Cedar River Municipal Watershed Draft Aquatic Restoration Strategic Plan

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EXECUTIVE SUMMARY

The Aquatic Restoration Strategic Plan describes the framework for implementing aquatic restoration within the Cedar River Municipal Watershed (CRMW). Consistent with the broad goals and objectives identified in the Cedar River Watershed Habitat Conservation Plan (HCP), plan elements include detailed descriptions of the strategic framework used to develop project specific goals and evaluate success as it relates to the conservation of biodiversity and the restoration of key habitats. Five types of aquatic restoration were identified in the HCP (2000):

- Culvert replacement for fish passage
- Culvert replacement for peak flows
- Streambank stabilization
- Streamside revegetation
- Large woody debris replacement

The identification of critical and sensitive aquatic habitats and assessing the threats to those habitats is based largely on an understanding of the processes critical to their formation and maintenance. To identify which processes are critical to the maintenance of aquatic resources throughout the CRMW, process-based classifications of streams and wetlands were made. In total, eighteen distinct geomorphic map units (GMUs) or stream channel types have been identified as well as 7 types of wetlands based on Brinson's (1993) hydrogeomorphic (HGM) classification.

Since the primary objective of the channel classification is to develop spatially explicit predictions as to where various kinds of restoration activities may be appropriate, 10 different types of low and moderate gradient channels, less than 4 and between 4 and 12 percent respectively, are distinguished based on differences in geology and drainage area as well as slope and degree of confinement by valley walls or other landforms. GMUs 9 and 10, for example, both include low (1-4%) gradient reaches where riparian processes which influence instream woody debris recruitment is critical to the formation and maintenance of fish habitat such as pools and gravel bars. An important distinguishing feature, however, is the location of GMU 10 channels downstream of reaches prone to scour and deposition of coarse sediment from episodic debris flows. Since the type of disturbance common in GMU 10 channels not only effects the local stability and integrity of the habitat in these reaches but reflects a much greater risk to the long-term success of any given restoration project, GMU 9 and 10 channels are differentiated. Differences between other GMUs may be more pronounced, but each GMU reflects a unique prediction about which physical watershed processes are critical to the formation and maintenance of that channel type. These classifications also facilitate predictions about probable linkages between these resources and threats posed by historic, current, or potential future management activities.

To clarify and communicate key assumptions about the important characteristics of each stream and wetland class, conceptual models are discussed. Section 2 also includes descriptions of the key ecological attributes and indicators as well as the identification of current and desired future conditions for the most sensitive and unique aquatic resources. Six key ecological attributes, defined as critical geomorphic or biological processes known to govern specific aquatic habitats, were identified. Selected attributes include: LWD recruitment processes, LWD function, flow regime and hydroperiod (peak flows), sediment transport and deposition, connectivity of aquatic habitats, and biotic community composition. Indicators for each attribute were then developed which represent measurable parameters readily quantified in the field. These indicators will be used to assess current conditions, define project goals, frame monitoring plans, and where appropriate, assess success of implemented projects.

An example of an application of this approach is an active restoration project conducted in 2005 on Rock Creek. Within the project reach, where low in-stream wood levels have contributed to degraded fish habitat, including few pools and poor spawning habitat, reach data was compared with target conditions to assess the problem, evaluate potential restoration options, and help quantify restoration objectives. In this case, current (pre-project) conditions included very low frequencies of large, stable woody debris (0.4 pieces/100 m) and deep pools (3.8 pools/100m). When compared to comparable streams in unmanaged watersheds where natural wood and pool frequencies were found to have a natural range of variation between 4-11 pieces of large wood and 6-24 pools per 100m, respectively, existing conditions reflect a degraded state. The correlation between low wood and low pool frequencies was also consistent with predictions based on our process-based channel classification and supported the decision that active restoration involving the placement of woody debris is necessary to improve key habitat elements in the short-term.

Section 3 discusses strategies for screening and prioritizing sites for aquatic restoration which integrate watershed-wide goals for maintaining biodiversity as well as those specific to aquatic targets. At a watershed scale, a "landscape synthesis" process has identified areas where synergy of restoration efforts in aquatic, riparian, and terrestrial ecosystems can best occur (Erckmann et al. 2007). These will be priority areas for restoration treatment among all restoration programs. Second, at a reach level, this strategic plan addresses how reaches within a "synergy area" will be prioritized for aquatic restoration. The process and decision-support tools used to screen, select, and prioritize sites for aquatic restoration projects in order to ensure the greatest ecological benefit for the cost are also described. Finally, Section 3 includes a list of projects to be implemented over the next 3 to 5 years.

Section 4 describes the framework for successfully documenting an aquatic restoration project once a site has been identified for implementation. To facilitate communication and adequate documentation of projects, the following elements have been identified as potentially critical to each project plan: Project Introduction; Project Site Description; Description of Project, Objectives, and Justification; Coordination with other projects; Evaluation of Potential Effects; Project Mitigation; Evaluation of Cost versus Benefits; Outside Review, Permitting, and Approvals; Contract Development; and Adaptive Management and Monitoring Plan.

Finally, Section 5 describes the tactical plan for revising and improving elements of this plan through time. Ongoing efforts by the Aquatic Restoration ID Team include focusing on refining knowledge gaps associated with desired future conditions, especially those related to the lower mainstem Cedar River where a Large Woody Debris plan is currently in planning phases. This is a working document and will be amended periodically.

1.0 INTRODUCTION

The stream and rivers within the Cedar River Municipal Watershed (CRMW) provide 60-70% of the drinking water supply of 1.3 million people in Seattle and King County. The same streams and rivers provide water to generate a small amount of electrical power for the citizens of Seattle. The CRMW (90,546-acres) is managed under a 50-year Habitat Conservation Plan and Incidental Take Permit under the federal Endangered Species Act. The overall goal of the HCP is to implement conservation strategies designed to protect and restore habitats of all species of concern that may be affected by the facilities and operations of the City of Seattle on the Cedar River, while allowing the City to continue to provide high quality drinking water and reasonably priced electricity to the region (City of Seattle, CRMW HCP 2.4-43, 2000). Aquatic restoration is a component of the watershed management mitigation and conservation strategies included in the Cedar River Watershed HCP (CRMW HCP). The Aquatic and Riparian Ecosystem strategies are "designed to protect the region's supply of high-quality drinking water, to preserve and enhance stream and riparian ecosystems within the municipal watershed, to restore and rehabilitate stream and riparian functions" (CRMW HCP 4.2-43) and to closely integrate with the mitigation strategies for the anadromous fish barrier at Landsburg (Section 4.3).

The Aquatic Restoration Strategic Plan is a working document that describes SPU's process for making decisions regarding aquatic restoration in the CRMW which are consistent with the CRMW HCP. Using an established framework, our intent is to create a road map which makes our decision making process transparent and helps to clearly communicate how we intend to use information to logically identify, prioritize, and implement aquatic restoration projects in order to meet specific goals and objectives. As described by Kauffman (et al., 1997), aquatic restoration necessitates the reestablishment of processes, functions, and related biological, chemical, and physical linkages between the aquatic and associated riparian and upland ecosystems; it is the repairing of damage caused by previous human activities.

1.1 Purpose of Document

The purpose of the Aquatic Restoration Strategic Plan includes the following:

- Develop Strategic Aquatic Restoration Plan that follows a biodiversity conservation and asset management framework
- Define the drivers, goals and objectives, and risks of the aquatic restoration program
- Describe the framework used to develop project specific goals and evaluate success.
- Describe the site selection and prioritization process used to screen potential aquatic restoration projects in order to ensure the greatest ecological and cost benefit
- Identify short-term lists of potential projects and long-term list of data and information needs critical to resolving key uncertainties
- Describe project specific restoration planning standards and guidelines.

1.2 HCP Goals and Objectives

The drivers of aquatic restoration are the CRMW HCP commitments under the Mitigation and Conservation Strategies for the Aquatic and Riparian Ecosystem (CRMW HCP, Section 4.2, p. 49) and Washington State regulations 222-24 (Forest Practice Rules) and 220-110 (Hydraulic Code Rules). The goal of the Cedar River Watershed HCP Aquatic Restoration Strategic Plan is the restoration of key aquatic processes, functions, and physical linkages, throughout the watershed, within an asset management framework to meet the commitments within the HCP and comply with all federal, state, and local regulations.

Objectives for the Aquatic and Riparian Ecosystem element of the HCP support the goal of avoiding, minimizing, and mitigating the impacts of any incidental take of species listed as threatened or endangered and additionally treat unlisted species of concern as if they were listed. They include a commitment to protect or improve the quality of the surface water in CRMW, to provide a net benefit for species of concern that are dependent on riparian or aquatic habitats, and to contribute to the recovery of these species while preserving and protecting the municipal water supply. As they relate to the Aquatic Restoration Strategic Plan, more specific objectives include:

1. Through a commitment not to harvest timber for commercial purposes (passive restoration)
    a. protect streamside habitats, both riparian and upland in nature, to maintain or improve stream temperature regimes, to recruit large woody debris, and to maintain bank stability through maintenance and recruitment of large-diameter conifers;
    b. protect wetlands, lakes, and ponds and all true riparian habitat from degradation of function and ability to support species addressed in the HCP as a result of land management activities;
    c. protect sensitive and highly erodible soils in floodplains and riparian zones from degradation and erosion caused by land management activities;
    d. avoid disturbance of sensitive and highly erodible soils on steep slopes within inner gorges and headwall basins, and in other areas, that can result in sediment delivery to streams, wetlands, and other water bodies;
    e. reduce the magnitude and frequency of human-influenced bank failures, landslides, mass wasting, and debris flows;
2. Through engineered road improvements, decommissioning, and improved maintenance, reduce the higher rate of fine and coarse sediment loading to aquatic systems from sources influenced by past timber harvest, poor past road design or construction, and continued road use and maintenance;
3. Implement management guidelines and prescriptions to provide protection for aquatic and riparian habitats beyond that afforded by a commitment not to harvest timber for commercial purposes;
4. By silvicultural intervention, contribute to restoration of natural ecological and physical processes and functions that create and maintain aquatic and riparian habitats;
5. Restore natural aquatic and riparian ecological processes and habitat complexity;
6. Where technically feasible, improve fish access to significant upstream habitat where connections are interrupted by roads;
7. Use the results of monitoring these and other conservation strategies to help realize the full measure of benefits offered by conservation efforts in the watershed and the Lake Washington Basin;
8. Provide connectivity among aquatic and riparian habitats through inclusion of upland forests to facilitate the dispersal and movement of organisms dependent on riparian and aquatic habitats

1.2.1 Linkage between Objectives and Aquatic Restoration Projects

Five broad project types have been identified within the CRMW HCP which target one or more of the above objectives. Since our restoration commitments are established based on expenditure of money for each project type, this section is intended to clarify which objectives are addressed by each project type. The project types include: Culvert Replacement for Fish Passage, Culvert Replacement for Peak Flows, Streambank Stabilization, Streamside Revegetation and Large Woody Debris (LWD) Replacement.

<u>Culvert Replacement for Fish Passage</u> - As the project title implies, these projects are intended to reestablish fish passage, where economically and technically feasible, between significant amounts of upstream and downstream aquatic habitats where these connections are interrupted by roads. Reductions in sediment delivery from surface runoff and scour of road tread, ditch and fill materials may also be anticipated following implementation of these projects.

Objectives for Culvert Replacement for Peak Flows - Using our comprehensive culvert inventory, replacement of undersized or improperly installed culverts will help reduce chronic impacts from erosion, scour, or altered sediment transport capacity. Similar to the projects targeting fish passage, these projects may also contribute to reductions in sediment delivery from surface runoff and scour of road tread, ditch and fill materials.

Objectives for Streambank Stabilization – Where active restoration measures can be identified which address the causes of chronic bank instability, projects will be implemented in order to minimize excessive rates of streambank erosion and sediment delivery caused by roads and land management activities. Additional objectives may include habitat enhancement within or downstream of the project site and the establishment of natural disturbance and habitat forming processes. Since large woody debris is an important form of roughness and energy dissipation in mountain streams throughout the CRMW, there will likely be overlap between these and LWD Replacement projects (described below).

Objectives for Streamside Revegetation - The objective of this element is to help restore ecological functions associated with altered or disturbed vegetation within riparian corridors. Other benefits may include stabilizing exposed soils otherwise prone to erosion and transport into nearby streams and enhancing near-term streambank stability by accelerating the recovery of dense root-mats associated with dense vegetative cover. In addition, by reestablishing diversity of native streamside forbs, shrubs, and trees, the development of functional riparian forests may also be accelerated in order to provide future LWD recruitment and improve habitat for fish and wildlife species.

Objectives for Large Woody Debris Replacement - The primary objective of LWD replacement projects is to improve fish habitat within degraded reaches which historically provided quality habitat for ESA-listed species in addition to other unique and sensitive aquatic areas. As these projects are considered short-term solutions and our long-term goal is the restoration of natural processes critical to the continued maintenance of this habitat, integration with riparian restoration efforts will be critical to achieving long-term success. Where practicable, this program will be integrated with streamside revegetation, streambank stabilization, and conifer under-planting projects.

With respect to the mainstem Cedar River, an effort is underway to develop an LWD management plan specific to the reach between 276th Ave SE and Cedar Falls. The objectives of this plan include 1) protection of the Landsburg intake facility, 2) maintenance of water quality, 3) protection and enhancement of aquatic habitat, 4) protection of SPU personnel and the public, and 5) maintenance of SPU's ability to manage water transmission between Chester Morse Lake, Landsburg, and Lake Youngs.

1.3 Relationship to Other HCP Planning Efforts

Five general categories of aquatic restoration include: 1) habitat reconnection, 2) road improvement, 3) riparian restoration, 4) in-stream habitat restoration, and 5) nutrient enrichment (Roni, et. al., 2002). As shown in Figure 1, implementing a successful aquatic restoration program in the CRMW will require coordination with other plans, most notably the Transportation Strategic Asset Management Plan (TSAMP) and the Riparian Restoration Strategic Plan (RRSP), in order to achieve our aquatic restoration goals. All of these plans are nested beneath the Landscape Synthesis Plan developed to coordinate all restoration activities in the CRMW. As identified within this plan, our restoration strategies focus on activities which target key aquatic habitat and those in-stream processes critical to their maintenance. As described in sections 1.3.1 through 1.3.5, linkages with all other planning efforts have been established in order to facilitate coordination between programs, thereby increasing the likelihood of achieving both project-specific and landscape-scale restoration objectives across all programs.

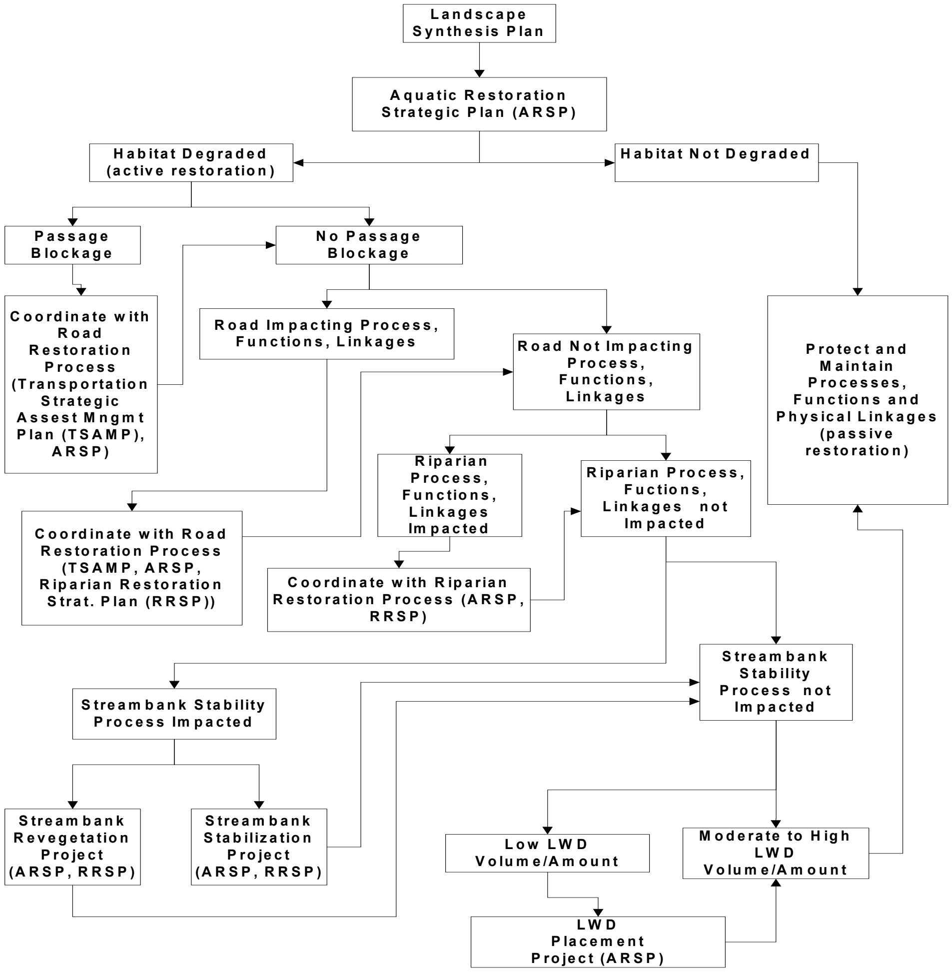

Figure 1: Relationship of CRMW HCP Aquatic Restoration elements to Aquatic Ecosystem Restoration (modified from Roni, et. al., 2002).

1.3.1 Landscape Synthesis Plan

In order to provide an integrated, landscape-level approach to planning restoration that most efficiently and effectively achieves the diverse goals of the HCP, a Synthesis Framework (Erckmann et al. 2007) was developed. Using a set of statements regarding an idealized set of future watershed conditions, the delineation of areas with unique species or high inherent biodiversity, and the identification of four interdependent ecological attributes (ecosystem resilience, natural disturbance regimes, natural biodiversity and ecological sustainability, and landscape connectivity), the framework is intended to focus restoration efforts on areas with the highest likelihood of achieving restoration goals set at a variety of spatial and temporal scales.

Statements used to describe an idealized set of future watershed conditions which are most strongly linked to the aquatic system include:

- Minimal hydrologic connectivity of roads with the aquatic network resulting in minimal road-generated fine sediment delivering to the aquatic system
- No road-associated (triggered) mass wasting events
- Sediment, wood loading, and LWD recruitment to all streams within natural range of variation for late-successional riparian forests
- No human-made barrier to fish or peak storm flows in any stream except Landsburg Diversion Dam (mitigated by a fish ladder), Masonry Dam (used to store water and control flood flows), and the Overflow Dike; and minimal human-made barriers to passing sediment and organic debris in any stream
- Natural processes key to channel and floodplain formation and maintenance (e.g., flooding, sediment storage and sorting, bank and bed stability, floodplain connectivity, channel migration) within natural range of variability
- Natural flow paths and hydrologic regimes in all unregulated streams
- Assemblage of aquatic benthic invertebrates within natural range of variability for undisturbed forested watersheds in the PNW.
- Natural fluvial disturbance regime influencing successional processes in riparian forests

In addition, reaches with current and potential future Chinook and coho salmon, and bull trout habitat were also identified as a means of focusing on areas with the greatest potential for restoration and/or the greatest need for amelioration of risks and threats. Areas identified through this landscape synthesis screen will then be assessed and prioritized using our project-level criteria discussed in detail in section 3.

1.3.2 Restoration Philosophy

The restoration philosophy guiding this and all other CRMW strategic plans is described in the Cedar River Watershed Restoration Philosophy document (2005). Consistent with this philosophy, we've defined ecosystem restoration and management in the CRMW as

> "*…a strategy that attempts to repair the composition, structure, processes, and/or function of human-disturbed ecosystems. To the extent possible, we seek to maintain them as self-sustaining natural systems that are integrated with current ecological landscapes and land use and that eventually require minimal human intervention. In the short-term, we also seek to provide "bridging steps" – restoration actions that will provide ecosystem functions directly until natural processes become self-sustaining." (Chapin et al. 2005)*

Implicit in this definition is that we are using the concept "restoration" very generally since our program is constrained by SPU's purpose and function to supply drinking water. Depending on the particular situation in the watershed, restoration may vary from trying to redevelop conditions similar to those prior to human disturbance (activities that are consistent with the strictest definition of the term) to trying only to redevelop some degree of the functional capacity of some components of ecosystems. In some cases, we may be substituting elements to achieve that functionality, such as providing drainage infrastructure that ameliorates the disrupting influences of roads on hydrology.

1.3.3 Riparian, Upland and Transportation Strategic Plans

Given the dynamic interactions between aquatic and riparian processes, successful restoration will require tight collaboration between restoration programs. Reflecting these tight links is the underlying physical template used to define unique aquatic and riparian systems. In addition, reach and project-level prioritization criteria for assessing LWD replacement sites, for example, require an assessment of local riparian conditions addressed within the RRSP. To ensure that plans are tightly linked and communication between project planning teams occurs in a timely manner, decisions requiring input from other plans are embedded directly into the prioritization decision criteria.

As the TSAMP is still under development, explicit linkages have not yet been defined. With respect to the Upland Restoration Strategic Plan (URSP), a few linkages have been identified between the processes likely impacted by upland restoration and in-stream processes associated with moderate and highly sensitive habitat. In particular, where restoration thinning is proposed adjacent to streams with alluvial banks, a tighter residual stem spacing of 8' by 8' is prescribed to ensure adequate root strength within these potentially erosive soils as well as promote more rapid development of mature coniferous riparian forests. Where projects are proposed along non-alluvial channels where the potential for subsequent erosion of stream-adjacent soils is low, standard upland prescriptions will be employed. Regardless of adjacent stream characteristics, however, no trees will be cut which are within the active channel or on or below the break in slope of inner gorges. Links have also been established where upland restoration occurs within one kilometer of depressional wetlands in order to ensure coordination of restoration efforts surrounding those features. These locations represent amphibian breeding and rearing habitat where connectivity between aquatic, riparian, and upland habitat is likely important.

1.3.4 Monitoring and Watershed Characterization Plans

The Monitoring and Research Strategic Plan summarizes the role of monitoring within the CRMW restoration program as well the probable resources and time needed to complete the project monitoring commitments identified in the strategic plans. The specific elements of both the long-term trend and project monitoring efforts are discussed in Appendix C (*Monitoring Strategies*). The Watershed Characterization Plan addresses strategies for ensuring integrity of relevant data as well as maintaining and archiving data critical to the implementation of the CRMW HCP commitments. Protocols and data critical to implementation of the ARSP are discussed in detail in Appendix D (*Information Management).*

1.4 Asset Management Framework for Aquatic Restoration

The Aquatic Restoration Strategic Plan is composed of the same essential components and serves similar functions as a Strategic Asset Management Plan (SAMP). SAMPs set the strategic framework for the organization. They are normally prepared looking forward for a 5-year period, but action plans coming from them are generally updated annually (Seattle Public Utilities, 2004). The Aquatic Restoration Strategic Plan describes the service levels, criticality criteria, asset profile, and strategic framework for planning aquatic restoration projects, data management, and project planning, design and implementation process. The plan also identifies the best and most cost-effective method(s) of achieving explicit goals using the most logical and pertinent current information. Additionally, the plan identifies strategies for restoration of the aquatic system that looks at alternatives and is integrated with other restoration activities (road, upland, and riparian) within the CRMW to obtain the highest benefit at the overall lowest cost. The document is intended to be modified any time in the future in order to stay current with HCP requirements, City of Seattle policies, and Federal, State and King County laws and regulations, and the latest pertinent information.

1.5 Plan Sections

This plan is divided into five sections. The first section is the *Introduction* that addresses the plan's purpose and legal/regulatory drivers for aquatic restoration within the CRMW. Section 2, *Strategic Framework for Aquatic Ecosystem Conservation and Restoration,* summarizes our understanding of key habitat and watershed processes within the CRMW using the "Measures of Success" framework described by Parrish et. al.(2003). Section 3, *Framework for Prioritizing, Designing, and Implementing Aquatic Restoration Projects*, describes the suite of restoration strategies, and their technical rationale, used to address restoration goals as well as how we identify and prioritize projects. This section also provides a near-term (5-year) project list. Section 4 describes the *Standards and Guidelines for Project*

Planning and Implementation. Section 5, *Tactical Plans*, presents our strategy and timeline for addressing knowledge gaps identified in Section 2.

Since a great deal of information was gathered and synthesized during the development of this plan, several elements are relegated to the Appendices in order to make the main document more concise and readable. Appendix A, Approaches to Aquatic Restoration in the Pacific Northwest, describes other approaches to developing aquatic resource objectives related to aquatic restoration, and reflects our attempt to benchmark our program and incorporate useful approaches established elsewhere. Strategies used to monitor aquatic restoration projects as well as long-term trends in aquatic conditions are described in Appendix C. Appendix D describes the protocols and procedures either in place or to be developed which are intended to ensure data quality and proper long-term data storage. Finally, Appendix E lays out the functions of Inter-disciplinary and project teams in carrying out projects and the responsibilities for coordination between groups.

2.0 STRATEGIC FRAMEWORK FOR AQUATIC ECOSYSTEM CONSERVATION AND RESTORATION

This section describes our current understanding of the CRMW aquatic systems within a strategic framework. This framework, reflecting a blend of numerous independent efforts to define measurable objectives for various conservation goals (e.g. Kernohan and Haufler, 1999; Royal Society, 2003; Parrish et al, 2003; Levy et al., 2003; Young and Sanzone, 2002), provides a rigorous basis for measuring success of restoration efforts. The Measures of Conservation Success framework has seven steps that assure the user that the most important issues that are within the users ability to manage are being addressed and the strategies for dealing with the issues will actually address the areas of concern. Figure 2 illustrates the seven steps in the Measures of Conservation Success for the CRMW HCP aquatic restoration program.

- Step 1 (Asset Identification) of this approach is to identify and describe clearly and specifically the ecosystem(s) type/process and/or species upon which the conservation, restoration, or protection effort should focus in a tangible way that can be managed. This step defines exactly what asset sub-category is going to be conserved, managed, and/or restored and why it is important.
- Step 2 (Asset Knowledge) is to develop conceptual model(s) of each conservation target. The primary purpose of this exercise is to develop a common understanding of the assumptions upon which the remainder of the framework rests. This step determines the most important processes, indicators, threats, information gaps, and assumptions associated with the service levels and how the service levels are going to be achieved.
- Step 3 (Service Levels and Benchmarking) is to develop measurable, specific indicators for the selected targets and desired future conditions for each indicator. Desired future conditions are based in widely accepted information (operational or research) that is pertinent for activities within the CRMW. This information is accepted as the standard for restoration activities (benchmarking). This step is the same as describing the asset management service levels to meet the legal and regulatory drivers.
- Step 4 (Asset Knowledge) is to evaluate current status of each key indicator and changes over time. This may involve inventory of key indictors within the aquatic ecosystem or review of widely accepted information. This step informs the process of what condition the aquatic ecosystem is in and what indictors do or do not meet the targets.

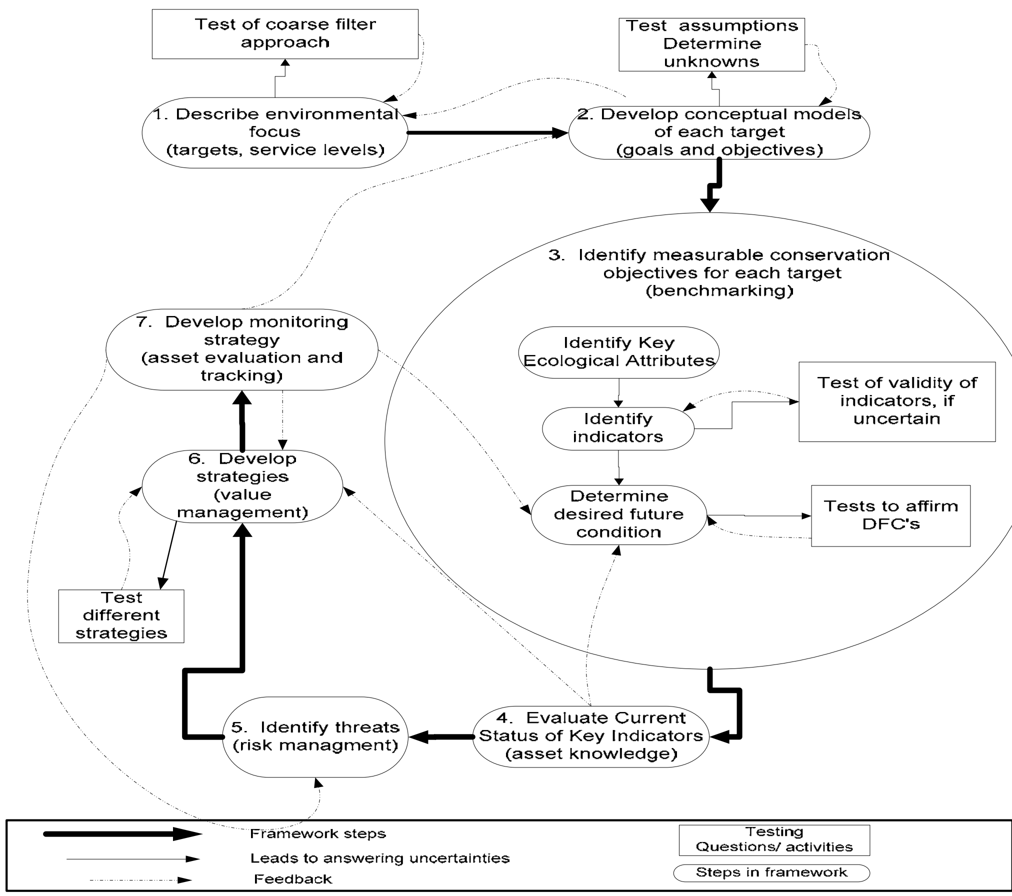

Figure 2: Strategic Framework for Conservation and Restoration of Biodiversity of the Aquatic Ecosystem.

- Step 5 (Risk Management) is to identify threats or stressors to the persistence or integrity of these targets. This is the same as a risk analysis. This step determines what the risks are that are preventing the restoration activities from meeting the targets (service levels).
- Step 6 (Value Management) is to identify specific restoration strategies to abate threats and achieve desired future conditions for each selected target. The restoration strategies identified provide an optimal triple bottom line for environmental, economic, and social needs.
- Step 7 (Asset Evaluation and Tracking) is to evaluate and track assets by integrating findings from monitoring and research of aquatic restoration activities into the existing conceptual models to refine targets, objectives, and restoration strategies.

In addition to these steps, Brown (2003) added two additional steps in order to develop a research agenda:

1. Identification of critical knowledge gaps or research needs
2. Development of a plan for addressing these research needs

2.1 Classification of the CRMW Aquatic Ecosystem

Within the context of aquatic restoration, ecosystem targets describe the biodiversity that the CRMW (within the HCP) plans to conserve. While the conservation of biodiversity often revolves around common and uncommon species as well as known and unknown species, our approach is to focus on the conservation and restoration of ecosystem processes. The approach of using ecosystems as surrogates for species (Haufler, 1999) begins by identifying the ecosystems that will be conserved. The assumption is that if these larger ecosystems and the processes that maintain them over time are successfully conserved, then species that rely on these systems and processes will also be conserved.

Identifying meaningful targets within a watershed as large as the CRMW requires a broad perspective of basin-wide conditions and the processes influencing habitat distribution and dynamics. A necessary tool for conducting an aquatic assessment includes a process-based stream channel classification scheme that integrates attributes that have the potential to exhibit strong controls on stream channel processes. Representing an early effort to gain this perspective, a stream channel assessment was conducted by Foster Wheeler Envir. Corp. (1995) in order to answer the following questions:

- What is the spatial distribution of channels with common physical attributes (e.g., gradient, confinement, geology, and floodplain/wetland connectivity)?
- Is there evidence of channel change from historic conditions?
- What do existing channel conditions indicate about past and present active watershed processes (e.g., flood regime, sediment loading)?
- What are the likely responses of channel reaches to potential changes in these regimes (e.g., increases in the frequency of bankfull flow events)?
- What are the dominant channel- and habitat-forming processes in different parts of the channel network?

In order to address the above questions, Foster Wheeler used a classification scheme based on the following attributes: lithology, position in channel network, confinement and entrenchment, valley floor gradient, channel planform, and disturbance regime. After partitioning the CRMW aquatic system into distinct reaches based on these attributes, channel surveys in 66 reaches and an historical analysis using a chrono-sequence of aerial photos was conducted. The additional field work and office review of aerial photos enabled Foster Wheeler (1995) to assess current aquatic conditions in representative reaches, evaluate hypotheses about dominant processes, and evaluate the extent to which various channel types have been impacted by past management activities.

The outcome of this work was the identification of 24 distinct valley segment types and an understanding about the dominant processes controlling them. However, an evaluation of this classification based on the current needs of SPU to efficiently prioritize, plan, implement, and monitor aquatic restoration projects, indicated that a reduction in the number of distinct channel types was needed. In particular, where Foster Wheeler channel types were determined to be controlled by the same suite of processes and respond similarly to an array of restoration projects (namely placing LWD in streams, stabilizing stream banks, and revegetating rapidly eroding stream banks), channel types were combined. In addition to lumping similar valley segment types (based on the Foster Wheeler classification), the revised channel classification also modified some segment locations and added others based on Montgomery and Buffington's (1998) channel classification. In particular, where the range in gradient of a given segment was overly broad and not consistent with the Montgomery and Buffington scheme, say between 2-8%, the segments were commonly split into a 2-4% and 4-8% reaches. Channels controlled by the same suite of processes within this revised classification will be referred to as geomorphic map units (GMUs) throughout this document.

Given that Geomorphic Map Units represent reaches which are controlled by the same suite of watershed processes, each unit represents a unique ecosystem target with a distinct set of predicted responses to changes in watershed processes and restoration efforts. The value of partitioning the aquatic system within the CRMW into GMUs is that it allows us to achieve the following: 1) identify key watershed processes (hillslope and fluvial) for each target which mostly strongly control/influence these targets; 2) determine (to the extent possible) the range of variability of these key attributes for each target; and 3) use current and historic information to assess the primary threats which jeopardize the short and long–term integrity of these targets. Before discussing the relative significance of various watershed processes within each GMU, however, a brief overview is needed of the landscape controls, namely areas with similar geomorphic processes and rock types that contribute to the character and composition of the streambed and banks.

Likewise, wetlands within the CRMW were classified using physical attributes which control the hydrodynamics and character of each wetland. Using the hydrogeomorphic method (HGM) (Brinson 1993), an analysis of topographic position of each wetland polygon on the landscape enables us to predict the dominant hydrologic processes controlling each wetland. Based on this assessment, we identified four distinct wetland classes (called HGM classes throughout this document) in the CRMW. Three of these classes were subsequently divided into subclasses to better characterize important ecological processes.

2.1.1 Landscape Controls and Geomorphic Processes

Prior to an in-depth discussion about processes and attributes specific to a given GMU or HGM class, it is helpful to understand the physical template, particularly the topography and lithology, which governs large scale aquatic ecosystem patterns and processes. While a wide variety of distinct rock types and landforms exist within the watershed, 4 basic lithologies occur within the CRMW: Continental Glacial, Alpine Glacial, Snoqualmie Batholith, and Tertiary Volcanic and Sedimentary Rocks. In order to describe the influence of these lithologies on the aquatic system, discussions will focus on 5 general areas within the CRMW, namely the Lower Cedar River Subbasin (between the Masonry Pool and Landsburg Dam), Taylor Subbasin, Alpine Glacial Valleys (in the upper watershed), Tributaries within Tertiary Volcanic Rocks, and Tributaries underlain by the Snoqualmie Batholith.

Lower Cedar River Subbasin - Continental Glacial deposits are located in the lower CRMW, primarily in the relatively subdued topography along the Cedar River, and include those from the Vashon stade of Fraser glaciation, including readily erodible outwash and ice contact deposits as well as the more erosion-resistant glacial till which represents a relatively impermeable layer upon which many extensive riverine wetland areas occur. While these glacio-fluvial deposits have varying degrees of stratification and consolidation, material is commonly composed of subrounded silts, sands, gravels, with lesser quantities of larger clasts.

Small, secondary tributaries originating in steep terrain on the perimeter are typically shallowly incised as they flow across these glacial deposits, reflecting the relatively low stream power present in these small channels. The headwaters of most of these tributaries are in volcanic and sedimentary Tukwila Formation, which includes breccias, conglomerates, sandstone and minor coal beds. The largely dendritic drainage pattern is partially controlled by relict continental glacial features. In addition, cascade channels within continental glacial deposits are commonly controlled by large boulders and cobbles derived from stream-adjacent till and recessional outwash deposits.

The lower mainstem has incised into the glacial deposits, resulting in low to moderate gradient (less than 2 percent) reaches with relatively narrow floodplains and gently sloping valley walls. River flows which formed the present day Cedar River valley above Landsburg were far greater than today as a result of the combined contribution of water from the Upper Cedar River, water from the Snoqualmie River system, and large quantities of glacial meltwater (Geomax P.C., 2004). Such large flows caused the channel to be heavily armored with coarse lag deposits eroded out of the till, resulting in a system with minimal bank erosion and a relatively limited supply of gravel between the Masonry Pool and Landsburg . Within this reach, the most significant source of gravel likely comes from Taylor Creek, and to a lesser extent Rock and Williams Creek basins.

Taylor Subbasin - Unlike most other basins in the CRMW, the Taylor Creek basin likely did not experience alpine glaciation. As a result, the drainage pattern is strongly dendritic and soils tend to be deeper and more developed. In addition, the abundance of large, low angle, deep-seated failures would likely have been scoured and removed by glaciation. It follows that this basin is largely a product of fluvial erosion processes similar to those observed today and represents a somewhat unique basin within the watershed.

The lower South Fork Taylor, much like the lower Taylor mainstem, occupies a u-shaped valley likely formed by continental glaciation and filled with thick deposits of silt and sand from a proglacial lake during the middle stage of the Puget Lobe advance. These deposits were subsequently buried by large amounts of outwash gravel. Subsequent stream incision into these deposits has resulted in system with a large source of sands and gravel which are accessible during high flow events.

Alpine Glacial Valleys - Within the upper watershed, alpine glaciation has produced numerous u-shaped valleys and left deposits which continue to exhibit a strong influence on the characteristics along the upper mainstem, North Fork, and South Fork of the Cedar River, Troublesome Creek, Goat Creek, upper Rex River, north and east of Findley Lake, and the upper reaches of Boulder and Lindsey Creeks. The upper basins are commonly glacial cirques characterized by a sparse network of tributaries on generally planar slopes which are locally dissected. Streams are often incised through glacial till, forming shallow, narrow valleys. As these small tributaries reach the cirque floor, gradients often decrease and channels are controlled by variable outcrops of bedrock and glacial/alluvial mantle. Valley hillslopes include areas veneered with glacial drift as well as inclusions of bedrock, alluvial fans, colluvium, and talus deposits. Due to the geometry of these u-shaped troughs, the linkage between stream and adjacent hillslope processes is highly variable and locally controlled by tributary incision into historic floodplain and glacial deposits. Where entrenchment has occurred, streams are often flanked by short, steep inner gorges, representing chronic source areas for sand and silt. Valley floors also include small alluvial fans, bogs, and Holocene alluvium. Alpine glacial deposits range from boulder till in uplands and upper valleys to gravel or sand outwash on the broad valley floors (Frizzell et. al., 1984).

Below these cirque floors, streams have frequently incised through bedrock ledges, resulting in steep bedrock cascades and falls and tightly confined valleys in which inner gorge failures are common. As these reaches approach the Rex and North and South Fork Cedar mainstems, valley confinement decreases and wide, complex floodplains have established.

Tributaries within Tertiary Volcanic Rocks - Tertiary rocks are located in the upper Cedar River and include Miocene to Oligocene rocks of the Fifes Peak (Miocene), Eagle Gorge (Miocene and Oligocene), and Ohanapecosh (Oligocene) formations. Lithologies include basaltic andesite and basalt flows, breccia, crystal-lithic tuff, and volcaniclastic sedimentary rocks which are frequently highly fractured and weathered. Streams within these lithologies, while frequently steep (>8%), have fairly small drainage areas and limited stream power, resulting in small, narrow valley floors inset into valley walls. Relative to streams draining glacial deposits, the linkage between stream and hillslope processes is more direct and less variable in areas underlain by both volcanic Tertiary rocks and relatively massive granites of the Snoqualmie batholith.

Within large subbasins such as Rack and Boulder Creeks, alluvial fans composed of poorly sorted cobbles and boulders have established, created by episodic floods and mass wasting events from numerous upstream inner gorge failures.

Tributaries underlain by the Snoqualmie Batholith - The Snoqualmie Batholith is located in the upper CRMW on the northern end of the catchment, primarily on the steep south facing valley walls along the upper Cedar River. The area is underlay by medium grained, mostly equi-granular Hornblende-biotite granodiorite and tonalite. Rocks of the Snoqualmie Batholith produce erosion resistant boulders and cobbles that can form coarse bedforms such as cascades and boulder steps that resist breakdown even during transport down steep channels. Similar to areas underlain by tertiary rocks elsewhere in the watershed, this bedrock is often overlain by undifferentiated glacial outwash and till underlie the lower portions of these areas which control and influence stream processes in comparable ways to those described above.

Though rocks from the Snoqualmie batholith tend to produce resistant boulders and cobbles whereas tertiary volcanic rocks tend to weather into less durable clasts, these differences did not translate into noticeable differences in channel characteristics. Stream inventories by Foster Wheeler and more recently by CRMW staff, support the hypothesis that streams underlain by these lithologies are controlled by the same suite of channel processes and have comparable sediment supply or transport regimes. In fact, the attributes used to distinguish between channel types, namely proximity and linkage to upstream mass wasting features, namely, inner gorge topography, unstable bedrock hollows, and earthflow complexes, appear to be generally independent of lithology. As a result, a given GMU frequently contains channels within both lithologies.

2.1.2 Dominant Aquatic Ecosystem Processes in the CRMW

Each GMU and HGM class within the CRMW is controlled by a unique array of hillslope, riparian, and habitat forming processes (Table 2 and Table 2a). Though the descriptions in these tables reflect attributes common to most segments within a given GMU, it is important to realize that variability in reach level processes may result in locally significant deviations. In addition, variability within a given GMU is also dependent on the number and spatial extent of streams within each unit and the uniformity of underlying landforms. Since the majority (63%) of streams described by this classification fall within GMU 4 (Variably incised cascade channels prone to catastrophic disturbance), this unit is likely to have more internal variability than the other GMUs. Since one of the goals of this reclassification, however, was to minimize the inter-GMU variability for streams where variations would likely be critical to the development, implementation, monitoring, and confident determination of success of individual restoration projects, the internal variability of GMUs 8-18 is expected to be less.

Brief descriptions of past and present management activities that threaten aquatic biodiversity (and the processes that control it) are also included in Table 2 and Table 2a. While many threats have been abated by the transition of the CRMW into conservation status, many GMUs and some specific wetlands require restoration from impacts of past threats, specifically those described below relating to timber harvest and road construction. Given this, the CRMW is defining threats not exclusively for purposes of threat abatement but also to describe specific past impacts (which have the potential to adversely effect aquatic conditions for decades to come) as substantial threats requiring restoration.

Table 1: Dominant geomorphic processes within each geomorphic map unit in the Cedar River Municipal Watershed

Geomorphic Map Unit	Dominant Processes and Characteristics		Primary threats to natural processes and aquatic integrity
	Riparian and Hillslope	Aquatic/habitat forming	
1: Steep, tightly confined bedrock and boulder cascade channels	Steep, v-shaped valleys with high transport capacity. No historic evidence of catastrophic disturbance. Bedrock and boulders limit role of riparian vegetation in bank protection, though riparian stands could provide energy dissipation of debris torrents should they occur. Infrequent depositional sites behind obstructions.	Channel spanning clasts of boulders and bedrock form constrictions that create infrequent pools. Isolated gravel patches associated with deep plunge pools provide limited spawning gravel for resident cutthroat and rainbow trout. Over-winter habitat also likely limited to deepest plunge pools.	Debris flows initiating from upstream GMUs have historically scoured and deposited sediment in these reaches. Removal of large stream-adjacent conifers has likely increased average travel distance of debris flows and lessened the short-term sediment storage capacity of these reaches. Reduction in size of trees in riparian zone capable of dissipating debris torrents and providing a lateral barrier to side slope/inner gorge failures.
2: Steep, incised, cascade channels in glacial outwash	Occurrence of unconsolidated outwash in channel banks, riparian vegetation likely helps regulate incision and reduce bank erosion. Debris flows have initiated within these segments and inner gorge topography is common. Segments likely have higher sediment loadings relative to GMU 1 channels.	Fish usage is likely very limited due to high flow velocities and limited spawning habitat. LWD jams occasionally create small steps though rearing habitat limited by seasonally low water and steep overall gradients.	Debris flows have initiated in this GMU from poorly constructed or maintained roads. Inadequately sized or maintained culverts can result in blockages at stream crossings that trigger landslides and debris torrents. Reduction in size of trees in riparian zone capable of dissipating debris torrents and providing a lateral barrier to side slope/inner gorge failures.
3: Moderate to steep gradient cascade and boulder step channels entrenched into recessional outwash.	Segments typically occupy the middle portions of small subbasins and are bordered by narrow floodplains and colluvial fills. Since channels have incised through unconsolidated outwash, these segments experience deposition of sand, gravel and boulders along channel margins and occasional in-channel berms.	Channels have naturally high fine sediment levels and forced bars are common. Though fish usage is generally limited, LWD may provide over-winter habitat along channel margins. Boulder clasts and LWD are primary step forming elements.	Fish passage through road crossing structures. Reduction in size of trees in riparian zone capable of dissipating debris torrents and providing a lateral barrier to side slope/inner gorge failures. In-filling of pools with coarse sediment
4: Steep, variably incised cascade channels prone to catastrophic disturbance.	High transport capacity channels with very little sediment storage. Riparian vegetation plays limited role in overall morphology and bank stability. As catastrophic disturbance has occurred in these segments, mature trees may influence the magnitude of these disturbances.	Morphology dominated by boulder cascades and boulder-formed steps. Flow is typically shallow and ephemeral. Spawning, rearing, and over-winter habitat is very limited.	Debris flows have initiated in this GMU from poorly constructed or maintained roads. Inadequately sized or maintained culverts can result in blockages at stream crossings that trigger landslides and debris torrents. Reduction in size of trees in riparian zone capable of dissipating debris torrents.
5: Variably confined, entrenched boulder-formed step-pool channels in glacial outwash and alluvium.	Channels typically entrenched in coarse material and boulders generally armor channel margins. Commonly zones of sediment transport where riparian vegetation plays limited role in bank stability but can be important to slowing and dissipating energy from flood flows. Historic aerial photos suggest mass wasting (MW) inputs commonly deposited in lower gradient, upstream reaches.	Limited sediment storage occurs in active channel (AC) and gravel bars comprise less than 5% of the AC. Large boulders form steps and provide dominant roughness elements. LWD accumulations elongate steps, trap sediment, and in some instances deepen step-pool habitat. High availability of gravel results in suitable spawning substrate for resident cutthroat and rainbow trout.	Debris flows initiating from upstream GMUs have historically scoured and deposited sediment in these reaches. Removal of large stream-adjacent conifers has likely increased average travel distance of debris flows and lessened the short-term sediment storage capacity of these reaches. Reduction in size of trees in riparian zone capable of dissipating debris torrents and providing a lateral barrier to side slope/inner gorge failures.

Table 1: Dominant geomorphic processes within each geomorphic map unit in the Cedar River Municipal Watershed

Geomorphic Map Unit	Dominant Processes and Characteristics		Primary threats to natural processes and aquatic integrity
	Riparian and Hillslope	Aquatic/habitat forming	
6: Confined, tributary channels controlled by boulder-formed steps often adjacent to inner gorge topography.	Tight to moderately confined boulder step and cascade channels. Often flanked by inner gorge topography which have delivered coarse and fine sediment. Riparian vegetation important for stabilizing the toes of inner gorge slopes. Stream banks generally well armored with boulders, cobble and bedrock.	Cascade and step-pool morphology generally controlled by boulders. LWD seldom initiates bed scour, though pieces help regulate transport of fine sediment and gravel. Due to location in upper watershed, fish usage is likely very low and limited to sparse resident trout.	Fish passage through road crossing structures. Zones of sediment deposition from upstream landslides and chronic sediment sources. In-filling of pools and bed fining has occurred as a result of large persistent inputs of coarse and fine sediment. Reduction in size of trees in riparian zone capable of dissipating flood flows.
7: Moderate gradient, bedrock-controlled mainstem Cedar.	Bedrock canyon greatly limits floodplain development and hillslope interaction. Zone of sediment transport and rapid conveyance of all material inputs.	Creation of steps and isolated gravel patches controlled by bedrock and boulders. High stream power is capable of transporting even large pieces of LWD out of this GMU. Channel generally unresponsive to upslope and adjacent disturbances.	No substantive long-term threats exist in this transport dominated bedrock, controlled GMU.
8: Unconfined plane-bed channels on alluvial fans	Sediment supply tends to exceed transport capacity. These alluvial fan segments represent depositional sites downstream from inner gorge topography and zones of sediment transport. These are dynamic channels prone to avulsion.	LWD plays critical role in pool formation, sediment trapping and bank stability. Standing trees play critical role in dissipation of energy associated with floods and debris flows.	Lack of in-stream LWD needed for pool formation and bank stability. Altered LWD recruitment processes. Reduction in size of trees in riparian zone capable of dissipating flood flows.
9: Unconfined plane-bed channels in alluvium and glacial outwash	Though unconfined, these channels are variably entrenched into glacial terraces. Unentrenched reaches such as Rock Creek have extensive associated wetland complexes. Adjacent hillslopes tend to be gently sloped and mass wasting inputs deposited in upstream segments. Banks are variably consolidated, with exposures of glacial till and alluvium common. Where unconsolidated, riparian vegetation with deep root mats is important for bank protection.	Pools are almost always associated with LWD and relatively low stream power results in functional wood with variable sizes. Bank erosion is likely an important source of locally high in-channel fine sediment levels. Roughness associated with LWD and riparian vegetation is therefore very important for pool scour, bank protection and maintenance of non-embedded gravel tailouts.	Fine sediment deposition from upstream mass wasting and road erosion jeopardizes spawning habitat. Coarse sediment inputs from mass wasting contribute to pool filling and channel widening. Lack of in-stream LWD necessary for pool formation and bank stability. Altered LWD recruitment processes.
10: Moderately confined, high sediment load, plane-bed channels.	Channel and riparian vegetation have been impacted by catastrophic disturbance in the past, resulting in low wood and pool frequencies and locally braided reaches. Riparian vegetation, which along many segments is currently dominated by hardwood, is important for bank and floodplain stability.	Plane bed and braided channels with large volumes of sediment stored within the active channel. Channels prone to coarse sediment deposition from upstream reach. LWD jams facilitate stability and promote scour into cobble, gravel substrate.	Coarse sediment inputs from mass wasting contribute to pool filling and channel widening. Lack of in-stream LWD necessary for pool formation and bank stability. Altered LWD recruitment processes. In addition, debris flows initiating from upstream GMUs have historically impacted these reaches.

Table 1: Dominant geomorphic processes within each geomorphic map unit in the Cedar River Municipal Watershed

Geomorphic Map Unit	Dominant Processes and Characteristics		Primary threats to natural processes and aquatic integrity
	Riparian and Hillslope	Aquatic/habitat forming	
11: Mainstem Cedar River (diversion pool above Landsburg Dam).	Some bank erosion (tree recruitment) on outside bend above dam. Some of these trees are large spruce trees with dbh's of approx. 4-5 feet.	While dam operations do not appear to be trapping gravel (Perkins, 2002), this segment appears to have a greater fraction of sand than observed in upstream reaches. LWD creates cover habitats and helps stabilize banks. Large LWD jams may facilitate the establishment/maintenance of side channels.	Fine sediment deposition from upstream transport. Coarse sediment inputs from bank erosion contribute to pool filling and channel widening. LWD necessary for formation of pocket pools and bank stability. Altered LWD recruitment processes. Policy of wood removal in reach immediately above Landsburg
12: Unconfined, headwater (low stream power) channels dominated by plane-bed and forced pool-riffle morphology.	Unconfined, unentrenched channels occupy u-shaped troughs created by alpine glaciers. Abundant gravel and cobble in active channel. Small drainage areas result in low transport capacity and coarse sediment readily deposited in segments from upstream tributaries.	Boulders and cobble-formed steps occur, though pool depth and complexity increases where LWD is present. LWD forms pools, traps sediment and forms steps regardless of piece size. As fine sediment is abundant in the bed and banks, LWD also creates high velocity zones where clean spawning gravel can be maintained. All segments are above fish barriers and are not accessed by adfluvial or anadromous fish.	Fine sediment deposition from road erosion. Coarse sediment inputs from mass wasting contribute to pool filling and channel widening. Lack of in-stream LWD necessary for pool formation and bank stability. Altered LWD recruitment processes.
13: Variably confined mainstem tributary within glacio-fluvial terrace.	Tight to moderately confined reaches within the Taylor Creek mainstem limit bar formation relative to GMU 14 and 15 channels. Though channel bed elevations currently controlled by bedrock knick points, segments have entrenched into alluvial and glacial outwash terraces containing a wide array of unconsolidated material.	Channel morphology varies between step-pool morphology, where gradients and confinement increase, to plane-bed (with a few pool-riffle sequences) where gradients are lower. Though in-stream LWD is extremely sparse, additions would help stabilize bar formations and increase the frequency of large pools.	Fine sediment inputs from road erosion and mass wasting. Coarse sediment inputs from mass wasting contribute to pool filling and channel widening. Lack of in-stream LWD necessary for pool formation and bank stability. Altered LWD recruitment processes.
14: Wide, alluvial mainstems with pool-riffle and braided morphology	Valley widths are generally at least 3 times greater than the bankfull channel width. Extensive off-channel habitat and floodplain wetland complexes occur, commonly associated with valley wall tributaries and relic channels.	Meandering and braided morphology is common while plane-bed morphology occurs where floodplain incision limits meandering and LWD is scarce. Riparian vegetation and LWD are critical to bank protection, maintenance of complex bank undercuts, and stability of off-channel habitat.	High flows and remobilization of upstream coarse sediment inputs has historically triggered channel widening and lateral shifts. Persistent fine sediment inputs contribute to filling and fining of off-channel pools. Alteration of floodplain vegetation needed for bank stability and hydraulic roughness during high flows. Lack of in-stream LWD necessary for formation of channel-margin pools, cover, and protection of side channels.
15: Unconfined, low gradient pool-riffle and riverine wetland channels.	These headwater and low-relief systems are often controlled by beaver-dam complexes and have stream adjacent wetlands. Due to their position within the landscape, these segments are not prone to catastrophic disturbance.	Pool-riffle and plane-bed morphologies occur within these silt, sand and gravel dominated channels. Hardwood LWD commonly initiates pool scour and helps create hydraulic complexity and gravel cleansing scour. Banks composed of fine grained, cohesive soil prone to erosion.	Fish passage through road crossing structures. Fine sediment delivery from roads may contribute to pool in-filling and gravel embeddedness. Alteration of floodplain vegetation needed for bank stability and shade. Lack of in-stream LWD necessary for formation of channel-margin pools and cover.

Table 1: Dominant geomorphic processes within each geomorphic map unit in the Cedar River Municipal Watershed

Geomorphic Map Unit	Dominant Processes and Characteristics		Primary threats to natural processes and aquatic integrity
	Riparian and Hillslope	Aquatic/habitat forming	
16: Mainstem Cedar River above Landsburg flat-water and plane bed reaches	Bank erosion leading to LWD recruitment. LWD contributing to side channel stability. No mass wasting or stream-adjacent instability noted. Unlike majority of other riparian zones, a few reaches appear to have a higher percentage of alder and other deciduous trees.	Relatively gravel-rich segment with uniquely low shear stress (0.9lbs/ft) relative to all other segments (Perkins, 2002). Pool-riffle to planebed morphology with medial and lateral bars. Sediment storage generally limited to active channel and processes typically controlled by patchy clusters of boulders. LWD traps sediment on channel margins and aids in scour of lateral pools. Large LWD jams may facilitate the establishment of stable side channels and reconnecting patchy floodplains.	Plane-bed (with a few pool-riffle sequences) morphology. Lack of in-stream LWD necessary for pool formation and bank stability. Altered LWD recruitment processes. Bank cover and pocket pools are likely somewhat reduced due to past timber harvest and LWD recruitment processes. Present fish usage strongly linked to these habitat elements.
17: Confined boulder rapids on mainstem Cedar River above Landsburg	LWD playing secondary role; less sediment storage in AC. Boulders providing stability to bed and banks. Upper half of reach was zone of extensive blow down during Dec. 2003 storm.	Boulder rapids (and weakly formed boulder step-pool morphology) common in this segment. LWD seldom initiates bed scour, though pieces facilitate the storage and sorting of gravel pockets. Less sediment storage in active channel than in GMU 16 segments. Little bank erosion or stream-adjacent LWD recruitment evident from this process.	Bank cover and pocket pools are likely somewhat reduced due to past timber harvest and LWD recruitment processes. Present fish usage strongly linked to these habitat elements.
18: Moderate to unconfined mainstem Cedar River above Landsburg Dam dominated by flat-water and planebed morphology	Bank erosion leading to LWD recruitment in some areas. LWD contributing to side channel stability. No mass wasting or stream-adjacent instability noted. Several large side channels are still connected to mainstem, providing sediment and flow storage.	Long flat-water reaches separated by boulder ledges; numerous large side channels; appears steeper than segment 6 or 8 (?)	Unusual reach due to presence of connected side channels. Old LWD jams observed at head of at least 2 of these channels.

Table 2. Dominant processes and threats within each hydrogeomorphic wetland classification type in the Cedar River Municipal Watershed		
Hydrogeomorphic Classification	**Dominant Processes and Characteristics**	**Primary threats to natural processes and aquatic integrity**
L: Lacustrine fringe	Area of open water next to a vegetated wetland larger than 20 acres and > 6.6 feet deep over 30% of the open water areas. Wetlands are characterized by bidirectional and horizontal hydrodynamics. Riparian vegetation may be seasonally inundated and LWD may raft into these wetlands from the adjacent lake.	- Invasive plants such as knotweed and reed canarygrass can reduce diversity of riparian vegetation and outcompete native species. - Periodic inundation by fluctuating reservoir levels alters plant community composition. - Infilling could reduce water storage potential with an influx of sediment supply from road erosion and other chronic sources.
DO: Depressional open DC: Depressional closed	Occur where elevations within the wetland are lower than the surrounding landscape. Movement of surface water and shallow subsurface water is toward the lowest point in the depression (vertical hydrodynamics). *Depressional open* wetlands have an outlet, but the lowest point in the wetland cannot be at this outlet. *Depressional closed* wetlands lack an outlet. Both subclasses of depressional wetlands may have channels entering them. Important as amphibian breeding habitat due to fluctuating hydroperiod that typically limits fish presence.	- Alteration of surface/subsurface water flow captured by the ditch system, or physical division of wetland by road. - Infilling could reduce water storage potential due to influx of sediment supply from road erosion and other chronic sources. - Invasive plants such as knotweed reduce diversity of riparian vegetation and outcompete native species.
RI: Riverine impounded RF: Riverine flow-through	Occur in valleys associated with stream or river channels where dominant hydrodynamics are unidirectional and horizontal. Scour marks in these wetlands are common. They lie in the active floodplain of a river and have direct links to the dynamics of the stream/river. The distinguishing characteristic or these wetlands is frequent flooding by overbank flow from the stream/river (2-yr return frequency). They can also receive significant amounts of water from groundwater and slope discharges. If wetlands lie in the floodplains but are not frequently flooded, they are not classified as riverine (*impounding*-flooded more than 1 week after the flood event, *flow-through*-do not retain surface water longer than the duration of a flood event). Riparian vegetation may be bent in one direction or have layers of sediment deposition.	- Hydrologic disconnection from stream through incision. - Disconnection of natural water movement by road prism or ditch system. - Fill of wetland by road prism. - Flow regulation limits natural flooding processes. - Invasive plants such as knotweed can reduce diversity of riparian vegetation and outcompete native species.
SC: Slope connected SU: Slope unconnected	Occur on hill or valley slopes where groundwater daylights and begins running along the surface. The downhill side of the wetland is always the lowest elevation point in the wetland. Characterized by horizontal hydrodynamics. *Slope connected* wetlands have a direct physical link to another wetland or stream, while *slope unconnected* wetlands are separate from any other water body.	- Infilling reduces water storage potential due to influx of sediment supply from road erosion and other chronic sources including roads in mass wasting high risk areas. - Alteration of subsurface water flow due to altered upland forest conditions or capture by ditch system.

2.2 History of Anthropogenic Disturbance and Landscape Transformation

Before human inhabitation in the CRMW, the major post-glacial disturbances to the landscape—volcanic eruptions, wildfire, debris flows, forest blow down—occurred with a natural frequency on the order of hundreds or thousands of years. Following human settlement by indigenous Native Americans, and especially following European-American settlement, the impacts to the aquatic ecosystem in the watershed became much more frequent, and also spatially extensive.

The alterations caused by Native American activities were likely minor and had little spatially extensive or temporally enduring systemic impact to the aquatic resources in the watershed. These activities include trail building and maintenance, lakeshore encampment, and fishing, hunting, localized burning, and gathering food and other resources. Major impacts to the watershed area began when settlers began to exploit the timber resources in the watershed. Major logging activities began in the lower watershed as early as the mid 19^{th} century, were extensive in the upper watershed in the 1920's – 1940's, and continued sporadically watershed-wide until the mid-1980's. The impacts to the aquatic ecosystem associated with timber harvest come almost exclusively from the direct and indirect effects of forest clearing, and from the construction of forest roads to access harvested timber.

In 1995, a watershed assessment was conducted in the Cedar River Municipal Watershed which provided categorical evaluations of aquatic ecosystem degradation within GMUs throughout the watershed. There are six major areas of degradation that are captured in the analysis and one additional area added for this plan, which together characterize the type and extent of anthropogenic impacts to the aquatic ecosystems of the watershed. The seven elements summarized below include past land management activities within inner gorges and on unstable hillslopes, hillslope surface erosion and runoff from road surfaces, past road construction methods, riparian zone degradation, and adverse impacts to the hydrologic regime.

Landslides in Inner Gorges

Land management activities such as timber felling, ground-lead yarding, and road construction within inner gorges have exacerbated the inherent instability on these commonly very steep, stream-adjacent slopes, producing a number of landslides that have delivered coarse and fine sediment directly to streams. In several instances, these failures triggered debris flows or dambreak floods that resulted in extensive scour and deposition of sediment as well as destruction of riparian vegetation within distant downstream reaches. The GMUs where these processes are common include: 1, 2, 4, 5, 6, and 7.

Road-Generated Shallow, Rapid Landslides

Similar to the situation with inner gorges, past land management activities such as timber harvest, yarding, and road construction using inappropriate methods on unstable or landslide-prone hillslopes have directly or indirectly led to a number of shallow, rapid landslides that have delivered both coarse and fine sediment to downslope streams. Within the CRMW, streams which have exhibited sediment aggradation in response to management-generated landslides include GMUs 1, 3, 5, 6, 8, 10, 12, 13, and 14.

Road-generated Fine Sediment

Increases in fine sediment generated from road surface erosion have contributed to pool in-filling and substrate embeddedness in GMUs 8, 9, 11, and 13-15. While GMUs 10 and 12 are also low gradient, transport limited streams, they are less vulnerable to fine sediment increases due to the naturally high levels observed in many of these streams. While road-generated fine sediment has also delivered to most other steeper gradient GMUs within the CRMW, the transport capacity in these streams is sufficient to route these inputs through streams.

Removal and Disturbance of Riparian Vegetation

The degradation of aquatic resources within the watershed has in part been a consequence of timber harvesting and road building within riparian areas and wetlands. Improper "typing" of streams (see CRMW HCP Section 3.2.4) has also led to the degradation of riparian vegetation resulting in increased sediment, nutrient, and solar energy inputs. These activities also have substantially depleted the supply of potentially recruitable large woody debris (LWD), especially coniferous LWD, in the floodplains of low-gradient streams, transforming their morphology over time. Though woody debris interacts and controls sediment deposition and storage within all GMUs, its role in controlling channel morphology and critical habitat characteristics is particularly important in GMUs 3, 5, 8-15.

Rain-On-Snow Generated Peak Flows
Within mid-elevation (roughly 1000–3500 ft) subbasins within the rain and rain-on-snow dominated zones, historic timber harvest resulting in large stands of immature (<10 years old) timber may have resulted in short-term increases in the frequency or duration of bankfull flows. Channels potentially sensitive to these threats tend to be low gradient depositional streams with gravel- and cobble-dominated beds and banks. In addition, channels tightly confined by valley walls or entrenched into glacio-fluvial deposits have less capacity to spread and dissipate flood flows, making them substantially more vulnerable to peak flow scour. GMUs vulnerable to rain-on-snow generated peak flow scour include 8, 10, 13, and 14.

Landsburg Dam and Water-Diversion
Landsburg dam has, until the recent construction of the fish ladder, prevented anadromous fish from accessing mainstem and tributary channels within the lower CRMW. In light of a recent study completed by Sue Perkins (2003) on sediment sources and transport processes through this reach, the dam does not seem to have dramatically altered the flow of sediment as no substantive changes in channel morphology have occurred in GMU 11 as a result of the dam. The short and long-term effects of water regulation and diversion above the lower Cedar River (GMUs 7, 11, and 16-18), however, is still a matter of speculation and will need to be addressed prior to significant stream or riparian restoration in these reaches.

Chester Morse Lake Water Storage
The Masonry Dam, completed in 1914, increased water storage capacity in Chester Morse Lake from a natural elevation of approximately 1,530 feet to a maximum of approximately 1,570 feet. Management of water for drinking water storage and in-stream flows for anadromous fish in the Cedar River downstream of Landsburg Diversion Dam causes seasonal fluctuations in the reservoir level. Periodic inundation of lacustrine wetlands surrounding Chester Morse Lake has led to changes in plant community composition and wildlife habitat (SPU unpublished data). Increases in storage capacity of the reservoir also backup river flow in the Cedar and Rex rivers immediately upstream of the reservoir altering natural channel processes. Further work is planned to determine effects to both lacustrine wetland and river habitat due to periodic inundation.

While it is beyond the scope of the description here, each of these types of anthropogenically generated impacts to aquatic ecosystems caused numerous direct and indirect impacts (both spatial and temporal) to the aquatic ecosystem of the CRMW. Greater detail on these impacts can be found in the CRMW Stream Channel and Fish Habitat Assessment as well as the Basin Condition Reports written by Foster-Wheeler (1995).

2.3 Conceptual models of CRMW Aquatic Ecosystem Targets
In order to clearly convey our understanding and assumptions about the key geomorphic processes and habitat characteristics of each GMU and HGM class, as well as to underline important differences between them, we developed conceptual models. Given the often limited information on these GMUs (targets), these models also help clarify and communicate the assumptions upon which our restoration plans rest. It should be noted that while channel-reach substrates, namely bedrock, alluvium and colluvium, can be used to define mountain channels (Montgomery and Buffington 1993), the CRMW classification focuses primarily on channels dominated by bedrock and alluvium. Colluvial channels, which are small headwater streams at the tips of a channel network that flow over a colluvial valley fill, exhibit weak or ephemeral fluvial transport. Since episodic transport by debris flows tends to account for most of the sediment transport in these channel types, we will address restoration of colluvial processes within the Upland and Roads Restoration Strategic Plans.

Within the CRMW, one GMU is almost exclusively controlled by bedrock and therefore lacks a contiguous alluvial bed, reflecting a high transport capacity relative to sediment supply. In contrast, all other GMUs are either dominated by or contain alluvial channels which exhibit a wide variety of morphologies and roughness configurations that vary with slope and position within the channel network, and may be either confined, with little to no associated floodplain, or unconfined, with a well-established floodplain. To organize this discussion of conceptual models around our process-based classification scheme, which is well suited to ecological analyses and watershed management (Montgomery and Buffington, 1997), sections are based on the following channel types: (i) cascade, (ii) step-pool, (iii) plane-bed, and (iv) pool-riffle

2.3.1 Conceptual Models of Fluvial Systems

Conceptual models were developed for each GMU to convey the key processes. These models use arrows to depict important linkages between the following elements: Threats to aquatic integrity (historic and current), Watershed Conditions, Geomorphic Processes, Habitat Effects, and Biological Response. In this scheme, threats include natural and management related activities which are likely to (or have already contributed to) the alteration of one or more watershed processes or conditions. The difference between Watershed Condition and Geomorphic Process is one of scale, in which a condition such as the quantity or timing of sediment supplied to a GMU can result in dramatic differences in processes such as sediment deposition or transport or debris flow scour if the timing is episodic. Habitat Effects describe critical elements which past research and watershed-specific observations have shown to be both dramatically impacted by changes to relevant geomorphic processes as well as those which are strongly linked to Biological Response. Many of the habitat effects described in these models (e.g., as shown in bold font in figures 3 through 7) are used to define the Key Ecological Attributes or Factors that underlie the integrity of the GMU and relate to factors we can manage and restore. While arrows are used to illustrate the most important processes, these models are not meant to completely describe all of the processes and interactions within a given GMU. In addition, where there can be dramatic feedback loops between processes and habitat effects, such as between channel migration and bank stability in GMUs 14 and 15 (Figure 7), arrows pointing in both directions are used.

2.3.1.1 Cascades

General description: Cascade channel types contain bedforms typical of steep headwater channels with an adequate supply of coarse sediment to maintain an alluvial bed. The term cascade connotes tumbling flow, although its specific morphologic definition varies and often is applied to both channel units and reaches (e.g., Grant et al., 1990). Our delineation of cascade channels focuses on streams in which energy dissipation is dominated by continuous tumbling and jet-and-wake flow over and around individual large clasts. Cascade channels generally occur on steep slopes, are narrowly confined by valley walls, and are characterized by longitudinally and laterally disorganized bed material typically consisting of cobbles and boulders. Tumbling flow over individual grain steps and turbulence associated with jet-and-wake flow around grains dissipates much of the mechanical energy of the flow. GMUs with predominantly cascade channels also tend to have reaches locally controlled by bedrock and others where clasts are better organized into Step-Pool sequences (see Section 2.3.1.2 below).

Given that cascade channels are frequently floored by coarse, relatively immobile alluvium and laterally contained by steep valley walls, changes in sediment supply or discharge are not expected to result in significant long-term changes to channel bed or banks. In addition, channel roughness needed to dissipate energy is frequently provided by large clasts, with LWD often playing a secondary role. Given their position near the head of many drainages, however, these channels are often subjected to episodic scour and deposition from upstream debris flows and adjacent inner gorge failures.

GMU Models 1-4: Cascades are the dominant channel type within each of these GMUs, though variations in geology and hillslope interaction translate into slight to modest differences in potential response to restoration efforts. As shown in Figure 3, threats to aquatic integrity include culvert design and maintenance, road-generated fine sediment, road-generated landslides, and historic alterations to riparian vegetation. While tight confinement and close proximity indicate that scour from debris flows is an important process in GMUs 1, 2, and 4, however, GMU 3 has historically experienced sediment deposition following remobilization of mass wasting deposits from upstream reaches. In addition, GMUs 1, 2, and 4 have very limited capacity to store coarse or fine sediment and, as a result, no long-term effects on in-stream habitat are predicted. In contrast, GMU 3 has experienced at least short-term responses to increased sediment loads, resulting in some pool filling. The role of riparian vegetation also breaks down along these lines, with observations in GMU 3 demonstrating a modest role of LWD in forming steps and storing sediment while those in GMUs 1, 2, and 4 exhibit a much lower level of potential influence.

While there are also differences between GMUs 1, 2, and 4, none of these influence aquatic restoration planning efforts in the CRMW. As a result, no addition discussion of GMU specific processes will be included, though this information can be obtained by referring back to the original Foster Wheeler Assessment (1995).

2.3.1.2 Step-Pool Channels and Bedrock Chutes

General Description: Like cascade channels, step-pool morphology generally is associated with steep gradients, small width-to-depth ratios, and pronounced confinement by valley walls. Step-pool channels are characterized by longitudinal steps formed by large clasts organized into discrete channel-spanning accumulations that separate pools containing finer material. Step-pool channels exhibit a pool spacing of roughly one to four channel widths, significantly less than the five to seven channel widths that typify self-formed pool-riffle channels. Steps provide much of the elevation drop and roughness in step-pool channels.

Typically, there are two thresholds for sediment transport in both cascade and step-pool channels. During moderate-recurrence-interval flows, bedload material is rapidly and efficiently transported over the more stable bed-forming clasts, which have a higher mobility threshold corresponding to more infrequent events. The lack of significant in-channel storage and the rapid scour of depositional sites during moderately frequent high flows suggest that sediment transport is effectively supply-limited in cascade channels. Bedload transport studies demonstrate that steep channels in mountain drainage basins can be seasonally or stochastically supply-limited. Because of this high transport capacity relative to sediment supply, cascade and step-pool channels function primarily as sediment transport zones that rapidly deliver sediment to lower-gradient channels.

Though persistent, long-term changes in pool depth or substrate composition are not common in step-pool channels, large, chronic increases in sediment have been shown to reduce pool depths and alter substrate compositions (Whittaker, 1987). In addition, LWD can aid in the formation of steps and storage of sediment, particularly in reaches with abundant supply of gravel and cobble.

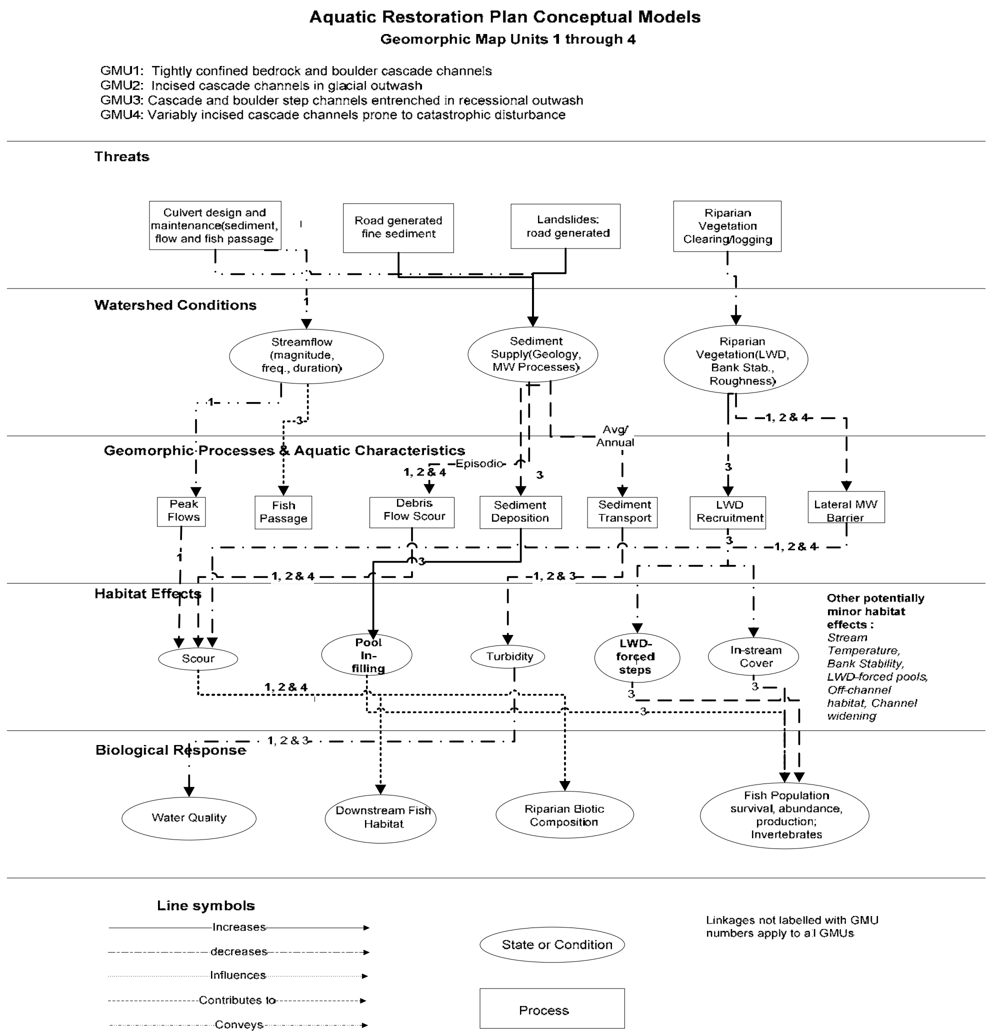

Figure 3: Conceptual models for geomorphic map units 1-4 in the CRMW

GMU Models 5-7: Though all three GMUs exhibit variable amounts of step-pool morphology and have average gradients of 4 to 8%, variations in bedrock control and stream power dramatically effect overall potential responsiveness to land use effects and restoration efforts. In particular, GMU 7 is largely bedrock controlled and the locations of channel spanning steps and pools are largely determined by bedrock. Like most bedrock channels, lack of a contiguous alluvial bed reflects high transport capacities relative to sediment supplies. As indicated in Figure 4, all of the sediment coming into this GMU is linked to important downstream habitat (e.g., GMUs 11 and 16 through 18) and therefore, while changes in sediment, flows, or wood are likely to have little effect on local habitat, such inputs could have important effects to more responsive downstream reaches. Common to all three GMUs, however, is the potential importance of intact riparian zones capable of providing lateral barriers to inner gorge slope failures and large peak flow events.

Though steps within GMUs 5 and 6 are commonly created by boulders, the presence of large wood is often associated with elongated steps and larger pools. As a result of localized entrenchment into glacial outwash and alluvium, GMU 5 banks tend to be more erodible and as a result have higher sediment levels and greater likelihood of sediment deposition triggering bank erosion and changes in substrate composition. Also common to both 5 and 6 is the potential influence of culverts on fish passage and habitat availability.

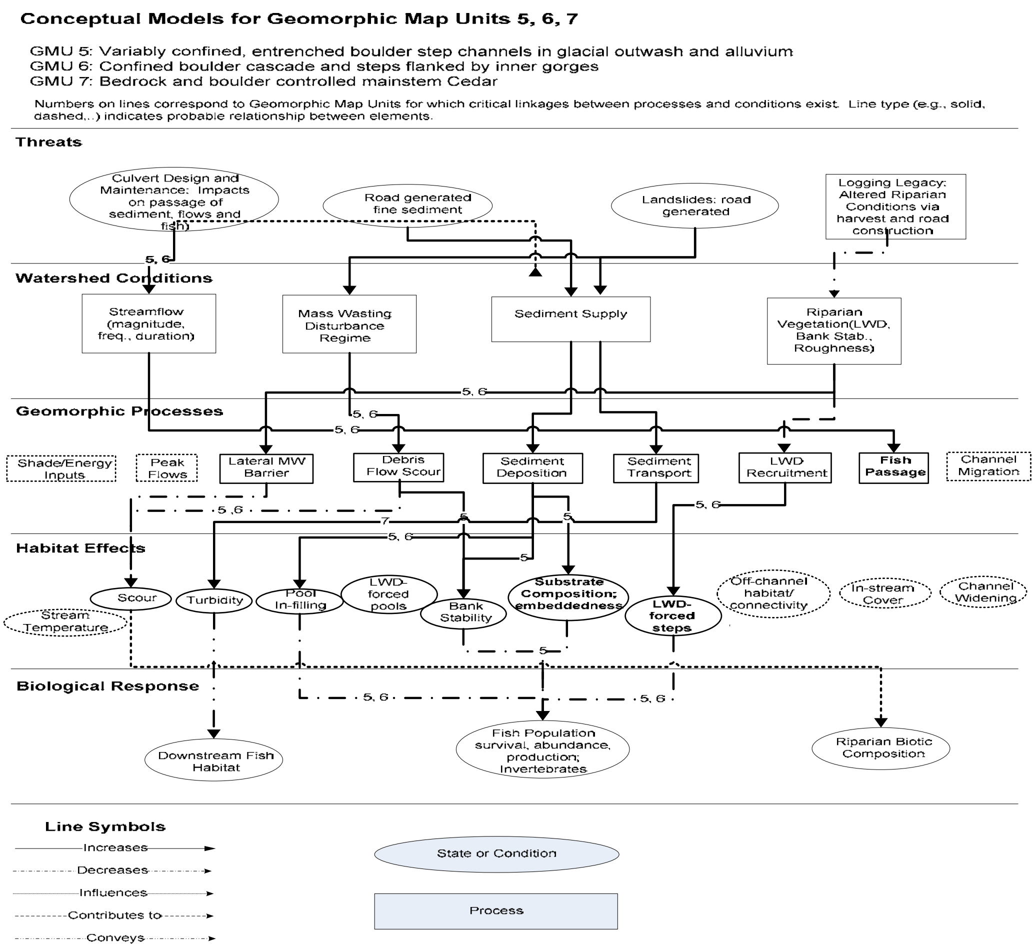

Figure 4: Conceptual models for geomorphic map units 5-7 in the CRMW

GMU Model 17:

GMU 17 is restricted to reaches within the lower Cedar River mainstem and is dominated by boulder rapids and weakly formed boulder step-pool morphology. While reach-average gradients are less than 3%, boulder-clusters in tightly confined reaches result in locally steep drops. The channel bed is composed predominantly of large cobbles and boulders and deep pools are the result of vertical bed oscillations, with no apparent pool initiation structure. LWD seldom initiates bed scour, though pieces facilitate the storage and sorting of gravel pockets. Extensive bed and bank armoring by boulders and large cobbles results in little bank erosion which in turn appears to limit stream-adjacent LWD recruitment. (Note: The conceptual model for this GMU is included with GMUs 16 and 18 discussed in Section 2.4.1.3 below).

2.3.1.3 Plane-Bed

General Description: Plane-bed channels lack discrete bars and encompass glide (run), riffle, and rapid morphologies (Montgomery and Buffington 1993). Plane-bed reaches occur at low to moderate slopes, typically 1 – 4%, in relatively straight channels that may be either unconfined or confined by valley walls. In mountain drainage basins of western Washington they typically are dominantly gravel- to cobble-bedded. Plane-bed channels differ morphologically from both step-pool and pool-riffle channels in that they lack rhythmic bedforms and are characterized by long stretches of relatively featureless, planar bed. Plane-bed channels typically exhibit armored bed surfaces calculated to have a near-bankfull threshold for mobility and are transitional between supply- and transport-limited morphologies. Variations in confinement dictate the channels capacity to widen in response to increases in sediment load. Where sediment or discharge regimes change, channel responses can include changes in bed surface texture, channel geometry (width and depth), or depth of scour while increased sediment supply to plane-bed channels is expected to result in either bed fining or aggradation. As LWD tends to provide sufficient flow convergence and divergence necessary to form pools in plane-bed channels, the presence of wood strongly controls the frequency and size of pools. Forced pool-riffle channels are the most common obstruction-controlled morphologies in forested mountain drainage basins and often occur in reaches that would assume a plane-bed morphology in the absence of LWD. Given the strong link between in-stream LWD and pool habitat, reaches with potential plane bed morphology will be a large focus of CRMW's in-stream wood restoration efforts.

GMU Models 8-13: The large number of plane-bed GMUs (figures 5 and 6) is primarily due to variations in confinement, sediment availability, and stream power (drainage area) which in turn influence potential channel response to changes in the delivery and flow of water, sediment, and wood. While GMUs 8, 9, and 12 are generally unconfined and underlain by glacial outwash, alluvium, and till, GMUs 10, 11, and 13 are either moderately confined or entrenched, producing reaches with less capacity to store sediment and adjust channel form in response to upstream inputs. Within the unconfined GMUs, differences in mass wasting processes (GMU 8) and stream power (GMU 12) produce variations in predicted response to disturbance (threats) and restoration efforts. In particular, GMU 8 channels occur on alluvial fans and therefore have sediment supplies and disturbance regimes strongly controlled by upstream mass wasting events. As a consequence, the role of riparian vegetation in mitigating the downstream propagation of debris torrents is important. Within headwater channels (GMU12) where stream power is locally insufficient to transport coarse sediment, large inputs would likely lead to channel widening, extensive bank erosion, and persistent reductions in pool frequency and depth.

In the more confined or entrenched plane-bed channels, where channel widening in response to sediment inputs is not generally feasible, channel response is restricted to adjustments in bed particle size, bank stability and pool filling and increased bedload transport. One notable exception to this discussion is GMU 10, where channel widening has occurred in response to sediment inputs even though the channel is moderately confined. This response is largely due to the relatively large quantity of sediment delivering to this GMU due to proximity to upstream sediment sources and location within the channel network (namely the upper-most (first) depositional reach within a subbasin).

GMU Models 16 and 18: These lower mainstem Cedar River GMUs represent moderately confined low gradient reaches (0.5-2%) reaches dominated by coarse planebed morphology, with lesser amounts of pool-riffle morphology and boulder ledges. Perhaps the most notable difference between GMUs is the relatively gravel-rich segments, with uniquely low shear stress (0.9lbs/ft) relative to all other segments (Perkins, 2003), in GMU 16 below the confluence with Taylor Creek. As a result of this gravel supply, pool-riffle morphology with medial and lateral bars are present, though sediment storage is frequently limited to the active channel and controlled by patchy clusters of boulders. Where present, LWD traps sediment on channel margins and aids in scour of lateral pools. Similar to GMU 18, large LWD jams may facilitate the establishment of stable side channels and reconnecting patchy floodplains. While GMU 18 includes numerous large side channels which represent potential significant winter fish habitat, gravel storage is less evident (likely due to limited gravel supply) and long flat-water reaches separated by boulder ledges are common.


Planebed reach on lower Cedar River mainstem (GMU16)

2.3.1.4 Pool-Riffle

General Description: Pool-riffle channels have an undulating bed that defines a sequence of bars, pools, and riffles. Pools are rhythmically spaced about every 5-7 channel widths in self-formed pool-riffle channels, but channels with a high loading of large woody debris exhibit smaller pool spacing. Pool-riffle channels occur at low gradients and are generally unconfined, with well-established floodplains. Substrate size in pool-riffle streams varies from sand to cobble, but typically is gravel-sized.

Pool-riffle channels have heterogeneous beds that exhibit a variety of sorting and packing, commonly with a coarse surface layer and a finer subsurface. Armored gravel-bed channels typically exhibit a near-bankfull threshold for general and significant bed surface mobility. Movement of surface grains releases fine sediment trapped by larger grains and exposes finer subsurface sediment to the flow, contributing to a steep rise in bedload transport with increasing shear stress. Bed movement is sporadic and discontinuous, depending on grain protrusion; very rarely is the whole bed in motion and material eroded from one riffle commonly is deposited on a proximal downstream riffle. Although both pool-riffle and plane-bed channels display a mix of supply- and transport-limited characteristics, the presence of depositional bar-forms in pool-riffle channels suggests that they are generally more transport-limited than plane-bed channels. The transport-limited character of both of these morphologies, however, contrasts with the more supply-limited character of step-pool and cascade channels.

As a result of being transport limited and generally unconfined, pool-riffle channels often exhibit the widest variety of responses to changes in sediment, water, and wood. Similar to unconfined plane-bed channels, a lack of confinement allows for channel widening in response to increased discharge or sediment. An increase in the timing or magnitude of peak flows also has the potential to cause bank erosion and alter meander development, resulting in off channel habitat connectivity and local changes in slope. Other likely responses to elevated coarse and fine sediment loads include pool filling, bed fining, and accelerated channel migration or alteration to braided morphology.

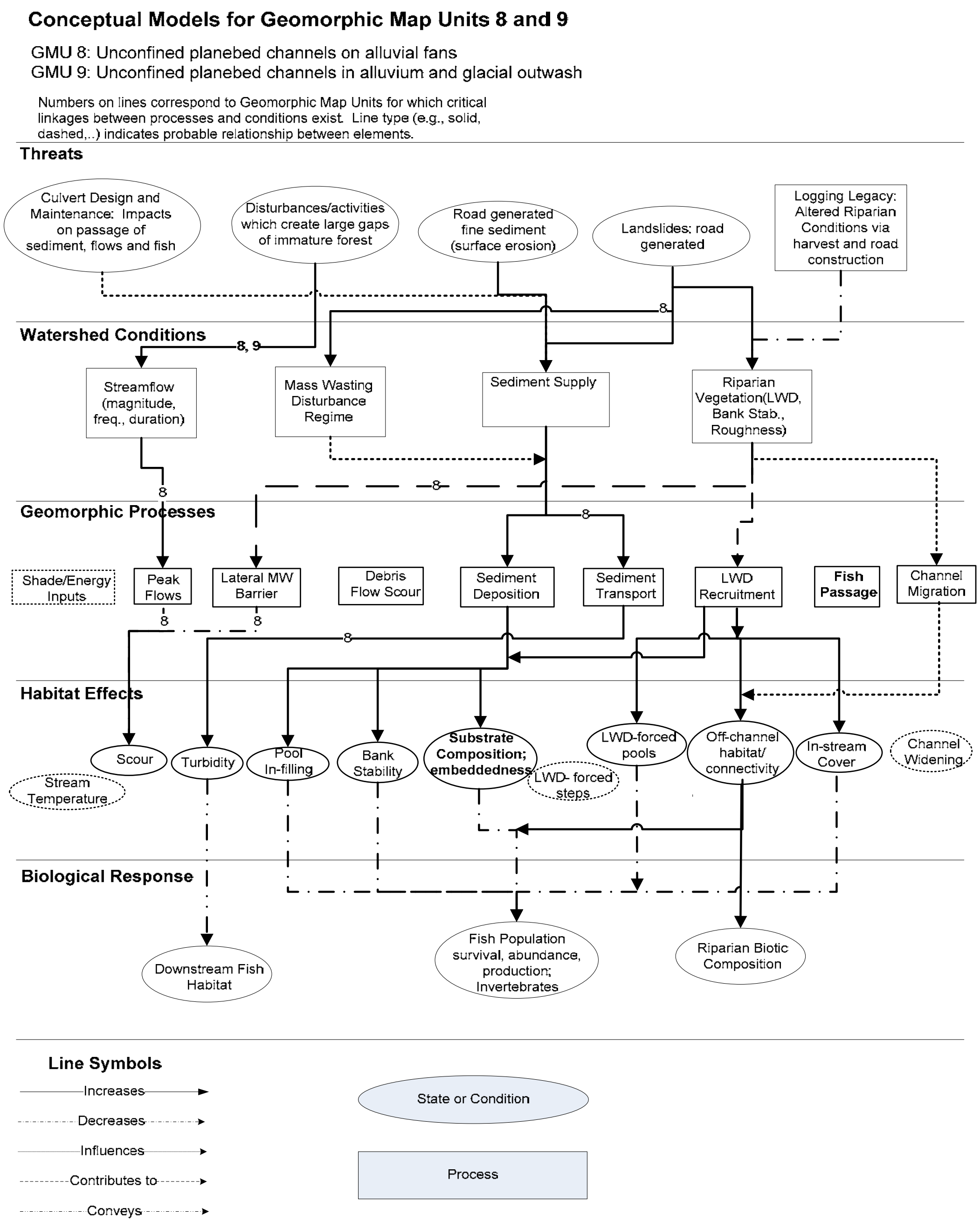

Figure 5: Conceptual models for geomorphic map units 8-9 in the CRMW

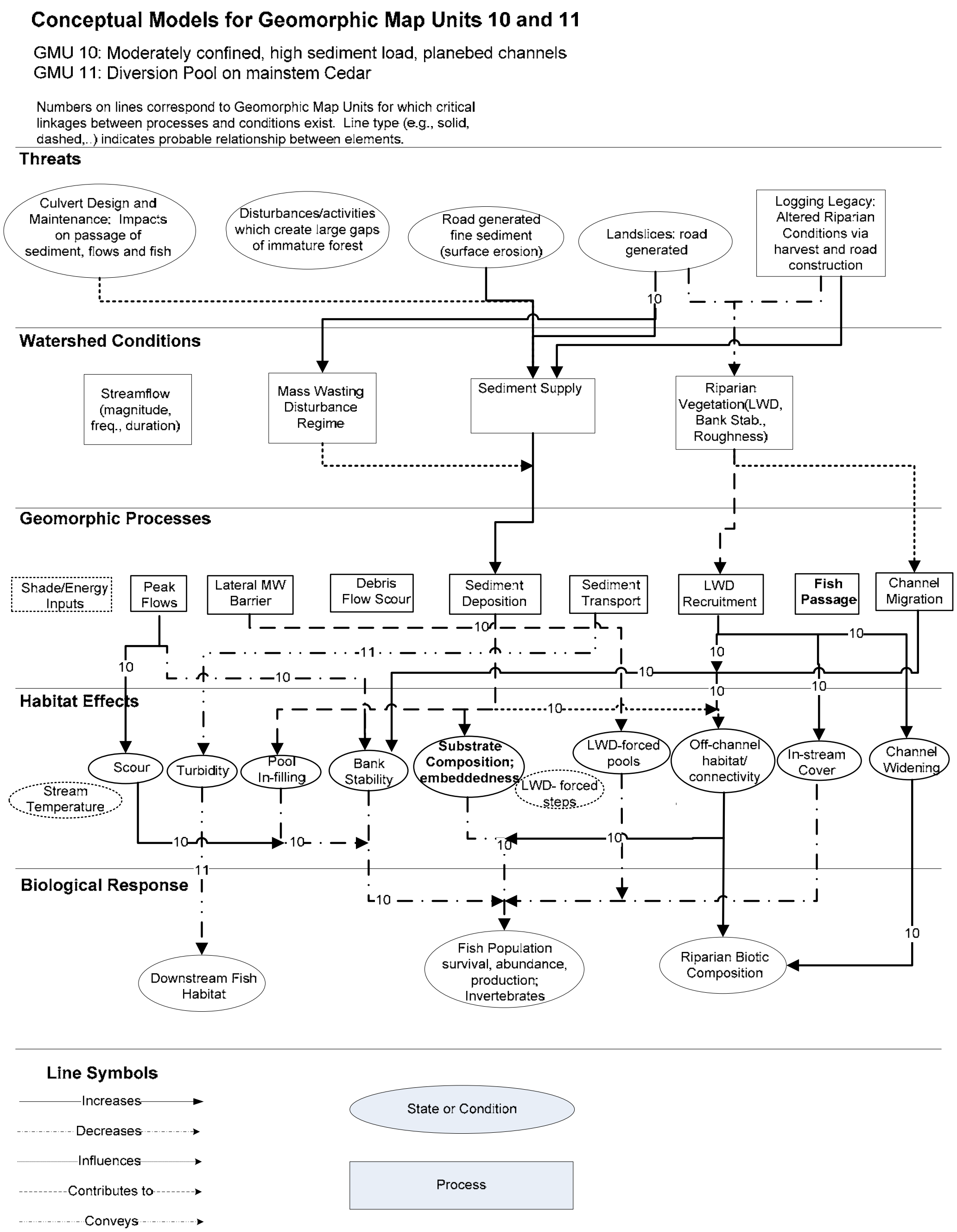

Figure 6: Conceptual models for geomorphic map units 10-11 in the CRMW

Conceptual Models for Geomorphic Map Units 12 and 13

GMU 12: Unconfined headwater (low stream power) channels with planebed and pool riffle topography
GMU 13: Mainstem Taylor entrenched in glacio-fluvial terrace

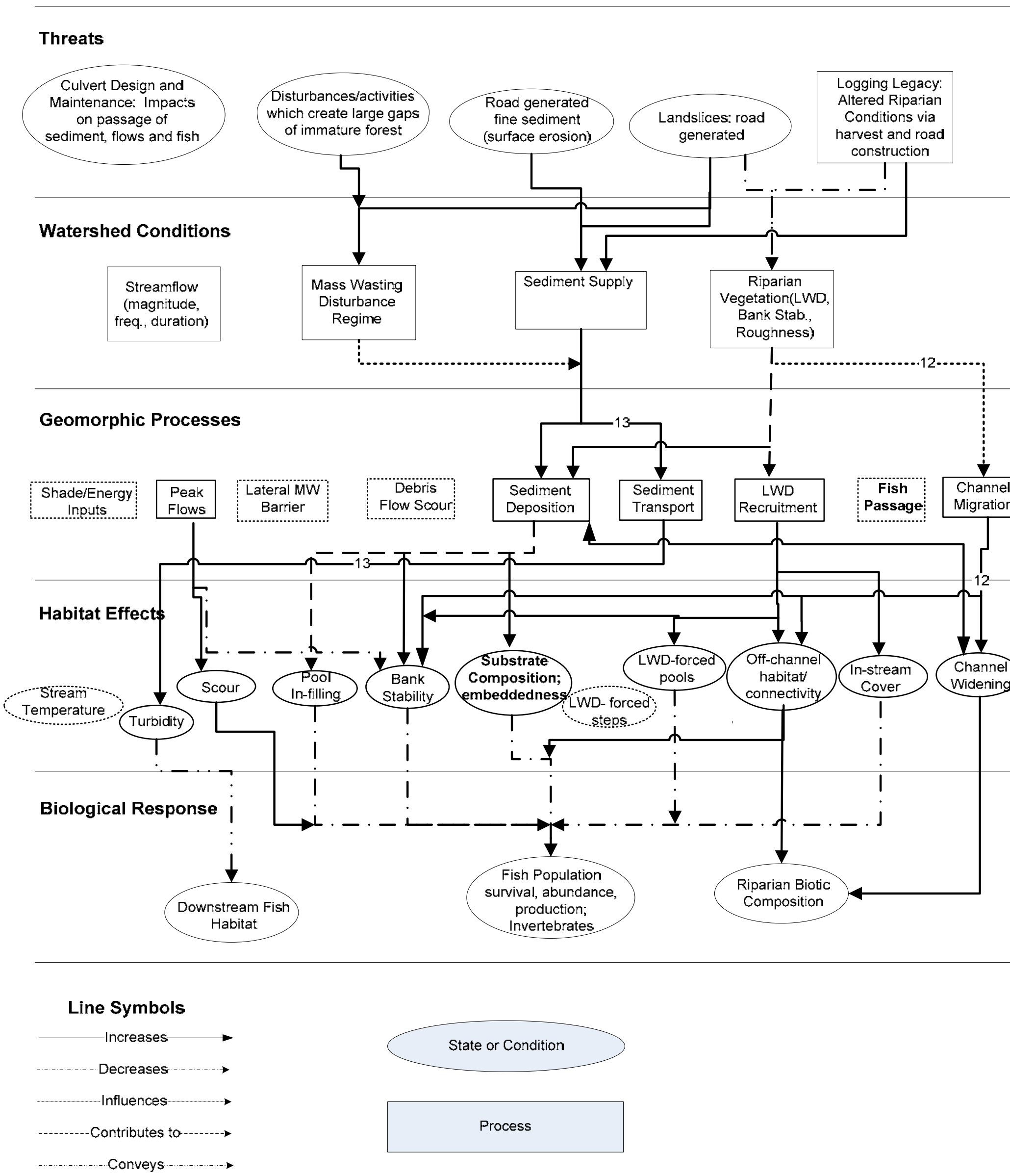

Figure 7: Conceptual models for geomorphic map units 12-13 in the CRMW

Conceptual Models for Geomorphic Map Units 14 and 15

GMU 14: Unconfined pool riffle mainstems (Upper Cedar and Rex Rivers)
GMU 15: Unconfined pool riffle and riverine wetland channels

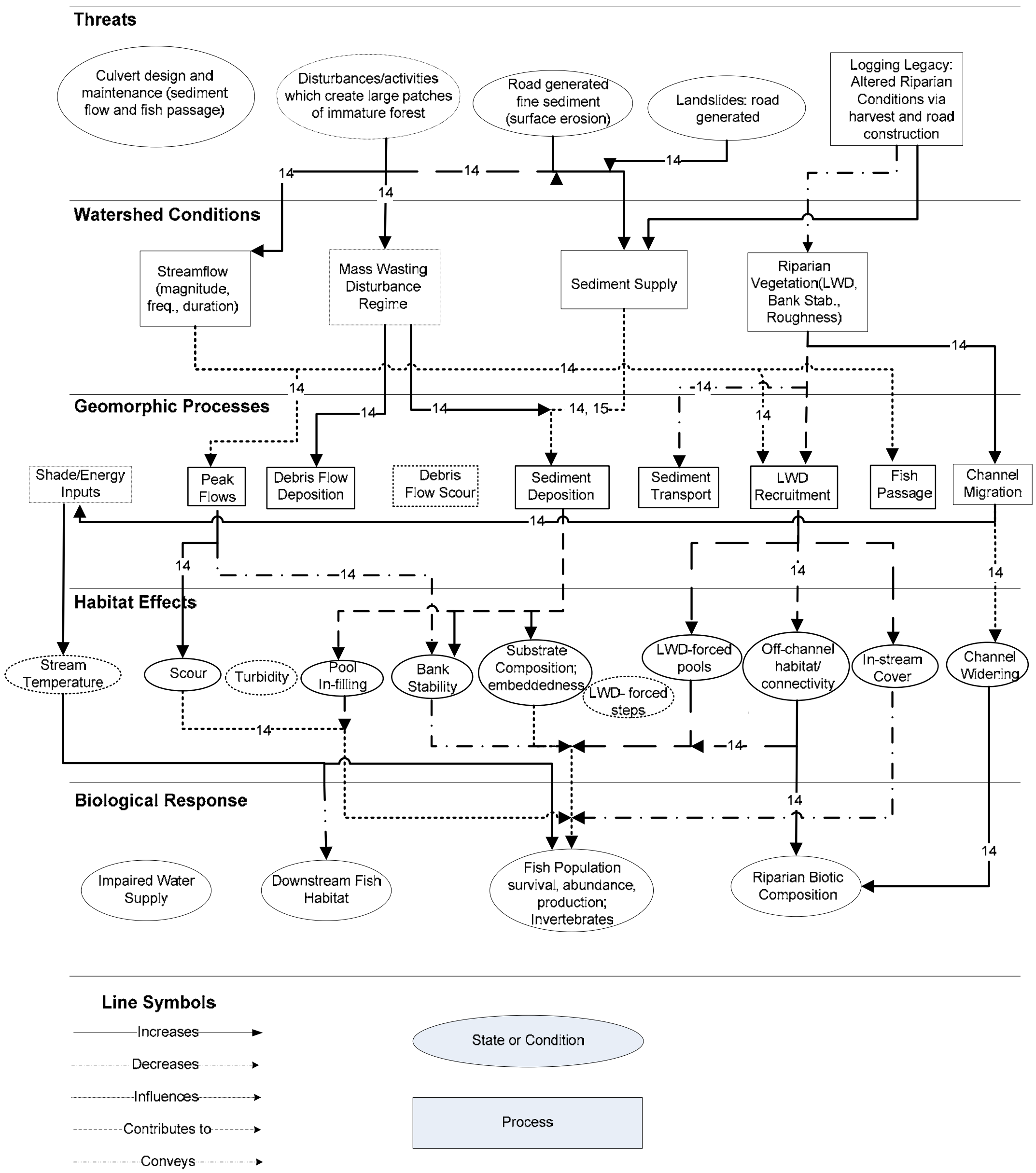

Figure 8: Conceptual models for geomorphic map units 14-15 in the CRMW

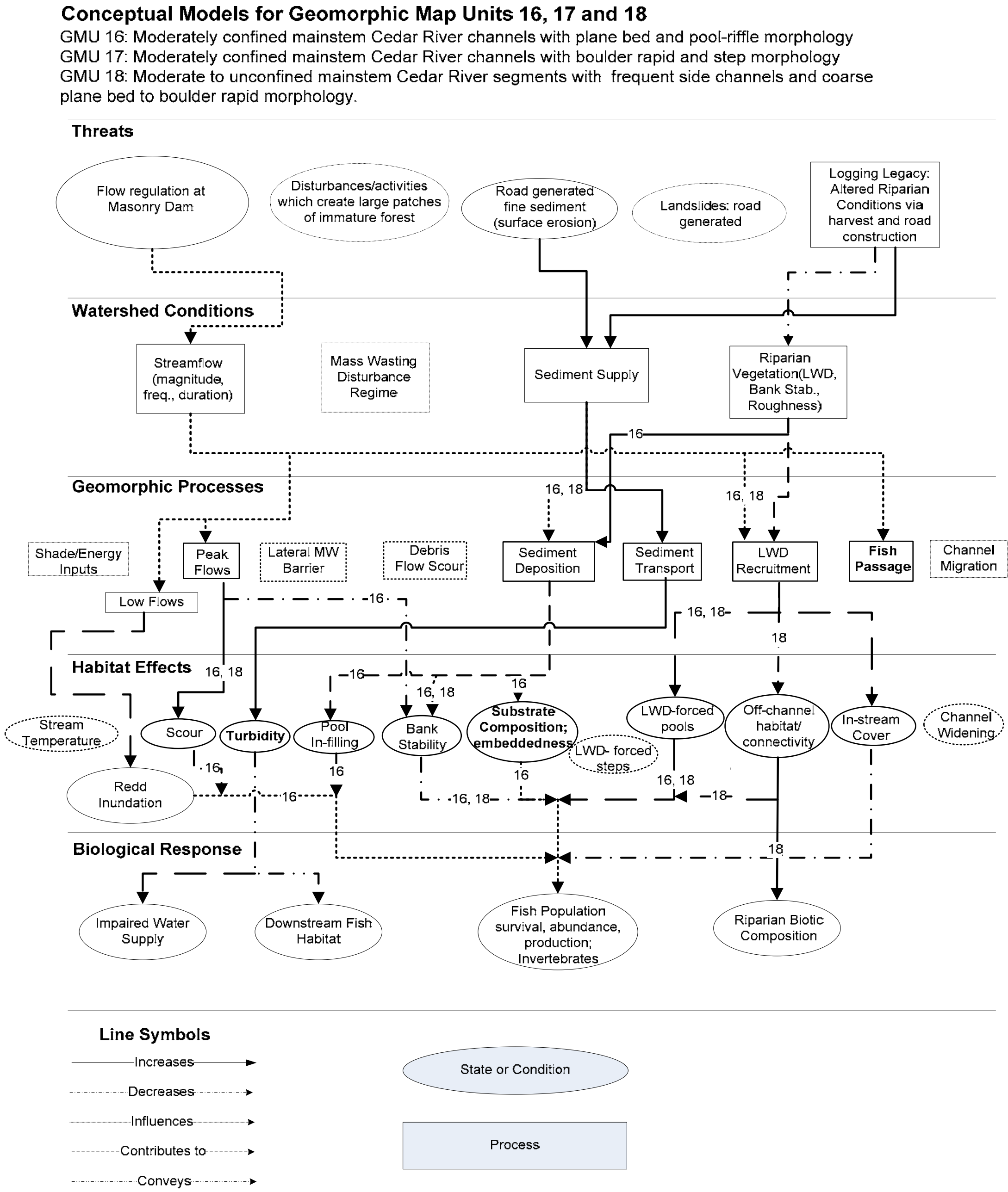

Figure 9: Conceptual models for geomorphic map units 16-18 in the CRMW

Given the dominance of unconsolidated alluvium in channel banks and the abundance of sand, gravel, and small cobbles within the channel bed, the role of riparian vegetation is critical to the maintenance of a variety of geomorphic processes within this channel type. For example, dramatic widening occurred in comparable channels in the North Fork Tolt watershed where riparian vegetation clearance triggered dramatic channel widening due to reductions in root strength. The dramatic bank erosion, in turn, delivered substantial quantities of sediment into the channel which triggered additional widening, loss of pools, and the transformation of pool-riffle into braided morphology. In addition to providing bank stability via root strength, intact riparian zones provide critical roughness needed to dissipate energy and store sediment and organics associated with large floods. Riparian vegetation is also a critical source of in-stream wood needed for bank and bar stability, the creation of channel margin pools and in-stream cover, and protecting off-channel habitat.

GMU 11 (Diversion Pool): Variable entrenchment and relatively low supplies of coarse sediment result in a relatively stable pool riffle reaches with gravel bars largely restricted to point bars and behind large in-channel obstructions. Though this reach is immediately upstream of the Landsburg Dam and operations do not appear to be trapping gravel (Perkins, 2003), this segment does appear to have a greater fraction of sand than observed in upstream reaches. A policy of wood removal in this reach, which is currently being evaluated within the LWD management plan for the Cedar River, is locally limiting cover and bank stability provided by LWD. The hydraulic effectiveness of in-channel LWD is likely restricted by flow regulation and backwater effects from the dam, however, suggesting that future habitat responses to LWD recruitment are likely to be less pronounced than upstream reaches within GMU 16. (Note: Conceptual model for GMU 11 is included with GMU 10 displayed in Section 2.4.1.3)

GMU Models 14-15: While the above discussion applies to both GMU 14 and 15, these units have very different sediment and flow regimes which result in significant differences in expected response to potential riparian and aquatic restoration projects. Most notably, GMU 14 corresponds to the mainstem Rex and Upper Cedar Rivers where high discharges during peak flows readily transport and redistribute wood and sediment. In contrast, GMU 15 channels drain relatively small areas, resulting in significantly less capacity to transport coarse sediment or woody debris. As a result, only large wood with rootwads tend to be stable and capable of providing key functions in GMU 14 whereas in 15 much smaller wood and even individual pieces may be sufficient to create pools and provide cover and bank protection. In addition, as shown in Figure 7, GMU 15 channels generally are only weakly connected to upstream sediment sources and as a result, dramatic changes in channel width or bank stability triggered by coarse sediment deposition, while possible, are not likely in these channels. However, given their low gradients and lack of confinement, both GMUs are vulnerable to inputs of fine sediment contributed by roads or upslope source areas.

Common to both GMUs is the importance of riparian vegetation in providing bank stability and the maintenance of off channel habitat. Though both GMUs may be responsive, an assumption was made that alterations to the riparian vegetation along GMU15 channels which significantly alters shade have the potential to cause elevated stream temperatures. This assumption is based on the relatively long residence times of water within these units given their low gradients. Though GMU 14 also has the potential to exhibit elevated stream temperatures in response to reductions in riparian shade, our assumption is that subsurface flows and upwelling of cooler hyporheic water within this GMU reduce the likelihood of elevated stream temperatures.

2.3.2 Conceptual Models of Hydrogeomorphic (HGM) Classes of CRMW Wetlands

Conceptual models for each wetland HGM class were developed based a) wetland processes , b) threats to wetland processes, c) habitat effects, and d) biological response, to show key processes and how these processes influence habitat quality. Threats to wetland processes represent threats leading to an alteration of key wetland processes, and may result from a legacy of past management practices or a potential threat from current forest or road conditions. Included in wetland processes are those elements thought most prevalent in the CRMW for ultimately determining wetland habitat quality. Many more ecological processes are important in wetland ecosystems, but were not included in these conceptual models because the current condition and management of the watershed gives them a limited role in changes to the function of wetland systems. For example, nutrient cycling is an extremely important function performed by wetlands especially in urbanized settings where increased levels of fertilizers and pesticides may alter this important ecological function. Habitat effects include specific characteristics of each wetland that past research and observations in the CRMW have shown to be tightly linked to response of biological organisms. Arrows are used to show important linkages between various elements of the model.

2.3.2.1 Depressional Wetlands (Open and Closed)
Depressional wetlands generally occur in topographic depressions where the main modes of water transfer are precipitation, snowmelt, intermittent flows from adjacent upland forest, and in some cases groundwater discharge. These wetlands experience vertical hydrodynamics, frequently on a seasonal basis. Duration of surface water retention varies annually and is heavily dependent on precipitation and snowmelt. Two subclasses for depressional wetlands are identified in the CRMW; depressional open and depressional closed wetlands. Depressional open wetlands contain an outlet leading away from the wetland (e.g., a cirque lake), while depressional closed wetlands lack an outlet (e.g., a pothole wetland). Inlets to both subclasses may be present.

2.3.2.2 Lacustrine Fringe Wetlands
Lacustrine fringe wetlands are located adjacent to lakes larger than 20 acres and more than 6.6 feet deep over 30% of the open water area. Water moves through these wetlands mainly in a horizontal direction from the lake, though vertical movement associated with groundwater discharge and precipitation also occurs. These wetlands lose water as it flows back into the lake after flooding and by evapotranspiration. Nutrients, sediments, organic matter, and aquatic organisms flow between the lake and lacustrine fringe wetland freely as higher lake levels inundate lacustrine fringe wetlands. Many lacustrine fringe wetlands in the CRMW are found bordering Chester Morse Reservoir. These wetlands may experience repeated inundation throughout the year as the level of the reservoir rises and falls by water management operations.

2.3.2.3 Riverine Wetlands (Flow Through and Impounding)
Riverine wetlands occur in river valleys where they are directly affected by streamflow including overbank flow or backwater effects. These wetlands lie in the active floodplain of the stream and experience frequent flooding (2 year frequency). In addition, riverine wetlands receive water through groundwater and slope discharge from the adjacent landscape as well. In the headwater reaches, most riverine wetlands interface to slope wetlands as the channel banks disappear. Riverine wetlands were divided into riverine impounded wetlands and riverine flow-through wetlands. The duration of flooding determines these subclasses. Any wetland that remains flooded for more than one week after the flood event is classified as a riverine impounding wetland. Riverine flow-through wetlands do not retain water for longer than the duration of the flood event.

2.3.2.4 Slope Wetlands (Connected and Unconnected)
Slope wetlands are found at slope breaks where groundwater “daylights” and begins running along the ground surface. The lowest point in the wetland is always at the downhill edge and no topographic depressions are present in the wetland. Principle water sources include groundwater discharge, surface and subsurface flow from adjacent upland forest, and precipitation. All water flow is directed unilaterally downslope. Subclasses of slope wetlands include slope connected and slope unconnected. Slope connected wetlands have a direct physical link to a wetland or stream, while slope unconnected wetlands are separate from any other water body.

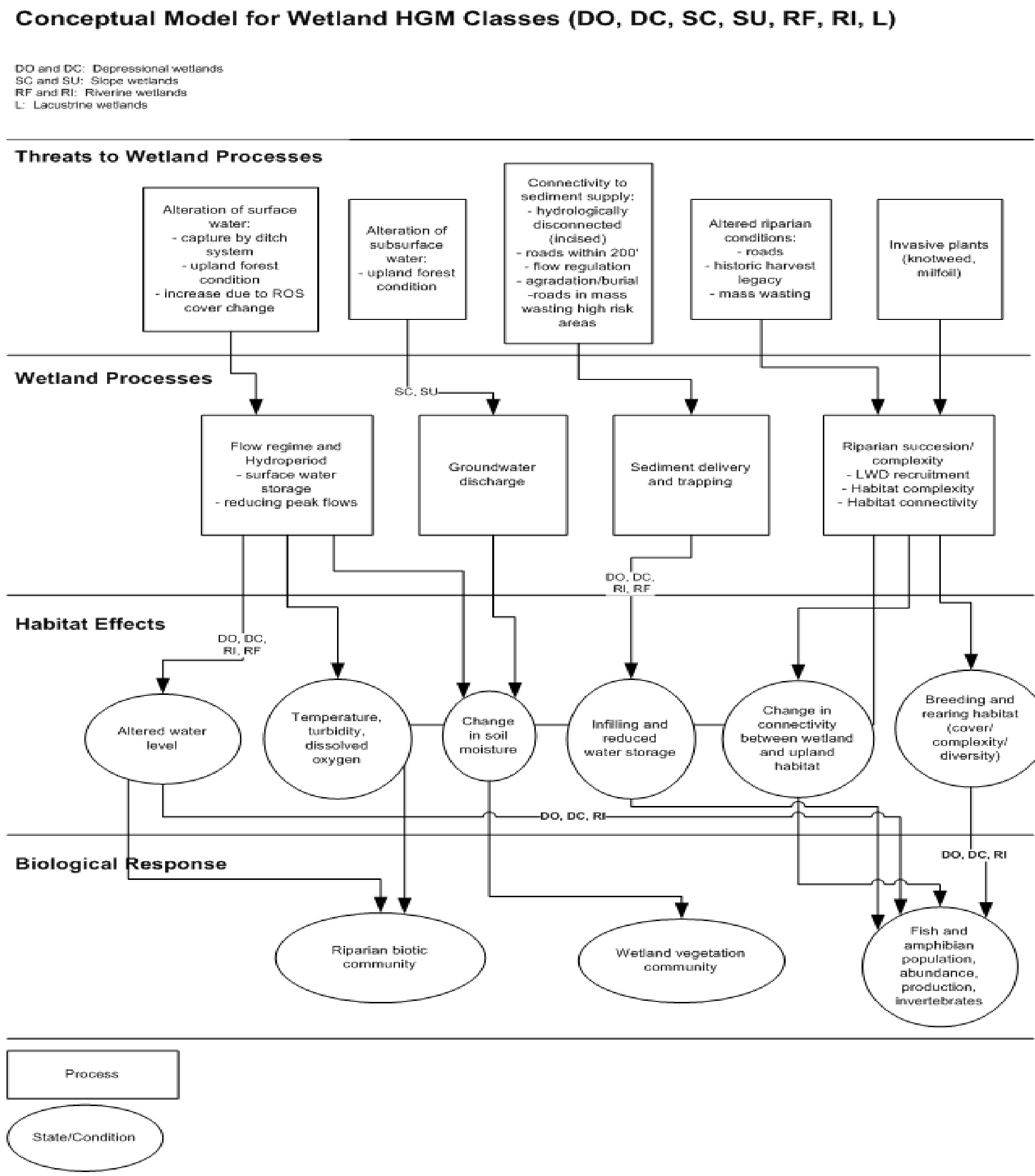

Figure 10: Conceptual models for Hydrogeomorphic (HGM) Classes of CRMW Wetlands

2.4 Key Ecological Attributes and Indicators

In order to define clear, measurable objectives necessary for successful monitoring and adaptive management, key ecological attributes were established which underlie the functioning of each target and the integrity of important geomorphic processes (factors). These attributes, rather than representing a laundry list of all potentially important things, represent the critical components of structure, function, and composition

(Groves, 2003) within one or more GMUs or HGM classes. Within our conceptual models, key attributes (shown in bold in figures 3-10) commonly represent habitat effects that are known to be associated with changes in various ecological factors (geomorphic processes). Other important characteristics of key attributes are their sensitivity to management and potential restoration efforts. Finally, given that all key attributes are monitored in some manner, an effort was made to limit the number to less than five (5) per GMU (target) or HGM class.

2.4.1 Key Ecological Attributes

Six key ecological attributes were identified for the stream/riparian forest and wetland ecosystems. These attributes include: LWD recruitment processes (an attribute also included in the Riparian Strategic Plan), LWD function, flow regime and hydroperiod (peak flows), sediment transport and deposition, connectivity of aquatic habitats, and biotic community composition. The technical rationale for employing these attributes is described below.

***Attribute*: LWD Recruitment Processes**
Technical Rationale: Habitat complexity and productivity are maintained largely by fluxes of water, sediment, organic matter, and large woody debris. LWD physically alters local channel hydraulics via flow obstruction, influencing sediment storage and transport and in large part determining the physical morphology of many channels. In particular, the complexity, spatial array, and hydraulic stability of habitat features, most notably pools, are strongly controlled by LWD (Keller and Swanson, 1979; Bilby and Ward, 1991). In most moderate- and low-gradient streams within the CRMW, LWD plays a critical role in pool formation, bank stability, and the creation and maintenance of off-channel habitat. In addition, stable and complex mixes of such habitat features formed by wood are particularly important for salmonids (Ralph et al., 1994; Murphy et al., 1989).

***Attribute:* LWD Functions**
Technical Rationale: Habitat complexity and productivity are maintained largely by fluxes of water, sediment, organic matter, and large woody debris. LWD physically alters local channel hydraulics via flow obstruction, influencing sediment storage and transport, and in large part determining the physical morphology of many channels. In particular, the complexity, spatial array, and hydraulic stability of habitat features, most notably pools, are strongly controlled by LWD (Keller and Swanson, 1979; Bilby and Ward, 1991). In most moderate and low gradient streams within the CRMW, LWD plays a critical role in pool formation, bank stability, and the creation and maintenance of off-channel habitat. In addition, a stable and complex mix of such habitat features formed by wood are particularly important for salmonids (Ralph et al., 1994; Murphy et al., 1989) as well as pond and terrestrial breeding amphibians in and near wetlands (Richter 1997).

***Attribute:* Flow Regime and Hydroperiod**
Technical Rationale: Flow regimes organize and define river patterns, and natural patterns of flow variability are directly related to aquatic community structure and help maintain native species (Poff et al., 1997). Hydroperiod is defined as the duration of time a wetland holds water. Within the CRMW, activities that have potentially altered flow regimes and wetland hydroperiod include forest management, namely timber harvest and road construction, as well as flow regulation and diversion (within the lower CRMW). Unlike riparian harvest and LWD recruitment processes, however, it is likely that peak flow regimes may have already returned to within their natural range of variation within most subbasins following timber harvest. In order to resolve this issue and evaluate the extent to which current and potential future forest stand conditions may be altering peak flow generating processes, as identified in Table 8 (Research question R12), additional hydrologic modeling will be conducted. A second knowledge gap, question R11, also has been identified regarding the extent to which flow management has altered channel forming processes (sediment transport and riparian interactions) between Chester Morse Lake and Landsburg. Alteration of surface and subsurface water flow by capture in the ditch system may have profound effects on wetland hydroperiod. Water may be

routed away from natural drainage patterns on slopes thereby heavily influencing supply to slope or depressional wetlands.

Attribute: **Sediment Supply and Movement**
Technical Rationale: Sediment transport and storage strongly determines the distribution of aquatic habitats. Rivers in a state of dynamic equilibrium frequently exhibit a balance between scour and deposition whereas when sediment supply exceeds local transport capacity, stable habitat elements and substrate may be buried. Within the CRMW, the Foster Wheeler (1995) channel assessment identified numerous reaches where past riparian and upland management activities have triggered landslides delivering large volumes of coarse and fine sediment to the aquatic system. As a result, significant long-term changes in channel morphology (pool-riffle and plane bed to braided morphologies), bank stability, and fish habitat have occurred. Sediment transport and subsequent storage alters wetland quality as breeding habitat for aquatic organisms and changes functional qualities of wetlands. Threats of elevated sediment deposition into wetlands may be posed by upslope roads within 200 feet of wetlands. Flow regulation also potentially effects natural sediment dynamics within wetlands, and burial or aggradation in wetlands may occur from altered sediment regimes.

Attribute: **Connectivity of Aquatic Habitat**
Technical Rationale: Off channel and seasonally wetted habitats reflect the interface between aquatic and terrestrial habitat which provide refugia during peak flow events and areas for reproduction, rearing, and feeding. Connectivity is also important for flood attenuation, promoting the deposition and long-term storage of fine sediment and organics, and the maintenance of diverse riparian plant communities. Within the CRMW, aquatic habitat connectivity is a particularly important attribute along both the upper and lower sections of Cedar River, lower Rex River (GMU 14), and patchy, riverine wetland channels (GMU15).

Attribute: **Biotic Community Composition**
Technical Rationale: While the above attributes operate at coarser scales and focus on indirect measures of aquatic habitat, tracking the integrity of the aquatic biota within the CRMW is essential if we are to understand whether the ultimate objectives of our restoration plan, namely the conservation of threatened and endangered species, are being attained. Changes in the composition of vegetation and aquatic organisms can signal effectiveness, or lack thereof, of restoration efforts. Controlling the spread of invasive plants such as knotweed, Himalayan blackberry, and milfoil and preserving natural vegetative diversity preserves habitat within stream and wetland systems.

2.4.2 Key Ecological Indicators

Indicators represent key information about the structure, function, and composition of an ecosystem (Dale and Beyeler, 2001). The most useful indicators are those which capture ecosystem complexities yet are simple and easy to monitor. According to Dale and Beyeler (2001), indicators should meet the following criteria: be easily measured; be sensitive to stresses on the system; respond to stress in a predictable manner; be anticipatory; predict changes that can be averted by management actions; be integrative; have a known response to disturbances, stresses and changes over time; and have a low variability in response. With this challenging set of requirements in mind, indicators were identified to characterize each of the aquatic attributes discussed above. As shown in the first two columns of Table 3, at least one indicator has been identified for each attribute. The selected indicators range from the site scale (assessments of individual projects) to the watershed scale (assessments of the cumulative effect of management across the entire watershed). While the utility of indicators discussed below are for the most part widely used and substantiated, as our understanding of each target (and the corresponding conceptual model) improves, it is likely that we will develop increasingly sensitive and efficient indicators. For each indicator (organized by attribute) listed below, a brief technical justification is provided. In addition, sources are listed for data and existing research used in establishing either desired future or natural range of conditions and interim objectives. Finally, knowledge gaps relevant to one or more of the indicators are identified. A detailed description of these issues and a plan for resolving them can be found in Table 8.

Table 3: Technical rationale, source of data and status of knowledge gaps for aquatic ecosystem indicators within the Cedar River Municipal Watershed.

Key Ecological Attributes	**Indicator**	**Relevant GMUs/ HGM Types**	**Technical Rationale**	**Data Source**	**Knowledge Gap** *(addressed in Table 7)*
LWD Recruitment process	Tree Species Composition, DBH, Tree Height, Tree Density		Addressed in Riparian Restoration Strategic Plan		
	Frequency of large woody debris (LWD) per 100 m of channel length	8-15	Individual pieces and LWD jams play an important role in controlling channel morphology as well as storage and transport processes of sediment and organic matter (Bisson et al., 1987). In addition to these important physical functions, LWD represents an important source of nutrients and insects to the aquatic system (Naiman and Sedell, 1979). As a result, LWD frequency represents an important measure of aquatic health, integrating of an array of important aquatic processes and conditions that are well established in the literature. Well established relationships exist between LWD frequency and fish habitat characteristics (Beechie & Sibley, 1997).	Use Fox (2003) thesis to define Desired Future Conditions (DFCs).	
	Key Piece frequency per 100m of channel length	8-15	Sizes of stable LWD, defined as being independently stable within the bankfull channel (i.e., not held or trapped by other material) and retaining or having the ability to retain other LWD (WFPB 1997), increase with channel width in small (<25m BFW) channels (Bilby & Ward, 1989). Others (Montgomery et al., 1995, and Beechie & Sibley, 1997) have found this relationship particularly true for pool creation and maintenance. Successful in-stream LWD restoration that provides habitat is also likely to be based on stability of pieces (Brauderick & Grant, 2000).	Use Fox (2003) thesis to define DFCs. Will tentatively define interim targets using the 25th percentile distribution of Fox's (2003) data.	
	Bankfull width	5, 6, 8-15	Needed to interpret relationships between channel characteristics, woody debris abundance, and habitat characteristics (e.g., pool or gravel areas)(Beechie & Sibley, 1997).		
LWD function • Formation of habitat features – pools, steps • Habitat complexity	Pool spacing	8-13, 15-18	Pools, including those formed by LWD, represent one of the most important habitat elements for salmon (Keller and Swanson 1979). In addition to providing low velocity areas for juvenile rearing, particularly for coho and Chinook, pools also represent resting sites for migrating fish (large pools) (Bjornn and Reiser, 1991). Pools associated with LWD are preferred habitats for juvenile coho salmon, cutthroat trout, and steelhead (Bisson et al., 1988).	Montgomery (et al. 1995) for DFC. CW/Pool of 1; range of 0.5-2. Beechie & Sibley (1997) for interim objectives: For 0.2-2% channels: CW/Pool = -6.2(LWD/m)+4.3 For 2.1-4.8% channels: CW/Pool = -14.7(LWD/m)+7.9	R1 and R3
	Residual pool depth	8-15	Where pools depths or volumes have decreased, species or age groups of salmonids requiring deep pools may be eliminated or reduced (Sullivan et al., 1987). In small streams, including GMUs 8, 9, 12, 13, and 15, deep pools provide important summer holding habitat during low flow periods.	Likely define DFCs and natural range of variation using USFS stream inventory data from unmanaged streams.	R4

Table 3 continued:

Key Ecological Attributes	Indicator	Relevant GMUs/ HGM Types	Technical Rationale	Data Source	Knowledge Gap
	LWD –Step Frequency per 100 m of channel length	5-6	CRMW stream assessments (Foster Wheeler,1995) observed greater pool depths and complexity in LWD-formed steps compared to boulder-cobble steps. Reductions in LWD attributed to past timber management may also have contributed to reductions in channel-spanning and lateral pools.	Likely define DFCs and natural range of variation using USFS stream inventory data from unmanaged streams. Interim objectives established using data from McGreer et al. (1999). Equation: LWD steps/100m= 0.41* (% slope)	R6
LWD function • Formation of habitat features – pools, steps • Habitat complexity	Frequency of side channel areas and sinuosity	11, 14, 16, 18	Off channel habitat includes low velocity areas which are hydraulically connected to but spatially distinct from the mainstem. This area is essential rearing habitat for juvenile salmonids such as steelhead, bull trout, and coho. In the PNW, winter and summer rearing habitat is the current freshwater factor limiting coho production (Beechie et al., 1994).	Define using historic aerial photo assessments of channel and floodplain processes for relevant GMUs. Assessment will also be used to determine appropriate sinuosity.	R10 and R15
	Percent wood cover in pools	8, 9, 12-15	Need to evaluate this as a critical indicator. Consider whether this issue would be addressed indirectly through restoration of indicators associated with the LWD Recruitment attribute.	If we retain as an indicator, likely define DFCs and natural range of variation using USFS stream inventory data from unmanaged streams. Interim objectives could be established using WFPB (1997) criteria (e.g., most pools have between 6-20% wood cover). DFC could be >20% cover.	R10
	Connectivity between wetland and upland habitat	DO, DC	LWD provides movement corridors for amphibians, small mammals and other wildlife between aquatic habitat and the surrounding upland forest. In addition, LWD provides cover from predators, a moist microclimate for movement or resting habitat and foraging habitat for many species.	No data sources yet identified	R19

Table 3 continued:

Key Ecological Attributes	Indicator	Relevant GMUs/ HGM Types	Technical Rationale	Data Source	Knowledge Gap
Flow regime and Hydroperiod – peak flows • Rain On Snow effects of thinning	Ratio of culverts to road length	DO, DC, RI, RF, L, SC, SU	An adequate spacing of culverts relative to the length of road upslope of a wetland is necessary to maintain natural flow pathways into the wetland.	Have needed data.	R20
	Roads intercepting wetlands	DO, DC, RI, RF, L	This is an indicator that wetland hydrology is not properly functioning. The road bisects habitat restricting the flow of water, plants, and animals.	Have needed data.	
	Pool frequency	8-13, 15	See above		R21
Sediment • Transport • Input	Percent of bank eroding	5, 8-10, 12-15	This is an indicator of bank stability and channel condition that can directly affect the quality of fish habitat. Unstable banks contribute sediment directly to the channel. Bank erosion not only delivers fine sediment, but also contributes to the processes described below (in change in channel cross section).	Likely define DFCs and natural range of variation using USFS stream inventory data from unmanaged streams. Interim objective: Banks along 80% or more of any CRMW segment are >90% stable. (USFWS, 1998, in Hillman and Giorgi, 2002)	R9
	Change in channel cross section (W/D)	5, 8-10, 12-15 RI, RF	Increases in bedload transport cause channels to widen their zone of bedload transport. When this zone abuts erodible banks, banks erode and channels widen until near-bank transport stops (Sullivan et al. 1987). This process can also be self-perpetuating where bank erosion processes deliver large quantities of coarse alluvium. Removal of streamside vegetation can also destabilize banks and trigger increases in channel width (Lyons & Beschta, 1983, in Sullivan et al., 1987).	Likely define DFCs and natural range of variation using USFS stream inventory data from unmanaged streams. Interim objective: W/D ratios stay the same or decline. BURPTAC (1999) recommends W/D of <10.	R8
	Change in channel width on aerial photos	11 and 14	Enable efficient, cost effective method of tracking large-scale changes in channel condition on large, alluvial channels within the CRMW.	Use existing historic aerial photos for GMUs 11 and 14 (and perhaps reaches within the Taylor Subbasin). Probable DFC: No change in channel width or a trend of decreasing channel width in restored channels	
	Culvert discharging directly into a wetland	DO, DC, RI, RF, L, SC, SU	This is an indication of potential sediment input to the wetland. The close proximity of a given culvert may contribute higher than normal levels of sediment.	Use Washington Road Surface Erosion Model WARSEM to determine potential areas of high sediment input.	

Table 3 continued

Key Ecological Attributes	Indicator	Relevant GMUs/ HGM Types	Technical Rationale	Data Source	Knowledge Gap
Sediment - continued • Transport • Input	• Presence of visible soil erosion at road improvement/ decommission-ing sites • Road length delivering to streams/ Total stream length • Road Sediment Production Delivered/Tota l stream length	Watershed wide	Surface runoff from forest roads has the potential to deliver large quantities of fine sediment to streams. GMUs prone to fine sediment deposition include 8-10, 12, and 15. Delivered fine sediment that potentially impairs water quality is also of particular concern in the lower CRMW. DFC: Use Road Erosion Model (WARSEM) to quantify pre and post- BMP implementation on sediment delivery to streams. Evaluation can occur at the scale of individual roads to the entire watershed. Interim objectives: No visible signs of soil erosion on road maintenance, improvement, decommissioning, or construction projects for 1 year following application of BMP's.	Suggested targets (FFR 2001): Ratio Road length delivering/total stream length: Not to exceed 0.15-.25 mi./mi. CRMW average to be below 0.20 mi./mi by 2050. Ratio Road sediment production delivered/total stream length: not to exceed 2-6 Tons/yr/mi. CRMW average to be below 4 Tons/yr/mi by 2050	R11
Connectivity of aquatic habitat	Linear feet of road within active floodplain or channel migration zone.	GMUs 14 and 15. To a lesser extent GMUs 8-13	The broad, generally flat valley floors where this habitat often occurs has frequently been impacted by timber harvest as well as construction of roads and other infrastructure.	DFC: No anthropogenic barriers to lateral channel migration and flood-related disturbances.	
	# impassable stream crossing where potential fish habitat exists above and fish are present	Not tied to particular GMUs. Already inventoried	Removing fish barriers is one of the most important and simple restoration measures the CRMW can implement to achieve HCP goals.	WDFW (2000). Upstream and downstream passage possible at all flows. DFC: No anthropogenic barriers by 2015.	R12
Biotic community composition	Benthic index of biological integrity (BIBI)	Potentially useful in all CRMW streams	A benthic index to biological integrity (BIBI) provides a useful way of evaluating the health of aquatic biological communities using multi-index analyses. Where established, indices provide a way of evaluating the current biological integrity with varying land management conditions (Black & MacCoy, 1999).	DFC: Have a BIBI for small (1st -3rd order) high elevation streams (>3000ft) (Black & MacCoy, 1999). BIBI's for small, low-elevation streams was not robust enough to extrapolate to non-surveyed streams. For large streams, > 4th order, a statistically significant BIBI capable of differentiating between sites has not yet been developed.	R13
	Dominance of knotweed	Watershed wide	Highly invasive species threatens natural riparian recruitment processes by preventing the establishment and growth of conifers or other native species. Knotweed also does not provide overhanging cover and has weak root structure that reduces its effectiveness at promoting bank stability.	DFC: No new areas of knotweed. No spread of knotweed where it already exists	
	Presence of pond-breeding amphibians	DO, DC	Amphibian breeding surveys provide a method to compare changes in habitat conditions, changes in species assemblages, or monitor changes in population levels. Because amphibians congregate in relatively small areas to breed, these surveys are easily repeatable over time.	DFC: No net loss of species expected to be present at a wetland given past survey information, and comparable egg mass count trends to those observed in other similar systems within Washington State.	R18

2.5 Current and Desired Future Conditions

In order to assess and prioritize stream and wetland habitat with respect to restoration potential and extent of current habitat degradation, comparisons between current and desired future conditions for key indicators is needed. As the natural range of variability in conditions of key indicators can be very high even between relatively short reaches within a given channel type, the challenge in assessing current conditions is to include a sample size (reach length) large enough to capture those natural variations. In addition, establishing DFCs for these indicators which include both means and standard deviations can also be problematic since they require data from either local, unmanaged/undisturbed streams or relevant data from other sources. Within these constraints, however, it is important to attempt these comparisons in order to make an unbiased assessment of current conditions and identify where the most significant habitat degradation has occurred.

With the exception of GMUs 1, 3, 4, 7, 8, and 11, reaches within each channel type were sub-sampled in order to evaluate the channel classification and quantify current conditions for key indicators (Tables 4-6). As discussed in Section 2.4.1.1, steep gradient GMUs 1-4 are largely bedrock and boulder controlled reaches which are assumed to be insensitive to all but very significant changes in wood, water, and sediment. As such, no DFCs are developed for these reaches. Since these reaches are typically efficient at transporting material inputs, their location and connectivity between headwater source areas and sensitive or unique downstream reaches is key to interpreting trends and changes to disturbance. As shown in Tables 4 through 7, significant variations exist in current conditions between GMUs, and most indicators are not relevant to every GMU.

This plan also establishes general DFCs for wetland habitat in the watershed, and prioritizes restoration needs based on a few key indicators expected to provide the largest change in functional capability of a wetland (Tables 3 and 7). In general, wetlands within the watershed are in the process of recovering key wetland functions impacted by past management activities on their own. It is only in cases where our current management of the landscape impacts wetlands directly that we will examine restoration potential. In these cases, rather than focus on establishing a DFC and range of variability for that DFC in the wetland unit, (of which very little comparable data exists for watersheds like the CRMW) we propose repairing the obvious problem causing degradation to the wetland. For instance, if a road bisects a wetland we will seek to remove the road and restore the hydrologic connectivity of the wetland corridor. Indicators can then be measured in a very general sense to determine the success of the restoration action in repairing natural wetland function at the site.

Table 4: Current range of conditions for important parameters in geomorphic map units within the Cedar River Municipal Watershed.

GMU	Slope (%)		Bankfull Width (m)		Bankfull Depth (m)		Dominant Pool Forming Factors[1]	Dominant bed material size	Percent bank erosion
	Average	Range	Average	Range	Average	Range			
1	>8						Bedrock/Boulder		
2	1- >8		13.8		0.56		Bedrock/Boulder	Co-Bo/Gr	1%
3	>8						Bedrock/Boulder/ LWD		
4	>8						Bedrock/Boulder/ LWD		
5	2.7	1.5 - 2.0	22.5		1.2		Boulder	Co/Bo	0
6	0.9	1 – 8	6.03		0.27		LWD	Gr/Sa-Co	19
7	4-8						Bedrock/Boulder		
8	2.5	1 – 4	7.3		0.51		Boulder/Banks	Co/Gr	3.8
9	0.97	0.4 - 6.9	6.07	3.1 – 10.4	0.26		LWD/ Boulder	Gr/Co/Sa	27.2 (5 - 72)
10	3.25	2.8 - 3.7	14.28	13.0 – 15.6	0.54		Boulder/ LWD/Beaver	Co-Bo/Gr	10.1 (9.2 – 11.1)
11	<1.0						Diversion Pool	Gr/Sa	
12	5.52		3.57		0.24		Boulder/Bank/LWD	Co-Gr	8.2
13	1.7	0.8 - 2.4	13.6	11.3 – 15.8	0.38		Boulder/ LWD	Gr/Co	11.1 (2.9 – 24.5)
14	0.56		29.8				Boulder	Co/Bo	
15	2.3		4.51		0.19		LWD/ Free-Formed/ Boulder	Gr/Co	5.8
16	0.6	0.3–0.7	35.8	13 - 37			Boulder/LWD/ Banks	Gr/Co	
17	0.8	0.5-0.9	31.1	13.2 - 41			Boulder/Banks/LWD	Co/Bo-Gr	
18	0.8	-	35.3	24 - 46			Boulder/LWD/ Banks	Co/Gr	

Table 5a: Current range, desired future condition, and interim objectives for LWD frequency and key piece frequency for relevant Geomorphic Map Units within the CRMW.

GMU	LWD Frequency per 100m					LWD Key Piece Frequency per 100m				
	Current Condition		Desired Future Condition			Current Condition		Desired Future Condition		
	Mean	Range	Median Condition	25th & 75th Percentiles	Interim Objectives	Mean	Range	Median Condition	25th & 75th Percentiles	Interim Objectives
8	4.5	-	46	29-63	29	0	-	7.5	4-11	4
9	32.5	15.9 – 45.8	46	29-63	29	1.5	0 – 3.5	7.5	4-11	4
10	9.6	7.6 – 12.1	46	29-63	29	0	0	2.5	1-4	1
11	17.2					0.8	-			
12	6.4	-	32	26-38	26	1.0	-	7.5	4-11	4
13	7.5	5.4 - 10	46	29-63	29	0	0	2.5	1-4	1
14	0.4	-	132	57-208	57	0	-	2.5	1-4	1
15	21.3	-	32	26-38	26	0	-	7.5	4-11	4
16	25.7(4.4*)	-	To be developed within the Mainstem Cedar LWD Management Plan			0.2	-	To be developed within the Mainstem Cedar LWD Management Plan		
17	25.7(4.7*)	-				0.2	-			
18	12.7(8.2*)	-				0.1	-			
19	9.8(5.5*)	-				0.1	-			

* Data from 2000-2001 stream inventory conducted by Peter Kiffney (NOAA).

Table 5b: Current range, desired future condition, and interim objectives for LWD frequency and step frequency for relevant Geomorphic Map Units within the CRMW.

GMU	LWD Frequency per 100m					LWD step frequency per 100 m of channel length				
	Current Condition		Desired Future Condition			Current Condition		Desired Future Condition		
	Mean	Range	Median Condition	25th & 75th Percentiles	Interim Objectives	Mean	Range	Mean	Natural Range of Variation	Interim Objectives
5	3.5	2.3 – 4.8	46	29-63		No data (nd)	nd	tbd	tbd	2.46
6	19.7	-	52	29.2-63.4	29.2	nd	nd	tbd	tbd	2.46
7	5.1*	-	Tbd			nd	nd	tbd		

Table 6: Current range, desired future condition, and current status for 2 key aquatic indicators (pool frequency and residual pool depth) for relevant Geomorphic Map Units within the Cedar River Municipal Watershed.

GMU	Pool Spacing (pools per channel width)				Residual Pool Depth			
	Current range	Desired Future Condition	Natural Range of Variation	Interim Objectives (in Pools per m)	Current range	Desired Future Condition	Natural Range of Variation	Interim Objectives *
8	0.37	1	0.5-2	3.61	0.57	Tbd	Tbd	0.25
9	0.35 (0.07-0.58)	1	0.5-2	2.49	0.42 (0.23-0.71)	Tbd	Tbd	0.25
10	0.25 (0.14-0.37)	1	0.5-2	3.61	0.45 (0.36-0.53)	Tbd	Tbd	0.30
12	0.12	1	0.5-2	4.15	0.33	Tbd	Tbd	0.2
13	0.4 (0.05-0.73)	1	0.5-2	2.49	0.68 (0.41-1.13)	Tbd	Tbd	0.3
14	0.1	1	0.5-2	4.15	0.21	Tbd	Tbd	0.4
15	0.14	Tbd	Tbd	Tbd	0.24	Tbd	Tbd	0.2
16	0.18 (0.09-0.29)	Tbd	Tbd	Tbd	0.97 (0.82-1.28)	Tbd	Tbd	0.4
17	0.08 (-)	Tbd	Tbd	Tbd	1.10 (1.01-1.18)	Tbd	Tbd	0.4
18	Tbd	Tbd	Tbd	Tbd	Tbd	Tbd	Tbd	0.4

* based on performance targets developed by the Cooperative Monitoring and Research (CMER) (PSM dated 2-22-05)

Table 7: Desired future conditions for HGM classes within the Cedar River Municipal Watershed.

HGM Class	Key Attribute	Indicator	Desired Future Condition
DO, DC, L, RI, RF	Flow regime and hydroperiod	Presence of roads intercepting wetlands	Minimal alteration of hydrologic flow paths to wetlands from the road network
DO, DC, L, RI, RF, SC, SU	Flow regime and hydroperiod	Culvert spacing to ditch length	Enable natural flow pathways by placing adequate culverts to ditch length.
RF, RI	Flow regime and hydroperiod	Loss of riverine wetlands	No net loss of riverine wetlands
DO, DC, L	Sediment supply and movement	Presence of culverts across roads within 200 feet of the wetland	No runoff directly into a wetland based WARSEM modeling.
DO, DC	Biotic community composition	Presence of expected amphibian species for elevation and wetland type, and egg mass count trends through time	No net loss of species expected to be present at a wetland, and comparable egg mass count trends to those observed in other similar systems within Washington State.
DO, DC, L, RI, RF, SC, SU	Biotic community composition	Presence of knotweed or other invasive plant or animal species	No new infestations of invasive plant species and reduction in extent of already existing patches. No introduction of non-native animal species such as bullfrog.

2.6 Restoration Treatments and Rationale

Both passive and active restoration measures are being employed to achieve restoration goals within the CRMW. Passive treatments being employed include no commercial timber harvest within the watershed and the identification and modification of management activities contributing sediment to streams. In contrast to passive treatments which are being applied throughout the CRMW, active restoration treatments which address LWD deficits in streams, chronic bank erosion in streams, and chronic sediment sources from the road network are being applied to specific reaches and areas based on the following rationale.

2.6.1 LWD Replacement in Streams

Using our understanding of the processes controlling reaches as well as the linkages between them, we have identified a subset of reaches where LWD plays a critical role in forming pools and contributing to other key habitat elements. In particular, pool spacing in channels dominated by planebed morphology, typically with slopes between 1 and 4%, declines exponentially as LWD abundance increases (Montgomery et al., 1995). In lower sloped channels (less than 1%) LWD abundance also controls pool frequency though spacing rarely exceeds 5-7 bankfull channel widths since pools form without wood at these slopes (Leopold et al., 1964).

Factors such as bankfull widths, current condition of riparian stands, and range of in-stream LWD abundance also strongly influence decisions about treatment strategy and relative priority. Evaluating stream size is important since stable LWD is needed to form pools and wood stability is a function of piece size relative to bankfull width (Beechie and Sibley, 1997). As described in Beechie et al. (2000), Beechie (1998) developed the following equation: Dpf = 2.5(Wbf), where Dpf is the pool-forming tree diameter (cm) and Wbf is the bankfull channel width (m). In addition to stream size, the current condition of the riparian forest is also evaluated in order to assess the likelihood that near-term (i.e., <10 years) recruitment of LWD is capable of providing the stream with trees with pool-forming diameters. Where stands are dominated by young conifers or alders of insufficient size, active restoration of the riparian and/or in-stream wood placement are considered viable treatment options. Where in-stream habitat is found to be within the natural range of conditions for select indicators (Sections 2.4 and 2.5), LWD replacement is not needed but active riparian treatments intended to enhance the capacity for future recruitment of functional wood is considered.

- √ Beechie's (et al., 2000) woody debris recruitment modeling underscores the importance of considering not only the current physical habitat but also the trajectory of current riparian conditions relative to stream size when considering restoration treatments. Where bankfull widths exceed 20 m, modeled LWD recruitment did not exceed expected depletion rates over a 100-year simulation. Factoring heavily into these high modeled depletion rates is the lack of very large, independently stable trees needed to encourage the formation of jams and retention of smaller pieces of woody debris. As a result, even though pool frequencies are naturally lower in these large, low gradient streams and the largest pools are commonly freely-formed, an absence of key piece recruitment was predicted to contribute to pool frequencies below desired future conditions. Consistent with these results, stands adjacent to these low gradient reaches exceeding 20 m in width are viable candidates for active in-stream and/or riparian restoration treatments.

- √ Evaluating restoration options for streams less than 20m wide presents more complicated scenarios, dependent largely on stream size and diameter of available trees. In general, pool spacing decreases more rapidly (faster recovery) as channel size decreases, since the LWD size needed to provide these functions also decreases. Simulations involving thinning of both alder and conifer stands predicted no increase in cumulative LWD abundance for any DBHq (quadratic mean diameter) in channels less than 20m. What this suggests is that along these smaller streams, active riparian thinning to enhance LWD recruitment may not be critical for the long-term recovery of pool habitat. Consistent with these findings, active LWD placement projects will only target reaches where fish habitat for ESA-listed species is significantly degraded and rapid recovery of this habitat is deemed beneficial to many generations of ESA species by adding LWD to streams until natural in-stream LWD loads and riparian recruitment processes have been attained.

2.6.2 Bank Stabilization

Restoration treatments which target bank stabilization are typically associated with sites where roads have encroached into riparian zones and are within or near the active channel. In these instances, restoration options may include road decommissioning, road realignment, and/or bio-engineering solutions which improve stability and help maintain or enhance reach-specific habitat elements. In other situations, where bank stability is chronic and analysis suggests that active restoration measures are appropriate, treatment may include a range of options including in-stream LWD placement, addressing upstream sediment sources, or changes in riparian conditions or pathways.

2.6.3 Streamside Revegetation

Given the common capacity for bare mineral soils to be rapidly colonized by adjacent vegetation in riparian areas throughout the CRMW, active restoration of streamside revegetation will largely be restricted to stream-adjacent areas associated with road improvement, road decommissioning, and bank stabilization projects. Within these potential areas, sites will be targeted based on likelihood of sediment delivery from surface erosion and potential for invasive plants such as knotweed, Himalayan blackberry, or Evergreen blackberry to become the dominant plant species.

2.6.4 Culvert Replacement for Fish Passage and Peak Flows

Active restoration to remove impacts from culverts which are obstructing fish from upstream habitat or obstructing the conveyance of flood discharges of water or sediment is an ongoing activity employing straightforward technical solutions to fix well documented and readily identifiable problems. By evaluating the increase in available habitat resulting from the removal of each management-related fish blockage, we have prioritized our list of culverts blocking fish passage. Using established design criteria developed by Washington Department of Fish and Wildlife (WDFW) and others, fixing these problems is also simple and relatively cost effective. With respect to peak flow concerns, and examination of indicators including chronic erosion above or below the culvert coupled with the use of regional culvert-sizing equations are used to screen and rank culverts for replacement.

2.6.5 Road Decommissioning and Improvements

Road work which potentially influences the aquatic system falls into one of three categories within the CRMW: Road Decommissioning, Improvements, and Maintenance. To evaluate the life cycle costs, environmentally and economically, for maintaining each road within the CRMW, and to identify those roads which are no longer needed to support watershed objectives, a Transportation Strategic Asset Management Plan (TSAMP) for the CRMW is being developed. As such, the range of treatments and rationale for decommissioning and maintaining various roads within the CRMW will be addressed in that document. To improve our understanding of the road network as well as provide a foundation for modeling the sediment delivery from them, a comprehensive road inventory was conducted. Using this information in conjunction with the Washington Road Surface Erosion Model (WARSEM) (WDNR, 2004), our intent is to prioritize road decommissioning, improvement, and maintenance projects such that we address those road segments that are predicted to be contributing the largest quantities of sediment to the aquatic system first.

2.7 Uncertainties, Threats, and Risks

Uncertainties, threats, and risks could undermine strategies to achieve stated conservation goals or limit our ability to reach DFCs. Uncertainties have been identified where there is limited knowledge of an aquatic system or restoration technique to the extent that the outcomes of restoration cannot be conducted with a reasonable level of confidence in the outcome without improvement in understanding. These uncertainties represent knowledge gaps and are listed in Table 8 along with strategies for addressing them.

2.7.1 Critical Knowledge Gaps

Refinement of the attributes and indicators as well as the conceptual models led to the identification of 18 critical knowledge gaps (Table 8). The following bullets summarize the current status and key issues associated with these gaps:

- Two of these gaps require external collaborations and are being actively worked on:
  - Identify how invertebrates might be used to indicate integrity of aquatic system and changes in sediment loads. (R13)
  - Threat to the Landsburg Dam of LWD recruitment along lower mainstem Cedar River above Landsburg Dam. Approaches to balance these threats with aquatic restoration objectives for these reaches. (Element of R1)
- Seven of the knowledge gaps can be met through literature reviews, conversations with experts, or synthesis of existing knowledge into a first set of hypotheses.
  - Define acceptable range of variability of step frequency. (R6)
  - Consider GMU-specific DFCs for acceptable change in width to depth ratio. (R8)
  - Consider percent bank erosion as indicator. GMU-specific ranges? (R9)
  - Determine which components of channel complexity should be integrated as indicators. (R10)
  - Develop catalogue of invertebrates present for each HGM class. (R13)
  - Collect data on LWD function as connection between wetland and upland forest habitat to determine range or variability (R16)
  - Determine ratio of culverts to road length adequate to maintain natural flow pathways to wetland habitat (R17)
- Five of the knowledge gaps will require data collection and analysis or running models to develop hypotheses; several of these efforts are already ongoing and one potentially needs more funding (R2)
  - Test variety of LWD placement strategies and their effectiveness in achieving DFCs in terms of pools, steps, bank erosion, and biological response. (R5)
  - Evaluate Lower mainstem Cedar River LWD recruitment rates associated with passive and active restoration scenarios. (R2)
  - Evaluate Lower mainstem Cedar River LWD aquatic restoration goals in light of altered flow and sediment transport regime between lake and Landsburg Dam. (R7)
  - Determine appropriate DFC for sinuosity within select GMUs. (R14)
  - Collect baseline data on amphibian breeding and abundance in each HGM class (R15)

Table 8: Plan for implementing research actions and filling knowledge gaps in streams and riparian forests.

Research/Monitoring Need (from Table 3)	Approach	Lead Staff	Status/ Timeline for Completion	Constraints (money or expertise)	Collaboration/ Other Opportunities	Potential Funding Sources
R1: For lower mainstem Cedar GMUs, review indicators and establish DFCs for LWD and other metrics.	Integrate with Cedar LWD Management Plan. Review literature and expert opinion	DB	Winter, 2008-09	Time	Incorporate into risk assessment of Landsburg Dam and identification of strategies towards achieving operational and ecological goals.	BPA and HCP Funding
R2: Estimate lower mainstem Cedar LWD recruitment rates associated with passive and active restoration scenarios.	Use Riparian plots, FVS output, and geomorphic template to model rates of LWD inputs through time using OSU STREAMWOOD (Meleason et al., 2004)	DB	On hold (Herrera working on different approach)	Time	Feed into Cedar LWD Management Plan. Incorporate into risk assessment of Landsburg Dam and identification of strategies towards achieving operational and ecological goals.	BPA and HCP Funding
R3: Refine GMU-specific pool frequencies.	Examine data used by Hillman and Giorgi (2002) so accounts for gradient as well as channel width	DB/TB	Winter -03/04 **Completed**			
R4: Define expected residual pool depths relative to channel width and GMU	Examine data used by Hillman and Giorgi (2002) so accounts for gradient and channel width; also look at USFS long-term monitoring data to develop acceptable range that is GMU specific	DB/TB	Winter 2003/2004 **Completed**			
R5: Test variety of wood placement strategies and their effectiveness in achieving DFCs in terms of pools, steps, bank erosion, and biological response	Experimental test of suite of LWD placement strategies in GMU 9	DB/TB	Ongoing	Staff time to place wood and monitor	Susan Bolton, UW; Dave Montgomery UW	Salmon Recovery Funding Board; NFWF Bring Back the Natives; NFWF General Challenge Grants;
R6: Identify acceptable range of variability of step frequency	Examine USFS Long-term monitoring data; DB to contact Jerry Ketchison	DB/TB	On Hold (low priority)	Staff time		
R7: Evaluate Lower Mainstem Cedar River aquatic restoration goals in light of altered flow and sediment transport regime between lake and Landsburg Dam.	Measure stage discharge relationships at USGS station on Cedar; aerial photos for changes in gravel bar area; bank armoring	TB/DC	Winter, 2008-09	Staff time		
R8: Consider GMU-specific DFCs for acceptable change in W/D	Literature	DB/TB		Time		
R9: Consider % bank erosion as indicator. GMU-specific ranges?	Literature	DB/TB		Time		

Table 8 continued:

Research/Monitoring Need (from Table 3)	Approach	Lead Staff	Timeline for completion	Constraints (money or expertise)	Collaboration/Other Opportunities	Potential Funding Sources
R10: Determine which components of channel complexity should be integrated as indicators	Discuss with Dwayne and Heidy to identify potential indicators; examine TFW ambient monitoring protocols	DB/TB		Heidy and Dwayne	Work done by others relative to bull trout	
R11: Identify road contributing sediment or triggering landslides, identify road ditches improperly sized; identify locations of unsupported fill; identify undersized culverts	Complete comprehensive road inventory; put results in WARSEM model to predict % increases in sediment to the stream by road segments	TB/ CC	Road inventory **Completed**			
R12: Identify culverts likely to maximize gain in access to fish habitat	Evaluate fish blockage inventory	DB	**Completed**			
R13: Identify how invertebrates might be used to indicate integrity of aquatic system and changes in sediment loads	Work with USGS to design study that can be used for long-term monitoring	DB	**Completed**	Specialty in aquatic invertebrates; Money	Bob Black – USGS	HCP funds; Centennial Clean Water Fund or Section 319; King County Block Grant; Salmon Recovery Funding Board (?)
R14R15: Determine appropriate sinuosity in each reach	Calculate and map from historical aerial photos and maybe meander surveys (GLO)	TB/DC	Winter, 2008-09	Staff time	Work with David C to integrate into Historical Assessment Work	
R15R18: Collect baseline data on amphibian breeding abundance in each HGM class	Establish protocols to monitor long-term trends in amphibian abundance. Stratify population by HGM class	HB	Some completed in 2002-05 pond breeding amphibian inventory. Pilot project in '07 & '08	Field/tech support. UW senior thesis project?	UW or other research groups	
R16R19: Collect data on LWD function as connection between wetland and upland forest habitat to determine range or variability		HB	Winter 2008-09	Staff time		
R17R20: Determine ratio of culverts to road length adequate to maintain natural flow pathways to wetland habitat	WARSEM?, review BMPs?	TB/DB	Winter 2008-09	Staff time		
R21: Evaluate potential impacts of changes in forest age and structure on water yield and summer base flows in CRMW streams. Also consider likely changes associated with climate change.	Conduct literature review to determine if previous findings are applicable to the CRMW. Also review the hydrologic and vegetative conditions in the studied watersheds and evaluate possible differences in results for the CRMW	TB/RG	Winter, 2009-10	Staff time	Work with Rolf Gersonde, other SPU scientists working on global climate change issues, UW, and perhaps the USGS.	

2.7.2 Threats

Many threats, which are known, expected, negative effects from tangible sources, are identified in the conceptual models developed for each geomorphic map unit and wetland type (HGM). To the extent practicable, these threats are being addressed via one or more project types addressed within each strategic plan. For example, old roads in unstable terrain that may trigger landslides have been identified and systematically addressed via road decommissioning and improvement work. Threats at the landscape scale, as well as some risks (e.g., of no action), are being addressed in the vulnerabilities analysis and thematic map layer described within Section 4.3 of the Synthesis Framework for the Cedar River Watershed Habitat Conservation Plan (Erckmann et al., 2007) Section 6.4 of this document also discusses strategies to address uncertainty and risks.

2.7.3 Risks

There are risks of undesirable outcomes occurring as a result of both planned activities as well as a lack of action. Where risk exists associated with active restoration, such as in-stream placement of LWD above a bridge, an analysis will be conducted prior to project implementation in order to fully consider the pros and cons of each proposal. Key elements to any discussion of risk in this context are further described in Section 4. Of course, risk to critical infrastructure and aquatic resources may also exist even if we do nothing. The following table identifies a few specific instances where a lack of recognition of a risk or a decision to pursue passive restoration could exacerbate risk. It should be noted that as our understanding of resource issues and the relevant science grows, this list will evolve.

Table 9: Aquatic processes likely to contribute to risk of key resources or infrastructure as a result of lack of action

Process	Potential Vulnerability	Strategy for Risk Abatement
Future natural recruitment of LWD to the Lower mainstem Cedar River	Obstruction of flows at Landsburg Dam due to LWD transport and accumulation.	Cedar LWD Management Plan will identify a range of risk abatement strategies. See Draft Cedar River LWD Management Plan for more details.
Modification of hydrologic regime, namely lower snow packs and lower summer base flows due to global climate change and/or altered forest characteristics.	Could reduce reservoir levels during late summer and early fall, thereby reducing water available for in-stream flows and creating difficult passage for bull trout to spawning streams.	Completed Bull Trout Spawning Impedance Report (2007) that evaluates risk for spawning barrier under low flow and low reservoir levels. Further geotechnical work is planned as part of a land-based pumping station, and will inform SPU of the need to create a Bull Trout Passage Assistance Plan to protect the ability of bull trout and other aquatic species to navigate to spawning grounds at low reservoir levels. Conduct literature review to further assess risk of changes in forest characteristics and climate change on summer base flows and water yield.
Channel migration immediately upstream of Upper Cedar Bridge (100-300 road) and Rex River Bridge (300 road)	Rapid channel avulsion could take out the bridge and/or approach roads. This scenario is currently much more likely on the Rex River at the 200 road.	Establish wide span bridges with abutments placed on well-armored relict islands within the floodplain/channel migration zone. Use LWD jams to stabilize bars and abutments.
Lateral migration of the lower Cedar River into the 50 road below Landsburg Dam	Chronic erosion of road fill as the river continues to migrate slowly to the south.	Either decommission this section of road or stabilize using bio-engineering designs in order to improve stability and improve in-stream habitat.
Colonization by invasive aquatic species	Alteration of aquatic community.	Identification of problem species and monitoring and removal where necessary.
Colonization by invasive noxious weeds	Alteration of riparian vegetation communities with potential consequences to aquatic community.	Identification of problem species and monitoring and removal where necessary.

2.8 Adaptive Management and Evaluation

In order to successfully implement adaptive management, an action plan needs to be established that defines pathways for using monitoring information in the decision-making process. For a good general discussion of adaptive management principles, please see the CRMW Monitoring and Research Strategic Plan (Nickelson et. al., 2008). Using select indicators identified in Section 2 and the following 4 steps identified by Ecosystem Management Initiative (2004), we have developed an action plan (Table 10 below) for implementing adaptive management principles:

1) define trigger points or predetermined values for each indicator that signify the need to consider action;
2) identify strategies or actions that might be taken in response to reaching a trigger point;
3) specify who is responsible for making decisions and following through on proposed actions; and
4) establish how this information will be summarized and stored.

While tables with comparable information will be established for specific restoration projects, Table 10 is intended to target broad questions not necessarily impacted by any one project or issue. Regarding the extent to which road work is contributing to improved aquatic resource conditions, for instance, three indices are used to evaluate improvements in sediment production and delivery as well as hydrologic connectivity to the aquatic system. With respect to questions about water quality improvements, one broad but operationally significant metric, namely the number of days the water supply intake at Landsburg Dam is shutdown due to elevated turbidity levels, can be used to assess improvements at least for flows and associated turbidities within a certain flow regime.

Consistent with the fundamental goal of improving and maintaining high quality fish habitat, a subset of indicators discussed in section 2 will be evaluated via long-term monitoring in low-gradient (less than 4 percent) GMUs to assess whether SPU is succeeding in meeting its long-term and most fundamental objectives. Detailed protocols of our Long-term Aquatic Monitoring Program can be found within SPU’s Science Information Catalog.

Table 10: Plan for using aquatic monitoring information in the decision-making process

Question	Indicator and Comparison	Trigger Point*	Possible Actions	Who Will Respond
Are road maintenance, improvement, and decommissioning projects reducing sediment delivery to streams?	Reduction in predicted delivery of road-generated fine sediment (Tons/yr/mi^2) within the CRMW since 2004. WARSEM (WA Road Surface Erosion Model, 2003) will be used to predict fine sediment delivery from road surface erosion.	Reduction in predicted road-generated fine sediment delivery of less than 10% by 2009. 2004 predicted total value for CRMW: 2359 Tons/year.	Compare list of completed road work with list of segments with high predicted sediment generation, evaluate model assumption and predictions, evaluate road improvement BMPs relative to road attributes critical to sediment generation and delivery. .	SPU lead hydrologist and Operations Manager
	Reduction in the ratio: Road length delivering to streams/ Total stream length. Suggested targets (FFR 2001) not to exceed 0.15-.25 mi./mi. CRMW average to be below 0.20 mi./mi by 2021(fifteen years).	Reduction in watershed average by 0.02 mi./mi. each year through 2021. Current average across subbasins: 0.48 mi./mi.	Compare list of completed road work with list of segments with high ratios of road length delivering to streams/ total stream length.	SPU lead hydrologist and Operations Manager
	Reduction in the ratio: Road Sediment Production Delivered/Total stream length. Suggested targets (FFR 2001) not to exceed 2-6 Tons/yr/mi. CRMW average to be below 4 Tons/yr/mi by 2021 (fifteen years).	Reduction in watershed average by 0.1 Tons/yr/mi. each year through 2021. Current average across subbasins: 5.40 Tons/yr/mi.	Compare list of completed road work with list of segments with high predicted road sediment production/total stream length.	SPU lead hydrologist and Operations Manager
Is drinking water quality improving?	Days with turbidity levels triggering a shutdown of the water intake at Landsburg	One or more intake shutdowns associated with less than bankfull flow events in Taylor Creek.	Reevaluate probable source areas, update mass wasting inventory, and reprioritize road and aquatic restoration projects to address findings.	SPU lead hydrologist

Question	Indicator and Comparison	Trigger Point*	Possible Actions	Who Will Respond
Is aquatic habitat improving? Indicators used to answer this question are included in our long-term trend monitoring program.	No road-related fish access barriers in the CRMW by 2030. Assumes we complete one fish passage barrier removal project every 2 years. Currently have 9 projects identified.	Project sites continue to obstruct fish passage or unable to complete a project every other year.	Evaluate reasons for failure where projects failed to improve fish access. Identify reasons for inability to complete one project every other year. Where fish access continues to be blocked, add to list of crossings to be upgraded, re-evaluate project design	SPU lead biologist, lead hydrologist, and Operations Manager
	Benthic invertebrate communities in response reaches (BIBI)	To be determined		SPU lead hydrologist
	Pool frequencies and residual depths in GMUs 8-14	Increasing trend based on long-term monitoring after X years? tbd	Evaluate relative to in-stream LWD frequencies and other factors such as sediment supply and riparian recruitment processes.	SPU lead hydrologist
	Large woody debris recruitment in selected reaches. LWD recruitment modeling will provide insights regarding specific indicators and trigger points.	Increasing trend in LWD frequency based on long-term monitoring after X years? tbd	Reevaluate sampling methods, reevaluate model and data, investigate possibility of other factors	SPU lead hydrologist
	Roads adjacent to streams	tbd		
Are the natural flow regimes changing in response to global climate change? (Question still being considered for inclusion in adaptive management process)	Identify array of ecologically significant indicators of alteration to the hydrologic regime within the CRMW. Evaluate IHA (Indicators of Hydrologic Alteration) developed by Richter (et al., 1996) to identify relevant parameters and trigger points.	tbd.	Assess USGS flow data to evaluate local trends in the frequency of bankfull flows; Reassess sensitivity of aquatic system to projected increases in flows and modify restoration strategies and priorities accordingly.	SPU lead hydrologist

* The Aquatic ID Team still needs to discuss and potentially revise some of the above trigger points

3.0 FRAMEWORK FOR PRIORITIZING, DESIGNING, AND IMPLEMENTING AQUATIC RESTORATION PROJECTS

Prioritizing aquatic and riparian sites for restoration treatment is being done at two levels. At a watershed scale, a "landscape synthesis" process has identified areas where synergy of restoration efforts in aquatic, riparian, and terrestrial ecosystems can best occur. These will be priority areas for restoration treatment among all restoration programs. Second, at a reach level, this strategic plan addresses how reaches within a "synergy area" will be prioritized for aquatic restoration. There may also be analysis of other areas outside of "synergy areas" for possible aquatic restoration.

3.1 Landscape Synthesis Prioritization Guidance

The intent of the landscape synthesis process is to "…provide an overall, landscape-level approach to planning restoration in an integrated fashion to most efficiently and effectively achieve the goals of the HCP" (Erckmann et al., 2007). One of the primary goals of the synthesis was to develop a watershed landscape template (or vision) that will be a guide for conservation and restoration of key ecosystems, communities, and species. The landscape template was derived from four themes representing different aspects of watershed biodiversity:

Fish – which includes the distribution of anadromous salmon and bull trout within the watershed;

Forest connectivity – which shows areas where existing late seral–old growth or high quality second growth forests occur and where the most effective areas for reconnecting occur;

Amphibian habitat – includes complexes of aquatic, riparian, and upland areas most likely to be important for amphibians in the watershed;

Areas adjacent to biodiversity hotspots – which include areas that either have high species diversity or contribute to overall diversity, such as rock, meadows and shrub lands, non-depressional wetlands, and old growth forest.

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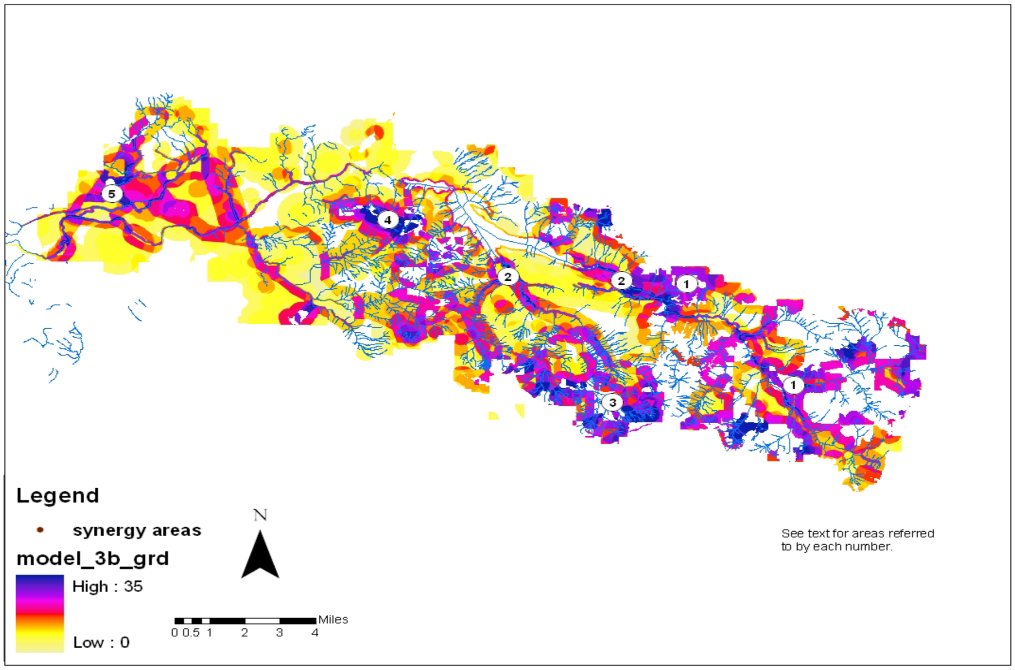
Buffers of varying widths were applied to these areas, and overlaps of habitat-buffers among themes were identified within the GIS. Weightings were given to the different themes, and areas of theme overlap were then ranked based on number of overlaps and theme weightings. Areas that rank high in this process are then considered priority areas for upland forest, riparian forest, or aquatic restoration. That is, these areas provide opportunities for synergy of restoration actions among upland, riparian, and aquatic areas. Focusing primarily on these identified "synergy areas" this strategic plan provides a process to prioritize sites (or stream reaches) for implementing aquatic restoration actions.

The Landscape Synthesis Framework identified high priority zones within five geographic areas across the CRMW (Figure 11, below). High priority zones, representing areas where collaborative projects have the greatest potential to achieve multiple restoration objectives, have been identified within both the upper and lower watershed. Reaches within the Lower Cedar River mainstem and tributaries (area 5), including the Cedar between Masonry Pool and Landsburg as well as Williams, Rock, and Webster Creek, contain large reaches identified as high priority based on both the Landscape Synthesis Framework and our Aquatic Prioritization Criteria (discussed below) based on the presence of ESA-listed fish (Chinook salmon, bull trout, and steelhead trout) and coho salmon. As such, these streams will be targeted first for potential restoration, followed by high priority zones within Synergy Area 2, Lower Cedar and Rex River Basin above Chester Morse Lake and finally by Synergy Areas 1, 3, and 4. While Area 2 will likely be the primary focus for In-stream LWD Replacement Projects over the next several years, more point-specific projects addressing peak flow passage, fish passage, and stream bank revegetation will integrate high priority areas across all five geographic areas into the initial prioritization process. In part this is due to the fact that many of these issues have already been addressed within Area 5.



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re 11. Map of synergy areas

3.2 Review of Prioritization Schemes and Overarching Synthesis

In order to implement the CRMW HCP, restoration of aquatic biodiversity and processes within the CRMW can be distilled into one of five categories: in-stream LWD, bank revegetation, bank stability, peak flow passage, and fish passage. In addition to the above, wetland restoration represents a sixth project type not initially prioritized within the HCP but which will be implemented in association with other upland, road, or riparian restoration projects. As the intent of individual projects may include the restoration of natural processes potentially upslope of the aquatic system, success will often require integration with one or more upland, riparian, or road strategies. The objective of this section is not only to discuss strategies for identifying and prioritizing projects but also to identify and highlight the most likely and important linkages between these and other restoration efforts occurring under the CRMW HCP (as shown in Figure 1). Table 11 lists restoration strategies most likely requiring integration when prioritizing and designing aquatic restoration projects. This list suggests that most aquatic restoration projects will require some integration with other projects and planning efforts.

Table 11: Relevant linkages with other restoration programs within the CRMW

HCP Aquatic Restoration Programs	Relevant HCP Watershed-wide Restoration Components

In-stream LWD	Riparian (conifer under-planting & restoration thinning), Road Decommissioning
Bank Revegetation	Road Decommissioning, Riparian (conifer under-planting & restoration thinning)
Bank Stability	In-stream LWD, Road (Improvement, Maintenance., & Decommissioning), Riparian (conifer under-planting & restoration thinning)
Peak Flow Passage	In-stream LWD, Road (Improvement, Maintenance, & Decommissioning)
Fish Passage	Road (Improvement, Maintenance, & Decommissioning)

Given the relative independence of each HCP component and to facilitate a logical discussion of prioritization criteria for aquatic projects, each HCP component will be addressed separately.

3.3 LWD Replacement Projects

Given the heterogeneity and complexity of interactions between riparian and in-stream processes which need to be considered during the prioritization of these projects, considerable additional effort is needed in order to rigorously prioritize LWD projects. Conceptually, however, our approach can be summarized in Figure 12. The decision tree illustrates the extent to which prioritization is based on the Landscape Synthesis Framework as well as riparian and aquatic project prioritization criteria and the necessity of integrating in-stream LWD and riparian recruitment restoration strategies within the planning process.

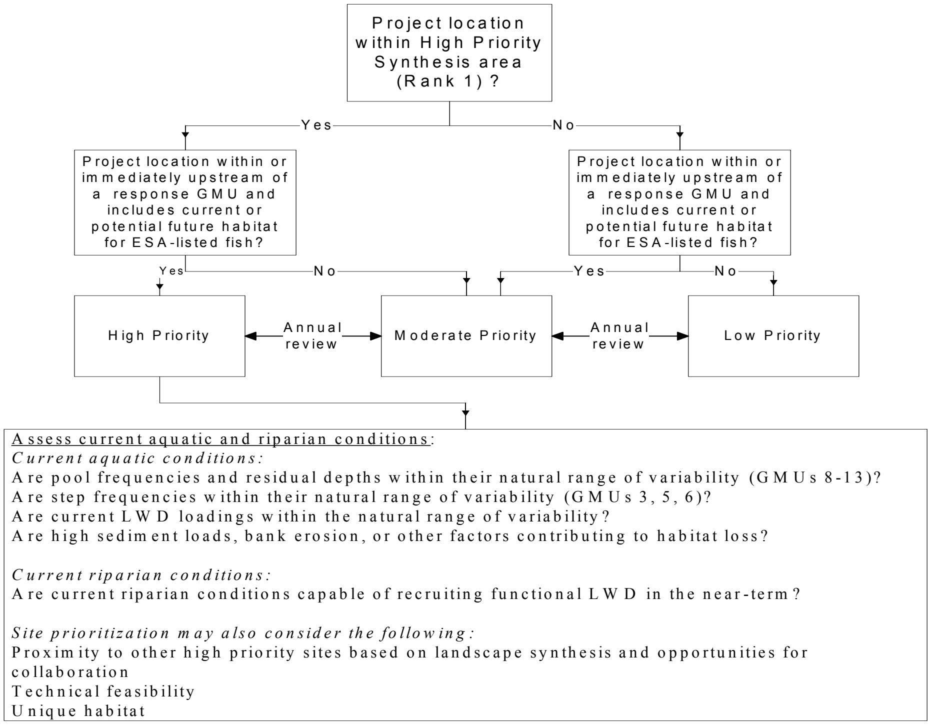

Figure 12: Decision tree for identifying and prioritizing In-stream LWD projects.

While recent projects have required best professional judgment in order to qualitatively assess the extent to which current riparian conditions pose a threat to short-term in-stream LWD levels, efforts to model riparian forest dynamics and woody debris recruitment processes have attempted to make this assessment more rigorous. Toward this end, Forest Vegetation Simulator (FVS) was used to model riparian successional pathways for various stand types along the lower mainstem Cedar River and OSU Streamwood (Mealson et al., 2003) was used to model in-stream LWD recruitment volumes to the Cedar River using FVS output. While intended to be included in the risk assessment conducted by Herrera, Inc. (mainstem Cedar River from lower Cedar Falls to Landsburg) and included in the Large Woody Debris Management Plan for the lower mainstem Cedar, model output was determined to be have inadequately captured the significant recruitment pathways and processes along the mainstem, and an alternative approach was used.

3.4 Streambank Revegetation Projects

As the CRMW lies in the western cascades and represents a landscape within which exposed soils tend to be quickly recolonized by adjacent vegetation, the utility of bank revegetation at a watershed scale as a restoration strategy is uncertain. As this component represents an HCP commitment, efforts over approximately the next two years will include assessments of the effectiveness of these strategies at meeting HCP objectives as well as how this money might be more prudently allocated to meet overarching aquatic restoration goals.

Projects completed in 2003 represent the first attempt at meeting this commitment. Lacking a comprehensive inventory of streambanks with exposed soils, an attempt was made to identify recently exposed soils adjacent to streams by evaluating recently decommissioned roads. The assumption was that recently decommissioned roads that either run adjacent to streams or have numerous stream crossings may represent chronic sources of fine sediment capable of delivering to the aquatic system. Though there were a few exceptions, principally along the 126 and 110.1 roads, the conclusion from this work was that with the exception of areas immediately adjacent to stream crossings, most previously decommissioned roads had very few locations warranting revegetation. As such, we decided to link revegetation sites to ongoing road decommissioning work, thereby addressing stream crossings and sites adjacent to riparian zones that have recently exposed soils and a high likelihood of delivery to the aquatic system. The efficiencies created by this approach include: 1) simultaneous evaluation of stream crossing designs and revegetation work by the hydrology group; 2) timely delivery and transport of plants and needed materials to these sites prior to road decommissioning (eliminating costly transport time if access is limited to foot traffic); and 3) consistent planting of riparian zones with the most appropriate species.

Given that future work will be linked with road decommissioning efforts, prioritization of these projects will be strongly tied to that prioritization process. A road inventory conducted in 2004 will enable the CRMW to identify and prioritize road decommissioning work, at least in part, by addressing roads currently delivering large quantities of fine sediment to the aquatic system. Linking streamside revegetation with road decommissioning strategies appears consistent with HCP goals.

3.5 Bank Stabilization Projects

Projects targeting chronic, extensive streambank erosion will be prioritized for bank stabilization based on probable impacts to aquatic resources, the water supply, and city infrastructure. Other considerations to project implementation include the clear determination of agents causing bank erosion, certainty that solutions would address current and likely future bank erosion processes, potential benefits from minimizing erosion, and ease of access for construction and maintenance. Streambank stabilization projects will use materials appropriate to the site conditions, and both conventional and bio-stabilization techniques will be used. Conventional methods typically use the placement of large rocks to protect eroding banks, whereas bio-stabilization methods will use a combination of logs, live plants, erosion control fabrics, and other materials to protect eroding banks (Sedell and Beschta, 1991; Johnson and Stypula, 1993).

As bank stability tends to be controlled by the interaction of hillslope, riparian, and fluvial processes, restoration efforts may require integrating strategies related to riparian recruitment, road work (maintenance, improvements, and decommissioning), in-stream LWD placement, bank revegetation, peak flow passage, and upland thinning. The following decision tree (Figure 13) will be used to prioritize projects and ensure the appropriate linkages are made with other restoration efforts.

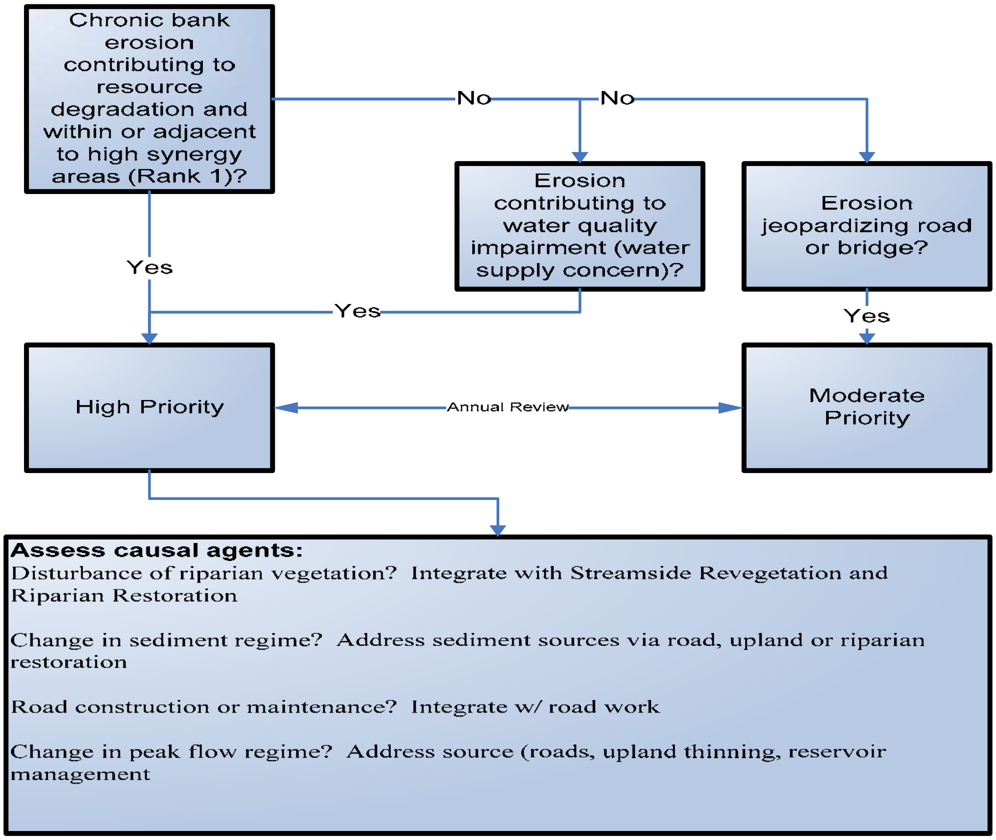

Figure 13: Decision tree for prioritizing bank stabilization work.

3.6 Peak Flow Passage Projects

The objective of peak flow passage projects in the CRMW is to identify and improve the capacity of water crossing structures to convey large flows (and associated sediment) within the aquatic system. For assessment and design purposes, we define large flows as those with a 100-year recurrence interval. Given the legacy of historic road construction throughout the CRMW, commonly involving the use of undersized or poorly located culverts, it is critical to prioritize this work such that the most critical projects are completed first. Using past culvert and fish habitat assessments, we have a comprehensive culvert inventory and fairly complete list of those where improved capacity is needed (Table 13). Figure 14 describes the general steps used to identify and prioritize projects. As peak flow passage problems can be triggered by changes in natural watershed processes such as mass wasting and sediment transport as well as the location of undersized water crossing structures, a thorough assessment of relevant processes in addition to traditional design parameters will determine long-term success. In addition, given how widespread this problem is within the CRMW, project prioritization will need to carefully evaluate the potential benefits such that the most critical projects are completed first.

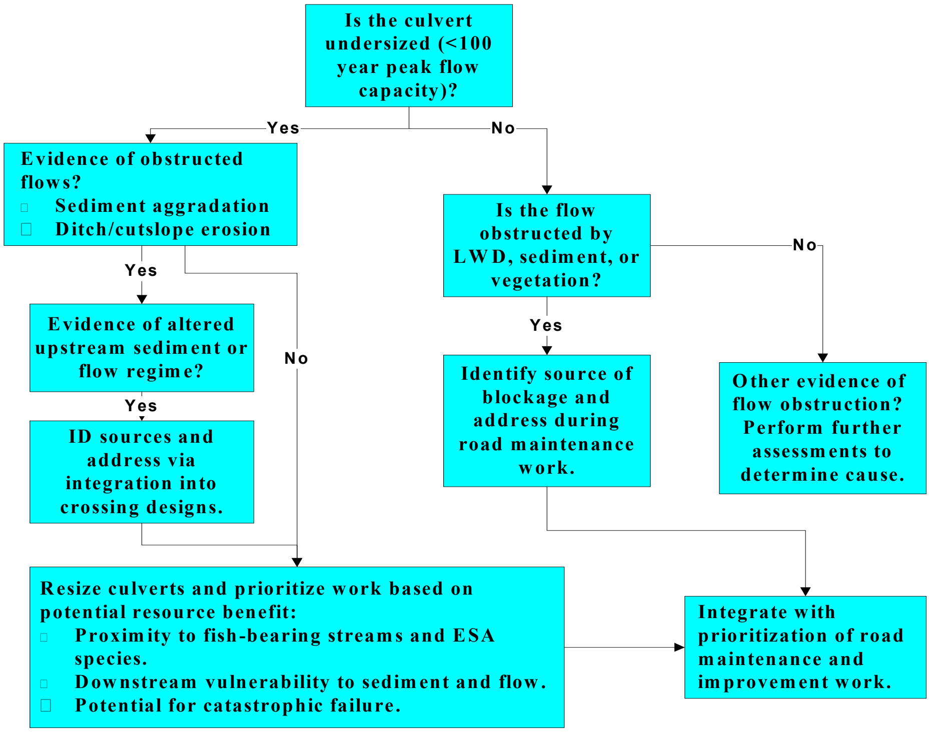

Figure 14: Decision tree for prioritizing peak flow passage projects.

3.7 Fish Passage Projects

The objective of fish passage projects in the CRMW is to identify and reestablish fish passage in locations where road crossings interrupt connectivity between significant habitat for resident or anadromous fish. Restoration of access to habitat by upgrading, replacing, and removing inadequate culverts on fish-bearing streams can be one of the most cost effective strategies for fish habitat restoration (Roni et al., 2001). Removing artificial migration barriers can also restore biological connections between upstream and downstream reaches that are an important part of natural stream functions (Ward, 1989). For assessment and design purposes, we define fish passage as any culvert that meets the State of Washington fish passage criteria within a stream classified as type F or Np.

Given the legacy of historic road construction throughout the Pacific Northwest, commonly involving the use of undersized or poorly located culverts, it is critical to prioritize this work such that the most critical projects are completed first. Parallel to our list of peak flow projects, we've developed a comprehensive list of culverts where fish passage is a concern (Table 13) using past culvert and fish habitat assessments. The following decision trees (Figures 15 and 16) describe the general steps used to identify and prioritize projects:

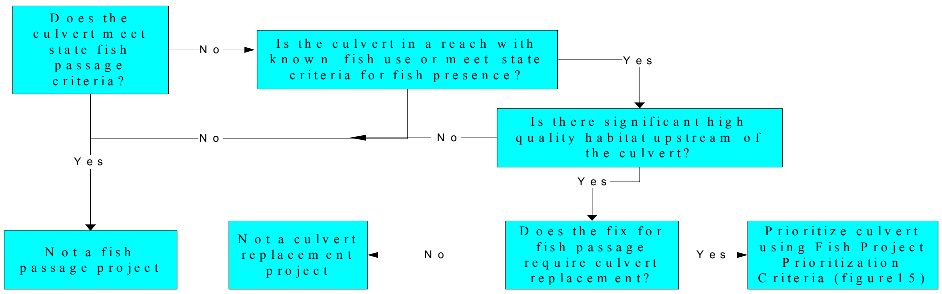

Figure 15: Criteria used to assess whether a project is a viable fish passage (through culverts) project

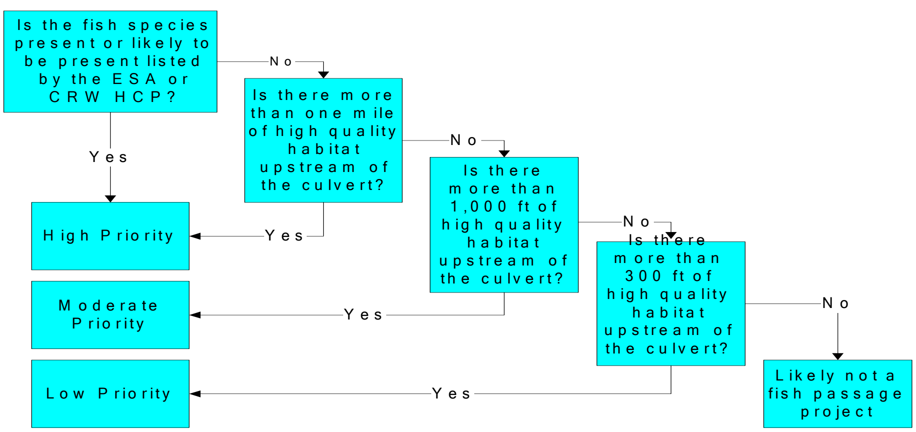

Figure 16: Fish passage project prioritization decision tree

3.8 List of Short-term Aquatic Restoration Projects

Initial site selection and prioritization of aquatic restoration project sites has been completed using currently available data and draft decision trees to identify near-term restoration project sites. This initial list will be likely be updated and improved annually using new information and based on any improvements or modifications to the prioritization decision trees. In general, fish passage projects will primarily occur around the reservoir or other areas needed to address bull trout issues, as most of the lower-elevation passage problems have already been addressed. Streamside revegetation will focus on stream crossings associated with road decommissioning projects. Bank stabilization projects will primarily address chronic bank erosion adjacent to roads and any areas newly disturbed due to land management activities or flood flows. LWD replacement projects will initially focus on habitat within high priority areas within the Lower Cedar River Mainstem and Tributaries (Area 5, Table 12, Figure 11). Finally, peak flow passage projects will utilize Table 13 to prioritize culverts distributed across all high priority areas as defined by the Landscape Synthesis Framework.

Table 12: Prioritized list of LWD Replacement and Streambank Stabilization Projects as of December, 2008

Project Type and Location	Resource Issues and Synergy Rank1	Opportunities for Collaboration	Work Completed	Tasks to be Completed	Status
LWD - Rock above 10 road	Potential Coho Habitat, Synergy Rank 1		Implementation in 2004;	Post 2006 flood LWD repositioning	Implementation in 2007
LWD & Bank Stab. - Rex River @300 bridge	Current Bull Trout Habitat; Synergy Rank 1	Bridge Replacement, Conifer underplanting	Draft project designs	Finalize designs; coordinated with operations and Forest Ecology Group	Design and implementation in 2008
LWD & Bank Stab - Upper Cedar (above Camp 18)	Current Bull Trout Habitat; Synergy Rank 1	Riparian Restoration	None	Map CMZ above 100-300 bridge; delineation of valley floor surfaces and assoc. riparian veg	Scoping. Design project in 2008 for implementation in 2009.
Status of other High Priority Sites					
LWD - Rock between Cedar River and 40 road	Coho Habitat, Synergy Rank 1	Walsh Lake Diversion Ditch, Riparian Restoration, NOAA Recolonization research	Comprehensive Stream Inventory; Walsh Ditch Fatal Flaw Analysis underway-4/08	Reevaluate following completion of Walsh Ditch Fatal Flaw Analysis (2008)	Status changed from High to Low Priority based on current habitat condition. Priority could change based on Walsh Ditch findings and discussions with NOAA.
LWD Williams (segments WIC3 and WIC4)	Potential Coho Habitat, Synergy Rank 1		Assessment of inventory data; Recon. by ID Team	None	Assessment of fish passage concluded that Coho have a low likelihood access to potential habitat. Status changed from High to Low.
LWD - Rock between 10 and 40 roads	Potential Coho Habitat; Synergy Rank 1	FR (Connectivity); RR(LWD)	Monitoring Cross Sections ('05 &'06)	Continue monitoring	On hold.
LWD & Bank Stab -Boulder Creek below 200 bridge	Current Bull Trout Habitat; Synergy Rank 1	Riparian Restoration; Bull Trout Pit Tagging Research	Field assessment by Hydrology and Fish and Wildlife staff (5/07)	Annual reconnaissance of channel location and dynamics	On hold. Connectivity between lake and headwater habitat currently limited by channel braiding
Bank Stab -50 road along Lower Cedar River	Current Chinook and steelhead Habitat;Synergy Rank1- 3	Road Improvement	Develop Design Criteria; Develop SOW	Assess annually for change in bank and road fill condition	Status changed from High to Low based on drilling results from road edge. On hold

[1] Synergy Rank of 1 indicates culverts located in highest 20% of priority areas as defined by Landscape Synthesis Framework, 2 includes upper 20-40%, 3 - 40-60%, 4- 60-80%, and 5 includes the lowest 20%.

Table 13: List of High Priority Peak Flow and Fish Passage Restoration Projects *(Projects highlighted in green have been completed as of December, 2008)*

Priority (Synergy rank[1])	Major Basin	Stream Name	Road Number	Culvert Number	Resident Species	Anadromous Species	Project Status
1	Walsh	Webster Cr.	20	11A&B	CUT, KOK, (RBT)	(COHO)	Removed in 2008. May replace
1	Taylor	Seventeen Cr.	60	5	CUT, (RBT)	None	Completed
1	Walsh	Webster	24	44A&B	CUT, KOK, (RBT)	(COHO)	Completed
1	CML	McClellan Cr.	100	30A&B	RBT, BLT**	None	Completed
1	CML	Shotgun	200	20A&B	RBT, BLT	None	Completed
1	N. F. Cedar R.	North Fork Cedar R.	565	1	RBT	None	
1	S. F. Cedar R.	South Fork Cedar R.	500-600	USGS weir	RBT, BLT	None	Completed
1	Upper Cedar	Bear Ck.	600	1	RBT, BLT	None	Completed
1	Walsh Lake	Webster Creek		Pipe	CUT, KOK, (RBT)RBT, BLT**	(COHO)	Passable after 2006 storm
2	Steele	Steele Cr.	20	4	CUT, (RBT)RBT, BLT**	(COHO)	
3	Steele	Steele Cr.	20	5	CUT, (RBT)RBT, BLT**	(COHO)	
4/5	CML	Green Point Cr.	100	23	RBT, BLT	None	Completed
5	Rock	Rock Creek Tributary	25	3	CUT, (RBT)	(COHO)	Removed in 2007
5	CML	Otter Cr.	100	11A&B	RBT, BLT	None	Replace in 2009
5	CML	Bridge Cr.	100	17	RBT, BLT	None	Replace by 2016
Not Ranked	Issaquah	Carey Cr.	19	2	CUT, (RBT)*	(COHO)	Completed in 2003
Not Ranked	Issaquah	Carey Cr.	19	4	CUT, (RBT)	(COHO)	Completed in 2004

CUT – Cutthroat Trout; RBT – Rainbow Trout; COHO – Coho salmon; KOK – Kokanee salmon; BLT—Bull Trout; CML – Chester Morse Lake

( ) – Species in parentheses have the potential to occupy upstream reaches but are not currently found below the culverts of concern.

* - Insufficient information

** - Stream passable to bull trout, but no documented records of use in these streams.

[1] Synergy Rank of 1 indicates culverts located in highest 20% of priority areas as defined by Landscape Synthesis Framework, 2 includes upper 20-40%, 3 - 40-60%, 4- 60-80%, and 5 includes the lowest 20%.

4.0 STANDARDS AND GUIDELINES FOR PROJECT PLANNING AND IMPLEMENTATION

The intent of this section is to provide a framework for successfully documenting an aquatic restoration project. The project planning process described below should be followed once an aquatic restoration project has been identified for implementation. Once a project has been identified for implementation, a project leader should be established and a time line set.

4.1 Project Plan Elements

The subsections below are intended to be specific sections in the plan and implementation document (subsection headings are intended as headings of the project plan). Plan sections should include; Project Introduction and Statement; Project Site Description; Project Description, Objectives, and Justification; Coordination with Other Projects; Evaluation of Potential Effects; Project Mitigation; Evaluation of Cost versus Benefits; Outside Review, Permitting, and Approvals; Contract Development; and Adaptive Management and Monitoring Plan. A project resulting from unusual or special circumstances may have additional or abbreviated sections to describe the circumstances that resulted in the project.

4.1.1 Project Introduction and Statement

The intent of this section is to provide a general overview of the project. This section should include background, a description of the type of project (placement of LWD using a helicopter, bank stabilization using wood and boulders, replacement of culvert with bridge for bull trout passage, reestablishment of wetland connectivity, etc.), and location(s) of project.

4.1.2 Project Site Description

This section should give a description of the project area in enough detail that the document can be used to gain understanding of where the site is located, what features, structures, and/or environment conditions are present at the project site. Potentially relevant site characteristics to be described may include:

- geomorphic context (floodplain, terrace, hillslope, valley width)
- physical habitat indices
- current or potential use by aquatic organisms
- site history and recent disturbances
- soils, geology
- subbasin context, and
- adjacent riparian conditions.

4.1.3 Project Description, Objectives, and Justification

The objectives of the project should be clearly and specifically stated and tied to the key ecological attributes and stated future desired conditions that the project attempts to achieve. The objectives should be written in a manner that can be measured during project monitoring. For example, an objective for a LWD project may be to increase the number of pools within a given reach of stream. This objective can be measured against a desired number of pools or acceptable range for pool frequency. The justification should clearly give the reasons for conducting the project and describe how the project contributes to meeting the desired future conditions for key ecological attributes. The justification should also describe how the site was selected and how the project ranked within the prioritization scheme, or if the project resulted from unusual or special circumstances.

4.1.4 Coordination with Other Projects

The project plan should discuss how the project fits into the general approach presented in the Landscape Synthesis documents. Specify what projects may need to be coordinated with this one, how that coordination is to take place, and a timeline for coordination with other restoration efforts.

4.1.5 Evaluation of Potential Effects

This section should identify and discuss all the potential negative effects of the project experienced during implementation. A discussion of how these negative effects were addressed should be included. The plan should also discuss any potential undesirable outcomes from project activities or from actions not taken during the project (passive actions).

4.1.6 Project Mitigation

If there are anticipated negative impacts or potential undesirable outcomes from implementing the project, the plan should discuss how the impacts and/or undesirable outcomes will be mitigated. The mitigation plan should list actions to be taken and provisions for their implementation spelled out.

4.1.7 Evaluation of Cost versus Benefits

This section needs to identify and discuss all costs and benefits of the proposed project. The cost and benefits need to be consistent with the 'Triple Bottom Line'(environmental, social, and budgetary) associated with the Asset Management Framework used by the Utility. Cost Effectiveness must describe a method for judging the cost effectiveness of (1) individual project designs (among alternatives considered) and (2) the overall choice of projects. Selection of a preferred alternative design should be justifiable as providing the greatest potential ecological benefit for the cost. On a landscape scale, compare alternative approaches in terms of overall ecological benefits per dollar spent, and specify the basis for determining overall ecological benefits so that the reasoning is transparent. Development of watershed/landscape benefits should be considered for very expensive or controversial projects.

4.1.8 Outside Review, Permitting, and Approvals

This section describes the process and extent of project plan review by outside entities or why outside review was not solicited. If the project is highly experimental, has high risk of adverse consequences, or has significant uncertainty, the project plan should be considered for external review. The section should describe what type of external review was requested, who reviewed the plan, and generally how comments (if any) where addressed.

Aquatic restoration projects are subject to several potential federal, state, and county regulations, some which have a long application timeframe. This section is to identify all applicable regulations and permits needed to complete the project.

This section should also describe the project approval process. The section should explicitly state who approved the project (supervisor, section manager, division director, branch director, utility director, mayor's office) and why that level of approval was obtained.

4.1.9 Contract Development

The project plan should describe how outside assistance will be obtained if it is necessary for any phase of project development or implementation. The plan should describe what planning, design, and monitoring work will be done with a consultant and how that consultant will be placed under contract. The plan should also discuss project implementation and if the project is going to be constructed in-house or put out to bid. If the project is to be put out to bid, the plan should discuss what type of service contract will be needed and how the contract will be obtained.

4.1.10 Adaptive Management and Monitoring Plan
This section should describe the proposed monitoring plan for the project. The monitoring plan must be tied back to the key ecological attributes, stated future desired conditions attempting to achieve, and project specific objectives. The type (compliance, effectiveness, etc.) of monitoring to occur and specific type of data to be collected must be explicitly laid out before the project is implemented. In some cases monitoring may be very limited, but monitoring measures should be explicitly laid out and justified before the project is implemented. To ensure that monitoring results are integrated into future management and restoration planning, the adaptive management elements discussed in Section 2.8 and Table 10 should be addressed in the project monitoring plan.

4.2 Standards and Guidelines for Implementing Aquatic Restoration Projects
An overview of the steps, logistics, and schedule for implementing the restoration action should be described in the project plan. A detailed Implementation Plan should be completed as a stand-alone document and included as Appendix A to the project plan. The Implementation Plan should be written for use in the field by personnel conducting the project. Content of the Implementation Plan should include the following considerations.

4.2.1 Completion of Baseline Monitoring
A brief description of what types of baseline monitoring will be conducted before the project begins should be indicated in the project plan. Details describing the proposed monitoring should be developed as an appendix to the project plan and any previously collected data relevant to the project reach summarized in this section.

4.2.2 Identification and availability of Needed Resources
Identify all materials, equipment, and labor needed for project implementation and determine the source and availability of all needed resources.

4.2.3 Mobilization, Initiation, Oversight, and Safety
Lay out the logistics of project implementation. Topics to address include: staging of equipment and materials, road access, communication with contractors, oversight of contractors or Operations personnel implementing the project, and safety concerns and measures are all important issues that may need addressing. Specify a schedule for project initiation and completion.

4.2.4 Project Specifications
Specifications developed in the project design should be clearly described so that personnel implementing the project can easily refer to them for guidance during implementation. If contractors are used, these specifications would be included in the contract.

4.2.5 Mitigation Measures
If there are anticipated negative impacts from implementing the project, any mitigation measures should be listed and provisions for their implementation spelled out. Details of mitigation measures should already be in the project plan.

4.2.6 Project Closure
Several activities need to be carried out following project implementation. These include:

- Demobilization: Staging areas should be cleaned up, equipment cleaned and returned to storage, extra materials returned to vendor or stored for future use.

- Compliance Monitoring and Documentation: Monitoring to determine whether specifications of project were complied with. Any changes in project design or specifications should be documented in an "as-built."
- Cost evaluation: Project costs should be documented and evaluated against project budget. Costs include those associated with planning, design, implementation, monitoring, and closure.
- Data management: Data collected for project planning, baseline monitoring, compliance monitoring, costs, and other purposes should be compiled, formatted, and stored in the appropriate hard and soft files, as designated by the CRMW Information Framework.
- Evaluation of project: If any special problems or situations were encountered during implementation of the project, they should be evaluated and documented in the Ecosystem's Annual Review Database. The evaluations should also include things learned, describing new approach that saved time, money, resources, etc. and describing approaches that worked well in completing the project.

5.0 TACTICAL PLAN

This document reflects considerable effort made to describe important aquatic resources within the CRMW as well as how we intend to restore and maintain these resources when developing projects using this decision framework. Given our incomplete understanding of the aquatic system as well as our lack of experience working with the decision framework laid out in this plan, however, revisions to this plan will be frequent and perhaps substantive, particularly early on in the implementation process. As part of the annual project review process, an assessment of the decision trees and criteria used to identify and prioritize project areas will be made, with the intent that significant changes to these decision-support elements will occur every 3 to 5 years. Ongoing efforts, discussed below, will also be initiated to address knowledge gaps identified in Table 8 in Section 2.8.

5.1 Next Steps

While many of elements of the Aquatic Restoration Strategic Plan will be revised and updated many times over the next several years, the action items listed below are necessary in order to move forward on all aquatic restoration efforts.

1 Continue to evaluate the suite of indicators identified in Table 3 to make certain that they cover all of the relevant scales.

2 Complete Table 8 by assigning responsibility and timelines to staff. Priority will initially be given to those analyses needed to the complete the LWD Management Plan for the lower Cedar (R1, R2 and R7). Most other items underlie implementation of our long-term monitoring program and shall be addressed in the next 1-3 years.

3 Though we have funding needed to address the two existing knowledge gaps where collaboration is needed (R1 and R13), funding sources could be identified to facilitate collaborative work associated with passive and active restoration projects along the lower mainstem Cedar River. In particular, habitat and fish response to future LWD recruitment in reaches currently used by anadromous salmonids would be very informative.

4 Assist with the development of pathways (curves) of desired future conditions for the riparian vegetation indicators and its role in recruiting LWD.

5 Review prioritization criteria for LWD-replacement projects in light of the established riparian desired future conditions identified in number 4.

6 Complete the identification of desired future conditions by completing activities identified in Table 8 that involve literature review, discussions with experts, and synthesizing information.

7 Integrate these indicators and desired future conditions into project-level and watershed-level monitoring plans

8 Evaluate USGS report regarding the use of BIBI and RIVPACS regarding long-term trend monitoring. Report completed by the spring of 2008.

6.0 ROLE OF AQUATIC RESTORATION INTERDISCIPLINARY AND PROJECT TEAMS

The Aquatic Restoration ID Team will remain active through the completion of the Aquatic Restoration Strategic Plan. Following completion of the strategic plan, the team will conduct annual reviews of upcoming projects to assess priority status and ensure integration with other spu staff and restoration projects. The ID Team will also evaluate the Strategic Plan at periodic intervals (every five years) and amend it to incorporate lessons learned through adaptive management of aquatic restoration projects. Smaller teams assembled to implement specific projects, called Project Teams, are responsible for ensuring that individual restoration projects align with the Synthesis Framework and are designed, documented and implemented consistent with the approach described in Section 4 of this document.

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Aquatic Restoration Strategic Plan Appendices A, B, and C

APPENDIX A: Benchmarking - Monitoring Trends in Aquatic Conditions in Pacific Northwest Mountains Streams

APPENDIX B: Monitoring Aquatic Restoration Projects

APPENDIX C: Information Management

APPENDIX A: Benchmarking - Monitoring Trends in Aquatic Conditions in Pacific Northwest Mountains Streams

The CRW HCP acknowledged the importance of conducting long-term monitoring of aquatic resources and identified three general objectives: 1) monitor stream health for the duration of the HCP; 2) document recovery from past water supply and land management operations; and 3) evaluate the success of stream habitat restoration projects. The physical scope of the long-term monitoring program includes both tributaries and mainstem Cedar River reaches. However, since the size of rivers such as the mainstem Cedar River precludes the use of field sampling methods suitable for streams that can be safely waded on foot, initial monitoring sites are restricted to wadable streams where established sampling protocols can be used. Detailed discussions of our sampling design, approach to randomized site selection, and survey protocols can be found in the Science Information Catalogue http://spu72.ci.seattle.wa.us:7781/dav_portal/portal/SIMS/APPS/SIC/Contribute/Science%20Sustainability%20and%20Watersheds/Cedar%20and%20Tolt%20Watershed%20Services/Watershed%20Ecosystems/WATERSHEDS_AND_ENV_PROGS/AQUATIC_LONG_TERM_TREND_MONITORING

Several large-scale aquatic monitoring plans have been developed recently to track trends in aquatic systems at a watershed-scale. Long term aquatic ecosystem trend monitoring within the CRW will integrate at least some elements from the four comprehensive plans listed below:

- Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) for the Northwest Forest Plan (Reeves et al. 2001)
- PACFISH/INFISH Monitoring Plan for Aquatic and Riparian Resources (Kershner et al., 2001)
- North Cascades National Park Service Complex, Long-Term Ecological Monitoring (LTEM) Conceptual Plan (Fleet et al., 1998)
- Washington Timber/Fish/Wildlife Effectiveness Monitoring and Evaluation Program (NWIFC-TFW)(Smith and Schuett-Hames, 1998)

As shown in Table A-1, differences between these plans stem largely from variations in goals, aerial extent, and availability of resources. However, since each of these plans identify protocols and strategies for the detection and quantification of trends in watershed processes related to aquatic habitats, elements from each can be used to develop long term aquatic monitoring methods in the CRW.

Table A-1: Comparison of Aquatic Monitoring Plans within the Pacific Northwest (based on a review of website information gathered by Amy Reichenbach).

Plan Elements	Aquatic and Riparian Effectiveness Monitoring Plan for the Northwest Forest Plan (AREMP) (2001)	Pacfish/Infish Effectiveness Monitoring for Streams and Riparian Areas within the Upper Columbia River Basin (2001/2002)	North Cascades NP Service Complex, Long-term Ecological Monitoring Conceptual Plan (LTEM) (1998)	Washington State NWIFC-TFW Effectiveness Monitoring Program Plan (1998/1999)
Geographical Extent	west of the Cascades, from northern California thru Washington	most of the Columbia Basin east of the Cascade Crest in Washington, Oregon, Idaho, and western Montana	Includes North Cascades NP, Ross Lake and Lake Chelan Recreational Areas, for a total of 276,000 hectares	Washington state watersheds
Major Goals	to evaluate the effectiveness of the Forest Plan, to characterize the ecological condition of watershed and aquatic ecosystems, to track trends in condition over time	effectiveness monitoring for PACFISH, INFISH, and PIBO (Pacific salmon and other anadromous species- PACFISH; resident fish species outside the anadromous areas Inland Native Fish Strategy- INFISH; and Biological Opinions- PIBO)	to track and understand how aquatic communities and habitats respond to natural processes, and to be able to distinguish differences between human-induced disturbance effects to aquatic ecosystems and those caused by natural processes	to evaluate whether the forest mgmt. system used in Washington state is effective in protecting aquatic resources from cumulative impacts of forest practices on a watershed scale
Years in implementation	2 years of pilot studies to test protocol and sampling strategies have been completed in 6-HUC watersheds, full implementation has not yet been undertaken?	four years of pilot studies have been completed and evaluated in 450 6-HUC watersheds; full implementation to begin in 2003	Conceptual plan developed in 1998, not yet implemented due to lack of funding from NPS. Several pilot studies have been completed however.	currently inactive, but manuals are available for download; pilot studies were planned for 1998 and 1999, implementation to occur afterward- not sure if the pilot studies led to full implementation
Data collection and extrapolation	over 5 years, 250 watersheds are to be sampled, to be extrapolated at the regional scale (e.g.. River basins, National Forests, BLM districts); can however implement at smaller spatial scales- would need 50 sampling units for statistical validity	sample one-half of potential "watersheds"- not sure how many this is	Envision that LTEM will occur in specific watersheds, and the data will be extrapolated to regional and landscape levels	stratified random sampling which can be extrapolated at the regional scale
Sampling frequency and scale	1 to 10 years at selected reaches in 6-HUC watersheds	every 5 years at selected reaches in 6-HUC watersheds	various, some parameters every 10 years, others every 1-5 years; watershed scale (i.e. channel types) can be 100% inventory or sub-sampled; detail sampling of selected reaches	varies, 5 year intervals or less
Aquatic resources sampled	streams only	streams only	streams, lakes/ponds, reservoirs	streams only
Physical	cross sections, profiles, substrate, wood, discharge	pools, % fines in pools, substrate, cross sections, wood; sinuosity, gradient, and transects- bank angle, bank stability, streambank stability, bank type, bank material, vegetation, bankfull	* see charts: sediment, wood, morphology, riparian habitat, flow, substrate, habitat units	mass wasting, surface erosion, riparian LWD recruitment, thermal energy/riparian shade, hydrology, fine sediment, coarse sediment
Biological	periphyton, benthic macroinvertebrates, fish, aquatic amphibians, terrestrial amphibians	macroinvertebrates, periphyton	* see charts: phytoplankton, zooplankton, benthic macroinvertebrates, amphibians, fish	none
Chemical	nitrogen, phosphorous, temp, dissolved oxygen, pH, conductivity	conductivity, alkalinity	* see charts: temp, pH, dissolved oxygen, nutrients, nitrogen, phosphorous, chlorophyll, conductivity, clarity	temp.

A.1 Channel Metrics

Consistent with the physical metrics identified by various groups in previous monitoring efforts (Table A.1), parameters to be measured at each stream sample site in the CRMW include three physical geomorphic features, water temperature, and photo documentation of stream conditions, as shown in Table A.2.

Table A.2. Physical stream parameters and measurement techniques for status and trend monitoring.

Category	Recommended Physical Parameter	Measurement Technique
Pools	*Residual pool depth* – distribution of pool depths by sample site of all pools/length of stream *# pools* – per unit length (gives distance between) *# pools formed by wood* – by sampled site, expressed as a %.	Longitudinal profile using auto level and rod. Include three cross-sections/sample site to augment interpretation of other channel geometric measures.
Woody Debris	*# pieces* per unit length of stream *# pieces/ size class* = volume estimate *Position in channel* – zones defined within active channel	Data sheet will include provisions to assign pieces into size categories, and will distinguish "jams" of > 5 pieces; and assign pieces to 4 zones within the channel*
Sediment	Cumulative size distribution – *D50 and D85*; estimate of % size fraction < 0.85 mm	Wolman (1964) pebble counts, 3 counts per sample site, at permanent cross-sectional transect locations
Stream Temperatures	*7 day average of the daily max*	Recommend sample interval at 2 hr interval or greater. Thermisters installed at each site.
Photo points	Establish *permanent photo points:* both upstream and downstream of sample reach midpoint, downstream from uppermost boundary and upstream of lowermost boundary.	

A.2 Hypotheses Associated with Selected Channel Metrics

A monitoring plan has been developed specifically for the CRMW in order to answer the following hypotheses regarding the health and recovery of low gradient streams (based on changes to the stream channel metrics listed above):

Pool characteristics

a) *Residual pool depth* – *Ho*: Residual pool depth remains unchanged over time both within and between sites.

   Ha: Residual pool depths will increase over time as sources and inputs of sediment (from hillslope and bank erosion) stabilize and are reduced; and existing accumulations of fine sediments are winnowed from stream beds and transported downstream.

b) *Numbers of pools* – *Ho:* The number of pools remains unchanged over time both within and between sites.

Ha: The number of pools per unit length of stream will increase over time as obstructions to flow (wood inputs) increase, sediment supply decreases and annual stream flow characteristics stabilize.

c) *Pools formed by wood* – *Ho:* The number of pools formed by wood remain unchanged over time.

Ha: The number of pools formed by wood per unit length of stream will increase over time.

Woody debris

a) *Woody debris pieces* – *Ho*: The number of pieces of woody debris per unit of stream channel will remain unchanged over time, both within and between sites.

Ha: The number of pieces of woody debris per unit length of stream within response reaches will increase over time.

b) *Woody debris volumes* – *Ho*: The volume of wood will remain unchanged over time, both within and between sites.

Ha: The volume of wood in response reaches will increase (i.e., number of pieces/ size class, as riparian zones recover from past logging).

c) *Position in channel* – *Ho*: Woody debris size classes and distribution within the active channel will remain unchanged over time, both within and between sites.

Ha: As the size of woody debris increases, more pieces of larger size will be positioned within the wetted width of the channel during base flow periods (i.e., in late summer/early fall months).

Sediment

Sediment particle size distribution – *Ho:* Sediment particle size will remain unchanged over time, both within and between sites.
Ha: the cumulative size distribution of the 50% and 85% particles will increase over time as sediment supply and flows equilibrate to more natural input processes (D50 and D85; estimate of % size fraction < 0.85 mm).

Stream temperatures

Stream temperature – *Ho:* Stream temperatures regimes during the summer months will remain unchanged over time
Ha: Stream temperature regimes during the summer months will correspond to those expected for streams un-impacted by commercial scale timber harvesting, and nominally conform to established water quality temperature criteria as evidenced by the moving, 7-day average of the daily maximum (MWAT) temperature.

APPENDIX B: Monitoring Aquatic Restoration Projects

The aquatic restoration program in the HCP consists of several different categories of restoration activities (Table B.1), each of which has individual goals and objectives. Though all aquatic restoration projects will focus on modifications to physical processes within the aquatic system, evaluation of success will determine whether relevant habitat characteristics are sustained by natural watershed processes as well as the subsequent biological responses to these changes.

In all project monitoring plans, selection of what, how, and when to collect on-the-ground data should be driven by project-specific goals and questions. Given the importance of having clear, concise monitoring objectives, which are needed to form specific questions and data collection strategies, additional resource-specific goals and objectives were developed within each of the broad HCP Aquatic Monitoring objectives. In addition to more detailed resource-specific goals, Table B-1 also describes general measures of success, performance targets based on Table 3 (of the Strategic Plan), frequency and timing of repeat monitoring, and geomorphic map units (channel types) within the CRW where specific monitoring efforts are most likely to detect meaningful changes.

To facilitate the establishment of effective monitoring efforts, every aquatic restoration project will have a brief written plan which delineates project goals and identifies key indicators and survey protocols, performance targets, and the frequency, intensity, and duration of data collection. Since costly, time-intensive monitoring will not be conducted for every project, Table B-2 states the criteria for prioritizing project sites where intensive monitoring efforts will be most beneficial.

Table B-1: Elements of project-specific aquatic monitoring plans.

Project Category	Resource Specific Goals and Objectives	Effectiveness Monitoring (measures)	Performance Targets (measures of success)	Probable Monitoring Strategies	Frequency and Timing	Response Potential of Relevant Geomorphic Map Units (channel types)*
LWD Placement	Restore and maintain pools and a favorable array of habitat sub-units	Increases in pool frequency and depth	Specific Performance Targets for individual restoration projects may utilize the DFCs identified in Tables 5 & 6 for the relevant GMUs. Depending on project-specific objectives and constraints, the project design/mgmt team may chose to refine targets for a given project. For example, a LWD project should create a specific target for number of created pools or percentage increase in pool area or depth.	Pre and post treatment comparisons of conditions within and above treatment reach.	Every five years, or following high flow event (10-yr or greater)	High:14, 8, 10, 15, 9, 13, 3 Moderate: 5, 6, 2
	Restore and maintain natural bank protection processes in order to minimize management-generated fine sediment delivery and maintain channel dimensions and morphology within their natural range.	Bank stability (percent bank erosion)		Pre and post treatment comparisons of conditions within and above treatment reach	Every five years, or following high flow event (10-yr or greater)	High: 5, 8, 9, 10, 12-15; Moderate: 3, 4, 7
	Restore and maintain natural in-stream LWD loadings in order to maintain channel dimensions and morphology within their natural range.	Increase in sediment storage (LWD-formed steps)		Pre and post treatment comparisons of conditions within and above treatment reach	Every five years, or following high flow event (10-yr or greater)	High: 5-7; Moderate: 8-13
	Restore in-stream habitat by creating cover, shade and substrate for macro-invertebrates	Percent cover, shade and substrate for macro-invertebrates		Pre and post-treatment comparisons through project area	Annually for first 5 years, and in 10th year, or following high flow event (10-yr or greater)	Variable response potential: 5-13

Streambank stabilization	Restore and maintain natural bank protection processes in order to minimize management-generated fine sediment delivery and maintain channel dimensions and morphology within their natural range	Bank stability (percent bank erosion or bank erosion pins) and permanent cross sections	See above	Above and within project area	Annually for first 5 years, and in 7th and 10th years	High: 5, 8, 9, 10, 12-15; Moderate: 3, 4, 7
Streambank Stabilization (continued)	Maintain natural ranges of turbidity	Turbidity	See above	Above and below project area	Years 1-3	High: 8, 9, 10, 12, 15; Moderate: 2-7, 13, 14
	Protect downstream fish habitat by stabilizing chronically-eroding banks delivering fine and coarse sediment	Pool area and volumes in downstream fish habitat	See above	Pre and post treatment comparisons of conditions within fish-bearing channels. Reference reach within same GMU.	Dependent on proximity of habitat to project area as well as the Geomorphic Map Units (channel types) that contain downstream fish habitat.	High: 5, 8, 9, 10, 12, 13, 14, 15; Moderate: 3, 7
Streamside Revegetation	Restore and maintain natural bank protection processes in order to minimize management-generated fine sediment delivery and maintain natural ranges of turbidity.	Turbidity and/or percent bank erosion	See above	Above and below project area	Years 1-3, and 5, or following high-flow events (10-yr or greater) within first 10 years	High: 2, 3, 4, 5, 6, 8, 9, 10, 12, 13, 14, 15; Moderate: 7
	Restore natural bank stability processes in order to maintain channel dimensions and morphology within their natural range.	Bank erosion pins and permanent cross-sections	See above	Above and below project area	Annually for first 5 years, and in 10th year, or following high-flow events (10-yr or greater) within first 10 years	High: 5, 8, 9, 10, 12-15; Moderate: 3, 4, 7

Table B-2: Criteria for prioritizing project sites for intensive monitoring efforts

Resource condition is common to many reaches with the CRW, making feedback on performance and success broadly applicable.
Resource condition represents unique or sensitive habitat where potential risks are higher and the need to track changes and potential to conduct additional projects may be greater.
Resource condition represents a large, persistent problem (e.g., chronic source of fine sediment) which will continue to jeopardize downstream fish habitat.
Project location has direct ties to other monitoring efforts providing synergy of information within a chosen subbasin.

B.1 Compliance Monitoring—All Aquatic Restoration Projects

To determine whether or not project specifications were met, a system of reach measurements should be collected to determine if the construction was completed as designed, and to obtain post-construction information in order to track changes over time. If contractors construct the project, this kind of sampling would likely be conducted as part of contract compliance. In order to ensure consistency with our data collection standards and methods, in-stream survey and post-construction compliance monitoring should either be conducted by Watershed Division staff or in close coordination with contractors when they are used to implement a project.

B.2 Effectiveness Monitoring

Most project monitoring effectiveness designs will incorporate the comparison of characteristics of treated areas before and after treatment (pre- and post-treatment design). The comparison of post with pre-treatment data will help validate that the prescription was applied as designed in the project plan. The second step requires the comparison of characteristics through time of treated areas to similar areas that are left untreated (treatment/control monitoring design). The comparison of these data will demonstrate the initial similarity of pre-treatment and leave areas, and provide a measure of the effects of the treatment through time. Combining the two designs can be utilized to assess a single treatment repeated across different sites or different treatments repeated across similar sites.

B.2.1 Stream Crossings for Fish and Peak Flow Passage

Culverts and bridges that are not sized or installed properly often fail to allow fish to migrate upstream, or they impede the conveyance of peak flows downstream. Also, undersized stream crossings that do not allow peak flows to pass through effectively can be overtopped, occasionally triggering dam-break floods and debris flows which deliver large volumes of coarse and fine sediment to downstream channels.. Monitoring these types of projects is often straightforward, however, since flow and fish passage requirements are both widely understood and easily documented. Therefore, most monitoring on these projects will simply involve photo documentation of "before and after" conditions. Where scour has occurred due to improper culvert sizing or placement, monitoring may also include up and/or downstream cross-sections as well as bank erosion surveys. In addition, many fish passage projects will often include monitoring fish migration (especially for anadromous salmonids) to ascertain that the restored crossings are, in fact, passable. Similarly we may install crest gauges and create discharge rating curves where fish or flow passage issues are critical.

B.2.2 Streambank Stabilization and Streamside Revegetation

Chronically eroding streambanks contribute fine sediments to aquatic systems that can result in elevated turbidity levels with potentially deleterious effects on instream organisms. Where persistent fine sediment inputs are delivered to spawning habitat, the interstices of spawning gravel may become clogged, smothering redds and resulting in cemented (embedded) substrate. Additionally, suspended fine sediments present an immediate and quite significant water quality concern for the municipal water supply in the Cedar River.

In contrast to LWD-placement projects, the primary monitoring focus for these projects will be quantifying bank stability and erosion following project implementation. While the intent of these projects is to restore or improve aquatic habitat and water quality, the most sensitive measures of project effectiveness are those on the banks (e.g., plant survivorship, percent vegetative cover, bank stability, and bank erosion within the project area) rather than in the stream. In order to evaluate trends in bank stability, however, channel cross sections and habitat inventories will also need to be conducted.

B.2.3 LWD Placement

Within streams (and wetlands) of LS/OG forests, large woody debris plays a critical role, providing numerous physical and biological functions. First, LWD interacts with the hydraulics of, and sediments within, flowing streams to influence the shape, substrate, depth, and general morphology of the stream channel and floodplain both locally, and in downstream reaches. Second, LWD provides in-stream habitat niches that provide cover habitat for resident and anadromous fish, and substrate for benthic macroinvertebrates. Third, the decomposition of woody material provides an important source of nutrients to the stream trophic structure.

Projects which seek to restore these processes through the placement of LWD into streams and wetlands should have monitoring plans designed to determine the effectiveness at doing so. In most cases, this monitoring will start with a pre-project survey of habitat conditions and channel processes both within, and upstream, of the proposed project area. Following implementation of project plans, compliance monitoring will be conducted to ensure that the correct/planned number of pieces were placed correctly. In addition, though post-placement monitoring may sometimes be as simple as the establishment of permanent photo points, in most cases permanent cross sections will be established in order to track changes in channel morphology through time.

Monitoring the changes in habitat over time will likely involve the periodic use of various sampling techniques including: (1) cross-section and profile measurement, (2) Wolman pebble count, (3) LWD placement stability/movement, (4) reach sediment budget, (5) pool-riffle ratio, pool frequency, and residual pool depth measurements, and (6) benthic index of biotic integrity (BIBI) measurement. In all cases the fundamental goal of LWD effectiveness monitoring will be the comparison of pre- and post-treatment conditions to assess if the LWD had the prescribed physical effect on aquatic habitat structure and physical process.

APPENDIX C: Information Management

C.1 Information Management Goal

Our strategic goal is that information acquisition, analysis and management associated with aquatic restoration are optimized over the life of the HCP. In this way we create a "life-cycle" approach to ensuring maximum return on our efforts. This strategic goal will be achieved by establishing and tracking progress toward a set of Information Management Objectives that are consistent for each area of restoration activity that the HCP encompasses.

C.2 Information Management Objectives

1. Implement a process for planning and design of data acquisition and analysis
2. Consistent use of documented protocols for data acquisition
3. Demonstrate rigor in analytical methods
4. Create metadata products that describe data acquisition
5. Provide access to data and information products derived from them

C.2.1 Implement a process for planning and design of data acquisition and analysis

Meeting this objective will ensure that we focus our resources on those data that address our key areas of concern and that those data we acquire are of the type and quality needed for their intended use. In addition, it will enable the Watershed Services Division (WSD) to play a leading role in development of data quality management processes for SPU.

C.2.1.1 Identify purpose / key questions addressed

The Aquatic Restoration Strategic Plan (ARSP) identifies the key needs for data acquisition and analysis using the Desired Future Conditions (DFC) paradigm. The DFC paradigm identifies ecological *attributes* and associated *indicators* as a means to plan and track the outcomes of restoration efforts. *Indicators* link directly to a proposed suite of data acquisitions. Key needs arise in two areas:

- Data that will close current knowledge gaps (see Table 3 in ARSP)
- Data that support trend monitoring at several spatial scales (project and watershed wide)

C.2.1.2 Statement of Data Quality Objectives

Data Quality Objectives (DQOs) are a statement of the levels of precision, accuracy and reliability of data that will be acquired. Meeting these DQOs ensures data are able to address the purpose of the acquisition. The ARSP explicitly identifies *indicators* that will be tracked through time. Each data acquisition will identify DQOs that are consistent with the ways in which *indicators* are measured and observed. DQOs are tied to the spatial scale of the question to be answered (e.g. Individual CIP project, individual stream reach, or multiple stream reaches).

C.2.1.3 Sampling and Analysis Planning

The ARSP proposes to characterize aquatic resources at a range of scales. The focus of data acquisition efforts will be in those GMUs that have been most severely impacted by anthropogenic impacts. In order to ensure that these GMUs are adequately characterized, a comprehensive inventory will be undertaken.

The aquatic long-term monitoring plan explains methods to conduct sampling and analysis designed to assess conditions of streams across the watershed through time. Statistical considerations and plans for sampling are carefully outlined in the plan.

For a specific aquatic restoration project, the sampling design and data analysis strategy are largely controlled by the restoration goals for the site. The DFCs for each site will determine what indicators are to be sampled and the analytical strategy that will be used to determine progress towards the DFCs.

C.2.1.4 Peer review and consultant input

Where uncertainty in outcomes of aquatic restoration is high or the projects pose a particular risk, there may be a need to seek peer review of proposed data acquisitions. The Aquatic Restoration ID Team may also seek consultant help on projects requiring data acquisition when workload becomes too great.

C.2.2 Consistent use of documented protocols for data acquisition

Meeting this objective will ensure the integrity of data for comparing *indicators* through time. Documentation of protocols will facilitate re-measurement with consistent DQOs and also enable subsequent users of our data to evaluate their suitability for new purposes.

The ARSP draws on protocols that have been established for:

Low-flow Stream Habitat Inventory (also used for Geomorphic Map Unit Sub-sampling) (http://spu72.ci.seattle.wa.us:7781/dav_portal/portal/SIMS/APPS/SIC/Contribute/Science%20Sustainability%20and%20Watersheds/Cedar%20and%20Tolt%20Watershed%20Services/Watershed%20Ecosystems/WATERSHEDS_AND_ENV_PROGS/MONITORING/StreamInventoryProtocol.doc)

Aquatic Habitat Restoration Project Monitoring (Appendix B).

Cedar River Large Woody Debris Inventory (2005 LWD Inventory)

C.2.2.1 Definitions of attributes and domains

The ARSP identifies *indicators* (Table 3) which are synonymous with *attributes* in the context of data acquisition. As many of these *indicators* are nominal values (e.g. LWD Function) there is a need to be explicit about the values that comprise their domains. Explicit values allow a degree of automation to be achieved in data acquisition (e.g., drop-down lists), data quality control (e.g., data integrity rules) and data exploitation (e.g., query formulation). In addition they provide a basis to cross-walk to data acquisitions by other agencies concerned with similar resource management issues.

C.2.2.2 Description of methods for measurements and observations

To achieve consistency in data acquisitions it is necessary to explicitly describe many measurement and observation techniques. The protocols listed above document those measurement techniques for which repetition of identical steps is critical.

C.2.2.3 Equipment requirements

The proposed data acquisitions to support aquatic restoration are dependent to some degree upon the use of specific equipment. Where this is the case, the documented protocols will indicate which equipment is necessary and any procedures for its maintenance. In the event that a protocol identifies the need for equipment calibration the details of the procedure and schedule will be presented and a process put in place for ensuring that they are completed.

C.2.2.4 Association and presentation within GIS

Geographic Information Systems (GIS) provide a tool for data for geospatial referencing and analysis of data acquisitions. Given the range of scales over which management of aquatic resources is being undertaken, the need to develop a strategy to encompass the geographic domain is central to our information management goal.

For field observations, each protocol developed will explicitly record the locations at which measurements are made. In order to enable comparative analysis between the spatial distribution of *attributes* it is necessary to summarize measurements of their *indicators* over explicit spatial dimensions (e.g., unit lengths or areas). To do this there is a need to develop a suite of tools that associate the observations to the spatial representation of the hydrological landscape. At the current time these tools are developed but are packaged within a much larger suite of GIS tools and as such are un-available for routine use. A strategic effort will be undertaken in the context of the Science Information Management Systems (SIMS) (see section D.2.5 below) to provide a suite of tools to associate field observations to GIS features and to enable spatial queries of the data.

The following list depicts core GIS products needed to support aquatic restoration planning and implementation.

- Geomorphic Map Units of Aquatic system
- Hydrogeomorphic classification of wetlands
- Current and potential fish distribution map (Coho, Chinook and bull trout)
- LIDAR and tools needed to generate cross sections and profiles
- Improved map of headwater streams (to the end of the perennial channel)
- Riparian stand types
- Culvert and road inventory
- Colored ortho photos
- Foster Wheeler Stream Assessment layer
- Foster Wheeler mass wasting layer (inventory and hazard potential)
- Inner gorge layer

The Watershed Characterization Strategic Plan (WCSP) summarizes the status and schedule for completion of the development of these GIS products.

C.2.3 Rigor in analytical methods
Meeting this objective will enable us present defensible conclusions based upon the data acquisitions we make. Recognizing that the development of analytical methods is frequently dependent upon a specific suite of data there is also a need to ensure that we maintain consistency between methods and acquisitions.

C.2.3.1 Currency and best practices for data analysis

The Aquatic Restoration ID Team will stay updated on new analysis methods developed in the aquatic restoration field. Appropriate software will be used to conduct analyses. New models and approaches to examining data are constantly developed and will be applied within the aquatic restoration projects where appropriate. One example might include evaluating recent work by Lee Benda and Dan Miller modeling debris flow reaches prone to scour and deposition from mass wasting events. These types of methods can greatly accelerate our understanding of natural processes and potentially indicate restoration areas of focus on the landscape.

C.2.3.2 Description of analytical methods

As analytical methods become more complex there is a growing need to document their approaches. Without descriptive tools (documents, metadata) the results of analytical work can be difficult to interpret. The ARSP has identified potential contributions to our decision making process from sediment delivery models (e.g., WARSEM) and landslide prediction modeling. An assessment of the need to parameterize these models will be made to determine what level of description of model inputs and products is optimal.

C.2.3.3 Statistical assessments of the results of analysis

The long term monitoring of aquatic ecosystems is under development and will outline important statistically rigorous methods to follow trends through time and across the watershed. In some cases statistical assessments of the results of analysis may be important. However, for many aquatic restoration projects we expect to generate a set of summary statistics relative to a specific habitat feature (e.g. pieces of wood/100m of stream length). These types of analyses likely do not require statistical assessments. In order to assess some aspects of DFC questions or to determine sites requiring restoration, models will be used (e.g. sediment modeling). Criteria clearly outlining all assumptions made within the model will be documented and appropriate model validation procedures followed.

C.2.4 Create metadata products that describe data acquisition
Meeting this objective is critical to being able to leverage our data acquisition sin the future. We are not alone in discovering that much of our data archive has been rendered worthless due to poor standards of documentation.

C.2.4.1 Data Acquisition Description Document (DADD)

For data acquisitions based upon field observations and measurements there is frequently a need to document an "as-built" description of the data, recording key descriptive information that captures any departures from protocols. A number of these documents (e.g., for Low-flow Stream Inventory observations in 2003) have been developed within a standard template identifying the following sections:

- Dataset Title
- Dataset Owner / Contact
- Abstract
- Methodology
    - Sampling Design / Site Selection
    - Sampling Protocol / Instrumentation / Observation Technique
    - Description of Measurements

Whilst the effort to create this descriptive document is frequently regarded as a needlessly expensive overhead, we propose to follow best practices as recommended by the USGS and make a concerted effort to describe our data.

C.2.4.2 Structured metadata built on templates

The central role of the geospatial domain in our restoration efforts allows us to leverage a suite of structured metadata tools that have been developed as a component of our GIS software package, ArcGIS.

C.2.5 Provide access to data and information products derived from them

Meeting this objective will ensure continuity in our investments in data acquisitions and enable us to reduce the risks of managing data over the lifetime of the CRMW HCP. Access to data has proven to be a major hurdle for SPU as a whole and it is anticipated that significant effort will be required to maintain data integrity as access is broadened.

C.2.5.1 Managed access

Managed access to data is an agreed set of procedures that will enable SPU to leverage its data holdings. Managed access can be implemented to varying degrees. The more restrictive access becomes the more expensive it is to implement. At some point the cost becomes prohibitive and negotiation is currently required to resolve appropriate levels of access control.

The degree to which access to data acquisitions associated with aquatic restoration efforts will be enabled remains to be determined. The SIMS project sets hierarchical privileges that control user access to data acquisitions. In each case assignment to the role of *Data Viewer*, *Acquirer* and *Data Steward* will enable an individual to edit data in an operational data storage application. Subsequent upload of the data to the SIMS data warehouse solution will enable all registered SIMS users to query the complete suite of observations. This strategy will be applied to all data acquisitions made in association with HCP restoration efforts there by facilitating integration of multiple suites of information.

C.2.5.2 GIS enabled interface

Association of data within a geospatial context (see section D.2.2.4 above) will enable us to access data via a map query interface. The geospatial context allows access on the basis of location names, geographic coordinates, user defined geographic limits and specific features within GIS data.

C.2.5.3 Query tools

As identified in section D.2.3.3 there is a need for a suite of query tools that can provide summaries of measurements and observations of *indicators*. In many cases we have an opportunity to present queries that are made repeatedly against different suites of observations in a menu-driven presentation. At the current time the following queries have been identified:

- Piece of wood/100m of stream
- Key pieces of wood/100m of stream length
- Number of pools/100m of stream length
- Residual pool depth by stream reach
- LWD steps/100m stream length
- Drainage area above a certain point on a stream
- Valley cross section

There is an additional requirement that we develop a tool that allows the development of ad-hoc queries. Such a tool greatly expands the potential for leveraging data as new insights to the aquatic restoration process develop.

C.2.5.4 Output tools

Acquisition and analysis of measurements and observations of *indicators* used to support our aquatic restoration strategy are typically presented in the form of tabular reports, graphs and symbolized maps. The degree to which an individual wishes to customize these outputs has a significant impact on the selection and costs of the tools used to make them. At the time of writing the SIMS project is assessing these costs.