

"Almost every aspect of modern human society in the Pacific Northwest has played some part in the decline of the wild salmon and the degradation of salmon habitat..."

BROWN, 1982

STUDY APPROACH

The Salmonid Refugia Project was designed to evaluate the current ecological condition of salmonid resources in the East Jefferson County and Kitsap County, Washington study areas. This report can be considered as the first step in the overall, long-term salmon recovery process. The report also makes recommendations for resource conservation, enhancement, and restoration.

The study area includes streams that drain into Hood Canal and west-central Puget Sound (see Figures 5 & 6). The study area encompasses parts of Water Resource Inventory Area (WRIA) 15, 16, and 17. This project can be described as a rapid identification and evaluation of high-priority areas for conservation of salmonid resources in our region. The study is a synthesis of existing data, scientific information, field surveys, and professional opinion. The report draws from what is known, published and described by “local experts” within agencies, tribes and watershed groups having direct knowledge of these ecosystems and populations. The assessment provides a prioritized listing of the most ecologically significant freshwater and nearshore habitats for salmon in the study area. This prioritized list of refugia, together with the summarized information and compiled sources, can be used to help guide cost-effective conservation decision-making in the near term for the benefit of salmon.



Figure 5: Location of Refugia Project Study Area.

A modified version of the refugia methodology developed by Frissell (1998 and 1999) was used to identify salmonid refugia habitat. The best available scientific data was utilized, including both quantitative and qualitative habitat data on each stream system, salmonid abundance data, and stock assessments, as well as historic and current watershed conditions on multiple landscape scales. Our approach is a modification of the Rapid Biological and Ecological Response (RBER) protocols (Doppelt et al., 1993), a watershed-based strategy developed during the FEMAT (1993) process. The scientific foundation for this approach can also be found in basic conservation reserve design principles (Noss and Cooperrider, 1994) and is grounded on the principle of “best available science” (Smallwood et al., 1999).

The State of Washington published guidance on *watershed assessment* to support salmon conservation efforts (WA-JNRC, 2001). This guidance document characterizes the watershed assessment process as being composed of three overlapping stages, each more detailed and



scientifically rigorous than the next. Watershed assessment is recognized as a critical early component in the overall salmon recovery process (Beechie, et al., 2003). The Salmonid Refugia Project covers the first stage of this overall process. The “Limiting Factors Analysis” (LFA), which was conducted within the same time period of this study, covers the second stage of the watershed assessment process as defined by the guidance document (WA-JNRC, 2001). The detailed watershed assessment process, which is currently underway in the study area, should cover the third and final stage of the overall process. Each of these studies involves different levels of effort and different levels of detail, but the overall goals of each are very complimentary and supportive of the next stage. The initial stage of the watershed assessment process, as outlined in the Washington guidance document (WA-JNRC, 2001), consists of characterizing the watershed, describing current habitat conditions, summarizing salmonid stock status and trends, and synthesizing this information into a summary report. The guidance document recommends using existing data as much as possible and utilizing the local expertise of scientists who are familiar with the watersheds under assessment. It is important to note that detailed, quantitative instream habitat assessment is not a part of this stage in the watershed assessment process, nor was it a part of the refugia project.

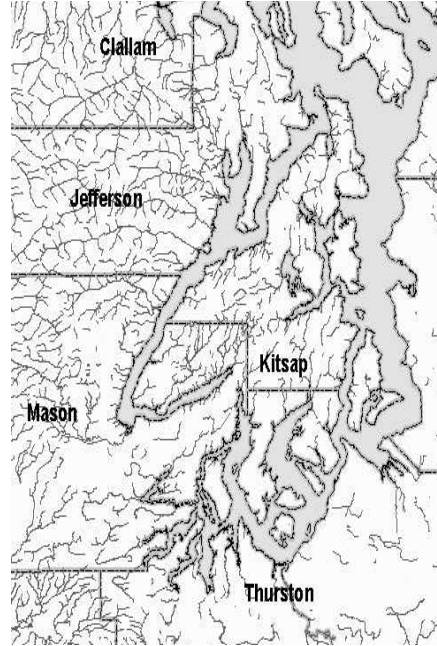


Figure 6: Boundaries of Refugia Project Study Area.



“We must work together to restore the integrity of our landscape and our native fishes, riparian areas, forests, and streams. The health of our watersheds depends upon the developing a proper land ethic, upon conducting ourselves in a manner consistent with the principles of that ethic, and upon correcting damage from past actions. The challenge is not an easy one, but one that is worthy of our best fight.”

BRUCE BABBITT, SECRETARY OF THE INTERIOR, 1997

LANDSCAPE APPROACH TO PROTECTION AND RESTORATION

Protection of aquatic resources involves preventing anthropogenic alterations to the structure and function of the ecosystem (NRC, 1992). Ideally, this would involve protection of biological, chemical, and physical processes that maintain salmonid habitat. The mechanisms for protection include regulation, acquisition, conservation easements, and stewardship. These are mainly policy issues and will not be addressed in this report. However, the scientific information outlined in this report can be used to make informed decisions about where protection may be an effective tool.

In contrast, restoration involves improving aquatic functions and related physical, chemical, and biological characteristics of riparian and aquatic systems. Restoration may involve reconstruction of previous physical conditions, adjusting physio-chemical processes, removal of invasive or exotic species, and/or biological re-introduction of extirpated species (NRC, 1992). Aquatic restoration activities often include improvements in water quality, water quantity, fish passage, and riparian vegetation (IMST, 2002).

Different types of restoration activities vary in the amount of human intervention involved and represent a continuum of “passive” to “active” restoration (NRC, 1996). The term restoration is typically used broadly to encompass activities that are sometimes classified as “rehabilitation”, “enhancement”, or “mitigation” (NRC, 1992). Figure 7 illustrates these concepts. As used in this report, watershed restoration is defined as the process of restoring systems and processes to the point they can

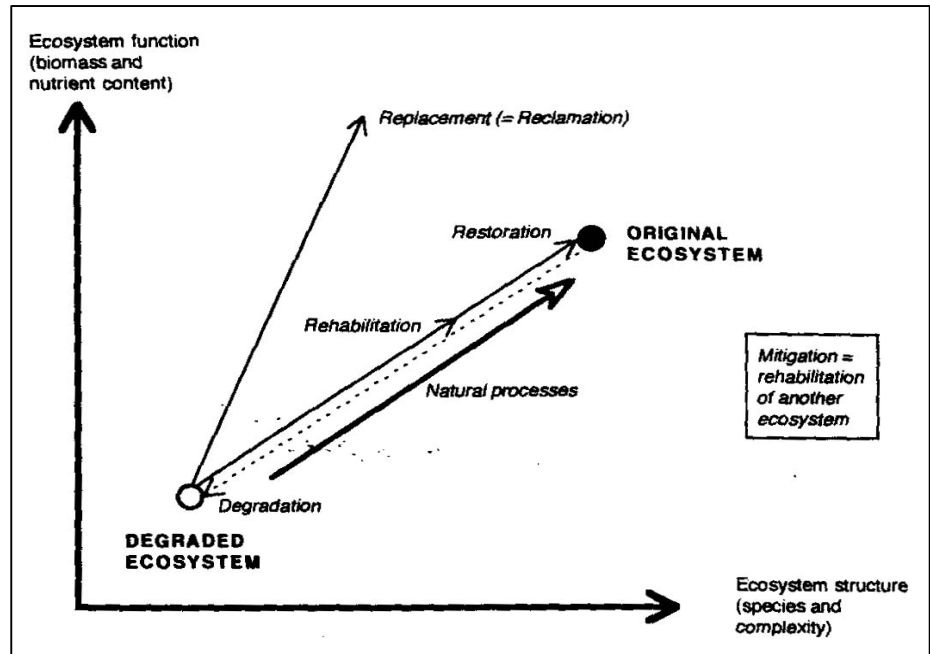


Figure 7: Resource management Concept Diagram (Bradshaw, 1983).



provide the natural materials and ecological functions that create habitat (IMST, 2002). In this report, protection and restoration of ecological function is emphasized. However, it should be acknowledged that enhancement and mitigation activities may have a role to play in salmonid recovery.

Rehabilitation has been defined as re-establishment of naturally self-sustaining or properly functioning aquatic-riparian ecosystems to the extent possible while acknowledging that irreversible human changes might permit only partial restoration of ecological functions (NRC, 1996). In the PNW, the restoration of pre-Euro-American settlement aquatic conditions and functions across entire watersheds is not usually feasible because of societal constraints and/or irreversible landscape changes. However, at individual sites or in specific sub-watersheds, restoration to pre-Euro-American settlement conditions may be possible and even desirable (IMST, 2002).

Enhancement focuses on improving selected habitat characteristics, and may involve technological approaches or artificial structures that mimic habitat elements, as well as natural methods (NRC, 1992). Mitigation describes a range of activities with the intent to, avoid, reduce, or compensate for the effects of environmental damage (NRC 1992). Based on this definition, one can see that mitigation is not designed to be 100% effective in protecting natural ecosystem structure and function.

Protection or restoration projects are usually applied to only a small portion of a watershed and may not provide measurable increases in salmonid production at the larger, watershed level (Roni et al., 2002). Most of these efforts have been conducted in upland reaches and on the site scale rather than the landscape or watershed scale (Frissell and Ralph, 1998). Common restoration activities, including barrier removal and in-channel restoration, are typically constrained to an individual site and protection efforts are often limited in scope by the availability of willing landowners to sell key parcels and/or a limited budget. One of the greatest challenges of recovery planning is selecting site-specific protection and restoration activities without losing the landscape perspective (Roni et al., 2002). To overcome this challenge, decision-making within a landscape approach needs to be informed by research and planning at the appropriate scales (IMST, 2002).

Productive salmonid ecosystems require a mosaic of favorable, interconnected habitats that are maintained by natural physical (geomorphic and hydrologic), chemical, and biological processes within a watershed. These habitats are linked in both space and time and support diverse salmonid life histories (Bisson, 1995; Reeves et al., 1995; IMST, 2002). Salmonid habitat is dynamic on several scales. Disturbances, such as wildfires, landslides, and floods produce a mosaic of habitats in different successional stages (Reeves et al., 1995). This dynamic mosaic argues for identification, protection, and restoration of habitat throughout the landscape, including floodplains, wetlands, and surrounding watersheds. Preservation of habitat fragments may not be sufficient to maintain natural diversity in aquatic ecosystems (Harding et al., 1999), and restoration may be effective only if watersheds are protected from land-use practices that disrupt fundamental ecological processes in streams (IMST, 2002). A watershed approach to salmonid recovery that considers the varied spatial and temporal distribution of key habitats needed by anadromous salmonids to complete their life histories has been recognized as necessary to the long-term recovery of salmonid stocks (NRC 1992; NRC 1996; IMST 1999; IMST 2002). The State of Oregon has undertaken an effort to designate critical, high-quality Salmon Habitat and Diversity Watersheds. These Salmon Habitat and Diversity Watershed designations could be used by agencies, private landowners, and watershed councils to prioritize assessments, monitoring, protection, and restoration efforts to most effectively to help in salmonid recovery (IMST, 2002).



“Water is the driver of all nature...”

LEONARDO DA VINCI

WATERSHED ASSESSMENT AND PRIORITIZATION

The role of this project in the overall watershed planning and assessment process to support salmon recovery is that of a screening tool. Identification of salmonid refugia areas and a description of their current conditions is the primary objective of the study. The report can serve as a basis for prioritizing preservation and restoration efforts in the study area. This includes identification of potential conservation areas, justification for obtaining salmon recovery project funding, and for evaluating potential risk of future land-use activities. The Limiting Factors Analysis (LFA) can be used in conjunction with the refugia report to identify problem areas that are impacting salmonid production and distribution, as well as to prioritize restoration or rehabilitation projects developed to correct these problems. This report provides information that can and should be used in the development of salmonid habitat protection and restoration strategies. It should be considered a living document, with additional habitat assessment data incorporated as information becomes available.

According to Washington guidance (WA-JNRC, 2001), the key objectives of the initial stage of watershed assessment include the following:

- Establish the current conditions of each watershed on a landscape scale.
- Describe the unique characteristics of each watershed, both natural and land-use related.
- Describe how current watershed conditions diverge from what is expected in a healthy, natural watershed.
- Establish the current salmonid habitat conditions in each stream ecosystem.
- Describe how current habitat conditions differ from properly functioning conditions (PFC).
- Where possible, identify the salmonid species found in each watershed
- Describe the current status of salmonid species, as well as the historic distribution, diversity, and productivity.
- Describe the extent of human-caused factors impacting salmonid habitat conditions.
- Describe the habitat-forming processes in the watershed.
- Identify data gaps, limitations of current data, and uncertainty of information.



Watershed assessment is an on-going process of compiling and analyzing technical information on watershed conditions, and the effect of human activities on those conditions. It is the first step in a long-term *ecosystem management* program (Montgomery et al., 1995). Ultimately, watershed management, including conservation and restoration efforts, will be a key local component in integrated regional ecosystem management efforts. Because data availability and technical resources vary across geographic areas, the way watershed assessment tasks are approached and the time frame for accomplishing them varies. A single assessment method or tool will likely not provide all the information needed to effectively manage a watershed based on multiple beneficial uses. However, a standardized assessment framework is needed to bring together different assessment elements, improve consistency, and synthesize data for more effective watershed management (WA-JNRC, 2001).

A science-based watershed assessment analyzes the past and current state of the watershed, captures its unique physical, chemical, and biological characteristics, and compares these conditions to those in natural “reference” watersheds. It should explicitly identify uncertainty of information and be supported by written records that provide a basis for decision-making. Assessments help us determine how well a watershed is functioning and how it responds to natural and human disturbances (see Figure 8). They should help us understand how a watershed “works” and how a watershed has changed as a result of human activities.

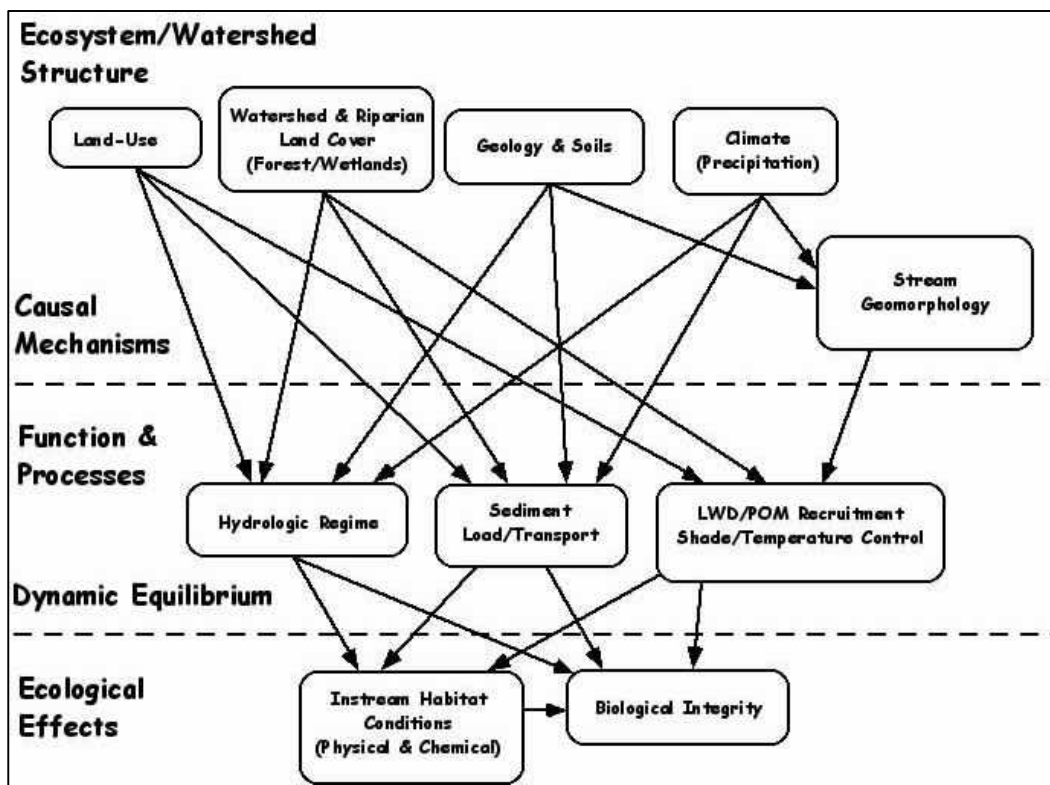


Figure 8: Conceptual Diagram of Watershed Structure and Function.



The key components generally involved with watershed assessment include the following (US-EPA, 2000):

- 1) Describe the general physical, biological, and chemical attributes of the watershed (i.e. geology, climate, topography, hydrology, and soil structure). This can be done at a qualitative or quantitative level.
- 2) Identify and describe factors within the watershed, both natural and human-caused, that affect the physical, biological, and chemical attributes of the watershed. This includes analysis of:
 - Hydrologic conditions - low flows, peak flows, water use, land cover, land-use, and impervious surfaces.
 - Soil erosion and sediment load and sources—roads, construction sites, landslides.
 - Natural vegetation patterns and characteristics—riparian corridors, upland forests, and other native vegetation.
 - Wetland, floodplain, and nearshore/estuary conditions within or adjacent to the watershed.
 - Biological communities – aquatic and terrestrial biota.
 - Water quality conditions – chemical characteristics and pollutants of concern.
- 3) Identify and describe human-caused factors existing outside of the watershed that affect the physical, biological, and chemical attributes of the watershed; (e.g., an upstream dam that regulates flow or modifies water temperature, a source of chemical pollution or turbidity, or degraded aquatic habitat).
- 4) Classify and subdivide the watershed into sub-watersheds to facilitate comparative assessment of existing conditions and prioritization of management prescriptions.
- 5) Identify data gaps that need to be filled to reduce uncertainty in the development of recommendations to address problems.

As a general principle, preservation and protection of intact, functional aquatic habitats should be the first priority (NRC, 1992; NRC, 1996; Beechie and Bolton, 1999; IMST, 2002; Roni et al., 2002). Maintaining high quality habitat is typically much easier than restoring degraded habitat (Roni et al., 2002). As an initial step in the recovery process, high quality areas that maintain healthy and diverse salmonid populations (refugia) should be protected from further human-caused disturbance that degrades habitat or biological conditions (Sedell et al., 1990; Frissell, 1993; Bisson, 1995; Nehlsen, 1997). Relatively intact habitat patches, including reaches, riparian corridors, sub-watersheds, or entire watersheds, that still sustain wild, native salmonid populations are a source of individuals to repopulate other areas (Niemi et al., 1990; Sedell et al. 1990; Frissell, 1993). These protected areas can also serve as “reference areas” or “templates” for restoration of already degraded habitat. These areas can provide fundamental information on natural processes and ecosystem structure, enable evaluation of temporal and spatial changes, and provide a basis for estimating attainable future conditions for restoration (Hughes et al., 1986).



Along with protecting refugia areas, a secondary priority should be to restore a system of habitats connected or adjacent to these protected watersheds. Salmonids have the capacity to recover, if enough favorable habitats are provided (Sedell et al. 1990). Although much salmonid life history diversity has been lost, there is evidence that this diversity can be reestablished as well (Nehlsen et al., 1991; Healey and Prince, 1995; Huntington et al. 1996). Areas with a high potential and opportunity for restoration should be selected, including habitats that historically had high productivity and diversity (Frissell et al., 1993; Nehlsen, 1997; Lichatowich et al., 1999). Restoration activities that emphasize reconnection of high quality habitats should also be strongly emphasized (Roni et al., 2002). Finally, rehabilitation of all habitat types across the entire landscape is needed, including habitats now used by anadromous salmonids and those not used but having potential for use (Roni et al., 2002).

The type of protection and restoration activities can be prioritized according to their likelihood for longevity of response and probability of success. However, the effectiveness of various restoration techniques to increase salmonid production is not always well known (Roni et al. 2002). Inherent variability in ecological data can make it difficult to detect real change. Long-term monitoring data is often needed to evaluate restoration success (Roni et al., 2002). Lack of effective monitoring, including an emphasis on physical rather than biological factors, has limited our understanding of salmonid response to restoration (Roni et al., 2002).

The location of protection and restoration activities can also be prioritized according to their probability of being effective. Prioritization can be conducted at multiple spatial scales such as basin, watershed, and sub-watershed scales. Many criteria may be weighed when prioritizing restoration and preservation of key habitats (NRC, 1992; Bradbury et al., 1995; Li et al., 1995; Nehlsen, 1997; Whidden and Lichatowich, 1999). These criteria include factors such as historical and current productivity (Whidden and Lichatowich, 1999), habitat quality (Li et al. 1995; Nehlsen, 1997; Roni et al., 2002), meta-population structure and dispersal rates (Rieman and Dunham 2000), hydrologic function (Reeves et al., 1995), riparian processes (Beechie and Bolton, 1999), and life history diversity (Nehlsen, 1997).

During prioritization of restoration activities within a watershed, landscape position is an important factor to consider. Some research indicates that restoration should proceed from headwater reaches downstream, largely because human disturbances proceeded from the river mouth into headwater areas (Sedell et al., 1990; Stanford and Ward, 1992; Stanford et al., 1996). As a result, headwater tributaries, often in forested areas and in federal ownership, are the often most intact (Frissell, 1993). Furthermore, successful preservation and restoration of any riverine habitat depends on upstream processes and upland land use (Sedell et al., 1990). Minimizing adverse impacts on small streams and restoring their ecological connections are of critical importance to the improvements downstream (NRC, 1996). Often, the effects of disturbances such as floods are magnified as they progress downstream. In addition, stream restoration without modification of upslope land-uses could be ineffective (Doppelt et al., 1993).

Nevertheless, headwater streams alone are not capable of producing large numbers of salmonids compared with more productive lowland systems (IMST, 2002). In addition, lowland streams and rivers provide connectivity with estuarine and nearshore habitat areas important to the completion of salmonid life cycles (Williams and Thom, 2001). Restoring habitats in lowland streams and rivers, which historically were more productive than headwater tributaries, is critical for increasing life history diversity and production (Sedell et al., 1990; Lichatowich et al., 1999; Nehlsen, 1997; Roni et al., 2002). Protection and restoration activities should be prioritized to focus on critical watersheds, streams, or reaches that have the potential to protect and reestablish core populations at strategic locations within mainstem river systems, estuaries, and tributaries (IMST, 1999; IMST, 2002; Roni et



al., 2002). Protection and restoration activities should be spread across the landscape to include all habitats within a watershed that historically supported salmonids (Healey and Prince, 1995; Williams et al., 1997; IMST, 2002; Roni et al., 2002).

Management strategies can then be developed based on the guiding principles of ecosystem management and the specific results of watershed assessments. Watershed management is continuous and needs a multi-disciplinary, flexible approach. A watershed management framework that supports community partnering, uses sound science, and takes well-planned actions should achieve positive results. Some would argue that we lack sufficient knowledge about the way in which watersheds work to implement an ecosystem-based management strategy. On the contrary, even if no further research were done, the current level of knowledge is adequate to do a much better job of aquatic resource conservation than has been done in the past. In general, watershed protection is more effective than restoration or rehabilitation. Therefore, conservation efforts should move forward and should not be delayed while awaiting “better” data. It must be acknowledged that science will never answer all the questions. Science is a process, not an endpoint. Rather than being paralyzed by the unknown as more ecosystems are degraded or more species are lost, action should be taken to apply the *best available science* toward conservation of the remaining functioning habitat. In conjunction with this conservation action, scientific research should continue so that the level of knowledge improves and *adaptive management* is supported in the long term. This also should reinforce the *precautionary principle*, in that watersheds and aquatic resources should not be managed right to the limit of their functional capacity, but instead should be managed conservatively (Franklin, 1993).



“When we try to pick out anything on earth by itself, we find it hitched to everything else in the universe...”

JOHN MUIR

REFUGIA ASSESSMENT METHODS

The salmonid refugia identification and evaluation process consists of two independent, parallel paths. These mutually supportive, concurrent paths both have the goal of identifying potential salmon refuge habitat and assessing the ecological integrity of that habitat on a quantitative basis. These two complementary paths will be referenced in this report as the *fish-centered approach* and the *landscape-centered approach* (based on the methodology of Frissell et al., 1999). This phased, parallel-path approach is similar to the protocol being used in other parts of the Puget Sound region to identify key salmonid habitat for protection or restoration (IPL, 2001). Figure 9 illustrates the two approaches and the general project flow-path. The fish-centered approach relies heavily on historical records of salmonid utilization, abundance, distribution, and instream habitat conditions, as well as the “local knowledge” of area biologists and natural resource managers. The landscape-centered approach utilizes landscape-scale data and a geographic information system (GIS) to perform assessment and rankings of watersheds within the study area.

The two independent assessment methods provide complementary information that can be used to help frame conservation efforts. The landscape-centered approach yields a relatively coarse-grained, but comprehensive assessment of factors that may influence the ecological integrity of salmonid streams and salmonid populations across the study area. By contrast the fish-centered approach rests on field data or accounts from local biologists on habitat conditions in specific stream segments and salmonid populations in individual stream systems, which is by nature more fine-scaled (e.g. reach level data).

For various reasons, the results of these two analyses generally correspond relatively well. Many areas are recognized as having value under both the landscape and fish-centered approaches. These are likely to be of unqualified conservation value and, where they remain unprotected, should be high priority for immediate conservation action. Areas identified as having relatively high ecological integrity on the landscape scale, but not identified during the fish-centered approach, may have significant ecological data gaps and should be targeted for further analysis and instream surveys to determine the status of their salmon populations.

Areas scoring low in the landscape analysis but high in the fish-centered assessment also merit concern. Some of these may represent populations at risk, destined to future decline as the effects of current and future land-use disturbances become fully realized, unless conservation action is taken quickly. Others may represent critical “hot-spots” of biodiversity where salmon habitat has remained exceptionally resilient or robust even with the cumulative impacts of past human perturbations. In these latter two cases, restoration and protection efforts may be warranted, but to be effective will need to be carefully crafted to fit the local ecological, historical, and social circumstances (Booth et al., 2001).



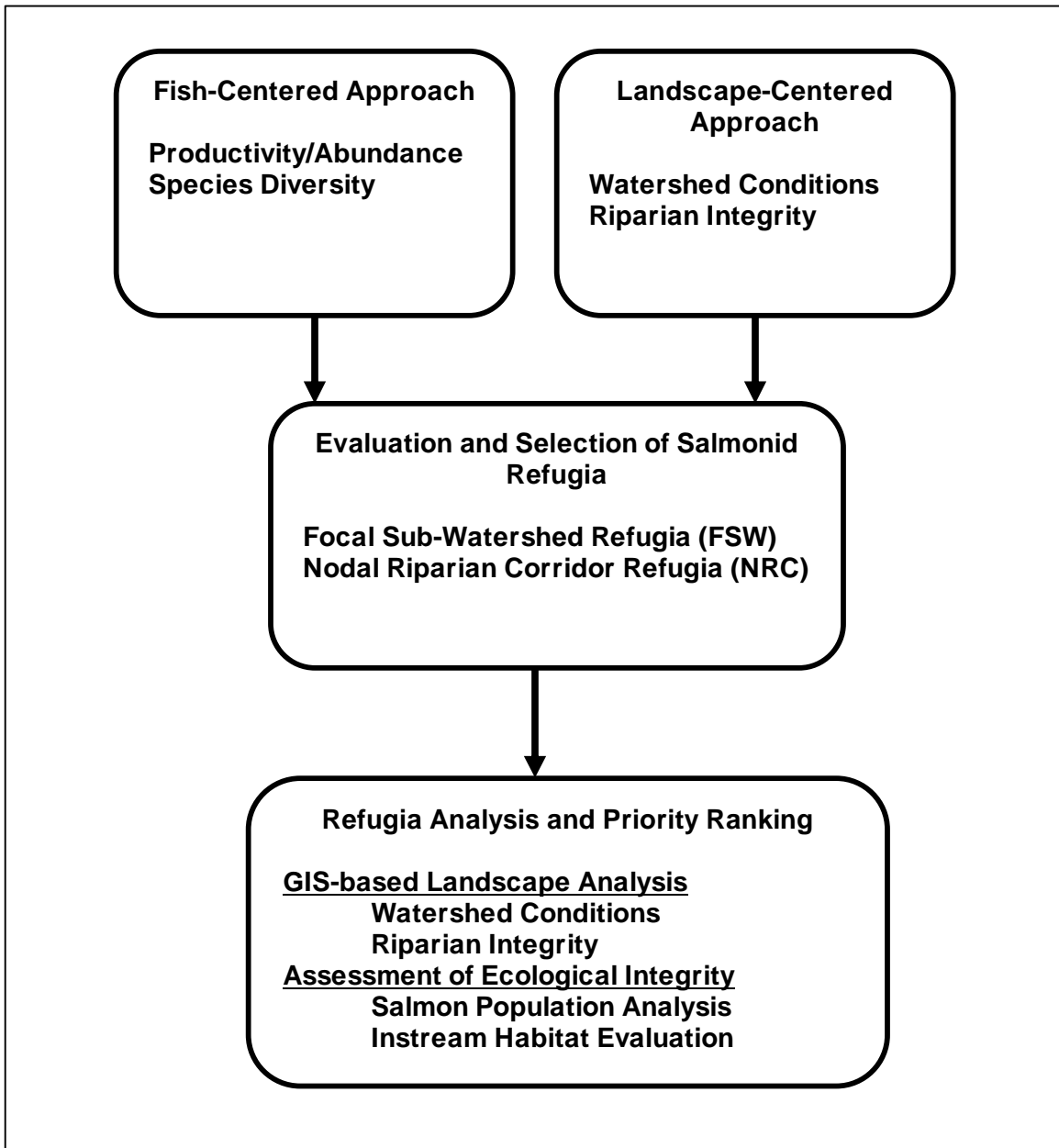


Figure 9: Refugia Project Study Approach and Project Flow Path.



“Conservation is a state of harmony between men and the land. By land it is meant all things on, over, or in the earth. Harmony with land is like harmony with a friend...”

ALDO LEOPOLD, 1949

FISH-CENTERED APPROACH

To identify key watersheds within the study area that are important to native salmonids, the *fish-centered approach* developed by Frissell (1989) was used. In this methodology, rivers, streams, and nearshore areas were evaluated based on the following general attributes:

- Historically productive and/or diverse salmonid resources.
- Large proportion of the historic species assemblage still intact.
- Current utilization by multiple salmonid species.
- Stable, productive populations of native, wild salmonids.
- Significant patches of the properly functioning instream habitat.
- Habitat supporting multiple salmonid life-history stages.
- Functional habitat forming and watershed-ecosystem processes.
- Relatively high level of stream-riparian corridor integrity.
- Potential for recovery of ecosystem structure and function.

During the process of identifying candidate refugia areas as part of this segment of the study, ecological “hot-spots” were also identified (Frissell, 1998 and 1999). These areas include those sub-watersheds, streams, or stream segments that currently support healthy, self-sustaining runs of native wild salmonids due to the convergence of high-quality habitat, accessibility, and watershed conditions supportive of salmonid habitat-forming processes. As can be seen from the above list, stream ecosystems with significant historic populations were also included as refugia candidates, as were ecosystems that currently support highly productive salmonid populations. In addition to streams with a large proportion of relatively intact natural, high-quality salmonid habitat, those with a high potential for rehabilitation were also selected for consideration as refugia.

The focus of this approach was not only ESA-listed species, but instead, a *multi-species approach* was taken so that all salmonid species native to the area were considered in the process. This approach is supported by basic conservation biology theory and by the ecosystem management strategy outlined earlier in this report (Noss, 1983). The refugia selection framework was based on the need for refugia habitat connectivity required to support all salmonid species and all phases of



salmonid life history. Including life history diversity provides a spatial and temporal framework to deal with the complexities of habitat connectivity while allowing the inclusion of integrated populations where they coexist (Frissell, 1998).

As was already discussed, the suite of habitat conditions necessary for the long-term survival of salmonid populations is often referred to as “properly functioning conditions” (PFC). Providing for PFC throughout the study region was a guiding principle in the selection of potential refugia and the foundation of the instream habitat assessment used in this project. The PFC concept is based on the matrix of “pathways and indicators” (MPI) guidelines originated by the National Marine Fisheries Service (NMFS) Habitat Conservation Branch (NMFS, 1996). This MPI guidance was further refined by the NMFS (1999) and the Washington Conservation Commission (WCC, 1999) for use in assessing salmonid habitat conditions for use in the *limiting factors analysis* (LFA) process. The basis for this guidance is that premise that salmonid survival in the wild depends on the proper functioning of certain ecosystem processes, including habitat formation and maintenance. Retaining or restoring functional habitats depends largely on allowing natural processes to increase their ecological function, while at the same time removing adverse impacts of current human activities (Stouder et al., 1997). These habitat-altering actions continue to affect salmonid populations, mostly in a negative manner (NMFS, 1996). PFC is defined as the sustained presence of natural habitat-forming processes in a watershed (e.g. natural hydrologic regime, riparian community succession, LWD recruitment, bedload transport, and channel migration) that are necessary for long-term persistence of species through the full range of environmental variation. PFC constitutes the physical habitat component of the salmonid biological requirements (NMFS, 1999).

The fish-centered approach utilizes available information on current salmonid habitat conditions, species diversity, salmonid distribution data, salmon productivity data, and other related data. Available salmonid data related to fish utilization, abundance, and diversity was obtained from federal, state, local, and tribal agencies. In addition, all available quantitative habitat assessment data was obtained from the same sources. Examples of data on salmonid distribution and species diversity include the historical references such as the Washington Department of Fish and Wildlife (WDFW) *Stream Catalog* (WDFW, 1975) and current sources such as the on-going Washington Conservation Commission (WCC) “Limiting Factors Analysis” (WCC, 2001, 2002, & 2003). Instream habitat survey data are also available for several streams within the study area, although some of this data is somewhat dated and is often based on methodologies that are no longer in use or are not in a standardized format. All physical habitat data were analyzed in relation to current standards and PFC guidelines.

There has been a significant amount of work done by USFWS and WDFW habitat biologists, habitat biologists from local Native American Tribes and the Point-No-Point Treaty Council (PNPTC), Kitsap Land Trust, Jefferson County Land Trust, the Jefferson Conservation District (JCD), the Kitsap Conservation District (KCD), citizen groups such as the Hood Canal Salmon Enhancement Group (HCSEG), North Olympic Salmon Coalition (NOSC) and Wild Olympic Salmon (WOS), and the technical team of the Hood Canal Coordinating Council (HCCC) on identifying and evaluating water resources in the region for potential conservation and restoration projects. This report builds on these efforts as summarized in the *Salmon Habitat Recovery Strategy for the Hood Canal and Eastern Strait of Juan de Fuca* (HCCC, 2001).

To verify and update recorded information, numerous resource professionals were interviewed as a primary source of information on fish distribution, population status, and habitat conditions (see Table 1).



- Peter Bahls, Habitat Biologist, Northwest Watershed Institute (NWI), Portland OR.
- Lee Bode, Habitat Biologist, Hood Canal Salmon Enhancement Group (HCSEG), Belfair WA.
- Ginna Correa, Washington Conservation Commission (WCC), Hood Canal Limiting Factors Analysis (LFA) Project Coordinator, Olympia WA.
- Jennifer Cutler, Northwest Indian Fisheries Commission (NWIFC) Geographic Information System (GIS) Database Manager, Olympia WA.
- Monica Daniels, Kitsap County Salmon Restoration Coordinator.
- Jeff Davis, WDFW Habitat Biologist, Port Orchard WA.
- Marty Ereth, Skokomish Tribal Habitat Biologist, Belfair WA.
- Christopher Frissell, University of Montana, Kalispell MT.
- Glenn Gately, Jefferson Conservation District (JCD).
- Jeff Heinis, Skokomish Tribal Habitat Biologist, Belfair WA.
- Ron Hirschi, Habitat Biologist, Port Townsend WA.
- Randy Johnson, WDFW Fisheries Biologist, Port Angeles, WA.
- Thom Johnston, WDFW Habitat Biologist, Discovery Bay WA.
- Ted Labbe, Port Gamble S'Klallam Tribal Habitat Biologist, Hansville WA.
- Al Latham, Jefferson Conservation District (JCD).
- Paula Mackrow, North Olympic Salmon Coalition (NOSC).
- Mark McHenry, US Forest Service (USFS) Habitat Biologist, Quilcene WA.
- Byron Rot, Habitat Biologist, Jamestown S'Klallam Tribe, Port Townsend WA.
- Doris Small, WDFW Habitat Biologist, Port Orchard WA.
- Steve Todd, Point-No-Point Treaty Council (PNPTC) Habitat Biologist, Hansville WA

Table 1: Salmonid Refugia Project Informational Interview Sources

SALMONID DISTRIBUTION MAPPING

Establishing the presence or absence of salmonids within a watershed can be problematic. A stream may have historically supported an assemblage of salmonid species, but one or more of those species may no longer utilize that stream due to natural habitat changes or because of human influences. These changes can affect all phases of the salmon life history (see Figure 1). For example, a passage barrier such as a poorly designed culvert or water-diversion dam could impact adult migration. The loss or degradation of spawning habitat can cause a contraction of spawning distribution. Rearing habitat can also be lost or degraded such that a stream segment no longer supports juvenile life-stages of particular species. A good example of this is the lack of instream large woody debris (LWD), which has particularly adverse impact on juvenile coho survival during the freshwater rearing life-stage (Maser et al., 1988). If any of these changes have occurred over the past 50-100 years, there may be no formal record of historic salmonid utilization. Few streams have long-term fish abundance or distribution data. In addition, salmonids are known to sometimes make only short-term, temporary use of streams, stream segments, or habitat patches based on changes in climatic or environmental conditions. Furthermore, there can be seasonal or year-to-year changes in habitat suitability and utilization based on fluctuations in flow regime or due to other environmental factors. Obviously, spatial and temporal variations in habitat conditions can complicate the verification of salmonid distributions and utilization.

The refugia project utilized the most current quantitative instream habitat data and *Limiting Factors Analysis* (LFA) information to develop baseline conditions for the streams, wetlands, and watersheds under consideration for refugia status. The LFA process has led to the development of the most comprehensive fish distribution maps currently available. These maps were used, along with the *WDFW Stream Catalog* (WDFW, 1975) as the basis for species distribution determination in this project. Because of the inherent uncertainties involved with salmonid distribution and utilization within natural ecosystems, a conservative approach to mapping salmonid distribution was taken for this project. As a starting point, records documenting current salmonid distribution and historic anadromous fish utilization were compiled (including known extirpated populations). Sources of this



data included LFA and WDFW records, Tribal records, data from the on-going Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP), WDFW Stream-Net data, WDFW Priority Habitat & Species Maps (2001), and other verifiable sources. These records were then combined with information on salmonid distributions gained during interviews with local aquatic biologists to determine the *known* or *historic* salmonid distributions in regional streams. Appendix B contains the current LFA fish distribution maps for the study region.

Species and life-stage habitat suitability criteria were used to identify the *potential* fish distributions. These areas are those with no definitive record of fish use, but conform to species and life-stage habitat criteria. These areas were evaluated based on their potential as salmonid habitat. For this project a modified version of the SSHIAP salmonid habitat criteria was used to identify *potential* salmonid habitat in study area streams (see Tables 2 & 3). This method is based on geomorphologic principles, a hierarchical view of stream systems, and standard stream delineation theory (Frissell et al., 1986; Montgomery and Buffington, 1993; SSHIAP, 1999). The standard Washington Watershed Administrative Unit (WAU) protocols are used as background for the SSHIAP delineation. This identifies the stream within the standard Water Resource Inventory Area (WRIA). Most standard stream assessment protocols delineate streams into segments based on gradient, valley-channel confinement, and habitat type (i.e. streams, wetlands, and lakes). This delineation technique is designed, in part, to recognize the inherent capacity of the stream to support a variety of salmonid species. For the refugia study a “gradient-confinement” matrix was developed to identify potential spawning and rearing habitat for each salmonid species (Tables 2 & 3). In the absence of definitive information on salmonid utilization (current or historic), the criteria in these Tables were used to determine *potential* salmonid species utilization.

In summary, this project took a more conservative approach than other parallel efforts (e.g. LFA) to identification of salmonid habitat within the study region. For the purposes of refugia assessment, current, historic, and potential salmon habitat were considered as potential refugia areas. In addition, watersheds were considered to support a species if any portion of that watershed was utilized during any life history stage. This approach is based on the precautionary principle outlined earlier in this report. While this is a conservative approach it is nonetheless scientifically sound in that water resources within a watershed are interconnected hydrologically, chemically (water quality), and biologically. Appendix B contains details on the species distribution of native salmonids in study area streams used in this project.

ESA-LISTED SPECIES CONSIDERATIONS

Currently Puget Sound chinook (PSC) and Hood Canal Summer chum (HCSC) are “listed” under the Endangered Species Act (ESA). Although no special consideration was given to these two species within this report, the status of these “threatened” species is worth noting. There are chinook salmon, spawning naturally in some Puget Sound streams, are not presently assigned to what the NMFS Technical Review Team has defined as an independent chinook population (NMFS, 2001). These streams are not considered “primary spawning habitat”, but are still utilized at certain times by wild chinook (NMFS, 2001). There are two main reasons why naturally spawning chinook may not have been assigned to a population. First, spawning adults are known to occur intermittently in certain streams, spawning in groups of tens to hundreds of fish in some years and none in others (NMFS, 2001). A plausible biological explanation for intermittent occurrence of chinook in some streams is that those adults are part of a larger independent population that uses “secondary” or alternative spawning habitats only during years of high abundance or favorable habitat conditions. The streams that intermittently harbor spawning adults could contain fish from more than one independent population. The locations of the streams relative to the primary spawning areas of independent populations dictate how many populations might contribute fish to these “spillover” spawning areas (NMFS, 2001). Second, it is possible that some streams presently containing chinook



never supported naturally spawning chinook historically. In many of these instances, the origin of the naturally spawning chinook currently present is most likely due to strays from nearby hatchery production (NMFS, 2001). Some streams may therefore contain chinook solely because of the presence of a hatchery, and they would not have represented historical (primary) chinook spawning habitat. As more information becomes available, it is possible that chinook in some intermittently used streams can be clearly associated with one or more populations, and their assignment will change to reflect their association with a particular population. Critical habitat and PSC outside of currently recognized independent population areas may still be important for overall Puget Sound ESU viability (NMFS, 2001).

In summary, there are only a few streams in the study area that could be considered as true chinook streams in the classic sense. However, this supposes that streams can be classified as “chinook streams” or “coho streams” for management purposes. This sort of classification scheme is really not supported by the ecosystem management perspective, which looks at streams from a more holistic point of view. The dynamic nature of ecosystems and salmonid populations does support a more flexible approach to classifying streams in relation to salmonid utilization. Several streams in the study area do support limited populations of Puget Sound chinook (PSC), but for the most part, chinook currently found in the study are believed to be wild or hatchery strays. However, many study area streams have gradient and channel characteristics that would support chinook spawning and rearing, but are limited in their chinook productivity by water flow. Some scientists believe that a mean annual flow of approximately 20 CFS is required to support a self-sustaining chinook population, but this has not been scientifically verified as yet. However, based on what we do know of salmonid population dynamics, it is highly likely that chinook would stray into “marginal” habitat (streams with adequate, but not ideal habitat), especially during higher rainfall or flow periods. In addition, in years when returning runs were especially large, it is also likely that more chinook would seek out alternative spawning areas in these “marginal” streams. It cannot be stated conclusively that this behavior is not critical to long-term survival of PSC (NMFS, 2001). Perhaps these small chinook streams also provide some unique refuge habitat during specific environmental disturbances that may make them “critical” habitat. Alternatively, these less than ideal chinook streams may also be very important from a genetic diversity perspective. In addition to spawning adults, juvenile chinook have been observed in the estuaries of several small streams throughout the Hood Canal (Hirschi, 2002). This habitat utilization may be related to a specific life-history adaptation of some populations of PSC. More information is needed to determine the true ecological value of smaller streams for chinook and other salmonid species.

Finally, there are several streams within the study area that likely supported historic runs of chinook as well as other salmonids not currently found in those watersheds. Based on the information found in this study, several potential refugia watersheds were identified as supportive of chinook. A scientifically conservative approach to salmonid protection necessitates this action. In addition to PSC, several study area streams also support Hood Canal Summer Chum (HCSC). Regional biologists have identified these streams and rivers as being of special importance to the overall salmon recovery effort (PNPTC & WDFW, 1999). It should be noted, however, that ESA-listed species were given no additional weight in the overall refugia model. The basis for this study was a multi-species, ecosystem approach and therefore all native salmonids were treated equally.



Channel Confinement	Gradient					
	<2%	2-4%	4-8%	8-12%	12-20%	>20%
Unconfined (VW>4CW)	Coho Chum chinook Steelhead Cutthroat	Coho Chinook Steelhead Cutthroat	Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A
Moderately Confined (2CW<VW<4CW)	Coho Chum chinook Steelhead Cutthroat	Coho Chinook Steelhead Cutthroat	Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A
Confined (VW<2CW)	Coho chinook Steelhead Cutthroat	Coho Chinook Steelhead Cutthroat	Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A

Note: VW = Valley Width and CW = Channel (bankfull) Width

Table 2: Potential Salmonid Rearing Habitat (modified from SSSLAP).

Channel Confinement	Gradient					
	<2%	2-4%	4-8%	8-12%	12-20%	>20%
Unconfined (VW>4CW)	Chum Cutthroat	Coho Chinook Steelhead Cutthroat	Coho Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A
Moderately Confined (2CW<VW<4CW)	Chum Cutthroat	Coho Chinook Steelhead Cutthroat	Coho Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A
Confined (VW<2CW)	Chum Cutthroat	Coho Chinook Steelhead Cutthroat	Steelhead Cutthroat	Steelhead Cutthroat	Cutthroat	N/A

Note: VW = Valley Width and CW = Channel (bankfull) Width

Table 3: Potential Salmonid Spanning Habitat (modified from SSSLAP).

Note: Pink and Sockeye are not included in these Tables due to lack of historic information and their generally low historic presence in the study area. Pink have similar habitat requirements as chum and chinook. Sockeye require a lake for rearing. See Appendix B for details on salmonid habitat requirements.



SALMONID DIVERSITY

Salmonid diversity was measured as the number of salmonid species that currently, historically, or could potentially utilize a given watershed. The maximum number of species that could be associated with a watershed is eight (8). The majority of the streams in the study area are relatively small in watershed size. These streams generally support coho and chum salmon, as well as cutthroat trout. Many of the larger streams and rivers in the study region, especially those draining to the Hood Canal, support other salmonid species, including chinook and steelhead. Appendix B contains details on the species distribution of native salmonids in study area streams used in this project.

SALMONID PRODUCTIVITY

As was the case with mapping salmonid distribution, evaluating and quantifying *productivity* of each watershed was also quite difficult. Productivity, as used in this report, is a measure of the relative mean annual abundance of salmonids produced by each stream system and does not refer to harvest levels associated with each stream. However, productivity does relate to the idea that large numbers of salmon returning to their natal streams does influence the overall productivity of the ecosystem in the form of marine-derived nutrient (MDN) inputs (Cederholm and Peterson, 1985; Cederholm et al., 1989; Willson and Halupka, 1995; Willson et al., 1998; Lichatowich, 1999; Cederholm et al., 2000; Lichatowich et al., 2000) This measure was added to the refugia model to account for the fact that larger watersheds generally, but not always, have the potential to produce larger numbers of salmonids (HCCC, 2001).

As was stated earlier, very few streams have long-term salmonid abundance data. Furthermore, seasonal or long-term changes in habitat suitability and utilization based on human impacts or other fluctuations in environmental factors can greatly influence productivity. Complicating this assessment are the cumulative impacts of harvest and hatchery operations. For this project, all available (WDFW and Tribal) salmonid abundance data was used to evaluate productivity. Based on this data and discussions with regional/local biologists, a “productivity rating” was assigned to each watershed being considered for refugia status. The criteria used to assign these productivity scores is shown in Table 4. Basically, watersheds were classified as high productivity, moderate productivity, or low productivity habitat based on historic and current habitat conditions, as well as watershed. The “raw” scores from the salmonid diversity and productivity scoring criteria were then converted to “synthetic” scores for use in the refugia model (see GIS

<p>5 = Natural, unimpaired system currently at or near historically or potentially high level of productivity. No natural barrier(s) that limit access or productivity and no man-made access barriers or hatchery influences.</p> <p>4 = Historically or potentially a high productivity system, but currently producing at a reduced level due to a combination of human impacts, including degraded habitat, man-made migration barriers, and/or hatchery influences.</p> <p>3 = Moderate productivity system, naturally limited by small watershed size and/or natural barrier(s). Currently at or near historic or potential level of productivity. No man-made access barriers or hatchery influences.</p> <p>2 = Moderate productivity system, naturally limited by small watershed size and/or natural barrier(s). Currently producing at a reduced level due to a combination of human impacts, including degraded habitat, man-made migration barriers, and/or hatchery influences.</p> <p>1 = Low productivity system, due to one or more of the following:</p> <ul style="list-style-type: none"> ● Natural barrier(s) ● Small watershed size ● Man-made barrier(s) ● Hatchery influences ● Degraded habitat conditions

Table 4: Salmonid Productivity Criteria



modeling methods section for details). Appendix B of this report contains both the diversity and productivity scores for each watershed and stream segment that was evaluated.

SALMONID HABITAT ASSESSMENT

A variety of instream habitat assessment protocols are in use in the PNW (see Table 5). Some of these “stream survey” guidelines are more quantitative than others. The Northwest Indian Fisheries Commission (NWIFC), Timber, Fish, and Wildlife (TFW) Ambient Monitoring Protocols are generally considered the “benchmark” for quantitative instream habitat assessment in the PNW (Schuett-Hames et al., 1999). Most of the tribes and government agencies in the region utilize these protocols or a modified version of the TFW protocols (see Table 6). Several government agencies have their own habitat assessment techniques, but most of these are at least as rigorous as the TFW Ambient Monitoring Protocols (i.e. USFWS, WDFW, and Washington Trout). Based on our primary study objective of identifying salmonid refugia and prioritizing them for conservation action, no extensive TFW-level habitat assessments were undertaken, but when available, TFW data were utilized in the assessment process.

For this project, all available quantitative habitat data was obtained for the most recent ten-year period. This data was evaluated for quality in comparison to the TFW standards. Data that was of sufficient scientific quality was used to score candidate refugia areas. Data that was not comparable to the TFW standards was used only after “qualitative” field surveys were conducted to verify the data or discussions with local habitat biologists indicated that the data reflected current conditions. In all cases, even when the most recent quantitative (TFW-level) data was available, local habitat biologists were consulted to verify the accuracy and applicability of the data. In addition, all candidate refugia were “field-checked” to ensure a representative assessment of habitat conditions for the stream was obtained.

- 1) *Timber, Fish, and Wildlife (TFW) Ambient Monitoring Manuals* (Schuett-Hames et al., 1999).
- 2) *Aquatic Habitat Indicators and their Application to Water Quality Objectives within the Clean Water Act*. US-EPA-910-R-99-014 (Bauer and Ralph, 1999).
- 3) *Fish and Fish Habitat Standard Inventory Procedures Handbook*. USDA, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report #346 (Overton et al., 1997).
- 4) *Rapid Bio-assessment Protocols*. US-EPA-841-B-99-002 (Plafkin et al., 1999).
- 5) *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. USDA, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report (Platts et al., 1983).
- 6) *Monitoring Wilderness Stream Ecosystems*. USDA, Forest Service, Rocky Mountain Research Station, General Technical Report (Davis et al., 2001).
- 7) *Monitoring Guidelines to Evaluate the Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*. US-EPA-910/9-91-001 (MacDonald et al., 1991)
- 8) *Stream Inventory Level II Handbook*. USDA, Forest Service Region 6 (USDA-FS, 1994).
- 9) *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*. USDA, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report #245 (Harrelson et al., 1994).
- 10) *Applied River Morphology*. (Rosgen, 1996).
- 11) *Stream-keepers Field Guide. Adopt-a-Stream Foundation* (Murdoch et al., 1996).
- 12) *Stream visual Assessment Protocol*. USDA, Natural Resource Conservation Service, Technical Note 99-1 (USDA-NRCS, 1999).
- 13) *Monitoring Urban Streams: Strategies and Protocols for Humid-Region Lowland Systems*. University of Washington, Center for Urban Water Resources Management. (Scholz and Booth, 1998).
- 14) *Aquatic Habitat Assessment: Common Methods*. American Fisheries Society (AFS, 1999).
- 15) *Aquatic Inventory Project: Training Materials and Methods for Stream Habitat Surveys*. Oregon Department of Fish and Wildlife (ODFW, 1999).
- 16) *Nature mapping for Fish and Streams*. Washington Department of Fish and Wildlife (WDFW, 1997).

Table 5: PNW Salmonid Habitat Assessment Protocols.



Protocol Name and Number	Protocol Citation
1. TFW Method Manual for the Large Woody Debris Survey	Shuett-Hames, D., A. E. Pleus, J. Ward, M. Fox, and J. Light. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-004. DNR #106. March. 33 pp.
2. TFW Method Manual for the Habitat Unit Survey	Pleus, A. E., D. Shuett-Hames, and L. Bullchild. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-003. DNR #105. June. 31 pp.
3. TFW Method Manual for the Salmonid Spawning Gravel Composition Survey	Shuett-Hames, D., R. Conrad, A. Pleus, and M. McHenry. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-001. DNR #101. March. 48 pp.
4. TFW Method Manual for the Salmonid Gravel Scour Survey	Shuett-Hames, D., A. E. Pleus, and D. Smith. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-008. DNR #110. December. 41 pp.
5. TFW Method Manual for the Salmonid Spawning Habitat Availability Survey	Shuett-Hames, D., A. E. Pleus, and D. Smith. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-007. DNR #119. November. 32 pp.
6. TFW Method Manual for the Reference Point Survey	Pleus, A. E., D. Shuett-Hames. 1998. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-008. DNR #002. May. 31 pp.
7. TFW Method Manual for Wadable Stream Discharge Measurement	Pleus, A. E. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-009. DNR #111. June. 13 pp.
8. TFW Method Manual for the Stream Temperature Survey	Pleus, A. E. 1999. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-005. DNR #107. June. 35 pp.
9. TFW Method Manual for Stream Segment Identification	Pleus, A. E., D. Schuett-Hames. 1998. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-98-001. DNR #103. May. 39 pp.
10. TFW Riparian Stand Survey	Smith, D. 1998. Northwest Indian Fisheries Commission. Olympia, WA. September. 12 pp.

Table 6: Timber, Fish, and Wildlife (TFW) Habitat Assessment Protocols.



The most current quantitative habitat data for each stream is summarized in the watershed description for each salmon stream, which can be found in Appendix A of this report. A detailed discussion of salmonid habitat requirements is also included in Appendix C. Based on the limited TFW-level data available and the requirements of this project, only the following “key” physical habitat parameters were utilized:

- 1) Large Woody Debris (LWD) quantity and quality.
- 2) Pool (rearing) habitat quantity and quality.
- 3) Riffle (spawning) habitat quantity and quality.
- 4) Canopy cover, shade, and temperature data.
- 5) Stream channel geomorphology data.

Based on a combination of field surveys conducted as part of this project, available quantitative habitat data, and input from local habitat biologists, each stream segment was then scored using a standard scoring criteria (see Figure 10 and Appendix C). This habitat assessment scoring criteria is based on the NMFS Habitat MPI Matrix discussed earlier (NMFS, 1999). This is basically the same matrix used in the LFA process (WCC, 1999). When no quantitative habitat data were available, the qualitative approach alone was adopted to get a basic, “reconnaissance-level” assessment of instream habitat conditions. Local habitat biologists were also consulted for their input. Like the salmonid diversity and productivity scores discussed earlier, the “raw” scores from the qualitative habitat scoring criteria were then converted to “synthetic” scores for use in the refugia model (see GIS modeling methods section for details). The salmonid habitat scores and scoring criteria are included in Appendix C to this report. The qualitative habitat assessment score sheet used in this project is shown below (Table 7). A brief description of the habitat assessment parameters included in this index is included as well.



Physical Habitat Assessment Qualitative Scoring Criteria	
1. Migration Access	This habitat parameter is used to assess the relative accessibility of the stream or stream segment to all species and life-stages of salmonid (juvenile and adult). The metric is graded based on the percentage of usable salmonid habitat that was blocked by artificial barriers such as culverts, dams, and water diversion structures.
2. Floodplain Conditions	This parameter is based on the degree of alteration of the natural floodplain and channel migration zone (CMZ). The metric also included an evaluation of off-channel wetlands as well as floodplain areas.
3. Spawning Habitat Quantity	This parameter measured the quantity of riffle habitat suitable for spawning throughout the stream or stream segment. A balance of rearing habitat (pools) and spawning habitat (riffles) is generally the optimum condition (see NMFS/WCC Habitat matrix in Appendix C).
4. Spawning Habitat Quality	This parameter measured the quality of spawning habitat (riffles) located within the stream or stream segment. This evaluation focused on the quality of spawning gravels as well as the level of fine sediment deposition and substrate embeddedness. The degree to which boulders, cobble, or gravel are surrounded by fine sediment indicates suitability of the stream substrate as habitat for benthic macroinvertebrates and for salmonid spawning and egg incubation. Embeddedness is evaluated by visual observation of the average degree to which larger particles are surrounded by sediment. A variety of substrate material sizes are also typically desirable. The presence of cobble and gravel in PSL streams is generally considered the most desirable habitat. Bottom substrate is evaluated and rated by observation of dominant substrate.
5. Rearing Habitat Quantity	This parameter measured the quantity of rearing (pool) habitat suitable for juvenile salmonid rearing throughout the stream or stream segment. A balance of rearing habitat (pools) and spawning habitat (riffles) is generally the optimum condition (see NMFS/WCC Habitat matrix in Appendix C).
6. Rearing Habitat Quality	This parameter measured the quality of rearing habitat (pools) located within the stream or stream segment. Pool quality is determined by a number of variables including residual pool depth (RPD) and pool type. A complex and diverse array of pool types is generally desired, including deep holding pools, plunge pools, scour pools, backwater pools, side-channel pools, off-channel wetland pools, dam pools, and beaver ponds. Pool quality is also evaluated based on the quantity and quality of cover on the pool. Large Woody Debris Quantity = The quantity of large woody debris (LWD) within the active stream channel and especially in and around pools is observed and tallied for this parameter.
7. Large Woody Debris Quantity	The quantity of large woody debris (LWD) within the active stream channel and especially in and around pools observed and tallied for this parameter.
8. Large Woody Debris Quality	In addition to the abundance of LWD, the complexity and diversity of LWD is also evaluated. Large (diameter > 0.5 m) LWD (especially coniferous) is highly desirable for its stability and longevity.



9. Streambank Stability	The degree of streambank erosion and streambank stability is rated by observing existing or potential detachment of soil from the upper and lower stream bank and its potential movement into the stream. Steeper banks are generally more subject to erosion and failure, and may not support stable vegetation. Streambank vegetation is also a major factor contributing to streambank stability. Bank soil is generally held in place by plant root systems and perennial vegetation. Erosional protection may also be provided by boulder, cobble, or gravel material, as well as LWD. An estimate of the coverage density of streambank vegetation provides a good indication of streambank stability.
10. Streambed Stability	These parameters relate to the destruction of instream benthic habitat resulting from excessive scour and/or aggradation. Characteristics to observe are scoured substrate and degree of siltation in pools and riffles. Scouring results from high velocity flows. The potential for scouring is increased by channelization and higher stormwater runoff volumes. Deposition and scouring result from the transport of sediment and may be an indication of larger scale watershed degradation. Deposition and scouring is rated by estimating the percentage of an evaluated reach that is scoured.
11. Channel Form	Stream flow relates to the ability of a stream to provide and maintain a relatively stable aquatic environment within the normal range of flows typical of a stream system. The quality of the aquatic habitat can therefore be evaluated, in part, in terms of a velocity and depth relationship. Combinations of slow/fast and deep/shallow flows zones are desirable. Habitat quality is reduced in the absence of one or more of these flow categories. Complexity and diversity are the keys. The character of a natural stream channel includes sinuosity, shape, and floodplain area. Channelization decreases stream sinuosity, thereby increasing stream velocity and the potential for scouring. Upstream impacts may cause channel widening and or incision due to higher peak flows and altered sediment loads.
12. Riparian Extent	The width of the riparian buffer and continuity of the riparian corridor (# of breaks for roads, utility lines, and other stream-crossings) is estimated by visual observation. A relatively wide, continuous riparian corridor is desirable. In general, one site-potential tree height (SPTH) is used as a gage of an ecologically functional buffer width.
13. Riparian Quality	The successional stage or stand-age is estimated by visual observation. A mature forest is more desirable than a clear-cut or young riparian forest.
14. Dominant Riparian Vegetation	The dominant riparian vegetation within 50 meters of the stream is observed and evaluated. Coniferous or mixed (coniferous and deciduous) forest is desired. Brush, shrubs, or grass are less desirable.
15. Canopy Cover	Typical small PSL streams are well shaded. This naturally dense canopy cover provides excellent temperature regulation, keeping PSL streams cool in the summer and insulated in the winter. A qualitative estimation for canopy cover was made based on visual observation.

Table 7: Physical Habitat Assessment Qualitative Scoring Criteria



REFUGIA PROJECT HABITAT ASSESSMENT SCORE SHEET			
STREAM: _____		REACH: _____	
DATE: _____			
<u>Habitat Parameter</u> (Score)	<u>Optimal</u> (4)	<u>Good</u> (3)	<u>Fair</u> (2)
1. Migration Access (Artificial Barriers)	All Habitat Accessible	<10% Blocked	10-20% Blocked
2. Floodplain Conditions (Habitat & Connectivity)	Natural Floodplain	<25% Area Altered or Lost	25-50% Area Altered or Lost
3. Spawning Habitat Quantity (% Riffles)	40-60% Balanced P-R	30-40% Few Riffles	20-30% Sparse Riffles
4. Spawning Habitat Quality (% Fines & Embeddedness)	<10% Cobble/Gravel	10-15% Gravel/Sand	15-20% Sand/Gravel
5. Rearing Habitat Quantity (% Pools)	40-60% Balanced P-R	30-40% Few Pools	20-30% Sparse Pools
6. Rearing Habitat Quality (Depth & Cover)	Frequent Deep Pools w/Cover	Some Deep Pools and Good Cover	Few Deep Pools Little Cover
7. LWD Quantity (Large Woody Debris)	Abundant Complex	Moderate Spotty	Sparse Infrequent
8. LWD Quality (Large Woody Debris)	Coniferous Large (Key)	Mixed Medium	Deciduous Small
9. Streambank Stability (Bank Erosion)	Stable (>90%) Fully Vegetated	75-90% Patchy Vegetation	Stable Sparse Vegetation
10. Streambed Stability (Scour and Fill)	Stable Natural Changes	Localized Scour and Fill	Degradation Aggradation
11. Channel Form (Shape/Sinuosity)	Natural Diverse/Complex	Flow-impacted Meandering	Flow Incised or Constrained
12. Riparian Buffer Width (w/in SPTH)	Wide/ Intact Continuous	Some Encroachment	Narrow Fragmented
13. Riparian Quality (Stand-Age)	Mature Forest > 20" dbh	Mixed Forest 12-20" dbh	Young Forest <12" dbh
14. Dominant Vegetation (w/in 50m)	Conifer Dominated	Mixed Conifer/Deciduous	Deciduous Dominated
15. Canopy Cover (Temperature Control)	Dense/Shaded Natural Temp	Filtered Sunlight Periodic Hi Temp	Sparse/Broken Frequent Hi Temp

Total Score: _____ (Minimum of 15 / Maximum of 60)

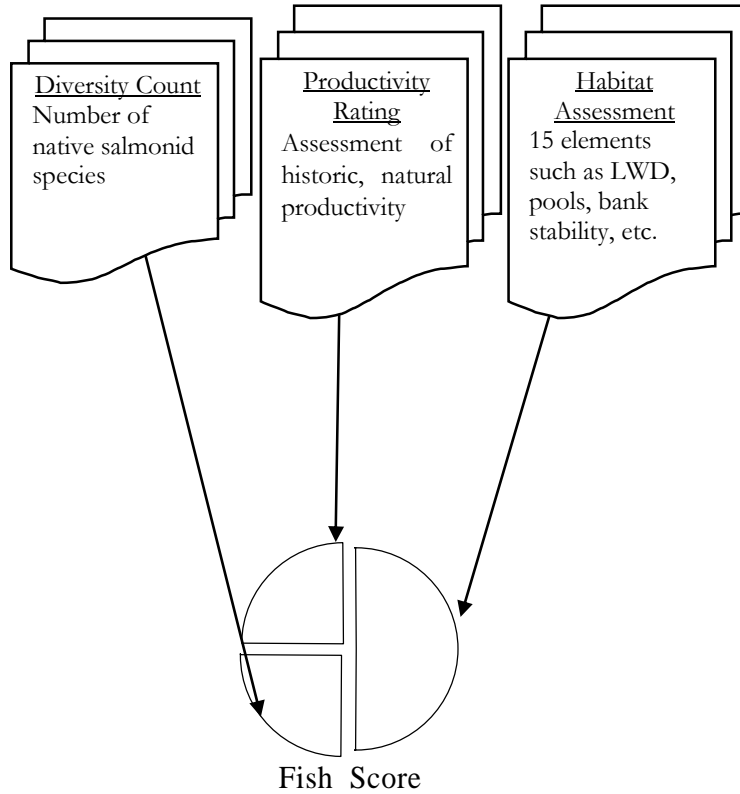
Note: Habitat Parameters derived from NMFS Properly Functioning Conditions (PFC) Matrix

Figure 10: Refugia Project Habitat Assessment Score Sheet



In summary, the fish-centered approach of this project includes the following components:

- 1) Salmonid Diversity Score
- 2) Salmonid Productivity Score
- 3) Salmonid Habitat Quality Score



These three independent scores are combined within the overall refugia model with the landscape metrics to produce a final refugia score. The landscape model components are described in detail in the following section.



“Nature, the earth herself, is the only panacea.”

HENRY DAVID THOREAU, 1859

LANDSCAPE-CENTERED APPROACH

The landscape-centered approach utilizes geographic information system (GIS) data to evaluate landscape-level parameters or GIS *map layers* in all watersheds and nearshore areas. Research in the PSL eco-region and elsewhere has shown that salmonid habitat and ecological integrity decline as landscape-level conditions are altered by human activities (Beechie et al., 1994; NRC, 1996; Richards et al., 1996; May et al., 1997; Horner and May, 1999; Booth et al., 2001). In many cases, the decline in salmonid abundance and diversity in the PNW, along with habitat quality can be directly related to the degree of watershed modification (Pess et al., 2002). During the “landscape” phase of the refugia project, GIS data was used to independently evaluate all watersheds for conditions that would be supportive of native salmonid populations or the processes that maintain salmonid habitat. The landscape-centered approach also served to verify potential refugia identified by the fish-centered approach, identify possible refugia that may have been overlooked by the fish-centered approach, and to make an initial quantitative evaluation of each candidate refugia on a landscape scale. The results of this assessment are based on analysis of multiple digital coverages.

The landscape approach is based on the principles of *landscape ecology*. Landscape ecology is based on the premise that landscape-level patterns at many spatial scales influence ecosystem structure and processes (Noss, 1983; Noss and Cooperrider, 1994; Richards et al., 1996; Abbruzzese and Leibowitz, 1997; Forman, 1997; Naiman and Bilby, 1998). This “ecological signature” of land-use and land-cover (LULC) patterns consists of landscape characteristics on spatial scales that correspond to specific ecological processes. In short, the structure of the landscape determines, in large part, the functionality of the ecosystems encompassed by its boundaries. In the case of native salmonid populations, genetic and life history diversity varies with spatial and temporal patterns of their aquatic habitat. Pacific salmonids have evolved within the framework of the natural disturbance regimes of the PNW and their habitats are also formed by those same natural disturbance patterns (Stouder et al., 1997). Therefore, a multi-scale assessment of LULC characteristics and landscape patterns is essential to understanding ecosystem function.

To understand why landscape-level analysis is a necessary component in salmonid habitat assessment, a graphical representation or *conceptual model* is often useful. A conceptual model expresses ideas about components and processes deemed to be important in an ecosystem, and our current understanding of how the components and processes are connected (Gentile et al., 2001). They are also useful in conveying information to decision-makers and the general public. The basic framework of conceptual model used in this project is shown in Figure 11.



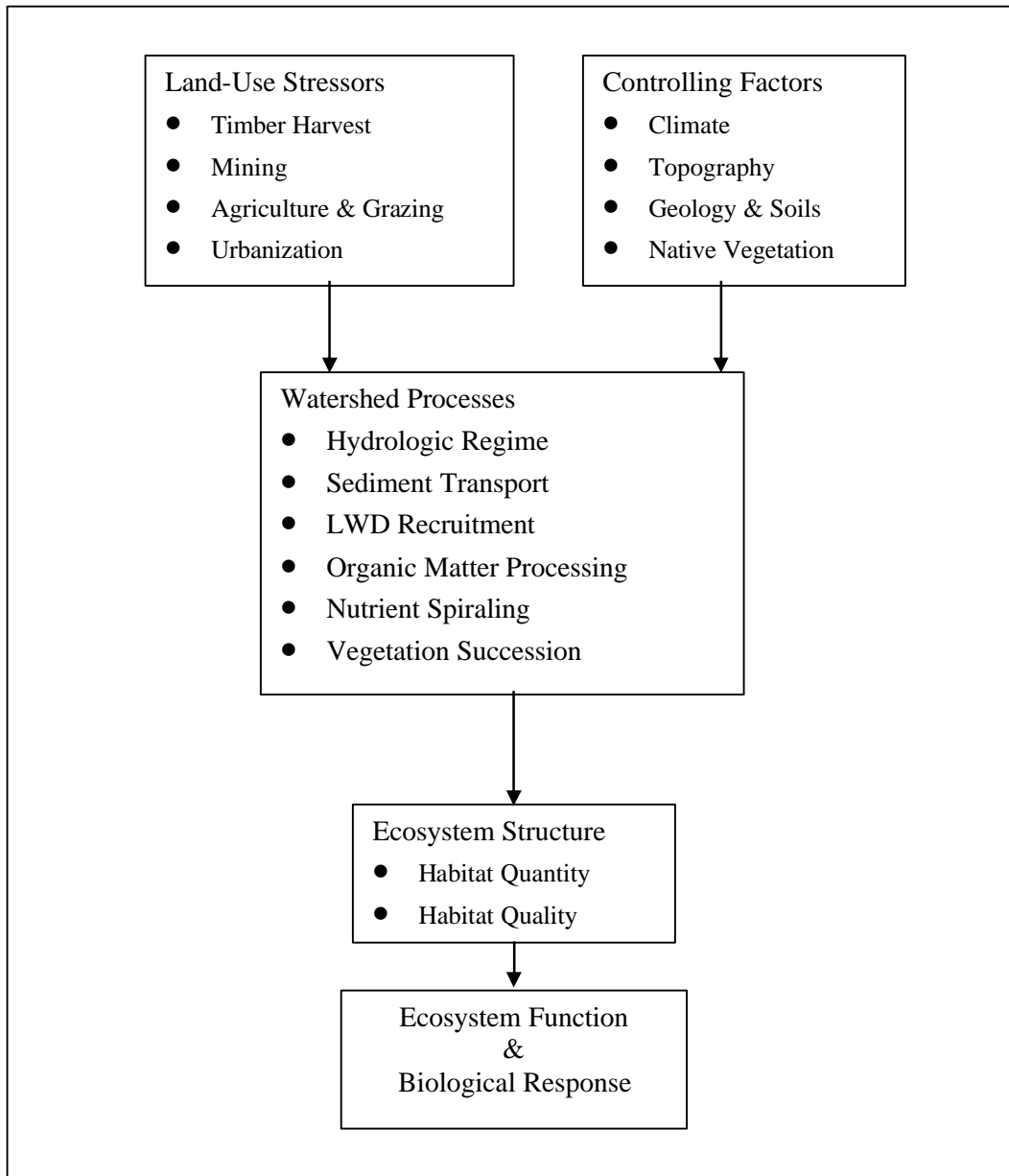


Figure 11: Conceptual Model Framework

The conceptual model approach suggested here is based on an ecosystem-based design. As was discussed earlier, salmon are adapted to local environmental conditions (including associated temporal and spatial variability). In most watersheds, a combination of natural landscape controlling factors and land-uses (human stressors) affect ecosystem processes (e.g., hydrology, sediment transport, riparian function, etc.), which shape the local habitat characteristics (ecosystem structure) on which salmon rely. Salmon and other biota respond to these habitat conditions (quantity and quality), as does overall ecosystem function. Thus an approach to habitat recovery that focuses on preserving and/or restoring ecosystem processes should provide quality salmon habitat over the long term. An advantage of this approach is that it is not species-specific and could provide benefits to the entire ecosystem. This may help to reduce conflicting management objectives and actions when



dealing with multiple natural resources. Each type of land-use activity (e.g. timber harvest, agriculture, and urbanization) tends to have a different level of affect on aquatic ecosystems, both in terms of the severity of degradation and the persistence of the cumulative impacts (Figure 12). These inherent differences often require different management and recovery strategies.

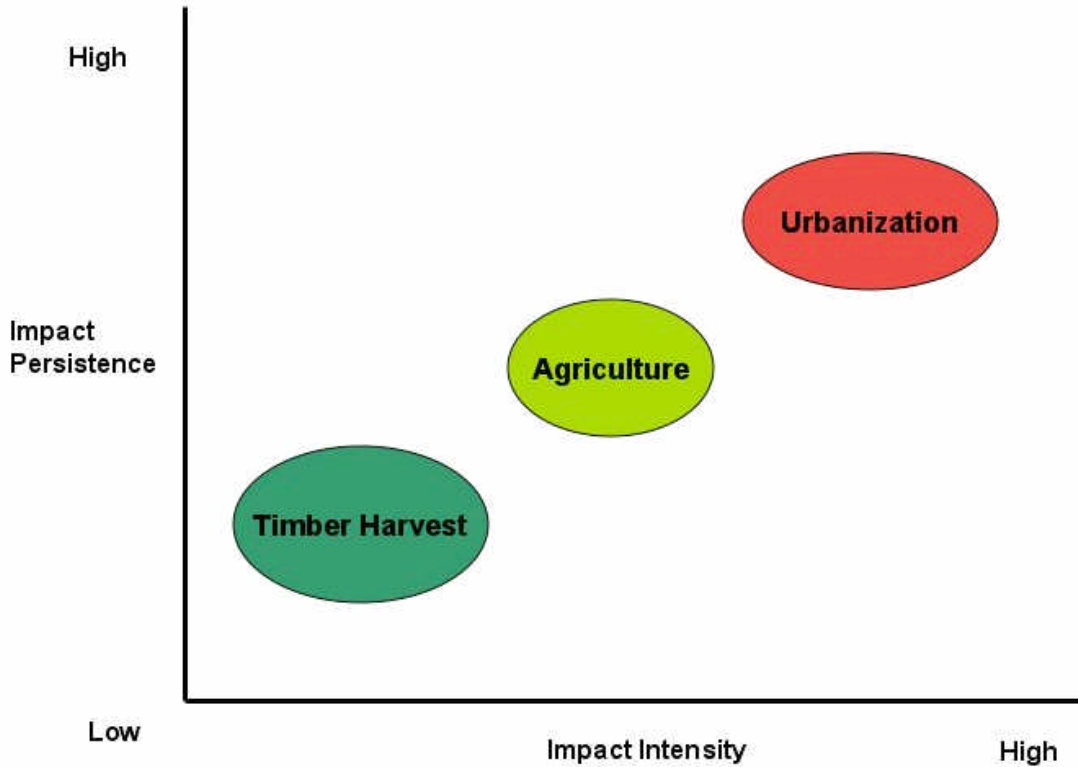


Figure 12: Land-Use Impact Matrix.

Habitat changes resulting from human stressors (e.g. land-use activities) can alter the abundance, productivity, spatial structure, and life history diversity of individual salmon populations (Beechie et al., 2003). At the landscape scale, watershed-based analyses can be conducted to quantify relationships among landscape attributes, land uses, and effects on salmon. Comparisons between historic (reference or optimal) and current habitat conditions can help assess potential productivity, diversity, and viability of salmon populations. Currently in the PNW, the most accepted methods include GIS-based analyses that predict the amount of habitat potentially available to salmonids and the Ecosystem Diagnosis and Treatment (EDT) model (Beechie et al., 2003). Both methods typically utilize data relevant to a specific watershed. GIS-based analyses rely on relationships derived from empirical data and expert opinion combined in a landscape-level model, whereas EDT relies on expert opinion, existing survival estimates, and biological rules in a mathematical model (Mobrاند et al., 1997).

In the GIS model used in this report, land use practices associated with habitat losses can be correlated with salmon abundance to identify potential causes for decline. This information can then be used to identify the causes of habitat loss or degradation in the watershed, as well as to identify actions that can be taken to restore habitat-forming processes to their natural range. In addition, model results can be used to identify areas of high habitat quality sufficient to sustain viable



populations. Results can also suggest areas where further or more detailed research should be conducted at the watershed level to gain a more complete understanding of factors affecting salmon viability. The use of a GIS-based landscape model to evaluate ecological conditions in watersheds has been used extensively in the PNW and other regions (Strittholt et al., 1999; Frissell et al., 2000; Staus and Strittholt, 2001; Pess et al., 2002). The methodology used in this project is also similar to the framework outlined by Hyman and Leibowitz (2000 & 2001).

Map layers considered for inclusion in the salmonid refugia model were selected to best represent those watershed factors considered to influence salmonid habitat conditions and stream utilization in the study region (May et al., 1997; Horner and May, 1999; Beechie et al., 2003). All of the map layers considered are ecologically significant in that they either directly or indirectly influence physical and/or biological conditions in streams or nearshore areas. In addition to ecological relevance, map layers were considered for inclusion in the model only if adequate data coverage existed for the entire study area. The selection of habitat map layers to measure at the reach scale was based on known relationships between those habitat features (e.g. LWD, pools, etc.) and salmonid utilization, diversity, and productivity (May et al., 1997). The selection of landscape-level map layers used in this project is based on empirical relationships between specific watershed characteristics and physical habitat conditions, as well as known watershed characteristic linkages with habitat-forming processes (Abbruzzese and Leibowitz, 1997; May et al., 1997; Beechie et al., 2003). In general, these landscape-scale relationships fall into three scales of analysis. These are the *watershed, riparian, and nearshore scales*. Tables 8, 9, and 10 list the potential landscape indices considered for use in this project. The final selection process for map layers used in the GIS refugia model is discussed in the following section.



Landscape Map layer	Definition	Potential GIS Data Source
Total Forest Cover	The percent of area with native forest cover.	Landsat 7 TM
Mature Forest Cover	The percent of area with mature or old growth forest cover.	Landsat 7 TM
Coniferous Forest Cover	The percent of area with conifer-dominated forest cover.	Landsat 7 TM
Deciduous Forest Cover	The percent of area with deciduous-dominated forest cover.	Landsat 7 TM
Mixed Forest Cover	The percent of area with mixed forest cover. Mixed forests have both conifers and deciduous tree species with neither type dominating.	Landsat 7 TM
Forest Clear-cut Cover	The percent of area clear-cut.	Landsat 7 TM
Wetland Area	The percent of area designated as wetlands per the NWI.	National Wetlands Inventory (NWI)
Developed Land-Use	The percent of area with anthropogenic/developed land-use. Anthropogenic alterations are represented by numerous categories.	Landsat 7 TM
Agricultural Land-Use	The percent of area with row-crop or grazing land-use.	Landsat 7 TM
Total Impervious Area (%TIA)	Calculated using Standard %TIA conversion factors for the region.	Landsat 7 TM
Mass Wasting/Steep Slopes	The percent of area with steep slopes. Steep slopes are defined as greater than 30%.	DEM based on USGS topography
Road Density	The ratio of road length (km) to the watershed area.	U.S. Department of Commerce Bureau of the Census Geography Division Tiger Roads
Drainage Density	Natural drainage density consists of the length of stream channel normalized by watershed area. Developed drainage density includes roads, stormwater conveyances, and other anthropogenic alterations to the environment that provide drainage routes to streams.	U.S. Department of Commerce Bureau of the Census Geography Division Tiger Roads Layer. Washington Department of Natural Resources (WDNR) Hydro-layer.
Basin Slope	Average Watershed Terrain Slope	DEM based on USGS topography
Soil Type	Soil Type Data	NRCS Soil Survey Data
Hydrologic Potential	Basin Area multiplied by Mean Annual Rainfall	DEM based on USGS topography and precipitation data

Table 8: Watershed landscape map layers considered for inclusion in the Refugia Model.



Landscape Map layer	Definition	Potential GIS Data Source
Riparian Forest Cover	The percent of riparian buffer area with forest cover.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Wetland Cover	The percent of riparian buffer area classified as wetlands.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM National Wetlands Inventory (NWI)
Riparian Coniferous Forest Cover	The percent of riparian buffer area with conifer-dominated forest cover.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Deciduous Forest Cover	The percent of riparian buffer area with deciduous-dominated forest cover.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Buffer Mixed Forest Cover	The percent of riparian buffer area with mixed forest cover. Mixed forests have both conifers and deciduous tree species with neither type dominating.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Buffer Shrub Cover	The percent of riparian buffer area with shrub cover.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Buffer Grass Cover	The percent of riparian buffer area with grass or turf cover.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Riparian Land Use	The percent of riparian buffer area with anthropogenic/developed land-use. Anthropogenic alterations are represented by numerous categories.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Stream Crossing Density	The ratio of the number of times a road, forest road, railroad, abandoned railroad, or trail crosses any stream within the total length of stream channel.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM U.S. Department of Commerce Bureau of the Census Geography Division Tiger Roads Layer.
Floodplain Modification	The area of floodplain modified by anthropogenic activities.	Washington Department of Natural Resources (WDNR) Hydro-layer. Landsat 7 TM
Barriers to Salmonid Migration	The number of anthropogenic barriers to salmonid migration. Anthropogenic barriers include culverts, dams, or water diversion structures that prohibits adult or juvenile salmonids from migrating either upstream or downstream.	Washington Department of Natural Resources (WDNR) Hydro-layer. Washington Department of Fish and Wildlife (WDFW) Data.
Length of Streams Blocked	Length of Type 1, 2, and 3 streams blocked by a salmon migration barrier relative to the total length of Type 1, 2, and 3 (WAC 222-16-031) streams within the watershed.	Washington Department of Natural Resources (WDNR) Hydro-layer. Washington Department of Fish and Wildlife (WDFW) Data.

Table 9: Riparian landscape map layers considered for inclusion in the Refugia Model.



Landscape Map layer	Definition	Potential GIS Data Source
Nearshore Habitat Type	The percent of shoreline area of each habitat type.	DNR Shore-Zone Inventory
Nearshore Modifications	The percent of shoreline area with anthropogenic alterations such as bulkheads or shoreline armoring.	DNR Shore-Zone Inventory County Records
Density of Docks, Piers, Wharfs, floats, and Boat Ramps	The ratio of the number of docks, piers, wharfs, and boat-ramps to the total length of shoreline.	DNR Shore-Zone Inventory County Records
Number of Marinas	Number of commercial or private marinas with boat maintenance facilities and/or sewage pump-out stations.	DNR Shore-Zone Inventory County Records
Aquatic Vegetation	The percent of nearshore area with native aquatic vegetation (eel grass, kelp, etc.).	DNR Shore-Zone Inventory
Shoreline Riparian Forest Cover	The percent of shoreline riparian buffer area with native forest cover.	Landsat 7 TM

Table 10: Nearshore landscape map layers considered for inclusion in the Refugia Model.



“There are some who can live without wild things and some who cannot. Like winds and sunsets, wild things were taken for granted until progress began to do away with them. Now we face the question whether a still higher standard of living is worth its cost in things natural, wild, and free”

ALDO LEOPOLD, 1949

GIS LANDSCAPE MODEL

A landscape-level (GIS) model measuring a variety of watershed, riparian, instream, and nearshore salmonid habitat factors was created in order to identify and rank the best salmonid habitat within the study area. The spatial data input, storage, analysis, modeling and output capabilities of GIS were used to display and rank salmonid refugia in the study area. Refugia ranks were computed via a model comprising all known and measurable criteria relating to salmonid habitat quality. Data were gathered from existing datasets, analyzed and then combined. The model was developed using concepts from habitat suitability modeling and multi-criteria decision analysis (MCDA) and implemented within the GIS framework (Malczewski, 1999).

Habitat suitability modeling is a formal process of identifying locations that are best suited for life and growth of a particular species and is often carried out in a GIS environment. The GIS environment is well suited to analysis of landscape patterns (Wickham and Norton, 1994). These GIS-based models can also be designed to produce a ranked set of sites from most suitable to least suitable. Common components include a set of standardized input data, weighting schema accounting for the relative importance of each dataset, and an algorithm to combine the weights and data (frequently of a weighted linear summation type). Because suitability is often a matter of opinion, but is measured in a systematic way, the suitability scores can be both subjective and quantitative. Many habitat suitability models use Landsat data and other satellite derived imagery as base data for the models. A review of satellite imagery products and their usefulness in environmental models can be found in Klemas (2001).

The MCDA method, first developed as an alternative to traditional neo-classical planning techniques, is a structured method of reaching a goal with an assigned decision-maker and a specified set of evaluation criteria (Chankong and Haimes, 1983; Carver 1991; Malczewski, 1999). It also involves a set of alternatives (e.g. refugia) and possible outcomes (rankings). The algorithms, decision-making techniques and methods of deriving standardized maps and weighting schemes of MCDA contribute to the success of a habitat suitability model. Using the terms of MCDA, the refugia model is considered a single objective, multi-attribute analysis. In this case, the decision maker is a scientist who represents the composite of available knowledge on freshwater and nearshore salmonid habitat in the study area, through the use of current literature, best available scientific data, and the inputs of local habitat biologists.

The East Jefferson and Kitsap County refugia models described here are adapted from the original Kitsap County Refugia Study (Kitsap County, 2000). Some additions and refinements to the original methodology were incorporated into the existing algorithm to produce the current study. Additional criteria were added to more accurately reflect habitat conditions. These were made possible by the acquisition of data that were not available for the original Kitsap study such as flood-prone zones and aquatic vegetation. The methods of computing some of the map layers were refined to reflect newer data and additional knowledge of habitat conditions. An update to the



Kitsap County refugia model was conducted concurrently to the Jefferson County refugia model and map layers for both studies were combined before being converted to synthetic scales. Results are reported for refugia and nearshore zones in both study areas.

HABITAT SUITABILITY MODELING

Habitat suitability modeling (HSM) techniques and case studies are covered in both the natural resources journals and the GIS literature. Examples of these models are numerous. In the United Kingdom, for instance, suitability modeling has been used to determine appropriate sites for radioactive waste disposal. The power of automating suitability modeling within a GIS was illustrated by the thousands of potential locations that were evaluated through automated GIS routines. The waste disposal study also showed that suitability modeling within a GIS provides a rational, objective and non-biased approach to determining the best sites for an activity (Carver, 1991).

A common suitability modeling technique is the use of proportions as a basis for quantifying land cover influence in a watershed or riparian zone. In Illinois, where urban and agricultural land uses dominate the state, prioritization of the remaining forest and wetland areas for preservation has received considerable attention. Because many of the intact natural areas are concentrated in riparian zones, a recent study sought to analyze the potential habitat within riparian zones in order to rank them for conservation. Using multiple land cover datasets including Landsat as well as wetland and watershed boundaries, grassland, forest and mixed successional vegetation types were identified. The proportion of each land cover within a buffer distance of the streams was calculated and from these a score of relative habitat quality was assigned (Iverson et al., 2001).

Another HSM application, incorporating an aquatic habitat component, conducted by NOAA in Casco and Sheepscot Bays, Maine, involved development of a HSM for several aquatic species. The study integrated the environmental variables of temperature, salinity, depth and substrate into a suitability algorithm that combined the four variables in a manner consistent with their collective roles in the aquatic species' habitat. The authors concluded that the model results were generally successful in delineating habitat for the selected species. Furthermore, maps produced from the NOAA model corresponded closely to sampling data and expert knowledge of the species distributions (Brown et al., 2000).

Some suitability models venture beyond the computation of feasible sites to include the ranking of all the suitable sites and/or quantifying the effects of model inputs on the resultant sites. For example, a ranked habitat suitability model was created by the Florida Marine Research Institute to identify and delineate fish habitats off the coast of Florida. The resultant predicted distribution map broke fish habitat into four categories: optimum, high, medium and low (Rubec et al., 1998). In another example, a habitat suitability model was constructed to determine the effects of individual habitat factors on the overall quality of wild pig habitat in California. This wild pig model quantified the influence of environmental factors (such as hunting) on the suitability of habitat and species abundance (Davis et al., 1997). HSM outputs such as these are sometimes referred to as a Habitat Suitability Index (HSI). A multitude of HSI models have been developed for freshwater and marine fish species (Brown et al., 2000; Rubec et al., 1998; Malczewski, 1999; Vadas and Orth, 2001).

The set of alternatives (sites) identified through HSI modeling can also be reduced and/or ordered using MCDA techniques (Malczewski, 1999). MCDA is not generally thought of as a core capability of GIS. It can, however, be implemented within a GIS through the use of algorithms applied to the GIS databases as well as applying MCDA techniques to decision making processes (Malczewski, 1999). This incorporation of HSM and MCDA within a GIS is an effective method of



minimizing the trade-offs and uncertainties involved in the modeling process (Carver, 1991; Jankowski, 1995; Malczewski, 1999; Store and Kangas, 2001).

The benefit of embedding MCDA in GIS is that it allows for the evaluation of various land areas on the basis of multiple criteria (Carver 1991). This could be accomplished solely within a GIS through an iterative habitat suitability analysis by reducing the set of alternatives in a step-by-step manner. The reduction would be achieved by applying Boolean logic at each step. In this way, an area would be accepted or rejected based on an ever-tightening threshold value. The longer an area remains "accepted", the higher its overall rank. Imprecise threshold values, however, could lead to loss of information or error propagation (Store and Kangas 2001). A less problematic and more rapid approach is the use of MCDA techniques (such as weighted linear summation) within the GIS (Jankowski 1995). An example of this integration is illustrated in the following red squirrel habitat analysis.

The Mount Graham red squirrel habitat evaluation criteria (e.g., maximize number of conifers, maximize number of large trees) were identified and the corresponding data obtained (e.g., land cover, tree diameter at breast height). The habitat criteria and data selection were based on expert opinion and then combined into a suitability model. Various MCDA techniques were used including a method of quantifying the expert knowledge of red squirrel habitat factors in order to produce meaningful criteria measurement data (criterion maps). The results of the final model were found to accurately predict habitat use when compared with data on actual habitat use (Pereira and Duckstein, 1993).

Prioritization of entire watersheds, as opposed to individual habitat units, is also feasible with the integration of habitat suitability modeling, GIS and MCDA. For example, in Gujarat, India, a model with the objective of minimizing excess runoff to prevent poor crop yields was needed (Sharma et al., 2001). By combining a GIS with the two modeling techniques mentioned above, this model could evaluate entire watersheds based on multiple criteria such as soil erosion and low moisture. Once the areas of concern were identified, alternative land use and management practices were input into the model to quantify their potential impact. The result of this alternative-future analysis showed a decrease in runoff from the pre-conservation value (Sharma et al., 2001). In another example a GIS-based model was used in Pennsylvania to predict fish distributions based on landscape-level indices (Argent et al., 2003).

The model examples described above could have been accomplished through a habitat suitability modeling process without the incorporation of MCDA. Without the decision-making techniques and data standardization protocols of MCDA, however, they may not have been as successful (Hopkins, 1977). The US-EPA Research Station in Corvallis Oregon has also developed a framework for prioritizing landscape features such as wetlands using a GIS-based MCDA-HSM model (Abbruzzese and Leibowitz, 1997; Hyman and Leibowitz, 2000; Hyman and Leibowitz, 2001).

An example of the use of MCDA and GIS-based techniques in evaluating salmon habitat in the PNW is the NMFS study of coho salmon in the Snohomish River of western Washington (Pess et al., 2002). This study used a GIS-based spatially explicit statistical model to correlate land-use and land-cover (LULC) variables (forest cover, wetland occurrence, local geology, agricultural land-use, and others) with measures of coho salmon abundance. The study found that median adult coho densities were 1.5 to 3.5 times as dense in forest-dominated sub-watersheds as they were in sub-basins where rural, urban, and agricultural land-uses dominated the landscape (Pess et al., 2002). This study and the others discussed above demonstrate the utility of GIS-based MCDA methods for identification, assessment, and prioritization of salmonid habitat for conservation and restoration activities.



REFUGIA GIS MODEL

One of the key components of the salmon recovery strategy in the PNW is the development of a better quantitative understanding of the relationship between watershed conditions, instream habitat, and salmonid population levels (Holtby and Scrivener, 1989). There have been numerous methods developed for relating salmonid population response to changes in instream habitat conditions (Reeves et al., 1989). However, until recently there have been only a few studies that have quantified the relationship between watershed-scale characteristics (LULC), salmonid habitat, and salmonid population diversity and abundance (Beechie et al., 1994; May et al., 1997; Montgomery et al., 1999; Pess et al., 2002). This project builds on those previous studies and expands the process using GIS and the MCDA techniques described above.

Multi-criteria decision analysis (MCDA) requires that habitat suitability modeling (HSM) begin with a definition of the objective and associated attributes. From there, criterion maps are produced that reflect the measurement of each attribute over the spatial extent. The terms "evaluation criteria" and "objectives" are used interchangeably. The terms "raw data" and "attributes" are also equal as are "criterion maps" and "map layers." The process of identifying evaluation criteria, determining relevant raw data, creating criterion maps, standardizing the criterion maps and combining them within a weighted algorithm constituted the habitat suitability model.

Two habitat types were evaluated: *freshwater* habitat (watershed-based) and *nearshore* (including estuarine) habitat. The overall goal of the refugia study was to quantify the suitability of each watershed and nearshore unit within the study area with respect to salmonid habitat quality. Watershed units and nearshore zones were evaluated separately to reflect the different habitat requirements of each. For example, flood-prone zone analysis was only relevant to the freshwater habitat while shoreline modifications were only relevant to the nearshore areas.

Objectives were developed using expert knowledge of salmon habitat requirements retrieved from recent literature and local expertise. They describe the components of salmon habitat in their idealized state. The datasets involved in measuring the extent to which each objective is achieved are referred to as attributes. Multiple attributes are sometimes needed in order to measure an objective. Whether or not an objective is measured through the use of one attribute or the combination of attributes, each objective is ultimately represented with a single map layer that is then input into the mathematical function. Because map layers have differing levels of effect on habitat quality, they are combined through a modified additive weighting algorithm rather than simply added together. The output of the map layer algorithm is a map of relative salmon habitat quality that then fulfills the goal identified for the model. See Figures 13 and 14 for illustrations of the relationships among goals, objectives and attributes in both the freshwater and nearshore models. Figures 15 and 16 illustrate the freshwater and nearshore model flow-paths.

The decision-maker (in the case of the refugia project, an ecologist familiar with the study region) chose the evaluation criteria to best represent those landscape-level watershed and nearshore factors that influence salmonid habitat conditions in the Puget Sound lowland eco-region. They are based on current research on the cumulative impacts of development on aquatic ecosystems in the region and the sum of local knowledge of salmon habitat requirements. A total of 20 *objectives* were identified: 15 freshwater criteria and 5 nearshore criteria (see Tables 11 & 12). Every effort was made to ensure that the evaluation criteria, as a group, would provide a comprehensive measure of salmonid habitat quality.

The objectives can be split up into four categories, watershed, riparian, instream, and nearshore (see Tables 11 & 12). All of the objectives are ecologically significant in that they either directly or indirectly affect physical and/or biological conditions within the stream or nearshore ecosystem.



Watershed-level criteria included hydrologic potential, total impervious surface area, agricultural land-use, road density, wetlands, urban development (including rural, suburban, and urban land-uses), and native forest cover. Many of these criteria have been identified as having a significant influence on watershed conditions and salmonid habitat (Beechie et al., 1994; May et al., 1997; Pess et al., 2002). Some map layers are measures of human influence (i.e. total impervious area, agricultural land-use, and roads). Some of the map layers selected also represent the natural landscape conditions found in the Puget Sound lowland eco-region prior to human disturbance (i.e. forest cover, wetlands, and riparian quality).

Riparian-based evaluation criteria included measures of riparian fragmentation (road and utility line crossings), riparian corridor extent/width, riparian vegetation quality, floodplain modification, salmonid migration barriers (blocking culverts, dams, and hatchery weirs), and mass wasting potential (slope stability). These measures represent measures of the *Riparian Integrity* of the stream ecosystem (May and Horner, 2000). Instream factors included salmonid diversity, salmonid productivity, and instream habitat quality. The instream factors represented directly measured stream conditions and other effects on population dispersal. The nearshore objectives of shoreline modifications, small boating related structures, marinas, marine vegetation and nearshore riparian vegetation comprise the known impacts to salmonid habitat in the nearshore zone.

In summary, the selection of the freshwater and nearshore *metrics* included in the model was based on the ecological significance of the map layers and their influence on the processes that create and maintain salmonid habitat. The selected metrics also represent multiple spatial scales of influence with regard to salmonid habitat quality (watershed, riparian, and nearshore) as well as influence on multiple life stages (migrating, spawning, and rearing). All watersheds and nearshore areas within Kitsap and East Jefferson Counties were evaluated using the selected GIS model metrics. The following section discusses the details of the scoring process. Based on the overall model scores, refugia areas were selected and classified.



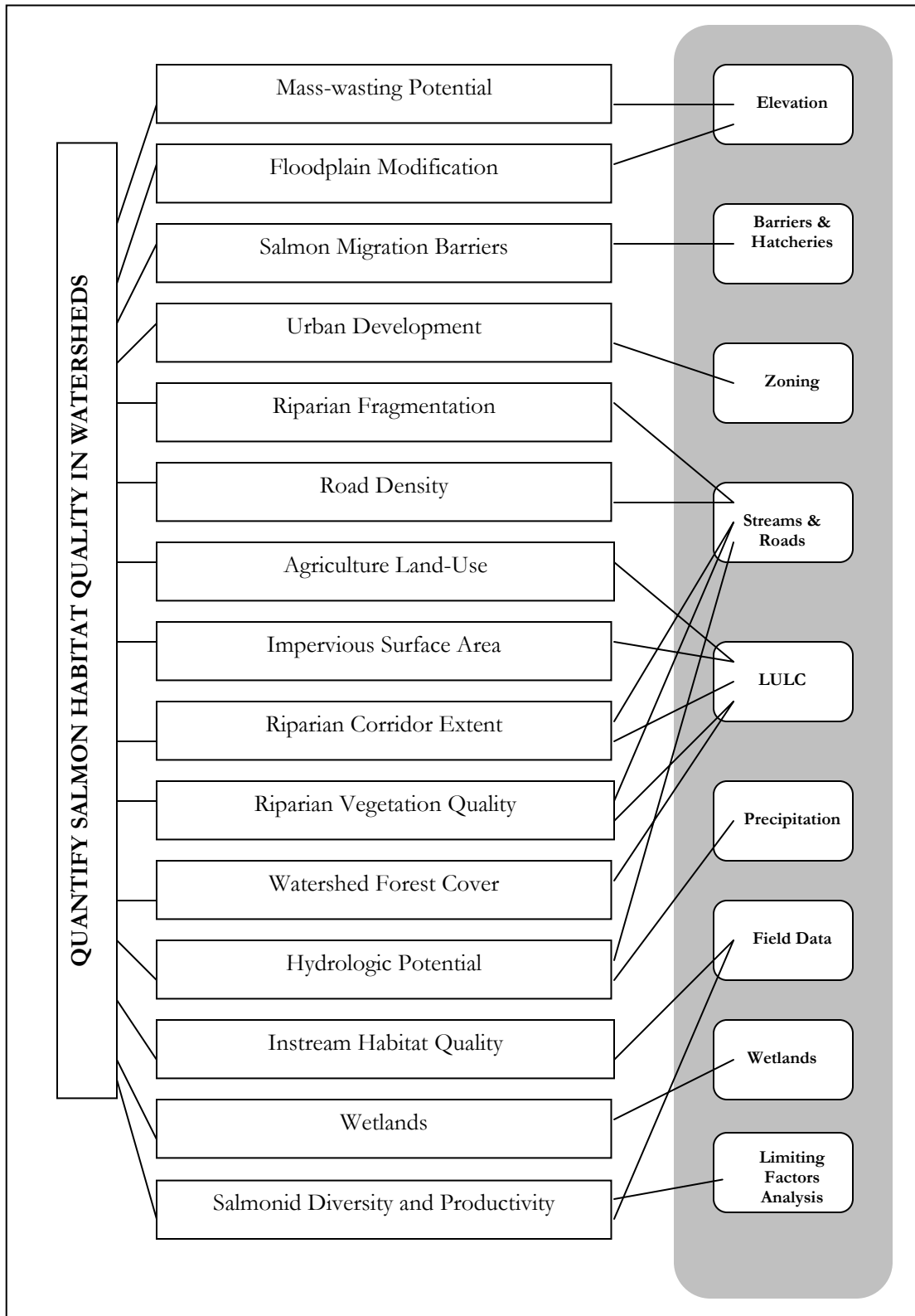


Figure 13: Freshwater Model Landscape Goals, Objectives, and Attributes.



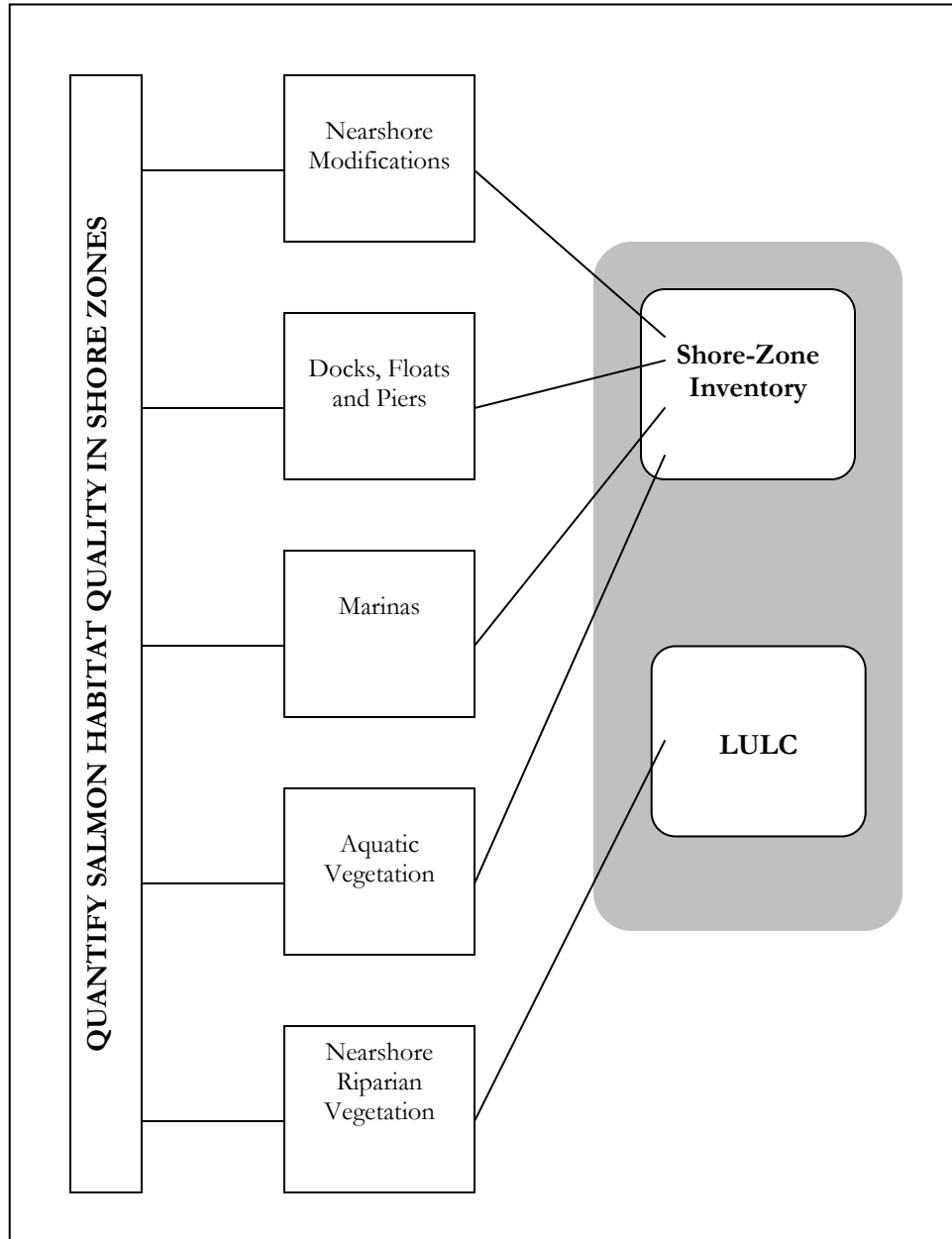


Figure 14: Nearshore Goals, Objectives, and Attributes.



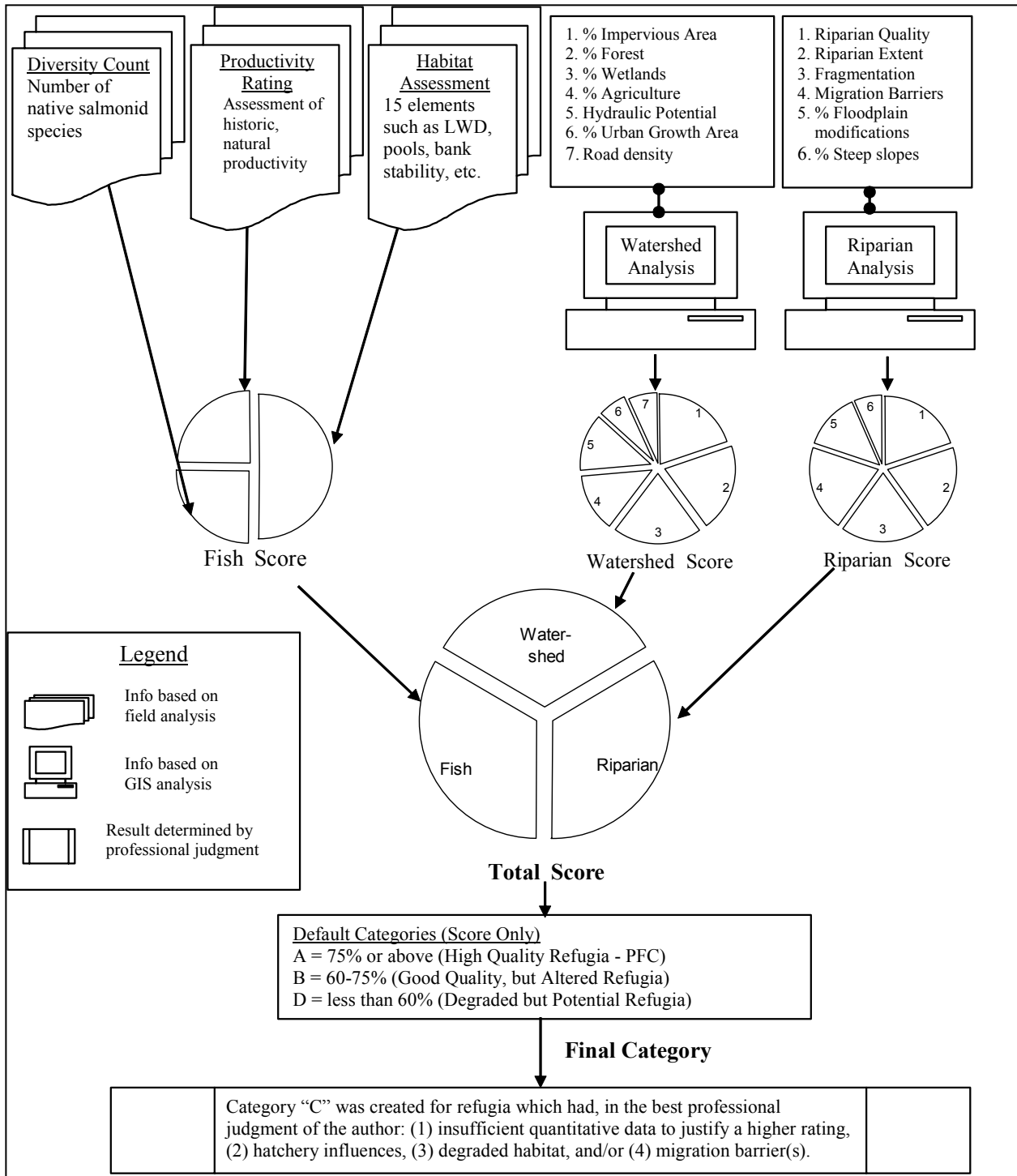


Figure 15: Freshwater Refugia Model Flow-Path.



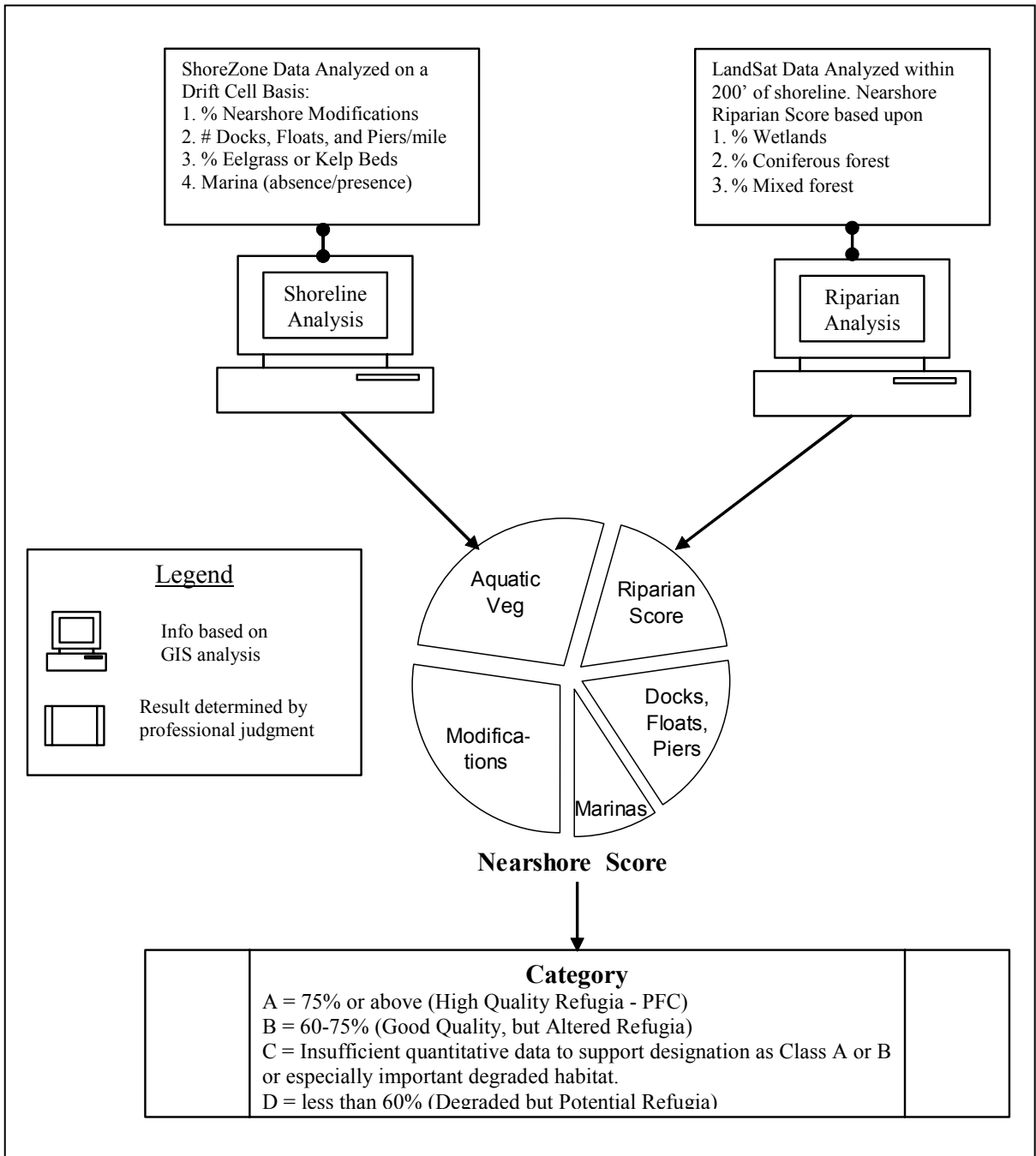


Figure 16: Nearshore Refugia Model Flow-Path.



GIS Layer	Calculation of Metric	Units	Main Data Source
Riparian Fragmentation	Road & utility stream crossings / stream mile	#	Roads Utility Lines Streams
Riparian Corridor Extent	Forest area / buffer area	%	Land use/land cover Streams
Riparian Vegetation Quality	Coniferous and mixed forest area / buffer area	%	Land use/land cover Streams
Mass Wasting Potential	Area of slopes greater than 30 degrees / watershed area	%	Elevation
Hydrologic Potential	Weighted addition of basin area (2) + drainage density (1) + average rainfall (3)	N/A	Precipitation Streams
Total Impervious Surface Area	Rural residential area (.1) + low intensity residential (.35) + high intensity residential (.6) + commercial (.9)	%	Land use/land cover
Agriculture Land-Use	Agriculture area / watershed area	%	Land use/land cover
Road Density	Miles of road / watershed area	km	Roads
Wetlands	Wetland area / watershed area	%	Wetlands
Urban Development	Urban development area / watershed area	%	Zoning
Salmon Migration Barriers	Blocked stream length / stream length	%	Barriers Hatcheries
Instream Habitat Quality	1 to 5, with 5 representing the best habitat quality	N/A	Field Data
Salmonid Productivity and Diversity	1 to 5, with 5 representing high salmonid productivity	N/A	Limiting Factors Analysis Field Data
Flood-prone Zone Modification	Human-modified flood-prone zone area / total flood-prone zone area	%	Elevation
Forest Cover	Weighted addition of clear-cut area (1) + deciduous forest area (2) + mixed forest area (3) + coniferous forest area (4)	%	Land use/land cover

Table 11: GIS layers selected for inclusion in the Freshwater Refugia Model.

GIS Layer	Calculation of Metric	Units	Main Data Source
Nearshore Modifications	Human-modified nearshore area / nearshore area	%	Land use/land cover
Docks, Floats, and Piers	Docks, floats, and piers / nearshore segment mileage	#	Shore-Zone Inventory
Marinas	Presence or absence of marinas	Yes/No	Shore-Zone Inventory
Eel Grass or Kelp Beds	Aquatic vegetation score / nearshore segment length	%	Shore-Zone Inventory
Nearshore Riparian	Wetland, coniferous, and mixed forest area / shoreline segment buffer area	%	Shore-Zone Inventory

Table 12: GIS layers selected for inclusion in the Nearshore Refugia Model.



GIS Data and Map-Layer Descriptions

Attribute data pertinent to the selected evaluation criteria were examined early in the study for completeness, accuracy, and timeliness. This section includes a description of specific datasets that were evaluated for inclusion or exclusion as well as datasets that were created when no adequate data were available. Table 13 contains a comprehensive listing of all the digital data used in the model.

	Scale/Resolution	Source
Salmon Migration Barriers	All culverts and dams inventoried to-date	Washington Department of Fish and Wildlife SSHEAR database representing unresolved fish passage problems outside of the Olympic National Forest
Elevation	10 meter DEM	Kitsap County, originating with U. S. Geological Survey
Digital Ortho-photos	1:24,000	Year 2000 quadrangles obtained from the Washington State Department of Natural Resources
Flood-prone Zones	Not applicable	Created for the current project
Instream Habitat Quality	Not applicable	Created for the current project
Land use/land cover	30 meter	Created for the current project
Limiting Factors Analysis	1:24,000	Draft for WRIAs16 & 17 from the Northwest Indian Fisheries Commission
Marine Vegetation	0.5 mile	Washington Shore-zone Inventory from the Washington State Department of Natural Resources
Precipitation	1.25 arc-minutes (~2 km)	Developed by the University of Oregon and Oregon State University
Refugia	1:24,000	Created for the current project
Roads	1:100,000	2000 U. S. Bureau of the Census TIGER database
Shoreline Modifications	0.5 mile	Washington Shore-zone Inventory from the Washington State Department of Natural Resources
Stream Types	1:24,000	Washington Department of Natural Resources hydrogeography
Streams	1:24,000	Washington Department of Natural Resources hydrogeography
Topography	1:24,000	Quadrangles obtained from GIS Data Depot, originating with U. S. Geological Survey
Hatchery Operations	Yes or No	Washington Department of Fish and Wildlife
Utility lines	1:50,000	Created for the current project
Watersheds	6th field	Olympic National Forest 6th field hydrologic units
Wetlands	1:24,000	USFWS National Wetlands Inventory
Drift Cells	1:24,000	Washington State Department of Ecology
Zoning	Unknown	County zoning theme

Table 13: GIS Refugia data

Multiple *map layers* were required as inputs to the salmonid habitat suitability model (HSM). These layers were either *collected* via field inventories and expert knowledge or *produced* from existing data through the use of spatial functions and analysis. An example of a “collected” layer is the instream habitat quality map that was created by converting field data to a digital spatial database. An example of a “produced” layer is the forest cover map that was created by interpreting Landsat satellite imagery to locate forest areas, and then calculating the amount of forest area within each watershed. Most of the map layers needed for the model are of the *produced* type.

A further distinction is made between map layers that measure objectives directly and those that are considered *proxy* map layers. A direct scale, such as habitat diversity (number of salmon species in the stream), measures the achievement of its associated objective directly. Other map layers, such



as mass-wasting potential, measure the degree to which its associated objective is met through an assumed indicator. For example, in the case of mass-wasting potential, the measurement of percentage of slopes greater than 30 degrees within each watershed was used as a proxy to indicate potential slope instability.

As was discussed earlier in this report, the selection of the freshwater and nearshore metrics or map layers included in the model was based on the ecological significance of the measured parameters and their influence on the processes that create and maintain salmonid habitat (Pess et al., 2002). The selected metrics also represent multiple spatial scales of influence with regard to salmonid habitat quality (watershed, riparian, and nearshore) as well as influence on multiple life stages (migrating, spawning, and rearing). In addition, sensitivity analysis was conducted with various combinations of potential metrics to determine which metrics were best suited for inclusion in the GIS model.

Freshwater Map Layers

Riparian Fragmentation

Landscape fragmentation is recognized as a significant factor in determining ecosystem structure and function (Sedell et al., 1990; Wahlberg et al., 1996; Hiebeler, 2000). In the Puget Sound lowland (PSL) region riparian fragmentation is a common by-product of watershed development, beginning with rural-agricultural land-use and continuing through suburban and urban development (Figure 17). This riparian fragmentation metric correlates well with declining biological integrity in PSL streams (Figure 18). GIS code was written to automate the process of determining the intersections

of roads and utility lines with streams. The resultant points of intersection where summed for each watershed and then divided by total watershed stream miles. The metric is defined as road and utility stream crossings per stream mile. The 1:100,000 scale TIGER roads data were determined to be most appropriate for the road-utility stream crossing analysis than the other road datasets described above. The use of this data minimized the occurrence of extraneous road-stream crossings upon examination of the analysis results.

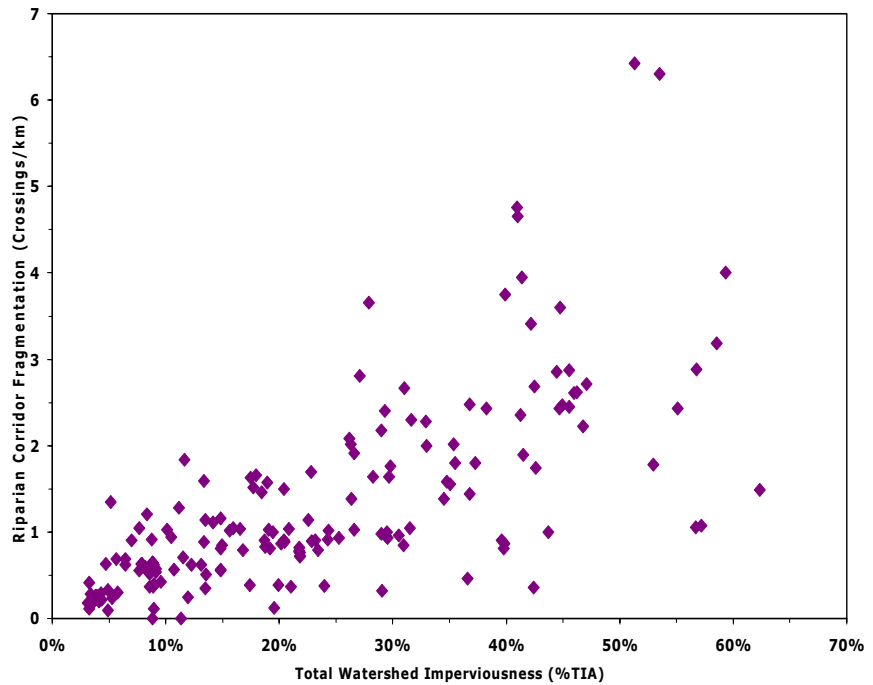


Figure 17: Riparian Fragmentation in Puget Sound Lowland Watersheds (May and Horner, 2000).



Riparian Corridor Extent

Like the longitudinal fragmentation of the riparian corridor, the lateral extent of the riparian zone has been shown to be a significant factor in the ecological integrity of PSL streams (May et al., 1997; May and Horner, 2000; Booth et al., 2001). Figures 19 and 20 show this relationship for PSL streams. Based on the established relationship between stream ecosystem quality and riparian extent, this metric was selected for inclusion in the GIS model. The total area of all forest types (coniferous, deciduous, and mixed) within a 200-foot stream buffer (both sides of the stream) was calculated. A 200-foot buffer was used because this distance approximates one site-potential tree height (SPTH) for the study area of interest. In general, one SPTH is considered an ecologically significant riparian width in forested watersheds (FEMAT, 1993; Spence et al., 1996; Knutson and Naef, 1997; Naiman and Bilby, 1998). The total forested area within stream buffers and a total buffer area were derived for each watershed and then divided. The metric is defined as forested area per total buffer area.

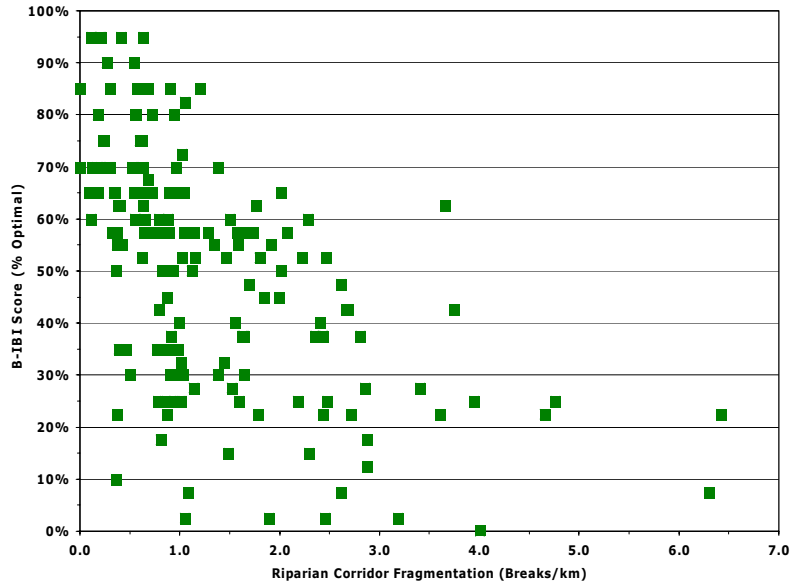


Figure 18: Riparian Fragmentation in Puget Sound Lowland Watersheds (May and Horner, 2000).

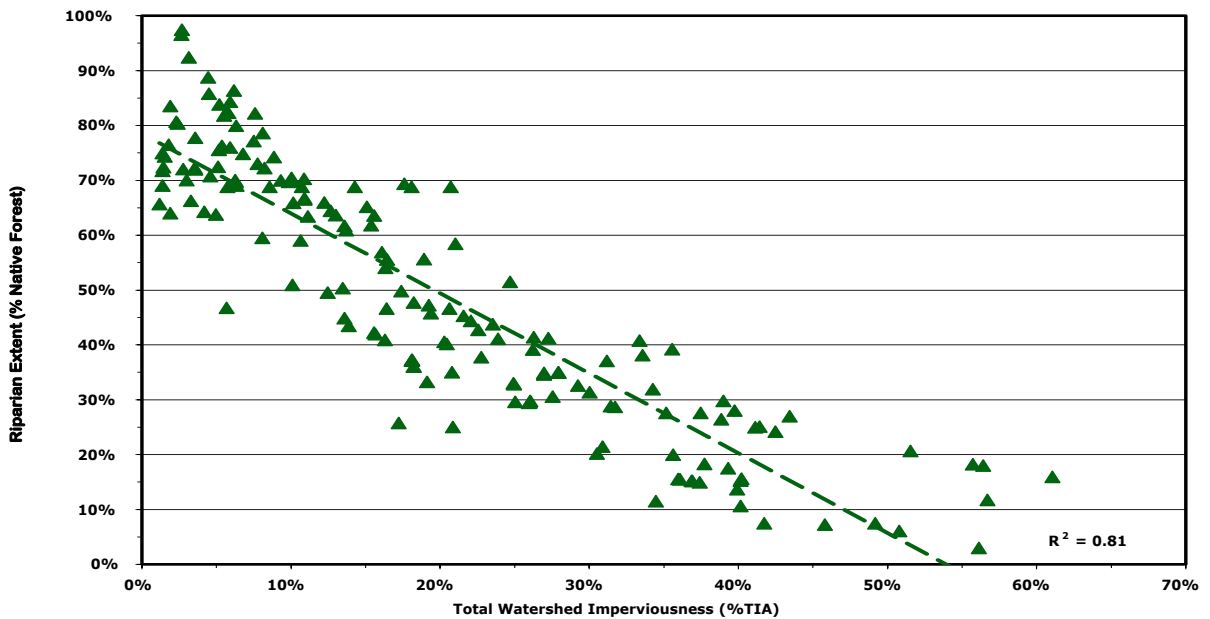


Figure 19: Riparian Corridor Extent in Puget Sound Lowland Watersheds (May and Horner, 2000).



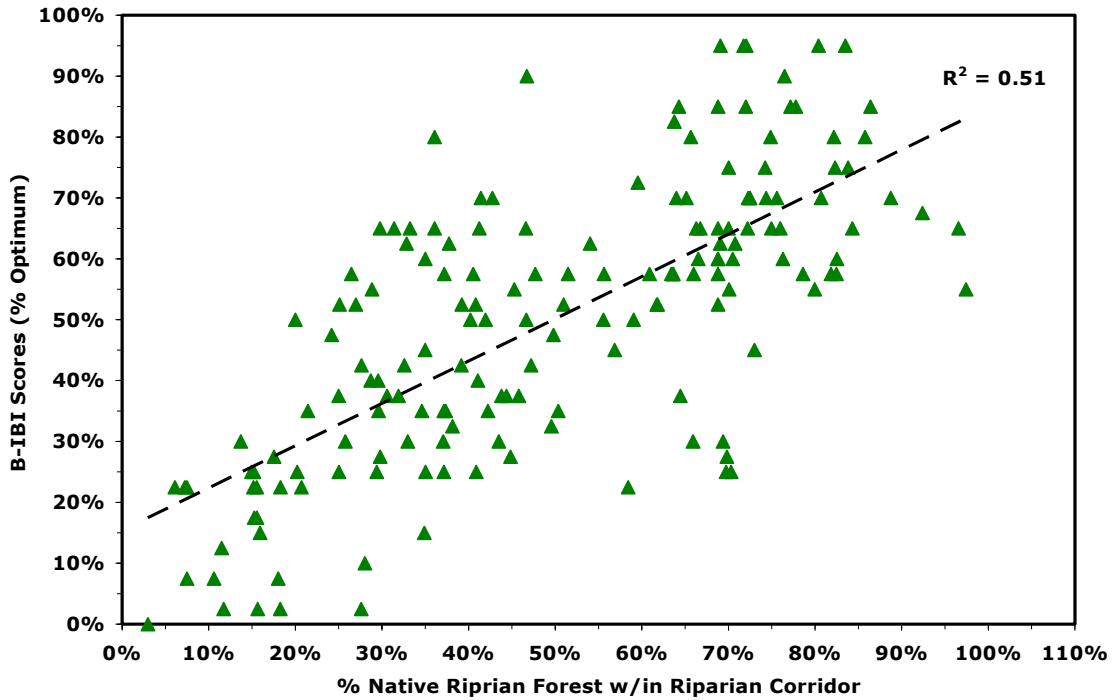


Figure 20: Riparian Corridor Extent in Puget Sound Lowland Watersheds (May and Horner, 2000).

Riparian Vegetation Quality

The total area of coniferous and mixed forest types within each 200-foot stream buffer was calculated. In general, coniferous and mixed forest is considered the most representative of pre-development conditions within the riparian zones of forested watersheds in the PNW (Naiman and Bilby, 1998). In the case of rivers and larger streams, the lower mainstem floodplain areas were often dominated by pioneer vegetation (mostly deciduous species) as a result of frequent flooding disturbance events that inhibit the forest succession process common to upland areas (Naiman and Bilby, 1998). For most lowland streams, the natural riparian corridor of streams in the PNW contain a mosaic of forest types (Naiman and Bilby, 1998), with coniferous forests (mixture of cedar, hemlock, and spruce) being the most common. Therefore, for this study *riparian quality* was defined as both coniferous and deciduous forest. A total coniferous and mixed forest area within stream buffers and a total buffer area were derived for each watershed and then divided. The metric is defined as total coniferous and mixed forest area per total buffer area.

Mass Wasting Potential

A land slope map was created from the digital elevation model (DEM) after sinks were filled. Slopes greater than 30 degrees were selected and their areas calculated. This value was selected based on current guidance from the Washington Department of Natural Resources (WDNR) on potential slope instability in forested watersheds (WDNR, 1995). The metric is defined as area of slopes greater than 30 degrees per total watershed area.



Hydrologic Potential

The *hydrologic potential* analysis used in this study is a composite of three independent analyses: watershed area, drainage density, and average annual precipitation. This metric was designed to quantify the streamflow potential of each watershed. In general, the greater the streamflow or hydrologic potential, the greater the available salmonid habitat area. The *watershed area* is simply the surface area of the watershed. The *drainage density* was computed by totaling the stream channel length per watershed area. The *average annual precipitation* was determined by intersecting the rainfall contours (precipitation) with the watershed map and then summing the total area of each resultant polygon, multiplied by its precipitation average. The watershed area measurement was then multiplied by two (2), drainage density was multiplied by one (1), and average annual precipitation was multiplied by three (3), then combined for a total metric score. The metric is defined as a synthetic score comprising the weighted addition of basin area (2) plus drainage density (1) plus average rainfall (3).

Land Use and Land Cover

Since eight out of the 23 objectives required land use/land cover (LULC) information for their measurement, it was important to acquire the most current and accurate data possible. To that end, a Landsat 7 ETM+ (30 meter pixel resolution) satellite image was classified into several LULC categories. Care was taken to use similar classification methods to those employed for the original Kitsap County Refugia Report (2000). Ortho-photo quarter quadrangles, DEM, digital raster graphics and ASTER satellite imagery were used as supporting data for the classification. ASTER data from the multi-spectral sensor of the TERRA satellite was chosen as a supporting dataset because of the additional spectral resolution it provided. The digital ortho-photo quadrangles were used primarily to provide ground truth information. It should be noted that higher resolution remote-sensing data are available from a variety of sources (e.g. digitized aerial photos, LIDAR, etc.). However, many of these various data sources were not available for all parts of the study area. Therefore, it was determined that the 2001 Landsat 7 ETM+ would be used as the primary LULC classification source. LULC data was used to determine both watershed and riparian scale landscape map layers.

Total Impervious Surface Area

The effects of watershed development on PSL streams are well documented (Booth, 1990; Booth, 1991; Booth and Reinelt, 1993; Horner et al., 1997; May et al., 1997; Horner and May, 1999; Booth et al., 2002). They include extensive changes in basin hydrologic regime, channel morphology, and physiochemical water quality. The cumulative effects of these alterations have produced an instream habitat that is significantly different from that in which salmonids and associated fauna have evolved. In addition, development pressure has a negative impact on riparian forests and wetlands, which are essential to natural stream functioning.

The most obvious manifestation of watershed development is the increase in impervious surface area and the corresponding loss of natural vegetation. Land clearing, soil compaction, encroachment on riparian corridors, and modifications to the surface-water drainage network all typically accompany human land uses. Total impervious area (%TIA) is the most commonly used measure of watershed development currently in use. In developing areas, imperviousness typically increases at the expense of native forest cover (see Figure 21). Although impervious surfaces themselves do not generate pollution, they are the major contributor to the change in basin hydrologic regime that drives many of the physical changes affecting stream ecosystems (Schueler, 1994). Figures 22 and 23 show the relationship between watershed development (as measured by %TIA) and selected measures of ecological integrity in the Puget Sound region. These relationships generally hold for most measures of ecological integrity (biotic integrity, physical habitat, water quality, etc.).



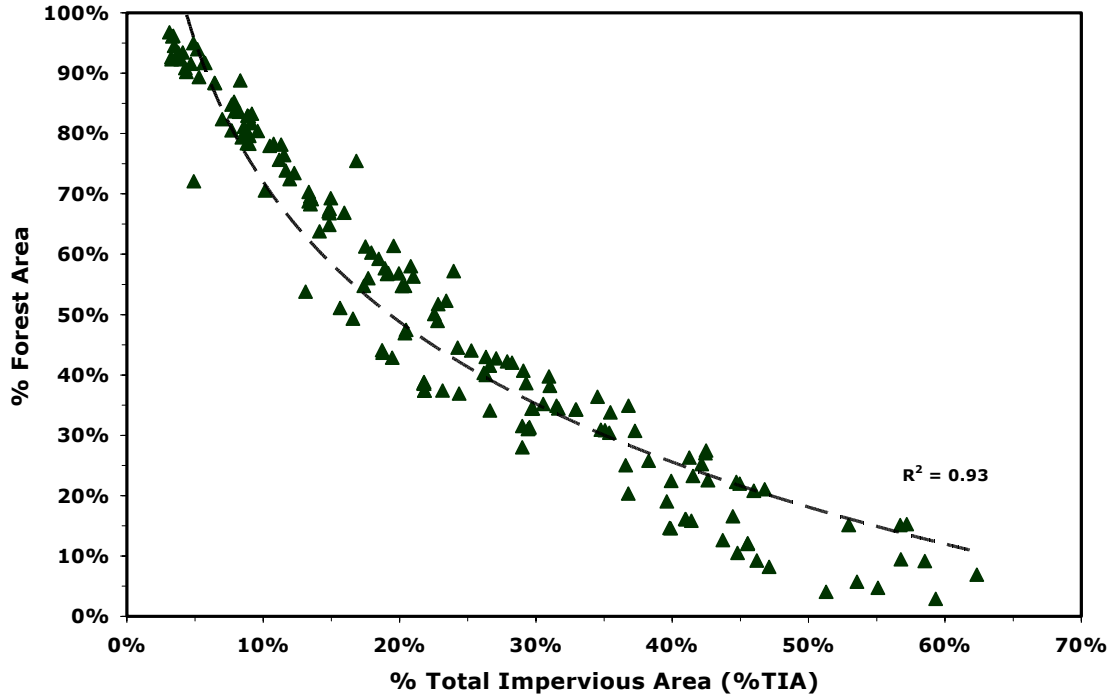


Figure 21: Forest Cover and Total Impervious Area in PSL Watersheds (May et al., 1997).

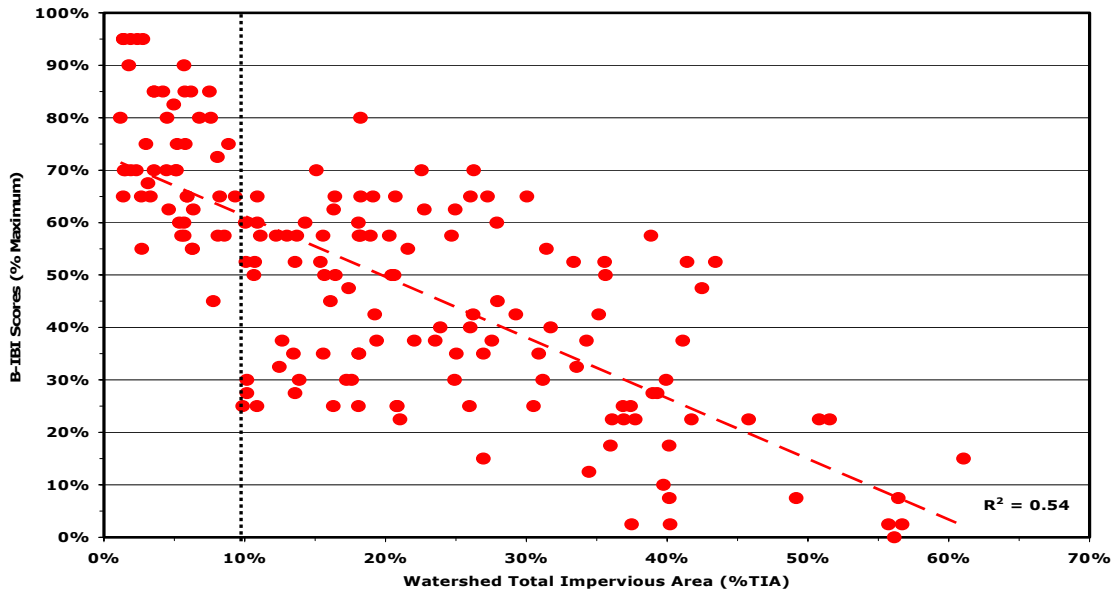


Figure 22: Relationship between Watershed Development in PSL Watersheds and Ecological Integrity (May et al., 1997).



WMI Puget Sound Habitat Assessment

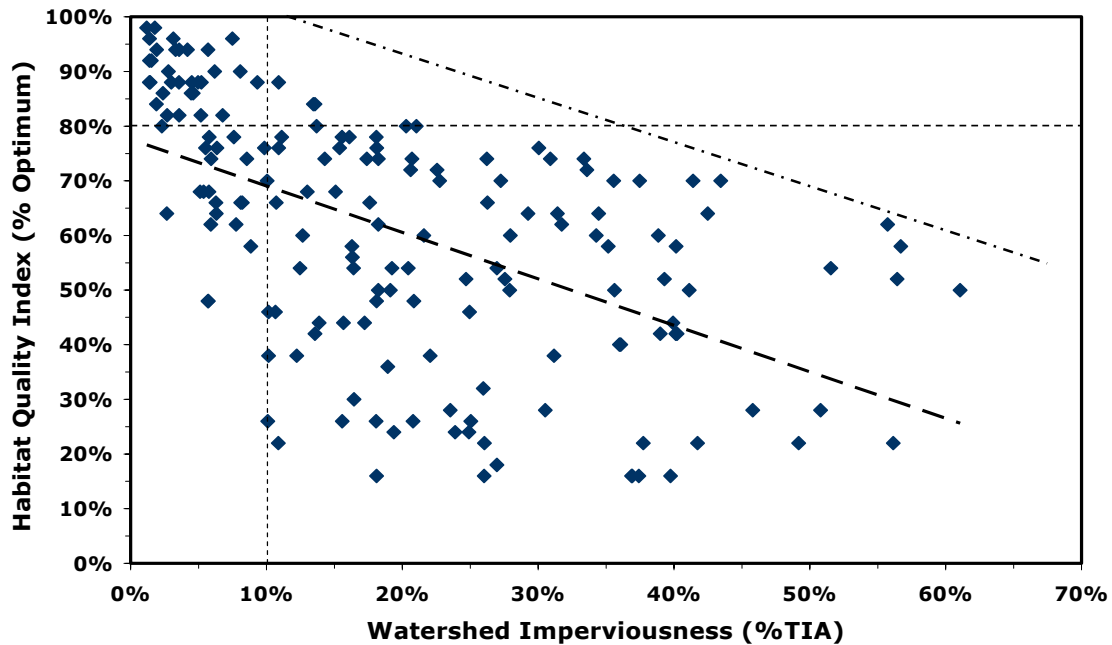


Figure 23: Relationship between Watershed Development in PSL Watersheds and Ecological Integrity (May et al., 1997).

As a landscape metric, watershed imperviousness (%TIA) generally is able to explain most of the cumulative impacts associated with stream ecosystem decline. A wide *range* of stream conditions, however, can be associated with any given level of imperviousness, particularly at lower levels of development. Land development that eliminates hydrologically mature forest cover and undisturbed soil can result in significant changes to the natural stream flow regime and, in turn, to the physical stability of stream channels, as well as to instream habitat conditions. These changes are manifested in altered stream flow patterns with higher volumes of storm flow, leading to accelerated channel erosion and habitat simplification. These hydrologic changes cannot be completely mitigated with structural stormwater control and treatment measures (Horner and May, 2001). Although factors other than hydrologic change (*e.g.*, declining water quality, riparian encroachment) can undoubtedly affect the magnitude of urban impacts, the breadth of the existing data suggest that improvements in these other factors can never fully mitigate the hydrologic consequences of watershed development (Booth et al., 2002).

Four impervious surface area categories were differentiated in the Landsat classification scheme: rural residential, low intensity residential, high intensity residential, and commercial/industrial. The total area of each type was computed in each watershed and then multiplied by its corresponding percent impervious factor: 0.10, 0.35, 0.60 and 0.90 respectively (May et al., 1997). The four adjusted area measurements were then summed and divided by total watershed area to compute percent total impervious area (%TIA). The metric is defined as rural residential area (.1) plus low intensity residential (.35) plus high intensity residential (.6) plus commercial (.9) combined into %TIA.



Forest Cover

It is generally understood that native forest cover is the most desirable LULC category for watersheds that support salmonids (Booth et al., 2002). In addition, mature forests are generally more desirable than young forests with regard to salmonid ecological requirements (Naiman and Bilby, 1998). Under the typical rural land use patterns found in the Puget Sound region, the magnitude of observed forest-cover losses affects watershed flow regime as much as, or more than, associated increases in impervious area (Booth et al., 2002). It should come as little surprise that the progressive loss of forest cover has been linked to declining stream quality indicators, given that forested watersheds are often routinely used to define natural reference conditions for streams (Booth *et al.*, 2001). Forest maturity is recognized as an important characteristic of the landscape in the PNW (Kruckeberg, 1991). For aquatic ecosystems, forest maturity or stand age is important from both a hydrologic and ecological perspective (Naiman and Bilby, 1998). Mature forest is also considered to be the main benchmark for defining pre-development hydrology within watersheds (WDNR, 1995). Consequently, forest cover is perhaps the most powerful indicator to predict the quality of streams within the lower end of the development spectrum (Booth *et al.*, 2001), as is found throughout the study area of East Jefferson and Kitsap Counties (see Figure 21).

Clear-cut logging area, deciduous forest area, mixed forest area, and coniferous forest area were identified as the main forest cover categories in the Landsat classification process. Each “forest-type” was summed separately per watershed and then weighted from an ecological basis. The weights were: 1 for clear-cut, 2 for deciduous, 3 for mixed forest, and 4 for coniferous forest. The metric is defined as a synthetic score comprising the weighted addition of clear-cut area (1) plus deciduous forest area (2) plus mixed forest area (3) plus coniferous forest area (4).

In addition, native forest age was identified as a contributing factor in the forest cover categories. A coniferous seral stage classification was thus derived from the land use/land cover classification. This was accomplished by overlaying an existing seral stage database covering forest service areas with DEM, Landsat ETM+ satellite imagery, Landsat band-4 forest texture and ASTER satellite imagery. The overlay provided enough information to derive unique spatial and spectral signatures for each stand age class. These signatures were then used to derive the classes through a supervised classification and modeling process. Four seral stages were thus mapped for the Jefferson County study area only: late seral, mid seral, early seral and recent clear cuts. However, in order to remain consistent with the original Kitsap refugia study, seral stage data were not incorporated into the GIS model, but is available for use in future refugia analysis updates and for use in other projects.

Urban Development

Urban areas were summed by totaling the area of certain zoning categories and any areas lying within designated urban growth boundaries (UGB). From the Clallam zoning theme, those categories were: general commercial, industrial, rural center, rural commercial, Sequim, Sequim urban residential, urban residential low, and Jamestown S'Klallam. From the Jefferson County zoning theme, those categories were: convenience crossroads, neighborhood crossroads, general crossroads, heavy industrial, light industrial, Port Townsend Urban Growth Area (UGA), rural village centers (Port Ludlow), airport, waste management, and all the MPR zoning types. Also included were the areas of the current Tri-Area proposed UGA for Jefferson County and the expanded commercial areas for Brinnon, Quilcene, and Port Hadlock. For Kitsap County, the following zoning themes were included: Kitsap County UGA, Joint Planning Areas, Local Areas of More Intense Rural Development (LAMIRD), public facilities, airports, and industrial. The metric is defined as total urban development area per total watershed area and is included as a measure of potential development pressure.



Agriculture Land-Use

Agriculture, like urbanization and timber harvest, is considered a significant landscape altering land-use (NRC, 1996). In the study area grazing and row-crop agricultural activity are both quite common. For this study, impervious was used to measure development and clear-cuts were used as a measure of recent logging activity. Likewise, agricultural lands were identified in the Landsat classification and summed within each watershed. The metric is defined as agriculture area per total watershed area and is expressed as a fraction (% agricultural land-use).

Wetlands

Wetlands are a significant ecological landscape feature both hydrologically and from a salmonid habitat perspective (Naiman and Bilby, 1998). Wetlands were identified using the National Wetlands Inventory (NWI). Wetland area within each watershed was then calculated. All NWI wetland types were included. The metric is defined as wetland area per total watershed area.

Flood-prone Zones

Floodplain location data exist in the form of Federal Emergency Management Act (FEMA) flood insurance rate maps (FIRMS). The FEMA FIRMS in the study area were last updated in 1998. The FEMA maps were developed for flood insurance purposes and do not adequately represent floodplain area from a salmonid habitat perspective. Floodplain areas are important to the stream-riparian ecosystem for hydrologic and ecological reasons. In general, the natural floodplain of streams in the PNW contains a mosaic of forests and wetlands (Naiman and Bilby, 1998). Floodplain areas provide storage for excess streamflows during extreme flooding events. In addition, they dissipate the energy of floodwaters and capture nutrient-rich sediments carried by the floodwaters. Salmonid habitat features found within the floodplain area include small tributary channels, off-channel wetlands, side-channels, and beaver pond wetlands (Stouder et al., 1997).

Therefore, new data showing *flood-prone zones* were created through an extensive analysis utilizing best available elevation data, known historical flood events, field verification and expert knowledge of known obstructions. The term *flood-prone zone* was coined to differentiate the area identified in this analysis from the existing FEMA floodplain areas already designated. The analysis built upon the methodology described in Garono and Brophy (2001). A description of the process steps involved in creating the flood-prone zones follows. The intended use of the dataset is for watershed comparison purposes within the context of this study and not for determining floodplain boundaries at greater than a 1:24,000 scale.

The *flood-prone zone* analysis began with an analysis of slopes within the study area. To this end, digital elevation models (DEM) at a 10-meter resolution were used as input into the GIS slope algorithms. Following a sensitivity analysis of various slope categories, it was decided that slopes of 0-5 degrees adequately reflected the flood-prone zones most applicable to salmon habitat. Once these areas were identified, any areas of less than 1.5 hectares were considered irrelevant and excluded from the analysis. Areas not coinciding with high flow locations (i.e., rivers and streams) were also excluded. Expert knowledge of plateau areas, as well as obstructions such as culverts or bridges, was utilized prior to incorporation into the analysis. Finally, any remaining areas in question were examined in the field to determine actual flood-prone area extents. Data on historical flows were also considered in the last portion of the analysis. The resultant digital flood-prone area delineations were used as input data for the flood-prone area modification criterion and are helpful in determining which watersheds contain the most flood-prone area modifications and which contain the least.

The flood-prone area was delineated using the methods described earlier in this report. The human land-uses, as identified in the Landsat classification, were then selected within the defined



flood-prone area. The total of human land-use areas within flood-prone zone was then computed and divided by the total area of the flood-prone zone. The metric is defined as the human-modified flood-prone zone area divided by the total flood-prone zone area.

Roads and Road Density

Road data for the study area exist in multiple databases. An evaluation of the many road layers was conducted early in the study. Although two of the existing databases: the Olympic National Forest road layer and the County road layers contained detailed road information, neither layer covered the entire study area. A third road layer, the 2000 U. S. Bureau of the Census TIGER database, was not as detailed as the Olympic National Forest layer but was comprehensive of the study area. Initially, a combination of the two datasets - using the ONF data in national forest lands and TIGER data in non-forest lands - was considered. However, it was determined that the TIGER database underrepresented logging-type roads in the study area and therefore a combination of the two datasets would create a bias between national forest watersheds and non-forest watersheds. In other words, watersheds within a national forest would receive a lower score than those outside of the national forest even if they contained the same amount of roads. Also, since the road databases were derived via dissimilar collection methods, the representation of roads versus reality could have been different in each database, therefore potentially raising or lowering a watershed's overall rank artificially.

The 1:100,000 scale TIGER roads data were determined to be most appropriate for the road-utility stream crossing analysis than the other road datasets described above. The use of this data minimized the occurrence of extraneous road-stream crossings upon examination of the analysis results. Major utility lines were also digitized from current ortho-photos. Locations where forest clearings were visible in long, narrow swaths were digitized and their locations verified as current utility line paths.

Road density was the metric used to quantify road impact on the watershed scale. The length of all roads within each watershed was calculated and divided by the watershed area. The road density metric is defined as total miles of road per watershed area in square miles (see Figure 24).

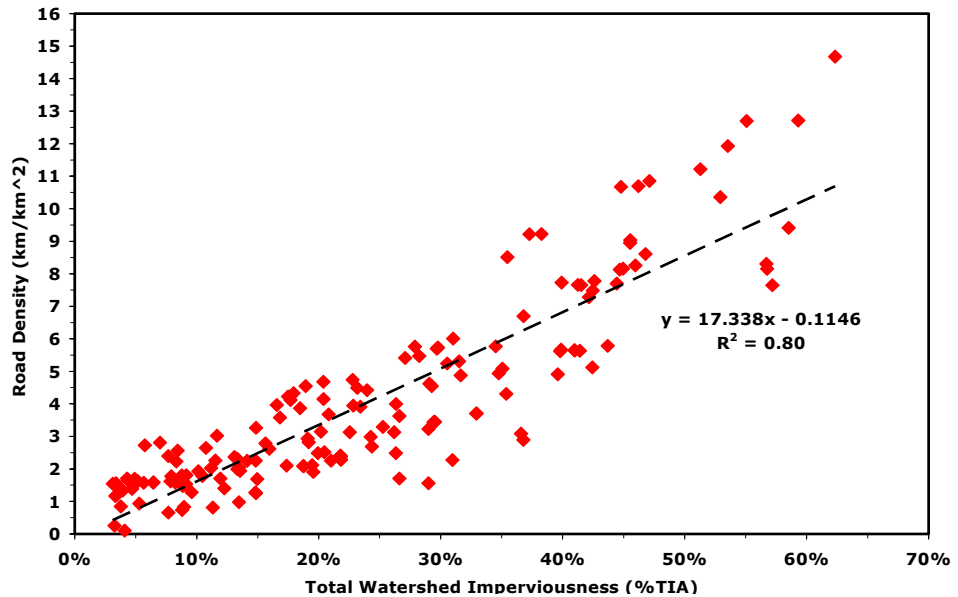


Figure 24: Relationship between Watershed Development and Road Density in PSL Watersheds (May et al., 1997).

Salmon Migration Barriers

The Salmonid Screening Habitat Enhancement and Restoration Database (SSHEAR database) was used to locate barriers in the study area. It is comprehensive of the study area and updated continually by the Washington Department of Fish and Wildlife. These data represent culverts and



dams inventoried to-date and do not include fish-ways. Barrier data was collated for all type 1-3 streams. The total length of type 1-3 streams upstream of a barrier was then computed and summed for each watershed. The metric is defined as blocked stream length per total stream length for all potentially fish-bearing streams in the watershed.

Instream Habitat Quality

Field data for several salmonid habitat characteristics (spawning, rearing, migration, canopy, LWD, water quality, streambank erosion, and riparian integrity) were collected and averaged to come up with an overall habitat quality score. The habitat quality metric is defined as a synthetic score from one to five, with five representing the best habitat quality (see previous section for detailed explanation).

Salmonid Productivity and Diversity

Data for salmonid diversity data were gathered from existing records as well as from interviews and from the on-going Limiting Factors Analysis (LFA) process. The diversity metric represents the combined number of fish species currently present in the stream, the number historically present in the stream, and the number that could potentially use the stream based on stream geomorphic characteristics. The maximum number of salmonid species found in the study area is seven (chinook, coho, fall/winter chum, summer chum, pink, steelhead, and cutthroat). The diversity metric is defined as a synthetic score from one to five, with five representing the highest salmonid diversity possible (see previous section for detailed explanation).

Productivity was scored using the qualitative criteria discussed in an earlier section of this report. The productivity metric is defined as a synthetic score from one to five, with five representing high salmonid productivity (see previous section for detailed explanation).

Nearshore Map Layers

A GIS-based landscape of the nearshore area was conducted for the first time during this project. The selection of landscape metrics was based on the current understanding of what factors are ecologically significant with respect to nearshore salmonid habitat (Williams and Thom, 2001). At the present time, our knowledge of nearshore salmonid utilization is relatively basic and is rapidly expanding. In addition, the database on nearshore salmonid habitat conditions is also relatively sparse. Therefore, this assessment of nearshore salmonid conditions should be considered as “interim” until more and better data is developed. Regardless of this limitation, the analysis presented here is scientifically sound and is based on the best available information. In addition to providing a foundation for future nearshore assessments, it provides decision-makers data on where potential nearshore refugia are located and what their current condition is based on the following criteria.

Nearshore Modifications

The percent modification data from Shore-zone data was used to create this map layer. Percent modification is the percentage of the Shore-zone segment that has been modified with wood, metal, or concrete bulkheads, riprap, landfill, or boat-ramps. The length of the nearshore segment was also calculated. This percentage was translated into percentage of the nearshore segment for use in the refugia model. The metric is defined as the percent of nearshore segment modified and is included as a measure of human impact along the shoreline (Williams and Thom, 2001).

Docks, Floats, and Piers

Using the Shore-zone data, the sum of piers, docks, small slips, large slips, and boat ramps was calculated for each nearshore segment. The length of the nearshore segment was also calculated.



The metric is defined as the number of docks, floats, and piers per mile of nearshore segment and is included as a measure of human impact along the shoreline (Kelty and Bliven, 2003).

Marinas

Presence or absence of a marina in each of the study area's watersheds was recorded for this project via a list of marinas. A list of known marinas was obtained from each county. It included any marina with at least one of the following services: fueling operations, human waste management and/or haul-out facilities. The following marinas were identified in East Jefferson County: Boat Haven, Port Hudson, Port Hadlock, Quilcene, Port Ludlow, and Pleasant Harbor. Marinas in Kitsap County include the following: Blake Island Marina (Yukon Harbor), Kitsap Marina (Sinclair Inlet), Port Orchard Marina (Sinclair Inlet), Port Orchard Yacht Club (Sinclair Inlet), Port Washington Marina (Dyes Inlet), Port of Bremerton, Bremerton Yacht Club Marina (Dyes Inlet), Port of Keyport (Liberty Bay), Port of Poulsbo (Liberty Bay), Liberty Bay Marina (Liberty Bay), Poulsbo Yacht Club (Liberty Bay), Port of Winslow (Eagle Harbor), Harbour Marina (Eagle Harbor), Eagledale Marina (Eagle Harbor), Seabeck Marina (Hood Canal), Driftwood Key Marina (Hood Canal), Port of Brownsville, Port of Kingston, and Port of Silverdale.

The total number of marinas with least one of the following services: fueling, human waste management, haul-out facilities was computed. The metric is defined as a synthetic score representing the presence or absence of marinas and is included as a measure of human impact along the shoreline (Kelty and Bliven, 2003).

Eel Grass or Kelp Beds

Using the Shore-zone kelp and eelgrass designations of absent, patchy and continuous, a synthetic score for each nearshore segment was computed. The metric is defined as the aquatic vegetation score divided by nearshore segment length.

Nearshore Riparian

A 200-foot interior buffer along the shoreline was created and the sum of estuarine intertidal wetlands, coniferous forest, and mixed forest area was computed per shore-zone segment. The metric is defined as the total wetland, coniferous, and mixed forest area per shoreline segment buffer area.

GIS REFUGIA MODEL ANALYSIS

The GIS analysis phase of the refugia model began with the creation of standardized map layers and weighting the criteria. Once these pre-processing steps were performed, weights and map layers were combined using a *value function*. The GIS assists in these tasks by performing the data standardization and generating results from the user-defined algorithm. Details concerning the pre-processing steps and the specifics of the algorithm are described in this section.

Each map layer described previously contains its own scale of measurement. For example, instream habitat quality is depicted via an integer number representing the relative habitat quality as assigned by the decision maker while the wetland map layer is measured as the percentage of wetlands within each watershed. An integral part of habitat suitability modeling and MCDA involves the transformation of values from the various criterion map layers into comparable units. In other words, the scales must be made commensurate in order for the map layers to be combined in a reasonable manner (i.e., before the map layers are input into the algorithm). This ensures that all the maps, some of which may consist of nominal or ordinal measurements, are converted to a common, interval value, scale. It also allows for the possible non-linearity between the raw (original map layer) and synthetic (transformed map layer) scales (Pereira and Duckstein, 1993).



The method of deriving non-linear synthetic scales usually involved the application of a classification called natural breaks to the raw data of each map layer. The natural breaks classification identifies breakpoints between classes using the Jenk's Optimization statistical formula. Simply put, this method minimizes the sum of the variance within the classes, finding groupings and patterns inherent in the data (Jenks, 1977). Raw data were transformed into a one to nine integer scale using the natural breaks classification computed in the GIS. Graphs of the raw and synthetic values for selected map layers are shown in Figure 25.

Even though all the map layer data were converted to the commensurate, synthetic scale through the above methodology, they could not yet be combined due to differences in their relative importance to salmonid habitat. For example, the salmon migration barrier criterion was identified by the decision-maker as having more effect on salmon habitat than the urban development criterion. A weighting scheme for the model was developed in order to represent this disparity between map layers. A *weight* is defined as the value assigned to each map layer to signify its importance relative to the other map layers (Malczewski, 1999).

The trade-off method was used to determine the weights. In the trade-off method, the decision-maker assesses trade-offs between pairs of criteria based on best available science (Malczewski 1999). In other words, the map layers were examined and a choice was made as to whether map layer *A* was preferred to map layer *B*, map layer *B* was preferred to map layer *A*, or whether the two map layers had equal importance relative to salmon habitat. In general, those map layers that most directly influence habitat (such as riparian conditions) were weighted the highest and those with somewhat less direct influence, or those that have an indirect impact (such as future land-use), were weighted lower. This rationale was justified based on current best available science relating watershed landscape alteration to salmonid habitat conditions. In general, there were three categories of map layers: watershed, riparian, and instream, as well as the nearshore map layers.

The weights derived via the trade-off analysis resulted in three coefficients for both the freshwater map layers and the nearshore map layers. Weights were normalized in order that their sum would equal 1. Both instream map layers were weighted equally (7.5 each) so that their sum would be equal to the sum of the riparian map layers (15) or the sum of the watershed map layers (15). This was done to reflect the decision maker's emphasis of equal importance for each of the three categories of analysis. It follows that instream map layers comprised a third of the overall rank, riparian map layers another third, and watershed map layers the remaining third. For the freshwater portion of the model, the map layers with three times the importance of the other map layers were multiplied by the coefficient 3/45. Those with two times the importance were multiplied by the coefficient 2/45 and those with one time the importance were multiplied by the coefficient 1/45. Similarly, the nearshore coefficients were: 3/11, 2/11 and 1/11. Once the weights were assigned and the coefficients derived, they were multiplied to the map layer's synthetic measurement values accordingly. Tables 14 and 15 summarize this information.

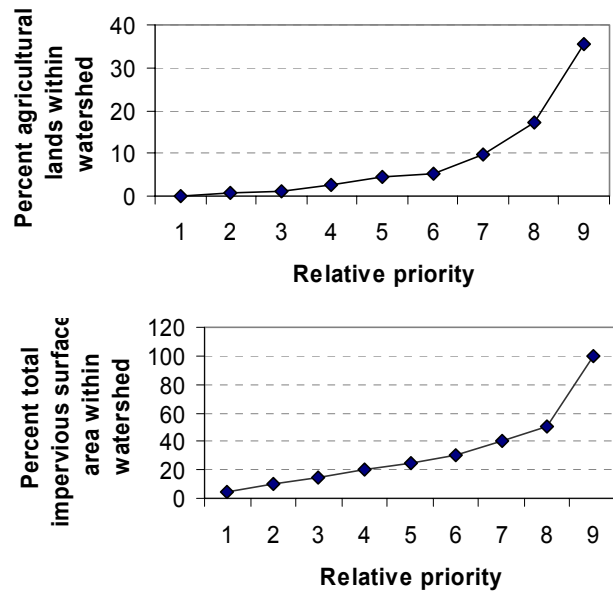


Figure 25: Priority functions as derived by the Natural Breaks Method.



Criterion	Relative Importance	Factor
<i>Instream</i>	--	.334
Salmonid diversity and productivity	7.5	.167
Instream habitat quality	7.5	.167
<i>Riparian Corridor</i>	--	.335
Salmon migration barriers	3	.067
Riparian fragmentation	3	.067
Riparian corridor extent	3	.067
Riparian vegetation quality	3	.067
Flood-prone zone	2	.045
Mass wasting	1	.022
<i>Watershed</i>	--	.335
Forest cover	3	.067
Total impervious surface area	3	.067
Wetlands	3	.067
Agriculture	2	.045
Hydrologic potential	2	.045
Road density	1	.022
Urban development	1	.022

Table 14: Freshwater Landscape Map Layers and Weighting Factors.

Criterion	Relative Importance	Factor
Nearshore modifications	3	0.2727
Aquatic vegetation	3	0.2727
Docks, floats, piers	2	0.1818
Nearshore riparian	2	0.1818
Marinas	1	0.0909

Table 15: Nearshore Map Layers and Weighting Factors

Evaluation criteria, standardized map layers and decision-maker preferences (weights) were combined into two algorithms (one for the freshwater ranking and one for the nearshore ranking) using multi-criteria decision rules. An additive decision rule, called a value function, was the method used for ranking the refugia in descending order of importance. The landscape refugia prioritization algorithm, adapted from Chrisman (1997) is written as follows:

$$R_l = \sum_m w_m v_{ml}$$

where R_l refers to the rank of each landscape refugia l , w_m refers to the weight assigned to each map layer m so that $\sum_m w_m = 1$, v_{ml} refers to the value of each landscape refugia l with respect to the m th map layer. The watershed characterized by the highest value of R_l has the best salmon habitat. The range of R_l is an integer scale from one to nine.



Similarly, the nearshore prioritization algorithm is represented as follows:

$$R_n = \sum_m w_m v_{mn}$$

where R_n refers to the rank of each nearshore zone n , w_m refers to the weight assigned to each map layer m so that $\sum_m w_m = 1$, v_{mn} refers to the value of each nearshore zone n with respect to the m th map layer. The nearshore zone characterized by the highest value of R_n has the best salmon habitat. The range of R_n is an integer scale from one to nine.

Once the landscape refugia and nearshore zones were ordered via the above algorithm, the rankings were translated into a percentage scale. For example, a refugia area with a final rank of 5.5 received a 61% score (or $5.5/9.0 = 61\%$). Both the one-to-nine scale and the percentage scores are reported for landscape refugia and nearshore zones in the results section and in Appendix G of this report. The frequency of freshwater refugia falling within each percentage category is shown in Figure 26. The mean of the percentage scores is 64.5 and the standard deviation is 11.0. The frequency of nearshore zones falling within each percentage category is also shown in Figure 26. The mean of the percentage scores is 65.5 and the standard deviation is 17.5.

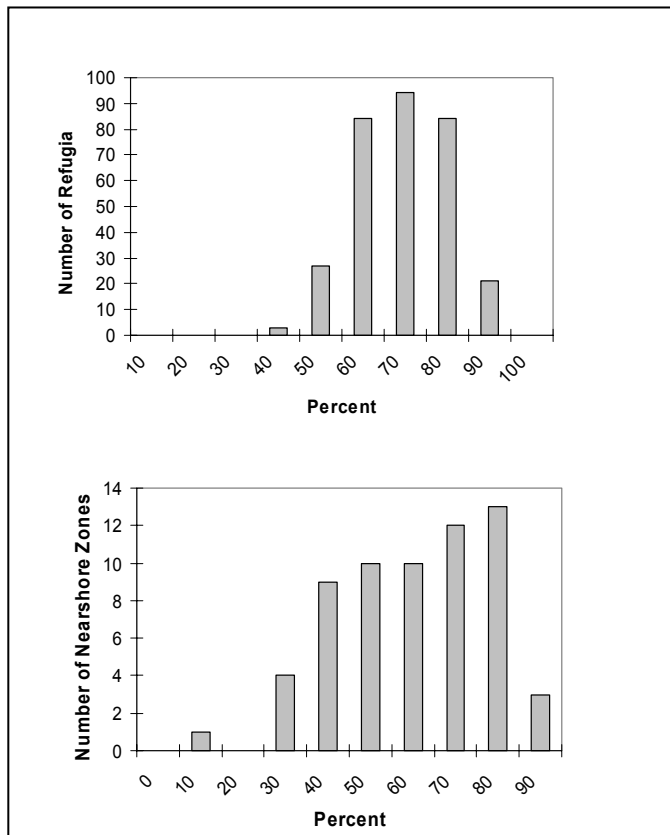


Figure 26: Frequency of Freshwater and Nearshore Refugia falling within each percentage category.

