A MODEL FOR PRIORITIZING CHINOOK SALMON HABITAT REMEDIAL ACTION IN A WATERSHED OF KING COUNTY, WA

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of MICHAEL DAVID BISHOPP find it satisfactory and recommend that it be accepted

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A MODEL FOR PRIORITIZING CHINOOK SALMON HABITAT REMEDIAL ACTION IN A WATERSHED OF KING COUNTY, WA

Abstract

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Chinook salmon populations in the Pacific Northwest have dramatically declined in the last century. This is due to many factors including ocean harvesting, relying on hatchery salmon, the conflict of fish and hydroelectric dams, and the degradation of salmon-favorable habitat. In March of 1999, the National Marine Fisheries Service listed Puget Sound Chinook salmon as threatened under the Endangered Species Act. This fact increases the need for tools to help decision-makers with limited budgets make wise decisions in regards to protecting salmon and their habitat.

This research presents a cartographic model that prioritizes sub-basins within a watershed in regards to salmon habitat remedial actions. The study watershed is in King County, WA and is referred to as Water Resource Inventory Area #9 (WRIA 9). The prioritization scheme used in this model is a coarse grain approach that will give decision-makers a means to focus their salmon habitat protection efforts. The modeling methodology utilizes Geographic Information System technology and readily available datasets.

The framework of this model establishes three very important factors that effect or indicate viable salmon habitat: Landscape health, salmon presence, and potential risk. The factor of in-stream quality is also important for understanding the health of salmon populations, but it is not addressed in this thesis. Each of these factors contains individual parameters that have been shown to effect salmon populations either directly or indirectly.

The end result of the model is a differentiation of sub-basins within WRIA 9 based on ecological actions (preservation, restoration, or structural best management practices (BMPs)) and implementation prioritization, and remedial actions and their implementation prioritization. The resultant prioritized sub-basins show a distinct pattern of BMP actions in the more populous areas to preservation in the most rural areas. These model results are very reasonable. The model could be enhanced with the addition of an in-stream conditions evaluation, the expansion of risk to include runoff potential, and the use of more up-to-date datasets. In final analysis, the framework of this model is sound and establishes a flexible means for decision-makers to decide how to prioritize salmon habitat enhancement projects.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CWA	Clean Water Act (Federal Legislation)
DEM	Digital Elevation Model
DENR	North Carolina Department of Environment and Natural Resources
DOE	Department of Ecology (Washington State)
EPA	Environmental Protection Agency
EROS	Earth Resources Observation Systems
ESA	Endangered Species Act (Federal Legislation)
ESRI	Environmental Systems Research Institute
ESU	Environmentally significant units
GIS	Geographic Information System
GMA	Growth Management Act (of Washington State)
IDs	Identification Numbers
NED	National Elevation Dataset
NRCS	National Resource Conservation Service
PBI	Pacific Biodiversity Institute
SEPA	State Environmental Policy Act (of Washington State)
SMA	Shorelines Management Act (of Washington State)
SRFB	Salmon Recovery Funding Board
USDA	United States Department of Agriculture
USGS	United States Geological Service
VAT	Value Attribute Table

WAC	Washington Administrative Code
WDFW	Washington State Department of Fish and Wildlife

DEDICATION

I dedicate this work to my gracious heavenly Father who has always believed in me.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In March of 1999, Chinook salmon (Oncorhynchus tshawytscha) in the Puget Sound Basin were listed as threatened under the Endangered Species Act (ESA). This critical situation has prompted efforts to address one of the major factors in salmon decline—habitat degradation and loss. This plight has created a difficult decision-making process for jurisdictions caught in the nexus of an ever increasing Puget Sound population, the habitat requirements of salmon, and limited budgets (Allen, M.A. and Hassler, 1986; Office of Financial Management, 2002, The Office of the Interagency Committee - Washington State, 2003a). The limitation in dollars for habitat projects calls for a solution that can bring the greatest collective good for salmon while using limited funds. Sometimes, unrealistic perceptions of where in-stream salmon population reside have focused restoration and/or preservation efforts in areas that may not produce the best protection for these salmon (Malcom, 2002). Perception should not be driving decisions because it can lead to misappropriated monies for ill-advised projects. The needed critical decisions on where to preserve or restore salmon habitat should be based on a holistic approach that evaluates the problem ecosystem wide, giving decision-makers rational, prioritized choices in which to focus limited monies.

1.2 INTENT OF RESEARCH

The intent of this research is to develop a means to determine sub-basins within a watershed that are most critically in need of appropriate actions in regards to salmon habitat conservation. The approach used in this study is based on developing a landscape based, cartographic model using Geographic Information Systems (GIS) technology. With this model, landscape factors that have known detrimental effects on stream environments are examined. The general categories of analysis in this model include landscape health, salmon presence, and potential risk to a sub-basin. In-stream factors, although important to the health of stream systems, are not addressed in this thesis. Instead, emphasis of this document is on terrestrial based factors that effect stream health.

From this analysis a determination and prioritization of sub-basins is made in regards to ecological actions and implementation order of both the ecological actions and remedial or restorative actions. Ecological actions include preservation, restoration, and structural best-management practices (BMPs). It should be noted that the landscape factors used in this research allow for a coarse assessment of habitat. This analysis is, thus, a first-line-of-defense approach that helps decision-makers focus their attention on the most pertinent areas for preservation or restoration, but does not necessarily address the specific habitat changes that need to take place.

In many ways, this approach is similar to the GAP Analysis methodology which locates ecological "gaps" (Jennings & Scott, 1997). In GAP, the intent is to identify at-risk areas so that decision-makers can target these areas for an ecologically beneficial action. This research not only addresses similar at-risk areas, but proposes a methodology to prioritize these areas so that the benefits to salmon can be maximized even if all enhancement projects cannot be undertaken.

1.3 STUDY AREA

To approach this problem, a case-study of the Green-Duwamish watershed in Western Washington was performed. This watershed is found in King County, an area that has a rapidly

Figure 1-1
WRIA 9 showing land cover over a hillshade model (Source: King Co., 2003)

growing population (The Office of Financial Management Washington State, 2002). The Green-Duwamish watershed is known as Water Resource Inventory Area 9 (WRIA 9) according to a delineation and classification made by the Washington State Department of Ecology.

WRIA 9 was chosen for this study not only because of its geographic location, resident salmon population, and demographics, but also because it displays the characteristic land-covers found in the Puget Sound region: forested, agricultural, suburban, and heavily urbanized areas (See Figure 1-1). These land-cover types each have their challenges in regards to salmon habitat destabilization. Because the Green-Duwamish contains these representative land-cover types, it is a very good choice as a case study to demonstrate the applicability of the proposed model throughout the Puget Sound basin.

1.4 QUESTION TO ANSWER

The primary research question pursued was:

- *How can a simplified prioritization model provide decision-makers with a means to narrow habitat enhancement project choices?*

Questions that need to be answered in order to develop a prioritization model:

- *What do the legal mandates require/inspire in protecting Chinook salmon?*
    - This is addressed in Section 2.3.B under Current Government Mandates
- *Is there an appropriate "scale" for this type of analysis?*
    - This is addressed in Section 2.3.B under Watershed planning and Watersheds in Washington.
- *What factors have an impact on habitat conditions for salmon?*
    - This is addressed in Section 2.4.D and 2.4.E
- *In landscape modeling, what tools seem appropriate for this type of analysis?*
    - This is addressed in Section 3.2.C

1.5 DOCUMENT ORGANIZATION

This document includes 6 chapters including this introduction. These include:

- Literature review. This examines the current literature and builds the case for the prioritization model.
- Introduction of General Model concept: This highlights why prioritization is needed and how a priority model can be implemented.

- Study Area review, Model review, and Input data chapter: This highlights the study area, introduces the specifics of the model, and examines the input data necessary for this model and how it was manipulated to "fit" into the model.
- Model results: This examines the findings from the model.
- Conclusions and Recommendations: This draws conclusions from the analysis and makes further recommendations to extend this research.

CHAPTER 2

LITERATURE REVIEW

This chapter introduces the salmon habitat problem further and then examines the life history of salmon—particularly the type of Chinook salmon found within the study area. It then discusses the population issue of the Puget Sound region and examines the legislative actions taken to protect salmon and their habitat. Watershed planning is then explored and a basin-wide approach is discussed. Finally, critical landscape parameters that affect the health of stream environments are examined.

2.1 INTRODUCTION

With the listing of Chinook salmon (Oncorhynchus tshawytscha**)** as threatened under the Endangered Species Act (ESA), the ever expanding population of Puget Sound citizens now needs to find a way to coexist with salmon. This ESA listing mandates that action must be taken to protect the salmon and their habitat and it must happen in a timely fashion. The ill effects and complexities of this concentrated population have made it difficult to protect salmon habitat.

Modern population growth that is amassed in a relatively limited land area creates urbanization. Urbanization, in its most obvious manifestation, creates a decrease in natural vegetation and an increase in imperious land cover (May, Horner, Karr, Mar, and Welch, 1997). May et al. (1997) found that an increase in urbanization resulted in significant changes in watershed or basin hydrological regime. It should be noted that other land-uses, such as agriculture and forest practices, can also have a dramatic effect on watershed hydrology. According to May, et al. (1997), these human induced alterations are the leading cause for the overall changes observed in in-stream physical habitat conditions. In other words, these land-uses and their associated impacts can dramatically decrease the viability of salmon due to habitat degradation. Therefore, these sectors of land-based influence need to be addressed in order to alleviate the problems associated with habitat decline for salmon. It will be the job of the various jurisdictions in the Puget Sound region to constructively deal with these problems and propose reasonable solutions and alternatives.

Of course, the crucial decisions in regards to protecting salmon habitat involve the balancing of critical resources---namely time and money---which are the practical means to bring about habitat conservation (The Office of the Interagency Committee, 2002; The Office of the Interagency Committee, 2003b). Also, tools are needed to evaluate the “where” and “how” to accomplish this habitat conservation within the bounds of these limitations.

But before the where and how can be evaluated, there needs to be a basic understanding of the “what” and the “why.” The “what” involves understanding the background information, both about salmon and about the factors in their decline. More specifically, understanding the major causative factor behind the decline of Puget Sound Chinook salmon involves understanding the impact of human population growth in the Northwest (Section 2.3.A); and understanding salmon involves a view into their life cycle and their basic habitat requirements (Section 2.2). After gaining this background information, there also needs to be an understanding of the “why,”---why is there a need to protect salmon? This is embedded both in the basic fact that certain populations and species of salmon are in decline and in legislative mandates that protect salmon (These are covered in Sections 3.1.C and 2.3.B).

Within the framework of this background information, this research deals primarily with the critical questions of "where" and "how" salmon habitat conservation can take place. The "where" is addressed by proposing a watershed based approach that examines the habitat problem in an ecologically holistic sense (See Section 2.4). As discussed earlier, the Green-Duwamish watershed, located in King County, Washington was chosen as a case-study watershed for this research. The 'how' is addressed both by the analysis tool chosen for this research, Geographic Information System (GIS) technology, and the general strategy of prioritization of sites based on an analysis of specific landscape attributes (See Sections 3.1 and 3.2.C).

2.2 SALMON

2.2.A Life of salmon

The life cycle of salmon is generally similar among the differing species and ancestral lines (often referred to as Environmentally Significant Units or ESU's (National Marine Fisheries Service, 2003)) found in the Pacific Northwest.

As shown in Figure 2-1, the life for any Pacific Northwest salmon begins with an incubation period followed by emergence (alevin stage), freshwater rearing (fry stage), estuary rearing (smolt stage), migration to the Pacific, ocean growth, returning to spawn, and spawning with death following soon after the fish have spawned.

Yet, even for these basic life cycle similarities, the differing salmon species and ESU's show distinct variations in the timing and length of residence in each phase of the cycle (Groot and Margolis, 1991, p. 314). Examples of this include the fact that a juvenile Chinook salmon and a juvenile Coho salmon will differ considerably in the amount of time they spend in a river system. Or, Chinook salmon from differing ancestral lines can vary in the time of year of their spawning runs, the length of juvenile freshwater rearing, or the residence time in the estuary. (Groot and Marjolis, 1991)

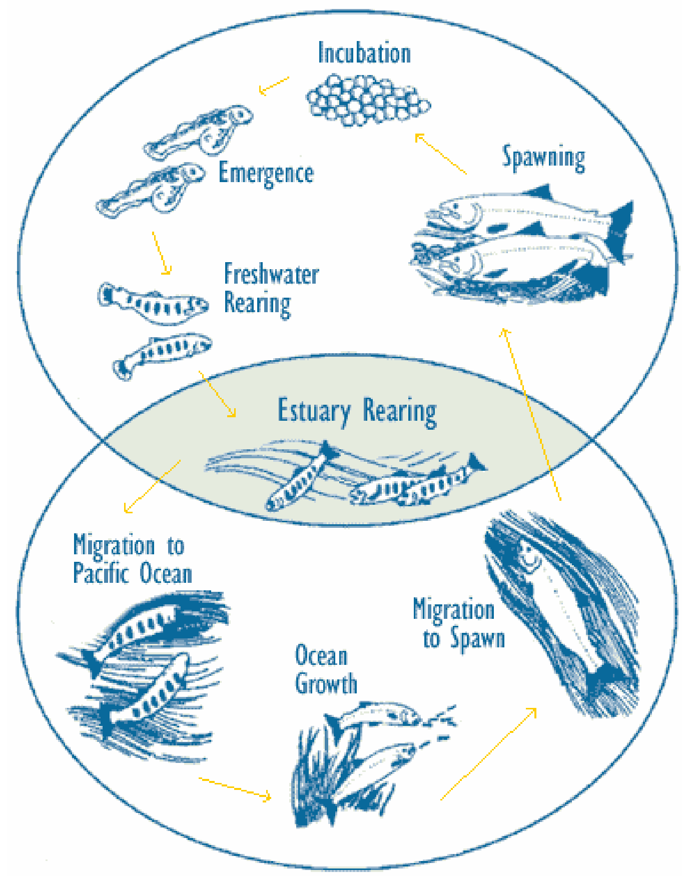

Figure 2-1
Life cycle of salmon (Source: WADOE, 2003)

Within this general life cycle, a salmon will experience many difficulties, both from natural predators and from man's influence. These dangers come at all stages in the cycle, but the early stages of life for salmon are especially fraught with the potential for disaster. A study conducted by Allen and Hassler (1986) noted that salmon eggs are particularly vulnerable to shock injury. Such injuries include gravel movement caused by bottom scouring and/or mechanical impaction. Other causes of egg mortality include low dissolved oxygen, high concentrations of toxic chemicals, excessively high water temperatures, and heavy sedimentation (Allen and Hassler, 1986).

Not only can eggs be affected by their environment, but emerging alevins are also affected by such things as gravel movement. Alevins often submerge themselves deeper into the gravel after emergence, and, thus, are endangered when it is disturbed (Allen and Hassler, 1986). Also, alevins remain relatively inactive until the fry stage unless they are forced to disperse in response to excessive levels of carbon dioxide, metabolic waste, or to avoid low flow conditions (Allen and Hassler, 1986). This suggests that they are very sensitive to their surrounding conditions. Any disturbance which causes alevins to disperse may in turn make them vulnerable to other dangers.

The perils for salmon at the fry stage include such things as an inadequate food supply, competition for food, or predation. And once the fry make the transition to the estuary, becoming smolts, they may find that there is not adequate habitat in which to acclimate themselves to the salinity of the ocean (City of Seattle, 2001). These struggles represent only some of the problems juvenile salmon may experience, but many of these struggles can be attributed to habitat issues which are influenced by the condition, or “health,” of the adjoining upland environment.

2.2.B Chinook Salmon

Chinook salmon are also popularly known as king salmon, but have also been called tyee, quinnat, and spring salmon (Allen and Hassler, 1986).

> Chinook salmon belong to the family Salmonidae and are one of eight species of Pacific salmonids in the genus *Oncorhynchus*. Chinook salmon are easily the largest of any salmon, with adults often exceeding 40 pounds; individuals over 120 pounds have been reported. Chinook salmon are very similar to Coho salmon in appearance while at sea (blue-green back with silver flanks), except for their large size, small black spots on both lobes of the tail, and black pigment along the base of the teeth. Chinook salmon are anadromous (adults migrate from a marine environment into the fresh water streams and rivers of their birth) and semelparous (spawn only once and then die). (Chinook Salmon, 2001).

2.2.C Green and Dumamish Chinook Salmon

Historically, the Green/Duwamish system—which is a part of the Puget Sound basin—supported two separate runs of Chinook salmon, both a spring run and also a summer/fall run. "Presently, only summer/fall run Chinook are thought to exist as a self-sustaining population, although spring Chinook are occasionally found in the system" (City of Seattle, 2001, p. 59). This population of summer/fall Chinook salmon that inhabit the Green/Duwamish basin are considered "ocean-type" Chinook (City of Seattle, 2001, p. 59). Ocean-type Chinook juveniles reside in the fresh-water portion of the river for a shorter amount of time than Chinook known as "river-type." (Figure 2-2 shows that juvenile rearing for Green/Duwamish Chinook is in months, not years, as for river-type Chinook). But, ocean-type Chinook also spend more of their river phase rearing in the estuary portion of the river than their "river-type" cousins. Although this estuary rearing period is not of extended duration—most of the fish in one study spent about 2 weeks in the estuary (Warner and Fritz in City of Seattle, 2001)—it represents a time when the juveniles grow significantly as they prepare to enter salt-water. One study discovered that hatchery

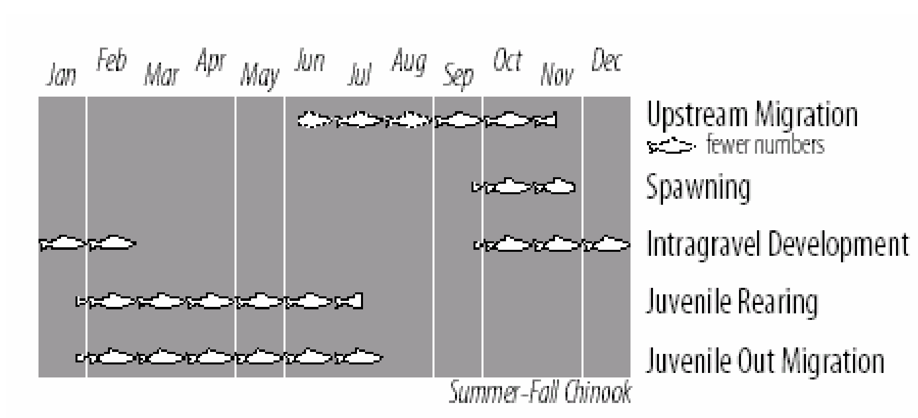

Figure 2-2
Graph showing in-stream durations of Green/Duwamish Summer/Fall Chinook salmon (Source: King County, 2003)

Chinook increased their body weight an average of 70 percent during the period between release and recapture in the estuary (City of Seattle, 2001, p. 61). This fact speaks of the importance of the estuary in not only the acclimation of juvenile salmon but also in their growth in preparation for life in salt-water.

Salmon face many other obstacles, including survival in the ocean phase and then the often treacherous journey back to their birthplace. When Chinook salmon return to the Green/Duwamish, their passage back to their spawning areas is relatively quick. Adults hold in the lower river (Duwamish to Kent area) until temperature and flow are adequate—which often is in mid-September. But, mainly, adults move through the estuary in a matter of days (City of Seattle, 2001, p. 59). It is critical that adults have clear passage back to their main spawning areas.

When adult female Chinook salmon reach their spawning grounds, they prepare a spawning bed, called a redd, in a stream area with suitable gravel composition, water depth and velocity. The adult female Chinook may deposit eggs in 4 to 5 "nesting pockets" within a single redd. After laying eggs in a redd, adult Chinook will guard the redd from 4 to 25 days before dying (Chinook Salmon, 2001).

In terms of survival, in-stream habitat issues are more critical for juvenile salmon then they are for the adults. Juveniles depend on the river to sustain them in the critical first months of life while adults return to the river only briefly to spawn and give themselves back to the ecosystem. The critical issue of in-stream habitat is then mainly focused on the viability of the early life stages of salmon but is also concerned with the fact that in-stream habitat must be healthy enough to provide a place for adult salmon to reproduce.

2.3 PEOPLE AND POLICY

2.3.A Population Growth

Population growth in the Pacific Northwest has been increasing at a rapid pace over the last 60 years. This is especially evident in King County, which includes Seattle, the most populous city in Washington State. King County has gone from a population of approximately 500,000 in 1940 to a population of over 1.7 million people in 2000 (Office of Financial Management Washington State, 2002) (See Figure 2-3 below). This population is clustered mainly in the western portion of King County on the shores of Puget Sound and also surrounding the large freshwater lake known as Lake Washington.

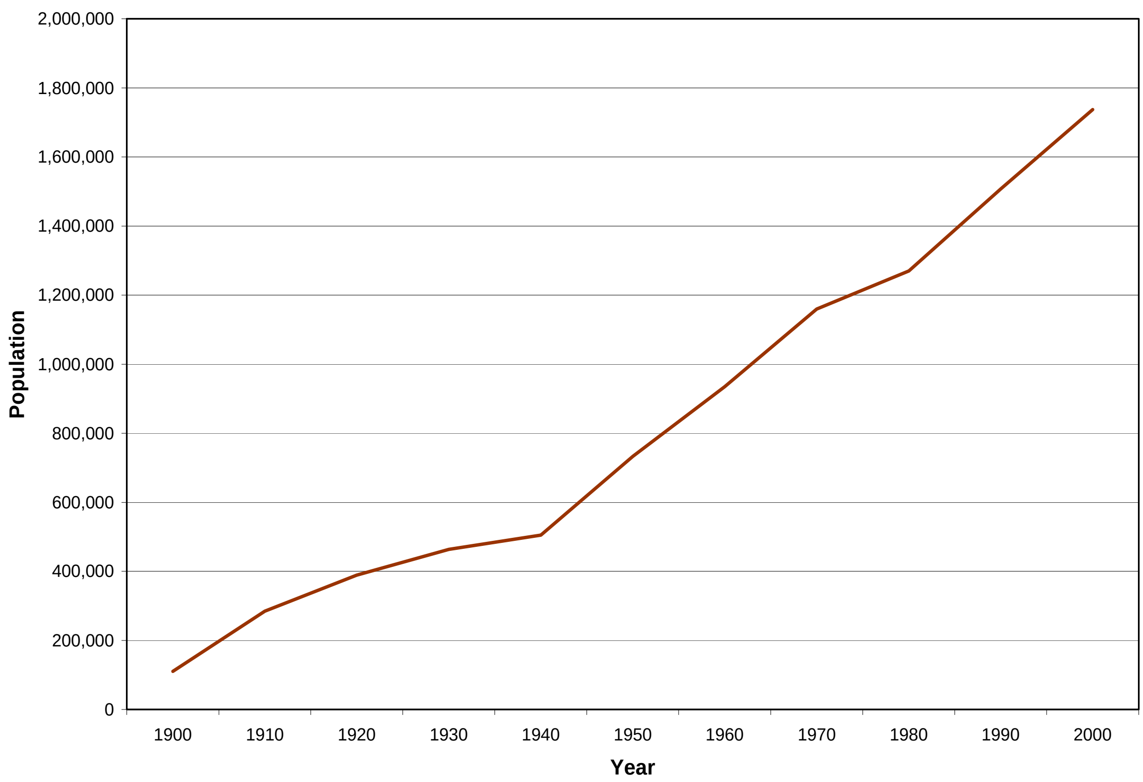

Figure 2-3 Population Change for King County 1900-2000 (Source Office of Financial Management, 2002 August)

This concentrated population has affected many of the rivers and streams that salmon have historically populated, including the Green/Duwamish river system (The Green and Duwamish Rivers are one continuous river system). At one point, this river flows through one of the most industrialized portions of Seattle, and because of this encroaching industrialization the river has seen extensive alteration. Amazingly, though, salmon have found a way to survive in these altered conditions.

2.3.B The Policy Direction of Salmon Protection

Current Government mandates/legislative action to protect salmon habitat

Puget Sound Chinook salmon were listed as threatened on March 24, 1999 (Puget Sound ESU listed endangered, 1999). A threatened listing means “likely to become endangered within the foreseeable future throughout all or a significant portion of its range” (16 USC Section 1532(6), (19)), (Parametrix, 2002, p. 1_5).

The ESA listing was put forth by the National Marine Fisheries Service (NMFS), the federal governing body that is accountable for animals that spend most of their lives in marine waters, including anadromous fish such as Pacific salmon. The listing was based on several factors of decline, including habitat, hydroelectric projects and flood control, harvest of salmon, and hatchery operation impacts (often referred to as the 4 H’s) (Parametrix, 2002, p. 1_5).

Because of this listing, a process to apply the mandates of the ESA was begun in the Northwest region. The sections of the ESA that apply to Pacific salmon and their habitat include Section 7 (controlling federal agencies’ actions), Section 4(d) (controlling state, local, tribal jurisdictions or individual’s actions), and Section 10 (Habitat Conservation Plans). It should be noted that the ESA basically provides “broad-brush emergency protection until local safeguards become effective,” (Salmon Recovery, n.d.) – therefore it puts the onus on local government entities to come up with specific protection measures to fulfill the requirements of the law.

Section 4(d) is the section that is of primary concern to state, local, and tribal jurisdictions. Within Section 4(d) is specific language that prohibits the “take” of a threatened or endangered species without specific authorization. “Take” is defined as, “harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct.” (ESA section 3[19]). “Harm” is defined as an act that actually kills or injures a protected species (50 CFR 222.102 (64FR 60727)). Harm can arise from significant habitat modification or degradation where it actually kills or injures protected species by significantly impairing essential behavioral patterns, including breeding, spawning, rearing, migrating, feeding, or sheltering (National Marine Fisheries Service, 2000).

While the language used in Section 4(d) is rather broad, any action that does not interfere with salmon survival and recovery can be allowed under the ESA. It is this take prohibition “exemption” that state, local, and tribal jurisdictions are seeking to obtain by submitting written plans (including Habitat Conservation Plans or HCPs) to the NMFS that outline how their specified actions will not constitute an illegal take, but rather what is termed an “incidental take.” Jurisdictions proposing development actions that they believe will not result in undue “take” must demonstrate how these actions will not excessively interfere or do harm to salmon and their habitat. If these actions, which are known individually as “incidental take” actions, are allowed by NMFS, then they are exempt from the take provision of the ESA.

The local government plans being submitted to NMFS are of direct concern to the research presented in this thesis because of the habitat management provisions that these plans have instituted to meet the conditions of section 4(d). In short, these provisions are being put in place so that actions that could affect salmon habitat do not impair properly functioning habitat, appreciably reduce the functioning of already impaired habitat, or retard the long-term progress of impaired habitat toward properly functioning habitat conditions (Parametrix, 2002, p. 1_7).

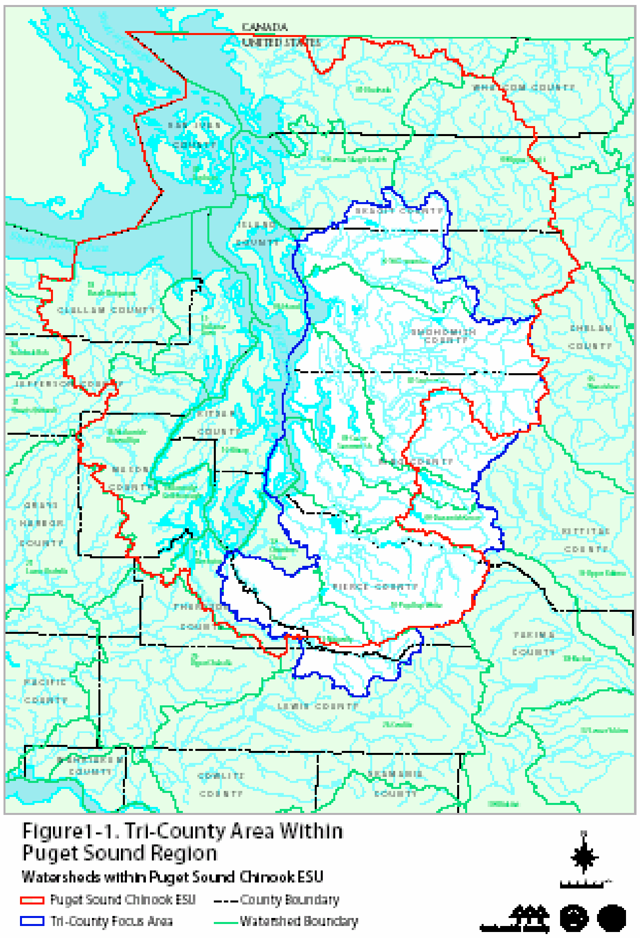

Figure 2-4
Tri-County Area within Puget Sound Region (Source: King County, 2003)

Currently, a local commission formed from representatives of all the jurisdictions within the three county region (King, Pierce, and Snohomish Counties) shown in Figure 2-4 is providing oversight to guide the direction of local entity 4(d) take provisions. This group is known as the Tri-County Commission. Their oversight has provided a general "model" (*from here on it will be referred to as the Model*) for how local jurisdictions can institute plans that will meet the 4(d) requirements. In general the Model is implemented by local jurisdictions in the following manner:

> Once the biological review is complete, local jurisdictions will have the following implementation options. These options are intended to provide each jurisdiction with the flexibility to determine how the Model best fits its particular circumstances.
>
> Implement the Land Management and Stormwater Management Programs as outlined in the Model and participate in the WRIA Based Planning, Monitoring and Adaptive Management, and Habitat Acquisition and Restoration Funding Programs. A jurisdiction would obtain a take limit under Limit 12 in the NMFS 4(d) Rule at such time as NMFS approves the jurisdictions's legislative or administrative actions to: 1) adopt necessary regulations and 2) commit to a schedule to implement all other programmatic elements. The Regional Road Maintenance ESA Program Guidelines could be adopted individually as a stand-alone program, without implementation of WRIA Based Planning and the Habitat Funding Programs.
>
> 1. Based on the specific circumstances or conditions in a watershed or the policy choices of a jurisdictions, a jurisdiction may propose and implement a modified Land Management Program, Stormwater Management Program, or both, plus all of the Model's long-term programs (including WRIA Based Planning, Monitoring and Adaptive Management, and Habitat Acquisition and Restoration Funding)...Jurisdictions proposing a modification would also need to demonstrate to NMFS that the modified 4(d) program provides protection equivalent to the Model program. Take limitations and/or reduction or elimination in take prohibition would apply once a jurisdiction adopts ordinances or rules and NMFS approves them, as noted in 1 above.
>
> 2. Use the Model to guide revisions to the jurisdictions's existing regulations and programs governing MRCI *[municipal, residential, commercial, and industrial]* development and redevelopment to achieve greater salmonid conservation protection and thereby reduce risks of take liability or third party actions without applying to NMFS for a formal 4(d) Rule on take limitation. This option would allow a jurisdiction to improve its regulations and programs to reduce risk on a schedule and to an extent that it determines is achievable given its specific circumstances. While this option would not directly qualify a jurisdiction for a take limit, it would allow a jurisdiction to later apply for a take limit if that jurisdiction later chose to fully implement the Model programs or a modified version of the program, as described in 1 or 2 above (Parametrix, 2002, p. 1_11).

As these points suggest, the Model provides a framework in which local jurisdictions can meet the requirements of the ESA. This Model is to work in conjunction with legislation and regulations that already exist in Washington State. These bodies of legislation include the Growth Management Act (GMA) and the Shorelines Management Act (SMA).

> Under the Washington State Growth Management Act (GMA), all cities and counties in the Tri-County region are required to adopt development regulations that designate and protect critical areas (RCW Chapter 36.70A). Critical areas include wetlands and fish and wildlife habitat conservation areas (RCW 36.70A.030(5)), and cities and counties are required to designate and protect these areas (RCW 36.70A.060 and 36.70A.170). Development regulations must be based on best available science, with special consideration given to measures necessary to preserve or enhance anadromous fisheries (RCW 36.70A.272).
>
> Washington's Shoreline Management Act (SMA) establishes a comprehensive program for the protection of Washington's marine shorelines and larger rivers and lakes (RCW Chapter 90.58). Cities and counties throughout the state are required to adopt shoreline master programs that meet these goals. These shoreline master programs must be approved by the Washington State Department of Ecology (Ecology) before they are implemented (Parametrix, 2002, p. 1_4).

Other applicable bodies of legislation include the Federal Clean Water Act (Originally: 33 U.S.C. 1251 - 1376; Chapter 758; P.L. 845, June 30, 1948; 62 Stat. 1155 and as amended in 1977 by P.L. 95-217), the Washington State Environment Policy Act (SEPA) (Chapter 43.21C RCW) and Washington State's Forest and Fish law also known as "Forests and Fish forever" (ESHB 2091), and the Comprehensive Watershed Planning Act (90.82 RCW).

The Federal Clean Water Act (P.L. 95-217) is the principal federal legislation directed at protecting water quality. The purpose of the Clean Water Act includes "the protection and propagation of fish, shellfish, and wildlife."   In Washington State, the Federal government's Environment Protection Agency (EPA) has delegated its Clean Water Act authority to the

Washington State Department of Ecology (DOE) (Washington Forest Protection Association, 2002b).

> "The SEPA provides a way to identify possible environmental impacts that may result from governmental decisions. These decisions may be related to issuing permits for private projects, constructing public facilities, or adopting regulations, policies or plans" (The State Environmental Policy Act, 2002).

The Forest and Fish law mandates more "fish friendly" forest practices rules to protect riparian and aquatic resources. This law is specifically applicable to private forestland management and is based on recommendations from a report that was formulated by a coalition of scientists, regulators, and policy makers from Washington State's private forest landowners; federal, state, and county governments; and Native American tribes (Washington Forest Protection Association, 2002a).

The Comprehensive Watershed Planning Act (ESHB 2514, Chapter 90.82 RCW) establishes a framework for developing local solutions to water issues on a watershed basis. This program is optional and allows citizens, local governments, and tribes to join together in collaboration to help manage the water resources found within their respective watersheds. Currently program participation is encouraged through a grant program administered by the state. Unfortunately, the habitat element of the plan is optional, but a watershed plan must at least include a water quality assessment (Municipal Research and Service Center of Washington, 2003).

These bodies of legislation have, for the most part, guided the protection of resource lands even before the salmon were listed as threatened under the ESA. This means that many jurisdictions already have regulations and guidelines in place to protect valuable resource lands. Still, these jurisdictions cannot assume that their current regulations will meet the requirements of the 4(d) rules. Therefore, they will need to reassess their regulations and guidelines to make sure they currently meet the 4(d) rule requirements. Tri-County has put their 4(d) response Model in place to help assist in this evaluation. This Model will also assist jurisdictions in the implementation of new regulations if they currently have none in place.

Watershed planning

For many years now, federal and state legislation pertaining to environmental law has had an emphasis on using the "best available science" to guide action and to determine the course in decision making processes. For example, the ESA clearly states that the "best scientific resources" will be used in determinations regarding endangered species (U.S. Fish and Wildlife Service, n.d. a). Also, the Governor of the State of Washington and the Washington State Joint Natural Resources Cabinet, in the "Statewide Strategy to Recover Salmon (or the Strategy)," says that "[i]n the context of the Strategy...the best scientific information available on a subject will be used to inform related public policy decisions." (Washington State Joint Natural Resource Cabinet, 1999, p. III 42.) In terms of salmon habitat viability, the best science available is focused on a holistic approach to understanding the dynamics of the landscape. This is clearly stated in the Strategy when it says,

> A conceptual scientific foundation helps clarify what is known and not known about watershed and ecosystem dynamics in relation to salmon conservation and recovery. It provides a way to view needs and issues using a *more holistic, ecosystem approach*, [emphasis mine] rather than in piecemeal or single-issue fashion. (p. III 43)

In the light of past regulation and its implementation, it is important to have a holistic approach when addressing the issue of salmon habitat protection. The benefits of watershed based planning, as discussed above, then are two-fold: to minimize the piecemeal approach of the past and to drive towards long term success for the future health of the ecosystem (Beechie, Roni, and Steel, 2003).

Watersheds in Washington (WRIA's)

In Washington State, the overall ecosystem approach in regards to salmon habitat is based on the hydrological system, and more specifically the watershed. As Reid (1998) says, "[a]n understanding of cumulative watershed effects is necessary if land-use activities and restoration projects are to be designed that accomplish their intended objectives" (p. 476). Another viewpoint states:

> The watershed is the proper scale for effective salmon habitat conservation. The biological and physical context of a watershed is necessary for identifying ecosystem issues in the watershed, for understanding the effects of humans on salmon and their habitat, and for designing locally-based conservation strategies that can be meaningfully linked to efforts at regional scales (Washington State Joint Natural Resources Cabinet, 2001, p.6).

As mentioned above, the Comprehensive Watershed Planning Act establishes a decision making process based on this watershed level framework. The watershed management units within Washington State are known as Water Resource Inventory Areas (WRIA). (WRIA's were established by the Water Resources Act of 1971 and roughly resemble the Federal Hydrologic Unit Code Boundaries (HUC's)).

2.4 FOCUSING ON WATERSHEDS FOR THE BENEFIT OF SALMON

2.4.A Assessing watersheds

One of the first stages in a proper perspective of watersheds, or WRIA's, is the assessment of the condition of the watershed (Washington State Joint Natural Resources Cabinet, 2001). As Washington State's Guide to Watershed Assessments (Washington State

Joint Natural Resources Cabinet, 2001) makes clear, proper assessment helps one to see how a watershed is functioning and how it responds to natural and human disturbances. With respect to assessments, the guide says,

> [A]ssessments should help us understand
> - How a watershed "works."
> - How these changes affect salmon and their habitat today and in the future.
> - What needs to be done and where to protect and/or return the habitat to a productive state for salmon. (Washington State Joint Natural Resources Cabinet, 2001, p. 3)

Goodwin (1996) states that watershed condition is a factor of the vegetation, soils, morphology, and hydrology modified by climatic and geologic conditions working within this watershed. Naimen, Fetherston, McKay, and Chen (1998) also discuss the effects of geomorphology and physical processes on stream environments. It is these processes that are the "workings" of the watershed and it is their modification that affects salmon and their habitat. But before addressing the spatial location of protection – the where – an understanding of what needs to be done is also important.

2.4.B Watershed Preservation and Restoration

Certainly what is needed is a strategy to protect salmon habitat on a watershed-wide basis. The *preservation* of ecologically healthy land areas within a watershed is a good starting point for a salmon habitat protection strategy. But, because of the problem of urban encroachment in land areas that ultimately affect in-stream salmon habitat, there is also a need for *restoration* within the watershed. Both of these land management options, preservation and restoration, are addressed in the Tri-County Model 4(d) Response Proposal (2002).

Preservation involves setting aside and managing natural land areas within the watershed that provide an ecological service beneficial to salmon habitat. Management of these areas is often "no-touch," meaning that they are excluded from any timber harvest, brush clearing, or any activity that would disturb the natural vegetation. The key is that the areas that are set aside benefit salmon habitat and are protected so that they can, more or less, continue through natural succession with minimal interference from humans.

Watershed restoration involves the return of the river's ecological system back to a state where it can function in a more self-sustaining manner and to a condition that more closely resembles its former order before anthropogenic influences (Ebersole, Liss and Frissell, 1997). Van Diggelen, Grootjans, and Harris (2001) have divided restoration into three directions or goals: reclamation, rehabilitation and true restoration. Each of these forms of "restoration" have an improved effect on the environment, but only true restoration attempts to restore the prior ecosystem. Reclamation may increase system biodiversity, but not necessarily benefit an endangered species; rehabilitation might make a system seem more "natural" but would not necessarily result in a significant increase in biodiversity. It is only true restoration that attempts to restore previous functions of the ecosystem along with its characteristic species, communities and structure (van Diggelen et al., 2001).

It is important to note that for scientists such as Ebersole, et al. (1997), restoration does not mean returning to some "pristine" condition but rather removing or minimizing the effects of human-induced change so as to allow a range of natural successional trajectories to re-emerge from the environment. Therefore, restoration can be seen as an attempt to restore ecological functions by removing the influence of humans, returning natural vegetative communities to a state where they can be successful in their successional stages, and allowing these natural communities to mature to a state of self-sustainability.

This type of restoration is what the Tri-County commission is aiming for. The Tri-County Model 4(d) Response Proposal states that one of its biological objectives is "[t]o maintain, if adequate, and restore, if inadequate, the biological communities that support recovery and sustainability of the species." The Model also states that one of its habitat objectives is "[t]o provide for habitat-forming processes crucial to maintaining and restoring aquatic and edge habitats" (pp. 2-8 and 2-9). From these objectives we can see that preservation and restoration efforts in the Tri-County region are not focused on returning an ecosystem to some pre-development state, but rather on facilitating the reestablishment of relatively more natural ecosystem processes.

2.4.C Watershed Protection through Best Management Practices

The application of preservation and restoration efforts can have a dramatic effect on the health of a watershed. These practices fall generally under what are known as Best Management Practices or BMPs.

Washington State Department of Ecology (WA-DOE) (2001) defines Best Management Practices as:

> "[S]chedules of activities, prohibitions of practices, maintenance procedures, and structural and/or managerial practices, that when used singly or in combination, prevent or reduce the release of pollutants and other adverse impacts to waters" (p. 1-4)

As the name implies, BMPs are the best available practices that, based on research and experience, can control impacts to surface waters. The concept of Best Management Practices fits very well with the stated goal in salmon conservation of using the best available science to facilitate protection strategies.

> "The primary purpose of using BMPs is to protect beneficial uses of water resources through the reduction of pollutant loads and concentrations, and through reduction of discharges (volumetric flow rates) causing stream channel erosion" (WA-DOE, 2001, p. 1-4).

BMPs fall generally into three categories: Source control, treatment, and flow or runoff control. Source control is concerned with reducing impacts by stopping discharges at the source. This is generally the most efficient and least costly type of BMP to apply (WA-DOE, 2001). Treatment, as the name implies, involves facilities that remove pollutants by some physical process. Flow control BMPs are those that control the "rate, frequency, and flow duration of stormwater surface runoff" (WA-DOE, 2001, p. 1-5).

BMPs can also be defined by the difference between procedural (non-structural) and structural applications (D'Arch & Frost, 2001). Procedural BMPs are more concerned with changing behaviors that would decrease pollutant loads and runoff; structural BMPs are physical changes to the environment that reduce the level of pollution and the amount of runoff. Most often, structural changes are what are commonly considered BMPs.

As was stated above, in a broad sense, preservation and restoration are BMPs. Preservation often comes in the form of land acquisition or conservation easements. Restraints may also be applied in the preservation zone so that no further disturbances occur—these types of restraints would be considered more procedural.

Restoration can include many practices that eventually return a watershed to more naturally functioning ecosystem processes. This can include the creation of riparian zones, the introduction of large woody debris (LWD) into the stream environment, replanting of native vegetation along the stream bank, or the re-establishment of adjacent wetlands. All of these can be considered structural BMP applications.

Although preservation and restoration can broadly be classified as BMPs, these practices have already been defined in this document with specific meanings. Therefore, BMPs will refer more to structural and procedural controls that commonly are applied in areas where preservation or restoration are feasibly unrealistic. These types of BMPs are those that attempt to minimize the impacts of pollutants and control the amount of runoff often found in urban and sub-urban areas. Examples of these BMPs include vegetated filter strips, porous pavers, constructed retention ponds, wet vaults, bioswales, and oil/water separators. Although these are all structural BMPs, procedural BMPs can also be applied in these areas including educating the public on issues such as the correct storage and disposal of hazardous chemicals and the removal of debris from roads/driveways by sweeping instead of spraying water.

2.4.D Watershed Health Factors and Indicators

Impervious Surfaces

"Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil" (Arnold and Gibbons, 1996, p. 244). The amount of impervious surface coverage has dramatically increased within the Puget Sound lowlands because of sustained, regional urban growth over the last 60-70 years (Moscrip and Montgomery, 1997). As Arnold and Gibbons (1996) point out, impervious surface concentrations can indicate the growing presence of urbanization, and this is certainly true in the Puget Sound region. But, most importantly, impervious surfaces are major contributors to the environmental impacts of urbanization. "As the natural landscape is paved over, a chain of events is initiated that typically ends in degraded water resources. This chain begins with alterations in the hydrologic cycle, the way the water is transported and stored" (Arnold and Gibbons, 1996, p. 244).

In Schueler's (1995) research, he proposed a classification system for sub-watersheds, which are sub-units of watersheds, based on the level of impervious percentages. These classifications basically demarcate the environmental condition of the sub-watersheds. The classes according to Schueler are:

- sensitive: 0-10% impervious
- degrading: 11-25% impervious
- non-supporting: 26-100% impervious.

Another system introduced by Arnold and Gibbons (1996) defines the categories as:

- protected: less than 10% impervious
- impacted: 10%-30% impervious
- degraded 30%-100% impervious

These divisions are based on scientific evidence showing negative changes in water quality and/or quantity at the break points of these categories. For example, the point at which steam-bank stability is compromised is at about 10% imperviousness (Booth, 1991, and Booth and Reinelt, 1993 in Schueler, 1995); runoff is increased by a factor of 5 to 10 for storms smaller than one year storm events when imperious levels are relatively low (imperviousness of 5-10%) (Hollis, 1975 in Schueler, 1995); fish in headwater streams—especially sensitive species such as trout—were vacant when imperviousness increased from 10-12% (Schueler and Galli, 1992 in Schueler, 1995). Another study (Luchetti and Feurstenburg, 1993 in Schueler, 1995) also found that Coho salmon, which, like all salmon are very sensitive to their environment, were seldom found in watersheds with 10 or 15% imperviousness. Also, according to Schueler's (1995) research, pollutant loading exceeds background levels for most of the common pollutants affecting streams once watershed imperviousness increases beyond 20-25%. Aquatic insect, or macroinvertibrate, diversity drops sharply at the 10-15% impervious level (Klein, 1979 in Schueler, 1995). Aquatic insects are, of course, a very important part of the ecosystem for salmon because they are a main food source. All of this varied evidence points to the applicability of using impervious surface percentages as an indicator of stream health.

A study done by Moscrip and Montgomery (1997) indicates that the effects of urbanization on stream health also influence the viability of salmon. In their study, they examined six Puget Sound lowland streams and found a correlation between increasing urbanization—often referred to in their study as increased imperviousness—and the decline of salmon species. Although their study did not directly measure imperviousness, but instead the change in urbanization through a numeric count of structures, they did say that,

> "[t]he construction of impervious surfaces during urbanization alters runoff generation mechanisms by reducing the effective permeability of the soil. The associated increase in rapid runoff by overland flow leads to increased flood flows which alter stream morphology through increased channel width or depth" (Moscrip and Montgomery, 1997, p. 1289).

They go on to report other changes in stream ecology caused by increased urbanization and increased flood frequencies including streambed scour, alteration of riparian zones, and the deleterious impact on aquatic fauna. Of course, all of these impacts damage valuable salmon habitat.

The focus of Moscrip and Montgomery's (1997) study was on the change in flood frequency found in the six study basins. Four of the basins (Flett Creek-study listed current imperviousness as 50% , Juanita Creek-40%, Mercer Creek-65%, and Swamp Creek-40%) showed significant increases in urbanization over the studied time period. These basins also showed a significant increase in flood frequency, which they postulated was the result of increased impervious surface creation. (Note: This was only postulated after examining the rainfall records for the study time periods and finding a decrease in rainfall over that same time span, thereby eliminating the possibility that increased rainfall could have caused increased flood frequencies). The other two basins (Coal Creek-study listed current imperviousness as 14% and May Creek-11%) had a smaller increase in urbanization when compared to the other four basins and neither basin showed an appreciable increase in flood frequency over the study time period (Moscrip and Montgomery, 1997).

Sufficient data to compare salmon counts between basins in the Moscrip and Montgomery study (1997) was limited to three of the basins: Swamp Creek, Fleet Creek (the urbanized basins), and May Creek (the less urbanized basin). The urbanized basins showed a weakly correlated, but significant trend towards salmon decline, while the less urbanized basin's trend was insignificant. Although the trend is weakly correlated, there is enough significance in the study data to suggest that increased urbanization in the form of impervious surfaces can lead to salmon decline.

Functional components and effectiveness of imperviousness

Schueler (1995) points out two anthropocentric functional components for imperviousness – rooftops and the transport system (roads, driveways, and parking lots). Natural forms of imperviousness also exist which include elements such as bedrock outcrops and compacted soils (i.e. wild animal compaction). Schueler (1995) contends that it is the transport system that is the major contributor to urbanizing watershed imperviousness. This is validated in a study done by the City of Olympia (1994) where transport related imperviousness ranged from 62% in a predominately single-family residential development to 70% in a commercial development.

Impervious surfaces can not only be represented by the percentage of coverage in a basin, but also by their functional components, such as sidewalks, roads, rooftops, etc (Arnold and Gibbons, 1996). This categorization of imperviousness has also been further characterized by the City of Olympia (1994) for its “effectiveness” – the amount of runoff from the impervious surface that is actually conveyed to a stream.

The effectiveness component of impervious surfaces is often alleviated by the surroundings of the surface. This is especially true in residential settings. For example, rooftop impervious surfaces generally drain to an adjoining lawn or permeable area, whereas a roadway or parking lot generally drains directly to a stormwater system. The Olympia study (1994) estimates that impervious areas in low-density residential developments are 40% effective, meaning that 40% of the runoff enters the stream system, whereas commercial and industrial areas are close to 100% effective, or close to 100% of the runoff enters the stream network. Even when a watershed basin has a relatively high amount of impervious surfaces, the presence of riparian zones, or vegetated zones around surface water sources such as lakes and streams, can have a buffering effect that can benefit the health of the waterway.

Riparian Zones

Riparian Zones Defined

Riparian areas or buffer zones have been defined in many ways. One example is,

> "[a] riparian habitat area (RHA) is defined as the area adjacent to aquatic systems with flowing water (e.g., rivers, perennial or intermittent streams, seeps, springs) that contains elements of both aquatic and terrestrial ecosystems which mutually influence each other" (Washington State Dept. of Natural Resources--- Knutson and Naef, 1997, p.5).

Naimen, Bilby, and Bisson (2000) state that riparian areas possess distinct ecological characteristics because of their interaction with the aquatic system. Thus, their boundaries can be delineated by changes in soil conditions, vegetation, and other factors that reflect this aquatic-terrestrial interaction. Still another definition from the U.S. Fish and Wildlife Service (n.d.b) says,

> Riparian areas are plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: 1) distinctively different vegetative species than adjacent areas, and 2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland.

These definitions highlight the complexity that riparian areas possess. As Naimen et al. (1998) found,

> "[r]iparian forest of the Pacific coastal ecoregion are floristically and structurally the most diverse vegetation of the region...exert[ing] strong influences on adjacent ecological systems by modifying the flow of materials and information (i.e. sound, visual communication) across the landscape."

May et al. (1997) found that natural riparian corridors along Pacific Northwest streams are among the most diverse, dynamic and complex ecosystems in the region.

Although riparian areas usually make up a small percentage of a watershed land-wise, their influence is far reaching within the hydrologic system. Riparian forests are critical to watershed health, yet insufficient attention is paid to their condition (Naimen, Fetherson, McKay, & Chen, 1998). And insufficient attention can have dramatic ramifications because riparian forest alterations have effects that go far beyond the initial site impact, often creating consequences felt throughout the entire river corridor (Naimen et al. 1998). These alterations are critical, even if they are relatively small in land area because riparian areas are small in size in comparison to the overall drainage basins they protect. Unfortunately, their location in the lowland topography and their general linear shape make them highly prone to disturbances when adjacent uplands are altered (Knutson and Naef, 1997). Of course, alterations in riparian landscapes can be natural or anthropogenic, but it is the anthropogenic alterations that have begun to accumulate in Pacific Northwest streams as urbanization, agriculture, and forest practices within the region continue to take their toll.

Positive Role of Riparian Buffers

Riparian buffers play a significant role in reducing impacts that negatively influence the stream ecosystem. May et al. (1997) discovered that there is a strong correlation between riparian buffer zone width and the biological integrity of streams. This means that riparian buffer zones play a critical role in the overall ecological scheme of a watershed. In fact, riparian zones act as interfaces between the terrestrial uplands and aquatic ecosystems, providing a buffer between the two which has been referred to as an ecotone (Gregory, 1997). Specific positive influences include stream temperature regulation, creation of cover for fishes in the form of large woody debris (LWD), trapping of sediments, bank stabilization from abundant root structure, the sequestration of nutrients, nourishment of stream organisms that in turn nourish other aquatic life, filtration of pollutants, and the regulation of runoff from the uplands (Malanson, 1993; Naimen et al.; 1998, May et al. 1997).

Riparian Zones and NPS/Sedimentation

Riparian zones have been shown to be effective filtering systems for the reduction of non-point source pollution (NPS) originating from adjacent terrestrial environments (Lowrance et al., 1984; Gilliam, 1994). Nonpoint source pollution (NPS) is defined as pollution that occurs over a wide geographic area, is diffuse in nature, but can accumulate, often in sudden surges from rainfall or snowmelt events, with major effects on surface and ground water (Griffin, 1991). NPS pollution is also now the primary source of contamination for surface and ground water (Jeer, Lewis, Meek, Witta, & Zimet., 1997; Novotny and Chesters, 1989). (For a summary of some of the impacts of various NPS pollution on fisheries, see Table 2-1 below).

Riparian buffers are especially effective at reducing sediment from overland flow and nitrates from subsurface or groundwater flow – two major sources of NPS pollution (Gilliam, 1994). Gilliam (1994) states that “sediment removals of 90% by riparian areas are not unusual” (p. 898). He also found that nitrate removal percentages range anywhere from 80% to 99% (p 898). Daniels and Gilliam (1996) found that grass and forest riparian areas that receive sheet and rill flows were able to reduce sediment load to a stream by about 60% to 90%. It should be noted, though, that not all vegetative filters are this effective in removal of sediment because of the formation of channels through the filters (Gilliam, 1994 p. 898). In a study conducted by Lowrance et al. (1984), it was found that riparian vegetation also acts as a filter for other elemental pollutants such as calcium, phosphorus and magnesium. Daniels and Gilliam (1996) also found this to be true and concluded that runoff nutrient loads of P and N were reduced by nearly 50% when passing through riparian areas. Yet, Daniels and Gilliam (1996) also found that more soluble forms of nutrients were filtered less effectively.

As was stated above, not only do riparian zones filter nutrients that can be detrimental to stream environments, but they can also “trap” sediments within the riparian zone (Lowrance et al., 1984; Gilliam 1994). Gilliam (1994) states that “riparian filters would be valuable if all they removed was sediment” (p. 897). This is the case because sediments often contain multiple pollutants, carrying these into the river system as a sort of symbiotic host. But sedimentation can also clog waterways (especially to the detriment of juvenile salmon) and create clarity problems that have a significant effect on in-stream environments.

Table 2-1
Nonpoint Sources of Pollution and Potential Impacts on Water Resources

Pollutant/Associated Land Use	Impacts on Fisheries
Sediment: construction, urban runoff, gravel operations, agriculture, logging, hydromodification	Decreases transmission of light, which affects plant production (food and cover), behavioral activities (nesting, feeding, mating), respiration, digestion, reproduction. Increases surface water temperature, which decreases dissolved oxygen concentration in water. Decreases spawning habitat (fills pools and nest sites). Transports absorbed contaminants.
Phosphorous and Nitrogen: urban development, gravel operations, agriculture, land disposal (sludge and septic systems), illegal waste disposal	Promotes algae blooms, which inhibit aquatic plant growth. Favors survival of less desirable species over more desirable (commercial and recreational) species. Reduces dissolved oxygen levels through increased productivity and decays of organic matter.
Metals: urban runoff, mining, land disposal, natural deposits	Accumulates in sediments, which poses risk to bottom feeders. Bioaccumulates in fish tissue. Affects reproductive rates and life spans of aquatic organisms. Hinders photosynthesis in aquatic plants
Pesticides and Herbicides: agriculture, urban runoff, hydrologic/habitat modification, lawn and golf course care	Accumulates in sediments, which poses risk to bottom feeders. Bioaccumulates in fish tissue. May kill fish and other aquatic organisms. Hnders photosynthesis in aquatic plants.
Pathogens-Bacteria and Viruses: agriculture, urban runoff, land disposal, septic tanks (or illegal waste disposal), sludge	Introduces disease-bearing organisms to aquatic life. Closes shellfishing areas
Thermal energy: construction, mining and gravel operations, logging, agriculture, urban runoff, hydrologic/habitat modification	Reduces vigor and growth of fish. Reduces resistance to disease. Reduces dissolved oxygen as stream temperature increases. Changes cold water sport fishery to warm water fishery.
Salts: mining, urban runoff, construction, road de-icing	Favors salt-tolerant species. Fluctuations in salinity create stressful environment. Destroys habitat and food source plants for some species. Alters species composition of affected areas.

Source: Adapted from Massachusetts Department of Environmental Protection (1993)

Adapted from Jeer et al. (1997) pp. 31-33

Riparian Vegetation and Runoff

Runoff, as subsurface flow and especially as overland flow, is significantly altered by the presence of riparian areas (Tabacchi et al., 2000). Riparian forests, which contain both living and dead plant material, have a physical impact on the hydraulics of runoff. The physical structure of living material changes with the seasons, and therefore, can create different degrees of resistance to overland flow at differing times of the year. Dead material can form a mobile yet resistant structure or a more stable, in-place resistance, often depending on the size and inter-connectivity of the organic material. All of these forms of resistance can obstruct, divert or facilitate water flow, thus affecting the hydraulic properties found within the zone (Tabacchi et al., 2000). These physical diversions and forms of resistance aid the uptake of runoff by the riparian forest by increasing the water's contact time and distance of travel through the vegetation. The vegetation also decreases the impact of "flash events," or brief storms with a significant volume of runoff. This contributes to more stable in-stream flow patterns.

Of course, riparian plants not only act as physical resistance to overland flow, but also participate in the hydrologic cycle. They do so by taking water in, storing it, and returning it to the atmosphere through evapotranspiration.

Tri-County Model Riparian Management Plan

Riparian habitat management for the King, Snohomish, and Pierce County area has been synthesized into a study done by the Tri-County Commission. In the Tri-County Model Biological Report (Parametrix, 2002), a recommendation has been put forth that says that riparian buffers be maintained, implemented or restored within specific parameters to bring salmon habitat to a sustainable level. This general mandate has been translated into specific management options that are listed in the table below (See Table 2-2 below).

Table 2-2
Widths of Prescribed Management Zones under the Model

Water Type	Total Management Zone	Rural Standards (ft)		Urban Standards (ft)	
		IMZ (Inner Management Zone)	**OMZ** (Outer Management Zone)	**IMZ**	**OMZ**
S	200	150			
F	200	150			
F - steep ravine delivered directly to marine shorelines	200	Greater of 100 ft or 25 ft from top of bank		Greater of 100 ft or 25 ft from top of bank	
N within 1/4 mile of type S or F water	115	115	0	115	0
N greater than 1/4 mile of type S or F water	65	65	0	65	0

(Source: Parametrix, 2002, page no. 4-15)
Refer to Appendix A for details of the water typing scheme used in this Prescribed Management Zones table.

These specific recommendations have been put forth because there is ample evidence that riparian buffers play a significant role in reducing impacts that negatively influence the stream ecosystem. These positive influences include stream temperature regulation, creation of cover for fishes in the form of large woody debris (LWD), trapping of sediments, bank stabilization from abundant root structure, the sequestration of nutrients, nourishment of stream organisms that in turn nourish other aquatic life, filtration of pollutants, and the regulation of excess runoff from the uplands (Malanson, 1993; Naimen et al.; 1998, May et al. 1997).

Roads

The road network found within a watershed has a negative impact on the hydrological condition of that basin. Not only is the transportation component the major contributor of impervious area within a basin (City of Olympia, 1994; May, et al., 1997), which can significantly alter the timing and intensity of runoff events, but road networks in rural areas can also have dramatic effects on runoff processes.

Road networks located in forested areas act in a similar fashion to a stream network. In other words, the network of roads can act as a conduit of material and water that "flows" from branch to branch and eventually works its way to the stream network (Jones and Grant, 1996; Jones, Swanson, Wemple, Snyder, 2000). Often this flow is found in a roadside channel, but even a road surface can act as a conveyance system or "tributary." Long term use of an unimproved road surface leads to soil compaction that persists long after the road is no longer used (Trombulak and Frissell, 2000). Because of this compaction, there is a decrease in infiltration rate which facilitates the flow of runoff over the surface of the road.

Cut and fill areas engineered for the creation of the road-bed are also problem areas in regards to surface runoff. Fill areas, or down-slope sections of roads, are significant contributors of sediment debris to a basin. This is especially true in steep forested landscapes (Jones, Swanson, Wemple, & Snyder, 2000). It has also been found that mid-slope roads above a watercourse are the major contributors to debris and sedimentation flow into the system. But, to counter this, roads that run along a watercourse in a valley bottom can act as a sink or barrier for materials such as debris slides (Jones et al, 2000). Regrettably, this positive effect of valley floor roads is offset by their fragmentation of the riparian zone, thereby straining the natural ecosystem processes of this zone.

Those road networks that cross watercourses create many problems that can significantly alter the in-stream habitat conditions for salmon. Some of the physical changes that occur both during and after the construction of a stream crossing include the removal of riparian vegetation, the disturbance and fragmentation of adjacent land, the constriction of the stream channel (both vertically and horizontally), and the placement of structures into the stream bank and channel that interfere with the flow patterns of the water. (Baggett, Chiao, and Harton, 2001). Road crossings over streams, especially for small and medium sized streams, are most often accomplished with the use of culverts.

Culverts have been a major source of concern for fish passage because many of the older installed culverts did not take into account the needs of migrating fish (Pacific Fishery Management Council, 1999). These culvert "barrier" conditions include constricted flow from small culverts that increases stream-flow so much that migrating fish cannot pass, elevation gains where fish cannot leap up to make the passage, or too low or shallow of a flow at critical times of year so that fish can not migrate. Road culverts can also be off-stream, meaning they are not a part of a direct stream crossing but instead are used for something such as a drainage ditch. These culverts can still be indirectly connected to the watercourse, though, and can have a significant effect on increasing the storm event water volume delivered to a stream system (Bowling and Lettenmaier, 2001).

Road crossings, especially as they grow in number within a basin, increase the number of downstream effects that can accumulate through the system. As the density of road-crossings increase, the downstream effects also increase, negatively effecting valuable in-stream habitat (Jones et al., 2000). May, et al. (1997) found that "the more fragmented and asymmetrical the buffer, the wider it needed to be to perform the desired function" (p. 486). Their study revealed that more than 2 stream crossing per kilometer correlated to a highly urbanized stream basin (May, et al, 1997).

Roads found within close proximity to a watercourse can also fragment the adjoining landscape or riparian zone (Trombulak and Frissell, 2000). Multiple stream crossings not only create barrier problems within the watercourse itself, but also fragment the adjoining terrestrial habitat. These fragmented patches become islands that can be negatively influenced in various ways. Some of these influences include runoff pressure from adjoining road networks, invasive species propagation, stress on native vegetation, and greater access by humans (Jones et al, 2000; Trombulak and Frissell, 2000).

Sedimentation

The impact of sedimentation on salmon nesting sites is significant. Sedimentation can cover over a redd, thereby depriving the eggs or alevins of much needed dissolved oxygen and often becoming fatal to their survival. Sedimentation is especially significant in streams with higher velocities because these swift waters more easily transport sediments into a nesting site (Lisle, 1989). It is also clear from Forman's (1995) work that streams of lower order (1^{st} and 2^{nd} order) require greater widths of buffer vegetation to protect these valuable areas. Although these lower-order streams are generally not of high velocity, their sheer numbers make them a probable source of sediment input into a stream environment (Schueler, 1995). Lower order streams can also be prime habitat for juvenile salmon not yet ready to take on the rigors of the faster velocity main-stems of streams and rivers. Therefore, the protection of lower-order streams is necessary to reduce sediment input for the health of the entire system and for the specific safety of resident, juvenile salmon.

Douglas (1985) outlined the relative sedimentation effects of various land use categories. These categories reveal that cropping or agricultural systems and construction sites have the highest potential to release sedimentation into a basin, while natural areas, permanent grass/abandoned fields and stabilized urban areas release significantly less sediments. In the Washington State Water Quality Assessment (1998), it was found that agricultural land uses have the highest percentage of pollution impacts on streams. Although this water quality assessment does not specifically focus on sedimentation, but rather on factors such as N and P pollution, it does reveal that agriculture has a dramatic impact on surface water quality in our state.

Steep slopes with unstable soils are also “hot-spots” for potential sedimentation, especially if they occur within the riparian zone. Any such area that is adjacent to a watercourse should be closely evaluated for its potential effects. The properties of soils give an indication of the erosion potential of the land. Soil properties can be found in the soil survey for King County (Golden, 1992; Snyder, Gale and Pringle, 1973).

2.4.E Redd Density

Redd’s, or salmon nesting sites, are a sure indication of salmon presence and represent a physical location where the salmon life cycle is very vulnerable to environmental conditions (See Section 2.2.A). Where adult salmon return year after year to lay their eggs indicates a successful completion of the salmon life-cycle. These locations need protection, both through upland and in-stream enhancement, for the proliferation of the species.

Adjacency to Estuary

The Green/Duwamish estuary is regarded as the last 11 miles of the stream system (City of Seattle, 2001), an area where the upstream environment is heavily inundated with industrial and urban development. As has been stated in the section 2.2.A, the estuary phase is of prime importance to the survival of Chinook salmon. The estuary is the place of transition for juvenile salmon as they prepare for their ocean phase and is a place where significant growth happens for this species. The natural intertidal habitat (meaning natural, tidally influenced shoreline) is the most frequently used areas for Chinook salmon because of the availability of prey and of sufficient cover (City of Seattle, 2001). These areas are, therefore, the critical estuary habitat for Chinook salmon. Although there is no proof, it is postulated that areas with adjacent, more densely vegetated riparian areas are more likely to have this type of intertidal habitat.

2.5 SUMMARY

Salmon habitat in the Green/Duwamish system is clearly being affected by the impacts of population pressure and its deleterious impacts on the environment. Salmon are especially vulnerable at the younger stages of their life histories, particularly to impacts such as sedimentation, lack of protective vegetative cover, and excessive runoff. Adult salmon can also be impacted by these landscape changes, but are most affected by changes that limit their access to the river system such as culverts and high flows.

With the listing of Puget Sound Chinook salmon as threatened under the ESA, a whole series of actions were required of State and local entities to ensure that Chinook salmon were protected. The protection strategies and plans that are being developed by these entities are to work in conjunction with State and Federal legislation that is already in place. These applicable bodies of legislation include the Growth Management Act, Shorelines Management Act, the Federal Clean Water Act, the State Environmental Policy Act, the Forest and Fish law, and the Comprehensive Watershed Planning Act. Although these legislative mandates guide decision making in regards to habitat issues, they do not give specific direction on how protection strategies can *best* be implemented.

The issue of how to best implement protection plans is addressed through the "best available science" emphasis found in many of the applicable pieces of legislation. This best available science perspective has given direction to salmon habitat protection. This direction says that a more holistic, ecosystem wide approach is needed to address the problem properly. This "ecosystem" approach boils down to dealing with the issue at a watershed scale (in Washington, watersheds are generally equal to Water Resource Inventory Areas or WRIAs).

In this research, the watershed is used as the overall extents of the study area. But, it is important to note that affects within the watershed are found at a more localized, "sub-watershed" scale. Therefore it makes sense to study these affects at this smaller sub-basin or sub-watershed scale.

What are the affects, according to the literature, that deserve attention in regards to impacts on salmon habitat? These include:

- *Impervious surfaces*: because of their negative influence on increasing stormwater flow and pollution runoff
- Impact on *riparian zones*, including:
    - *vegetation density*, because of its potential to filter pollutants and slow overland flow
    - *road crossings* because of their impact on fragmenting the riparian zone and being places where fish passage may be an issue
- *Road impacts*: especially road density which is a component of impervious surfaces but also through culvert and drainage connections to the stream system.
- *Sedimentation: because of its impact on salmon eggs and alevins*

Understanding where salmon are most frequently found is also important in determining places to focus protection efforts. This presence is hard to ascertain, but an adequate precursor is salmon nesting sites or redds. Of course, it is necessary to be very protective of the estuary, since a critical part of salmon's life history is spent there.

Protection efforts range from preservation, or the setting aside of a portion of land for the benefit of salmon habitat, restoration, or the return of the land to a more properly functioning ecological trajectory, and, in the worst case, structural Best Management Practices, or practices and implementations that limit harmful effects on the stream environment like runoff and pollution. These protection efforts form the backbone of the protection strategy.

With an understanding of the possible impacts on a sub-watershed scale, a good grasp of where salmon are most likely to be found, and a definition of ecologically mandated protection efforts, the beginnings of a priority scheme can be developed. The next chapter discusses this prioritization scheme in general terms and addresses how a model can be developed from the idea of specific impacts on the landscape.

CHAPTER 3

PRIORITIZATION AND THE MODEL

This chapter examines the need for prioritization by addressing the habitat funds available for preservation and/or restoration projects. It also addresses the critical decline of salmon. An example of coarse scale analysis is examined and then a prioritization approach specific to this research is proposed.

3.1 PRIORITIZING HABITAT PROJECTS BENEFICIAL TO SALMON

3.1.A Habitat prioritization

Prioritizing to protect the most viable salmon habitat is a necessary step in determining where enhancement should take place. Without some sort of priority system, enhancement efforts can be applied in ways that could be characterized as random and devoid of the big-picture, additive effects of individual projects (Washington State Joint Natural Resources Cabinet, 1999). Of course, with unlimited time and resources, a multitude of watershed factors and processes could be examined—each one a finer grain look at a smaller segment of a watershed—but because time and resources are at stake, an initial approach must be found that can help researchers narrow their choices while not expending too many resources.

3.1.B Restoration/Protection Project Funding and Entities

As of October 31, 2002, $146,346,311 in State and Federal Salmon Recovery Funds had been granted on 655 projects over a 4 year period in Washington State. These ‘projects’ include both habitat projects and program grants (See Table 3-1 below).

Table 3-1
State and Federal Salmon Recovery Funds awarded by the State of Washington in State Fiscal Years 1999-2002 (as of October 31, 2002).

State FY	State Funds ($)	Federal Funds ($)	Total Awarded ($)	No. of Grants*
1999-GSRO**	0	19,417,207	19,417,207	168
1999-IRT**	5,412,924	0	5,412,924	94
2000-SRFB**	21,515,415	4,000,000	25,515,415	94
2001-SRFB**	7,067,831	41,907,207	48,975,038	159
2002-SRFB**	14,302,137	32,723,690	47,025,827	140
SRFB Sub-total	42,885,383	78,630,897	121,516,280	393
Grand Total	48,298,307	98,048,104	146,346,411	655

*Includes both habitat project and program grants. Dollar amounts do not include the use of non-SRFB funds or the value of in-kind services. (Source: The Office of the Interagency Committee, 2002)

In the third round of funding, the Washington State Salmon Recovery Board (the Board) approved $1,806,000 out of a requested amount of $3,401,955 for WRIA 9. (The Office of the Interagency Committee, 2003a). Currently, in the Board's fourth round of funding, an award amount of $1,275,085 has been approved out of a requested amount of $2,342,175 for WRIA 9 (The Office of the Interagency Committee, 2003b). Clearly, salmon recovery funding has been substantially cut for WRIA 9 in the current funding year.

Strategically the effort to protect salmon is a regional effort, with the complications of multiple jurisdictions having to work together using the available funding. The entities involved include City, County, State and Tribal governments (not to mention the myriad private interests involved). Having a clear strategy to save salmon has also been the goal of State Government as indicated by the establishment of the Governor's Salmon Recovery Office (Governor's Salmon Recovery Office, 2003) and the many regional coalitions including the Tri-County Commission. All of these efforts are now approaching their fifth year of existence.

3.1.C Critical Situation for Salmon

Unfortunately, the size of Puget Sound Chinook salmon run has declined significantly, as is indicated by Figure 3-1 below (Cramer, 1999). Although it is unknown whether this trend has continued since 1998, the downward trend over the past 30 years indicates that Chinook salmon populations are in eminent danger of extinction.

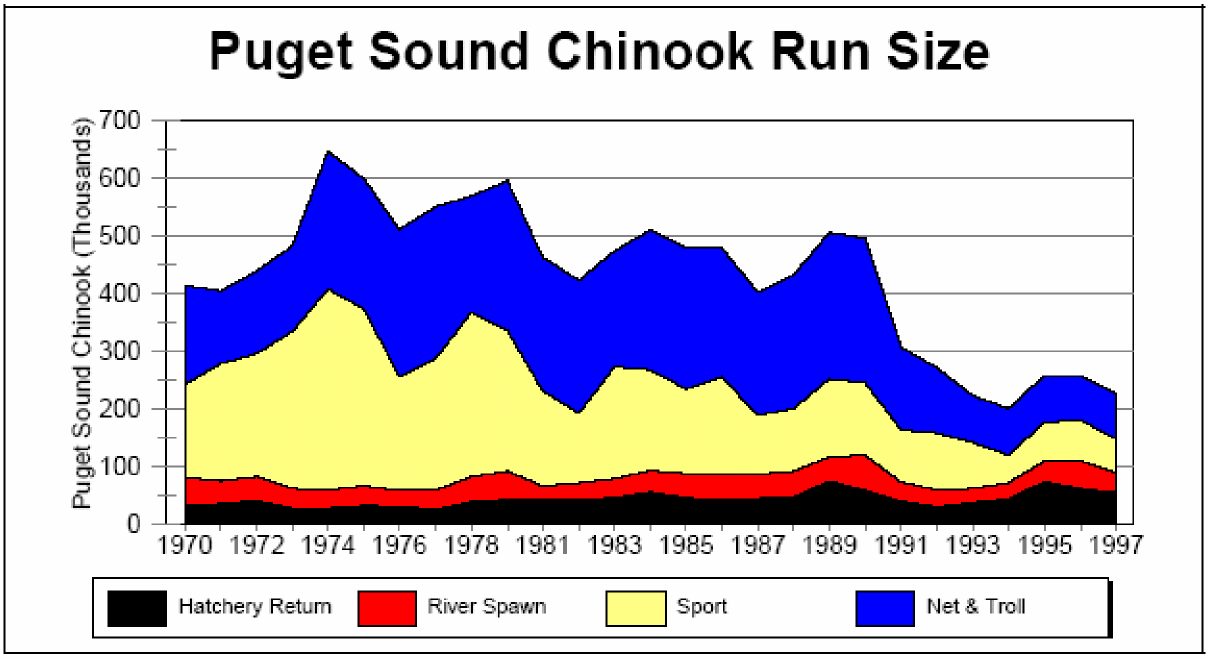

Figure 3-1
Total catch and spawner escapement of Chinook in Puget Sound during 1970-1997.
Catches include some Chinook that originated outside Puget Sound, and exclude catches of Puget Sound fish in the ocean. CWT data indicate that non Puget Sound stocks are a minor component of fish present in Puget Sound (PSC Exploitation Rate Database). River spawners includes hatchery fish that spawned naturally (Source: Cramer, 1999).

With each passing year, the criticalness of the situation is intensified, especially if proper prevention efforts are not instituted. This critical need of finding a solution to restore salmon populations does not minimize the necessity of good planning, but it does increase the need to implement plans in a timely fashion.

3.2 APPROACHES TO THE PRIORITIZATION PROBLEM

3.2.A The Coarse Scale Approach

What is needed, then, are plans that can utilize the limited monetary funds available while providing a system to identify areas that would be most benefited by recovery efforts in regards to salmon habitat health. With the above constraints of time and money in mind, it is more constructive to first determine priorities based on a coarse scale for an ecosystem and then look at finer scale priorities within these prioritized areas. This will minimize the time wasted on applying recovery efforts to areas that will not produce as much benefit to salmon as other areas within the watershed.

There are many examples of the coarse-scale, watershed-wide approach to prioritize land management actions for overall ecosystem/habitat benefits. One such approach used the criteria of wetland occurrence, local geology, stream gradient, and land-use to determine watershed factors that influence the abundance of Coho salmon (Pess, Montgomery, Steel, Bilby, Feist, and Greenberg, 2002). Another study examined landscape-level attributes that affect numbers of Chinook salmon. These factors included mean-annual precipitation and geometric mean road density (Thompson and Lee, 2000).

These studies indicate that in any large scale ecosystem analysis it is important to define the land-based characteristics that influence the health and functioning of that ecosystem (Pess, et al. 2002; Randhir, O'Conner, Penner, Goodwin (2001); Thompson and Lee, 2000). It is also important to understand that in such an ecosystem analysis, some characteristics are time sensitive—in other words, some characteristics change relatively rapidly and other characteristics are relatively static in regards to temporal change or relatively unaffected by anthropocentric influences.

The characteristics that are “static” are also the physical constraints of an ecosystem. Such characteristics include soils, hillforms, and geology. (McCammon, Rector, and Gebhardt 1998). Many of these physical constraints are characteristics that indicate the underlying potential of the ecosystem.

Ecosystem characteristics that change relatively rapidly include the closely linked characteristics of vegetation composition and impervious surface coverage. These factors can have a profound impact on the health of an ecosystem in a relatively short time span. This is evident from the impacts of 70 years of growing urbanization within the general Pacific Northwest Coastal eco-region and the changes this urbanization has wrought on vegetative composition and impervious cover within the region.

What is important in a prioritization of preservation/restoration sites is to understand that ecosystem characteristics can help determine the category of remedial action (i.e. preservation or restoration) and also can suggest a timing for this action (i.e. short-term, long-term). Those sites that have optimal present conditions, based on the combination of static and time-sensitive characteristics, should be preserved. Conversely, those sites that do not have optimal present conditions are prime candidates for restorative action.

3.2.B GAP Analysis example

The National Gap Analysis program (GAP) presents a very good strategy for analyzing species and habitat correlations and finding subsequent geographic areas in which to concentrate conservation efforts to protect species of interest. The basic strategy that GAP has employed is to map the natural vegetation, the predicted distribution of species, and public land ownership and private conservation lands (showing the “network” of conservation lands), using these layers to do an overlay analysis through GIS processing that locates relationships between the vegetation, species distribution, and conservation network. Where there are “gaps” in this network of lands and species distributions is where the analysis suggests that conservation efforts should be concentrated (Jennings & Scott, 1997).

The original GAP program was an effort to help protect the habitat of land-based vertebrate species. A similar GAP strategy was put forth in 1995 to analyze aquatic species and their habitat. In the aquatic model, the goal was to predict relative levels of fish and macroinvertibrate diversity and find stream reaches with high biodiversity that were not protected or managed (managed in the definition of the aquatic pilot project were areas where fish stocking occurred, streams with public fishing easements, and regulated fishing waters). These unprotected and unmanaged reaches with high biodiversity would then be the focus for conservation (Meixler & Bain**,** 1999).

The aquatic New York GAP pilot project (Meixler and Bain, 1999) methodology classified stream segments into habitat types by stream size, habitat quality, water quality, stream gradient, and riparian forest cover. In addition, further habitat characterization was applied using discriminant analysis. The additional attributes used in this analysis included point source pollution, surficial geology, bedrock geology, depth to bedrock, and priority water status. (Meixler and Bain, 1999). GIS technology was used throughout the analysis and was even used to automate the classification of habitat types (Meixler and Bain, 1999).

This type of model, which is considered a coarse-grain approach, has some similarities to the model frameworks mentioned above in research done by Pess, et al., (2002) and Thompson and Lee (2000). In all these approaches, landscape attributes were examined to either elucidate their impact on species or to find an optimal combination of habitat factors for determining species presence. In all these approaches, the habitat attributes are key elements in helping to select priority areas.

3.2.C The Modeling Approach and GIS

How to Prioritize

From the above, the obvious approach in a prioritization scheme for locating sites to preserve or restore is to address the "where" on a holistic, watershed basis. The difficulty with this is that an actual physical survey of a watershed and its many components and processes is problematic at best—and at worst is nearly impossible in terms of the time and money necessary to complete such a survey. Therefore, a 'best-science' strategy is called for that can meet the demands of narrowing rational choices for habitat protection while providing a savings in resources spent on such an endeavor. The most likely candidates for a best-science strategy are tools that can adequately simulate the landscape of a watershed, thereby allowing researchers to take a watershed into the "laboratory." Just such a tool is found in a Geographic Information System (GIS).

Modeling the Landscape

A GIS can be defined as a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. The GIS uses hardware, software, data, people, and training to accomplish these tasks (Geographic Information Systems, n.d.).

It is evident from a variety of sources that modeling of the natural landscape, specifically in terms of using Geographic Information Systems (GIS), has been embraced by the scientific community. (Goodchild, Parks, & Stayaert, 1993; Lyon and McCarthy 1995; Makuch and Emmert, 1994). In fact, in the Makuch and Emmert bibliographic listing entitled, “Simulation Models, GIS and Nonpoint-Source Pollution,” there are 337 different articles or books listed dealing with the topic of landscape modeling using GIS. In Lyon and McCarthy (1995) many examples of using GIS to study problems in wetlands and environmental research are given. In Goodchild , Parks, & Stayaert (1993) there are sections on atmospheric modeling, hydrologic modeling, biological/ecological systems modeling, and land-surface-subsurface modeling, all using GIS as a research tool. These volumes of research point to the widespread use of GIS as a tool to facilitate the modeling of the natural environment.

The overall model used in this research can be called an environmental simulation model – a computer based model that acts to imitate the patterns found in the real world (Steyaert, 1993). A GIS, because of its ability to analyze spatial data, works very well for converting real-world, land-based information into a computer simulation. For example, a grid coverage (where landscape patterns are represented by square cells covering known amounts of ground) is a common data-set used in GIS. Grid cells can simulate the landscape through GIS software by representing real-world data such as vegetation or elevation.

Still, it is important to recognize that GIS simulation models (which include environmental models) are usually, at best, just a simplification of real world processes (Steyaert 1993). For example, grid cells, which are of a certain spatial extent (in many cases this is 30 sq. meters) represent a “blending” or averaging of small-scale patterns that happen “within” the cell’s area in the landscape, and are, thus, a generalized representation of real-world details. This type of simplification has not, and should not deter the use of GIS based models for addressing new hypothesis and investigations. It should, though, temper conclusions that can be drawn from their use. Environmental processes are complex, time dependent, and three dimensional, and they cannot be easily modeled (Steyaert 1993) without simplification and qualifying assumptions. Because of this fact, the assumptions and limiting factors of the research need to be addressed.

Limitations

One critical limitation is the “grain” of data sources for input into a GIS. Grain is the finest level of spatial resolution possible with a given data set as defined by Turner, Dale, and Gardner (1989). In the case of a raster data set (such as a grid coverage), this is the pixel size. In an environmental model, a larger grain will create a more generalized data set, while a finer grain will represent more of the patterns found in the landscape. A grain of 30 meters for a raster data-sets could be considered large if this data were used for the purpose of examining a small, local landscape, such as a few hundred feet along a stream. But, if a study area is large---say as big as a watershed---a grain of 30 meters is relatively small.

The spatial extent or the size of the study area being examined for prioritization is also very significant. It is important to recognize that ecosystem processes operate at multiple spatial scales (Bohn and Kershner, 2002). Therefore, researchers must find an appropriate level of detail to examine in relation to the overall spatial extent of the project. For example, if the spatial extent is a watershed, any examination or study of the watershed requires a view that takes into account watershed-wide processes and actions. This “large” scale, or coarse grain, approach is a proven method used in studies done by Randhir, et al. (2001), Thompson and Lee (2000) and Pess, et al. (2002).

The notion of grain and extent are important in both the understanding of how to approach the research and how to interpret the experimental results. Grain and extent can be synthesized down to the single term *scale*, which is the spatial dimension of an object or process. Turner, Dale, & Gardner (1989) noted that it is important that the scales represented in a model must be appropriate for the phenomenon of interest. The phenomena of interest in the case of this research are the large landscape processes and characteristics that effect salmon habitat.

The above factors are general limitations found in environmental research involving the use of digital spatial data. The more specific limitations of this research are addressed in Chapter 6.

3.3 CONCLUSION

A prioritization of land areas to preserve and restore for the benefit of salmon and their habitat is a necessary step if salmon-enhancement projects are to do the most good using the available, limited resources. In a “perfect world” scenario, all habitat that is degraded or in need of preservation would be restored or saved. But, since there are limitations both in resources (time and money) and practicality (all impervious surfaces can’t be removed), then a system should be developed that can select areas to focus on that maximize the benefit to salmon. If such a system is not developed, then projects are often done on a piece-meal basis, with little regard for the overall, holistic benefits to salmon. In the long run, this type of piece-meal approach can generally be detrimental to the goal of saving salmon and, therefore, a waste of valuable resources.

The information needed for a coarse grain approach includes those factors mentioned above in Section 2.4.D.: Landscape health, potential risk to the system as defined by sedimentation and salmon usage as defined by redd densities. Landscape health includes the factors of imperviousness, transportation impediments (including stream-crossings and road density), and vegetation density in the riparian zone. Sedimentation is an important factor, as detailed in Section 2.4.D, because of its adverse impact on the health of the river system. And redd densities are a good measure of salmon presence, especially if averaged over a number of years.

It is clear from the literature that the above factors are appropriate analysis layers. Once these factors are analyzed, a general characterization of each sub-basin can be established. From this characterization a generalized ranking, or prioritization, of sub-basins can be developed. This combination of landscape factors analyzed in a modeling approach will allow a rational, prioritization scheme that can ultimately benefit Chinook salmon habitat.

CHAPTER 4

MODEL OVERVIEW AND INPUT DATA

This chapter introduces WRIA 9 in general terms, especially in regards to the land-cover distribution found within the study area. The prioritization model used for sub-watershed prioritization of WRIA 9 is then outlined followed by a discussion of the hardware/software specifications for the GIS processing. Following this is a discussion of the datasets necessary for analyses and how these datasets were preprocessed, preparing them for further analysis. The last section details how the datasets were finalized in preparation for the sub-basin characterization.

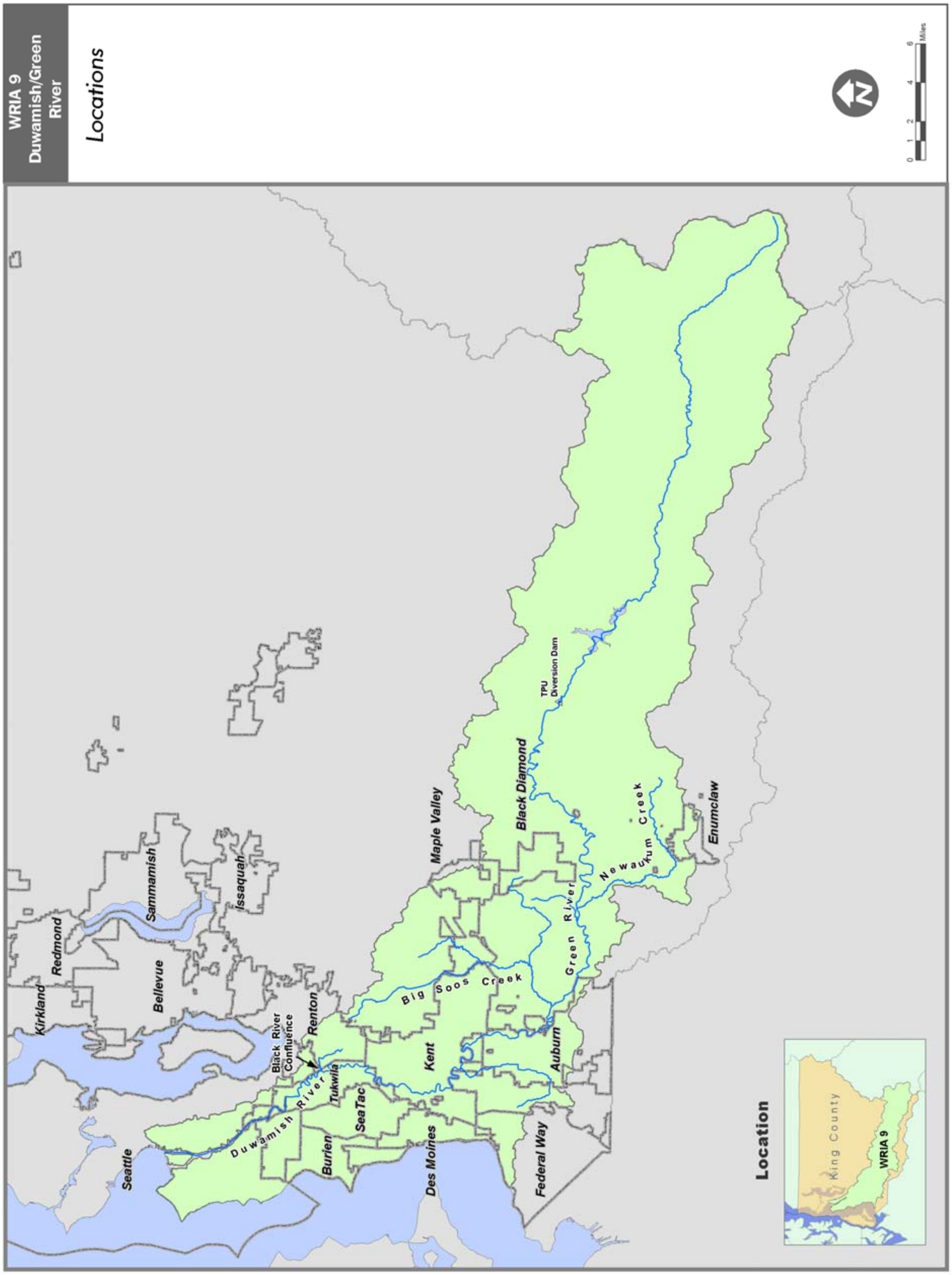

Figure 4-1 Locations within WRIA 9
(Source: Author)

4.1 STUDY AREA

The study area of WRIA 9, located in King County, WA, contains the Green/Duwamish river system. The first 11 miles of this river system—from the City of Seattle's Elliot Bay to the City of Tukwila—is known as the Duwamish River. The most upper portion the river is often referred to as the Duwamish waterway, signifying its use as a port area frequented by larger ships. Upstream of the Duwamish River, at the confluence with the Black River, the river is known as the Green River (See Figure 3-1 above).

Malcom characterizes the Duwamish/Green river system (2002) by saying,

> "Historically, the Duwamish/Green River drained a 1,642 square mile watershed (US Army Corps 1997 from Malcom, 2002). The three main sub-basins, the Black, Green, and White Rivers were separated for navigation and flood control in the early 20th century (Blomberg *et al.* 1988 from Malcom, 2002). Currently the Green/Duwamish drains 483 square miles. The City of Tacoma built a water diversion dam at RM 61 in 1913. The US Army Corps of Engineers' Howard Hanson Dam was constructed at RM 64.0 in 1961. Neither dam was built with fish passage facilities, eliminating access to an estimated 107 miles of historical anadromous fish habitat (US Army Corps 1998 from Malcom, 2002) as well as dramatically altering the quantity and quality of downstream salmon habitat. The lower floodplain, below RM 37.3, historically consisted of rapidly shifting meanders, but now this area is almost completely contained within levees or revetments resulting in the lack of riparian cover, large woody debris, off-channel rearing areas, and reduced channel storage capacity (US Army Corps 1997; Fuerstenberg *et al*. 1996 from Malcom, 2002)." (Malcom, 2002)

Within the boundary of WRIA 9, study basins were created for this research. These study basins were only created in areas where salmon redds were present which included up to the salmon accessible reaches of the Duwamish/Green at the Tacoma Public Utility (TPU) diversion dam (RM 61). Salmon redds, as described in the Malcom (2002) report, were found on the mainstem of the Green Duwamish and on two major tributaries—Big Soos Creek and Newaukum Creek.

For the purposes of this research, basin numbering was established (See Figure 3-2 below). These basins can be characterized according to their dominate land-cover (See Figure 4-3 and Figure 4-4 below for summary information).

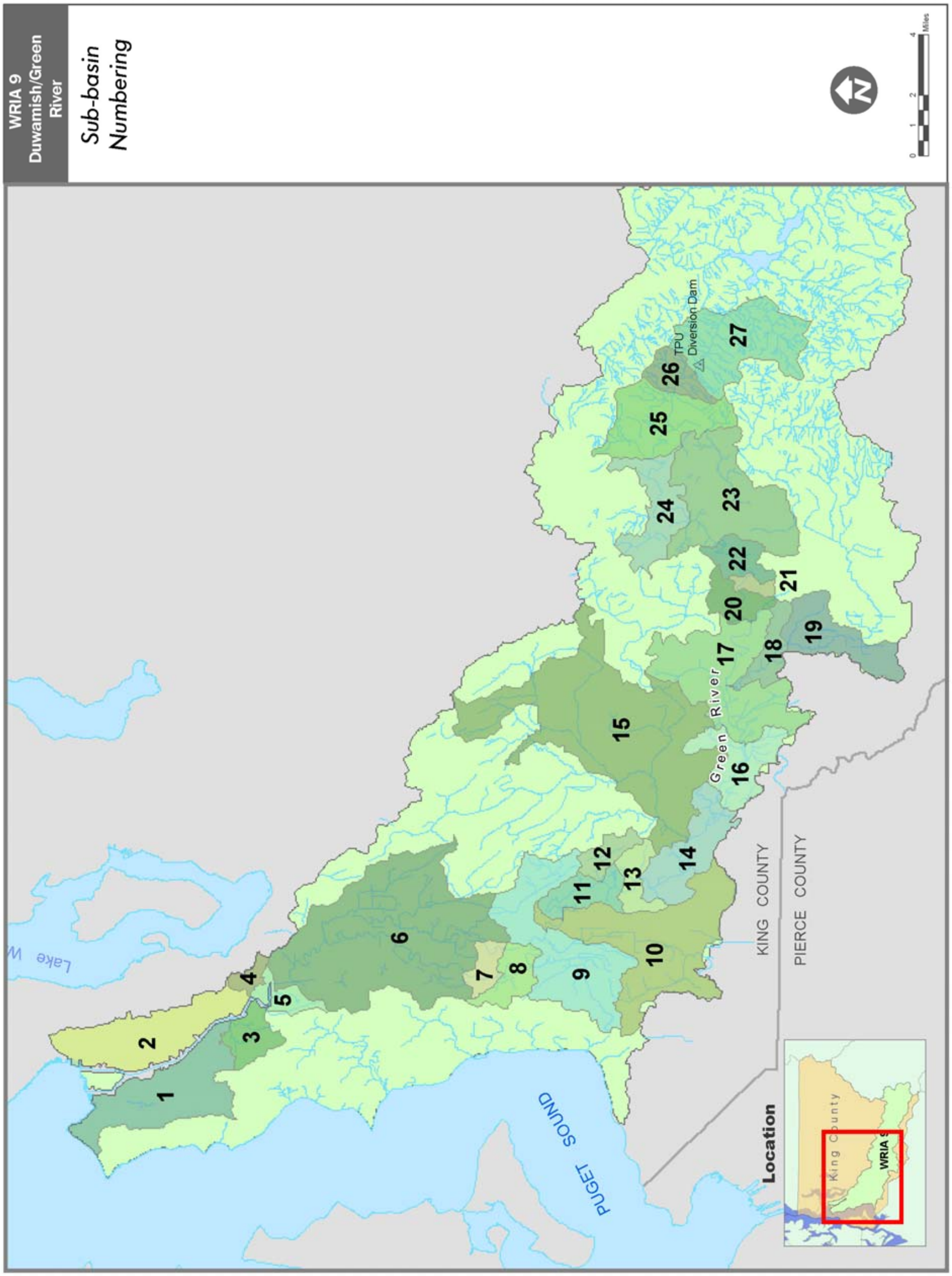

Figure 4-2 Sub-basin numbering
(Source: Author)

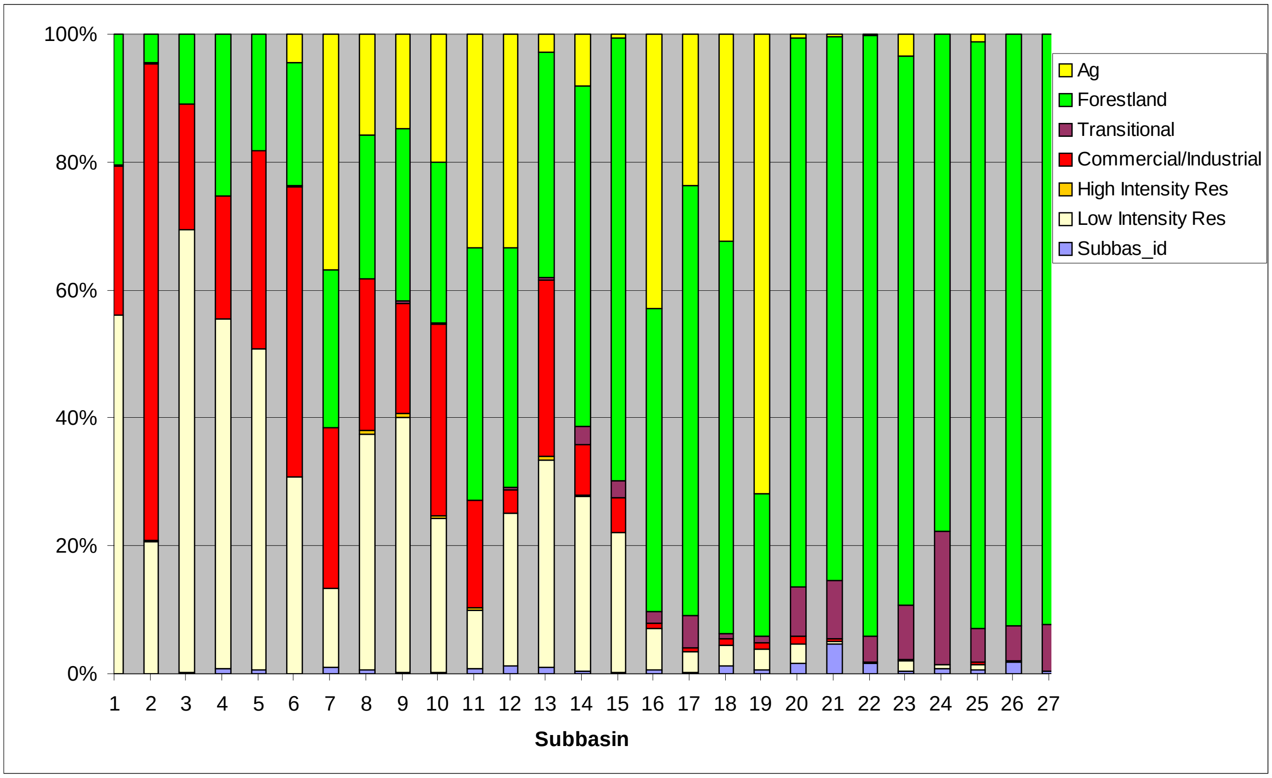

Figure 4-3 Sub-basin Land cover Characterization
(Source: Author)

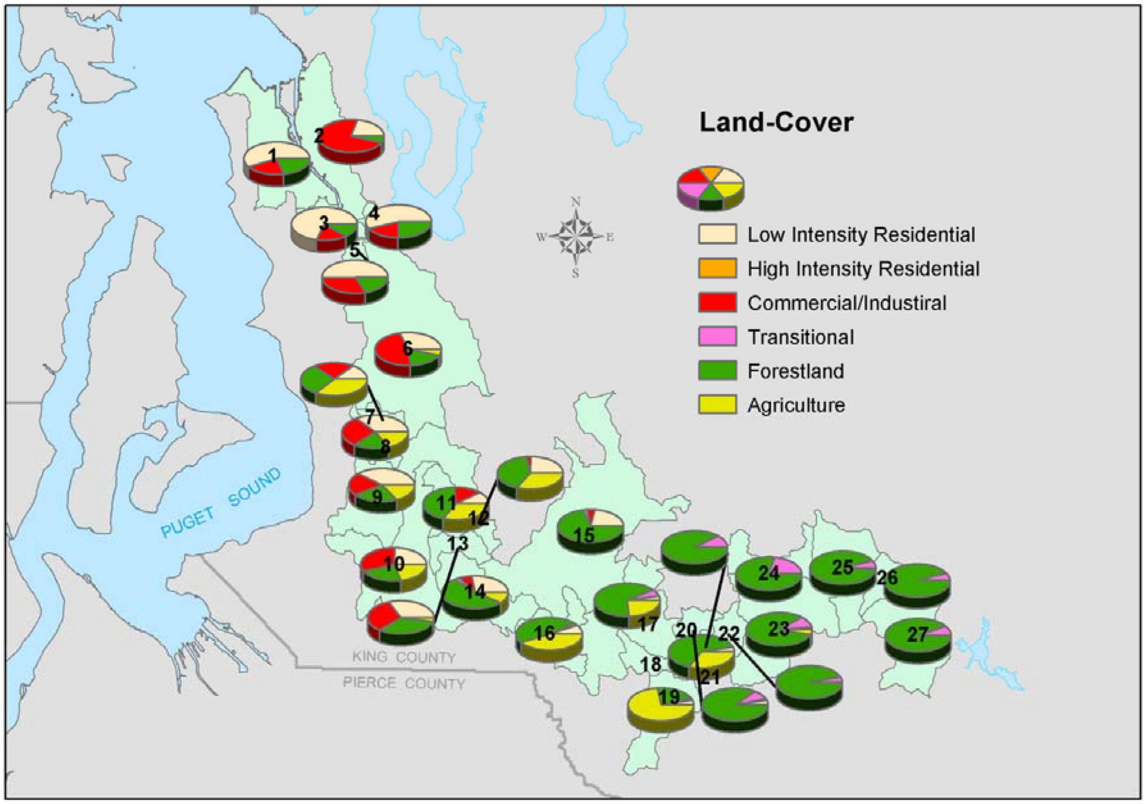

Figure 4-4 Relative Land cover found in each Sub-basin
(Source: Author)

From the figures above, it can be seen that the lower portions of the study area are more highly urban, with basins 1, 3, 4, 5, 8, and 9 showing high levels of Low Intensity Residential development. There are also basins that are predominately Commercial development in this region, namely basins 2, and 6. Basins in the middle of the study area are more highly mixed, with many showing an almost even mix of various undeveloped and developed land cover (Ag/Forest mix such as basin 11, or Forest/Commercial/Low Intensity Residential mix as in basin 13). The next region upstream (basins 16-19) shows a more dominant Agriculture/Forest mix (It should be noted that there is also substantial Agricultural land cover in basins 7-12). The final region (basins 20-27) are predominately Forest, but do show significant Transitional land cover (especially basin 24).

From this analysis, it is apparent that the study area contains a mixture of low-intensity residential basins, more dominant commercial basins, a significant number of agricultural basins, and many forested basins. These land cover types are indicative of both the population growth along Puget Sound and the more natural conditions found as one approaches the Cascade mountains.

4.2 OVERVIEW OF MODEL

This research implements a model that prioritizes remedial actions that benefit Chinook salmon habitat. This prioritization was based on a sub-basin assessment that examined the adjacent critical landscape factors of overall landscape health, the potential risk factors of each sub-basin, and salmon presence.

Landscape health factors include impervious percentage, vegetation density within the riparian zone, continuity of the riparian zone measured by stream crossings, and density of the road network. Salmon presence is based upon a census of redd density. Potential risk considers sedimentation potential and its effect on adjacent river reaches of differing stream order.

These three factors—landscape health, salmon presence, and risk potential—are the determining factors for sub-basin characterization. These factors are applied in a filtering framework that begins with landscape health, flows to salmon presence and concludes with risk potential.

The first level of characterization suggests the general direction of the ecological action, namely, preservation, restoration, or limited improvement through the application of BMPs. The second level of analysis, based on an assessment of salmon presence, proposes the initial ordering of actions. The third level of analysis, determined by considering risk factors, results in proposed order of implementation and suggested types of landscape based remedial action(s).

It should be noted that estuary presence within a sub-basin was also taken into account as part of the salmon presence factor. "Estuary presence" received an initial action order of "E1," meaning #1 implementation of ecological action, because of the estuary's importance in juvenile Chinook salmon rearing.

Ideally, a fourth level of analysis would be applied that suggests the ordering and type of in-stream remedial action. However, for this project, this analysis could not be performed due to lack of data. Therefore the in-stream quality prioritization factor is shown in the model (Figure 3-5), but not implemented in the current study.

4.2.A Model Details

The process of basin prioritization started with determining the ecological action based on landscape health. As stated above, the ecological actions included preservation, restoration, and structural BMP applications.

The next level of prioritization determined if salmon were present in the basin. Then, if they were, redd density determined the ecological action order. If redds were high, then ecological action should be implemented first; if redds were of medium density, then ecological action should be implemented second; if redd densities were low, then ecological action should be implemented only after the #1 and #2 implementations have taken place. In reality, there should not be a significant time difference between implementations #1 or #2 of the ecological action. These designations are only given as a means for decision-makers to make the hard choices in case there are very limited resources available to implement remedial projects. If this is the case, then the implementation #1 projects should be implemented first. If resources are not as much of a problem, then, for the sake of saving habitat used by salmon, implementation #1 and #2 projects should be put into effect almost simultaneously. Finally, if no salmon are present, then the basin should be studied to see if salmon can return based on both landscape and in-stream factors. If salmon can return, then remedial action order should be based on the appropriate landscape and in-stream factors.

The next level of prioritization was based on remedial action implementation order in the landscape. This was determined by the potential risk (in this study, sedimentation factor). If the risk factor was high, then more immediate remedial action was deemed necessary (remediate #1); if risk was medium, then remedial action in these basins came after the #1 basins. These "remediate #2" sub-basins should be further investigated to ascertain if more immediate action is necessary; finally, if risk was low, then remedial action timing was given the lowest ranking of #3. This could mean a more "long-term" view of remedial actions in these basins, but these basins should be monitored carefully and any possible future disturbances should be immediately controlled.

The specific remedial action(s) needed were based on an evaluation of the individual parameters ratings of the landscape factors (namely, imperviousness, road crossings, road density, and vegetation density). The ordering of these remedial actions was based on the final value of each parameter—the highest landscape parameter(s) was deemed first priority remedial action, then the next highest parameter, and so on.

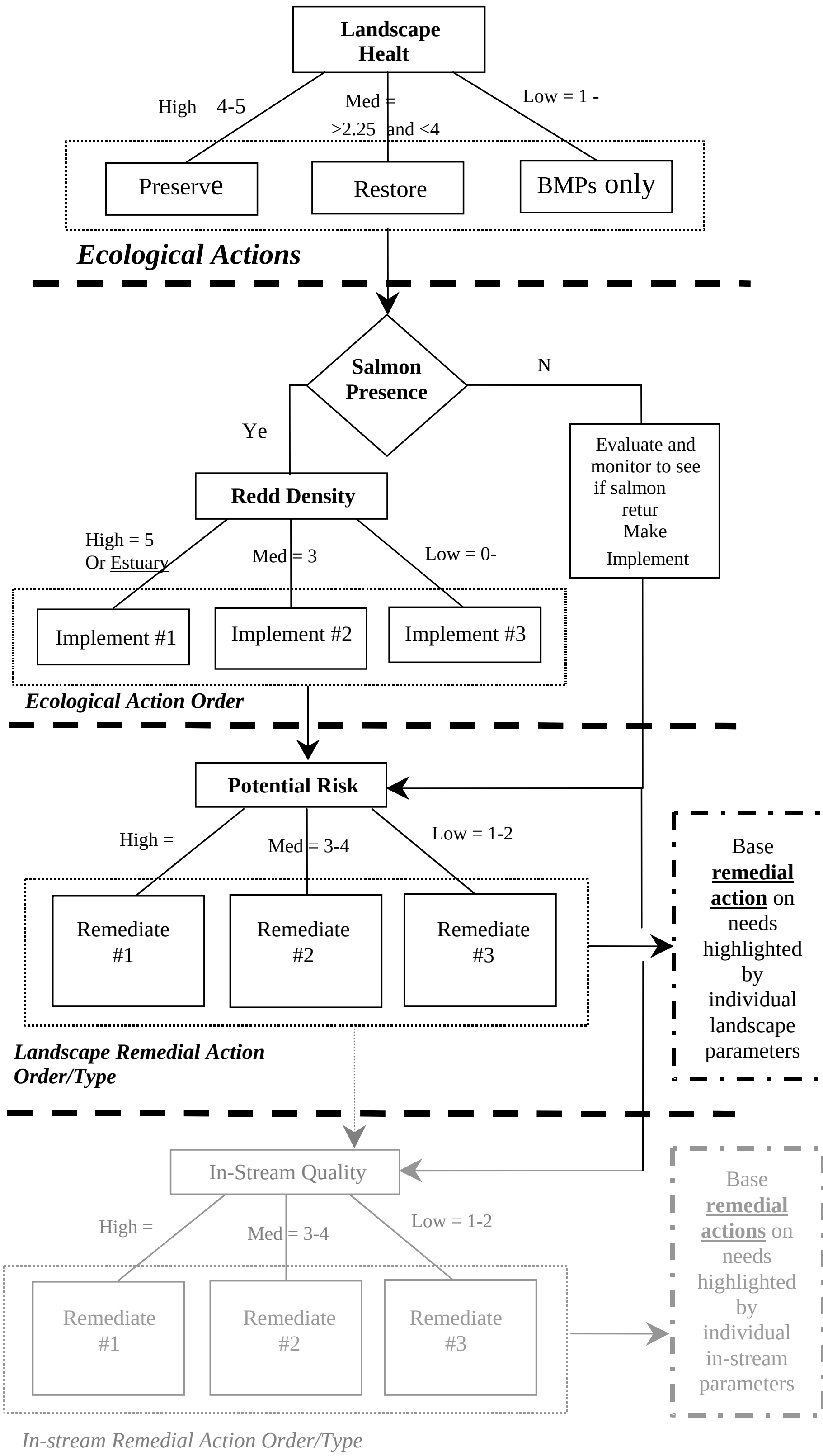

Figure 4-5 Generalized Prioritization Model
(Source: Author)

4.2.B Software and Hardware

For this research, GIS software including Arc/Info Desktop 8.3 and ArcView 3.3 developed by the Environmental Systems Research Institute (ESRI, 2003) of Redlands, California were used. Both the capabilities of ArcGIS and Arc/Info workstation within Arc/Info desktop were utilized to complete this research. This software was run on an Intel-Pentium 3 Personal Computer with a processor speed of 866 Mhz (dual processors) and RAM of 2 GB.

4.3 DATASETS NECESSARY FOR ANALYSIS

The datasets used for this analysis are listed in Table 4-1 below. Each dataset was projected to the Horizontal Coordinate system of Washington State Plane, North American Datum 1983, North Zone (FIPS Zone 4601). This step was necessary so that all data could be analyzed in a common coordinate system. When necessary, the data was clipped to the WRIA 9 boundary so that analysis could be narrowed to this spatial extent. (All the maps that follow show the original data clipped to the WRIA9 study boundary. Much of the original data was obtained for a greater spatial extent than just this boundary, but only the data within the boundary is shown).

Table 4-1
Summary description of data used in analysis

Data	Source	Source Date	Source Scale	Classes
Redd Locations	Malcom, 2002. Cropp, 2004	1997-2003	NA	None
Land cover	USGS	1992	1 : 24000 30 meter grid	21 classes – See Appendix B for Metadata
Soils	NRCS	1973 for W. King County and 1992 for E. King County (digitized 2003 - draft)	1 : 24000	Soil classifications (many)
Digital Elevation Models (DEM)	USGS	Unknown	1 : 24000 30 meter grid	Based on elevation
Hydrography	King County	2000	1 : 24000	See Appendix B, Open Water, Streams for Metadata
Transportation (roads)	King County	2000	1 : 24000	See Appendix B, KC Street Network for Metadata
Sub-basins	Pacific Biodiversity Institute	2000	1 : 24000	None
Dams	Streamnet.org	2002	Lat, Long 4^{th} decimal place	See Appendix B for Metadata

(Source: Author)

4.3.A Discussion of Data Sources

Redd Locations

The original redd densities estimates were obtained from a study done by Malcom (2002). This study reviewed Chinook salmon redd data that was collected by the Washington

State Department of Fish and Wildlife (WDFW) for the years 1997-2000. The WDFW survey was done exclusively on the mainstem of the Duwamish/Green River. Initially, the river was divided by WDFW into 10 river reach segments for reporting purposes. In 1999, these 10 reaches were further subdivided into 31 reach segments. This further segmentation was done to help "gain a better understanding of the location of spawning Chinook" (Malcom, 2002. p.5). Additional data was obtained directly from the Washington Department of Fish and Wildlife that also detailed redd information from 2001-2003.

Both Malcom's (2002) report and the data obtained from WDFW summarized the data and provided analysis tables that reported the absolute distribution, the relative distribution, and the cumulative distribution of Chinook redds. They also detailed the percentage of redds contained in each reach as compared to the overall distribution of redds in the system and the redds per mile (density of redds) as found in each reach. For the purposes of this research, the redd density information developed by WDFW provided a means to more closely approximate existing prime habitat for Chinook salmon.

Land Cover

Land cover was obtained from the United States Geological Survey (USGS) website. This data set is know as the National Land Cover Data (NLCD) and was processed by the USGS in 1992. This is the most current form of land cover data covering the geographic extent of interest (See Figure 4-6 below).

The original data has 21 classifications of "generalized" land cover found within the United States. These generalized classes are listed in Table 4-2 under the column 'Original

Value' and described under the column labeled 'Description.' These classification values are found within the associated attribute table (Value attribute table or VAT) of the digital grid.

Table 4-2
Land cover descriptions

Description	*Original Value*
Water	11
Perennial Ice, snow	12
Low intensity residential	21
High intensity residential	22
Commercial, Industrial, Trans	23
Bare rock, sand, clay	31
Quarries, strip mines, gravel pits	32
Transitional	33
Deciduous forest	41
Evergreen forest	42
Mixed forest	43
Shrubland	51
Orchards, vineyards, other	61
Grasslands, herbaceous	71
Pasture, hay	81
Row crops	82
Small grains	83
Fallow	84
Urban, recreational grasses	85
Woody wetlands	91
Emergent herbaceous wetlands	92

Source: USGS (n.d.)

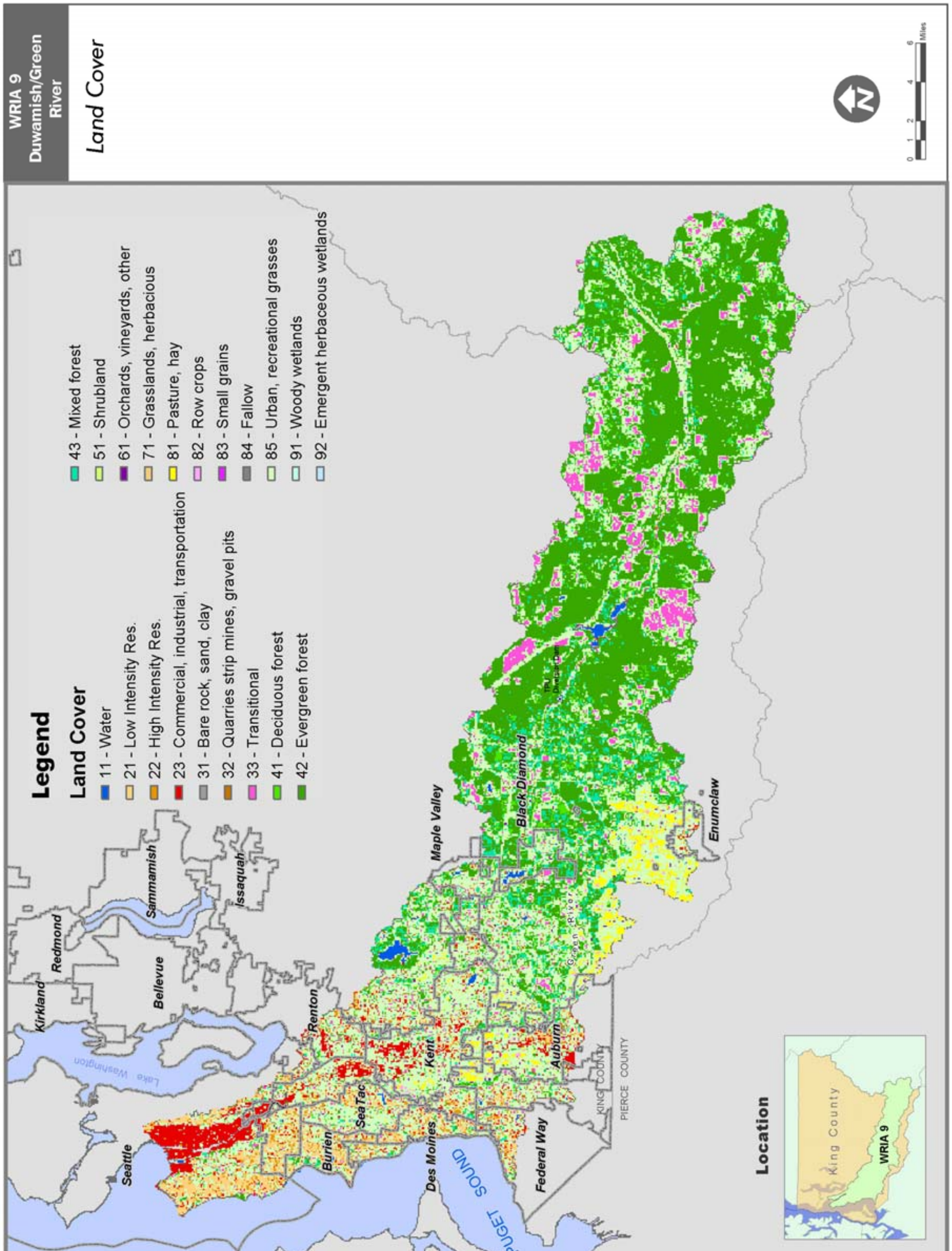

Figure 4-6 Land Cover
(Source: Author)

Soils

Soils data were obtained from the Natural Resource Conservation Service (NRCS). For western King County, the data was in preliminary status (meaning that this data was a pre-release version that was not yet available to the public). The Eastern King County soils data was obtained from the publicly available data-sets offered over the internet. The soils mapping units are a digital representation of soil units that were originally delineated on hardcopy maps. (See Figure 4-7 below).

The soils maps delineate boundaries between different soil types. These delineations are estimates of locations of soil type extents and show distinct boundaries. In reality, boundaries between soils are not as distinct or abrupt, but blend or gradually merge together. Still, these soil units give a good approximation of the extents of a soil.

The digital soils data also have associated tabular data that was obtained in MS-Access© format. The tabular data is currently going through a conversion process performed by the Natural Resource Conservation Service (NRCS). Some of the tabular data is consistent with the old soil series hard-copy volumes while some of the data has been changed or dropped in the conversion process.

For this research it was also necessary to extract information from the original soils series hard-copy books. Both the Soil Survey: King County Area, Washington (Snyder, Gale, & Pringle, 1973) and the Soil Survey of Snoqualmie Pass Area, Parts of King and Pierce Counties, Washington (Golden, 1992) were used. Some of the tabular data from these surveys were converted to digital form so that it could be associated with the digital soil maps. Specifically from the King County Area soil survey, Table 6 – Woodland Groups, Wood Crops and Factors in Management and the Erosion Hazard were recorded. From the Soil Survey of Snoqualmie Pass Area, Table 7 – Woodland Management and Productivity, the Erosion Hazard was recorded. The original, hard-copy table had verbose descriptions for Erosion Hazard (Slight, Moderate, and Severe). These were converted to numeric values in the digital table (1 - Severe, 2 - Moderate and 3 - Slight).

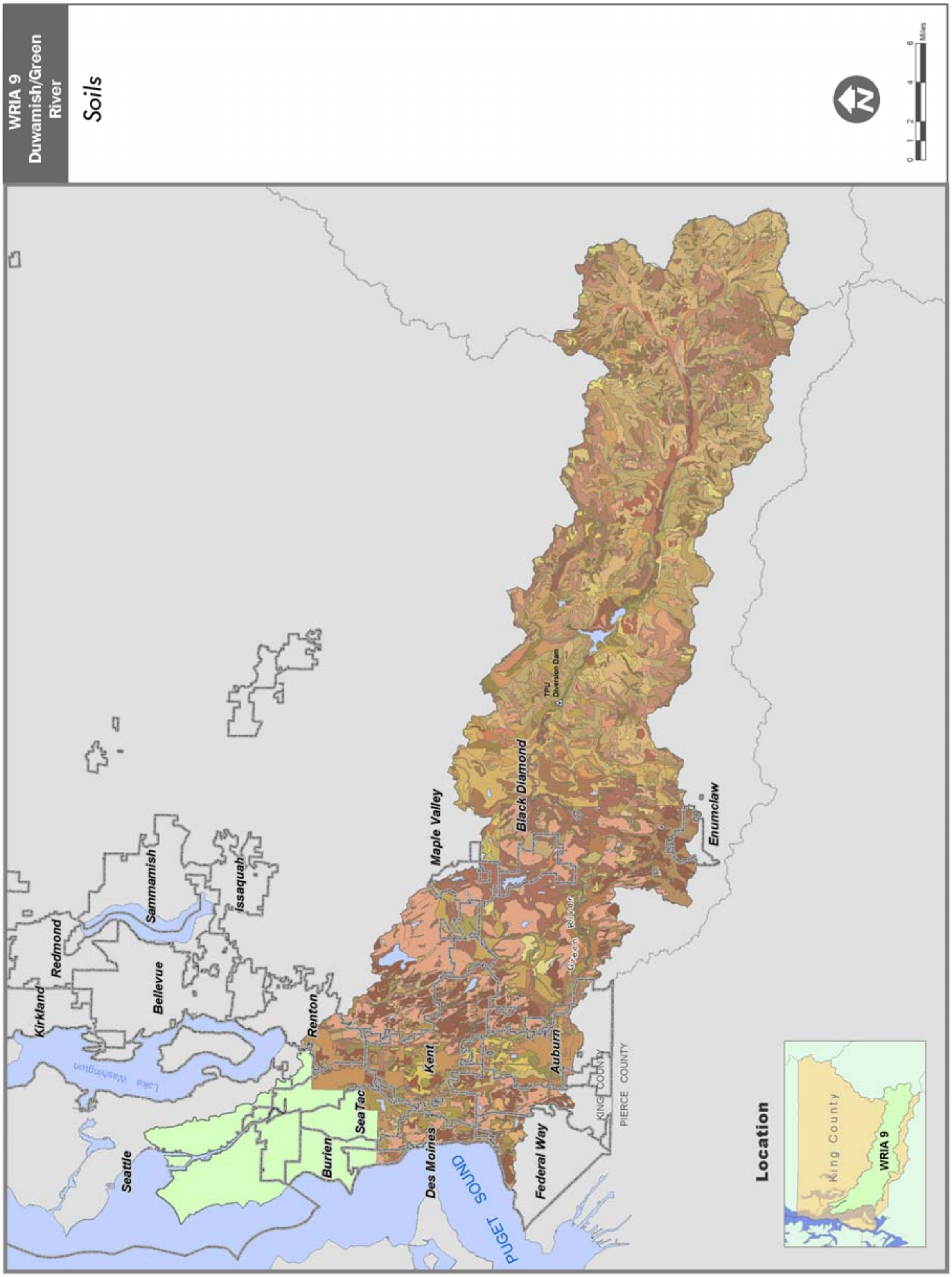

Figure 4-7 Soils

(Source: Author)

DEM

Thirty-meter digital elevation model data was obtained to facilitate the determination of slope. This DEM data was originally obtained from the USGS EROS data center as a national dataset (This dataset was otherwise known as the USGS National Elevation dataset or NED). The DEM data was clipped to the Green/Duwamish watershed boundary and then projected to Washington State Plane coordinates. (See Figure 4-8 below).

DEM data is in a grid format that has associated attribute data (in the VAT) that contains elevation values. The elevation data for this DEM was originally in meters and was converted to feet by multiplying the grid by 3.28083 ft/m.

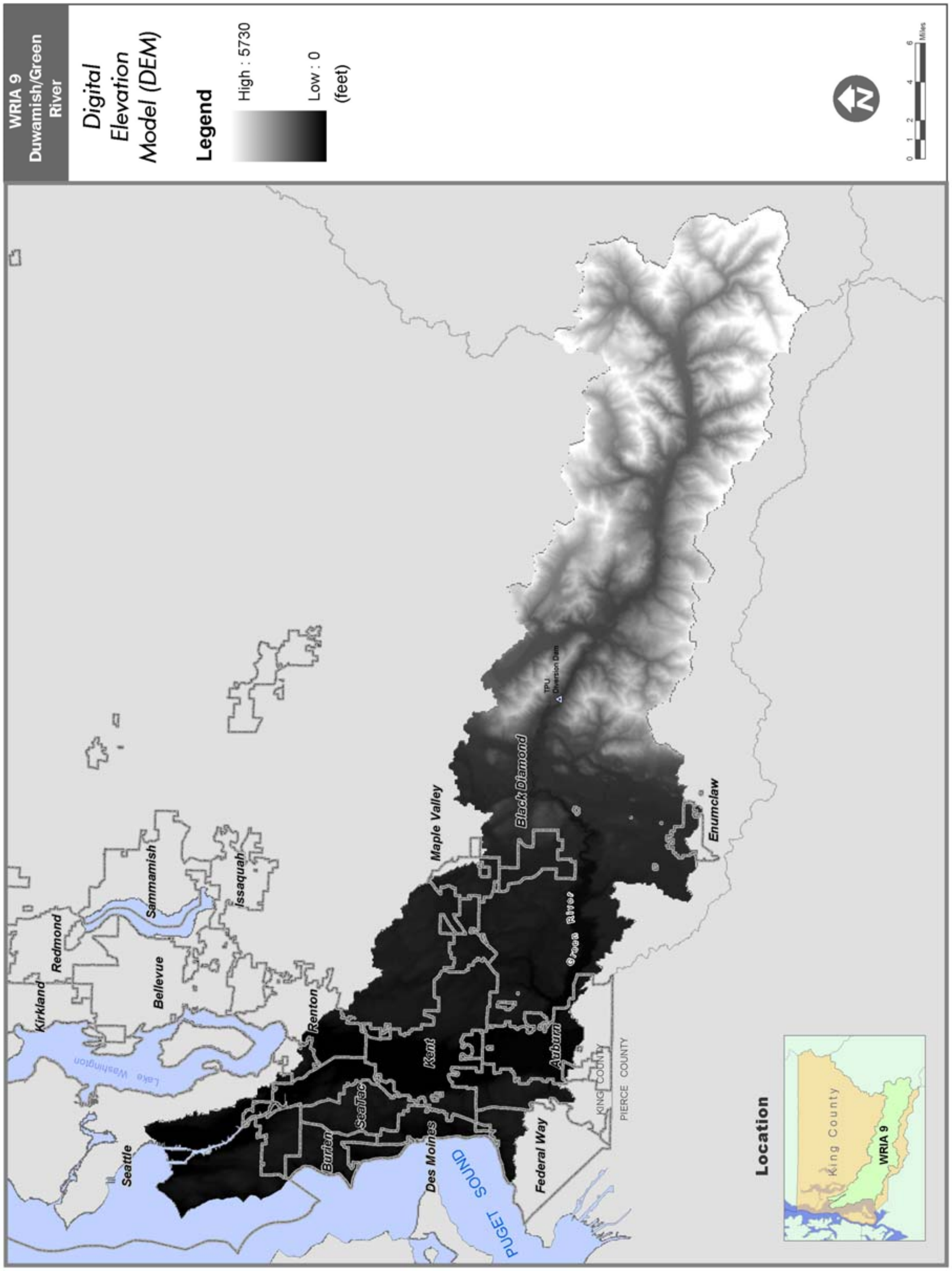

Figure 4-8 Digital Elevation Model

(Source: Author)

Hydrology

Hydrology data was obtained from King County GIS Department. The original dataset was called WTRCRS (Water-course). The dataset was clipped to the WRIA 9 boundary and was renamed to hyd_all_kc. (See Figure 4-9 below).

This dataset contains the centerlines for the hydrologic network found within WRIA 9. This dataset was hydrologically correct, meaning that all branches of the river system “pointed” downstream (in other words, the from and to nodes of the arcs were aligned so that they were in the correct direction of flow).

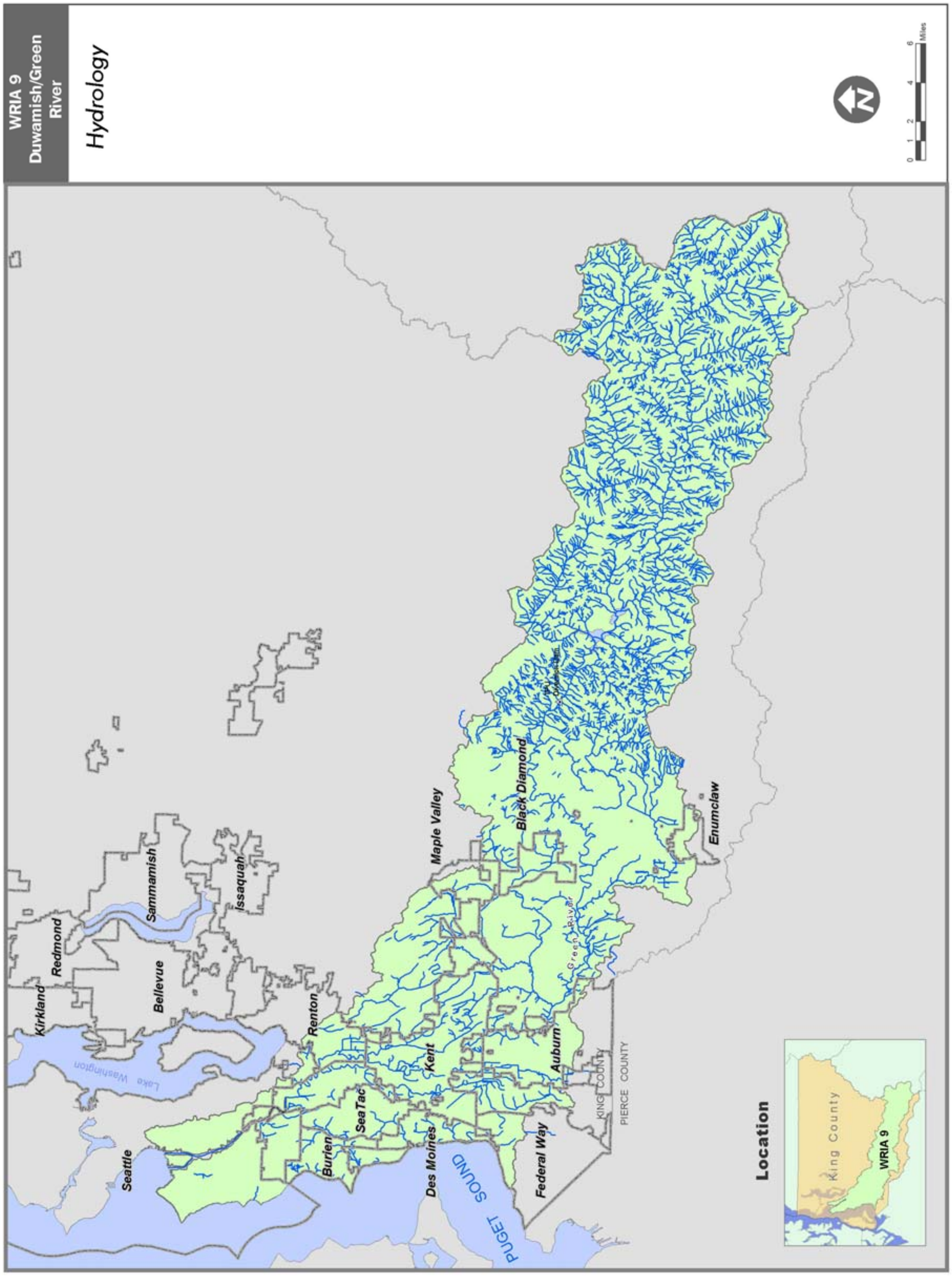

Figure 4-9 Hydrology

(Source: Author)

Roads

Roads were obtained from King County GIS Department. The original coverage was called KCSN (King County Street Network) and contained road centerlines for all of King County. This coverage was clipped to the WRIA 9 boundary and renamed to roads_sp83. All road types were considered significant and were used for analysis purposes. (See Figure 4-10 below).

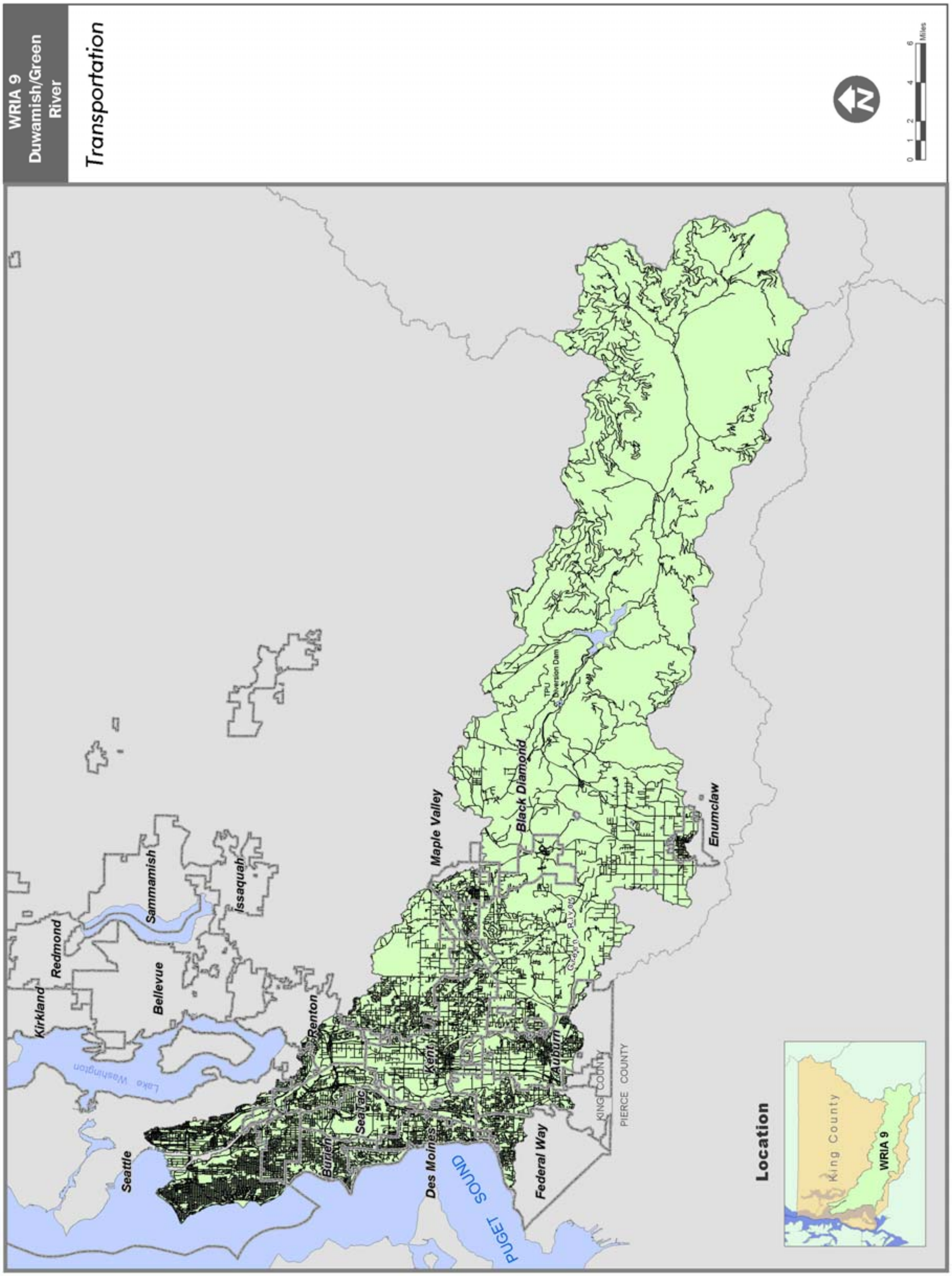

Figure 4-10 Roads

(Source: Author)

Sub-basins

Sub-basins were obtained from Pacific Biodiversity Institute (PBI). PBI had previously done a study that created sub-basins of watersheds for most of the Puget Sound region. The sub-basins obtained for WRIA 9, although somewhat useful, were not deemed appropriate for this research because of their large size. It was determined that smaller sub-basins were necessary, but PBI sub-basins were used where smaller sub-basins could not be generated accurately (the PBI sub-basins used were near the mouth of the Duwamish River).

Dams

A dams coverage was obtained from Streamnet.org (online http://www.streamnet.org) to locate the Tacoma Public Utility (TPU) diversion dam which marks the salmon accessible extent of the Green River. Migrating Salmon cannot pass by the TPU Diversion Dam and thus it is the upper limit of the system.

4.3.B Preprocessing of Datasets

Creation of Sub-basins

The first step in creating a new sub-basins coverage was to develop a depressionless DEM (a DEM containing no sinks or "holes"). To do this the following procedure was used:

First, a flowdirection grid was created, and then sinks were determined from this flowdirection grid. A flow direction grid shows the direction of flow from each cell in the grid to its steepest downslope neighbor. After the flowdirection and sink grids were created, a process was used to find the sink depth necessary to "fill" the sinks. (The following lists the GRID commands used for this process. The original DEM was called wria9_sp2).

GRID: wria9_flow = flowdirection (wria9_sp2)

GRID: sinks = sink(wria9_flow)

GRID: sink_areas = watershed (wria9_flow, sinks)

GRID: sink_min = zonalmin (sink_areas, wria9_sp2)

GRID: sink_max = zonalfill (sink_areas, wria9_sp2)

GRID: sink_depth = sink_max – sink_min

The end result of this process was the determination that sinks needed to be filled to a depth of 84.875 ft. The depressionless DEM was created by using the GRID FILL command to remove the localized sinks (GRID: Fill wria9_sp2 wria9_fill SINK 84.875).

After these steps, a flow accumulation grid was created by applying the appropriate GRID command to the flow direction grid (GRID: wria9_acc = FLOWACCUMULATION(wria9_flow). A flow accumulation gird creates a grid showing the accumulated flow to each cell. In other words, this is a grid showing the accumulated weight for all cells that flow into each downslope cell.

From this flow accumulation grid, a basic stream grid could be created that showed the likely places that water would accumulate to form streams and rivers. (GRID: wria9_strm = con(wria9_acc gt 400, wria9_acc). When this grid was compared to the existing hydrology layer, the correspondence between the two was very good. There were some areas (especially in the more urban north-western portion of WRIA 9) that did not correspond. This was deemed a limitation of the original DEM data.

Using the newly created stream grid and the existing hydrology coverage, pour points were determined. Pour points are locations were water would exit a drainage basin (much like a drain at the bottom of the bathtub). The determination of pour points was challenging for creating smaller sub-basins that would be appropriate for analysis. Pour points were only placed on the major tributaries that contained salmon redd information (see Salmon redd data below). These reaches included the mainstem of the Duwamish/Green River, Big Soos Creek, and Newaukum Creek. It was decided that any stream that stretched a distance of less than 4000 feet from these major tributaries would not receive a pour point. This was decided because adding pour points for all tributaries below 4000 ft would have created very small drainages. These smaller drainages were deemed not appropriate for this analysis. Their small could be considered smaller than sub-basin size—a size that would not be appropriate for the grain of the data. Pour points were placed at each stream entering the major tributaries and watersheds were created. These pour points were first placed as a shapefile and then were converted to a grid format (Using ArcMap Spatial Analyst tools) so that they could be used in the appropriate GRID command for creating "watersheds," or in this case sub-basins (GRID: wshed = watershed(wria9_flow, pour_pt).

After some trial and error, some pour points needed to be removed because they were redundant. Final sub-basins were created with the final pour points and then a coverage of sub-basins was created by converting the grid to features (this was performed in ArcMap using the Spatial Analyst extension capabilities). The final analysis basins were chosen by selecting any sub-basin that intersected the redd density information (See Figure 4-11 below).

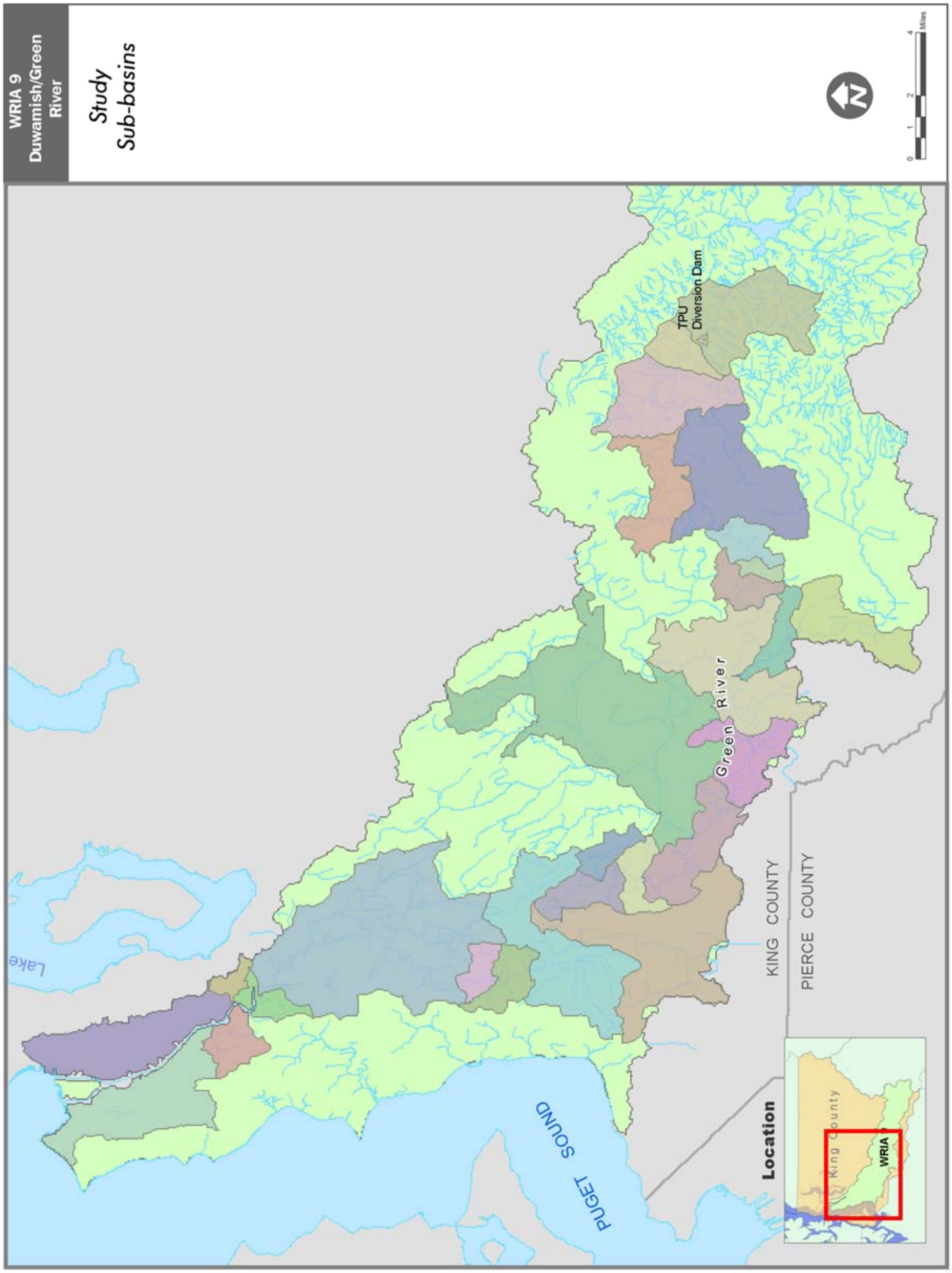

Figure 4-11 Study Sub-basins

(Source: Author)

Hydrography

Linear Reference

It was necessary to create a hydrologic dataset that could receive river-mile information from the tabular data representing salmon redds. This hydrologic dataset included the centerline of river reaches within WRIA9 that had redds recorded from the Malcom (2000) and WDFW (2003) tabular reports. These reaches included the mainstem of the Green/Duwamish, Big Soos Creek and Newaukum Creek. (See Figure 4-12 below).

Once this river system coverage was established, a linear referencing system for this arc coverage needed to be created. (A linear reference system is a means to apply measurements of any chosen units—in this case, miles—to a line in the Arc/Info-ArcGIS programming system. From these measurements, tabular data can be graphically shown on the line as long as it has a corresponding measurement system. These tabular data "overlays" are called events in the terminology of Arc/Info-ArcGIS). This new linear referencing system was based on miles to match the WDFW measurement system of River Miles (RM) for reporting stream reaches (Note: the original measurement system for the arc coverage which represented the river was based on feet). From Malcom (2002), the endpoint of the mainstem of the Green/Duwamish is known to be the Tacoma Public Utility (TPU) diversion dam at RM 61. When the referencing system was initially applied to the river, RM 61 appeared just before the TPU dam. To correct this, the REMEASURE command was used in Arc/Info to redistribute the measurement system so that it ended at RM 61 at the dam location. The other tributaries (Big Soos Creek and Newaukum) had the measurement system applied as is.

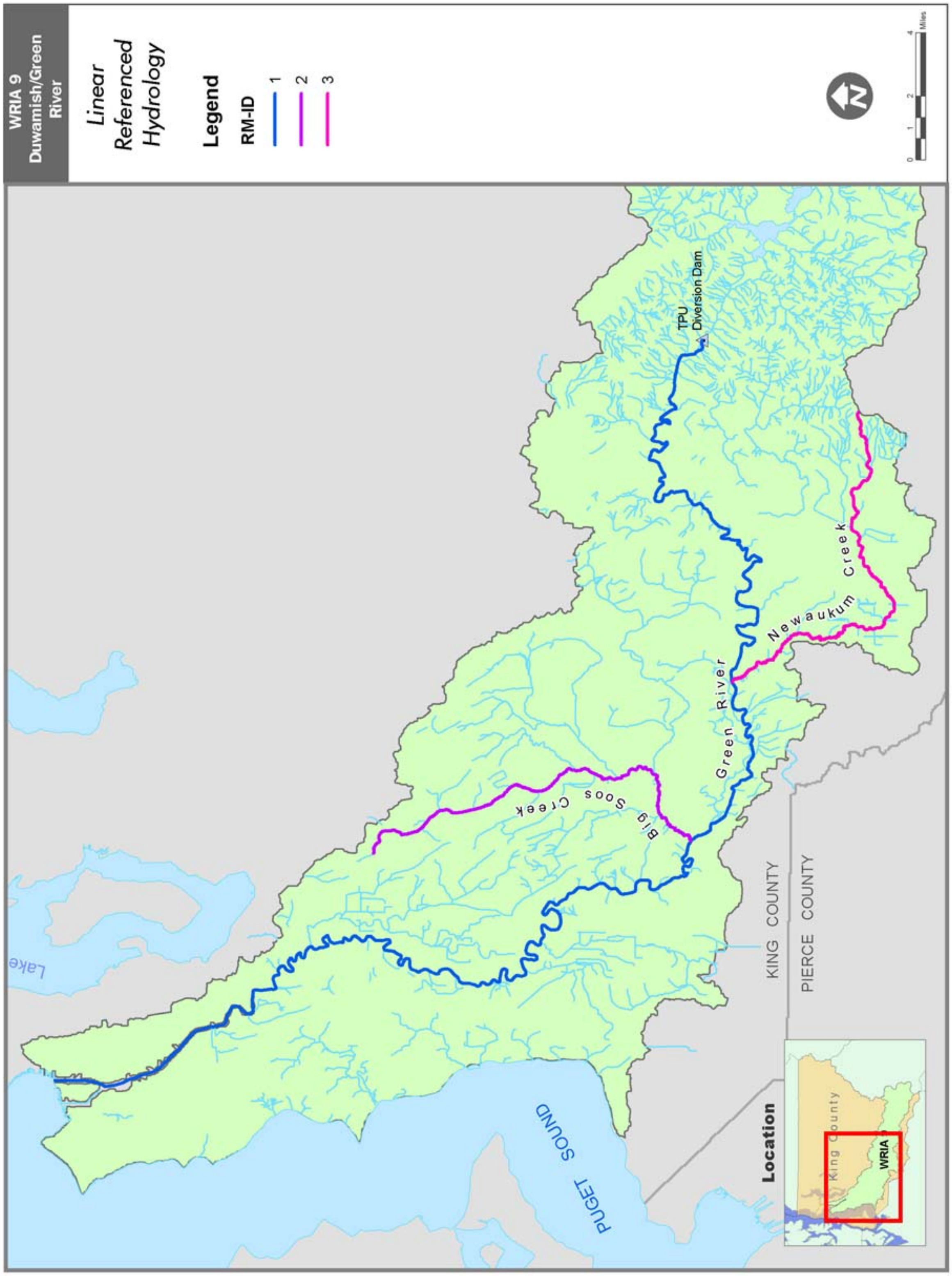

Figure 4-12 Linear Reference System

(Source: Author)

Stream-Order

To determine stream-order, which was necessary for further analysis of the hydrography layer, the ArcView extension "Create Strahler Stream Order" by Duncan Hornby courtesy of ESRI (2004) was used. The extension was run and automatically created an item called STRAHLER in the hydrography layer. (See Figure 4-13 below).

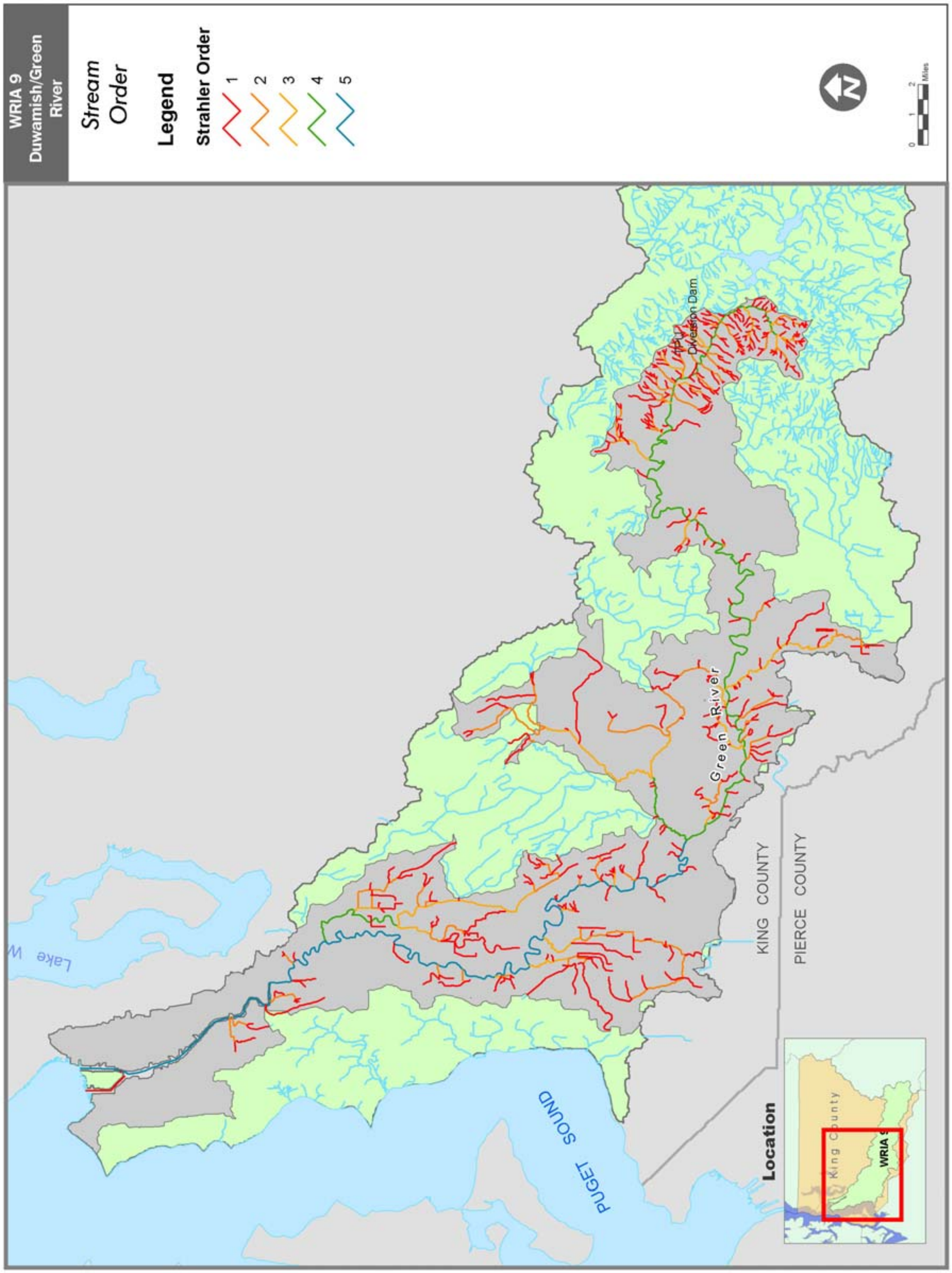

Figure 4-13 Strahler Stream Order

(Source: Author)

Redd density

This GIS processing step required an association of redd density to individual stream segment measurements as detailed in the WDFW tabular data. To accomplish this task, the tabular redd density information needed to be spatially joined to the Duwamish/Green River and then further manipulated so that a general Chinook redd density measurement could be developed for the system. Once the linear referencing system for the hydrology was in place, then the event data—the redd density for each survey year from 1997 through 2003—was easily added.

The event data was added in 3 segments; first for the years 1997-1998, then 1999-2001, and finally 2002-2003 (This was done because the original data was obtained in these three segments). This data was then unioned (or joined together) using the route events geoprocessing wizard in ArcMap. This tabular information was then averaged to obtain an average redd density in the study area reaches for the years 1997-2003. (See Figure 4-14 below).

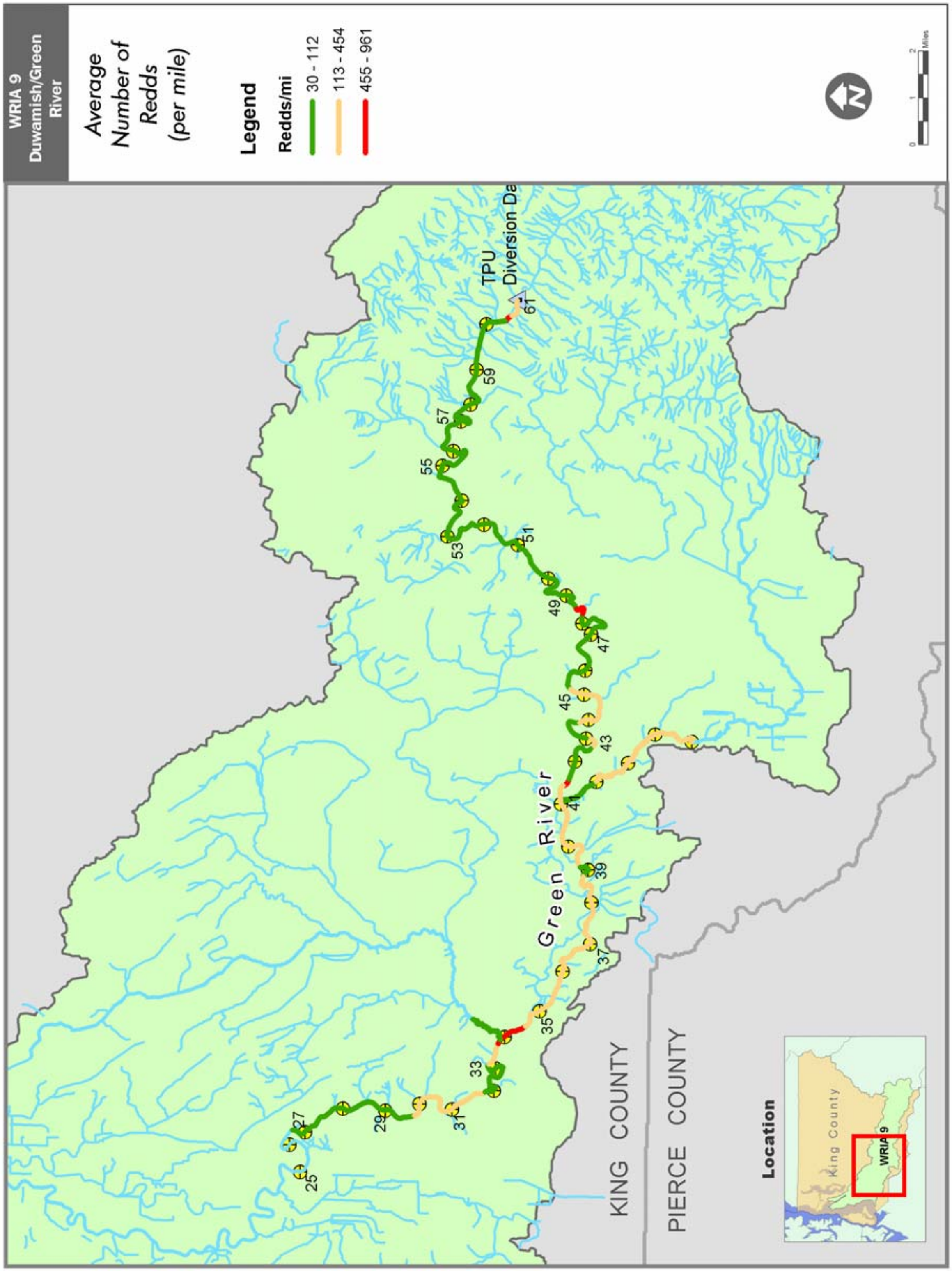

Figure 4-14 Redd Density (redds/mile)

(Source: Author)

The event table was then turned into a shapefile theme. This was done so that the average redd density could be determined per sub-basin. To do this, the average redd density theme was intersected with the sub-basins coverage to produce a coverage that would have the sub-basins “imbedded” into the redds information table. The average redds table was then summarized for the sub-basin id (subbas_id) and the redd density was averaged per basin.

Land Cover

Impervious

This land cover data had associated impervious values assigned to each land cover class as shown in Table 4-3 under the column ‘Related Imperviousness.’ These impervious associated values were developed by evaluating the impervious data obtained from the North Carolina Department of Environment and Natural Resources (DENR) (2002) and the United States Department of Agriculture (1986) and discovering the average impervious area for a particular land-use/land-cover (lulc) type.

Table 4-3
Impervious lookup table

Description	Original Value	Related Imperviousness (%)*
Water	11	0
Perennial Ice, snow	12	0
Low intensity residential	21	28%
High intensity residential	22	65%
Commercial, Industrial, Trans	23	78%
Bare rock, sand, clay	31	50% (bare rock)
Quarries, strip mines, gravel pits	32	50%
Transitional	33	38%
Deciduous forest	41	1%
Evergreen forest	42	1%
Mixed forest	43	1%
Shrubland	51	2%
Orchards, vineyards, other	61	2%
Grasslands, herbaceous	71	2%
Pasture, hay	81	2%
Row crops	82	1%
Small grains	83	1%
Fallow	84	1%
Urban, recreational grasses	85	2%
Woody wetlands	91	0%
Emergent herbaceous wetlands	92	0%

Source: North Carolina Dept. of Environment and Natural Resources (2002) and USDA, (1986)

For the most part, the evaluation of impervious percentages was straight-forward, but for some land-cover types extrapolation and interpretation was necessary. The Water and Perennial Ice categories were considered 0% impervious because they are either water or constituents of water. Although the assumption of 0% impervious may be inaccurate for ice, this was not seen as critical for this model because this land-cover type was not found in the study area. Low Intensity Residential imperviousness was an average of the percentages given in the USDA (1986) study for 1/4 acre, 1/3 acre, 1/2 acre, and 1 acre home sites (38%, 30%, 25%, and 20% respectively). High intensity Residential imperviousness was the percentage given for the 1/8 acre home site in the USDA (1986) study. The Commercial and Industrial land use impervious percentage was the average for these same categories listed in the USDA (1986) study (85% and 72% respectively**).** Both the "bare rock, sand, and clay" and "quarries, strip mines and gravel pits" percentages were difficult to arrive at. Both these categories received the value of 50% given for 'Railroad right of way' in the North Carolina DENR study (2002). It was felt that these categories shared some feature with railroad right of way, but this certainly is an assumption. The most difficult land use category to assign an impervious value to was the Transitional type. Transitional land use, by its very nature, is in flux. This means it could be in a state of being highly developed, such as for a commercial site, or it could be a new low intensity residential development. Because of this difficulty, it was decided that the ¼ acre home site impervious percentage value from the USDA (1986) study would be used. Although it is not empirically proven, it is believed that the ¼ acre home site is very common for new development and that transitional land use in the King County region is often representative of new home site development.

The land use categories of listed forests (Deciduous, Evergreen, and Mixed) were given an impervious percentage value of 1% because this was the value given for forest and wooded land in the North Carolina DENR (2002) study. The Row crops, Small grains, and Fallow fields were also given an impervious percentage of 1% because of the value given in the North Carolina DENR (2002) study for similar land use types. Grasslands and Urban/Recreational grasses were given a value of 2% impervious which was the value for ‘Agricultural: Open Grass Land’ stated in the North Carolina DENR (2002) study. Orchards, Vineyards and Shrubland were given a value of 2% because it was assumed that these land use areas also have similar properties to open grass land. The wetland land-cover categories were given a value of 0% imperviousness because of their ability to absorb and retain water.

Generalized land-cover

A more generalized land-cover dataset was used to determine the density of vegetation within the riparian buffers, and, in combination with the DEM, with the sedimentation potential of the buffer zones (See Table 4-4 below). This table was developed so that vegetation densities could be assigned to more generalized categories. The densities percentages used in this study are listed as “veg density” within the table.

Table 4-4
Generalized Land-cover (Source: Author)

Reclass Value	Landcover Type	Veg Density	Original NLCD values
0	Water	0%	11, 12
1	Low Intensity Residential	62%	21
2	High Intensity Residential	20%	22
3	Commercial/Industrial	12%	23
4	Barren	0%	31, 32
5	Transitional	25%	33
6	Forestland	85%	41, 42, 43
7	Shrub	50%	51
8	Non-natural wooded	50%	61
9	Herbacious Natural/Unnatural	75%	71, 85
10	Agriculture	75%	81, 82, 83, 84
11	Wetlands	75%	91. 92

Vegetation densities were derived by using comparisons to the impervious cover table and making sure that percentage vegetation values fell within the range specified by a table found in ProLogic's SAGE API Manual (Prologic, 2003) that compared NLCD to Woody Vegetation (a surrogate of all vegetation) (See Table 4-5 below). The 62% vegetation for Low Intensity Residential is derived from 28% impervious. In other words, (100% land-cover) – (28% impervious) = 72%---of this, 10% was left off for other pervious surfaces besides vegetation such as bare soil and loose rock. This left 62% vegetation, which fell within the range of values specified in the SAGE API Manual (Prologic, 2003) table. This same sort of equation was applied to Commercial/Industrial areas to arrive at 12% vegetation. High intensity residential was given a value of 20% because this is the upper range specified in the SAGE API Manual (Prologic, 2003) table. Transitional was also given the high value of 25% listed in the SAGE Manual (Prologic, 2003). Forestland was an educated guess that 85% of land covered by forest would be vegetated. The Non-natural wooded (mainly orchards, vineyards) value of 50% vegetation was also an educated guess. The Herbaceous Natural/Unnatural, Agriculture, and Wetlands values were all the lowest range values listed in the SAGE API Manual (Prologic, 2003).

Table 4-5
From ProLogic's SAGE API Manual Table 5.4.g (Prologic, 2003)

NLCD Code	Category	Description	Woody Vegetation Density
11	Water	Open Water	0-25%
12	Water	Perennial Ice/Snow	0%
21	Developed	Low Intensity Residential	20-70%
22	Developed	High Intensity Residential	0-20%
23	Developed	Commercial/Industrial/Trans	0-100%
31	Barren	Bare Roc/Sand/Clay	0%
32	Barren	Quarries/Strip Mines/Gravel Pits	0%
33	Barren	Transitional	0-25%
41	Forested Upland	Deciduous Forest	25-100%
42	Forested Upland	Evergreen Forest	25-100%
43	Forested Upland	Mixed Forest	25-100%
51	Shrubland	Shrubland	25-100%
61	Non-Natural Woody	Orchards/Vineyards/Other	25-100%
71	Herb. Upland Nat./Semi-nat. Veg	Grasslands/Herbaceous	75-100%
81	Herbaceous Planted/Cultivated	Pasture/Hay	75-100%
82	Herbaceous Planted/Cultivated	Row Crops	75-100%
83	Herbaceous Planted/Cultivated	Small Grains	75-100%
84	Herbaceous Planted/Cultivated	Fallow	0%
85	Herbaceous Planted/Cultivated	Urban/Recreational Grasses	01-00%
91	Wetlands	Woody Wetlands	25-100%
92	Wetlands	Emergent Herbaceous Wetlands	75-100%

Soils

Spatial data

The soils data was in two geographic extents basically divided between Western King County and Eastern King County. The western data was obtained as draft data because it has not been released as a final coverage from the NRCS. The Eastern portion was publicly available and was downloaded from the NRCS website (http://soils.usda.gov/ --Note: As of September 2004, this data seems to no longer be available on the public web-site).

The two datasets were first individually clipped to the WRIA9 study boundary. This was done to reduce the amount of edge-matching that would need to be done between the datasets. The datasets nodes were then matched between the West King County coverage and the East King County coverage. Once nodes matched, the coverages were appended. A basic Arc/Info CLEAN command was run on this coverage using a dangle of 2 feet and a fuzzy tolerance of 0.5 feet. This created the preliminary King County soils coverage. Once this coverage was established, labeling errors were detected and fixed. Any soil unit that did not have a label (these were mostly at the interface between the West and East coverages) was examined by listing the soil unit that corresponded to it from the other side and given its proper label. This final coverage was built for polygons and was used in corresponding analysis.

Tabular data

Tables were created from the Soils Survey hardcopy information for both western and eastern King County (Dale, 1973; Goldin, 1992) to relate to the spatial data so that soil erosion potential could be shown. (Note: all relates of this tabular information were done through the item Musym). Unfortunately, there was not a standard measure between the two soil surveys for soil erosion potential, so some data manipulation needed to be performed and relationships needed to be built.

For Eastern King County, the erosion hazard was listed as Slight, Medium, and Severe. These were changed to numerical representations of Slight = 1, Medium = 2, and Severe = 3 (See Table 4-6 below). For western King County, the erosion potentials were listed with descriptors such as Slight, Slight to very Severe, Slight to Severe, Moderate to severe, etc. It was decided that Slight would equal 1, Moderate = 2, Severe = 3, and Very Severe = 4. Then, any descriptive range such as Slight to Severe would be an average of these two descriptions (i.e. Slight = 1, Severe = 3, so this would be (1+3)/2 = 2 for a potential erosion value of Slight to Severe). (Note: Urban land received a value of 2.5 and all Muck soils in Western King County received a value of 1 because of information found in page 69 of the King County Soils Manual (Dale, 1973) (See Table 4-7 below). The tables for these areas were created and the data was related to the spatial soils information so that the erosion hazard could be displayed.

Table 4-6
Eastern King County Erosion Hazard Conversion table (Source: Author)

Erosion Hazard	*Numerical Erosion Hazard*
Slight	1
Medium	2
Severe	3

Table 4-7
Western King County Erosion Hazard Conversion Table (Source: Author)

Erosion Hazard	*Numerical Erosion Hazard*
Slight	1
Slight-Moderate	1.5
Moderate	2
Moderate-Severe	2.5
Severe	3
Severe-Very Severe	3.5
Very Severe	4
Slight – Severe	2
Moderate – Very Severe	3
Urban Land	2.5
Muck Soils	1
Other combinations	(value of first hazard + value of second hazard) / 2

A coverage was created that contained final soils erosion values. This coverage was clipped to the riparian zone and further evaluated.

Riparian Zone Delineation

It was hoped that riparian zones could be established based on differences in soil properties between the aquatic and terrestrial zones. Naimen, Bilby, & Bisson (2000) states that riparian areas can be differentiated by a change in soil conditions. To examine this theory, hydric soils, which involve a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part (United State Department of Agriculture – Natural Resource Conservation Service, n.d)**,** adjacent to the Green and Duwamish river system (including Soos and Newaukum creeks) were evaluated. Unfortunately, hydric soils were not consistently represented on either side of the Green/Duwamish system, especially in the lower portion of the system near the mouth.

It was further felt that flood zones could be used to clarify the riparian area, but once again this proved inadequate and was abandoned. Another attempt was made to establish riparian zones using the ridge tops above the Green/Duwamish system as boundaries. The process necessary for this delineation did not result in clearly defined boundaries.

After all of these efforts were abandoned, it was decided that a generalized riparian area would be established that equaled 100 meters on each side of the river system. This distance is recorded in the literature as the greatest distance that will support all necessary wildlife preservation functions (May, 2000 in Tri-County, 2002).

DEM/Slope

A slope grid was derived from the DEM data using the functionality of Spatial Analyst within ArcGIS. The slope categories used in proceeding analysis were: 0-5%, 5-27%, 27-49%, 49-70%, and >70%. (from Green, Bernath, Lackey, Brunengo, and Smith, 1993).

4.4 PROCESSING OF DATASETS

Drainage basins that had adjacent stream reaches showing evidence of salmon redds (as derived frin the Malcom, 2002 study and WDFW information) were chosen for analysis. This excluded the area above the Green River Diversion Dam and Howard Hansen Dam, since adult Chinook salmon cannot currently access this part of the watershed. All of the following health ranking factors (See Table 4-8 for these values) were added to the sub-basins table. In other words, the determined impervious values were added to an item called IMPERVIOUS in the sub-basins coverage; the determined stream crossing values were added to an item called CROSSINGS in the sub-basins coverage, and so on.

4.4.A Landscape Health Ranking

For each of the health factors, a rating scale was developed. This rating scale for each factor was a basic 0 to 5 range, 5 being the most healthy and 1 being the least healthy (0 represented “no value”). The following factors were analyzed:

Impervious

Impervious percentages for each study drainage basin were calculated by first using the Arc/Info GRID function COMBINE to combine the land-cover grid and the sub-basins grid. Then the table containing the impervious percentages was related to the appropriate land-cover value and added to the Value Attribute Table (VAT) of the newly combined grid. The values for imperviousness percentages for differing land-cover types are found in Table 4-3. These percentages were then used as multiplication factors for the number of cells represented by each land-cover class (in other words, the number of cells representing each land-cover class were multiplied by the percentage of impervious giving the number of impervious cells for each land-cover class). Then the number of impervious cells per basin were added together and divided by the total number of cells in the basin to give the impervious percentage per basin. The Schuler (1995) categories of sub-basin imperviousness of Near Natural (0-5%), Sensitive (6-10%), Degrading (11-25%), and High Risk (26-100%) were used in this analysis so that Near Natural received a 5, Sensitive a 4, Degrading a 2, and High Risk a 1 (See Figure 4-15 below).

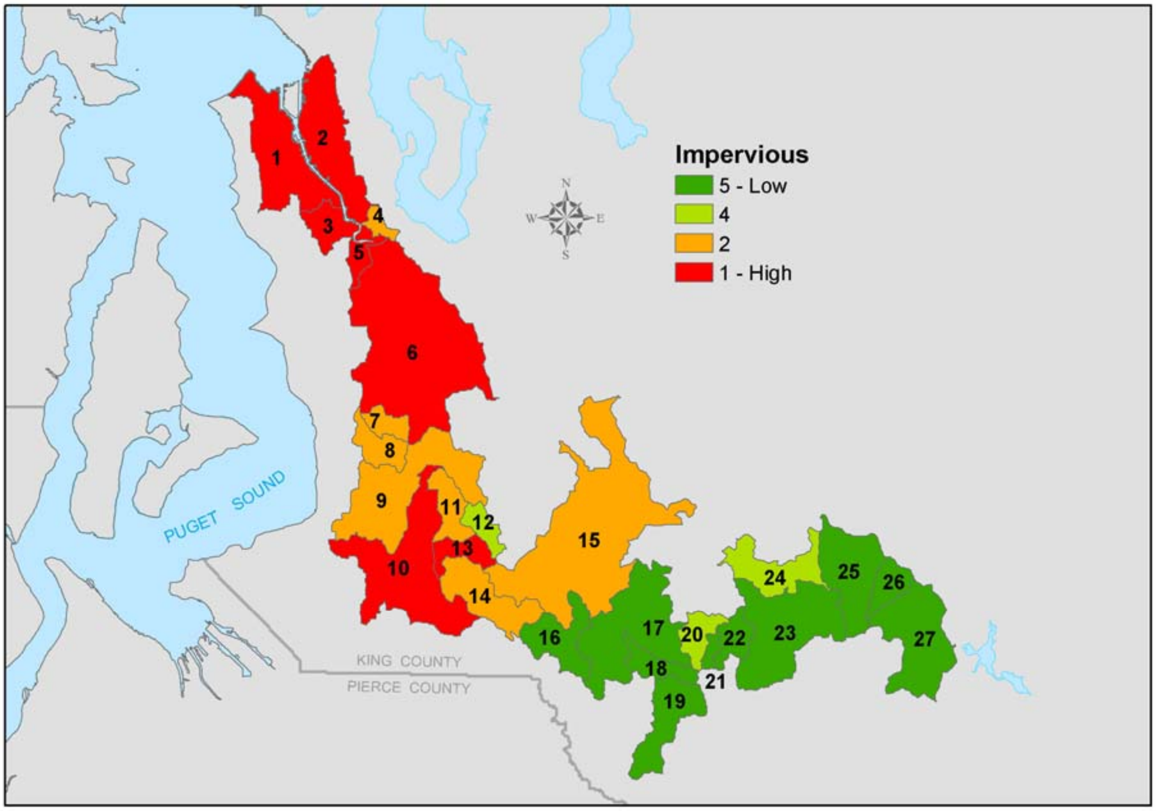

Figure 4-15 Impervious Percentage per Sub-basin
(Source: Author)

Transportation

The transportation layer was used to determine road density and stream crossings (in combination with the hydrography layer). The first step in this process was to union the road network and the sub-basins so that the road network arcs would contain the unique sub-basin ID's (identification numbers).

Stream Crossings

For the calculation of road-stream crossings, the ArcView extension "Themes intersections to points (TIP)" courtesy of Dr. Arun K. Saraf and ESRI (2004) was used. This extension was run for the intersection between the hydrography and transportation layers. This generated stream-crossing points in shapefile format. Then, for each unique sub-basin, the stream crossing points were selected and this total number per sub-basin was calculated to an item called CROSSINGS created in the sub-basins coverage. Also, an item called STRM-LGTH (stream length in miles) was determined for each sub-basin. The final crossing density was calculated by dividing the number of crossings per basin by the length of stream miles. Where stream crossings were <1 per mile, the rating was 5, where the stream crossings were 1-3 per mile, the rating was 3, and where the stream crossings were >3 per mile, the rating was 1 (See Figure 4-16 below).

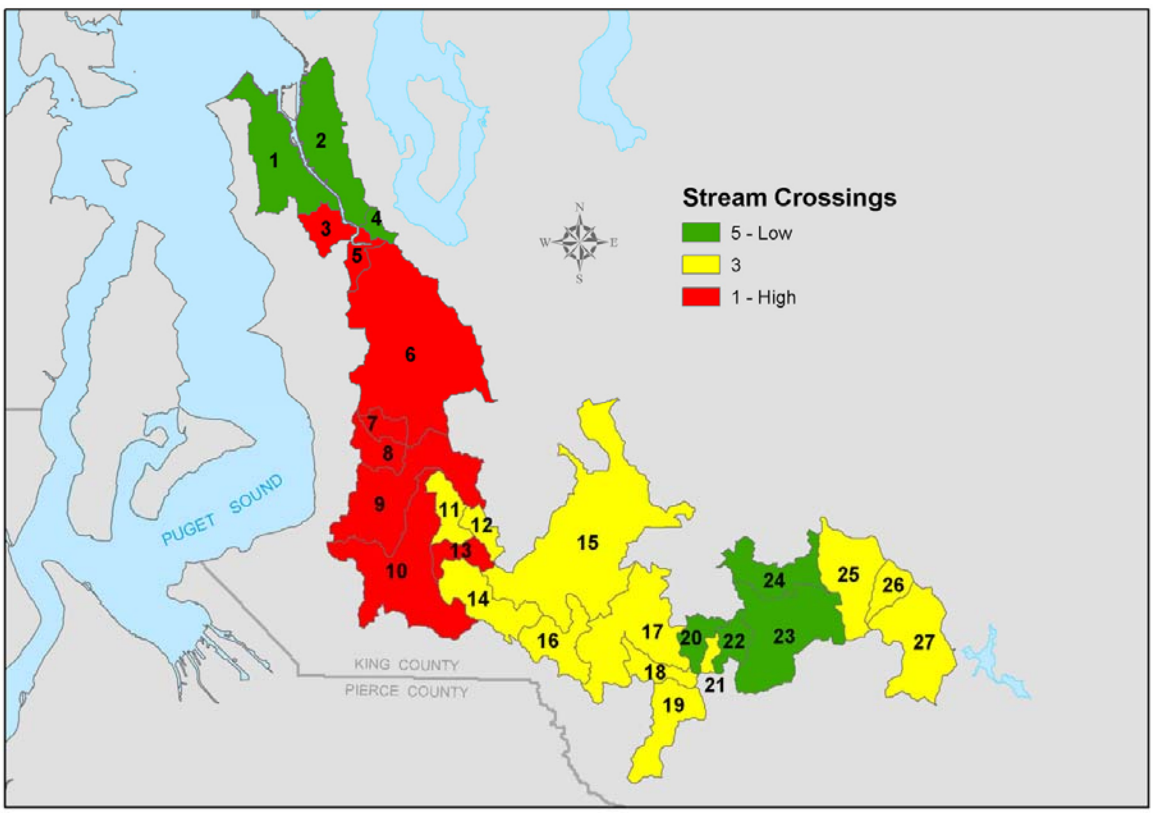

Figure 4-16 Road-Stream Crossings per Sub-basin
(Source: Author)

Road Density

For road density, the table generated from the union of the stream network and road network was used. This table contained the area of each sub-basin and the length of each road segment within each of these sub-basins. A new summary table was generated from this data by totaling the length of road segments found in each sub-basin (in miles) and carrying over the area of each sub-basin into the summary table. A new item was added to this table called TOTAL_LEN. Lastly, an item called DENSITY was added to the final summary table. This item represented the total road density per sub-basin and was calculated by dividing TOTAL_LEN by the area of each sub-basin (in miles^2).

Although the Habitat Limiting Factors and Reconnaissance Report (King County and the Washington State Conservation Commission, 2000) listed road density parameters (as quoted from NMFS), these values did not have a good correlation to the value range found in this study. (NMFS reported that any value >3 mi/mi^2 indicated poor habitat. There was only one basin in the study area below 3 mi/mi^2. Although this might indicate that all basins are in poor condition according to road density, there seemed to be some discrepancies after visual inspection of study basins. I believe that the NMFS values need to be reevaluated and, thus, the ranking system in this study differs from their findings.) After evaluation of the data, it was decided that any sub-basin with a density between 2 and 3 mi/mi^2 was given a rating of 4, any sub-basin with a density >3 and <=4 mi/mi^2 was given a rating of 3, any sub-basin with a density >4 and <=13 mi/mi^2 was given a rating of 2, any sub-basin with a density of >13 (mi/mi^2) was given a rating of 1 (See Figure 4-17 below). The evaluation of the data was done according to quantile breaks. Although this gives some basic understanding of the data, it needs future refinement.

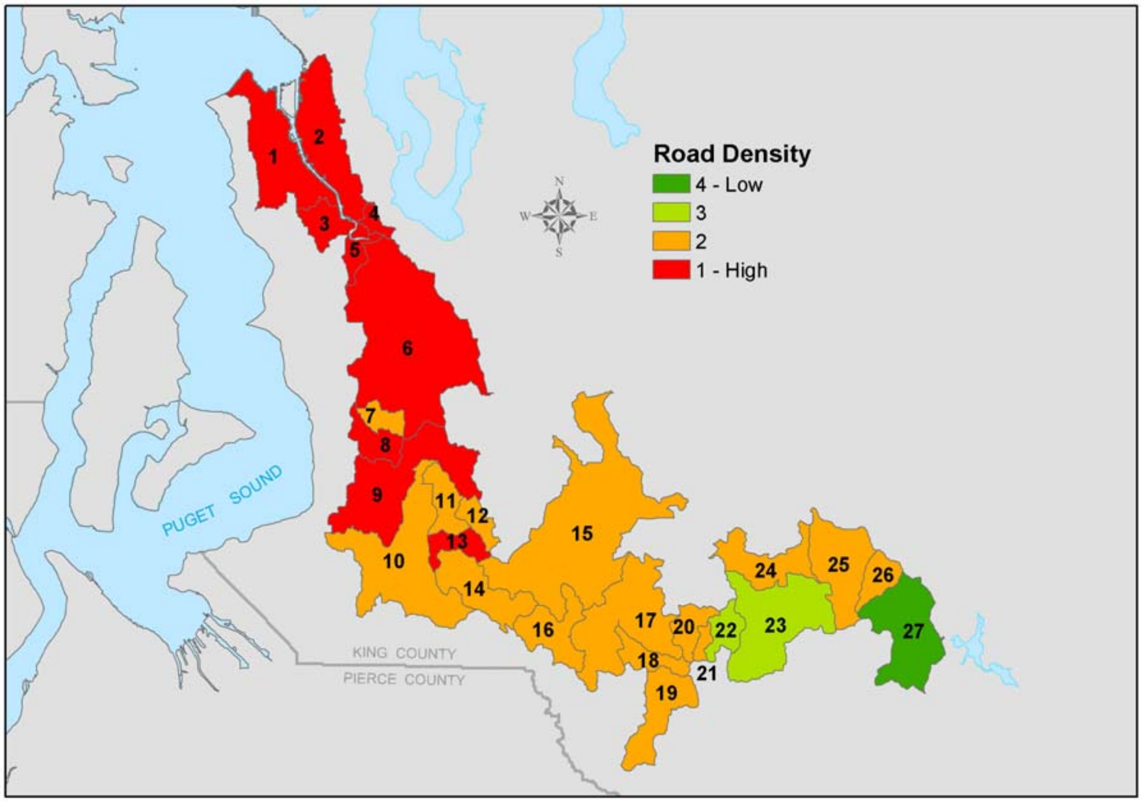

Figure 4-17 Road Density per Sub-basin
(Source: Author)

Vegetation Density

Once the riparian zone areas were established, the vegetation composition within this zone was determined by clipping the generalized land-cover grid by the riparian buffers coverage. Then, using the GRID COMBINE command, the new riparian/vegetation grid was combined with the sub-basins grid. The vegetation density values as found in Table 4-4 were joined to the VAT of this new grid. Then, using the vegetation percentage of each land-cover class, this value was multiplied by the number of cells of each class into a new item. This gave the number of vegetation cells. This value was divided by the total number of cells in each sub-basin riparian zone to get the vegetation density per sub-basin. Referring to densities found in the Habitat Limiting Factors and Reconnaissance Report (King County and the Washington State Conservation Commission, 2000), a >67% vegetation density received a value of 5, a 20-67% vegetation density received a value of 3, and a vegetation density of <20% received a value of 1 (See Figure 4-18 below).

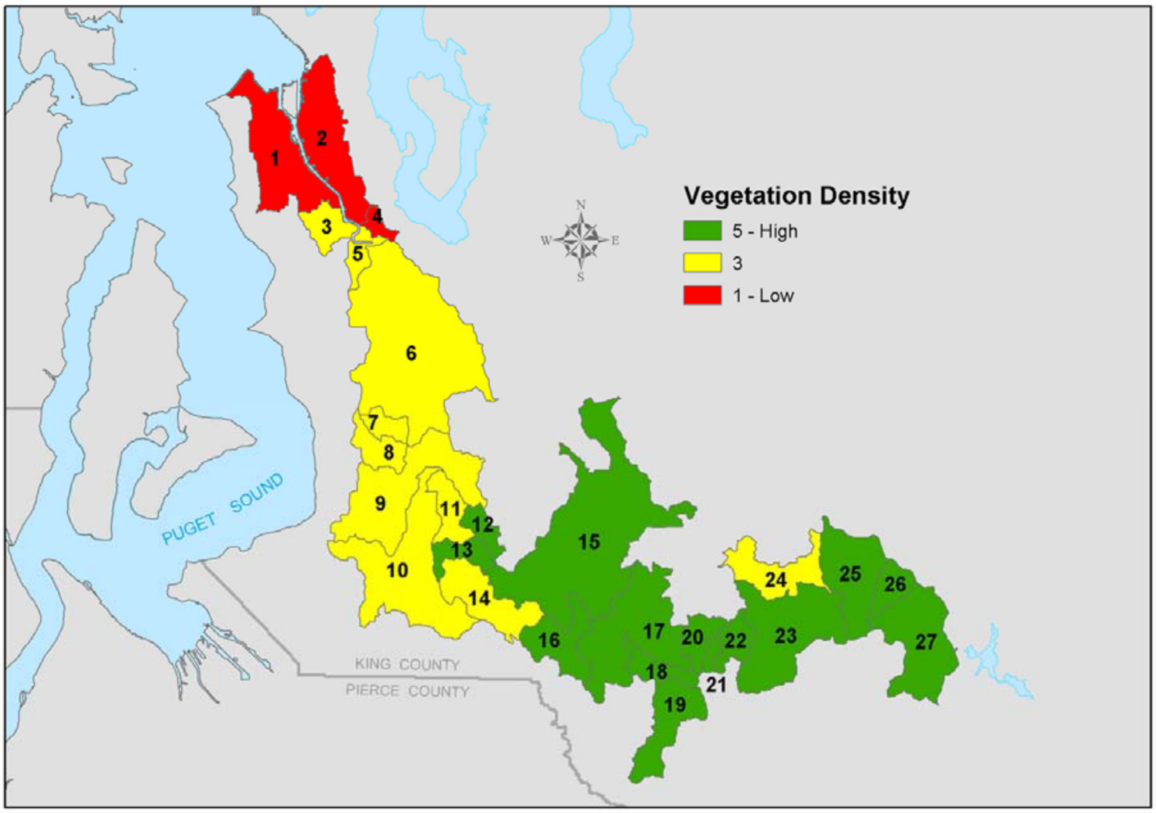

Figure 4-18 Vegetation Density per Sub-basin
(Source: Author)

4.4.B Potential Risk

Sedimentation potential

To determine this parameter, the reclassed land-cover grid was used (See Table 4-4). The first step was to convert this grid to a polygon coverage. Then all polygons that had a

GRID-CODE value of 4 (Barren), 5 (Transitional), 7 (Shrub), 8 (Non-natural wooded), and 10 (Agricultural) were chosen. This selection was then further modified by selecting only polygons that had an area >= 38,000 ft^2 (this is roughly equivalent to the area of 4 cells and approximates an acre—although this area is a bit under the 43560 ft^2 of a true acre). A final selection was made of polygons that fell within 100 ft. of the hydrography coverage. These polygons were made into a new coverage that represented areas of potential sedimentation.

From these polygons, the centroid points were put into a new coverage. This was done so that the NEAR command in Arc/Info could be used to obtain stream order information from the hydrography layer. Once the stream-order values were captured in this point coverage, the points were put back into the original polygons that formed the potential sedimentation zones. This coverage was built into a polygon coverage that now contained stream-order.

The new potential sedimentation with stream-order polygon coverage was converted to a grid. This grid was combined with the slope grid (Note: the slope grid was clipped to the riparian zone before the combine and was reclassed according to the following: 0-5% slope = 0, 5-27% = 1, 27-49% = 2, 49-70% = 3, >70% = 4). A new item called Value1 was added to the VAT of this newly combined grid. Value1 was calculated by multiplying the reclassed slope range by the following weights for stream order: Stream-order 1-2 = 2, stream-order 3 = 1.5, stream-order >3 = 1. (In other words, any small order stream (order 1 or 2) increased the grid value by 2 times (twice the potential for impact), any medium order stream (order 3) increased the value by 1.5 (1.5 times the impact), all other streams did not increase the value or impact). A intermediate grid that represented erosion areas with particular slopes and their corresponding nearest stream order was created that was the result of value1. (i.e. <New intermediate grid> = <Old grid>.value1).

An erosion hazard grid was developed from the erosion potential information developed for the soils coverage (See Section 4.3.B Soils/Tabular data above for information). Both this new erosion hazard grid and the sediment/slope grid described above were multiplied by 2 (This was done to round up decimal values so that they would be accounted for in the grid combine because COMBINE creates integer grids). Using GRID COMBINE, this erosion hazard grid and the sediment areas/slope grid were combined. A new item was added to the VAT of this newly created grid called FINAL. FINAL was calculated to equal the value of the erosion hazard grid multiplied by the value of the sediment/slope grid. A final classified grid was created that was the result of item FINAL (<New grid> = <Old grid>.final).

The next step to determine erosion potential was to use the sub-basins coverage and do a Zonal Statistics in ArcGIS on the final grid. This gave the MEAN value of erosion potential per sub-basin. This mean value was further quantified by taking the total number of cells that determined erosion potential per sub-basin and dividing this value by the total number of cells per basin. This gave a percentage of soil erosion cells per sub-basin. This percentage was multiplied by the erosion value to give a final erosion potential value. The final erosion potential per sub-basin was divided into classes by using the Jenks Natural Breaks algorithm of ArcGIS using 5 class breaks.

An item called EROSION was added to the final sub-basins coverage to contain the ranking. The classes were as follows: 0 – 0.217 = **1**, 0.218 – 0.548 = **2**, 0.549 – 1.269 = **3**, 1.27 – 1.919 = **4**, 1.92 – 3.214 = **5** (See Figure 4-19 below).

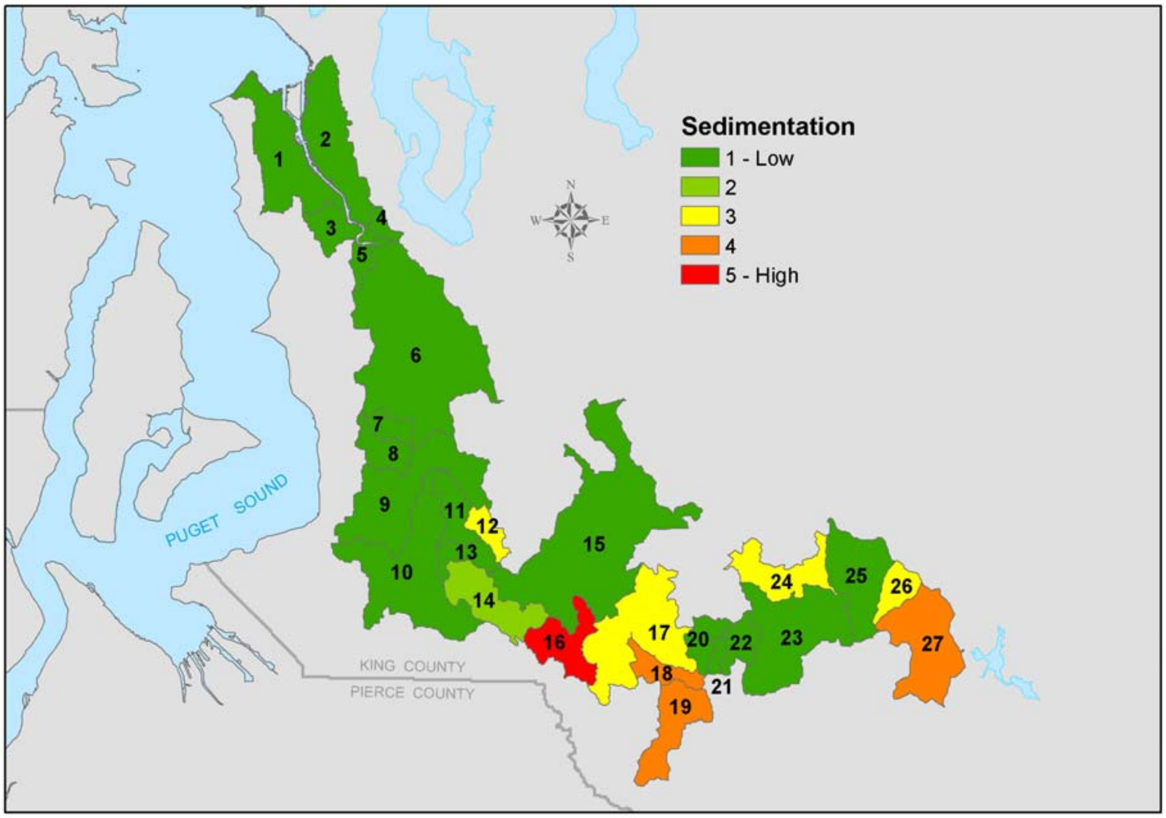

Figure 4-19 Sedimentation Factor per Sub-basin (Which is also equal to Potential Risk) (Source: Author)

4.4.C Salmon Presence

Redd-densities

The redd density tabular data was joined to the modified centerline (see explanation above about creation of this centerline) so that percentages listed in the table could be associated with the spatial component of the river centerline. These individual percentages were then aggregated using the line-on-line union (a routing function). These aggregate percentages were then averaged into a new field. The arc segments of this aggregated route were then split at sub-watershed boundaries and the new arc segment percentages were again averaged into a new item. This final added item represented the average redd density found within the sub-watershed.

Average redd densities were evaluated between the various sub-basins and were categorized into three categories: Low, medium, and high redd density. These categorizations were according to a strategy that Malcom (2002) had developed. In his system, a high-density system is one in which the redd density is at least twice the mean of the reported densities. A medium density range is from one half to twice that of the mean. A low-density system has redd densities that are less than half that of the mean. A low density sub-basin received a rating of 1, a medium density sub-basin received a rating of 3, and a high density sub-basin received a rating of 5. There were a number of basins that had no redd density information (either meaning that there was no data available or no salmon built redds in that area), these received a value of 0.

4.4.D Additional Selection Criteria

Inclusion of Estuary

The Duwamish Estuary runs from River-mile 0.0 to approximately River-mile 11. Presence of the estuary in a sub-basin is significant because of Chinook juvenile salmon rearing. Because of this fact, any basin that contained estuary was given the highest order (Implement #1) for its ecological action (See next chapter for discussion of ecological actions and order factors).

4.5 PARAMETER SUMMARY

Figure 4-20 below summarizes the input datasets and how they were applied to the model. This diagram shows sub-basins on the extreme left because sub-basins are the basic unit of measurement in this analysis. In this diagram, the input coverages are shown as clear boxes while tabular data is shown as grayed boxes. Each of the datasets are passed through the GIS process “cloud” to arrive on the other side as processed datasets. The GIS process cloud represents manipulations of the data that are discussed in their respective sections under Section 4.4.

The model flows from left to right, but also from top to bottom. Following from the top, the landscape health parameters are made up of impervious percentage, road crossings, road density, and vegetation density. These parameters were added together and divided by 4 to arrive at the Landscape Health Ranking. This Landscape Health Ranking was then divided into three categories to derive the Ecological Action.

The redd density measurement and estuary presence make up the salmon presence parameter. This parameter determines the order in which the ecological action is applied.

Finally, the sedimentation potential determines the potential risk parameter. This is used to establish the landscape remedial action order. In other words, the timing of more specific remedial actions are to be applied to sub-basins based on the potential risk categorization. The type of remedial action(s) needed is based on the landscape health parameters table.

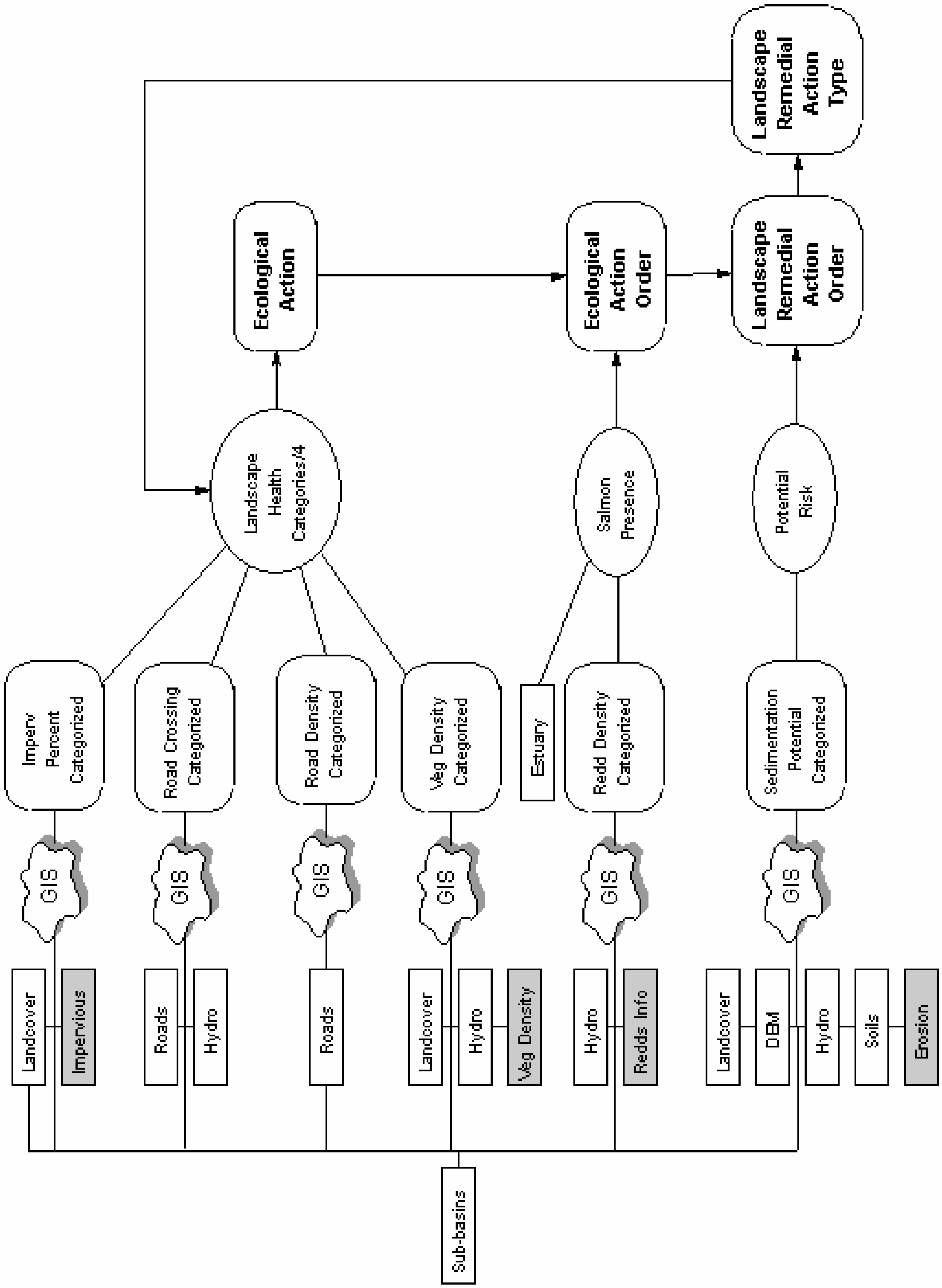

Figure 4-20 Parameters applied to the model

(Source: Author)

4.6 PARAMETER RESULTS

In review, the end product of factors that determine ecological actions are: Landscape Health factors (combined from imperviousness, road crossings, road density, and riparian vegetation density); Redd density or salmon presence; and Potential Risk (based on Sedimentation). The summary of all model parameters is shown below.

Table 4-8
Summary of health ranking values:

Health Factor	***Measured values***	***Ranking***
Landscape Health: Imperviousness	0-5% 6-10% 11-25% 26-100%	5 – Low = *High Health* 4 2 1 – High = *Low Health*
Riparian Health: Road Crossing	<1/mile 1-3/mile >3/mile	5 – Low = *High Health* 3 1 – High = *Low Health*
Landscape Health: Road Density	<=2 mi/mi^2 >2 to <=3 mi/mi^2 >3 to <=4 mi/mi^2 >4 to <=13 mi/mi^2>13 mi/mi^2	5 – Low = *High Health* 4 3 – Medium = *Medium Health* 2 1 – High = *Low Health*
Riparian Health: Vegetation Density	>67% 20-67% <20%	5 – High = *High Health* 3 1 – Low = *Low Health*
Potential Risk: Sedimentation	1.920 – 3.214 1.270 – 1.919 0.549 – 1.269 0.218 – 0.548 0 – 0.217	5 – High 4 3 2 1 - Low
Redd Density *(precursor to In-stream quality)*	>378.7 94.6 – 378.7 <94.6 0	5 – High 3 1 – Low 0 – No Values

(Source: Author)

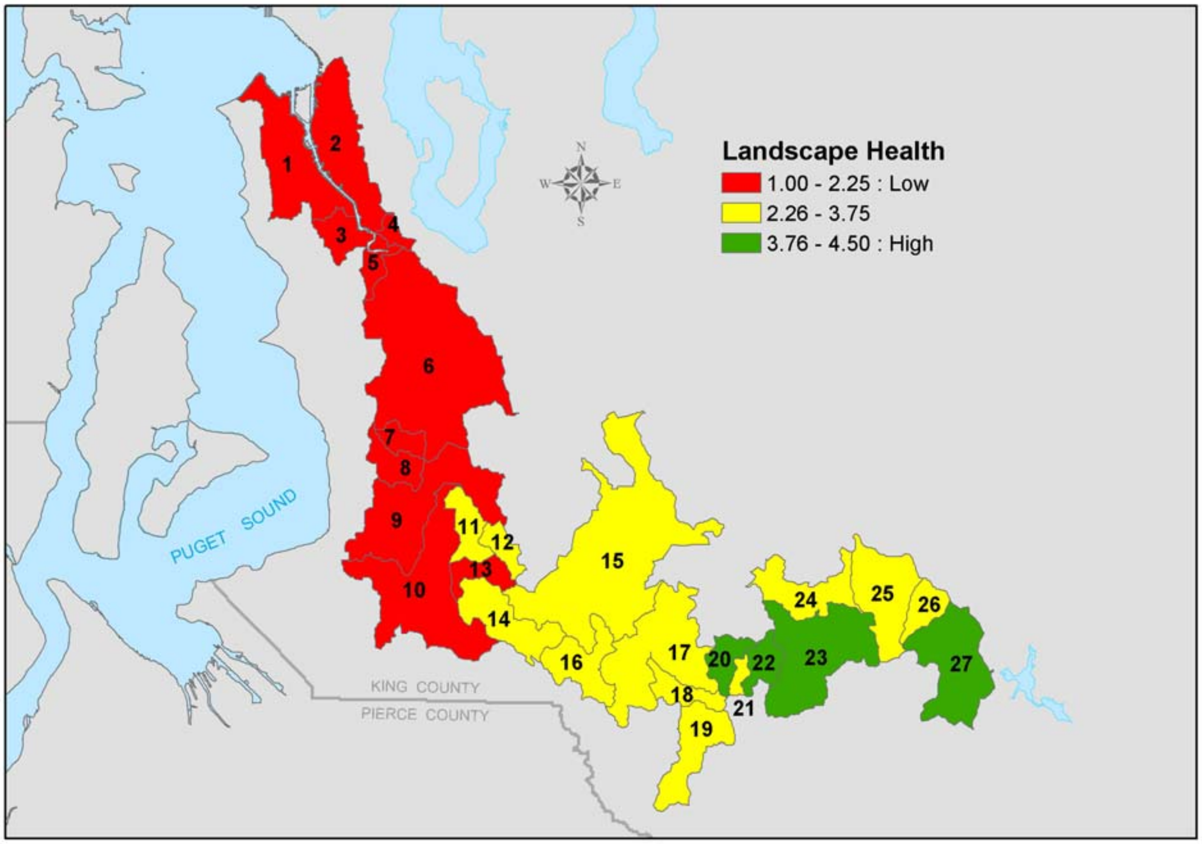

Figure 4-21 Landscape Health
(Source: Author)

As can be seen from the Landscape Health map (Figure 4-21), the majority of the lower portion of the basin towards the mouth of the Duwamish estuary has a low health ranking. This stands to reason since most of the population density is located in this lower portion. As one works up-stream, the health of the system increases in regards to the stated landscape factors. This is reasonable in the fact that there is an increase in vegetation (namely trees), a decrease in impervious cover, and a decrease in roads found in these upstream sub-basins. The exceptions to this are sub-basins 21 and 24-26. These have a medium landscape health, but it should be noted that these basins are in the upper range of medium health values. Because these basins have higher values within the medium landscape health ranking, they should be considered for preservation.

The generalized redd density map (Figure 4-22 below) reveals that redds are found in their highest concentrations in the middle portion of the drainage and near the accessible extents for salmon in close proximity to the TPU diversion dam. Also, salmon redds are not found in the lower, estuary portion of the drainage, but, as stated before, this does not negate the importance of the estuary portion of the river system. It is interesting to note that for the two basins that are of highest landscape health, one of those basins has a low redd density. This does reveal that salmon will not always use that portion of river that has a high landscape health ranking. Therefore, salmon usage does become an important factor for determining actions and order on the basis that protecting or restoring a sub-basin which salmon do not use could prove fruitless to helping the resident salmon population. (This should not negate the understanding that salmon possibly do not use a portion of river because of other factors that can be remedied, but it should highlight the need to further study these basins and their associated river reaches).

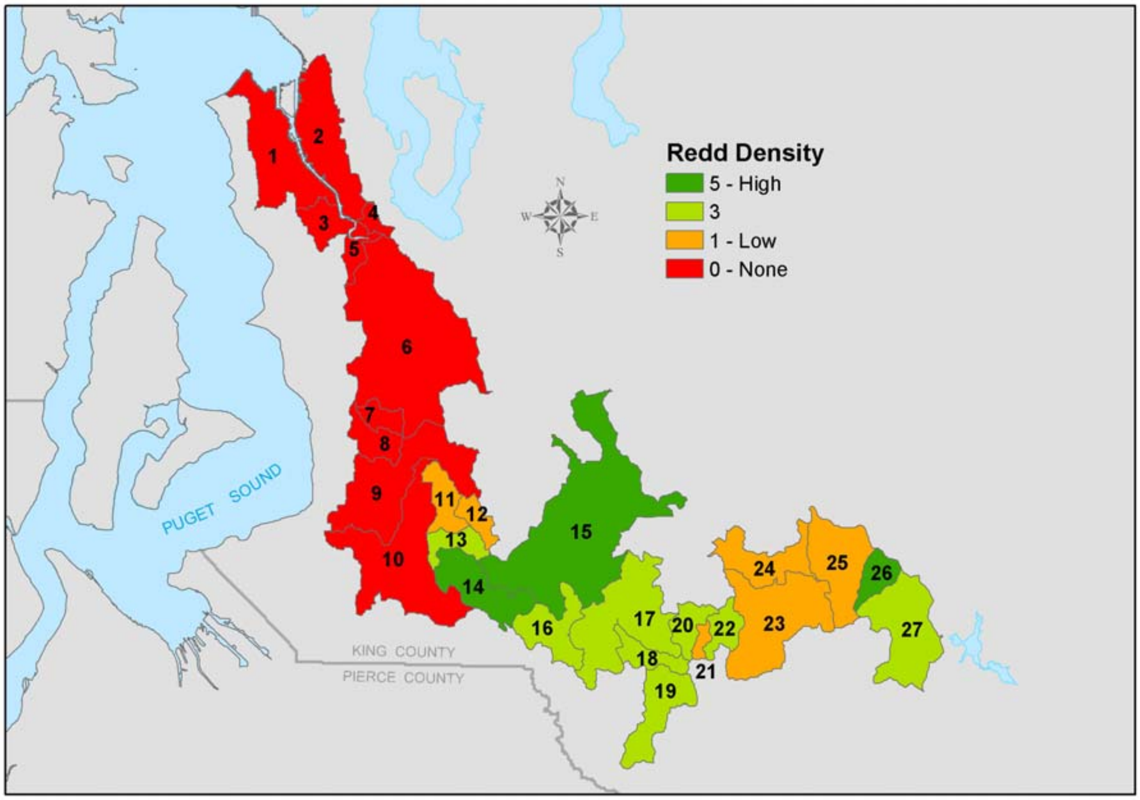

Figure 4-22 Redd Density
(Source: Author)

The potential risk map, based on sedimentation, (Figure 4-23 below) reveals the expected—that sedimentation is highest in sub-basins where there is a good deal of agriculture (sub-basins 16 and 19) or in sub-basins that have many 1st and 2nd order streams with adjacent transitional land-cover (sub-basin 27). Where this "risk" model breaks down is in the aspect of not evaluating the risk involved with stormwater runoff from areas high in impervious surface coverage (This is evident in that the lower portion of the drainage has low potential risk even though this is an area high in population and impervious cover). Of course, impervious is a factor accounted for in landscape health, but stormwater runoff from each basin is unknown and may be variable in the differing basins because of in-place BMP practices. This type of stormwater data is difficult to obtain, but would be a welcome addition to the model (more is discussed in the conclusions).

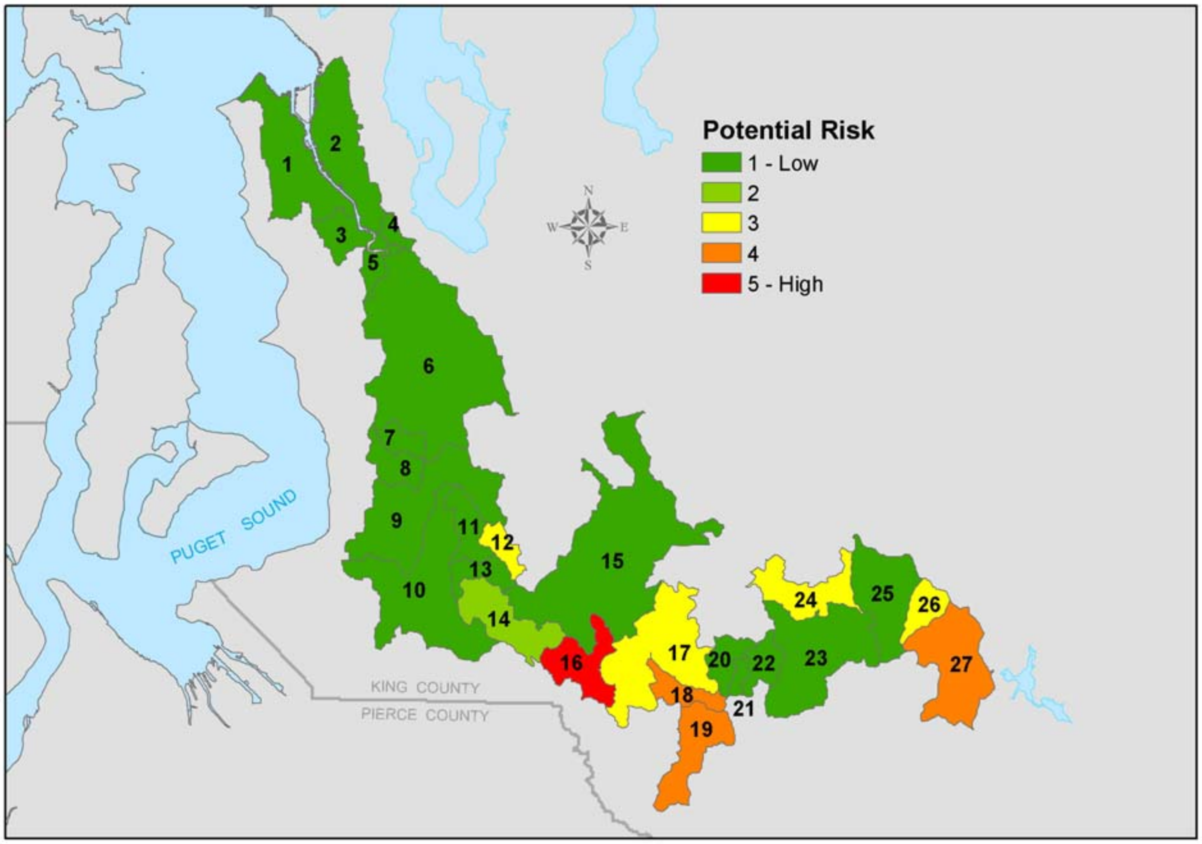

Figure 4-23 Potential Risk (Equal to Sedimentation)
(Source: Author)

CHAPTER 5

MODEL RESULTS AND SUBBASIN PRIORITIZATION

This chapter reviews the Ecological Actions that are the first level of prioritization in the model developed in this research. It then reveals the action matrices that were the basis of ecological actions, action order, and recommended remedial action focus and order. Finally it discusses each individual sub-basin's action and implementation order. These prioritized actions and ordering of implementation are the foundation on which decision-makers can act to benefit salmon habitat.

5.1 ECOLOGICAL ACTIONS DESCRIBED

The prioritization scheme of this model leads towards recommended ecological actions which include preservation, restoration, and Best Management Practices (BMPs). Preservation can be considered the setting aside (through purchase, conservation easement, etc.) of significant portions of land adjoining the stream corridor and the protection of this basin's land assets (especially stream related) into the foreseeable future. Restoration involves, as discussed above in Section 2.4.B, the return of a basin, and especially the riparian zone, to a state where it can function in a more self-sustaining manner. This requires a general attitude of restoring ecological processes so that the system can function more naturally with limited intervention. Restoration may include specific actions such as the replanting of native vegetation along a stream system and/or the designation of areas as "no-touch" or limited activity zones—especially in the riparian zone. BMPs can include such structural applications as detention ponds, vegetative filter strips, constructed wetlands, or porous pavement. BMPs can also be procedural, meaning that they are more regulatory, such as limiting the usage of a waterway; or they are educational—for example people are instructed to sweep their driveways, not wash them with water. A BMP approach can be applied to specific contamination and/or runoff issues in a basin, but cannot return a basin to a self-sustaining system. Instead, BMPs act as control measures to help minimize the effects of overland or stormwater flow.

5.1.A Action Matrices

To determine a proposed action for an individual sub-basin and a prioritization within an action category, matrices were developed, as summarized in Tables 5-1, 5-2 and 5-3 below. As described in the model chapter above, these matrixes are designed on a system in which Landscape Health, Redd Density, and Potential Risk are all taken into account. It should be recalled that adjacency to an estuary became a special modifier in this ranking system—any sub-basin that contains any portion of the estuary is prioritized higher in its initial action order.

As noted in Chapter 3, the prioritization scheme is based on a three level system—first basins were analyzed to determine landscape health. These results were used to categorize the basins by ecological action. Secondly, salmon presence (redd density) was evaluated and used to propose the order of ecological actions. Thirdly, potential risk was evaluated and used to guide recommendations for remedial action. These three levels of analysis are represented in Tables 5-1, 5-2, and 5-3. These tables are interpreted and discussed in more detail below.

Table 5-1
Landscape Health Values and Ecological Actions

SUBBAS_ID	Impervious	Road Crossing	Road Density	Riparian Vegetation Density	**Overall Landscape Health**	***Ecological Action***
1	1	5	1	1	2	BMP
2	1	5	1	1	2	BMP
3	1	1	1	3	1.5	BMP
4	2	5	1	1	2.25	BMP
5	1	1	1	3	1.5	BMP
6	1	1	1	3	1.5	BMP
7	2	1	2	3	2	BMP
8	2	1	1	3	1.75	BMP
9	2	1	1	3	1.75	BMP
10	1	1	2	3	1.75	BMP
11	2	3	2	3	2.5	Restore
12	4	3	2	5	3.5	Restore
13	1	1	1	5	2	BMP
14	2	3	2	3	2.5	Restore
15	2	3	2	5	3	Restore
16	5	3	2	5	3.75	Restore
17	5	3	2	5	3.75	Restore
18	5	3	2	5	3.75	Restore
19	5	3	2	5	3.75	Restore
20	4	5	2	5	4	Preserve
21	5	3	2	5	3.75	Restore
22	5	5	3	5	4.5	Preserve
23	5	5	3	5	4.5	Preserve
24	4	5	2	3	3.5	Restore
25	5	3	2	5	3.75	Restore
26	5	3	2	5	3.75	Restore
27	5	3	4	5	4.25	Preserve

(Source: Author)

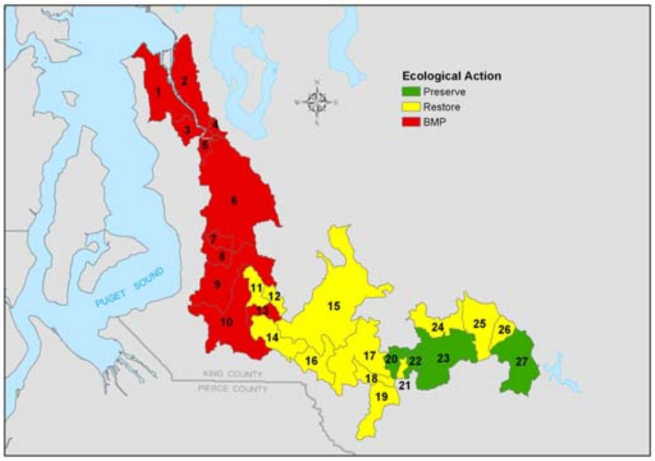

Table 5-1 above reveals the results of evaluating the Landscape Health parameters. The first column lists the sub-basin ID. This sub-basin ID corresponds to sub-basin numbers found in the inset map above (this is true for all proceeding inset maps). The individual Landscape Health parameters are the next four columns in this table. The very next column, “Overall Landscape Health,” is the average of the four landscape health parameters. These numerical values were the basis of the described ecological action (see the “Ecological Action” column above). Values in the overall landscape health column between 3.76 and 5 (inclusive) were interpreted to an ecological action of preservation, values greater than 2.25 and less than 3.76 were interpreted to an ecological action of restoration, and values between 1 and 2.25 (inclusive) were interpreted to an ecological action of structural BMPs only. The highest and lowest categories contained 31.25% each of the possible range of values. The middle category contained 37.5% of the possible range of values. The middle category was expanded to contain more values in this study because it was felt that restoration should be emphasized in WRIA 9 while preservation and BMP actions should be limited to basins at the more extreme ends of the health rankings.

Table 5-2
Redd Density Table and Ecological Action order

SUBBAS_ID	Redd Density	ESTUARY	Ecological Action Order
1	0	Yes	E1
2	0	Yes	E1
3	0	Yes	E1
4	0	Yes	E1
5	0	Yes	E1
6	0	Yes	E1
7	0	No	E3
8	0	No	E3
9	0	No	E3
10	0	No	E3
11	1	No	E3
12	1	No	E3
13	3	No	E2
14	5	No	E1
15	5	No	E1
16	3	No	E2
17	3	No	E2
18	3	No	E2
19	3	No	E2
20	3	No	E2
21	1	No	E3
22	3	No	E2
23	1	No	E3
24	1	No	E3
25	1	No	E3
26	5	No	E1
27	3	No	E2

Note:
E1 = Implement #1
E2 = Implement #2
E3 = Implement #3

(Source: Author)

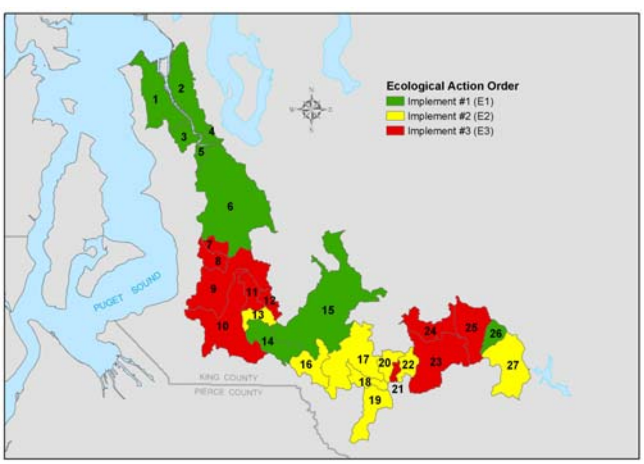

Table 5-2above lists the sub-basin ID, redd density parameter value, estuary presence, and ecological action order. The redd density column represents the value from the dataset processing as described in Section 4.4.C above. The Estuary column lists whether a sub-basin contains a part of the estuary. The final “Ecological Action Order” is abbreviated to E1 for Implementation #1, E2 for Implementation #2, and E3 for Implementation #3. As was discussed in Section 4.4.C and Section 4.4.D, any sub-basin that contained a part of the estuary was given a Implementation #1 (E1); sub-basins with a high redd density (5) were given Implementation #1 (E1); sub-basins with a medium redd-density (3) were given Implementation #2 (E2); sub-basins with a low redd density (1) were given Implementation #3; and sub-basins with no redds present were also given a timing of Implementation #3.

Redd density rankings were based on Malcom (2002). High redd density basins (5) were those with at least twice the mean redd density. Low densities (1) were basins with densities less than half that of the mean. Medium densities (3) were those that ranged from one half to twice that of the mean. (The mean in this study was approximately 189.3 redds/river mile. High density (5) therefore was > 378.7, Medium (3) = 94.6 - 378.7, and Low (1) < 94.6 redds/river-mile).

As noted previously, the ordering of sub-basins between implementation #1 and #2 is only for the purpose of giving decision makers a choice in case resources are low and only #1 implementations can be realized. (It is suggested that #2 implementations be executed concurrently or shortly after #1ecological action implementations). Of course, in the case of a delay between #1 and #2 implementations, the actual time-frame of action is determined by the decision making body.

Table 5-3
Landscape based Remedial Action order

SUBBAS_ID	Potential Risk	Remedial Action Order
1	1	R3
2	1	R3
3	1	R3
4	1	R3
5	1	R3
6	1	R3
7	1	R3
8	1	R3
9	1	R3
10	1	R3
11	1	R3
12	3	R2
13	1	R3
14	2	R3
15	1	R3
16	5	R1
17	3	R2
18	4	R2
19	4	R2
20	1	R3
21	1	R3
22	1	R3
23	1	R3
24	3	R2
25	1	R3
26	3	R2
27	4	R2

Note:
R1 = Remediate #1
R2 = Remediate #2
R3 = Remediate #3

(Source: Author)

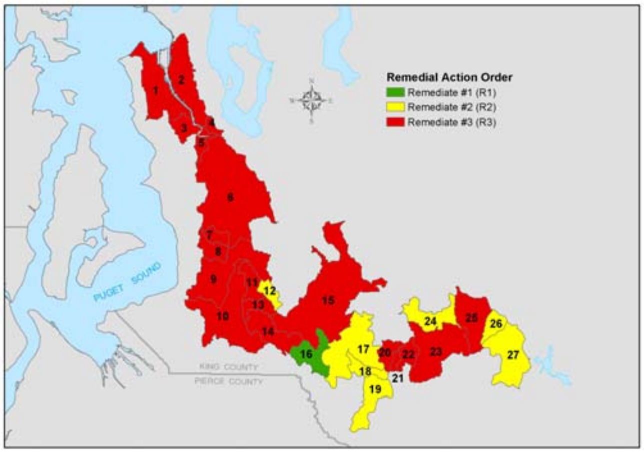

Table 5-3 above lists the sub-basin ID, potential risk value and remedial action timing value (abbreviated). The potential risk value is from the data procession step as described in Section 4.4.B (an evaluation of sedimentation potential). The value of potential risk was evaluated to the "Remedial Action Order." Any sub-basin with a potential risk value of 5 (high-risk for sedimentation) was given the remedial action implementation order of #1 (R1); sub-basins with values of 3 or 4 (medium-risk for sedimentation) were given an implementation order of #2 (R2); sub-basins with a value of 1 or 2 (low-risk for sedimentation) were given an order of #3 (R3).

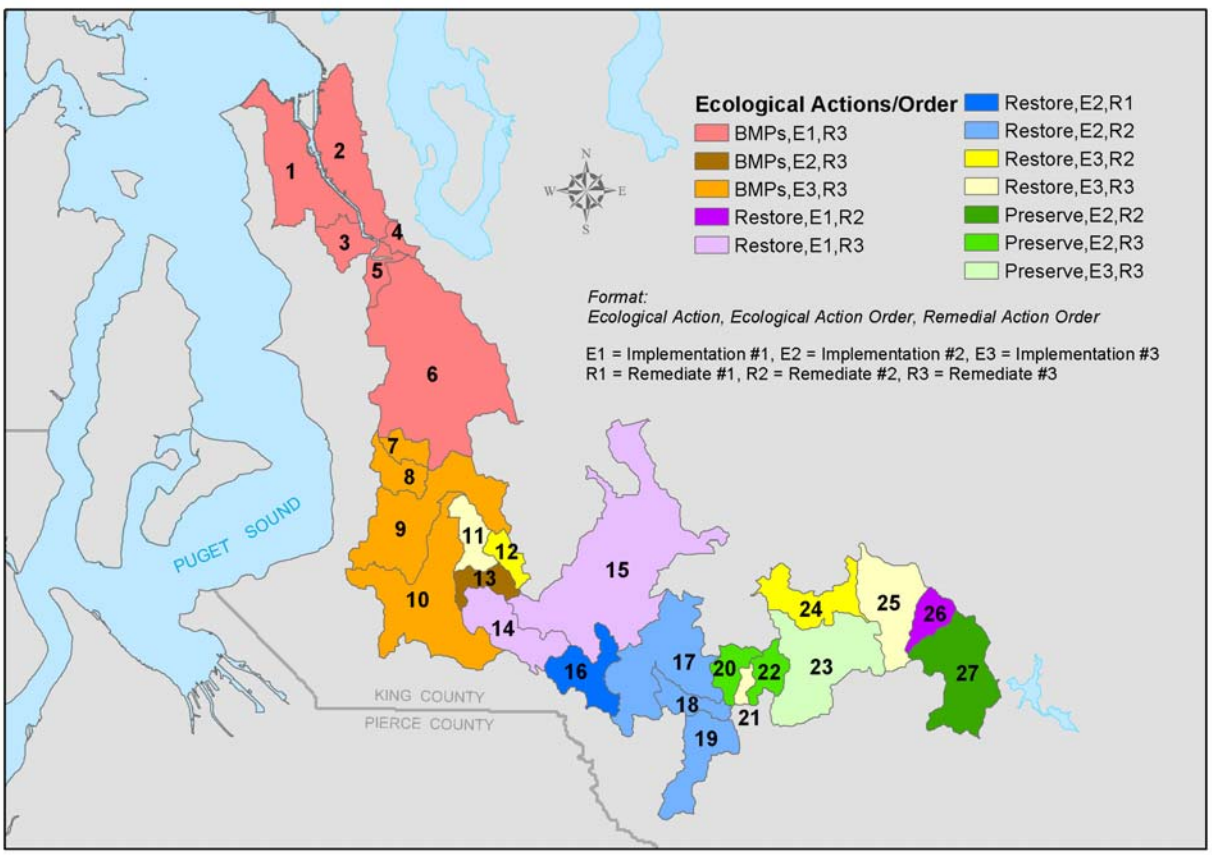

Figure 5-1 Results: Ecological Actions and Order
(Source: Author)

5.1.B Sub-basin actions and orders explained

The results of the model interpret 11 sub-basins as BMP only, 12 basins as restoration, and 4 basins as preservation (See Figure 5-1 above). The ordering for ecological actions and remedial actions are varied among these basins and are explained below.

BMP sub-basins

The BMP only basins are all found in the lower portion of the drainage. This stands to reason since the majority of the population and all of its deleterious impacts on sub-basins are found in this area. The ecological action implementation orders for these basins are mainly the result of presence of estuary, but these orders are also the result of salmon redd presence. The presence of estuary is found in basins 1 through 6, therefore these basins were given the implementation designation of #1 for the ecological action. Sub-basin 13 was given a designation of implementation #2 of the ecological action. This ecological action order is the result of sub-basin 13 having a redd density of medium ranking (sub-basin 13 does not contain any part of the estuary). Sub-basins 7-10 were given an implementation ranking of #3. This is the result of these basins not containing any portion of the estuary or having any redd's present. This implementation order does not mean that these sub-basin's actions should be delayed far into the future as to be destructive to the stream environment, it only designates their ecological action order—and prioritization—as being lower than sub-basins 1-6 and 13.

After a designation of ecological actions for the BMP only sub-basins, a further differentiation was determined along the lines of remedial action order and type (meaning BMP type). This remedial action order was based on sub-basin potential risk. All of the BMP basins were given a designation of remedial action order #3. This is a weakness of this model because it does not accurately account for risk factors in these types of basins. (A further discussion of this problem is found in the conclusions and recommendations chapter of this research).

In general terms, the specific types of recommended remedial actions are found by examining the separate landscape health factors and determining which of these factors are of low quality and might need significant improvement. It is recommended that the lowest rated health parameters be dealt with first, then the next lowest parameter(s), etc. This allows for a priority focus between remedial actions. This does not mean that parameters of greater health than those of lower health should be neglected for any significant amount of time (and in many ways they cannot be because they are interconnected with the other parameters). In other words, the parameter health rankings give decision makers a focus for remedial action, but not a license to ignore the other issues.

The following is a description of primary recommended remedial actions types for the BMP sub-basins found in the Green/Duwamish system: Sub-basins 1 and 2 have low health rankings in impervious, road density, and vegetation density. These remedial areas should be focused on in these sub-basins because of their low quality in. The issues in sub-basin 4 of prime importance are road density and vegetation; for sub-basins 3, 5, 6, and 13 it is impervious, road-crossings, and road density; for sub-basin 7 it is road-crossings; for sub-basins 8 and 9 it is road crossings and road density; and for sub-basin 10 it is impervious and road-crossing. These are factors that decision makers can address initially using the recommendations from the table below.

Table 5-4 below represents an example of actions that jurisdictions might consider when addressing the specifics of remedial actions. This table is not all inclusive and is only given for illustrative purposes. It is recommended that each jurisdiction develop its own standards for remedial action, but this list gives a starting point. The actions described in this table were compiled from various sources including Schuler (1995), Pierce County (2002), and Yu and Nawang (1993).

Table 5-4
BMP Recommendations

	Impervious	*Road Crossings*	*Road Density*	*Vegetation Density (lack of)*	*Sedimentation*
BMP only recommend actions (representative list)	Wet ponds, extended dry ponds Vegetative filter strips Constructed wetlands Cluster development Designation of commercial zones away from mainstem Berm areas of concern Connect runoff system to water treatment system Install oil/water separators	Improvement and/or replacement of culverts Traffic design to reroute unnecessary crossings Restricting further crossings	Porous pavement on new projects Vegetative filter strips Implement roadside media filtration and absorption Cluster development Create laws that reduce size of roads	Increase in natural vegetation in parks Increase of natural vegetation near inlet streams cluster development Increase veg in riparian zone	Vegetation filter strips in ag lands Barriers and retention facilities during logging
Restoration (most restoration will take place in the riparian zone, but some of these BMP practices can be applied to halt further degradation).	Same as above	Same as above	Same as above	Same as above and Replant native vegetation along stream in riparian zone Eliminate impervious surfaces in riparian zone Restrict agricultural practices to outside of riparian zone Restrict certain uses in riparian zone	Same as above and selective cutting of timber only No-touch zone in riparian area for livestock (fencing if needed)
Preservation	Same as above	Save as above	Same as above	Same as above	Same as above

(Preserve riparian zone, but use BMP practices to halt further degradation)				and set aside vegetated riparian zones Restrict most uses in riparian zone so as to preserve natural processes	

(Source: Author)

Restoration sub-basins

The restoration basins also have ecological action implementation priorities that range from #1 to #3. These action priorities are all based on redd densities found within each sub-basin. Because sub-basins 14, 15, and 26 all have high redd densities, their ecological action prioritiy is implementation #1. These basins should be addressed in the short-term because of the historical usage of salmon within their boundaries and the present importance of these areas to salmon. Basins 16-19 all have implementation #2 for their ecological action. These basins should be addressed as soon as possible after the short-term basins because of the presence of salmon within their limits. Although "implementation #2" might suggest a time gap between #1 and #2 implementations, it is recommended that this time period be minimal because of the importance of protecting salmon. Basins 11, 12, 24, and 25 are all implementation #3 sub-basins. These sub-basins should be carefully monitored for the appropriate time-frame when the ecological action of restoration can be applied. A monitoring of these basins is necessary to see if salmon can return or do return to their waters.

In the case of restoration basins, the potential risk factor is a better indicator than it was with the BMP basins. Sedimentation is a good indicator for these basin's potential risk factors because they have land-cover types that account for sedimentation input into the stream environment (predominately forested or agricultural). Among the implementation #1 ecological action basins, basin 26 has the highest remedial action order (remediate #2). Sub-basins 14 and 15 are remediate #3, or more long-term remedial action basins, because of their relatively low sedimentation risk. This ranking stands in contrast to the ordering of the ecological action of these sub-basins. In other words, the landscape health recommends short-term (implementation #1) restoration for these basins, but the potential risk of sedimentation suggests that remedial action be delayed, or remediate #3 (risk to salmon is not great because sedimentation is low but is significant according to the other landscape factors). Since these basins have high redd-densities, restoration should still take place as-soon-as-possible. The caveat is that sedimentation does not necessarily need immediate attention but should be watched carefully. Therefore agricultural and forest practices should be monitored for potential sedimentation in these sub-basins, but restoration should proceed in the riparian zone according to the other low health landscape factors (a more focused approach on impervious and road density issues).

The specific remedial actions needed in the restoration basins are as follows: In sub-basin 11, 14, and 15, impervious and road density issues should be dealt with; in sub-basin 12, road densities and road crossings should be examined; in sub-basins 16-19, 21, 25 and 26, road crossings and road density should be examined; in sub-basin 24, the issues of road density and riparian vegetation density should be dealt with.

Preservation sub-basins

The preservation basins are categorized according to ecological action priority from Implementation #2 to #3. The lack of Implementation #1 ecological action priority is based on the fact that none of these basins have high salmon redd densities.

The implementation #2 preservation basins have the following remedial action implementation priorities and suggested remedial action type: Sub-basin 27 has the highest sedimentation (potential risk) of all the preservation basins (medium) and is given a remedial action order of #2. The initial focus for sub-basin 27's landscape improvements should be in the area of road crossings. Sub-basins 20 and 22 have a low potential risk and therefore are classified as remediate #3. The road density issue is of prime importance in these basins (especially sub-basin 20) and should be addressed to halt further degradation. The ecological action implementation #3 preservation basin (sub-basin 23) should have the road density issue dealt with first.

These preservation basins all have relatively low redd densities (this gives the implementation #2 and #3 ranking for ecological action order). Salmon still use these basins as nesting sites, and because of the variability of salmon nesting site densities over different years, these basins could be significant. These basins are also important because they form contiguous land units with other basins that have a higher remedial action priority. These contiguous units can contribute to the health of adjacent basins and this should be taken into account.

The greatest need for landscape improvements in each of these long-term action basins is in the area of roads. All of these basins have their lowest landscape health ranking in road density or road crossings. This suggests that to halt further landscape induced pressure on the stream environment, regulations and structural BMP actions regarding roads will need to be implemented. The other landscape health rankings should be carefully reviewed for preservation basins to see if any application of BMP actions for these parameters would help improve the basin or halt further losses.

It may be suggested that because of a lack of high salmon redd densities in the preservation sub-basins, another use other than preservation is called for. But 3 out of the 4 basins have at least a medium salmon redd density—only basin 23 has a low density (and, therefore, a more long-term ecological action priority of Implementation #3). Because these basins show an excellent landscape characteristic and their salmon redd densities are relatively high, preservation is a good option. These basins, if preserved, may become a haven for future runs of salmon in this drainage. Because of the contiguousness of basins 20, 22, and 23, these basins are a good choice for a preservation zone. In this zone, laws could be applied that preserve this area for salmon far into the future (this zone could also include the eventual restoration of basin 21).

Although the remedial action priority is #3 for all of the restoration basins except sub-basin 27 (priority #2), this only suggests that sedimentation is not much of a problem in these basins. Sedimentation should still be monitored and controlled to further protect these basins.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter draws conclusions from the resultant data and suggests how prioritization within ecological action classes may be applied. It then considers some of the limitations of this study and makes final recommendations on how this research may be improved and expanded. The prioritization results are shown below in Figure 6-1.

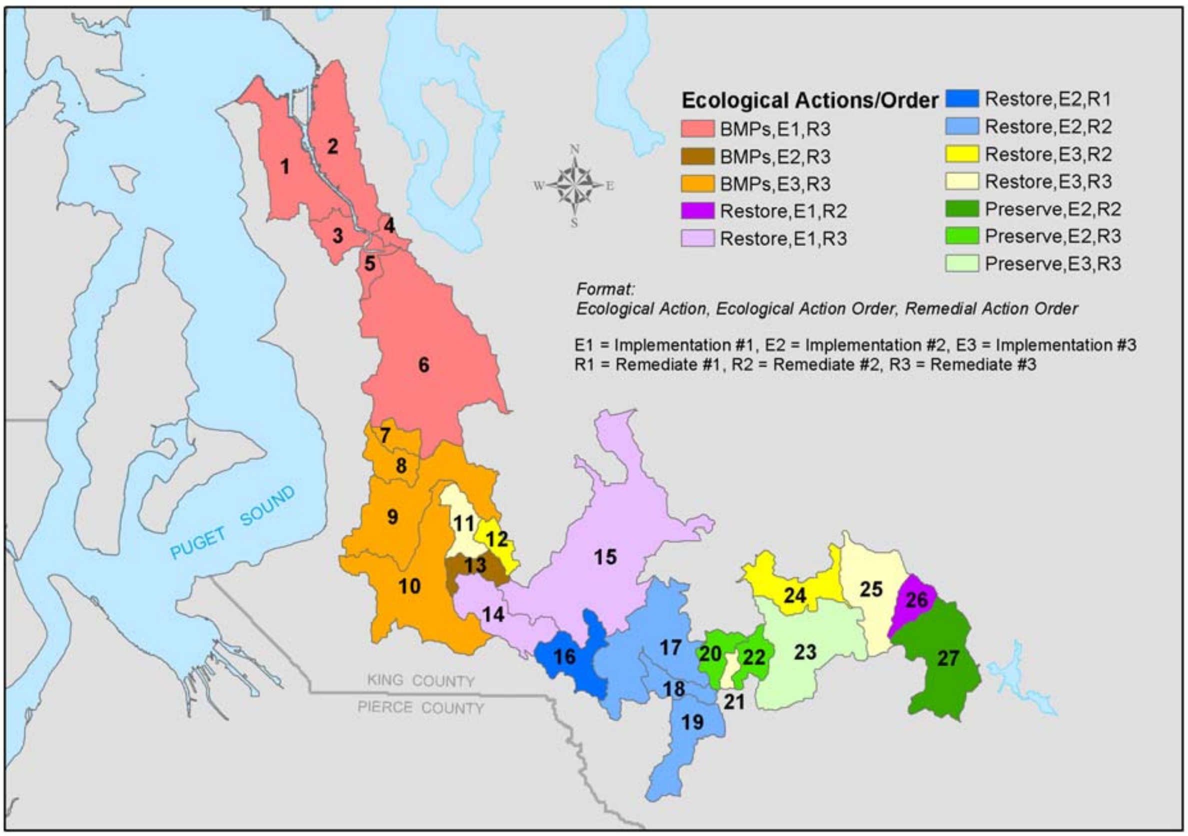

Figure 6-1 Sub-basin prioritization
(Source: Author)

6.1 CONCLUSIONS

The clustering of sub-basin ecological actions is very reasonable in the sense that suggested BMP actions are in sub-basins that contain the most developed land, while restoration and preservation actions are in basins that are more highly forested and agricultural (See Figure 6-2 and Figure 6-3 below). The sub-basins also reveal patterns that are explained below.

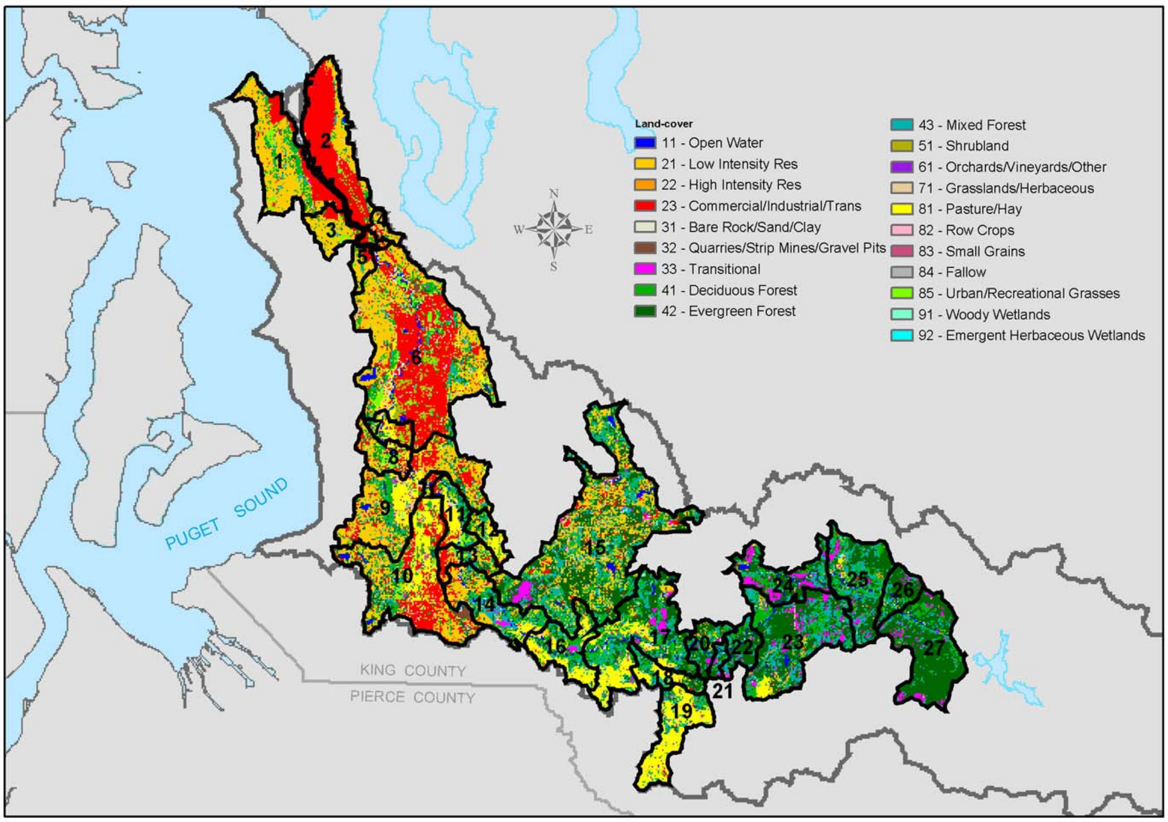

Figure 6-2 NLCD Land-cover and Sub-basins
(Source: Author)

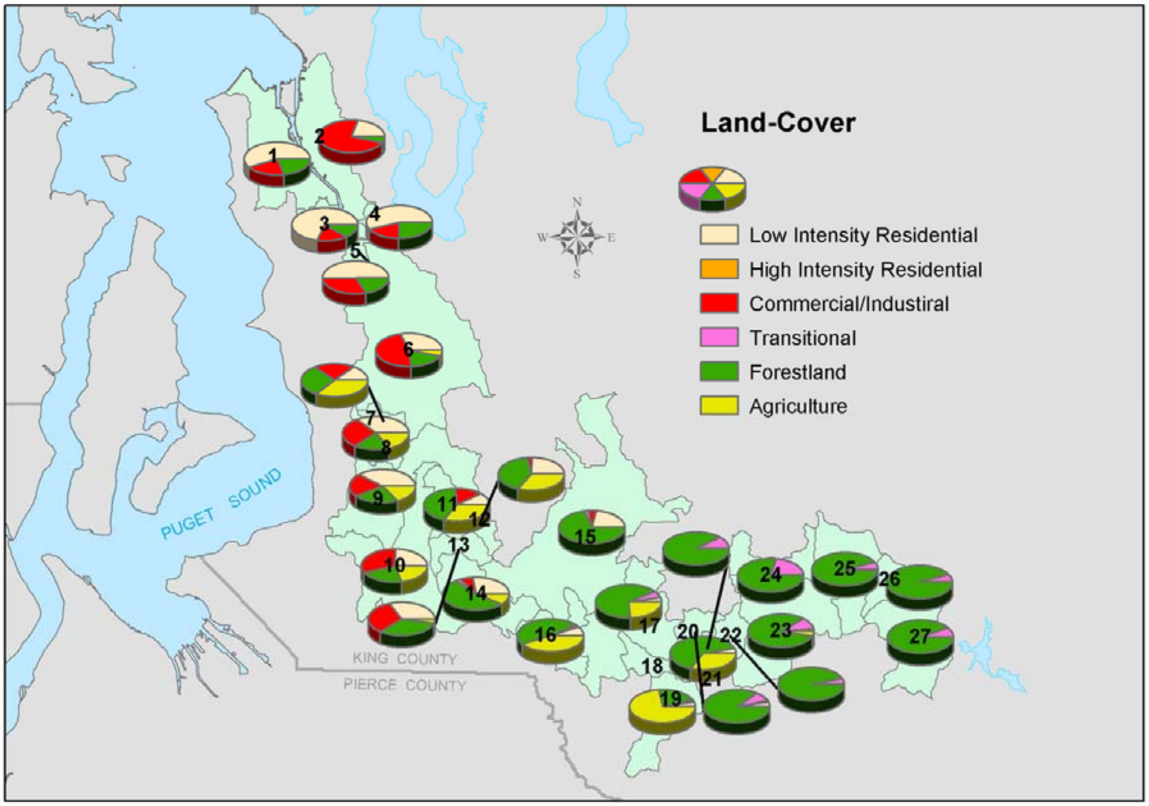

Figure 6-3 Land-cover percentages per Sub-basin
(Source: Author)

BMP

As was noted in Chapter 4, BMP priorities are highest towards the up-stream end of the watershed because of the presence of the estuary. Basin 6 is an especially good candidate for BMP actions because of this proximity to the estuary, but also because of its shear size. Although there is a difference in ecological action priority within this cluster of Implementation #1 and #3 (with the break coming at sub-basin 6), there is a great need to implement BMPs in sub-basins 7-10 as-soon-as-possible because of their probable impact on downstream basins. This highlights the fact that there might not be much difference in actual time of implementation between the different ecological action implementation priority rankings. Still, it is important that the most care be given to the estuary sub-basins (1-6). In other words, if there are limited resources for actions in all the designated BMP sub-basins, then sub-basins 1-6 should receive the most thorough applications and implementations. Also, it would make more sense to allow development in sub-basins 7-10 because of their lesser degree of impact on the estuary and their lack of known redd's. This, of course, should be done with caution and close observation because of the impact these basins could have on the downstream environment. This suggested "development allowance" in no way excludes these basins from BMP treatments, instead development should be done so as to protect the stream environment (i.e. design for cluster development, limit the size/amount of new impervious surfaces, runoff barriers and pre-treatment during development, educate homeowners on lawn treatment with fertilizers).

Restoration

The restoration sub-basins are found mainly in the center of the study area. It is interesting to note that sub-basins 14 and 15 are high priority in regards to ecological action timing but low priority in terms of remedial action timing. This, of course, is contradictory. This highlights the problem with potential risk and its influence on determining remedial action timing. Potential risk only takes into account sedimentation (sub-basins 14 and 15 have low potential sedimentation values) but does not account for the potential risk posed by loss of vegetation or runoff from impervious surfaces in these sub-basins. This needs to be improved in this model for a better prioritization of these types of sub-basins. Because of sub-basins 14 and 15's high redd densities and low landscape health factors, their restoration should take place short-term but involve controlling runoff from impervious surfaces and negating the effect of high road density.

Sub-basins 16-19 have higher sedimentation potentials caused by large amounts of agricultural land adjacent to low-order streams. This results in remedial actions ranges from remediate #1 to remediate #2 for these sub-basins. Sub-basins 16-19 have medium redd densities and are therefore are given an implementation priority of #2 for ecological action. Implementation of the ecological action, in this case, should follow soon after the Implementation #1 sub-basins because salmon need the protection resulting from the suggested landscape improvements.

Sub-basins 11, 12, 24 and 25 have an ecological action implementation priority of #3—in other words, their redd densities are low. This suggests that development, agriculture, or timber production could be higher in these basins because the basins' overall effect on salmon in the system would be minimal. This "higher usage" designation for these sub-basins should be done with caution, though, because of the impact this might have on the downstream basins and the fluctuating nature of salmon usage in the river system.

Sub-basin 21 is a special case that might need to be evaluated as a preservation basin. First of all, it is very small in terms of area and, therefore, its impact is small. It does have relatively low health values for road crossings and road density, but these are most likely a result of its small area. Any deleterious impacts could be resolved for this basin and it could become a part of the contiguous "preservation zone" of sub-basins 20, 22, and 23.

Preservation

The preservation basins are dominated by forestland and are found in the upper portions of the study area, mainly in a cluster, although sub-basin 27 is not a part of this cluster. The sub-basins that form a mostly contiguous cluster (20, 22, and 23) have either a medium or low redd density. Preservation in these basins would help to retain the continuity of the preservation region.

It would also make sense to allow more recreation activities where salmon are less likely to be found. This is the case for sub-basin 23.   Of course, this type of recommendation needs a more thorough ground survey for accuracy assessment, but this information gives decision-makers a focal point for a possible recreational designation. Sub-basin 27 has a higher potential sedimentation value, and, therefore, if it is preserved it needs to have some remedial action applied to limit this possible sedimentation.

The prioritization scheme developed in this research has promise in providing decision-makers with a tool for narrowing their focus for potential projects. With this type of tool, resources can be better allocated and justified, hopefully making decision-makers more confident in their decisions and salmon populations more stable. Of course, to show the merit of this model, a ground based study should be conducted to check on the conclusions reached.

6.2 LIMITATIONS AND RECOMMENDATIONS

6.2.A Temporal or Currentness Issue

Any analysis using digital data has the issue of not being a current "snap-shot" of the area in question—especially digital data that has a more temporal element. The datasets listed in Table 4-1 that have a more temporal element include redd locations, land-cover, transportation, and to a lesser extent hydrography. The transportation layer and hydrography layer are 4 years old, while the redd information is just 1 year old and the land-cover data is about 12 years old.

The data age is not seen as a major problem for the transporation, hydrography, and redd density layers, although more current data would be beneficial.

There is concern, though, with the age of the land-cover data. Having current land-cover data is critical for this analysis, but it is a difficult dataset to obtain in more current form. Contemporary land-cover data could be developed for a limited spatial extent (such as our study area) by remote sensing techniques, but probably at a substantial cost. It would be beneficial, though, to have this more up-to-data information, especially in regards to higher risk land-cover types. Of prime importance is transitional land because, by its very nature, it is in great flux and may not stay a transitional type for a great length of time. Transitional land may go from barren land to development in a matter of months, or it may be a clear-cut that is replanted and have substantial vegetation in 2 years. To have a model that is responsive to these types of change, a more current land-cover dataset is critical.

A suggestion to obtain current and appropriate land-cover data would be to have an analysis performed using available, recent satellite imagery that defines the higher risk land-cover types such as transitional and agricultural land-cover. A full land-cover analysis for a study area would not be necessary, and this type of limited analysis would possibly be a cost savings over a full land-cover delineation.

It should be noted that there is an existing effort to produce a new national land-cover dataset, but this work was not completed at the writing of this research and could not be incorporated into the analysis. This new national dataset should be available soon. Still, this newer data would not necessarily give the up-to-date information that is really needed for an analysis that reflects the current conditions—but anything is better than the current land-cover data that is over 12 years old.

6.2.B Grain

A major limitation found in analysis of digital information is the grain of the data. The grain, in this case, refers to the source scale of the vector data and pixel size of the raster data. For the purposes of this research the vector data sources were mainly 1:24000 in scale. This is an appropriate scale for the spatial extent examined.

The issue of grain and this analysis is once again with the land-cover data. The land-cover data has a pixel size of 30 meters. This is a significantly large land-cover area that loses much of the detail found on the ground by generalizing to the majority land-cover found in this 30 $meter^2$ zone.

For the spatial extent of the study area and the purposes of this research, 30 meter pixels are acceptable, but a finer grain dataset would help immensely with analyzing the sub-basins. Finer grain data would allow a better understanding of vegetation patterns and it would also give a better understanding of sedimentation "hotspots." As was mentioned above, a finer grain dataset is not currently available and would add substantially to the cost of this type of analysis if its creation was deemed necessary.

6.2.C Soils

Digital soils information is currently in a state of improvement by the USDA. Much of the data found in the original hard-copy soil surveys is being transferred over to a new digital database. The woodland management tables in the digital conversion process were not populated at the writing of this thesis. It is not known what the status of the conversion is or if it will take place at all.

Unfortunately, one of the major drawbacks of this data is consistency between the various soil surveys. In the two King County surveys that were examined for this analysis, it was found that methodologies of listing potential woodland productivities were different. This makes for difficult comparisons. It would be very beneficial if in the new digital soils conversion process a method could be found to make the soils survey tables consistent, at least in a regional zone.

6.2.D Riparian Zone

Difficulties surfaced with defining the riparian zone. The literature pointed towards a differentiation in vegetation and/or soil properties to distinguish the riparian area or zone. Because of the 30 meter pixel size of the land-cover data, a detailed vegetation study was ruled out. The soils were examined to see if they would help in determining a delineation of the riparian zone. This proved to be fruitless. A combination of flood zone information and soils information was also examined, but this also was inconclusive. Even a methodology using the DEM was attempted to see of a ridgeline that marked the top of the bank of the river system could be determined. This also proved very difficult and gave uncertain results. In the end a 100 meter buffer was instituted which represented, in a crude way, the riparian zone.

A method of defining the riparian zone is a very valid research question in its own right. A study should be attempted that defines a way to delineate the riparian zone using available digital datasets. This type of study would be beneficial to habitat inventory, helping to define the base conditions of the study area.

6.2.E Data Categorization

The data division for sedimentation was done using the Jenks Natural Breaks algorithm found in ArcGIS. Although this is a sound way to evaluate data among itself, it does not necessarily establish breakouts that are sensitive to the actual ecological conditions being studied. A better method would be to do scientific studies (using ground conditions) to establish the proper categorical definitions or to find literature that more clearly define categorizations for sedimentation.

6.2.F Coarse grain approach

It should be re-emphasized that this model is a coarse grain approach that helps to determine locations in which to apply appropriate remedial actions. This approach emphasized a view of the watershed at a sub-basin scale. In other words, all parameters were examined at this sub-basin scale. All parameters were generalized and associated with a rating scale of 1 to 5. This categorical generalization of parameters is appropriate for a coarse scale approach, but may introduce error if these same parameter categories are used at a finer resolution (finer than the sub-basin level). Also, the parameter categorization for sedimentation was based on the discretion of the software. This was used only because information pertaining to sedimentation levels was not obtained from the literature. A more thorough understanding of the pertinent literature may eliminate this error.

Users of this modeling approach can use the techniques described to locate sub-basins in which to apply appropriate measures, but on-the-ground surveys should be done to confirm these findings and locate specific sites in which to apply the remedial actions. The modeling approach should not be applied at a finer resolution because the generalized parameter values established in this study can miss important details at the finer scale.

6.2.G Weighting

All of the model parameters were given a rating scale of 1-5. Because of this ranking scheme, no parameter was weighted higher than another. This was done because it was believed that all parameters had the same effect and importance. This is a limitation of this study because in truth, impervious percentage may have a more dramatic effect on stream health than road crossings, or riparian vegetation density may effect streams more than road density, etc. Further research may be able to ascertain which of these parameters should receive a higher weighting.

6.3 MODEL IMPROVEMENTS

As with most models, their development is an on-going process and, in this case, the overall model could use some further development. The categories of Landscape Health, Salmon presence/Redd density, Risk Factors, and In-stream quality are a good framework in which to add further parameters. In other words, the framework is good, but the parameters that fill in the framework could use some expansion.

For example, the Risk factor only contained sedimentation as a parameter—this does not totally define risk for salmon. A furthering of this Risk category would be to add a run-off model to develop a finer differentiation in Risk or to obtain specific run-off data for the study area. This would help with the prioritization issues that were apparent with sub-basins 14 and 15 and with the designations of remedial action timings of long-term for all the BMP only sub-basins.

Although it is listed in the model framework, the details of an in-stream categorization methodology needs to be added to this model so that a researcher can identify where in-stream habitat may be viable even if salmon are not prevalent. This added step in the methodology would account for habitat that is not presently used by salmon, but has the potential for use. With this type of factor added to the model, habitat would only be ranked as "low" for in-stream quality if salmon usage was not evident and/or not potentially feasible.

As was mentioned above, weighting of parameters may be necessary to derive more meaningful results. Certain parameters may have a greater impact on the stream environment than others, and some form of weighting could account for these differences. Research to understand these differences should be done.

6.4 CLOSE

The need to save precious salmon stocks is of prime importance. Not only does the ESA legislation mandate that protection for salmon be put in place, but making every effort to save salmon has value for other reasons as well. These reasons not only include ecosystem considerations, but also cultural, socio-economic, and symbolic reasons. The Puget Sound region and the world would be a poorer place for the loss of salmon.

It is imperative that tools are found that can help decision-makers make critical decisions regarding protection of salmon and their habitat. Of course, in a perfect world, all salmon bearing streams that are in trouble would be protected to the maximum capacity. Unfortunately, there are limits on the amount of money that is available for enhancement projects and there are other limitations, such as existing infrastructure, that make total protection difficult if not impossible. Because of these facts, tools are needed that can help to prioritize habitat enhancement projects.

Many of the legal mandates surrounding the issue of salmon protection require that the “best science” approach be used to attack the problem. As was found in this study, this best science approach in regards to the prioritization of enhancement projects involves GIS and a sound modeling approach. The model in this study establishes which health parameters need the attention of remedial action and also how these parameters determine prioritization. GIS tools are then used to combine these parameters in a spatial format that can be evaluated.

What was revealed in this study was that a GIS, using readily available datasets, allows a watershed to be studied in a timely and cost effective approach. This method gives decision-makers the ability to find areas to focus their remedial action efforts and dollars. Of course, the methodology suggested in this research only gives a coarse assessment of basin conditions, but this is much better than a piecemeal approach that does not look at the watershed as a whole. Piecemeal approaches should be avoided because they can potentially put efforts in areas that have little benefit to salmon, thereby wasting precious dollars and doing little good. The model proposed in this research eliminates the piecemeal approach and gives a solid basis for pointing remedial action projects to the areas that can derive the most benefit for salmon.

The positive results of this model make it a useful tool for evaluating sub-basin prioritization for salmon habitat protection. The framework categories of landscape health, salmon presence, and sub-basin risk factors are very good groupings that allow for a better understanding of sub-basin characterization. Of course, other parameters can be added within these categories, increasing the effectiveness of the model. Also, adding the in-stream factor would give this model greater applicability.

All-in-all this model framework gives a good basis for establishing remedial action prioritizations and the use of GIS facilitates this process. With this tool, decision makers should be better armed to take on the critical decisions needed to save salmon and their habitat.

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APPENDIX A

Details of water typing scheme used in the Prescribed Management Zones of the Tri-County Model:

(1) "Type S Water" means all waters, within their bankfull width, as inventoried as "shorelines of the state" under chapter 90.58 RCW and the rules promulgated pursuant to chapter 90.58 RCW including including periodically inundated areas of their associated wetlands.

(2) "Type F Water" means segments of natural waters other than Type S Waters, which are within the bankfull widths of defined channels and periodically inundated areas of their associated wetlands, or within lakes, ponds, or impoundments having a surface area of 0.5 acre or greater at seasonal low water and which in any case contain fish habitat or are described by one of the following four categories:

(a) Waters, which are diverted for domestic use by more than 10 residential or camping units or by a public accommodation facility licensed to serve more than 10 persons, where such diversion is determined by the department to be a valid appropriation of water and the only practical water source for such users. Such waters shall be considered to be Type F Water upstream from the point of such diversion for 1,500 feet or until the drainage area is reduced by 50 percent, whichever is less;

(b) Waters, which are diverted for use by federal, state, tribal or private fish hatcheries. Such waters shall be considered Type F Water upstream from the point of diversion for 1,500 feet, including tributaries if highly significant for protection of downstream water quality. The department may allow additional harvest beyond the requirements of Type F Water designation provided the department determines after a landowner-requested on-site assessment by the department of fish and wildlife, department of ecology, the affected tribes and interested parties that:

(i) The management practices proposed by the landowner will adequately protect water quality for the fish hatchery; and
(ii) Such additional harvest meets the requirements of the water type designation that would apply in the absence of the hatchery;

(c) Waters, which are within a federal, state, local, or private campground having more than 10 camping units: Provided, That the water shall not be considered to enter a campground until it reaches the boundary of the park lands available for public use and comes within 100 feet of a camping unit, trail or other park improvement;

(d) Riverine ponds, wall-based channels, and other channel features that are used by fish for off-channel habitat. These areas are critical to the maintenance of optimum survival of fish. This habitat shall be identified based on the following criteria:

(i) The site must be connected to a fish habitat stream and accessible during some period of the year; and

(ii) The off-channel water must be accessible to fish.

(3) "Type Np Water" means all segments of natural waters within the bankfull width of defined channels that are perennial nonfish habitat streams. Perennial streams are waters that do not go dry any time of a year of normal rainfall. However, for the purpose of water typing, Type Np Waters include the intermittent dry portions of the perennial channel below the uppermost point of perennial flow. If the uppermost point of perennial flow cannot be identified with simple, nontechnical observations (see board manual, section 23), then Type Np Waters begin at a point along the channel where the contributing basin area is:

(a) At least 13 acres in the Western Washington coastal zone (which corresponds to the Sitka spruce zone defined in Franklin and Dyrness, 1973);

(b) At least 52 acres in other locations in Western Washington;

(c) At least 300 acres in Eastern Washington.

(4) "Type Ns Water" means all segments of natural waters within the bankfull width of the defined channels that are not Type S, F, or Np Waters. These are seasonal, nonfish habitat streams in which surface flow is not present for at least some portion of a year of normal rainfall and are not located downstream from any stream reach that is a Type Np Water. Ns Waters must be physically connected by an above-ground channel system to Type S, F, or Np Waters.

(5) For purposes of this section:

(a) "Residential unit" means a home, apartment, residential condominium unit or mobile home, serving as the principal place of residence.

(b) "Camping unit" means an area intended and used for:

(i) Overnight camping or picnicking by the public containing at least a fireplace, picnic table and access to water and sanitary facilities; or

(ii) A permanent home or condominium unit or mobile home not qualifying as a "residential unit" because of part time occupancy.

(c) "Public accommodation facility" means a business establishment open to and licensed to serve the public, such as a restaurant, tavern, motel or hotel.

(d) "Natural waters" only excludes water conveyance systems which are artificially constructed and actively maintained for irrigation.

(e) "Seasonal low flow" and "seasonal low water" mean the conditions of the 7-day, 2-year low water situation, as measured or estimated by accepted hydrologic techniques recognized by the department.

(f) "Channel width and gradient" means a measurement over a representative section of at least 500 linear feet with at least 10 evenly spaced measurement points along the normal stream channel but excluding unusually wide areas of negligible gradient such as marshy or swampy areas, beaver ponds and impoundments. Channel gradient may be determined utilizing stream profiles plotted from United States geological survey topographic maps (see board manual section 23).

(g) "Intermittent streams" means those segments of streams that normally go dry.

(h) "Fish habitat" means habitat which is used by any fish at any life stage at any time of the year, including potential habitat likely to be used by fish which could be recovered by restoration or management and includes off-channel habitat. (From WAC 222-16-030)

APPENDIX B

NATIONAL LAND COVER DATA

Product Description:

Derived from the early to mid-1990s Landsat Thematic Mapper satellite data, the National Land Cover Data (NLCD) is a 21-class land cover classification scheme applied consistently over the United States. The spatial resolution of the data is 30 meters and mapped in the Albers Conic Equal Area projection, NAD 83. The NLCD are provided on a state-by-state basis. The state data sets were cut out from larger "regional" data sets that are mosaics of Landsat TM scenes. At this time, all of the NLCD state files are available for free download as 8-bit binary files and some states are also available on CD-ROM as a Geo-TIFF.

The TM multi-band mosaics were processed using an unsupervised clustering algorithm. Both leaves-off and leaves-on data sets were analyzed. The resulting clusters were then labeled using aerial photography and ground observations. Clusters that represented more than one land cover category were also identified and, using various ancillary data sets, models developed to split the confused clusters into the correct land cover categories.

A hierarchical land cover classification scheme of 21 classes was developed and applied in a consistent manner across the entire United States. The classification scheme follows:

NLCD Land Cover Class Definitions

The classification system used for NLCD is modified from the Anderson land-use and land-cover classification system. Many of the Anderson classes, especially the Level III classes, are best derived using aerial photography. It is not appropriate to attempt to derive some of these classes using Landsat TM data due to issues of spatial resolution and interpretability of data. Thus, no attempt was made to derive classes that were extremely difficult or “impractical” to obtain using Landsat TM data, such as the Level III urban classes. In addition, some Anderson Level II classes were consolidated into a single NLCD class.

Water
- 11 Open Water
- 12 Perennial Ice/Snow

Developed
- 21 Low Intensity Residential
- 22 High Intensity Residential
- 23 Commercial/Industrial/Transportation

Barren
- 31 Bare Rock/Sand/Clay
- 32 Quarries/Strip Mines/Gravel Pits
- 33 Transitional

Forested Upland
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest

Shrubland
- 51 Shrubland

Non-Natural Woody
- 61 Orchards/Vineyards/Other

Herbaceous Upland Natural/Semi-natural Vegetation

71 Grasslands/Herbaceous

Herbaceous Planted/Cultivated

81 Pasture/Hay
82 Row Crops
83 Small Grains
84 Fallow
85 Urban/Recreational Grasses

Wetlands

91 Woody Wetlands
92 Emergent Herbaceous Wetlands

NLCD Land Cover Class Definitions

Water - All areas of open water or permanent ice/snow cover.

11. *Open Water* - all areas of open water, generally with less than 25% cover of vegetation/land cover.
12. *Perennial Ice/Snow* - all areas characterized by year-long surface cover of ice and/or snow.

Developed Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

21. *Low Intensity Residential* - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
22. *High Intensity Residential* - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.
23. *Commercial/Industrial/Transportation* - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

31. *Bare Rock/Sand/Clay* - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.
32. *Quarries/Strip Mines/Gravel Pits* - Areas of extractive mining activities with significant surface expression.
33. *Transitional* - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).

Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. *Deciduous Forest* - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
42. *Evergreen Forest* - Areas dominated by trees where 75 percent or more of the tree species `maintain their leaves all year. Canopy is never without green foliage.
43. *Mixed Forest* - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. *Shrubland* - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Non-Natural Woody - Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.

61. *Orchards/Vineyards/Other* - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.

Herbaceous Upland - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.
71. *Grasslands/Herbaceous* - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. *Pasture/Hay* - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.
82. *Row Crops* - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
83. *Small Grains* - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
84. *Fallow* - Areas used for the production of crops that do not exhibit visable vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
85. *Urban/Recreational Grasses* - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.

91. *Woody Wetlands* - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.
92. *Emergent Herbaceous Wetlands* - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

Reference

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe, 1979. Classification of Wetlands and Deepwater Habitat of the United States, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Similarities and differences between Anderson and NLCD systems are as follows:

> **Urban or built-up classes:** Commercial, Industrial, Transportation, and Communications/Utilities (all separate Anderson Level II classes) were treated as one NLCD class (Commercial/Industrial/Transportation). No attempt was made to derive Anderson Level III classes in NLCD. “Recreational” grasses, such as those that occur in golf courses or parks (treated as an urban class by Anderson) are considered to be a non-urban class in NLCD (a subdivision of “Herbaceous Planted/Cultivated). Residential (an Anderson Level II class) was divided into Low and High Intensity classes in NLCD.
>
> **Water:** Anderson Level II Water classes (Streams/Canals, Lakes/Ponds, Reservoirs, Bays, Open Marine) were classed as a single class (Open Water) in NLCD.

Agriculture: Agricultural areas that are herbaceous in nature (Cropland and Pasture; Anderson Level II) are subdivided into four NLCD classes: Pasture/Hay, Row Crops, Small Grains and Fallow.

Rangeland: No rangeland class (Anderson Level I) is identified by NLCD. Rather, “rangeland” is subdivided by NLCD into Grasslands/Herbaceous and Shrubland classes.

Forest land: Evergreen Forest, Deciduous Forest and Mixed Forest are the same in both Anderson and NLCD. Clearcut and burned areas are classed as “Transitional Bare” areas in NLCD.

Wetlands: Two classes are defined by NLCD. These are Woody wetlands and Emergent/Herbaceous wetlands. These are very analogous to the Anderson Level II wetland classes.

Bare: Three NLCD classes are recognized. These are: Bare Rock/Sand Clay, Quarries/Strip Mines/Gravel Pits and Transitional Bare. These represent a consolidation of Anderson Level II classes.

Tundra: While “tundra” is treated as a distinct Anderson Level I class, tundra (including arctic/alpine vegetation) is considered to be either “Grasslands/Herbaceous” or “Shrubland” classes by NLCD.

DAM FACILITIES

Abstract:

This coverage is a spatial representation of most of the Pacific Northwest dam facilities in the StreamNet database. Information about the location of each dam facility was collected from StreamNet personnel at WDFW (Washington Dept of Fish & Wildlife), ODFW (Oregon Dept of Fish & Wildlife), IDFG (Idaho Dept of Fish & Game), and MFWP (Montana Fish, Wildlife & Parks) and the tabular information about each hatchery in the StreamNet database was then added to each dam facility point in the GIS coverage. Original information for most facilities was derived from the National Inventory of Dams and then revised and amended when better information could be found by the StreamNet data compilers.

For more information about this coverage, please contact:

Travis Butcher (StreamNetGIS@psmfc.org)

Purpose:

Data is intended for use in a variety of applications where location of and information about dams is important.

Limitations_of_Data:

Dam facility locations were determined from longitude/latitude coordinate or 1:100,000 scale stream based information submitted by StreamNet personnel at the state agencies. Longitude and latitude coordinates were generally determined to 4 decimal places (ie. long 123.5763, lat 44.2345) but may be less precise for some hatcheries. Wherever possible, dams were linked to 1:100,000 scale streams via the LLID routing system, so that they would plot out directly on the stream. The event table data format only includes the data records that are linked to this stream routing system. Information on more dam facilites were provided by some state data compilers than others, so this coverage should not be used for cross-state comparisons of the number of dam facilities.

Entity_and_Attribute_Overview:

Attribute	Type	Definition
AREA	Binary Fl.Point	Internal field- Not applicable to this data set
PERIMETER	Binary Fl.Point	Internal field- Not applicable to this data set
DAMS#	Integer	Internal feature number for each point
DAMS-ID	Integer	User-assigned feature number for each point
DAMNAME	Character	The name of the dam facility
STATE	Character	The state where the dam facility is located

FISHWAY	Character	Description of fish passage facilities
FISHWAYTYP	Character	Description of type of fishway
OWNER	Character	The owner of the dam
OWNERTYPE	Character	The institutional status of the dam owner
YEARINIT	Binary	The year that construction of the dam began
YEARCOMPL	Binary	The year that the dam was completed
YEARREMOVE	Binary	The year that the dam was removed (if applicable)
DAMLENGTH	Binary Fl.Point	Dam crest length, in feet
NIDHEIGHT	Binary Fl.Point	The maximum of dam, structure, or hydraulic height, in feet, according to the National Inventory of Dams
SNETHEIGHT	Binary Fl.Point	The height of the dam, in feet, from a source other than the National Inventory of Dams
NORMSTORAGE	Binary Fl.Point	The normal storage capacity of the reservoir in acre feet
MAXSTORAGE	Binary Fl.Point	The maximum storage capacity of the reservoir in acre feet
REFID	Binary Fl.Point	The primary reference number describing the source of the dam information. For a corresponding table of references, see ftp://ftp.streamnet.org/pub/streamnet/ASCII_Data/Reference.txt
NID#	Character	The National Inventory of Dams ID number
FERCSITEID	Character	The Federal Energy Regulatory Commission Site Locatin Code
LLID	Character	The unique stream identifier for the 1:100,000 scale stream that the dam is located on.
STRMNAME	Character	The name of the stream that the dam is on.
BEGFT	Integer	The coordinate on the LLID routing system that the dam is at (event table only)
DAMID	Binary Fl.Point	Unique StreamNet identifier for the dam
MAJOR	Character	Is this a major dam? (Y=yes, N=no). This attribute was determined by examining the height, width, storage capacity, and FERC information on energy production for the facility, and is subjective.

Procedures_Used:

Generated a geographic coverage with the longitude/latitude coordinates for each facility based on location information
from the StreamNet hatchery facility database. Dam facilities that did not have longitude/latitude or stream-based locations
were not included. Projected the coverage to the StreamNet lambert projection and added additional data fields to the point
attribute table. Imported the StreamNet dams information table, related it to the point attribute table by StreamNet
Dam ID, and populated the additional information to the point attribute table.

Revisions:

This is the first version of this data file (created June 2002). Further updates will be made if/when new facility information
is submitted by the state data compilers.

Reviews_Applied_to_Data:

Visual Q/A.

Related_Spatial_and_Tabular_Data_Sets:

The StreamNet Dam Table - Available for download at http://www.streamnet.org/online-data/asciitables.html

Currentness_Reference:

Data is current as of year 2002.

Access_Constraints:

None

Data_Set_Credit:

Data was compiled by the StreamNet project (http://www.streamnet.org). Data was provided by Washington Dept. of Fish & Wildlife, Oregon Dept. of Fish & Wildlife, Idaho Dept. of Fish & Game, and Montana Dept. of Fish, Wildlife & Parks,
Much of the original data was collected from the National Inventory of Dams.

Completeness_Report:

Complete data set. See "Limitations of Data" for limitations.

KING COUNTY: STREAMS

Identification_Information:
Citation:
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: WTRCRS:Streams
Geospatial_Data_Presentation_Form: vector digital data
Description:
Abstract:
Streams
Purpose:
This coverage contains water courses for King County drainage basins, including some areas in adjoining counties. WTRCRS is designed as a topologically complete network of stream centerlines, with extensive related attribute tables.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:
Currentness_Reference: publication date
Status:
Progress: in work
Maintenance_and_Update_Frequency: randomly
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -122.5
East_Bounding_Coordinate: -121.1
North_Bounding_Coordinate: 47.8
South_Bounding_Coordinate: 47.1
Keywords:
Theme:
Theme_Keyword_Thesarus: None
Theme_Keyword:
Access_Constraints:
None
Use_Constraints:
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Point_of_Contact:
Contact_Information:

Contact_Organization_Primary:
Contact_Organization: King Co. Water and Land Resources
Contact_Person: Ken Rauscher
Contact_Position: GIS Analyst
Contact_Address:
Contact_Address_type: mailing
Address: 201 S. Jackson St. Suite 600
City: Seattle
State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206) 296-1922
Contact_electronic_Mail_Address: ken.rauscher@metrokc.gov
Hours_of_Service: 7:30 - 4:00 Mon. - Fri.

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: none
Logical_Consistency_Report: none
Completeness_Report: none
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
This data set is not conflated to the King County Cadastral Base. The positional accuracy of this data set is undetermined.
Lineage:
Source_Information:
Process_Step:
Process_Description:

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: Entity point
Point_and_Vector_Object_Count: 0
SDTS_Point_and_Vector_Object_Type: Complete chain
Point_and_Vector_Object_Count: 30041
SDTS_Point_and_Vector_Object_Type: GT-polygon composed of chains
Point_and_Vector_Object_Count: 0

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:

Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 5601
Lambert_Conformal_Conic:
Standard_Parallel_1: 47.5000
Standard_Parallel_2: 48.7333
Longitude_of_Central_Meridian: -120.8333
Latitude_of_Projection_Origin: 47.0
False_Easting: 1640416.66667
False_Northing: 0
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abcissa_Resolution: not determined
Ordinate_Resolution: not determined
Planar_Distance_Units: survey feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137
Denominator_of_Flattening_Ratio: 294.98

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: WTRCRS.AAT
Entity_Type_Definition: Arc attribute table
Attribute:
Attribute_Label: SOURCE
Attribute_Definition: Source of information about watercourse
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR.ORIG.DT
Attribute_Definition:
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_CRS_ID
Attribute_Definition: ID assigned to watercoursed during original project. Not maintained.
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_NAME
Attribute_Definition: Watercourse name
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_ORIG_DT
Attribute_Definition: Date when data added to database during original project. Not

maintained.
Attribute_Definition_Source: ARC/INFO

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center
Contact_Person: Cheryl Wilder
Contact_Address:
Contact_Address_type: mailing
Address:
201 S. Jackson St.
Room 706
City: Seattle
State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206) 263-5220
Contact_electronic_Mail_Address: cheryl.wilder@metrokc.gov
Hours_of_Service: M-F 8-5 PST
Resource_Description: WTRCRS
Distribution_Liability:
King County disclaims any warranty of use of any digital product beyond that for which it was designed.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name:
ARC/INFO Coverage, ARC/INFO Shapefiles
Format_Information_Content:
The standard distribution compact discs contain either ARC/INFO Coverages, or ARC/INFO Shapefiles, or dBase data format. HTML documentation is provided on all CDs.
Digital_Transfer_Option:
Offline_Option:
Offline_Media: CD-ROM

Metadata_Reference_Information:
Metadata_Date: 20040510
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center

Contact_Person: Lisa Castle
Contact_Address:
Contact_Address_type: mailing
Address:
201 S. Jackson St.
Room 706
City: Seattle
State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206)263-4862
Contact_electronic_Mail_Address: lisa.castle@metrokc.gov
Hours_of_Service: 7-4 M-F
Metadata_Standard_Name: FGDC Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608
Metadata_Time_Convention: local time

KING COUNTY: OPEN WATER

Identification_Information:
Citation:
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: WTRBDY:Open Water
Geospatial_Data_Presentation_Form: vector digital data
Description:
Abstract:
Lakes & Rivers
Purpose:
This coverage contains water bodies such as lakes and rivers for King County drainage basins, including some areas in adjoining counties. WTRBDY also includes other "water" bodies such as sewage lagoons, so users are encouraged to make use of the water type codes in the attribute table to accurately display this data. For most water body display purposes, displaying water type codes 101, 116, 402, 412, 414, and 421 is sufficient.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:
Currentness_Reference: publication date
Status:
Progress: in work
Maintenance_and_Update_Frequency: randomly
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -122.5
East_Bounding_Coordinate: -121.1
North_Bounding_Coordinate: 47.8
South_Bounding_Coordinate: 47.1
Keywords:
Theme:
Theme_Keyword_Thesarus: None
Theme_Keyword:
Access_Constraints:
None
Use_Constraints:
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Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. Water and Land Resources
Contact_Person: Ken Rauscher
Contact_Position: GIS Analyst
Contact_Address:
Contact_Address_type: mailing
Address: 201 S. Jackson St. Suite 600
City: Seattle
State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206) 296-1922
Contact_electronic_Mail_Address: ken.rauscher@metrokc.gov
Hours_of_Service: 7:30 - 4:00 Mon. - Fri.
Cross_Reference:
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: WTRBDYPAT.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item WTR_TYPE_CD in table WTRBDYPAT.LXT relates on the right to WTR_TYPE_CD in WTRBDY.PAT

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: none
Logical_Consistency_Report: none
Completeness_Report: none
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
This data set is not conflated to the King County Cadastral Base. The positional accuracy of this data set is undetermined.
Lineage:
Source_Information:
Process_Step:
Process_Description:

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: vector
Point_and_Vector_Object_Information:

SDTS_Terms_Description:
SDTS_Point_and_Vector_Object_Type: Entity point
Point_and_Vector_Object_Count: 6878
SDTS_Point_and_Vector_Object_Type: Complete chain
Point_and_Vector_Object_Count: 8225
SDTS_Point_and_Vector_Object_Type: GT-polygon composed of chains
Point_and_Vector_Object_Count: 6879

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 5601
Lambert_Conformal_Conic:
Standard_Parallel_1: 47.5000
Standard_Parallel_2: 48.7333
Longitude_of_Central_Meridian: -120.8333
Latitude_of_Projection_Origin: 47.0
False_Easting: 1640416.66667
False_Northing: 0
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abcissa_Resolution: not determined
Ordinate_Resolution: not determined
Planar_Distance_Units: survey feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137
Denominator_of_Flattening_Ratio: 294.98

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: WTRBDY.PAT
Entity_Type_Definition: Polygon attribute table
Attribute:
Attribute_Label: SOURCE
Attribute_Definition: Source of information about waterbody
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WATER

Attribute_Definition: Code to filter out islands in waterbodies (1 = waterbody, 0 = island)
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: 1
Enumerated_Domain_Definition:
Enumerated_Domain_Definition_Source: WTRBDYPAT.lxt
Attribute_Label: WTR_ACRE
Attribute_Definition: Not maintained. From original project
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_BDY_ID
Attribute_Definition: ID assigned to some waterbodies during original project. Not maintained.
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_CRD_X
Attribute_Definition: X coordinate located inside waterbody. Not maintained.
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_CRD_Y
Attribute_Definition: Y coordinate located inside waterbody. Not maintained.
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_NAME
Attribute_Definition: Waterbody name
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_TYPE
Attribute_Definition: Description of waterbody type
Attribute_Definition_Source: ARC/INFO
Attribute_Label: WTR_TYPE_CD
Attribute_Definition: Code for type of waterbody
Attribute_Definition_Source: ARC/INFO
Codeset_Domain:
Codeset_Name: /plibrary/hydro/final/WTRBDYPAT.lxt
Codeset_Source: ARC/INFO

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center
Contact_Person: Cheryl Wilder
Contact_Address:
Contact_Address_type: mailing
Address:
201 S. Jackson St.
Room 706
City: Seattle

State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206) 263-5220
Contact_electronic_Mail_Address: cheryl.wilder@metrokc.gov
Hours_of_Service: M-F 8-5 PST
Resource_Description: WTRBDY
Distribution_Liability:
King County disclaims any warranty of use of any digital product beyond that for which it was designed.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name:
ARC/INFO Coverage, ARC/INFO Shapefiles
Format_Information_Content:
The standard distribution compact discs contain either ARC/INFO Coverages, or ARC/INFO Shapefiles, or dBase data format. HTML documentation is provided on all CDs.
Digital_Transfer_Option:
Offline_Option:
Offline_Media: CD-ROM

Metadata_Reference_Information:
Metadata_Date: 20040510
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center
Contact_Person: Lisa Castle
Contact_Address:
Contact_Address_type: mailing
Address:
201 S. Jackson St.
Room 706
City: Seattle
State_or_Province: WA
Postal_Code: 98104
Country: USA
Contact_Voice_Telephone: (206)263-4862
Contact_electronic_Mail_Address: lisa.castle@metrokc.gov
Hours_of_Service: 7-4 M-F
Metadata_Standard_Name: FGDC Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608

Metadata_Time_Convention: local time

KING COUNTY: KC STREET NETWORK

Identification_Information:
Citation:
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSN:KC street network
Geospatial_Data_Presentation_Form: vector digital data
Description:
Abstract:
King County Street Network
Purpose:
This coverage contains the features comprising the countywide road and street network, including such related transportation links as selected driveways, transit connections, alleys, etc. Attributes of the network arcs include address ranges, adjacent features, road classification, and other codes. Based on TIGER data, KCSN is suitable for general reference, small-scale map displays, and network analysis. Future enhancements include deriving this data set directly from RECDNET.
Supplement:
Nightly batch process runs QC AML (ae_qc.aml) to ensure key identifier uniqueness and correspondence with related tables . Distribution database constraints control integrity with c ertain attributes.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:
Currentness_Reference: publication date
Status:
Progress: complete
Maintenance_and_Update_Frequency: daily
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -122.5
East_Bounding_Coordinate: -121.1
North_Bounding_Coordinate: 47.8
South_Bounding_Coordinate: 47.1
Keywords:
Theme:
Theme_Keyword_Thesarus: None
Theme_Keyword:
Access_Constraints:
None

Use_Constraints:
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Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: GIS group - Transit Infrastructure and Integration
Contact_Person: Tamara Davis
Contact_Address:
Contact_Address_type: mailing
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Country: USA
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Cross_Reference:
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSNSTNAME.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item PREFIX in table KCSNSTNAME.LXT relates on the right to PREFIX in KCSN.STNAME
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSNAAT.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item ROAD_CLASS in table KCSNAAT.LXT relates on the right to ROAD_CLASS in KCSN.AAT

Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSNNEWARCS.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item FEATURE in table KCSNNEWARCS.LXT relates on the right to FEATURE in KCSN.NEWARCS
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSNTEMP1.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item PREFIX in table KCSNTEMP1.LXT relates on the right to PREFIX in KCSN.TEMP1
Citation_Information:
Originator: King County
Publication_Date: 20040510
Title: KCSNTEMP2.LXT
Geospatial_Data_Presentation_Form: tabular digital data
Other_Citation_Details:
Item PREFIX in table KCSNTEMP2.LXT relates on the right to PREFIX in KCSN.TEMP2

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report: none
Logical_Consistency_Report: none
Completeness_Report: none
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
This data set is not conflated to the King County Cadastral Base. The positional accuracy of this data set is undetermined.
Lineage:
Source_Information:
Process_Step:
Process_Description:

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: vector
Point_and_Vector_Object_Information:
SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: Entity point
Point_and_Vector_Object_Count: 0
SDTS_Point_and_Vector_Object_Type: Complete chain
Point_and_Vector_Object_Count: 98202
SDTS_Point_and_Vector_Object_Type: GT-polygon composed of chains
Point_and_Vector_Object_Count: 0

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 5601
Lambert_Conformal_Conic:
Standard_Parallel_1: 47.5000
Standard_Parallel_2: 48.7333
Longitude_of_Central_Meridian: -120.8333
Latitude_of_Projection_Origin: 47.0
False_Easting: 1640416.66667
False_Northing: 0
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abcissa_Resolution: not determined
Ordinate_Resolution: not determined
Planar_Distance_Units: survey feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137
Denominator_of_Flattening_Ratio: 294.98

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.AAT
Entity_Type_Definition:
Attribute:
Attribute_Label: BARRIER
Attribute_Definition: Trip planning defines streets where pedestrian crossings are not allowed
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:

Enumerated_Domain_Value: 1
Enumerated_Domain_Definition:
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: BLKL
Attribute_Definition: Cencus block code on left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: BLKR
Attribute_Definition: Cencus block code on right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: CFCC
Attribute_Definition: Census feature class code (road class)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: COUNTYL
Attribute_Definition: County FIPS code on left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: COUNTYR
Attribute_Definition: County FIPS code on right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: CTBNAL
Attribute_Definition: Cencus Tract BNA code on left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: CTBNAR
Attribute_Definition: Cencus Tract BNA code on right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: DATECR
Attribute_Definition: The YYMD feature was created
Attribute_Definition_Source: ARC/INFO
Attribute_Label: DATEUP
Attribute_Definition: The YYMD feature was updated
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FMCDL
Attribute_Definition: FIPS minor civil division code on left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FMCDR
Attribute_Definition: FIPS minor civil division code on right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FPLL
Attribute_Definition: FIPS place code on left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FPLR
Attribute_Definition: FIPS place code on right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FRADDL
Attribute_Definition: Address at the from node on the left side of street

Attribute_Definition_Source: ARC/INFO
Attribute_Label: FRADDR
Attribute_Definition: Address at the from node on the right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: GRADE
Attribute_Definition: Slope of streets
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: 1
Enumerated_Domain_Definition:
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: HOV
Attribute_Definition: Numbers indicate the direction of the HOV lanes
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: 4
Enumerated_Domain_Definition: West
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: 2
Enumerated_Domain_Definition: South
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: 1
Enumerated_Domain_Definition: North
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: 3
Enumerated_Domain_Definition: East
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: 5
Enumerated_Domain_Definition: Both
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: HSS
Attribute_Definition: Numbers identify streets as HSS
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: 1
Enumerated_Domain_Definition:
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: KCGIS_RECNUM
Attribute_Definition: King County GIS unique id of the street link to the trolley
Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYALIAS1
Attribute_Definition: Second link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYALIAS2

Attribute_Definition: Third link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYNAME
Attribute_Definition: Link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: RAMKEY
Attribute_Definition: RAMIS database link
Attribute_Definition_Source: ARC/INFO
Attribute_Label: RAMTYPE
Attribute_Definition: This item is not used and can be dropped
Attribute_Definition_Source: ARC/INFO
Attribute_Label: RATSTREET
Attribute_Definition: This item is not used and can be dropped
Attribute_Definition_Source: ARC/INFO
Attribute_Label: RECNUM
Attribute_Definition: Unique id of street link to the trolley
Attribute_Definition_Source: ARC/INFO
Attribute_Label: ROAD_CLASS
Attribute_Definition: Classificatiion codes for roadway
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: C
Enumerated_Domain_Definition: Collector arterials
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: F
Enumerated_Domain_Definition: Freeways
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: L
Enumerated_Domain_Definition: Local
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: M
Enumerated_Domain_Definition: Minor arterials
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Enumerated_Domain_Value: P
Enumerated_Domain_Definition: Primary arterials
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: TOADDL
Attribute_Definition: Address at the to node on the left side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: TOADDR
Attribute_Definition: Address at the to node on the right side of street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: TRANSIT
Attribute_Definition: Transit codes indicate if used by transit

Attribute_Definition_Source: ARC/INFO
Attribute_Label: TROLLEY
Attribute_Definition: Numbers identify streets as trolley overhead
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Enumerated_Domain_Value: 1
Enumerated_Domain_Definition:
Enumerated_Domain_Definition_Source: KCSNAAT.lxt
Attribute_Label: UFLAG
Attribute_Definition: Codes indicate if modified since Oracle update
Attribute_Definition_Source: ARC/INFO
Attribute_Label: VERSION
Attribute_Definition: Version number
Attribute_Definition_Source: ARC/INFO
Attribute_Label: ZIPL
Attribute_Definition: The Postal zip code on the left side of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: ZIPR
Attribute_Definition: The postal zip code on right side of street
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.NAT
Entity_Type_Definition:
Attribute:
Attribute_Label: RAMKEY
Attribute_Definition: RAMIS database link
Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 0
Range_Domain_Maximum: 9998
Attribute_Label: TPKEY
Attribute_Definition: timepoint identifier
Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 0
Range_Domain_Maximum: 9998
Attribute_Label: UFLAG
Attribute_Definition:
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.RATDHD
Entity_Type_Definition: route attribute table for active deadheads

Attribute:
Attribute_Label: DATEACT
Attribute_Definition: Date that TPI will be activated
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FROMTP
Attribute_Definition: timepoint at the start of the TPI
Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 1
Range_Domain_Maximum: 9820
Attribute_Label: SIGNUP
Attribute_Definition: This item is not used and can be dropped
Attribute_Definition_Source: ARC/INFO
Attribute_Label: TOTP
Attribute_Definition: timepoint at the end of the TPI
Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 1
Range_Domain_Maximum: 9819
Attribute_Label: TROLLEY
Attribute_Definition: Numbers indicate if has Trolley lines
Attribute_Definition_Source: ARC/INFO
Attribute_Label: UFLAG
Attribute_Definition: Indicates if modified since last Oracle update
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.RATTPI
Entity_Type_Definition: route attribute table for active timepint interchanges (TPIs)
Attribute:
Attribute_Label: DATEACT
Attribute_Definition: Date that TPI will be activated
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FROMTP
Attribute_Definition: timepoint at the start of the TPI
Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 1
Range_Domain_Maximum: 9820
Attribute_Label: SIGNUP
Attribute_Definition: This item is not used and can be dropped
Attribute_Definition_Source: ARC/INFO
Attribute_Label: TOTP
Attribute_Definition: timepoint at the end of the TPI

Attribute_Definition_Source: ARC/INFO
Range_Domain:
Range_Domain_Minimum: 1
Range_Domain_Maximum: 9820
Attribute_Label: TROLLEY
Attribute_Definition: Indicates if has trolley overheads
Attribute_Definition_Source: ARC/INFO
Attribute_Label: UFLAG
Attribute_Definition: Indicates if modified since last Oracle update
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.RATPATTERN
Entity_Type_Definition: section attribute table for patterns
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.RATZONE
Entity_Type_Definition: route attribute table for zones
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.SECDHD
Entity_Type_Definition: section attribute table for active deadheads
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.SECPATTERN
Entity_Type_Definition: section attribute table for patterns
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.STNAME
Entity_Type_Definition: Street Name
Attribute:
Attribute_Label: FEATURE
Attribute_Definition: Full street name (without space between street name & suffix direction)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: FEATURE2
Attribute_Definition: Full street name (without space between street name & suffix direction)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYNAME
Attribute_Definition: Link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: PREFIX
Attribute_Definition: Prefix direction of the street

Attribute_Definition_Source: ARC/INFO
Codeset_Domain:
Codeset_Name: /plibrary/street/final/KCSNSTNAME.lxt
Codeset_Source: ARC/INFO
Attribute_Label: STNAME
Attribute_Definition: Name of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: STYPE
Attribute_Definition: Type of the street
Attribute_Definition_Source: ARC/INFO
Codeset_Domain:
Codeset_Name: /plibrary/street/final/KCSNSTNAME.lxt
Codeset_Source: ARC/INFO
Attribute_Label: SUFFIX
Attribute_Definition: Suffix of the street
Attribute_Definition_Source: ARC/INFO
Codeset_Domain:
Codeset_Name: /plibrary/street/final/KCSNSTNAME.lxt
Codeset_Source: ARC/INFO
Attribute_Label: UFLAG
Attribute_Definition: Codes indicate if modified since Oracle update
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.TLID
Entity_Type_Definition: storage of record numbers or TIGER line identifiers (TLIDs)
Attribute:
Attribute_Label: DATE
Attribute_Definition:
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.NEWARCS
Entity_Type_Definition:
Attribute:
Attribute_Label: FEATURE
Attribute_Definition: Full street name (with space between street name & suffix direction)
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: KEYNAME
Attribute_Definition: Link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: PREFIX

Attribute_Definition: Prefix direction for street
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: STNAME
Attribute_Definition: Name of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: STYPE
Attribute_Definition: Type of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: SUFFIX
Attribute_Definition: Suffix direction for street
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: UFLAG
Attribute_Definition: Indicates if modified since last oracle update
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.RATEMITT
Entity_Type_Definition:
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.SECEMITT
Entity_Type_Definition:
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.SECTPI
Entity_Type_Definition:
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.SECZONE
Entity_Type_Definition:
Attribute:
Attribute_Label: ROUTELINK#
Attribute_Definition:
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.TEMP1
Entity_Type_Definition:
Attribute:
Attribute_Label: FEATURE
Attribute_Definition: Full street name (with space between street name & suffix direction)

Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYNAME
Attribute_Definition: Link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: PREFIX
Attribute_Definition: Prefix of the street
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: STNAME
Attribute_Definition: Name of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: STYPE
Attribute_Definition: Type of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: SUFFIX
Attribute_Definition: Suffix of the street
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: UFLAG
Attribute_Definition: Codes indicate if modified since Oracle update
Attribute_Definition_Source: ARC/INFO
Detailed_Description:
Entity_Type:
Entity_Type_Label: KCSN.TEMP2
Entity_Type_Definition:
Attribute:
Attribute_Label: FEATURE
Attribute_Definition: Full street name (with space between street name & suffix direction)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: KEYNAME
Attribute_Definition: Link key identifier to street name table (kcsn.stname)
Attribute_Definition_Source: ARC/INFO
Attribute_Label: PREFIX
Attribute_Definition: Prefix of the street
Attribute_Definition_Source: ARC/INFO
Enumerated_Domain:
Attribute_Label: STNAME
Attribute_Definition: Name of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: STYPE
Attribute_Definition: Type of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: SUFFIX

Attribute_Definition: Suffix of the street
Attribute_Definition_Source: ARC/INFO
Attribute_Label: UFLAG
Attribute_Definition: Indicates if modified since last Oracle update
Attribute_Definition_Source: ARC/INFO

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center
Contact_Person: Cheryl Wilder
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Contact_Address_type: mailing
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Hours_of_Service: M-F 8-5 PST
Resource_Description: KCSN
Distribution_Liability:
King County disclaims any warranty of use of any digital product beyond that for which it was designed.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name:
ARC/INFO Coverage, ARC/INFO Shapefiles
Format_Information_Content:
The standard distribution compact discs contain either ARC/INFO Coverages, or ARC/INFO Shapefiles, or dBase data format. HTML documentation is provided on all CDs.
Digital_Transfer_Option:
Offline_Option:
Offline_Media: CD-ROM

Metadata_Reference_Information:
Metadata_Date: 20040510
Metadata_Contact:

Contact_Information:
Contact_Organization_Primary:
Contact_Organization: King Co. GIS Center
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Hours_of_Service: 7-4 M-F
Metadata_Standard_Name: FGDC Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608
Metadata_Time_Convention: local time