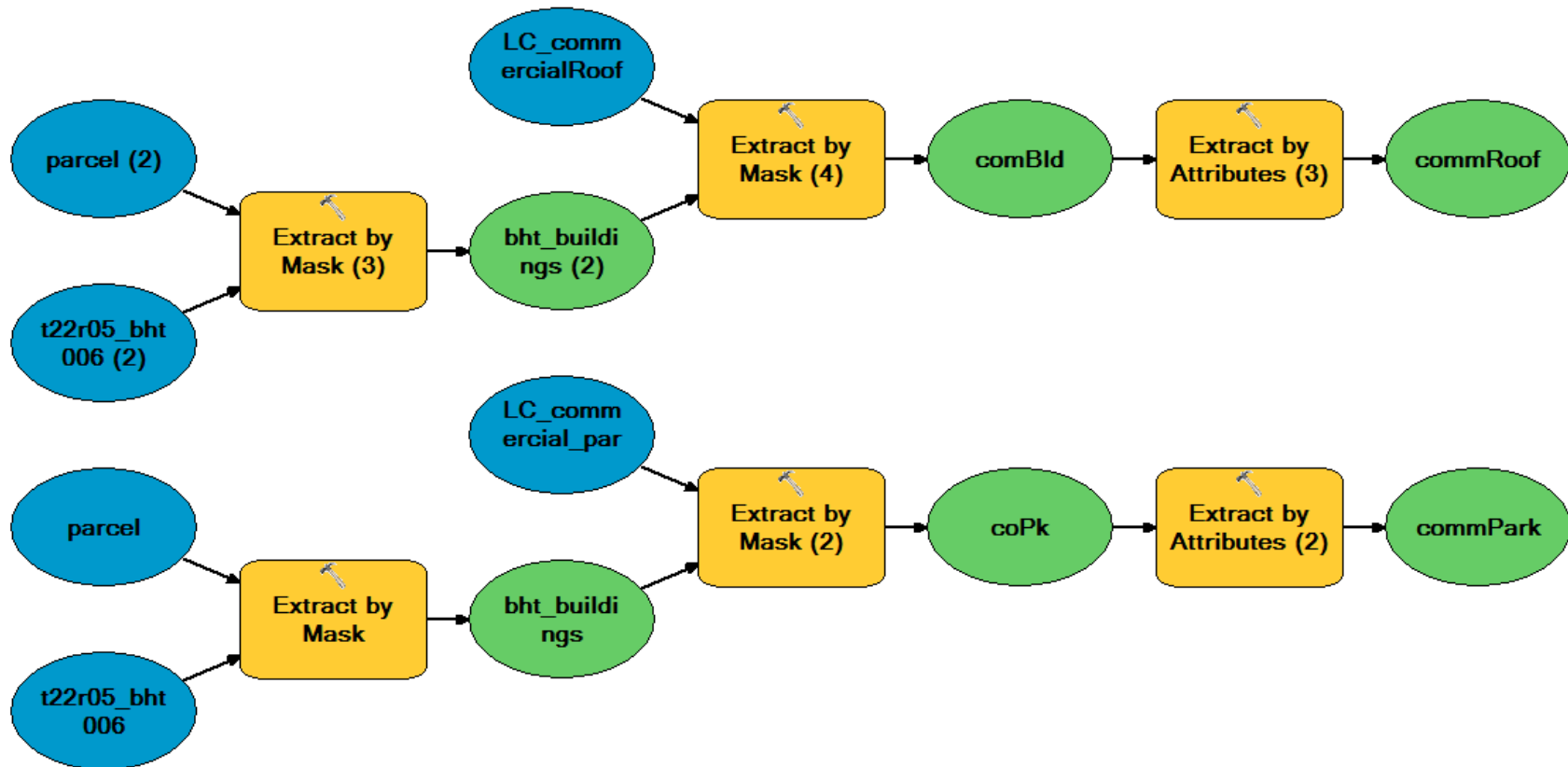
Select the parking areas of all the industrial buildings from inPk by using select by values tool.

Input: inPk

Where clause: "Values" <= 14 (we select anything lower to or equal to 14' because freight trucks and semi-trailers may have a maximum height of 14'. Similarly, roof elevations in industrial areas tend to be taller. By setting the elevation threshold at 14', areas where trucks are parked are mapped as pavement rather than as buildings/roofs.)

Output: industPark

Commercial Workflow



Commercial Roof

Goal: Create a new raster that only includes commercial buildings from the t22r05_bht 006 raster file.

Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Use the extract by mask tool on bht_buildings to obtain a raster data output that represents the commercial roof areas.

Input: bht_building

Input Mask: LC_CommercialRoofs

Output: comBld

Select the roofs for all the commercial buildings from comBld by using select by values.

Input: comBld

Where clause: "Values" > 10 (we select all cells where the elevation greater than 10', representing roofs)

Output: commRoof

Commercial Parking

Goal: Create a new raster that only includes the commercial buildings from the t22r05_bht 006 raster file.

Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Use the extract by mask tool on bht_buildings to obtain a raster data output that represents commercial parking area.

Input: bht_building

Input Mask: LC_commerical_Parking

Output: coPk

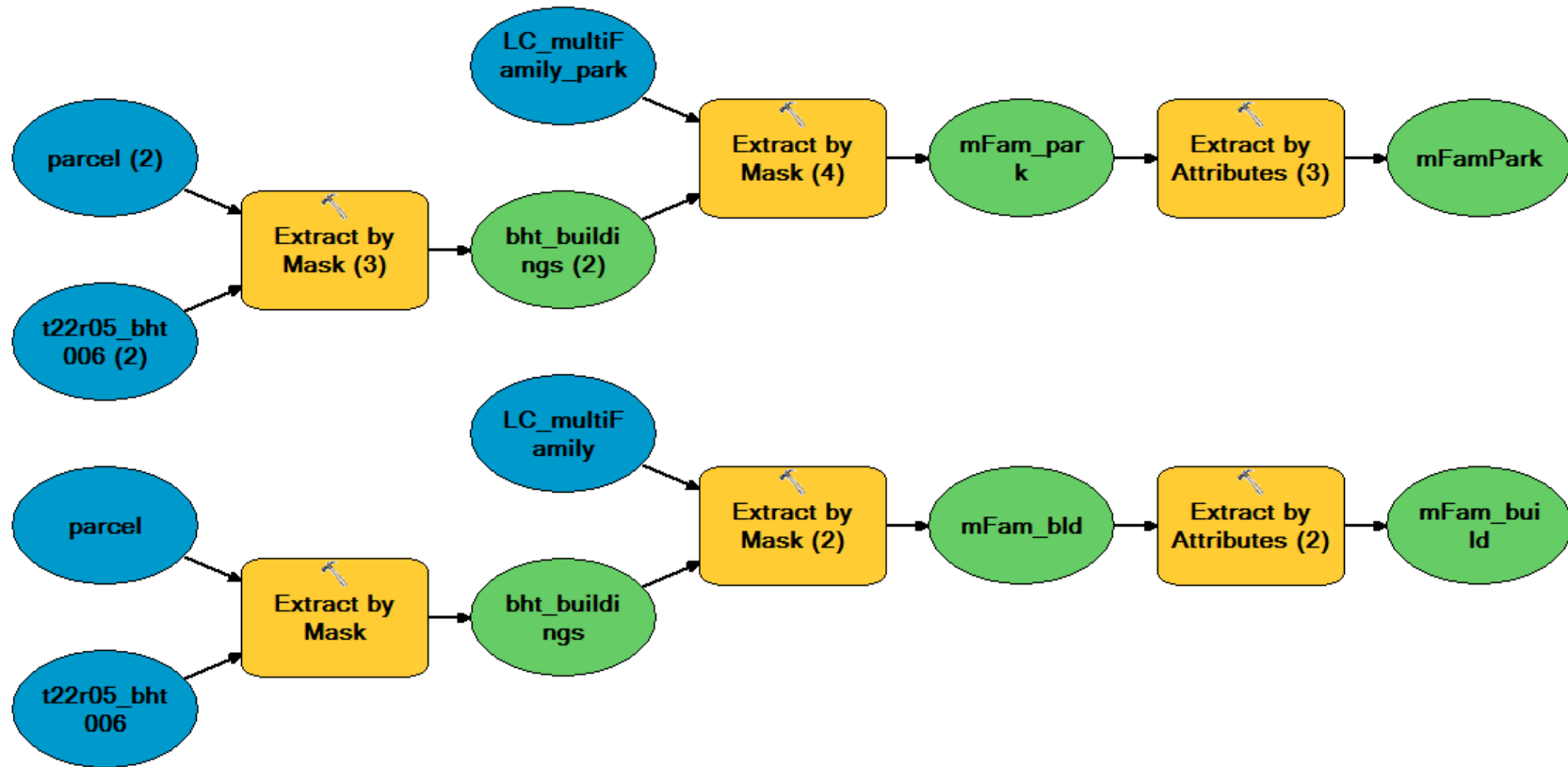
Select the parking areas of all the commercial areas from coPk by using select by values.

Input: coPk

Where clause: "Values" <= 10 (we select all cells where the elevation is less than 10', representing parking lots/pavement.)

Output: commPark

MultiFamily Workflow



MultiFamily Roof

Create a new raster that only includes the buildings from the t22r05_bht 006 raster file.
Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Extract by mask on bht_buildings to obtain a raster data output that represents MultiFamily roofs areas.

Input: bht_building

Input Mask: LC_multiFamily

Output: mFam_bld

We are then going to try and select the roofs of all the MultiFamily buildings from comBld by using select by values.

Input: mFam_bld

Where clause: "Values" > 6 (we we select all cells where the elevation is greater than or equal to 6', representing roofs; the 6' threshold captures low-hanging eaves.)

Output: mFam_build

MultiFamily Parking

Create a new raster that only includes the buildings from the t22r05_bht 006 raster file.

Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

Extract by mask on bht_buildings obtain a raster data output that represents multifamily parking area.

Input: bht_building

Input Mask: LC_multiFamily_park

Output: mFam_park

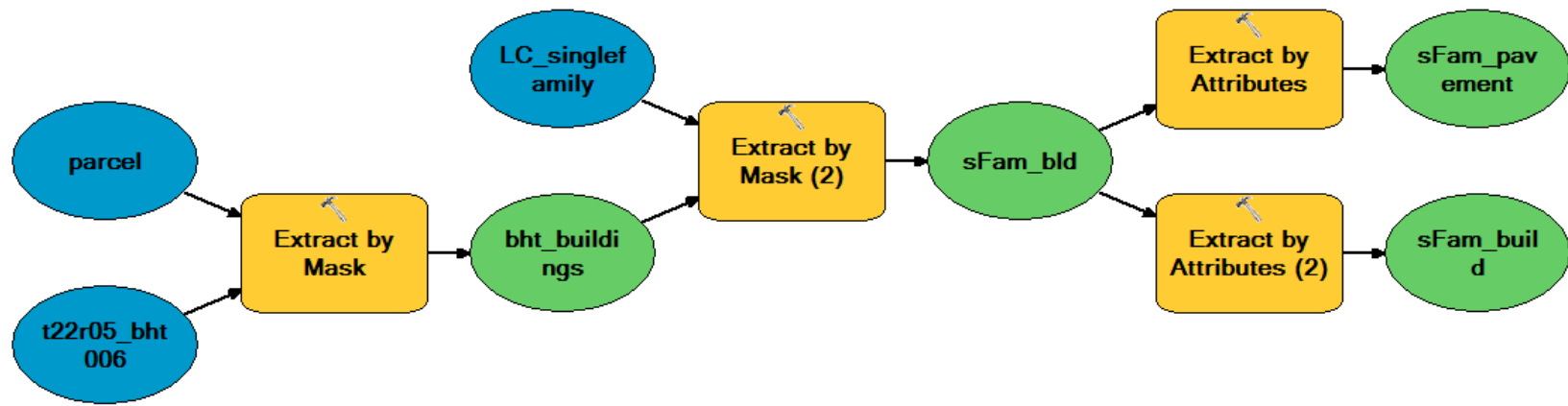
We then select the parking areas of all the multi family areas from mfPk by using select by values.

Input: mFam_park

Where clause: "Values" <= 6 (we select all cells where the elevation is less than or equal to 6'.)

Output: mFamPark

Single Family Workflow



Goal: Create a new raster that only includes the buildings from the t22r05_bht 006 raster file. Using the extract by mask tool the raster is clipped to parcel shapefile to exclude roads.

Input: t22r05_bht006

Input Mask: parcel.shp

Output: bht_buildings

We are going to extract by mask on bht_buildings to obtain a raster data output that represents MultiFamily roofs areas.

Input: bht_building

Input Mask: LC_multiFamily

single family area.

Input: bht_building

Input Mask: LC_singlefamily

Output: sFam_bld

We then select the pavement areas of all the single family areas by using select by values.

Input: sFam_bld

Where clause: "Values" <= 6 (we select anything where the elevation is less than or equal to 6' to represent pavement.)

Output: sFam_pavment

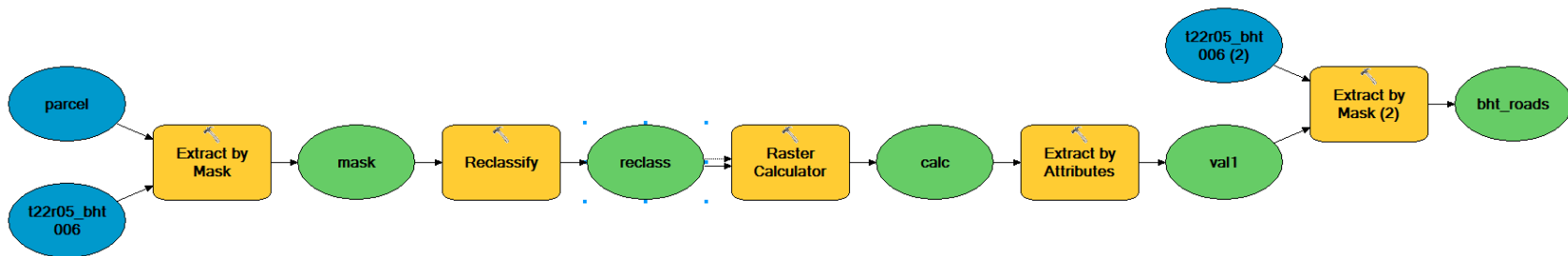
We then select the building areas of all the single family areas by using select by values.

Input: sFam_bld

Where clause: "Values" > 6 (we select all cells where the elevation is greater than or equal to 6', representing roofs; the 6' threshold captures low-hanging eaves.)

Output: sFam_build

Roads Workflow



Essentially we want obtain the areas of t22r05_bht006 that are not covered by the parcel shapefile, to get the roads.

We start by extracting all the parts of the t22r05_bht006 raster that are covered by the parcel polygon

Spatial Analyst Tools → Extraction → Extract by mask

Input: t22r05_bht006

Mask: parcel

Output: mask

After extracting all the parts from t22r05_bht006 that are covered by the parcel polygon, we want to give the entire raster one value. In this case we selected a value of "1".

Spatial Analyst Tools → Reclass → Reclassify

Input: Mask

Reclass Field: Value

Classify...

Method: Equal Interval

Classes: 1

Reclassification

New Values: 1

Output: Reclass

Once we set all the values to 1, we create another raster that will convert all the values of 1 to 0, and all the null values within the extent of t22r05_bht006 will turn into 1. We change the values in reclass (raster created from the last step) from 1 to 0 because we are not interested in the areas of the t22r05_bht006 that are covered by the parcel shapefile. We change all the null values in the extent of t22r05_bht006 because that represents the areas we are interested in-- in other words, those areas not covered by the parcel polygon).

Spatial Analyst Tools → Map Algebra → Raster Calculator

Expression: IsNull("reclass")

Output: Calc

We extract all the values of 1 to serve as a mask in the following step.

Spatial Analyst Tools → Extraction → Extract by Attributes

Input Raster: calc

Expression: "VALUE" = 1

Output: val1

Now we can extract the areas that are not covered by the parcel polygon by using val1 (raster created from the previous step) as the mask. The output of this process will create a new raster of all the roads within the study area.

Spatial Analyst Tools → Extraction → Extract by Mask

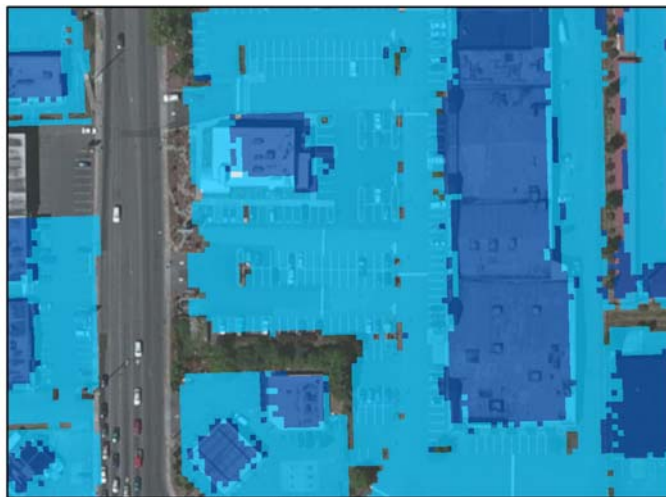
Input: t22r05_bht006

Mask: val1

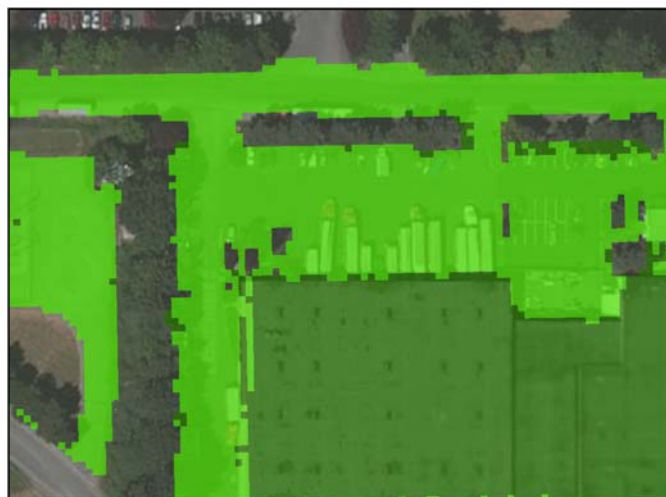
Output: bht_roads

APPENDIX C: MAPS OF IMPERVIOUS SURFACE DATA OUTPUT

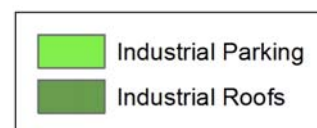
Impervious Surface Tool Output: Commercial and Industrial Land Cover Types



0 35 70 140 210 280
Feet



0 45 90 180 270 360
Feet

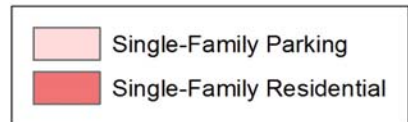


Data source: Bing Maps Aerial (c) 2010 Microsoft Corporation and its data suppliers

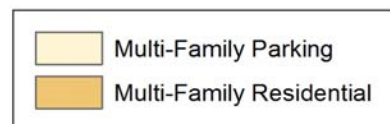
Impervious Surface Tool Output: Single-Family and Multi-Family Land Cover Types



0 45 90 180 270
Feet

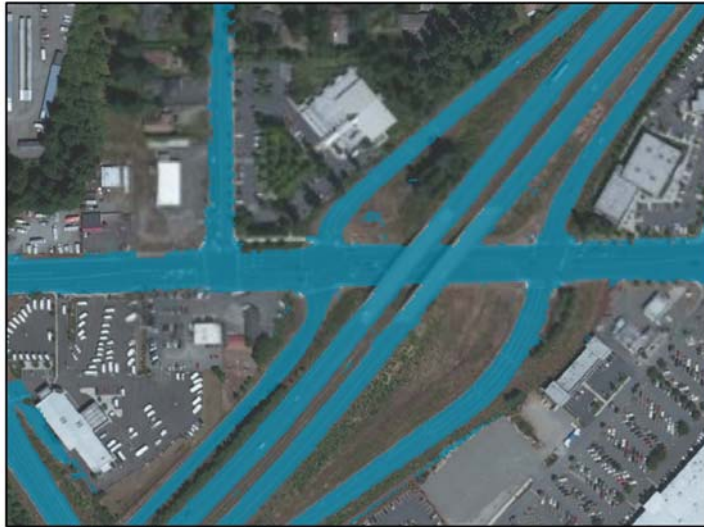


0 50 100 200 300
Feet



Data source: Bing Maps Aerial (c) 2010 Microsoft Corporation and its data suppliers

Impervious Surface Tool Output: Road Land Cover Type



0 145 290 580
Feet



Data source: Bing Maps Aerial (c) 2010 Microsoft Corporation and its data suppliers

APPENDIX D: DETAILED FINANCIAL AND RISK ANALYSIS

FINANCIAL ANALYSIS

The financial analysis was conducted using the Financial Detail worksheets provided in Lerner *et al*'s Building a Business Case for Geospatial Information Technology: A Practitioner's Guide to Financial and Strategic Analysis. These worksheets act as a template and include eleven variables of which many are automated based on functions included in each cell. All of these variables were factored into each year for the next 10 years of the project.

1. Inflation rate
2. Opportunity cost of capital
3. Job categories and descriptions
4. Average hourly rates for employees
5. Fringe rates
6. Avg. annual regular hours
7. Valuation method
8. FTEs dedicated to project in each project year
9. Contract and procurement costs
10. Productivity benefits per job category
11. Other benefits

The inflation rate used is 2.5% is the default provided in the worksheet and is comparable to Bureau of Labor Statistics 2012 rates (<http://www.bls.gov/data/>). The second variable is opportunity costs of capital at 5% which is a percentage that represents forgone investments by the project sponsor. The analysis also includes job categories and descriptions. Three positions were identified in this analysis which is a GIS programmer, hydrologist (environmental engineer) and supervisor. These categories are used to provide details for labor costs for current and future employees that will spend efforts on project development, but also any individuals that will benefit from the project. Job descriptions are assessed to determine the hours or FTEs spent by employees for the tasks needed for project implementation. In this case labor costs include annual salary which influences many other sub-variables among these is the valuation method which in this case per FTE. Fringe rates, or the burden rate, include the cost of taxes, insurance and related overhead items for each employee. A rate of 30% was used which is based on estimates provided by the project sponsor. (Lerner et al, Appendix A, 2007). Contract and procurement costs include items such as software and hardware upgrades or staff development and training.

Ultimately the majority of the sponsor's costs are determined by time needed for implementation which includes a pilot project. The pilot project consists of the labor costs of the WLRD Science Section integrating mapping tool output with their current water quality and storm-water management models.

Appendix D

Benefits are the avoided labor or FTEs saved by implementing the mapping tool. Other benefits could include new services that can be offered using the output of this tool, but those were not included in the analysis.

The worksheets include Common Financial metrics such as net present value (NPV), the sum of present values of all future cash flows, annualized return on investment (ROI), breakeven point and payback period (Lerner et al, 2007). NPV is used at the key metric in this analysis because it is more straightforward compared to other metrics. ROI can be somewhat deceptive and cannot be used in comparing mutually exclusive investments. Another concern with ROI is that when subjective assumptions are made in a financial analysis such as consolidating workload it can result in an inaccurate ROI. Internal Rate of Return (IRR) is another important metric, but a high NPV does not always correspond with a low IRR which becomes an issue when comparing two alternative projects or conducting a sensitivity analysis as was done here. A sensitivity analysis was conducted by calculating costs for a pilot project that focuses on WRIA 9 and then changing the hours to reflect the costs if the pilot project focused on all of King County. The majority of the financial and strategic analysis will focus on the resources need to complete the project for WRIA 9.

For WRIA 9:

Project Name:	Impervious Surface Mapping Tool
Date Analyzed:	7/25/2012
Net Present Value (Net Benefits):	\$27,881
Annualized Return on Investment:	16.87%
Breakeven Point:	This Year
Payback Period (in Years):	0
Inflation Rate:	2.50%
Opportunity Cost of Capital:	5.00%
Project Life (Number of Years):	10
Method for Determining Future Years' Cost of Labor: Derived by Applying Inflation Rate to Current Costs	

STRATEGIC ANALYSIS

There are only a few individuals involved with the outset of implementing the mapping tool. These include a member of the KC GIS Center staff, a hydrologist modeler from the WLRD Science Section and Science Section supervisor. The GIS staff will work to develop and integrate the tool with the GIS Center in the beginning stages. However, implementation of the tool will be influenced by a pilot project coordinated by the Science Section staff. The hydrologist modeler will work closely with the GIS person and provide specifications for the mapping tools test case with the Science Section group. These two individuals represent the main factor of costs in this analysis in addition to the Science Section supervisor that will work closely with the hydrologist. A ten year financial analysis was conducted and

includes cost and benefit estimates for first year and subsequent years 5 and 10. These periods were chosen because the Science Section will revisit with the GIS Center when new mapping tool input data such as LiDAR data becomes available. This data can then be used to process new impervious surface data. So the costs identified in the first year are then repeated every five year period as this new data becomes available. While the tool will be fully implemented in the County's GIS before these later years there will be additional labor costs required for tool updates. These updates are associated with tool modification necessary for its functionality with new hardware and software, such as newer versions of ArcGIS.

The costs included in this analysis represent tool implementation costs such as upfront labor costs and tool updates and maintenance, but does not consider other costs needed for developing specialized impervious surface layers for other groups or departments within KC. One of the intangible benefits gained by KC is the GIS Center's ability to offer a new service to these other groups. *(insert text on the other applications described by Jim in last meeting? Or is that somewhere else?)*

An increase in interrelated projects then becomes an intangible benefit of this mapping tool. WRLD performance measures are influenced by many separate groups, but many of these groups will be able to work together on the water management projects that require information on impervious surfaces of King County. Finally, KC may also want to consider how the new impervious surface information created by this tool can benefit outside agencies and organizations in the Puget Sound region.

Project Risks

Seven factors were adopted to highlight potential risks involved in implementing the tool. These include technology, organizational interactions, constraints, stakeholders, overall complexity, project planning project management and project resources. Described below is how each of these could negatively impact the project's success as well as ways of mitigating these effects. (Tomlinson, 2011)

Technology

There will be no additional hardware or software needed to implement the mapping tool and software bugs or flaws should not be an issue for the first year. This may depend on the data used to operate the tool because if the data is not in the correct format the tool will not function. This is unknown in later applications of this tool as King County purchases new hardware and Esri releases new version of ArcGIS.

Current KC technology should be adequate but there is a risk that computer processing may be slow, however it is not expected that the project sponsor will have to contract out because of this. This can be mitigated by purchasing a small hardware upgrade such as increasing RAM.

Organizational Interactions

It is expected that there will be increased interaction between the KC GIS center and the WLRD: Science Section, but sharing information is not an issue between departments. Because the information produced by this tool has multiple applications KC GIS Center workload will increase for a short period of time while they setup the tool and coordinate with different groups in the DNRP. Once the tool is programmed it will only require a small number of minor changes to meet the needs of these other groups.

Constraints

Surface water management fees generate \$1 - \$2 million annually, which KC DNRP LWR uses to fund both modeling and implementation of stormwater management activities. It is not expected that there will be any risks regarding budget. The time needed for initial discussion regarding the tool, tool development and generating the desired data will not be substantial. Time spent by the GIS Programmer position the first year could be as much as 150 hours or about three and half weeks. 140 hours is needed by the Science Section Hydrologist and 10 hours by the Science Section Supervisor. It is important to note that out of the 140 hours spent by the Hydrologist 120 hours is spent on integrating impervious surface layers with SUSTAIN and HSPF models which is something not directly related to the development of the tool. However, if testing is necessary this task could be included as a pilot project for the tool.

Stakeholders

Stakeholder's outside of the DNRP are not considered an immediate risk to the implementation of the tool in this report. Interactions with organization, other government entities or the public will not take place during tool development, however these groups may see value in the tool or the data layers produced from the tool and ask the DNRP for information. Stakeholder involvement is somewhat unforeseen at the moment and will depend on how the tool is applied and what sections of King County will utilize it.

Overall complexity

As it exists now developing this tool and generating output is not complex in terms of time and funding resources needed. Stakeholder involvement will be limited, there should be no violation of state or federal regulations and vendors will not be used at least for the first year. However, it is expected that this tool will be used every few years when new input data is acquired. Depending on how King County

obtains input data they may be required to contract with outside organization. Time associated with this activity is factored into updating/maintenance work included in the time table for years 5 and 10.

Project Planning

The planning is sufficient for implementing this tool into KC's GIS environment. But the tool is developed for ArcGIS version 10.1 so it will not function in earlier versions such as ArcGIS 9.3. Employees within the Science Section group are currently using version 9.3, but they will not have an issue with viewing impervious surface data layers in this layer

Project Management The project management methods are adopted from Professor Robert Aguirre of the University of Washington, Roger Tomlinson's book Thinking About GIS: Geographic information System Planning for Managers and Paul Harmon's book Business Process Change: A Guide for Business Managers and BPM and Six Sigma Professionals which are both proven resources. Development of the tool and future implementation is majorly contributed to the author's knowledge and experiences as well as to the methods and functions in Esri's ArcGIS software which have been tested and used for several years. Use of ArcGIS software provides built-in accountability and quality control.

Project Resources

Trained staff at King County is not an issue as the tasks to be completed during project implementation are within the abilities of the County. The employees of KC GIS Center have experience with Esri ArcGIS and have the skills necessary to implement tool development and maintenance.

Other risks can include changes in the organization, such as departmental functions, but this should not be a major concern. Responsibilities may increase for the DNRP such as assessing SWM fees per parcel. Another risk could be project scheduling problems such as reasonable deadlines or developing reachable milestones.

Overall the risks will not be too burdensome for the first year if King County implements the mapping tool as outlined. Each of the risk identified above should be considered, but they are present in any project and seem insignificant if compared to the benefits. There may be issues with updating the mapping tool to generate new impervious surface data every few years. During times of use the tool will need to be altered to function with new hardware and software that is adopted over those few years.

Values in the Labor Costs table below (Table D.1) were derived from the annual gross pay of KC employees for each job category. The average gross pay of GIS programmer was determined by averaging the salaries of the three employees in this position at KC.

Appendix D

(<http://www.thenewstribune.com/soundinfo/kingsalaries/?appSession=343203812510513&cbSearchAgain=true>)

The fringe rate was determined by dividing the sum of 2011 annual gross pay salary wage, taxes, insurance, and related overhead items for Curtis DeGasperi, Hydrologist/Environmental Engineer for Surface Water Management Group, by their 2011 annual gross pay salary wage.

$$(\$120,000 / \$91,974) - 1 = 30\% \text{ fringe rate}$$

This was applied to all positions in the Labor Costs worksheet. The assumption is that positions are full-time equivalent (FTE) The benefit of labor costs saved was calculated with the assumption that it would take a hydrologist at KC 100 hours per 200 acres for modeling a fully developed landscape using SUSTAIN and 50 hours per 200 acres in a suburban landscape. Employee labor savings were estimated at 0.1 FTE per year or 10% of the hydrologist's workload.

Detailed Financial Analysis Tables for WRIA 9

See Tables D.1 and D.2 for estimated time requirements for years 1 and 10.

Table D.1: Estimated Time Requirements for Year 1

	Tasks	Hours
GIS Programmer	<i>Emails, phone calls, meetings, etc.</i>	<i>10</i>
	<i>Tool setup</i>	<i>20</i>
	<i>Data processing</i>	<i>60</i>
Subtotal:		90
Science Section Hydrologist	<i>Emails, phone calls, meetings, etc.</i>	<i>20</i>
	<i>Integrate layers with Sustain/HSPF models</i>	<i>60</i>
Subtotal:		80
Science Section Supervisor	<i>Emails, phone calls, meetings, etc.</i>	<i>10</i>
Subtotal:		10

Table D.2: Estimated Time Requirements for Year 10

	Tasks	Hours
--	--------------	--------------

GIS Programmer	<i>Emails, phone calls, meetings, etc.</i>	<i>10</i>
	<i>Tool setup</i>	<i>20</i>
	<i>Data processing</i>	<i>60</i>
	<i>Updating/maintenance</i>	<i>10</i>
<i>Subtotal:</i>		<i>100</i>
Science Section Hydrologist	<i>Emails, phone calls, meetings, etc.</i>	<i>20</i>
	<i>Integrate layers with Sustain/HSPF models</i>	<i>60</i>
<i>Subtotal:</i>		<i>80</i>
Science Section Supervisor	<i>Emails, phone calls, meetings, etc.</i>	<i>10</i>
<i>Subtotal:</i>		<i>10</i>

Table D.3: Detailed Financial Sheet

	This Year	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Future Cash Flows										
Internal Labor Costs	(\$7,892)	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	(\$10,732)
Contract/Procurement Costs	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Productivity Benefits	\$15,245	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Other Benefits	\$29,167	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Present Value Multiplier:	100.0%	97.6%	95.3%	93.0%	90.8%	88.6%	86.5%	84.5%	82.5%	80.5%

Present Values

Internal Labor Costs	(\$7,892)	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	(\$8,640)
Contract/Procurement Costs	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total Annual Costs	(\$7,892)	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	(\$8,640)
Cumulative Costs	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$7,892)	(\$16,531)

Productivity Benefits	\$15,245	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Other Benefits	\$29,167	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total Annual Benefits	\$44,412	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Cumulative Benefits	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412	\$44,412

Cumulative Net Benefits	\$36,520	\$36,520	\$36,520	\$36,520	\$36,520	\$36,520	\$36,520	\$36,520	\$36,520	\$27,881
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Breakeven Year:	This Year
Payback Period (in Years):	0
Net Present Value:	\$27,881
Present Value of Costs:	\$16,531
Return on Investment:	16.87% (Annualized)

Labor Rates

Job Category	Current Average Hourly Rate (\$/Hour)	Fringe	Burdened Hourly Rate	Average Annual Regular Hours	Average Annual Cost Before Overtime	Average Annual Overtime Hours	Average Overtime Multiplier	Average Annual Cost of Position
Hydrologist, Environmental Engineer	\$47.90	30.00%	\$62.27	2080	\$129,583.87			\$129,583.87
GIS Programmer	\$53.95	30.00%	\$70.14	2080	\$145,950.94			\$145,950.94
Science Section Supervisor	\$56.41	30.00%	\$73.33	2080	\$152,605.97			\$152,605.97

Labor Cost Multipliers¹

	Current	Current	Valuation Method	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Job Category	Average Hourly Rate	Average Annual Cost/FTE		Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost	Labor Cost
Hydrologist, Environmental Engineer	\$62.27	\$129,584	per FTE	\$129,583.87	\$132,823.47	\$136,144.05	\$139,547.65	\$143,036.35	\$146,612.25	\$150,277.56	\$154,034.50	\$157,885.36	\$161,832.50
GIS Programmer	\$70.14	\$145,951	per FTE	\$145,950.94	\$149,599.71	\$153,339.70	\$157,173.19	\$161,102.52	\$165,130.09	\$169,258.34	\$173,489.80	\$177,827.04	\$182,272.72
Science Section Supervisor	\$73.33	\$152,606	per FTE	\$152,605.97	\$156,421.12	\$160,331.65	\$164,339.94	\$168,448.44	\$172,659.65	\$176,976.14	\$181,400.55	\$185,935.56	\$190,583.95
Valuation Method Options	Description												

¹Future Years' Labor cost derived by Applying Inflation Rate to Current Costs

Internal Labor Usage

Job Category	Valuation Method	Nature of Work	Year 1 Hrs or FTEs	Year 2 Hrs or FTEs	Year 3 Hrs or FTEs	Year 4 Hrs or FTEs	Year 5 Hrs or FTEs	Year 6 Hrs or FTEs	Year 7 Hrs or FTEs	Year 8 Hrs or FTEs	Year 9 Hrs or FTEs	Year 10 Hrs or FTEs
Hydrologist, Environmental Engineer	<i>per FTE</i>	Provide GIS Programmer with parameters; overlay/integrate tool output with HSPF and SUSTAIN models; provided reports on information found	0.03846	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03846
GIS Programmer	<i>per FTE</i>	Coordinate with Hydrologist/other departments; run processes in ArcMap; provide impervious surface layers based on requests	0.01490	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.019712
Science Section Supervisor	<i>per FTE</i>	Oversee Hydrologist/Science Section group; coordinate with Hydrologist on reports; review	0.00480	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00480

Internal Labor Costs

<i>(in future year dollars)</i> Job Category	This Year Labor Cost	Year 2 Labor Cost	Year 3 Labor Cost	Year 4 Labor Cost	Year 5 Labor Cost	Year 6 Labor Cost	Year 7 Labor Cost	Year 8 Labor Cost	Year 9 Labor Cost	Year 10 Labor Cost
Hydrologist, Environmental Engineer	\$4,984	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$6,224
GIS Programmer	\$2,175	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$3,593
Science Section Supervisor	\$733	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$915
Total Internal Labor Costs	\$7,892	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10,732

Total Internal Labor Investment	\$18,624
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Productivity Benefits

<i>(in future year dollars)</i> Job Category	Valuation Method	This Year Savings
Hydrologist, Environmental Engineer	<i>per FTE</i>	\$15,245
GIS Programmer	<i>per FTE</i>	\$0
Science Section Supervisor	<i>per FTE</i>	\$0
Total Productivity Benefits		\$15,245
<i>(in future year dollars)</i> Specific Other Benefits		This Year Benefits
Initial entry-level analysts labor cost savings		\$29,166.67
Total Other Benefits		\$29,167

**Future land use analysis for Water Resources Inventory (WRIA) 9
For
King County Department of Natural Resources and Parks**



Figure 1 WRIA 9

By Robert Fogle, David Krogh & Brian Thornquist – co-authors
Kate Weber and Krystle Jumawan – contributing authors

University of Washington
Professional Master's Program in GIS
Geography 569: GIS Workshop

17 August 2012

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I. Background

WRIA 9, which is known as the Green/Duwamish River watershed encompasses a wide range of territory. From its origin in the Cascade Mountains northeast of Mount Rainier it flows downstream to where it meets Puget Sound at Elliot Bay (see Figure 1). According to the Puget Sound Regional Council, the population between 2000 and 2040 in WRIA 9 (excluding the city of Seattle and areas upstream of the Howard Hanson Dam) is projected to grow by a quarter of a million people (EPA Grant Application, 2010). It is well known that growth and development have a direct link with environmental impacts, sometimes these impacts being irreversible. Some examples of our impact on the environment include riparian development, habitat loss and fragmentation, expanding impervious surface coverage, polluted sediment and developed shorelines (Puget Sound Regional Council, 2008). The Chinook salmon, which inhabit the streams and rivers within this watershed, are impacted by growth and development. As of 1999, the Chinook salmon have become threatened under the Endangered Species Act (Washington State Conservation Commission, 2000).

Stormwater runoff is a serious problem within this watershed which is linked to growth and development. According to the Washington State Department of Ecology stormwater is the “most significant contributor to reduced water quality in the Puget Sound” (King County, 2008). In association with the federal Clean Water Act of 1972, the National Pollution Discharge Elimination System (NPDES) permit program was established that attempted to control “water pollution by regulating point sources that discharge pollutants into waters of the United States” (EPA, 2012). In Washington State, King County was the first to be issued a stormwater municipal permit in 1995 (King County, 2008). Under the current version of King County’s stormwater municipal permit, the requirements focus mostly on stormwater impacts associated with new development (preventing the existing situation from getting worse). The permit requirements do not consider the impacts associated with older developed areas of

King County, which have a lack of stormwater control methods in place or utilize ineffective ones (EPA Application Grant, 2010). The Water and Land Resource Division’s Science Section is in the process of developing a stormwater retrofit plan for key areas of WRIA 9 (excluding the city of Seattle and areas upstream of Howard Hanson dam) that would include older developed areas of King County. More specifically, the Science Section needs to know if this plan and its associated costs will change due to future population growth and climate change in the study area (Simmonds, 2012). These key pieces of information will enable the Science Section to “successfully implement stormwater BMPs and LID techniques in previously developed areas of WRIA 9” (EPA Application Grant, 2010) For more insight into the basic structure of the Science Section please refer to the organizational diagram in Figure 2.

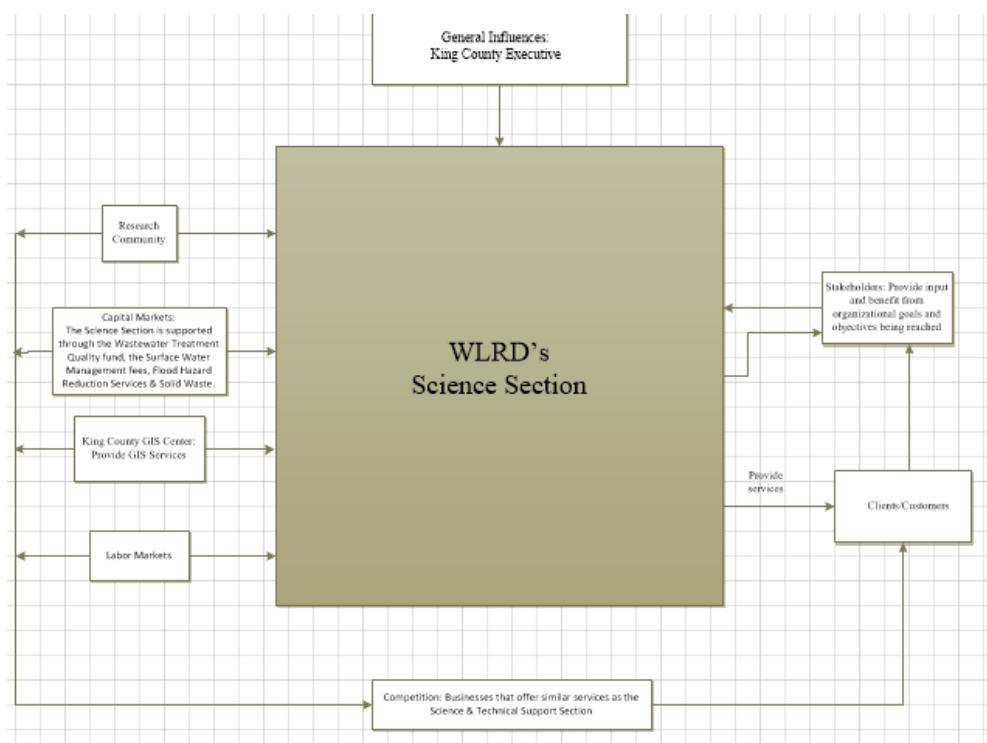


Figure 2 External & Internal relationships within the Science section

Project Statement/Goal/Objectives

The primary goal (deliverable) of our project is to suggest improvements to the process to create a 2040 land use layer that can be used to help the Water and Land Division complete their overall Stormwater Retrofit Project for the Green River Watershed (WRIA 9).

To meet this goal our first objective is to reduce the complexity of the current 2040 land use layer from 14 to 8 categories. The second objective is to match the 8 land use categories to the recommendations of the Soil Conservation Service Methodology. The third objective is to use the Soil Conservation Service Methodology to help the KC DNRP estimate future stormwater runoff using a simple linear model.

When carried to logical extremes, making elements and relationships yet more specific and concrete does not necessarily result in a more realistic simulation, particularly when it comes to modeling large systems that adapt their own internal control mechanisms. A pragmatic approach based on a simple linear model may produce acceptable results when compared with reality even when the elements of the model do not faithfully represent what we would assume to be the true complexity of the system under investigation (Bennett and Chorley 1978).

Existing Process Workflow

The executive board within K.C oversees all divisions and provides quality driven local services (extrapolated through the divisions). The County Executive is responsible for his/her department within K.C (in this case we are looking at the DNRP). Within each department lie different divisions; each division being run by a director. The WLRD is driven both by current issues and by future planning (driven in this instance by the DOE). Within future planning there is the collection and maintenance of data and the Retrofit Plan. The overall process workflow includes the UW's small effort within future planning but this could include any applicable affiliate for planning processes.

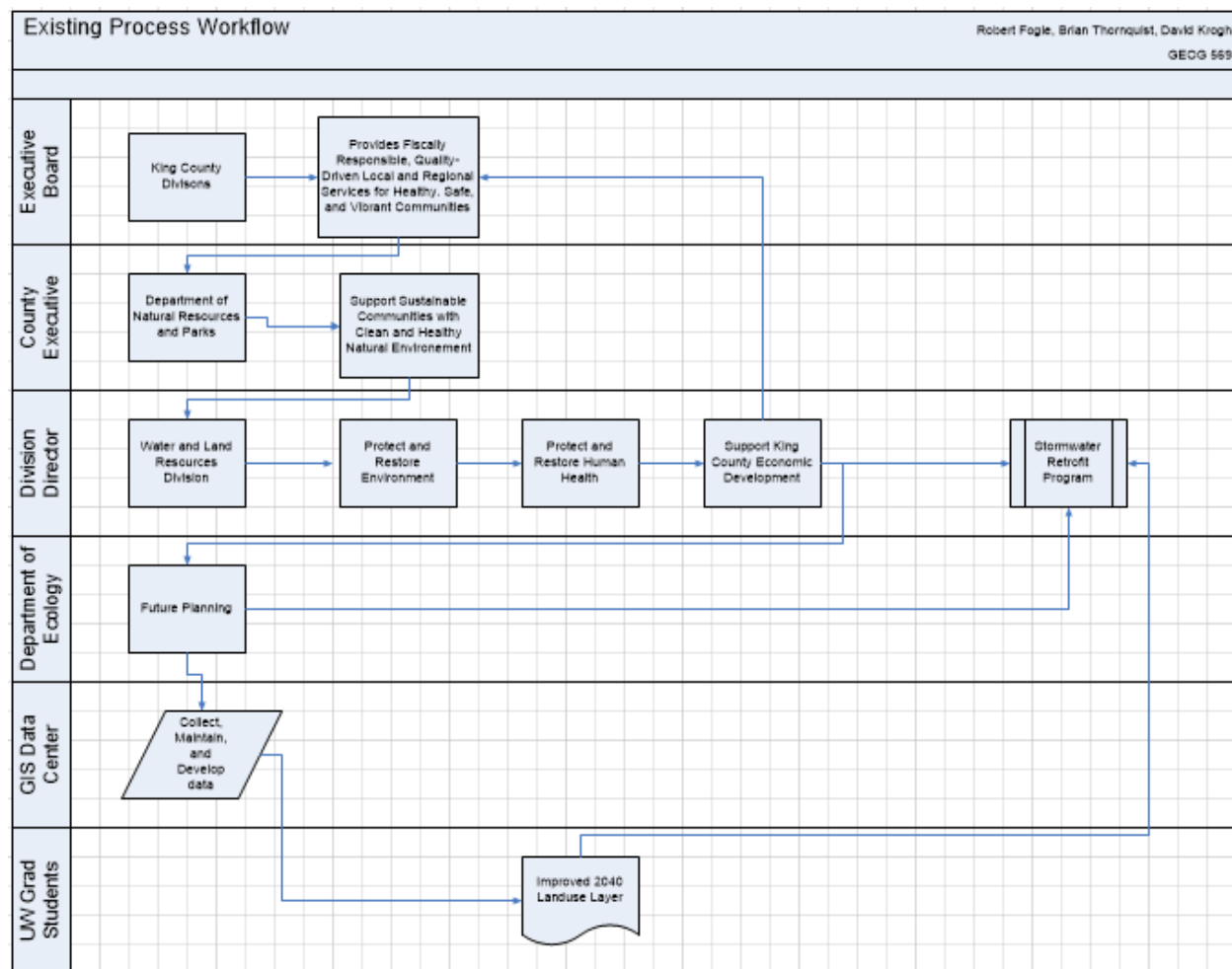


Figure 3 Existing Process Workflow

Existing Activity Workflow

This workflow (see Figure 4) depicts what the Science Section had originally planned to do meet their stormwater infrastructure needs for this project. Originally, the UW Urban Ecology Research Lab created a 2040 land use layer to meet their needs. It can be assumed that in order to create the layer, the research team had to conduct a literature review and research on UrbanSim. This research and literature review gave the research team an idea of their data needs, which was obtained through another party such as a GIS analyst. This data allowed the research team to create the 2040 land use layer. The Science Section obtained the 2040 land use layer and evaluated it against their needs for the stormwater retrofit plan. It was determined that this layer will not fully meet the needs for their purposes and they want to look at and compare with other methods of estimating future land use.

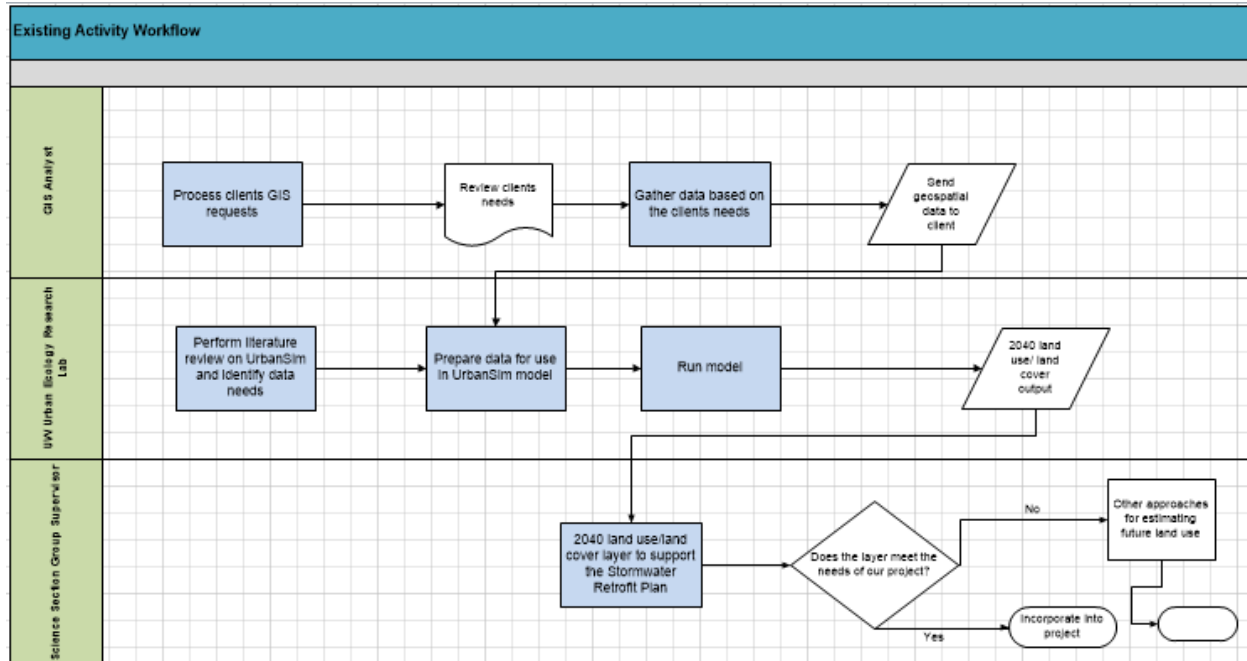


Figure 4 Existing Activity Workflow

Proposed Activity Workflow

This workflow (see Figure 5) depicts our overall proposed activity workflow. Our project management team was assigned the task of working with the Water and Land Resource Divisions Science Section who are currently in the process of working on a stormwater retrofit plan project. Our objective is to suggest an improvement to the existing 2040 land cover change layer. The existing activity workflow was thoroughly reviewed to give our team an idea of what direction we want to head. Our team decided that it was a good idea to explore options that don't involve running a model, such as in Envision. The U.S Soil Conservation Service has a technique for estimating impervious surface that allowed our team to reduce the 2040 land use categories from 14 to 8. The reclassify technique was used to reduce the land use categories to the ones recommended by the U.S Soil Conservation Service. This process resulted in a new raster layer with our proposed seven land use categories. Our results will be reviewed in depth by the Science Section to see if it's a strategy that will be beneficial. If the Science Section does not use our results then they will go back to the drawing table to explore other feasible options. If the Science Section decides to use our results then the next step would be estimating stormwater runoff from rainfall for the 2040 layer based on the chart from the U.S Soil Conservation Service. Based on the stormwater runoff estimates, this will allow the Science Section to make recommendations for stormwater BMP's and LID's for the study area.

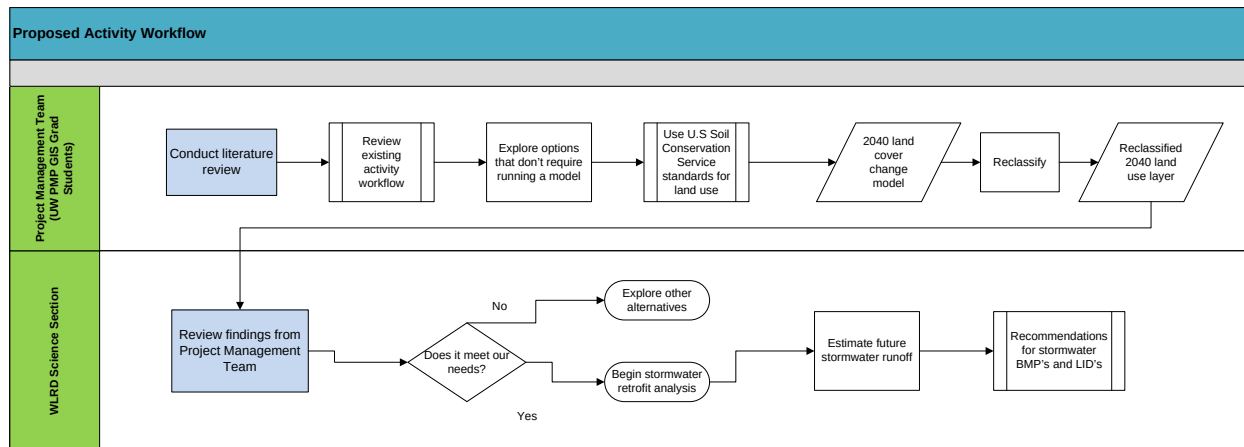


Figure 5 Proposed Activity Workflow

Information Categories Anticipated

The successful completion of this product would use current land use categories as defined by the U.S Soil Conservation Service to develop the improved 2040 land use layer. Each land use category would have a hydrologic soil group number (pertaining to the geographic region) associated with it. In addition to the land use categories any other applicable feature classes will be added (roads, urban growth, stream networks, urban areas, etc.) The land use categories will need to be researched and created to ensure accuracy for the various land usage scenarios in WRIA 9 (See figure 7 and 8 for hypothetical output).

Information Products

At the completion of our project we will have translated the existing land use categories into the categories provided by the U.S Soil Conservation Service produced for urban and suburban land use. With these categories we represented (ArcMap outputs) the difference in the 2040 layer based on the new designation, and explain the potential benefits that will be available by using the new categories. (See Appendix)

Hardware Requirements

Due to the scale of this project King County's Water and Land Resource Division should have all necessary capabilities and storage capacity. Our produced database will be relatively small in size and can be stored/shared with even the most basic systems. The current system is a central DMBS server with workstation clients on with windows based operating systems. This system will be sufficient for current and future needs.

Software and Networking Requirements

Existing King County Water and Land Resource Division Ethernet network is sufficient for a project of this size. Within our project we are able to accomplish data sharing and collaboration by virtue of using free file-sharing websites and Skype file transfer. We are using Windows based PCs running ArcGIS 10 to accomplish our tasks. A Windows based server (such as at King County) would greatly help in processing time but is not a large hindrance for the project. Graphics based programs such as Visio and MS Project would be a requirement for better visual display of process flows and organization charts. ArcGIS Diagrammer has been very helpful in the portrayal of our data models and would be a nice addition to a software suite.

Personnel and Time Requirements

Estimations from the Science and Technology Division for the work effort of this project was 1 man-month (1 person working for 4 weeks full time). This estimate was based on an experienced person who was familiar with King County and their processes. The UW project team estimates for time is for 3 people working over a 9-week period part time (between 10 and 20 hours/week). This would give us an estimate of 270 – 540 hours total.

II. Data Acquisition

Data Design

For our project, (Figure 14) progressing from Box 1: Reality to Box 7: Spatial Temporal Database first involves exploring the reality of our situation. This constituted the earlier phases and stages of our project and involved gaining a thorough understanding of the Science & Technical Support Section within the Water and Land Resources Division as well as having a better understanding of the project in terms of its goals, objectives and deliverables. These tasks were accomplished through background research and conference calls with our sponsor. Box 1 can be thought of as the baseline; in essence our understanding of the reality up to this point will shape the way we tackle other stages of the project, as well as how we proceed from reality to the spatial-temporal database. We can always revisit reality to refine our understanding of the situation, but better sooner than later. As our project progressed we realized that our project scope was way too broad, so we had to go back to investigate reality which allowed us to eventually narrow our project scope to something much more manageable.

Having narrowed down our project scope allowed us to move on to explore our data needs, which will be briefly discussed in the Input Data sub section of the Data Analysis section of our report. Having identified our data needs allowed us to go straight into our proposed activity workflow. This process represents Box 4: Space-Time. A database is not really necessary to store the one raster layer; a simple file will work well in this situation.

Data Source, Fitness for Use & Metadata

See Input Data section below.

Future Database Development

Planning for future scenarios is going to be a continual process that will be revisited annually. In the case of this project, we are looking at a 2040 land use model (because that is how far population projections currently reach). In the future efforts will be made to look even further down the road and

similar analyses will be completed. With this in mind we need to be able to access/gather the applicable data to do similar projects in the future. The data categories will stay the same but future analysis will need to use updated versions of the data layers. Some of this data will be incorporated into the data center, but because of their strict requirements of data, some of it will not be included in the data center. The entirety of the data will be stored within the Water and Land Resources Division.

The data used for this project is based on reality and space-time essentially; we are trying to replicate real world scenarios to produce an accurate layer(s) that will be used in current and future analysis. Ideally, all data used will be similar in format and stored in a database that is created within ArcCatalog. The data that is being used in this analysis is aimed at 2040 projections so future analysis will most likely look at 2050 or 2060 as proposed years; this means that some of the data (population, rainfall, and development) will have to be updated to be accurate. Washington State has a set urban growth boundary, in which we are not allowed to develop past that boundary; this will stay the same for all analysis. A database of this size will be relatively small and easy to maintain, the system requirements will not surpass that of any standard King County Division capabilities. Any judicial changes to stormwater management issues, land development, technological advances (permeable pavement, runoff management, and other environmental technological advancement) will have to be addressed as they develop. The main issue is going to be the location of the database, over the next 30 years personnel within King County is going to change several times, it will be easy for data to get misplaced or lost over time, and perhaps even recreated costing more money and man power. There are several solutions to the issue, we will review our proposed solution in the following.

Proposed Solution

King County is very diverse with many different sections and divisions that span across all public and environmental factors. This often creates an issue with data access and development. As Jim

Simmonds (Supervisor of water quantity and quality in the Water and Land Resources Division) stated in conversation

Typically we do work with data center, they are in high demand, in addition, WLR staff (about 30 people), use GIS. It is a tool for doing their job. We use layers and data that are maintained by the data center in their project specific analyses. We want to get an improved 2040 layer but it isn't something they want to push to the data center at this point. We are billed for GIS center time so they do not want to approach them without a very specific project that they can't complete with their own knowledge.

As mentioned they do not want to work through the data center, which means we will be gathering and developing our own data. To find all applicable data we have to look through the data center, WAGDA, graduate students at UW, and through the Water and Land Division. I suspect that a lot of "rework" takes place because of lack of accessibility to existing information. Rework costs extra time and money and can be avoided if projects are coordinated across all divisions.

What we propose for future data management and research is a search engine of sorts which will provide data, metadata, location of data, and who developed the data. The data information could be uploaded by all users (instead of the rigorous process it takes to get it into the data center) and searched by all users. This would streamline the information process for data and information acquisition. This search engine would even allow people to look up what types of projects have been completed. At this point we are not trying to store all of the data in one location (the cost and manpower to implement something of that scale would be extreme), all we are proposing is a simple, user maintained, search engine that allows all organizations and divisions to quickly see what is available and where it can be located. A tool like this would eliminate a lot of the rework that takes place on similar projects in separate divisions where communication across the organization is minimal.

III. Data Analysis, Information Products and Findings

Input Data

The input data being used in coordination with our proposed activity workflow is the 2040 land cover change model developed by the UW Urban Ecology Research Lab using UrbanSim. This data is in raster format that is divided into 14 land cover classes which is accompanied with supporting documentation that identifies the class names and definitions.

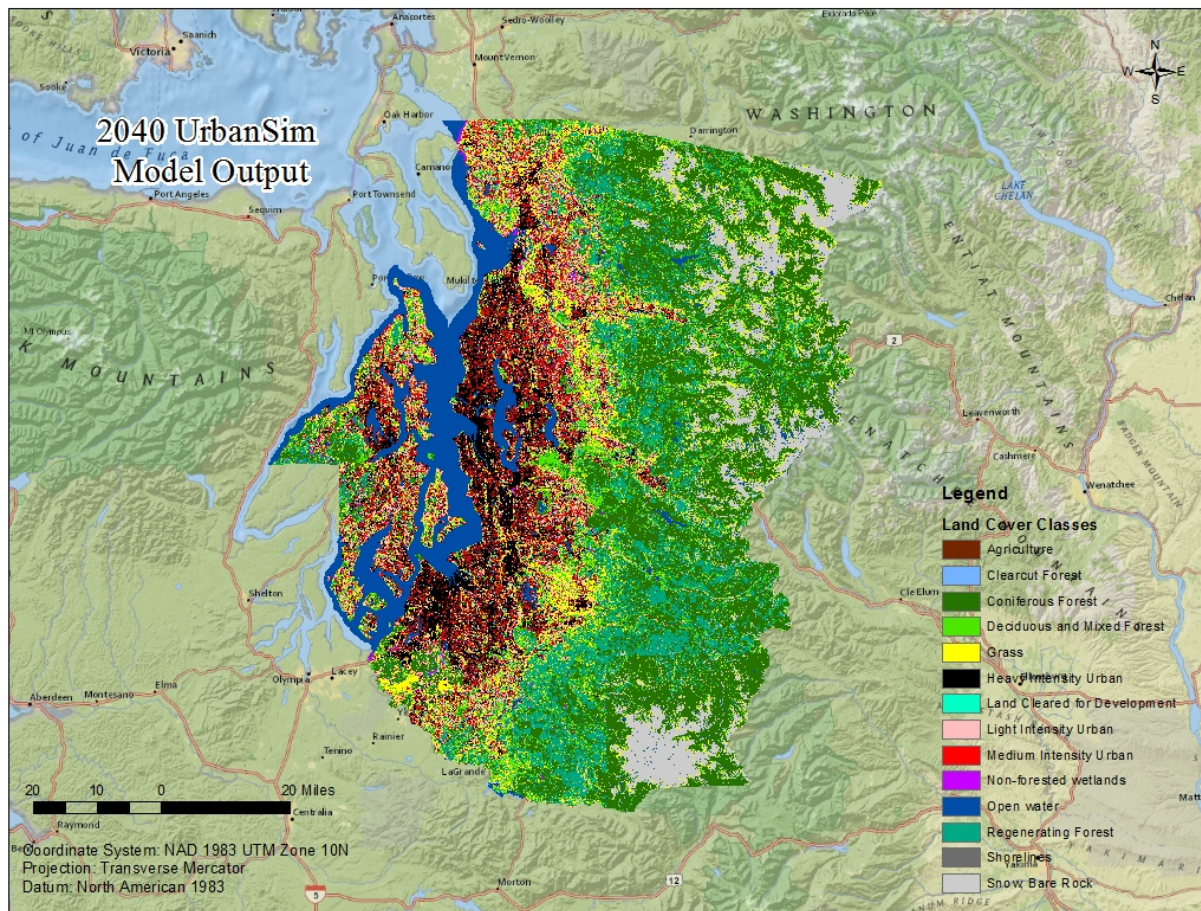


Figure 6 Existing Model Output

Data Analysis

Data analysis/development is an important resource for the Water and Land Resources Division within in King County. Typically it is developed by the GIS Center, but in this case the Water and Land Resource Division will be working in collaboration with other organizations and UW to develop the necessary components. According to our project sponsor, the main goal “is to continual gather and develop science based data pertaining to environmental factors”. Our group will be working on only one small aspect of the overall project; we will be suggesting categorical improvements to the mentioned 2040 land use layer, however, these incremental improvements will provide crucial data acquisition improvements for use in future analysis.

During our collaboration with King County we will be looking at their existing 2040 land use layer and the existing 14 land use categories. The current categories look at three levels of urbanization, land cleared for development, grass, four designations of forests, agriculture, wetlands, open water, shoreline, and bare rock. We are proposing using less, but more defined categories that will provide more quantifiable information and can be used in various analyses when actual facility planning begins.

Analysis Within our Project Scope

In our collaborative effort in King Counties Stormwater Retrofit Analysis we will be suggesting categorical improvements to the existing 2040 land use layer for use in planning and budgeting the WRIA 9 area. The goals of this project are not unlike that of the MOLAND project in which we want to provide up-to-date, standardized, and comparable information on the past, current, and likely future land-use development (Campagna, 2005). We will not be doing any work on the 2040 layer but will be showing how the suggested categorical improvements will improve upon the 14 existing land use categories. The simple land use category improvements will provide the base information for many other potential hydrologic analyses (to what degree is up to King County). The simple addition of

hydrologic soil group classifications to each land use category provides an associated curve number. This curve number can be used with existing charts to model runoff.

The information potentially provided by our incremental improvement will help aid the Retrofit Plan's overall goal in returning stream health to an acceptable level.

Out of Scope

- Flow and water quality data throughout the study area.
- Computer Modeled flow and water quality conditions in selected study area rivers and streams for idealized fully forested conditions, current conditions, and anticipated 2040 conditions considering population growth and climate change.
- Stream flow and water quality goals throughout WRIA 9.
- Analysis of stormwater retrofits needed to achieve in-stream flow and water quality goals, including estimated costs.
- Prioritized watershed scale stormwater retrofit plan.
- Planning-level cost estimate(s) and methodology to implement stormwater retrofit projects throughout the Puget Sound region.

IV. Financial and Strategic Analysis

Financial Analysis

The crux of financial analysis involves looking at “cash flows related to an investment” (Awwa Research Foundation, 2007). When doing financial analysis there are many variables that need to be carefully considered. Rather than present numbers associated with key variables, which in some respect is well beyond the scope of this project, recommendations will be made as to which variables one should highly consider when performing financial analysis. These key variables will be explained in detail

shortly and will reference our proposed activity workflow as much as possible. Also, it is important to document any assumptions being made when performing financial analysis.

The inflation rate is an important variable one might consider when performing financial analysis. The Bureau of Labor Statistics is a reliable source one can use to obtain this information. For longer projects that estimate the future values of costs and benefits it is strongly encouraged that the inflation rate is taken into consideration. If taken into consideration, this variable should be used thoroughly within the process of financial analysis. If not taken into consideration it should be documented as one of the assumptions within the financial analysis (Awwa Research Foundation, 2007).

Labor rates are another important category that has key variables which should be addressed when performing financial analysis. It is highly advised that one fill this worksheet (see appendix) out in coordination with the Human Resources Department in their organization. It should be noted that for this project since we are not working with the Human Resources Department and given time constraints, it is not possible to fill this worksheet out in its entirety. One important variable involves identifying job categories that are affected by the project and their associated costs. In terms of the scope of our project, Jim Simmonds from the Water and Land Resource Division said our work would be the equivalent to one county employee working for about a month, which would cost around \$10,000 (2012). When calculating the average hourly rate for each job category one has identified, if this is for a future project, it is advised that one use the current hourly rates for the identified job categories (Awwa Research Foundation, 2005). The information filled out in this worksheet will be used to fill in the labor cost multipliers worksheet, which has variables that one may need to consider when performing financial analysis. One needs to consider here whether labor costs will be calculated per hour or per FTE. Based on the input (the labor cost and valuation method), this worksheet calculates future labor costs based on the inflation rate that was identified (Awwa Research Foundation, 2007).

It is important to consider any benefits one's project generates when performing financial analysis. A tangible benefit is a variable that is used to identify benefits which are quantifiable. It is important to note that not all benefits are quantifiable. In this case, these benefits should be incorporated into the strategic analysis section, which focuses specifically on intangible benefits (Awwa Research Foundation, 2007). Relating to our proposed activity workflow, our recommendation does not involve physically running a model, such as in Envision. Using Envision is a time-consuming process as well as a complex task. This is a benefit to our project sponsor that is quantifiable in terms of the money they are saving from attempting to run a model.

When performing financial analysis to take a look at your project's future investment, it is a good idea to perform sensitivity analysis. Sensitivity analysis involves experimenting with the values for the variables associated with financial analysis. For example if any of the contract or procurement costs change as the project progresses, this may change the results of the financial analysis (Awwa Research Foundation, 2007). Thus, sensitivity analysis is a way to deal with and document the uncertainty associated with the variables identified above as well as others.

Strategic Analysis

The creation of a 2040 land use layer would add strategic value by allowing KC DNRP to be able to better manage and plan projects going forward. Ideally, the 2040 land use layer might be able to provide geographic areas of focus for stormwater management.

Usage of this layer could be shared with groups outside of the Sciences and Technology division and even outside of the King County organization. City planners within the affected areas could use the output in their planning efforts.

While the 2040 layer is a portion of a larger Stormwater Retrofit project, the work effort and data could also be utilized in other UW projects such as the digitization of photos for determining pervious/impervious layers.

Types of possible Risks

The identified risks below are based on Tomlinson, pp. 159 – 160. The measurement of risk is taken from Tomlinson but based on industry best standards as documented in the ISO 31000 Risk Management publication.

Risks are discussed with mitigation strategies for Medium Risk and above (no High Risk factors were identified.) A measurement of each risk is included using *Probability of Risk X Financial Impact = Total Risk* as a score. Mitigation of risk will not be considered to calculate a Residual Risk Score due to the overall minimal project risk but should be considered for larger, more complex projects.

Probability of Risk

This will be measured on a scale of 0 – 1.0 with 0 meaning that it will not occur to 1.0 meaning that it will definitely occur within the timeline of the project.

Financial Impact

This will be measured on a scale of 1 – 5 with 1 meaning no financial impact if the risk comes to fruition to 5 meaning a financial impact so great the project will have to be abandoned.

- *Technology* – current technology (both hardware and software) exist and are sufficient for the creation of a 2040 land use layer. Low Risk ($.1 \times 2 = .2$)
- *Organization functions* – there should not be an organization changes required or as a result of the creation of the 2040 land use layer. Low Risk ($.1 \times 1 = .1$)
- *Organizational interactions* – this project is being done within a single team/group within the King County Department of Natural Resources and Parks so coordination with outside teams is minimal. Low Risk
- *Constraints* – funding issues are almost nonexistent for this project due to the fact that the work is being done by UW students at no cost to King County. Due to our reduced scope there should not be any time constraints for the completion of the 2040 land use layer. Low Risk ($.2 \times 2 = .4$)

- *Stakeholders* – our stakeholder for this project is the Science and Technology division within the KC DNRP. Thus, single level of complexity with a centralized point of contact. Low Risk. (.1 X 2 = .2)
- *Overall Complexity* – the only complexities within this project are the technical proficiencies of the co-leads. Our ability to create a usable 2040 layer will require skills that, while we have learned, we are not experts with. There are not any federal mandates we must follow and the work is basically self-contained within our group, meaning little reliance on outside groups. Low to Med Risk (.4 X 2 = .8)
- *Project Planning* – Originally our project was not well defined within the UW project team. This has been corrected and we now understand our deliverables and timelines. Low Risk (.2 x 1 = .2)
- *Project Management* – Single point of project management is helping deal with issues. While all members are contributing, one person is responsible for final report and QC efforts. Low Risk (.2 X 1 = .2)
- *Project Scheduling* – Usage of Visio timelines has helped with project scheduling. Outside influences such as life and work have delayed a couple of deliverables but we are back on track. Med Risk – mitigation is more frequent touch-bases during project (.4 X 2 = .8)
- *Project Resources* – As mentioned in Overall Complexity, having the correct and adequate training in the usage of ArcGIS and other modeling software could prove to be slightly encumbering. That being said, having three people should help mitigate this. Med Risk – mitigation is team member spending extra time to familiarize ourselves with the software (.4 X 3 = 1.2)

A summary of risk/migration statement follows in the “Recommended Course of Action” section.

Recommended Course of Action

Our progression through the planning and proposed implementation of the improved 2040 land use layer has brought to light many potential risks and benefits. The strategic and financial analyses do raise some questions about cost versus benefit; however, I think we have shown that the benefit has the potential to be much greater than the cost. In the following we will look more closely at both the financial and strategic risk before we form our final recommendation.

The relatively small nature of this project means there is not that much financial risk involved. King County already utilizes the hardware, software, and personnel necessary for implementing/managing this project. With that being said there are virtually no startup cost and the ongoing cost should stay stagnant if the project is implemented efficiently. Labor costs were estimated to be in the 250 man hour, \$10,000 in wages range, this should be reasonably managed with existing staff. Quantifiable benefits would include flood potentials, runoff quantities, and peak discharges. This will improve accuracy and significantly aid in stormwater facility planning. This project could potentially eliminate the need to run one of the models, the simple linear methodology does have some unknown factors, but not to the extent of the models.

The low strategic and financial risk of the improved 2040 layer makes it easy for us to recommend a forward progression with this. The improved quantifiable data that will be obtained from the new land use categories will have numerous positive impacts on modeling with minimal alteration to the land use categories.

V. Future Direction

The Stormwater Retrofit Program focuses on planning for hypothetical (but plausible, based on historic patterns) land change. The idea is to preemptively plan for stormwater management to return local stream health to an acceptable level. This proactive planning addresses not only the sustainability for WRIA 9 but will produce a streamlined process that can be used for other resource index areas. Our

proposed action of reclassified runoff categories for use in the existing 2040 layer will provide more science based data, application, and potential analysis (Figure 7). As you can see between figure 7 and figure 12 the patterns displayed in the raster data do not change much when looking at the issues that affect runoff, however, the information content has been greatly increased by changing the class designations.

The suggested improvement to this layer is based on the nationally accepted categories produced by the U.S Soil Conservation Service. With minimal effort land use categories can be developed for WRIA 9 that use the associated hydrologic soil group classification. By using this classification the door is opened to quantifiable runoff, flood potential, and peak discharges (Dunne and Leopold, 1978). This information will be extremely valuable when planning stormwater facilities and the flow quantities that they will potentially have to handle. Using the hydrologic soil group designation along with the associated curve number will provide a user with runoff data in inches. Using this information in collaboration with precipitation data, watershed analysis, and existing stormwater facilities a user will be able to look at potential high flow hazardous areas that need to be addressed to ensure runoff pollution management. Having accurate pervious/impervious designations will aid when imputing data into Envision.

Ideally, this information will fuel the modeling that will take place in Envision. To be as comprehensive as possible several future scenarios should be ran through envision each dealing with potential land use, policy, development, and urban change. A traditional approach to exploring the future has been to extrapolate the past” (Walker & Salt, 2008). This method has been proven to be limited when attempting to explore future scenarios of social ecological systems. Social ecological systems are complex and there will be bound to be surprises that we don’t anticipate (Walker & Salt, 2008). Rather than look at the past to gain insight into the future we can develop multiple scenarios for what might happen. This is referred to as scenario planning. With this strategy there is no best strategy,

instead “rather a series of strategies which allow an organization to be prepared for different situations” (UW Urban Ecology Research Lab, 2008).

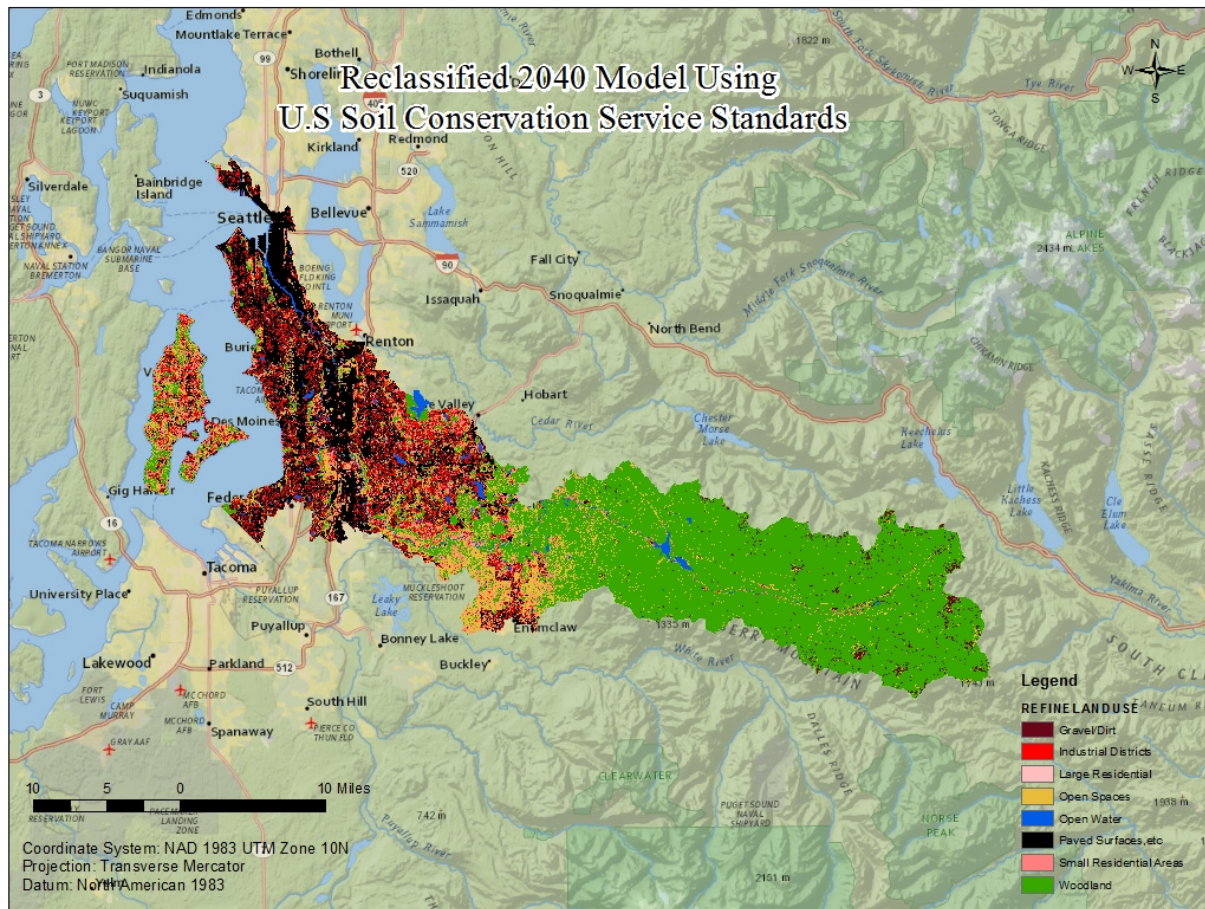


Figure 7 Reclassified Layer

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Appendix

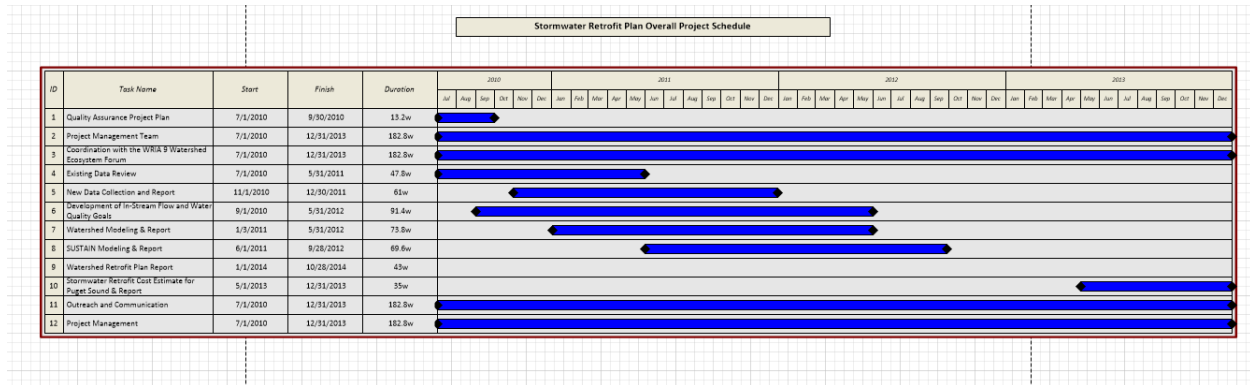


Figure 8 Project Schedule

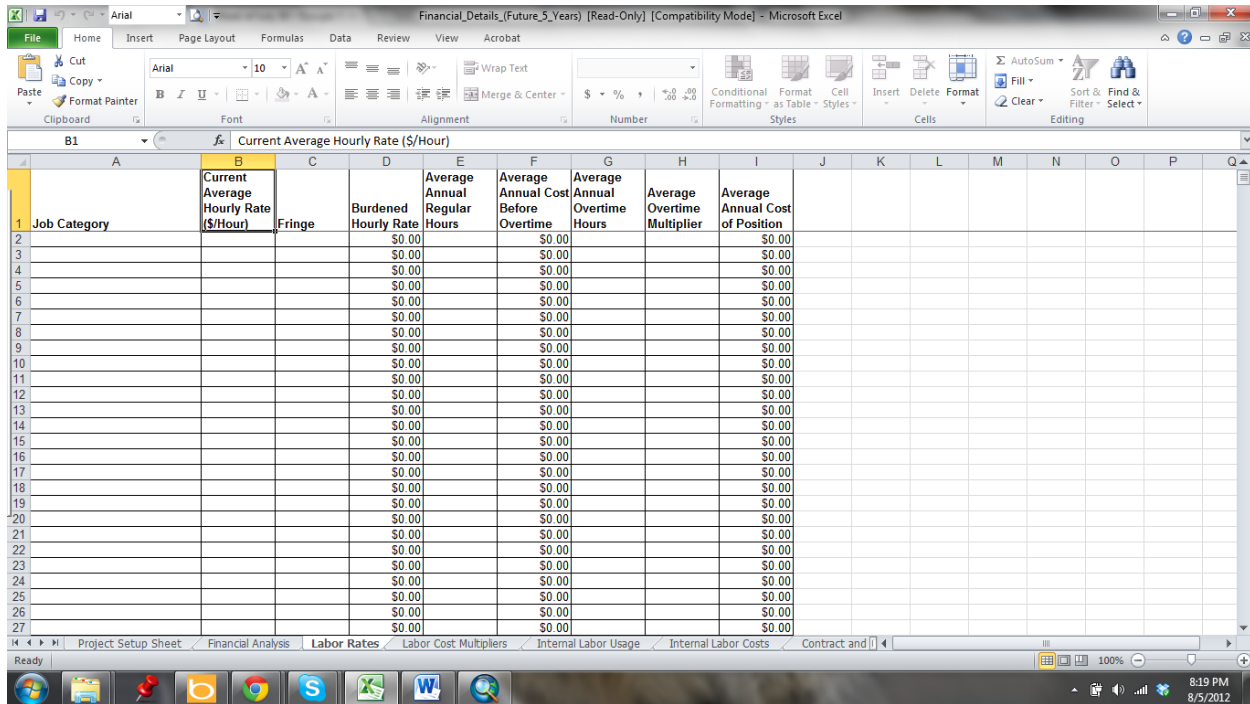


Figure 9 Labor Rates

Land Cover Classes	Class #	Class Definition
Heavy Intensity Urban	1	> 80% Impervious Area
Medium Intensity Urban	2	50-80% Impervious Area
Light Intensity Urban	3	20-50% Impervious Area
Land Cleared for Development	4	Land that was vegetated in a previous time step and developed in a later time step
Grass	5	Developed Grass and Grasslands Non-vegetated
Deciduous and Mixed Forest	6	>80% Deciduous Trees, 10-80% each Decid./Conif. Trees
Coniferous Forest	7	>80% Coniferous Trees
Clearcut Forest	8	Clearcut Forest
Regenerating Forest	9	Re-growing Forest
Agriculture	10	Row Crops, Pastures
Non-forested Wetlands	11	Non-forested Wetlands
Open Water	12	Water
Bare Rock/Ice/Snow	13	High elevation areas with no vegetation or snow cover
Shoreline	14	Tidal areas bare during low tide

Figure 10 Existing Land Cover Class Codes

Land Cover Classes	Class #	Class Definition	U.S.S.C.S
Heavy Intensity Urban	1	> 80% Impervious Area	Paved Parking Lots, Roofs, <u>Driveways</u>

		etc.(Impervious) 98	
		Commercial and Business Area (85% Impervious) 92	
Medium Intensity Urban 2		50-80% Impervious Area	Industrial Districts (72% Impervious) 88
Light Intensity Urban 3		20-50% Impervious Area	Small Residential Area (30-65% Impervious) 72-85
Land Cleared for Development 4		Land that was vegetated in a previous time step and developed in a later time step	Large Residential (20-25% Impervious) 68-70
Grass 5		Developed Grass and Grasslands	Open Spaces (Grass cover 50-75% of area) 69
Non-vegetated			
Deciduous and Mixed Forest 6		>80% Deciduous Trees, 10-80% each Decid./Conif. Trees	Woodlands 60
Coniferous Forest 7		>80% Coniferous Trees	Woodlands 60
Clearcut Forest 8		Clearcut Forest	Open Spaces 69
Regenerating Forest 9		Re-growing Forest	Woodlands 60
Agriculture 10		Row Crops, Pastures	Open Spaces 69
Non-forested Wetlands 11		Non-forested Wetlands	Water
Open Water 12		Water	Water
Bare Rock/Ice/Snow 13		High elevation areas with no vegetation or snow cover	Gravel/Dirt 85
Shoreline 14		Tidal areas bare during low tide	Water

Figure 11 Proposed Reclassified Codes

Note: Categories were reclassified using a logical linear approach; the numbers given in the U.S.S.C.S are the associated curve numbers that can be used for load calculations, flood potentials, and runoff rates.

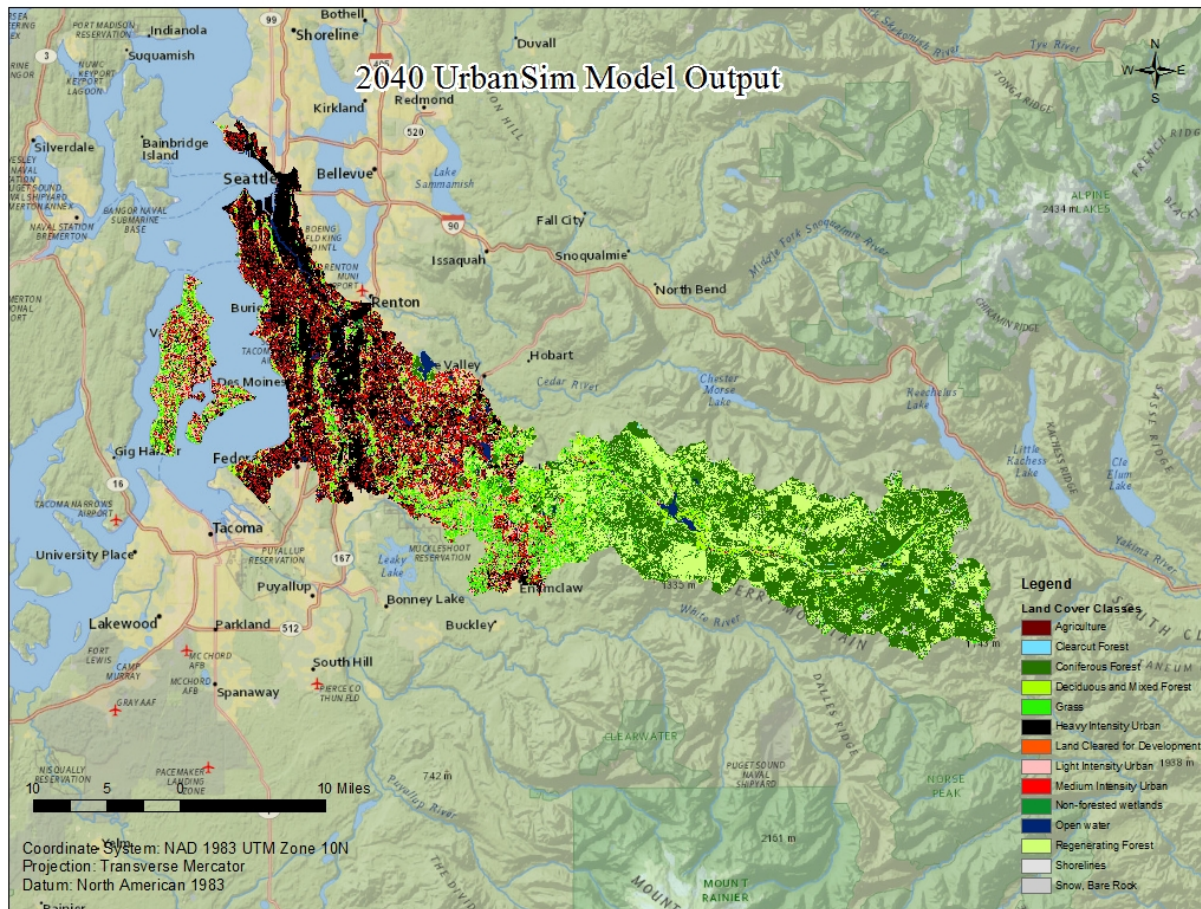


Figure 12 Urban Sim WRIA 9 output

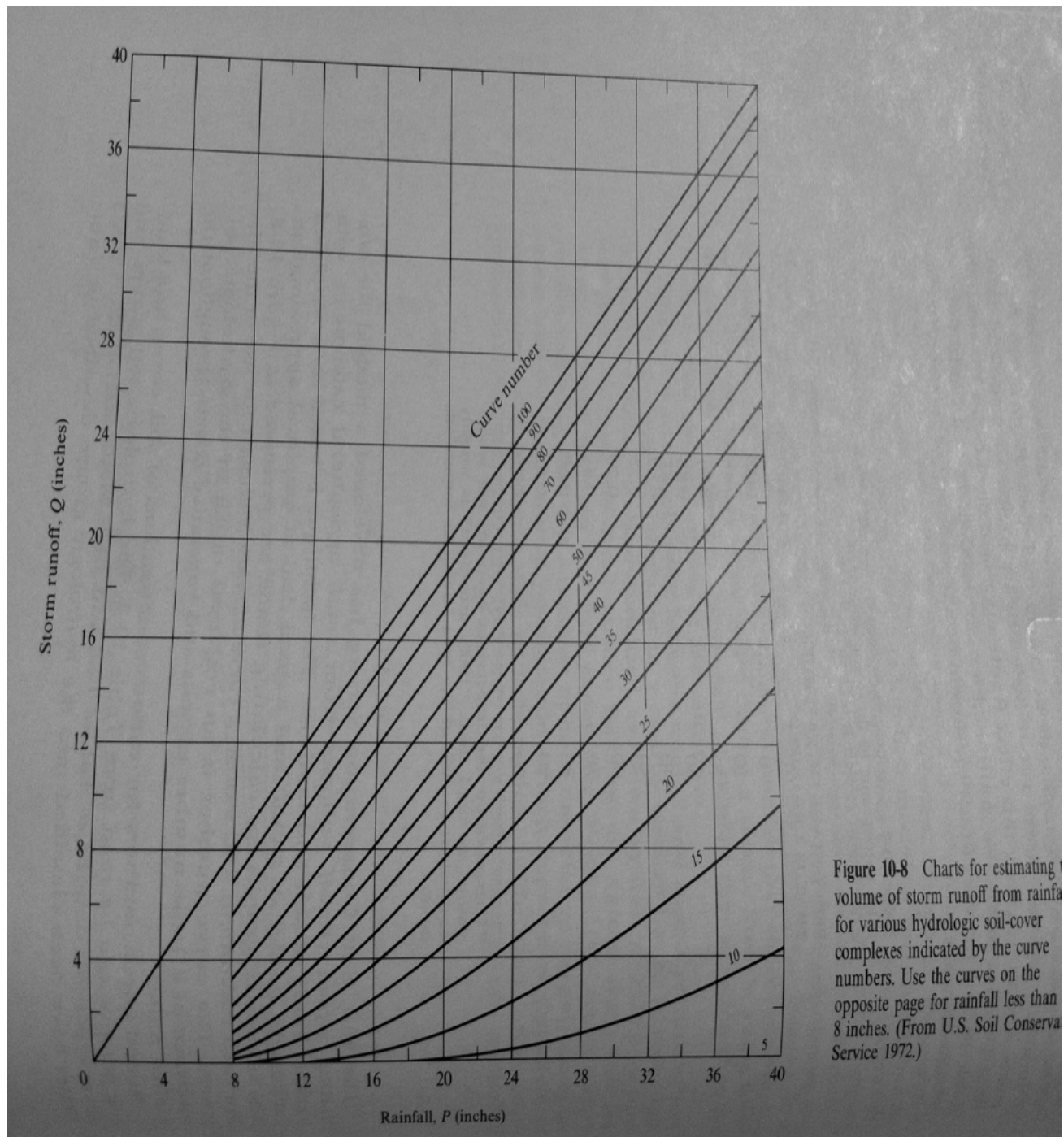


Figure 10-8 Charts for estimating volume of storm runoff from rainfall for various hydrologic soil-cover complexes indicated by the curve numbers. Use the curves on the opposite page for rainfall less than 8 inches. (From U.S. Soil Conservation Service 1972.)

Figure 13 Curve Number Runoff Chart

Table 10-8 Runoff curve numbers for urban and suburban land use for antecedent moisture condition II. (From U.S. Soil Conservation Service 1975.)

LAND USE	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Open spaces, lawns, parks, golf courses, cemeteries, etc.				
good condition: grass cover on 75% or more of the area	39	61	74	80
fair condition: grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business area (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential*				
Average lot size Average % Impervious [†]				
1/8 acre or less 65	77	85	90	92
1/4 acre 38	61	75	83	87
1/3 acre 30	57	72	81	86
1/2 acre 25	54	70	80	85
1 acre 20	51	68	79	84
Paved parking lots, roofs, driveways, etc. [‡]	98	98	98	98
Streets and roads				
Paved with curbs and storm sewers [‡]	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89

*Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[†]The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[‡]In some warmer climates of the country a curve number of 95 may be used.

Figure 14 U.S.S.C.S Soil Group Codes

Sustainability Practitioner's Worksheet v.1 (Spring 2012)

References: Draws from Peuquet (1984, 69), Longley et al. (2011, 208-209), Cumming (2011), Resilience Alliance (2010), Brinberg and McGrath (1985), NRC (2006), and Peirce ("What is a sign?").

Domain of meaning	Resilience thinking	Spatial thinking	Geographic information processing
	Box 3	Box 6	Box 9
Symbolic (spokesperson)	Resilience assessments & interventions: Graphic or narrative representations useful for conveying something to someone else about the likely capacity of a geographical setting at a particular phase in its adaptive cycle to absorb a certain magnitude of change or disturbance without changing a characteristic or preferred state of relations between its elements (e.g., overall identity including its structure, function, feedbacks, and associated ecosystem services); including representation, process, and evaluation models as well as change, impact & decision models	Indicators: Graphic or narrative representations useful for conveying something to someone else about the characteristic or preferred state of relations between the properties of elements of a geographical and historical setting in space and time; including representation, process & evaluation models	Maps: Graphic or narrative representations useful for conveying something to someone else about a geographic and historical setting as a likeness; yielding a representation model
	Box 2	Box 5	Box 8
Conceptual (systems thinker)	Social-ecological systems (SES) models: Abstractions of reality that model or simulate the likely capacity of a geographical setting at a particular phase in its adaptive cycle to absorb a certain magnitude of change or disturbance without changing a characteristic or preferred state of relations between its elements (e.g., overall identity including its structure, function, feedbacks, and associated ecosystem services)	Spatial-temporal models: Abstractions of reality that model, statistically analyze, or simulate the state of relations between the properties of the elements of a geographical and historical setting in space and time	Spatial-temporal data models: Abstractions of reality that incorporate and display the measured properties of elements relevant to the application at hand expressed in diagrams, lists, and arrays reflecting the logical recording of data in a spatial-temporal database
	Box 1	Box 4	Box 7
Referential (area expert)	Reality: The place and time of interest within which things existed and occurred, whether or not anything is observed and recorded about them by an individual or a device	Space-time: The specific geographical and historical setting, scale, or domain of interest within which the spatial and temporal properties of certain selected things are observed and measured by an individual or a device as the properties of a database element (e.g., an event)	Spatial-temporal database: The computers and machines, software code, serves, and networks supporting the storage, processing, and exchange of geospatial information and within which space-time database elements are recorded and accessed as data files
		33	

Figure 15 Practitioner's Worksheet

