1 INTRODUCTION

> A central premise of the ASRP approach is that protecting or restoring **all** ecological regions to some degree is important to achieve the ASRP's vision, though restoration needs are not equal across all regions.

This document describes the Scientific Foundation used to develop the Chehalis Basin *Aquatic Species Restoration Plan* (ASRP). The Scientific Foundation encompasses the science-related principles, assumptions, concepts, and approaches used to develop the scientific conclusions that inform the ASRP decision-making process. Some of these are derived from research and monitoring specific to the Chehalis Basin, and some are derived from the more widespread body of scientific research. This document also presents the rationale for various parts of the plan and helps to ensure the plan is credible and effective.

This Scientific Foundation was developed recognizing the long-term vision of the ASRP for the Chehalis Basin: to utilize the best available scientific information to protect and restore habitat in the Chehalis Basin, in order to support healthy and harvestable salmon populations, robust and diverse populations of native aquatic and semi-aquatic species, and productive ecosystems that are resilient to climate change and human-caused stressors, while honoring the social, economic, and cultural values of the region and maintaining working lands.

The ASRP is based on the premise that ecological processes and functions within the Chehalis Basin can be protected and restored to meet this long-term vision by supporting and sustaining productive, diverse populations of native aquatic and semi-aquatic species. To be successful and accepted, the ASRP must be based on sound science. It must set appropriate priorities, incorporate successful strategies and actions, be appropriately scaled, and be fully implemented to meet the vision, even in the face of climate change.

Restoration cannot result in the same conditions that existed prior to large-scale human-caused watershed changes that began in the mid- to late-19th century, but it can achieve the vision by restoring ecological processes and functions to a "sustainable high-functioning condition"—that is, a partially restored state exhibiting the norms of conditions needed to support and sustain productive native species assemblages. For example, for salmon species this means that the range of life histories that were adapted to the basin prior to extensive habitat alterations would be supported and sustained at levels that ensure species viability and deliver ecosystem services. Under these conditions, natural and cultural elements would be integrated, supporting diverse native aquatic populations while society's present uses of the watershed continue, although not without modification (Liss et al. 2006). The specific mix of natural and cultural elements to be achieved is to be defined through policy-driven goals and objectives.

While the ASRP is called a restoration plan, protection of ecosystem processes and aquatic habitats is a vital part of the plan. For brevity, therefore, use of the word "restoration" in this document often refers to both restoration and protection. Also, for brevity, the word "salmon" refers to all species of anadromous salmonids; similarly, reference to "aquatic species" includes semi-aquatic species.

2 FOUNDATIONAL PRINCIPLES

The scientific principles on which the ASRP is based are grouped into the following two sets:

- Principles that govern scientific practice and the pursuit of knowledge necessary for developing, evaluating, and updating the ASRP (Section 2.1)
- Fundamental conservation principles of fish conservation and restoration ecology (Williams 2006) and the scientific literature associated with habitat restoration (Section 2.2)

2.1 Principles for Scientific Practice

For the ASRP to succeed, it must be based on the best available science. Moreover, that science needs to be understandable, credible, and relevant to the many participants engaged in development, management, and future updates of the ASRP. Relevant science is not done in a vacuum. The challenges of reversing declines of native aquatic species, then restoring them, require advancing scientific understanding of the factors that affect those species. That improved knowledge becomes relevant and useful to society as the public and governance accept it. Science and policy processes, working together, are essential for effective, sustainable management of natural resources (Lee 1993; Bocking 2006).

Principles for scientific practice within the context of the ASRP include the following:

- **Linkage Between Recommendations and Scientific Support:** Findings and recommendations must be transparent and supported by available data and the best available science determined through peer review or other credible processes.
- **Need to Identify Assumptions:** Assumptions must be clearly stated, along with information indicating their likely validity and impacts on findings and recommendations.
- **Need to Identify Uncertainties:** Uncertainties must be disclosed and addressed, including their potential consequences.
- **Criteria for Evaluating Effectiveness:** Criteria and measures to evaluate the effectiveness of the restoration plan (or its components) need to be provided. A Monitoring and Adaptive Management (M&AM) program will address this for the ASRP.
- **Time Frames for Outcomes Made Explicit:** Expected outcomes, including the time frame for restoration actions to become fully functional, need to be made explicit.

2.2 Conservation and Restoration-Related Principles

Conservation and restoration-related principles address restoration-focused concepts for aquatic ecosystems like the network comprising the Chehalis Basin. These principles, while especially applicable to migratory species like salmon, are also relevant to a broader suite of native aquatic species in the Chehalis Basin. The principles were largely developed for application to restoration planning in the

Columbia River system, but they are just as applicable for aquatic system restoration across the Pacific Northwest. The following principles are distilled from Zedler (2000), Williams (2006), and Lichatowich et al. (2017):

- **Defining the Ecosystem:** Restoration and management of wild, native aquatic species must address the ecosystem that encompasses their entire life history. This includes where life histories are affected by human development, as well as within habitats largely unaltered by humans. The ASRP addresses the freshwater portion of the ecosystem.
- **Linkage Between Life History Connectivity and Production:** Sustained production of wild, native species, such as salmon, requires a network of complex interconnected habitats, which are created, altered, and maintained by natural physical processes.
- **Importance of Diversity:** Genetic, life history, and population diversity are the basis of native wild aquatic species sustainability over time. Diversity contributes to the ability of these species to cope with variation typical of the environments they utilize (in the case of salmon, freshwater and marine environments). Habitats are the templates that organize life history traits (Southwood 1977) and similarly influence genetic structure (Waples et al. 2001). Knowledge about the genetic, life history, and population diversity needs of non-salmon species is growing but still limited at this time.
- **Viable Salmonid Population (VSP) Concept**: The VSP concept is a commonly used framework for defining the characteristics of a viable salmon population (i.e., one that has less than a 5% probability of extinction over the next 100 years [McElhany et al. 2000]). While it is often used in Endangered Species Act (ESA)-related recovery assessments for salmon, it also enables analysis of salmon populations regardless of ESA status. The VSP concept is incorporated into the ASRP to characterize performance for all salmon species in the Chehalis Basin under past, current, and future habitat conditions and applies a conceptual basis for assessing salmon performance that is widely understood and employed throughout the Pacific Northwest.
- **Public and Treaty Trust:** The participants in the ASRP have a collective legal and moral responsibility to ensure proper stewardship of wild salmon, other native aquatic species, and the aquatic environments they inhabit as part of our natural heritage.

3 FOUNDATIONAL ASSUMPTIONS

The process of building scientific knowledge invariably relies on the use of assumptions about the systems involved. Some assumptions are inferences based on well-established facts, theory, and knowledge or a body of related observations. In any scientific endeavor, all assumptions must be clearly defined and include reasoning and justifications. As long as assumptions are clearly defined, one can determine if and how they may affect outcomes. If assumptions are not stated, it can be impossible to understand why any particular outcome occurs.

The overarching assumption of the ASRP is that ecological processes and functions within the Chehalis Basin can be protected and restored to support and sustain productive, diverse populations of native aquatic species. Given this assumption, it is understood that the ASRP must be based on sound science and that a well-developed, appropriately scaled, and fully implemented ASRP can restore and protect ecological processes sufficiently to support these populations, even in the face of climate change. It is understood that such restored conditions would not be the same as those that existed prior to large-scale human-caused watershed changes that began in the mid- to late-19th century.

The premise asserts that ecological processes and functions can be restored to a "sustainable high-functioning condition"—that is, a partially restored state exhibiting the conditions needed to support and sustain productive native species assemblages. For native aquatic species, this means that the range of life histories that were adapted to the basin prior to extensive habitat alterations would be supported and sustained at levels to both ensure species survival and deliver ecosystem services. Under these conditions, natural and cultural elements are integrated, supporting diverse native aquatic populations while society's present uses of the watershed continue, although not without modification (Liss et al. 2006).

The overarching assumption described in this section leads to 10 foundational assumptions about the past, present, and future states of the Chehalis Basin and the performance of certain native aquatic species relative to those conditions. These foundational assumptions shaped development of the ASRP and guided the selection and extent of restoration measures. Selected assumptions can be formulated as hypotheses for research questions testable as part of the ASRP. This implies that these assumptions may evolve over time as new information is developed.

The 10 foundational assumptions are as follows:

1. The viability and performance (e.g., abundance) of native aquatic species are largely controlled by habitat conditions experienced by these species across their full life histories. For salmon, this includes their life histories in freshwater, estuarine, and ocean environments.
2. In addition, abundance of native aquatic species is controlled by both the amount of suitable habitat (capacity) and by the quality of the habitat for the species (productivity). In many cases,

actions that address constraints on habitat quality will be more useful than those that address the quantity of habitats, unless the actions open access to high-quality habitat. It is imperative that streams and rivers have sufficient space to accommodate floodplains, wetlands, riparian forests, channel migration, and secondary channels. Process-based restoration is fundamentally dependent on space, as is habitat capacity and habitat quality; it must be ensured that sufficient space exists for habitat to form and change through time.

3. Salmon and selected co-evolved non-salmon species can serve as indicators of physical and biological processes operating at local, regional, and global scales affecting these species and co-evolved species. For example, habitats important to salmon species, such as streams and riparian wetlands, are critical to many other native aquatic species. It also needs recognition that some habitats, such as seeps, have non-salmon species indicators that important fish indicator species never use.
4. The abundance, productivity, and spatial distribution of salmon and non-salmon species in the Chehalis Basin have declined due to diverse environmental changes resulting from urbanization, agriculture, timber harvesting, channel and floodplain modifications, dam construction, and the spread of invasive plant and animal species.
5. Climate change in its current trajectory will affect temperature, precipitation, instream flow, and other factors that will further degrade habitat conditions and thus further reduce the abundance and survival of many native aquatic species in the Chehalis Basin. This is likely to jeopardize the continued existence of some species.
6. Based on the current approaches and patterns of human development, future human development of the Chehalis Basin will further degrade habitat conditions and further diminish the performance of native aquatic species.
7. Restoration actions, including engineering of specific environmental conditions, can improve watershed and ecological processes and attenuate the negative effects of climate change and past, current, and future development.
8. Historical conditions, when appropriately defined, provide a useful reference baseline to assess the intrinsic conditions of the Chehalis Basin defined by climate, geology, and biogeography against which to evaluate current and future habitat conditions, as well as the results of restoration actions.
9. If restoration actions are to succeed at reversing the effects of past habitat degradation and/or countering future adverse effects of climate change and new development in the basin, restoration actions will need to be extensive and effective over the long-term.
10. To be effective and long-lasting, restoration must be focused on correcting systemic causes of degradation. Restoration and protection of watershed and ecological processes at some level are essential for sustaining productive aquatic habitats that support native aquatic species in the face of continued human population growth in the basin, climate change, and proliferation of invasive plant and animal species.

4 FOUNDATIONAL CONCEPTS

4.1 Use of Potential Indicator Species

The ASRP is an ecosystem restoration plan. Given this ecosystem focus, the emphasis shifts away from assessing a single species toward the use of indicator species for assessing and monitoring the aquatic ecosystem conditions. Because it is not practical or feasible to monitor and assess all species, the use of appropriately selected indicator species addresses the problem of how to assess the condition of ecosystems, given their inherent complexity (Soule 1987; Karr 1992; Siddig et al. 2016). Indicator species are a shortcut to pursuing conservation objectives, given limited funding and time coupled with the complexities of species distributions and the various ways that different species respond to environmental change (Caro 2010).

Species that serve as useful indicators are ones that, because of their habitat utilization patterns or life histories, represent particular species assemblages or communities and indicate environmental changes or habitat conditions important to those species (McGeoch 1998; Carignan and Villard 2002; Niemi and McDonald 2004). Their use has been applied to diverse conditions, ranging from revealing patterns of pollution (Harlan 2008) to discerning patterns of spatial continuity (Rolstad et al. 2002) or species richness (MacNally and Fleischman 2004). In more recent years, indicator species have been used to monitor restoration success (Siddig et al. 2016). However, use of indicator species has also been criticized, particularly for vertebrates, based on lack of consensus of what the indicator should reveal, the difficulty in determining the best indicator (Simberloff 1998), and the inability of an indicator to reflect changes in the entire species suite of interest or having universal application (Caro 2010).

Landres et. al (1988) summarized the following eight criteria that can avoid most criticisms when using indicators:

1. Clearly state your assessment goals.
2. Use indicators only when other assessment options are not available.
3. Choose indicators by explicitly defined criteria in accordance with assessment goals.
4. Include all species that fulfill stated selection criteria.
5. Know the biology of the indicator well, and treat it as a formal estimator in conceptual and statistical models.
6. Identify and define sources of subjectivity in selecting, monitoring, and interpreting the indicator.
7. Submit assessment design, methods of data collection and statistical analysis, interpretations, and recommendations to peer review.
8. Develop an overall strategy for monitoring wildlife that accounts for natural variability in population attributes and incorporates concepts from landscape ecology.

The criteria of Landres et al. (1988) were used to develop a potential indicator species list for the ASRP. The overarching assessment goal is to identify positive changes in species responses to the ASRP's broad-based restoration effort. The ASRP avoids the further issues of having only one indicator species by identifying a suite of potential indicators under a scheme partly explained in the ASRP's precursor, the *Aquatic Species Enhancement Plan* (ASEP) drafted in 2014, where indicator species were labelled as key species (ASEPTC 2014). That scheme captured representation among all major vertebrate taxonomic groups with aquatic or semi-aquatic members except birds (namely amphibians, fishes, mammals, and turtles), and within taxonomic groups, the best representation within each guild.[1] Guilds were structured around life history similarities but often reflected systematic relationships and geographic patterns. Representation within guilds was determined from some combination of the best integrators among habitat compartments (aquatic, oceanic, or terrestrial) or their sub-compartments (pond, small river); having some local, state, or federal listing status; holding cultural or economic importance; and possessing an ability to engineer habitat (specifically, North American beaver).

The ASRP potential indicator list is more encompassing than the key species list in the ASEP in that it also includes birds species and one invertebrate (the Western ridged mussel), but the basis for potentially selecting these taxonomic groups was the same. Inclusion of the Western ridged mussel reflects a link to salmon species, on which its early life stages necessarily depend, and acts as a nod to recognizing the high importance of habitat water quality and conditions in the larger stream network.

The potential indicator species suite for the ASRP and basis for their potential selection are listed in Attachment 1. It is appropriate that the M&AM Team refine and select a suite of indicator species from the list in Attachment 1 to include in the comprehensive M&AM Plan.

4.2 Life History

Restoration activities need to consider the full life history of targeted species (Lichatowich et al. 1995). Life history is the entire developmental sequence of life stages that occur from birth through death, as they relate to survival and reproduction. Successful completion of a species' life history depends on the string of connected habitat conditions of suitable quality and quantity for each life stage at appropriate times and places. Over the course of its life history, a species encounters varying habitat conditions that ultimately determine its abundance and persistence.

Species life histories have evolved to exploit a range of expected habitat conditions. Life histories can vary greatly due to differences in where, when, and how individuals respond to environmental factors. For example, location within a species' geographic range can markedly influence variation in life history (Berven and Gill 2015).

Knowledge about the life history of indicator species like salmon in the Chehalis Basin is crucial in assessing watershed conditions and diagnosing habitat limiting factors. Habitat requirements can vary

[1] In ecology, a guild is a group of species that each exploit the same kinds of resources in comparable ways.

greatly between the life stages of a single species, as can the potential effects of habitat degradation or restoration. A species' response to degradation or restoration needs to be understood for each life stage and across its full life history.

Analytical models that include life stage responses and performance over a species' full life history can contribute to evaluating species performance in relation to degradation and restoration, and have been used to craft restoration programs for salmon species (Mobrand et al. 1997; Scheuerell et al. 2006; Thompson et al. 2009).

4.3 Population Structure

Animal populations typically are structured spatially across the landscape. This distribution reflects selection of key habitats (see the discussion about key habitats in Section 4.5) by different life stages as well as natural and artificial impediments to movement of different life stages. This structure is important to recognize in an effort like the ASRP because of implications on where the plan should focus, both for restoration and protection.

Across a geographic area the size of the Chehalis Basin, species like salmon frequently demonstrate genetic and life history variation within a single species (Waples et al. 2001, 2008) and in some cases may even exhibit multi-species differentiation, such as among torrent salamanders (Good and Wake 1992). Such differences are known to occur, for example, in river entry and/or spawning timing of both Chinook and coho salmon produced in different sub-basins of the Chehalis Basin (WDW and WWTIT 1993). This suggests that genetic differences exist among the various spawning aggregations within the Basin. The arrangement of these aggregations relative to one another (i.e., their proximity to one another and their overall distribution) is often referred to as spatial structure.

Some understanding of population structure in a basin the size of the Chehalis is essential for both conservation and management (Allendorf and Luikart 2007). The Washington Department of Fish and Wildlife (WDFW) continues to be engaged in assessing the genetic structure of the salmon species in the Chehalis Basin.

Although genetic studies are incomplete, the diverse nature of sub-basins in the Chehalis suggests that significant genetic structure should exist within the different salmon and other aquatic species. Lacking better knowledge, it is useful to recognize the differences among sub-basins based on patterns of environmental attributes such as topography, geology, flow regimes, water temperature, and other habitat characteristics (Waples et al. 2001). Distinct patterns, which exist among sub-basins in the Chehalis Basin, are informative about how ecological diversity within a basin of this size is likely to affect genetic and life history diversity. This approach is currently used in the Hood Canal watershed for recovery planning of ESA-listed summer chum salmon (Sands et al. 2009).

4.4 Viable Salmonid Population Concept

The VSP concept was developed by National Oceanic and Atmospheric Administration (NOAA) Fisheries to define the characteristics of a viable salmon population (i.e., one that has less than a 5% probability of extinction over the next 100 years [McElhany et al. 2000]). The concept provides a theoretical basis for describing salmon performance as it relates to long-term viability. In ESA-related recovery assessments for salmon, the concept serves as a framework to help determine if one or more populations should be ESA-listed and similarly when it is appropriate to delist.

The concept also enables analysis of salmon populations regardless of ESA status. It provides a useful framework to evaluate the potential of salmon populations to provide ecosystem services. As such, the concept provides a framework for analyzing potential changes in population performance in response to restoration or further habitat degradation. Analytical models are used for this purpose.

Table A-1
Definitions of the Characteristics (Parameters) Used to Assess the Performance of a Viable Salmonid Population

VSP CHARACTERISTIC OR PARAMETER	DEFINITION (MCELHANY ET AL. 2000).
Abundance	The size of the adult population, subpopulation, or other relevant demographic unit. Measured as adult spawners or total adults recruited to fisheries.
Productivity	Two definitions are used: 1) the population growth rate, which is the number of returning spawners produced per parent spawner calculated for each generation; or 2) the estimated average number of returning spawners produced per parent spawner at low population density. The second definition is also called intrinsic productivity, meaning that it is the number of surviving offspring in the absence of all competition with other members of the population.
Biological diversity	Diversity within the population in genetics, life histories, and physical traits (body size, age, run timing, migration patterns).
Spatial structure	The population's geographic distribution (population structure). Relevant distribution includes the areas of spawning and can also include the distribution of juveniles.

The four VSP characteristics (or parameters), defined in Table A-1, are all vitally important to the ASRP. Each provides needed information to evaluate how well a population can thrive; provide sustainable ecological services (such as harvest); and be resilient to environmental disturbances, land use, and climate change:

- **Abundance** is a key component of population viability**.** Small populations are at greater risk of extinction than large populations and provide fewer ecosystem services than larger ones. Both habitat quantity and quality in each life stage contribute to observed abundance. Habitat capacity, which determines maximum abundance, is the result of both habitat quantity and habitat quality (Moussalli and Hilborn 1986). This is a key concept in developing the ASRP.
- **Productivity, and specifically intrinsic productivity**, determines how rapidly a population can rebound when abundance is driven to low levels due to some form of disturbance (such as a

flood or inadvertent overharvest). Populations with low intrinsic productivity are at higher risk of extinction due to future degradation resulting from watershed development or climate change. Habitat quality, **not** habitat quantity, determines intrinsic productivity. Improvements made in habitat quality in any life stage will benefit intrinsic productivity and usually increase overall abundance regardless of the population's current status (Lestelle et al. 1996; Mobrand et al. 1997).[2]

- **Diversity** in genetic and life history characteristics provides resilience for a population to cope with short-term environmental disturbances or long-term changes over time. In this sense, these characteristics are similar to diversification in an investment portfolio—long-term success depends on this diversity.
- **Spatial structure** is a geographic analog to biological diversity (Kaje 2008; Lestelle et al. 2017) because it operates to diversify the spatial distribution of the population, protecting it against differential short- and long-term changes across the environment. Over long periods of time, diverse spatial structure leads to biological diversity through evolutionary processes. Spatial structure, which is a measurable characteristic, can therefore serve as an indicator of biological diversity, which changes slowly over time.

The VSP concept raises the following important questions for the ASRP:

- How should restoration efforts be balanced geographically to address the different VSP characteristics?
- Should efforts be aimed at increasing the performance of core production areas if restoration actions can make them even more productive?

Focusing restoration efforts in core production areas with the goal to quickly increase total salmon abundance could be an appealing idea, but this approach ignores the need to consider spatial structure of the aggregate population of the species in the Basin (termed metapopulation). Since it is important to improve both abundance and spatial structure, the ASRP is uses an approach that balances these two aspects of population performance while focusing on the core areas for spring-run Chinook salmon due to low run sizes and an elevated risk of extinction.

The ASRP approach, described in Section 5, establishes a spatial structure for the Chehalis Basin based on geological, topographical, and hydrological patterns. This structure recognizes ten ecological regions (see Section 5 of the ASRP Phase 1 document):

- Willapa Hills
- Cascade Mountains
- Middle Chehalis River
- Central Lowlands
- Lower Chehalis River

[2] There are certain situations where an increase in abundance will not occur, but this will typically not apply to this discussion.

- Black River
- Black Hills
- Olympic Mountains
- Chehalis River Tidal
- Grays Harbor Tributaries

The ASRP Science and Technical Review Team (SRT) believes that the population structure of most aquatic species is captured within this geographic organization.

4.5 Role of Habitats

In its simplest definition, the habitat of an organism is where it lives. But a more complete definition is necessary for the purposes of developing the ASRP. Habitat is the environment from the perspective of a specific species. It is a subset of environmental conditions that provides for occupancy, survival, and—at the appropriate time—reproduction by a given organism (Krausman 1999). It is the sum of all the resources needed by organisms, which include food, cover, space, and any special factors needed for survival and reproduction (Leopold 1933; Thomas 1979). These factors include chemical properties (e.g., oxygen) and temperature, among others.

Habitat requirements differ among species, even among closely related ones like salmon species. Habitat requirements also differ significantly among life stages for a single species, such as egg incubation, small juveniles, larger juveniles, and adults. The annual cycle of seasonal changes in habitat conditions often drives species- or life stage-specific patterns in habitat use.

Habitats are key determinants of species performance, and the abundance of a breeding population, such as the number of salmon that spawn in a river, is the cumulative result of all habitats experienced by the population over its full life cycle, as well as other factors (Mobrand et al. 1997).[3]

4.5.1 Habitat Formation and Degradation

Aquatic habitat in a watershed is created, maintained, and renewed by watershed processes that operate across various temporal and spatial scales (Benda et al. 1998; Waples et al. 2009; Beechie et al. 2010). Over long timescales (tens of thousands of years), glacial, fluvial, and mass wasting processes have shaped the landscape within which present-day riverine and floodplain habitats have formed (Beechie et al. 2010; Gendaszek 2011). In recent millennia, natural disturbance in watersheds due to fire, floods, and erosion have shaped the habitats and disturbance regimes to which aquatic species have adapted (Benda et al. 1998; Waples et al. 2008). Salmon life histories, for example, developed within these patterns in a watershed, resulting in life history patterns characteristic of that watershed (Stanford et al. 1996).

[3] In this case, fisheries that harvest some of the population prior to spawning can be thought of as predators, which in the strictest sense can be considered part of the habitat experienced by the population. Alternatively, the number of spawners that would be produced in the absence of all fishing would be the result of all habitat conditions (excluding fisheries) experienced over the life cycle.

With the recent more rapid alteration due to human activities, watershed processes were altered outside the range of their historic variation. Habitat conditions that had been more or less stable were changed in ways that adversely affected the abundance and survival of native aquatic species, like salmon (Beechie et al. 2003).

4.5.2 Habitat Restoration

Restoration ecology includes human efforts to restore the historical character of habitats usually with the intent to benefit specific species such as salmon. Restoration actions can deal with proximal or systemic issues in an environment. Proximal restoration attempts to restore specific local features, such as instream wood or riparian forests, that are lacking and thereby negatively affecting performance of the target species. Systemic restoration deals with the watershed processes responsible for formation and maintenance of habitat features. For example, a conclusion that the lack of large wood in a stream is detrimental to salmon might be addressed proximally by adding large wood or engineered wood structures. A systemic approach would identify the processes responsible for loss of large wood in the system, such as those resulting from logging or urbanization, and attempt to restore those processes by planting trees for long-term wood recruitment to the stream. The two approaches are not in conflict. A proximal solution can provide restoration in the short term while the longer-term systemic approach, such as restoration of riparian forests, can occur.

Process-based restoration aims to re-establish rates and magnitudes of physical, chemical, and biological processes that create and sustain the aquatic ecosystem (Beechie et al. 2010). Process-based restoration focuses on mediating anthropogenic disruptions to watershed processes, such that the river-floodplain ecosystem can adjust to ongoing human activities with minimal corrective intervention that otherwise might be needed to address specific habitat issues. This approach to restoration requires space for channel movement (to form multiple channels, wetlands, and floodplain habitats) and adjacent hillslope riparian forest, which allows the system to respond to future perturbations, such as climate change, through natural physical and biological adjustments. Such an approach is expected to enable the riverine ecosystem to evolve and continue to function through natural processes, though it would remain altered from pre-development conditions (Beechie et al. 2010).

Process-based restoration is complex. Different processes, including associated thresholds, and the strategies to restore them can require vastly different amounts of time to mature to full effectiveness, from less than a year to a century or more (Roni et al. 2002). Different strategies can also vary substantially in their effectiveness and the amount of uncertainty in projecting benefits over time.

4.5.3 Habitat Quantity, Quality, and Distribution

A basic consideration in developing a restoration plan is recognizing how habitat quantity, quality, and distribution in a watershed affect species performance. The following two questions are critical:

- Is it better to have a **greater quantity** of habitat or **higher-quality** habitat relative to the current condition?

- **Where** should habitat be restored in a watershed—for example, high in the watershed, in small streams, or within the floodplain (e.g., off-channel habitats)?

The short answer to both questions is that it depends on watershed-specific conditions. Such questions are essential to consider in developing and implementing an effective restoration plan.

It is important to recognize the differences in what is meant by habitat quantity and habitat quality. Each of these aspects of habitat has a different effect on species performance, detailed as follows:

- **Habitat quantity** is the amount of useable living space available to a species during a particular life stage. It is the living space that is selected (or used) by the species (Krausman 1999). Those physical features of the environment that are used in different life stages are often called **key habitats**. Examples for coho salmon would be the amount of spawnable area (pool tailouts and riffles) for spawners or the amount of slow-velocity water for young-of-the-year juveniles. The quantity of habitat affects the amount of competition that occurs between members of that species for the available habitat. Survival within a life stage is affected by the intensity of competition.
- **Habitat quality** is a more abstract term, but it is an essential concept to grasp. It is easiest to conceptualize with respect to a single animal (Johnson 2005). Habitat quality is defined by the characteristics of habitat that affect the probability of survival of an individual animal when competition for resources is absent. For example, fine-sediment sedimentation in spawning gravels affects all eggs even when the number of eggs is low, just as very high water temperature affects all juveniles equally when juveniles are at low abundance. Put simply, any factor that affects the survival of a species in the absence of competition among the members of the same species within a habitat is a characteristic of habitat quality. These factors can be structural (e.g., escape cover), chemical (e.g., toxic pollutant), thermal (e.g., water temperature), or biotic (e.g., invasive predator). All of these can affect survival in the absence of competition for resources by an indicator species. There is abundant evidence that larger portions of the Chehalis Basin channel network have experienced significant incision, which makes them prone to bed scour that can directly impact salmon egg survival and even reduce the extent of viable spawning gravels in the basin.

  Other aspects of habitat quality that merit consideration are as follows (Mobrand et al. 1997):
  - The effect of habitat quality on life stage survival occurs at all abundance levels of a species, whether abundance is low or high—this means that habitat quality is the primary determinant of survival at low population abundances (when competition for resources is minimal), which occurs when species are at critically low levels (ESA-listed or approaching listing).

- Improvements in habitat quality can result in substantial gains in population performance, as measured by abundance and survival, where quality has been reduced in the past by habitat degradation.[4]
- The need for improving habitat quality through restoration becomes greater as the threats of human activities in a watershed or climate change loom larger—these threats will have their greatest effects on species performance by impacting habitat quality characteristics.
- The distribution of key habitats within a stream system, particularly when they are limited or when they function as refugia during extreme environmental conditions, such as major freshets or periods of extreme temperatures, is an aspect of habitat quality. In these cases, the probability of individual animals finding the habitat they are searching for can have a strong effect on survival and population performance. Well-distributed habitats that act as refugia increase survival; shortage of refugia or an animal required to move long distances to locate a habitat type may decrease survival (Soto et al. 2016).

The quantity or quality issue is also raised when reconnecting habitats by removing or correcting fish passage barriers. The value of reconnecting habitat depends greatly on the quality and quantity of the habitat that is being connected. Opening fish passage into upstream habitat that is of poorer quality than the downstream habitat can actually decrease overall survival.[5] Similarly, the quantity of reconnected habitat is a key determinant of the value of enhancing fish passage at culverts and other blockages. In short, both habitat quality and habitat quantity need to be considered in prioritizing efforts to reconnect artificially disaggregated habitats (Roni et al. 2002; Beechie et al 2003).

[4] Abundance in this context refers to the abundance of an indicator species at the breeding stage or at an intermediate life stage for a large segment of the population. High density of a particular species in a life stage at a particular location may not reflect good habitat quality for various reasons (e.g., Van Horne 1983).

[5] A related issue is how culvert replacement can impact habitat quality. An impassable "perched" culvert may be maintaining channel grade in the vicinity of the culvert. Replacing the culvert with a larger culvert or bridge can cause the headcut to propagate upstream of the culvert, which in turn can convert a pool-riffle channel into a plane bed gully disconnected from its floodplain (reducing habitat quality). Understanding the science of how channels respond to particular disturbances is essential to assess the implications to habitat.

5 BASIS FOR DEVELOPING STRATEGIES AND ACTIONS

This section describes the approach for developing restoration strategies and prioritizing actions for the ASRP.

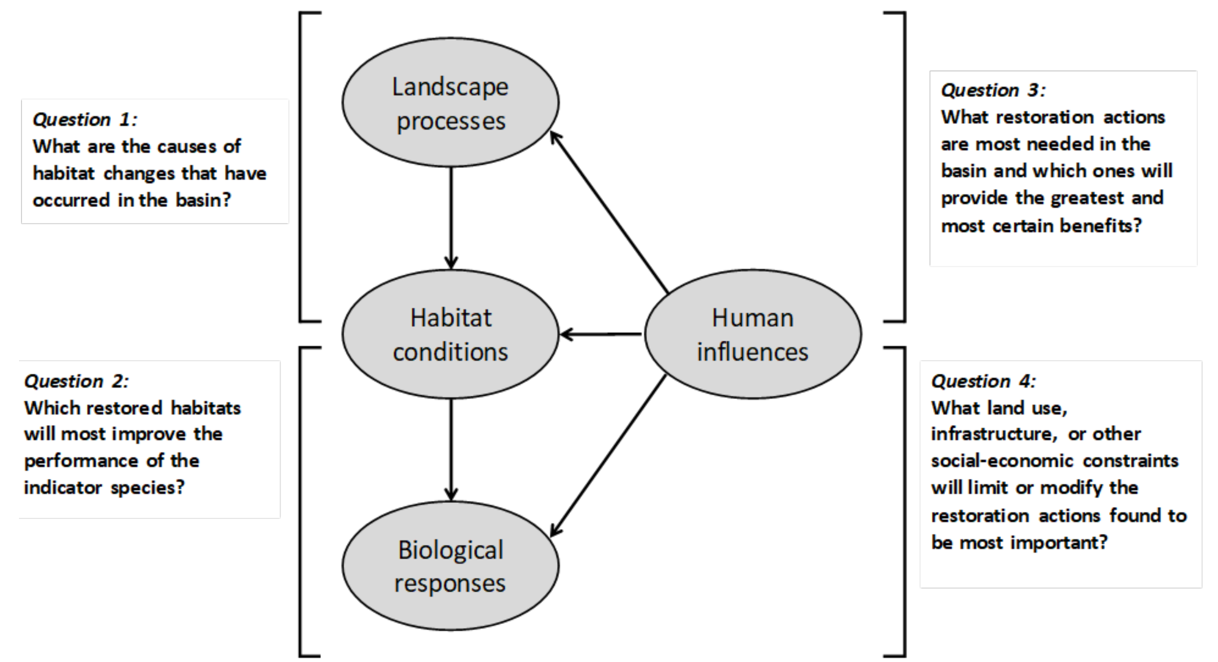
5.1 Assessment of the Aquatic Ecosystem

The restoration plan needs to be based on an assessment of the condition of the aquatic ecosystem sought to be restored to a more productive, sustainable state. That assessment diagnoses what could constrain achieving the plan vision. Without diagnosis, inadequate understanding exists of which watershed processes and habitat conditions need attention. In brief, the diagnosis asks: What is broken and what needs to be fixed?

Restoration strategies need to focus on key cause-effect linkages between watershed processes, habitat conditions, and biological responses of the indicator species, illustrated in Figure A-1. The figure, adapted from Beechie et al. 2013, is organized around the following four questions that need to be addressed to develop an effective restoration plan:

1. How has habitat changed from historic conditions, and what are the causes of those changes? Effective restoration can only be done after the causal mechanisms of habitat degradation have been clearly identified. Answering this question identifies the root causes of habitat changes, not merely their symptoms.
2. Which restored habitats will most improve the performance of indicator species (based on VSP characteristics or similar traits for other indicator species)? Answering this question identifies the relative importance of different habitats, including their locations, to the performance of the indicator species.
3. What restoration actions are most needed to address habitat changes in the watershed, and which ones will provide the greatest and most certain benefits? Answering this question identifies the actions—or treatments—deemed to be most important to include in the restoration plan.
4. What land use, infrastructure, or other socioeconomic constraints will limit or modify the restoration actions found to be most important? This question recognizes that human development and existing land uses will constrain what restoration actions may be feasible and their effectiveness. Scientists are responsible for evaluating these effects and constraints, but policy-makers and related governing bodies are responsible for decisions on land use, infrastructure, and social-economic constraints.

Figure A-1
Conceptual Diagram of Process Linkages Between Landscape Processes, Habitats, and Species Performance and Key Questions to Be Addressed in Identifying Restoration Actions to Be Implemented



Source: Adapted from Beechie et al. 2013.

Fundamental to the diagnosis is an assessment of how the watershed and its aquatic habitats have been changed over the past 200 years (Lichatowich et al. 1995). Its underlying assumption is that the intrinsic physical conditions of the Chehalis Basin and its habitats have been determined by natural geologic, climatic, and biogeographic interactions over millennia with lesser human populations. Before extensive human-caused disturbance, the aquatic environment had intrinsic limitations on what it could produce.

The overarching assumption of the diagnosis is that the aforementioned intrinsic conditions limit the performance of salmon and other species. The goal of restoration is not to restore the watershed to its intrinsic condition, which may be viewed as theoretically desirable but is not functionally possible within the backdrop of current human population activities and impacts. Rather, restoration aims to restore enough of the lost intrinsic potential consistent with achieving the ASRP vision.

Diagnosis assesses the degree to which changes have occurred to aquatic habitats from their intrinsic state and how these changes have impacted aquatic species performance. That said, development of the diagnosis is a set of serial steps, described in the following paragraphs.

Step One is to assess (or reconstruct) historic conditions of the entire watershed as it existed before extensive human-caused disturbance (Doppelt et al. 1993). This is done from old maps (such as those from the General Land Office), survey notes, aerial photos, miscellaneous documentation, and various scientific investigations done over time (Beechie et al. 2003). The purpose of this reconstruction is to develop a reasonable picture of how the relatively undisturbed system looked and, as a consequence, how it functioned compared to how it functions today.

Mobrand Biometrics (2003) developed an initial reconstruction of historic habitat for the entire basin. That reconstruction has been substantially updated and refined via recent work as part of the Chehalis Basin Strategy by Natural Systems Design, Inc., and NOAA Fisheries; however, historical conditions are still not fully understood. This reconstruction is the historical "template" used to evaluate the type and magnitude of habitat changes that have occurred.

Step Two is to assess the current state of the watershed and its habitats. In the Chehalis Basin, a substantial amount of information has been assembled over the past several decades to characterize the current condition of aquatic habitats across the basin. Notably, more recent assessments of habitat conditions have been done in large parts of the upper basin, including the mainstem Chehalis River, by WDFW, Anchor QEA, LLC, and Natural Systems Design, as described in McConnaha et al. (2017). NOAA Fisheries performed additional assessment work on current conditions. Important aspects of current conditions remain unknown. For example, no data collection or characterization has been done on the current extent of bedrock channels that were once likely alluvial or channels with unstable gravels where egg mortality is likely. Little data also exist regarding connectivity to coho salmon rearing areas in floodplains.

Step Three in the diagnosis compares the historic to current conditions across the basin to draw conclusions about the extent and distribution of changes that have occurred to watershed processes and habitat conditions. This step also then draws conclusions about the significance of these changes to species performance (Figure A-1). These conclusions are actually hypotheses about how the aquatic ecosystem is currently functioning and the factors that limit the performance of indicator species. These hypotheses are the basis for identifying and prioritizing strategies and actions for restoration.

An important part of the diagnosis is understanding geomorphic processes at work in the Chehalis Basin. For example, almost all stream channels of the basin have undergone large wood removal. Wood not only traps sediment but also partitions shear stress within the stream system, which reduces sediment transport capacity. Wood removal leads to bed coarsening (Manga and Kirchner 2000; Abbe et al. 2015) and channel incision[6] that increases sediment transport capacity and ultimately can convert a gravel-bedded channel to a bedrock channel (Stock et al. 2005). Incised channels also have a greater capacity to move wood; therefore, restoration of large, stable wood is important to reverse this pattern. Without addressing the root causes and creating stable instream structure to capture bed material, stream restoration will not be possible. Montgomery et al. (1996) show how wood removal converted gravel-bedded channels to bedrock in the Satsop River watershed.

[6] Incision is the process of downcutting into a stream channel leading to a lowering in the channel bed elevation. Incision is often caused by a decrease in sediment supply (e.g., from construction of a dam) and/or an increase in sediment transport capacity.

The analytical models—Ecosystem Diagnosis and Treatment (EDT) and NOAA Fisheries Life-Cycle Model (LCM)—have been used in Step Three to quantitatively assess the relative impacts to salmon performance by the changes from historic to current condition habitats (see Appendix C for details about EDT and LCM modeling). The models enable the quantification of a limiting factors analysis, enabling identification of the habitat factors (or stressors), and their geographic distributions, that have the greatest impacts on salmon performance. Analytical assessment for non-salmon species uses a combination of occupancy or simpler models combined with changes in historical versus current species-specific habitat footprints to assess the relative impact to non-salmon indicator species performance. The latter modeling provides a generalized sense of habitat loss rather than the sub-basin or geographically finer specificity of the modeling addressing salmon.

A high-level example of a diagnostic procedure applied to the Chehalis Basin is given in Attachment 2. The layout for the example is presented in the form of a process-based strategy framework. It illustrates the logic chain connecting the issues of concern (i.e., those environmental issues related to watershed alterations affecting species performance) to identification of strategies and actions. The framework is intended to help answer the question: What's broken and what needs to be fixed? The example is based on information summarized from the citations listed under Steps One and Two.

Step Four in the diagnosis provides a means to assess the future potential impacts of climate change on aquatic habitats and salmon performance (McConnaha et al. 2017). Projected increases in water temperature and peak winter flows have been translated into impacts on habitat conditions in the basin. These future changes, which are hypotheses, provide the basis for projecting effects on salmon performance using quantitative modeling and generalized impacts on non-salmon species given understanding of specific habitat conditions and physiological requirements, such as thermal requirements for selected amphibian species.

5.2 Strategies and Actions

The restoration plan consists of strategies and actions intended to mitigate human-related pressures on the Chehalis Basin aquatic ecosystem and restore processes and habitats sufficiently to achieve the goals and vision of the plan. A strategy is usually a bundle of actions that, when combined, are intended to achieve a common objective (PSP 2016). Strategies are usually developed with a long-term time horizon, such as 20 to 50 years or longer, with associated specific actions addressing nearer-term objectives.

Roni et al. (2002) and Beechie et al. (2013) organized commonly employed strategies into four categories, also used in WDFW's *Stream Habitat Restoration Guidelines 2012* (see Chapter 4 of Cramer 2012):

- Protect habitat
- Reconnect habitat
- Restore habitat-forming processes
- Recreate or enhance habitat

Certain aspects of each category merit highlighting here as follows:

- **Protection:** Protection of relatively intact, functioning parts of the ecosystem through legally binding actions to protect designated areas is often a far more cost-effective approach to conserving the integrity of biological communities than restoring an ecosystem after degradation. Habitat protection helps to conserve biodiversity and functioning habitats and processes, and it provides a source of locally adapted native plants, fish, and wildlife to recolonize nearby restored areas. Moreover, at-risk species frequently inhabit specific habitat types that are rare, and protection is a key strategy for these species.

Protection may also need to be combined with other strategies to sufficiently protect relatively intact habitats in a milieu of human-induced changes in adjacent habitats and the current climate change trajectory. These strategies include the following:

- **Reconnection of Habitats:** This strategy as presented here only includes those actions aimed at restoring passage of fish and other aquatic species within the aquatic environment. Issues of ecosystem connectivity that involve the flow, exchange, and pathways that move energy and matter through the system are included under habitat-forming processes (watershed processes). Dams, culverts, levees and road fill, floodplain fills, and channel incision are the principal ways that habitats become disconnected for fish passage. It is critical to recognize that reconnecting habitats for fish passage may not produce desirable benefits if the habitat being reconnected is poor quality, which may result in a decline of performance of indicator species following reconnection. In addition, creating connections between aquatic and terrestrial habitats or the presence of suitable migratory habitats among isolated aquatic sites, critical for most amphibians and other aquatic indicator species, is an important part of reconnecting habitat for those species but is not expressly addressed here.
- **Restoration of Habitat-Forming Processes:** Habitat is an outcome of inputs (e.g., large wood), physical processes (e.g., channel-forming floods), and other variables (e.g., tree growth increasing shade). Sustainable habitat restoration therefore requires the restoration of these inputs, processes, and variables that create, maintain, and periodically renew habitat. Restoration of degraded habitat requires that the root causes of degradation be identified and addressed at appropriate scales if the treatment is to provide long-term, sustainable results. In the Chehalis Basin, the issues causing degradation occur at a large scale and will require extensive, widespread treatment to be effective and take long periods of time to produce substantial benefits.
  One example of timescales with different treatment types is useful to make this point. Riparian vegetation restoration can require variable amounts of time to mature and provide benefits, depending on the situation, stream type, and strategy. Riparian zones along small streams flowing through wetlands only require a few years to be revegetated with willows using plantings and farm animal exclusion actions. In contrast, restoration of riparian corridors along larger streams that once flowed through old-growth riparian forests can require multiple decades (greater than 100 years) to mature and function in a manner needed to reform and

sustain important habitats. For example, the recruitment of large in-channel wood from large conifers within young riparian buffers is largely absent, and such recruitment to stream channels will require many decades to develop; thus, immediate actions to add functional in-stream wood would be required and would need to last as long it takes riparian areas to generate a sustainable supply of large functional wood.

For comparison, across managed forests in the Chehalis Basin—except for typically the upper portion of non-fish-bearing streams—policies to improve riparian buffers have been established to better enable passive restoration, but little scientific evidence exists to evaluate how well these new policies are working (both in terms of enforcement and effectiveness), partly due to the relatively short period of time these policies have been in place. Whether the current buffer policy will adequately address issues like wind throw or blow down remains unknown. Benefits from shading to cool water temperatures are occurring gradually. In this case, an active large wood-restoration strategy can be implemented in conjunction with the riparian strategy to accelerate the habitat-forming processes driven by large in-channel wood (Abbe and Brooks 2011). Island and secondary channel reformation can also be accelerated to provide high-quality spawning and rearing habitats for salmon. Large deep-pool habitat can be reformed by the scouring forces following the placement of large wood. These features, which form naturally as a function of large wood within the channel, also provide critically important cool temperature and slow-velocity refugia, especially with the advance of climate change.

- **Recreation or Improvement of Habitats:** This strategy involves restoring, creating, or improving specific habitat features at the site or reach scale. It is important to recognize that this category is not aimed at restoring habitat-forming processes, generally due to some human-caused constraint that exists or the very long periods of time (e.g., centuries) that would be needed to form these habitats. However, in situations where population performance is severely impacted by past habitat alterations, particularly if species viability is jeopardized, these strategies can be important where the benefits of restoring habitat forming processes would be realized in the distant future.

  Notably, this category of strategies has sometimes been ignored in restoration planning because it has been listed as the lowest priority of strategies (Beechie et al. 2003; Cramer 2012). However, it should be noted that those authors specifically stated that their prioritization was provided only as an interim recommendation when information on watershed-specific limiting factors is unavailable. Moreover, the general concern has been that actions aimed at recreating or creating specific habitats apart from restoring natural processes may be short-lived and not provide the needed benefits.

  An example of potential benefits of employing this category of strategies is seen in the creation of off-channel ponds, which are heavily used by juvenile coho salmon when available and are frequently the breeding habitat of primary importance to a number of stillwater breeding amphibians (Henning 2004; Henning and Schirato 2006; Henning et al. 2006, 2007). These habitats can significantly improve life cycle intrinsic productivity for coho salmon by improving overall habitat quality and diversity during winter (Lestelle 2007) and may be the critical

Chehalis River floodplain breeding habitat for the northern red-legged frog, an indicator species that is a probable umbrella species for the suite of stillwater amphibians that occur there (Hayes et al. 2019). Effective low-cost overwintering ponds have proven successful in rivers on the Olympic Peninsula (Cederholm et al. 1988) and in the Klamath River in Northern California (Soto et al. 2016). The ponds described in Cederholm et al. (1988) were created more than 30 years ago, and they remain in good condition and are heavily used by overwintering coho salmon. The relative importance of these ponds to coho salmon appears much greater in streams where natural wood loads have been reduced due to logging-related activities, such as in the Clearwater River on the Olympic Peninsula (Lestelle 2009). Most of the Chehalis River and its tributaries have severely reduced amounts of large wood compared to historical conditions.

5.3 ASRP Approach to Prioritization

Prioritization is the process of ranking watersheds (or sub-basins), habitats, and actions to determine their relative importance for funding and implementation for restoration work. Its overall purpose is to maximize the effectiveness of the restoration plan in achieving its goals while minimizing costs in time, resources, and efforts. Prioritization is an essential part of restoration planning.

Building on the fundamental assumptions that the current and historic patterns of habitat conditions over the Chehalis Basin create corresponding patterns of species performance (as abundance, productivity, or distributional extent) and population structure that are measurable (Fullerton et al. 2011), the ASRP approach to prioritization uses these measurements to estimate the degree to which restoration is possible using EDT and LCM model simulations, studies and monitoring data, and scientific judgments of the ASRP SRT and basin scientists.

5.3.1 Rationale for Prioritization Approach

A fundamental goal of ecosystem restoration is to protect and restore the biological diversity of native species, a condition essential to both ecosystem and population resilience (Schindler et al. 2010; Fleming et al. 2014). Focusing first on biological spatial structure (rather than population abundance) allows for more equitable allocation of restoration effort across the basin by weighing differences among sub-basins based on their size and degree of habitat degradation and, as a consequence, on their levels of restoration need.

The ASRP assumes that the spatial structure of habitats for salmon and non-salmon species in the Chehalis Basin environment reflects a hierarchical metapopulation organization. Thus, it is a key hypothesis that these biological patterns are adaptations to the underlying habitat template and have a genetic basis reflecting selection. As such, the pattern of species production across the basin is a critical piece of the ASRP for addressing species protection and restoration and habitat-forming processes. Ideally, the biological structure of species across the Chehalis Basin would be based on genetic information reflecting selection of behaviors, life history, and genomes across spatial scales. However, such data are currently limited for nearly all species in the Chehalis Basin.[7] Lacking detailed genetic information, it is assumed that the genetic structure reflects the structure of physical habitat across the basin and that the latter can be delineated based on available data.

The environmental characteristics of the Chehalis Basin—and the spatial pattern of conditions across the basin—are the templates that over millennia created the pattern and structure of species production across the basin that resulted in robust and resilient aquatic species populations. Human land use practices have altered the historic structure of habitat across the basin resulting in a change in species production. The maintenance of population structure is a critical component of the ASRP.

An approach that incorporates the concept of population structure was developed for salmon restoration by Waples et al. (2001) and Sands et al. (2009), but is equally applicable to non-salmon species (Murphy et al. 1990; Heppell 1998; Di Minin and Griffiths 2011). This approach places high importance on maintaining or restoring enough of the native species' spatial distribution by restoring or protecting enough of the spatial structure of the appropriate habitats. With sufficient habitat structure and distribution restored, it is anticipated those populations would be able to perform at levels that ensure long-term viability and deliver desired ecosystem services, including sustaining harvest, even in the face of climate change.

The ASRP references the spatial distribution of the aquatic populations and their habitats as spatial structure in the sense of the VSP concept for salmon (McElhany et al. 2000). This component of biological performance is also critically important in building a robust ASRP. Because the purpose of the ASRP is to guide restoration of physical habitat across the Chehalis Basin, it is important to address how the environment is structured spatially.

5.3.2 ASRP Spatial Structure

The ASRP prioritization is organized around the hierarchical spatial structure of species habitats described in this section based on geological, topographical, and hydrological patterns across the Chehalis Basin. It is hypothesized that the hierarchical structure described herein can capture the population structure of most aquatic species. The proposed structure is a nested hierarchy; that is, boundaries of the smaller units never overlap those of larger units. The proposed hierarchical spatial structure of species habitats for the ASRP is as follows:

- Chehalis Basin
  - Ecological regions
    - Sub-basins
      - Geospatial units

[7] Efforts are underway to address this need for salmon. Notably, the genetic data for salmon developed to date by WDFW generally supports the approach described here.

Within this spatial structure, the ASRP delineates 10 ecological regions, listed in Section 4.4. Non-mainstem ecological regions consist of collections of sub-basins down to the confluence with the mainstem Chehalis River. Mainstem ecological regions include the mainstem Chehalis River plus the associated floodplain features such as sloughs, side channels, and floodplain ponds as well as small, short tributaries not included in the other regions. The extent of tidal influence (near the entry to the Satsop River) or changes in gradient (near the confluence of the Skookumchuck River and at Rainbow Falls) delineate mainstem ecological regions. Delineation of these ecological regions agrees with the related concept of ecoregions developed by the U.S. Environmental Protection Agency (USEPA; Omernik and Griffith 2014). A full description of tributary ecological regions is shown in Table A-2.

The central premise of the approach is that protecting or restoring **all** ecological regions to some degree is important to achieve the ASRP's vision, although the restoration needs are not equal in every region. The long-term health of the basin requires restoration to improve ecological health within each ecological region. The level of effort in each ecological region will vary due to differences in land use and habitat degradation among ecological regions. Also, the potential gain in species performance from restoration will result in differences in restoration needs and strategic priorities among regions. Some level of restoration effort would be committed to each region, but the intensity of efforts will vary among regions.

5.3.3 Prioritization Tools and Methods

The ASRP SRT utilized available data, findings, and modeling tools, along with reconnaissance field assessment and consultation with basin researchers and field scientists to formulate priority strategies and actions for each ecological region, as well as priorities between ecological regions. Several analytical models have been applied in the basin, including habitat, fish performance, amphibian occupancy, temperature, hydraulic, and climate models, to simulate historical, current, and future conditions, and in some cases directly identify factors that limit distribution. Quantitative studies included genetic analysis, otolith chemistry, and native fish and amphibian studies. Numerous multi-year monitoring programs provided abundance and distribution data for all salmon species, native fish, and amphibians.

Attachment 2 provides a framework for the Chehalis Basin that describes the major process-based watershed and ecological issues affecting the performance of certain indicator species. Major processes include sediment, flow, riparian, and wood, among others. The framework presents a high-level description of the rationale for why these issues are important and for the potential solutions and actions that can reverse their effects. The ASRP SRT used the framework to support prioritizing issues and solutions within the Chehalis Basin for protection and restoration.

Table A-2
Description of Ecological Regions for the ASRP

ECOLOGICAL REGION	MAJOR SUB-BASINS OR CHEHALIS RIVER SEGMENTS	USEPA LEVEL III ECOREGION	USEPA LEVEL IV ECOREGION	COMMENT
Willapa Hills	Stearns Creek, South Fork Chehalis River, entire Chehalis River sub-basin upstream of Rainbow Falls	Coast Range	Willapa Hills, Volcanics	These sub-basins generally originate in the higher elevations of the eastern parts of the Willapa Hills and encompass the most southern portion of the Chehalis Basin.
Cascade Mountains	Skookumchuck River, Dillenbaugh Creek, Newaukum River	Puget Lowland and Cascades	Cowlitz/Chehalis Foothills, Cowlitz/Newaukum Prairie Floodplains, Western Cascades Lowlands and Valleys	These sub-basins originate in the foothills of the Cascade Mountains.
Middle Chehalis River	Mainstem Chehalis River from Skookumchuck to Rainbow Falls plus associated floodplain features			This is a very low-gradient section of the river characterized by low summer water velocities and high temperature.
Central Lowlands	Workman Creek, Delezene Creek, Rock Creek, Garrard Creek, Independence Creek, Lincoln Creek	Coast Range	Willapa Hills	All of these smaller sub-basins are located on the southwest side of the mainstem Chehalis River.
Lower Chehalis River	Chehalis River mainstem from Satsop River to Skookumchuck River plus associated floodplain features			The gradient of the mainstem Chehalis River increases downstream of the Black River. This section includes some side channels and floodplain features.

ECOLOGICAL REGION	MAJOR SUB-BASINS OR CHEHALIS RIVER SEGMENTS	USEPA LEVEL III ECOREGION	USEPA LEVEL IV ECOREGION	COMMENT
Black River	Black River, Scatter Creek	Puget Lowland	Southern Puget Prairies	Both sub-basins are almost entirely within the Level IV Southern Puget Prairies ecoregion. This low-gradient area historically drained southern Puget Sound rivers through the Chehalis Basin to the Pacific Ocean prior to the recession of the Continental Glacier. Extensive prairies and wetlands exist in these sub-basins.
Black Hills	Cloquallum Creek, Porter Creek, Cedar Creek	Coast Range	Willapa Hills, Volcanics	These sub-basins originate entirely or partially within the Black Hills, though the lower reaches flow through the Willapa Hills Level IV ecoregion.
Olympic Mountains	Wynoochee River, Satsop River	Coast Range and Puget Lowland	Central Puget Lowlands, Coast Range Outwash, Willapa Hills	Both major sub-basins originate in the southern parts of the Olympic Mountains, though both rivers flow through two or more Level IV ecoregions.
Chehalis River Tidal	Tidally influenced mainstem up to Satsop River plus associated floodplain features			The tidally influenced section of the mainstem includes sloughs (e.g., Preacher's Slough) and small tributaries.
Grays Harbor Tributaries	Humptulips River, Hoquiam River, Wishkah River, South Bay streams	Coast Range	Coastal Uplands, Coastal Lowlands, Coast Range Outwash	Lower reaches of these sub-basins are within the Coastal Lowlands Level IV ecoregion. Similarities exist in stream types among all of the sub-basins, though the forks of the Humptulips River differ substantially due to topography (canyons and steeper terrain transitioning to the Olympic Mountains).

6 UNCERTAINTIES

Most knowledge, and hence science, regardless of its quality, contains uncertainties (Sullivan et al. 2006). Scientific and other uncertainties are inherent in ecosystem restoration. Natural variability is large in watershed and ecological processes. Biological responses, such as salmon performance, are subject to a high degree of natural fluctuations, produced by external forcing factors (such as ocean conditions) and complex interactions within the Chehalis Basin's aquatic ecosystem. Restoration planning must identify the sources of variability in a system driven by natural or human actions. It must then develop recommendations that work within this variability to increase the probability of achieving goals and thereby minimizing uncertainty. Managing for uncertainty is discussed by Beechie et al. (2003), Darby and Sear (2008), and Skidmore et al. (2011). A major conclusion is that uncertainty should not halt or delay restoration actions. While not everything is known, sufficient information exists to make informed decisions that will benefit aquatic species.

6.1 Framework for Presenting Uncertainties

Diverse sources of uncertainty exist, and many frameworks have described them (see Hilborn 1987; Wynne 1992; and Elith et al. 2002 for frameworks applicable to the aquatic sciences). Morishima (2018) provides the following five-step framework that is useful to consider in the ASRP:

1. Determine the intended audience and most informative information.
2. Identify the specific content of the information to be conveyed.
3. Examine the source and nature of uncertainties and determine what to include in the analysis.
4. Perform the uncertainty analysis, which includes evaluating the degree of uncertainty and potential consequences of the uncertainty to the work
5. Present uncertainties, including their disclosure and documentation.

Details of the approaches that should be used for addressing uncertainties depends on characteristics of the uncertainties. Morishima (2018) advises that, at minimum, disclosure and documentation should be formalized, traceable, and capture the following six elements:

- Findings and assumptions (what relationships affecting uncertainty are assumed, hypothesized, or relied upon)
- Description of the evidence base relied upon in support
- Identification of sources of uncertainty in input data, analyses, and models and an understanding of how uncertainty can be reduced, along with the costs and benefits of doing so
- If possible, estimation of the magnitude of uncertainty in predictions (though this is often not possible because of the complexity of natural systems)

- Examination of the consequences of uncertainties in restoration decisions, either qualitatively or quantitatively, and the significance of a range of possible outcomes
- Statement of confidence and likelihood

M&AM is crucial for reducing uncertainty and risks as a restoration plan progresses. Therefore, it is imperative that explicit rationale for prioritization and decision-making be well documented to improve activities under the M&AM program in the future.

6.2 Recognized Uncertainties in the ASRP

In context of the ASRP, important sources of uncertainty are likely to include the following:

1. Lack of historical geomorphic and habitat information, including channel conditions through much of the drainage network (e.g., specific geographic extent of bedrock channels, spawning gravels, stability of spawning gravels)
2. Lack of basic biological information or information on functional relationships (e.g., between populations and environmental factors)
3. Precise timing and number of storms in a given year, which is difficult to predict
4. High variability in key parameter or variable estimates

This list is not exhaustive; it merely illustrates major categories. Importantly, an adequate understanding of uncertainties is also important for prioritization, as high levels of uncertainty could be viewed as a reason for either advancing or delaying projects if project results will substantially reduce uncertainty or if uncertainty puts the risk of project failure too high until better information becomes available, respectively.

Some additional elaboration on the nature of uncertainties in the ASRP is merited with regard to potential complications with invasive species. A large body of literature indicates that successful responses to restoration efforts can result from diverse structural changes in habitat due to restoration efforts (Roni et al. 2002, 2008; Wortley et al. 2013). This assumption is probably most valid, however, under those conditions where invasive species are absent. Under those conditions, one can have reasonably high confidence (low uncertainty) that the species for which restoration is targeted will respond in an expected and positive fashion. The ASRP makes the assumption that historic habitats were optimal to native species. The ASRP also assumes that current degraded conditions put native species at a disadvantage to invasive species, which are at an advantage in altered habitats. Science clearly does indicate that native species are impacted by existing degraded habitat. Science is also clear that native species will benefit from restoring historic habitat in the absence of invasive species. However, high uncertainty exists around how invasive species will respond in restored habitats and also how invasive species and invasive-native species interactions will respond to restoring historic habitats.

Studies integrating the potential effects of invasive species with structural habitat restoration that have actually examined the response are sparse. More specifically, since such studies are non-existent for salmonid species and other aquatic species in the Pacific Northwest, restoration conditions where invasive species are present should recognize either that uncertainty may be high or the range of uncertainty is broad enough to make accurate predictions about expected outcomes more difficult. Under such conditions, it may be necessary to approach the restoration in an experimental fashion—that is to say, by incorporating unmanipulated reference site or sites that are monitored in concert with the experimental site(s). This approach would better enable gauging species response to restoration in an adaptive fashion (i.e., it would be useful to future efforts to allow adjustments to the restoration approach likely to increase success). Whether an experimental approach is needed has to be gauged on the level of uncertainty faced; if uncertainty is judged to be high, an experimental approach is likely the more appropriate route.

6.3 Communicating Uncertainties with the Non-Science Audience

Uncertainty imposes a unique challenge for clear communication of study paths and results with non-scientists. Morishima (2018) states that uncertainty is best viewed from the systemic perspective of uncertainty analysis, which addresses the challenge of informing decision-makers of the limitations of data and methods of analysis so that study results and models can be properly understood and interpreted. He emphasized the critical need for uncertainty analysis to inform decision-making with ecological consequences and risk because of the challenge of clearly conveying the scope and magnitude of uncertainty to an audience with disparate backgrounds and experiences—and therefore perspectives, as well. Where uncertainty generates unacceptable risks, these risks must be diminished by reducing either the probability of undesirable outcomes or their consequences for people, species, or property. Recognition of the limitations of data and knowledge gaps (uncertainties) improves rather than diminishes the quality of scientific advice and can contribute to the development of trust between scientists, decision-makers, and stakeholders (Ryder et al. 2010).

7 ADAPTIVE MANAGEMENT, MONITORING, AND EVALUATION

Monitoring and adaptive management are essential components of ecosystem restoration. Adaptive management is an iterative process of decision-making in the face of uncertainty, with the intent of reducing uncertainty through monitoring and continually adapting implementation strategies and actions as knowledge that informs the best way to meet the stated goal (Skidmore et al. 2011).

Adaptive management is not managing by trial and error—it requires that purposeful actions be taken, then monitored and scientifically evaluated so that policy, management, and actions become more effective for restoration over time (Joint Natural Resources Cabinet 1999).

Adaptive management and monitoring are linked. Without monitoring, no scientifically valid way exists of assessing progress and knowing whether investments in actions are beneficial. Well-designed monitoring should do the following: 1) indicate whether the restoration measures were designed and implemented properly; 2) determine whether the restoration results met the objectives; and 3) provide new insights into ecosystem function and response (Kershner 1997). Hence, besides measuring progress of the plan, monitoring also serves a research role in addressing critical uncertainties.

For the ASRP Phase 1 document, an M&AM Framework (Appendix B) has been developed. Built on the ASRP vision statement components as well as this Scientific Foundation, the M&AM Framework describes the purpose, elements, and types of studies that will be included in the M&AM Plan (to be developed in Phase 2 of the ASRP). It also acknowledges the need for hypothesis testing and studies to fill critical data/knowledge gaps. The M&AM Plan will apply principles outlined in this foundation. This foundation underscores the basic principles on which the ASRP is developed and is a starting point for the M&AM Plan to be developed.

8 PLANNING FOR SCIENTIFIC CREDIBILITY

The scientific basis for decisions relating to the ASRP and the Chehalis Basin Strategy will assuredly be subjected to intense scrutiny as the components of plans are formulated and moved forward. It will be vital for decision-makers and the public to be confident that decisions and recommendations being contemplated and taken are based on the “best available science”—a term commonly used by management agencies and in the scientific literature (Sullivan et al. 2006; Ryder et al. 2010). The term “best available science” is commonly applied to engender credibility and trust among scientists, managers, stakeholders, governments, and the public. The ESA has been a focal point for defining best available science in the scientific literature, defining “best” as information that is collected by established protocols, properly analyzed, and peer-reviewed before its release to the public (Brennan et al. 2003; Ryder et al. 2010).

This Scientific Foundation incorporates a description of the guidance, principles, and processes that have been employed to ensure that best available science is utilized in the development of the ASRP. As implementation of the ASRP begins, ongoing standards and protocols will be needed to continue to guide the ASRP to maintain its scientific credibility; these will include the following:

1. Standardized terminology (e.g., habitat names, acronyms, symbols)
2. Continued scientific review to guide implementation and adaptive management actions
3. Development of criteria and standards for ASRP implementation projects
4. Regularly scheduled reviews by the sponsors and participants in the ASRP of all ASRP components and projects, including the Scientific Foundation, as a way of adapting and updating the plan and adjusting to new information
5. Procedures for record-keeping
6. A central location to facilitate data management

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Attachment 1
Potential Indicator Species for the Aquatic Species Restoration Plan

This attachment documents the rationale for potential indicator species for monitoring and adaptive management of the ASRP. Salmon are widely recognized as indicator species for watershed restoration in the Pacific Northwest (Lestelle et al. 1996; Hyatt and Godbout 2000). Their freshwater life history depends on streams, the arterial system of a watershed. The conditions of streams generally reflect overall watershed condition, since water drains downhill, bringing with it characteristics created upstream. Salmon are sensitive to these conditions, upon which their survival and abundance depends. Moreover, because some salmon species have complex life histories that utilize extensive parts of a river system, from estuary to headwaters, their life cycle acts to integrate the mosaic of conditions within an entire stream system. Salmon have another important, unique role—they connect ecosystems through their extensive migrations, connecting freshwater, estuarine, and oceanic systems (Irvine and Riddell 2007). In summary, salmon are the ideal taxa to gauge ecosystem health because they integrate across saltwater, freshwater, and terrestrial systems because of reciprocal subsidies.

Salmon are also recognized as being keystone species to watershed ecosystems. For example, they convey large quantities of marine nutrients from the ocean to watersheds as a result of their oceanic migrations and their return to their natal streams. In doing so, they are a key part of food webs for both aquatic and terrestrial ecosystems within a watershed (Cederholm et al. 2000).

Salmon have also been identified as a cultural foundation species. In ecology, the term “foundation species” refers to a species that has a strong role in structuring a community (Dayton 1972). Wild salmon are a cultural foundation species for Native American tribes throughout the Pacific Northwest (Hurlburt [unpublished]). The two indigenous peoples in the Chehalis Basin—Chehalis and Quinault—like other Northwest indigenous peoples, have viewed salmon as the symbol and lifeblood of their way of life (Capoeman 1990; DeLoria 2012).

Coho and spring Chinook are two species of salmon that are potential indicator species in the Chehalis Basin. Coho salmon have the greatest breadth of habitat use of the salmon species in the basin, spawning or rearing in virtually all streams of any notable size throughout the basin. They spawn in relatively steep headwater streams as well as on the margins of the largest rivers, extending to the head of tidewater. They rear in the smallest stream channels, in larger mainstem river channels, and in off-channel habitats on the floodplains. They spend approximately 1.5 years in the freshwater environment before migrating to the ocean as smolts, then return as mature adults after a comparable time spent in the ocean. Their time spent in freshwater as eggs or juveniles includes periods of the highest annual flows as well as the lowest annual flow. They experience the hottest times of the year and the coldest times. This diverse use of the basin exposes them to a wide variety of conditions and potential threats, which are also potential threats to many aquatic species.

The other potential salmon indicator species for the ASRP is spring Chinook. This race of Chinook salmon is particularly sensitive to habitat changes in a river basin like the Chehalis. These fish enter the river as immature adults (called premature migrating fish) in the spring and early summer, and then they ascend to the middle or upper reaches of the river and its largest tributaries. As a consequence, they experience the hottest part of the summer, often in very low flows when water withdrawals are highest for out-of-stream water uses, and when they are vulnerable to high rates of pre-spawning mortality if conditions are too severe (Quinn et al. 2016). Spring Chinook salmon populations are generally declining coast-wide due to their sensitivity to degraded habitats, as seen over the past 20 years in the Queets and Hoh rivers on the Washington coast. This species is especially valued by Native American tribes due to their early river entry timing and high fat reserves. The species is also an important food source for orca whales. There are growing conservation concerns about their future status, particularly in light of climate change (Prince et al. 2017).

Along similar lines, amphibians are widely recognized as potential indicator species (Welsh and Ollivier 1998; Adams 1999; Waddle 2006). Similar to salmon, the success of many amphibians depends on life history integration across ecosystem compartments. In the case of stillwater-breeding and stream-breeding amphibians (two-thirds of the amphibian species present in the Chehalis Basin), that integration occurs between freshwater and terrestrial habitats, which are utilized by aquatic obligate life stages (larvae or tadpoles) and post-metamorphic life stages that migrate seasonally between the aquatic (breeding) and terrestrial (non-breeding active season) compartments (Hayes et al. 2008; Semlitsch 2008). Amphibians are also unique among vertebrates in having a kidney physiology adapted to ridding themselves of fresh water, a condition they constantly face in the aquatic or moist environments they inhabit because they possess a water-permeable skin that doubles as a lung (Feder and Burggren 1992). This physiology has consequences that both limit the habitat conditions in which amphibians occur and make them more vulnerable than other vertebrates to selected environmental insults. These include the following: 1) their skin cannot function as a lung when dry, which restricts amphibians to either aquatic or relatively moist habitats; 2) maintaining a moist skin carries the cost of rapid water turnover (both rapid gain and loss), which makes them vulnerable to rapid absorption of water-soluble contaminants; and 3) their water-voiding kidney makes them capable of tolerating only the most dilute saltwater, which is reflected in the absence of truly marine amphibians (Feder and Burggren 1992). Amphibians are also key contributors to ecosystem services, especially through what can be labeled supporting services. In particular, amphibians can affect habitat structure through aquatic bioturbation, decomposition and nutrient cycling via waste excretion and indirectly through predatory changes in food webs, and primary production through consumption directly and nutrient cycling (Hocking and Babbitt 2014). Finally, also similar to salmon, several native amphibians in the Chehalis Basin are cool-adapted stenotherms for at least selected life history stages (Hayes et al. 2008).

The aforementioned features led to the identification of two amphibian species—northern red-legged frog and Oregon spotted frog– as potential indicator species in a manner similar to the two salmonids that were identified. The northern red-legged frog, a quasi-analog to coho salmon, is widespread in the basin. However, it can act as an umbrella species for most (four of the six) of the other native stillwater-breeding amphibian species because its presence increases the likelihood of occurrence of that segment of the native stillwater-breeding amphibian suite (Hayes et al. 2008). Northern red-legged frog is also a useful potential indicator species because its embryonic life stages have the lowest critical thermal maximum (approximately 20°C) of any North American frog, which restricts its breeding to the late winter interval, typically January to February (Licht 1971). The temperature requirements make it particularly useful for tracking changes that may result from climate warming. The second selection, the Oregon spotted frog, a quasi-analog to spring Chinook salmon, is a marsh habitat specialist that is currently only known from the Black River system in the Chehalis Basin (Hallock 2013). This completely aquatic frog was listed as threatened under the ESA in 2014 and is especially vulnerable to warm-water invasive predators, notably the American bullfrog and warm-water fishes (especially centrarchid fishes that include basses, crappies, and sunfishes; Hallock 2013). Its sensitivity to warm-water invasive species also make it useful for tracking changes that may result from climate warming, since warmwater invasive species are suspected to respond positively to climate warming. The Oregon spotted frog is an even better umbrella species than the northern red-legged frog because its presence increases the likelihood of occurrence of all six of the remaining native stillwater-breeding amphibians. However, its restricted distribution limits its utility as an umbrella species.

Besides fish and wildlife species, the variety of plants that occur in the aquatic, riparian, and floodplain habitats of the basin play a major role in providing the structure and function of the habitats. While not displayed as potential indicator species in this iteration, plant species are noted as key components of the habitats used by the fish and wildlife species. The widespread distribution of invasive plant, fish, and wildlife species also affects the structure and function of the ecosystem and the productivity and survival of fish and wildlife species. Inclusion of key plant species as selected indicator species could be incorporated into the comprehensive M&AM Plan.

Table A1-1
Potential Indicator Species for the ASRP

STANDARD ENGLISH NAME (COMMON NAME)	SCIENTIFIC NAME	STATUS[1]	HABITAT INTEGRATOR[2]
Winter-run steelhead	*Oncorhynchus mykiss*		AOT
Coho salmon	*Oncorhynchus kisutch*		AOT
Fall-run Chinook salmon	*Oncorhynchus tshawytscha*		AOT
Spring-run Chinook salmon	*Oncorhynchus tshawytscha*		AOT
Chum salmon	*Oncorhynchus keta*		AOT
Mountain whitefish	*Prosopium williamsoni*		AT
Eulachon	*Thaleichthys pacificus*	SGCN, FT, SC	AOT
Pacific lamprey	*Entosphenus tridentatus*	SGCN, FCO	AOT
Olympic mudminnow	*Novumbra hubbsi*	SS	AT
Speckled dace	*Rhinichthys osculus*		AT
Largescale sucker	*Catostomus macrocheilus*		AT
Riffle sculpin	*Cottus gulosus*		AT

STANDARD ENGLISH NAME (COMMON NAME)	SCIENTIFIC NAME	STATUS[1]	HABITAT INTEGRATOR[2]
Reticulate sculpin	*Cottus perplexus*		AT
Coastal tailed frog	*Ascaphus truei*	FFR	AT
Western toad	*Anaxyrus boreas*	SC,FCO	AT
Northern red-legged frog	*Rana aurora*		AT
Oregon spotted frog	*Rana pretiosa*	SE,FE	AT
Van Dyke's salamander	*Plethodon vandykei*	FFR	
Great blue heron	*Ardea herodias*	SGCN	AOT
Barrow's goldeneye	*Bucephala islandica*	SGCN	AOT
Wood duck	*Aix sponsa*	SGCN	AT
North American beaver[3]	*Castor canadensis*		AT
Western pond turtle	*Actinemys marmorata*	SE,FCO	AT
Western ridged mussel	*Gonidea angulata*		AT

Notes:
1. Key:
    - SS: state sensitive
    - SC: state candidate
    - SE: state endangered
    - SGCN: species of greatest conservation need (Washington 2015 State Wildlife Action Plan)
    - FCO: federal species of concern
    - FT: federal threatened
    - FE: federal endangered
    - FFR: Forests and Fish Law target species
2. Key:
    - AOT: aquatic-ocean-terrestrial
    - AT: aquatic-terrestrial
3. North American beaver is also a habitat engineer.

Attachment 2
Process-Based Strategy Framework

This attachment provides a framework and summary of the major process-based watershed and ecological issues affecting the performance of the indicator species used in the development of the ASRP. The framework presents a high-level description of the rationale for why these issues are important and for the potential solutions and actions that can mitigate their effects. Addressing watershed-scale processes rather than trying to restore specific habitats is more likely to be successful in restoring aquatic species populations and habitats over time (Beechie et al. 2010).

This summary is intended to provide the flow of logic necessary to link the issues to proposed strategies and actions.

Table A2-1
Watershed and Ecological Process-Based Strategy Framework

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: ACCESS TO INSTREAM AND OFF-CHANNEL HABITATS				
Access to instream habitats: The ability of juvenile and adult native fish species to move upstream and downstream to access spawning grounds and rearing areas and to migrate to the ocean (as applicable) is vital to species performance and long-term sustainability. Poorly designed or deteriorating culvert and bridge installations, as well as other barriers to passage, such as dams, can block or impede movements of juvenile and/or adult fish. **Access to off-channel (floodplain) habitats:** The availability and accessibility of off-channel habitats (ponds and wetlands) are important determinants of the performance of some salmon populations and other species such as Olympic mudminnow. Human-made structures, low flows, or other altered features can block access to these habitats.	Fish passage barriers block or limit access to upstream and downstream habitats that were used historically by a species, resulting in reduced population abundance due to loss in available habitat (quantity of habitat; Cramer 2012). Fish passage barriers block access to upstream cooler water habitats and refugia that will become more important with climate change (Beechie et al. 2012) Off-channel habitats are especially important to juvenile coho salmon for overwintering, which is a critical life stage to many coho salmon populations in the Pacific Northwest (Lestelle 2007). Accessibility and likelihood of juvenile coho salmon finding these habitats is a habitat quality characteristic, though these habitats also provide important habitat quantity (Lestelle 2009). Fish passage barriers can alter the spatial structure, life history diversity, and genetics of a population, thereby potentially impacting its long-term sustainability (Thompson et al. 2019).	Historically, culverts were simply designed to handle a given storm flow (e.g., 25-year flood event) with no regard to passing fish and other species. These culverts can cause perched outfalls or result in excessively high velocities that restrict passage. Concrete- or metal-bottomed culverts , particularly those with flat bottoms, can have shallow water or high-velocity conditions without hydraulic variation, thereby limiting the ability of fish to pass through. Old culverts can collapse or become plugged, restricting fish access. Dams, such as Skookumchuck Dam, can be a complete barrier to upstream and downstream passage. Small or seasonal channels or swales connecting off-channel ponds and wetlands to the main stream can be blocked by road or levee fills or poorly designed culverts and gates. Filling and drainage of wetlands to facilitate other land uses has reduced their availability. Invasive plants can choke access to off-channel habitats or within small streams.	Remove stream crossing structures on abandoned or closed roads. Redesign and rebuild stream crossing structures to accommodate flows and provide fish and other aquatic organism passage. Alter partial barriers to fish passage to maintain connectivity along the river as it supported fish populations historically. Restore, enhance, and maintain good access between stream channels and off-channel ponds and wetlands where infrastructure or other obstructions impede passage. Control invasive plant species while native plant revegetation is occurring.	**Road crossings:** Periodically evaluate stream crossing structures for passage effectiveness, maintain crossing structures consistent with best management practices, remove crossing structures on closed or abandoned roads, and replace or upgrade outdated structures on a priority basis. **Dam removal:** Remove dam that blocks upstream and downstream passage. **Improving access to off-channel habitat:** Improve access to off-channel habitats by removing obstructions, deepening connection channels, and/or adding structure where opportunities exist to improve access. Consider the presence of invasive species in the planning of this strategy/action. **Invasive species:** Inventory invasive plant species such as Japanese knotweed and reed canary grass. Identify methods of control and management to be implemented separately or in conjunction with native species revegetation. Periodic maintenance activities at prior restoration sites may be necessary to obtain adequate control. Activities listed for riparian protection and restoration can be important to help control invasive plant species.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: SEDIMENT REGIME (SUPPLY, TRANSPORT, AND STORAGE)				
Excess sediment: Erosion and sediment transport is a natural process that shapes stream channels and floodplains, as well as associated habitats and aquatic biota. The sediment supply is produced from ongoing land erosion (e.g., landslides), as well as from the recapture of sediments (due to channel migration and avulsions) previously stored in flood plains and streambanks. Watershed alterations and management (such as forest practices, agriculture, and development) have disrupted the natural process, resulting in changes (often very significant ones) to the supply, storage, and transport of sediments. These changes had led to increased fine sediment levels within spawning gravels, channel and habitat instability, and in some cases, severe channel aggradation. **Sediment reduction:** Downstream of a dam (several exist in the Chehalis Basin), the channel can be sediment starved, leading to channel bed coarsening (armoring), incision, and/or a lack of stable spawning gravel. Bank armoring can reduce channel migration and the natural recruitment of sediment from floodplain deposits. Climate change is expected to increase sediment loading in many streams in Western Washington from increased landslides and erosion (Mauger et al. 2015; Beechie et al. 2012).	Increased sediment supply over levels typically found in old-growth forests or conditions prior to the modern era of watershed development results in increased mortalities of salmonid embryos and juveniles during egg incubation and overwintering life stages (Bjornn and Reiser 1991; Cederholm and Reid 1987). Increased sediment supply can cause channel aggradation (buildup of sediment in the channel), resulting in shallowing of pools and riffles (even dry channels), channel braiding, and greater habitat instability, thereby reducing population performance (SIT and WDFW 2010). Decreased sediment supply can cause channel incision and loss of suitable spawning habitat for salmon.	Runoff from road building and vehicular traffic on unpaved roads increases sediment delivery to streams. Landslides associated with roads, fires, and timber harvest increases sediment delivery. Blowouts and slides associated with undersized culverts increase sediment delivery to streams. Ongoing erosion associated with old road drainage networks due to failed culverts and unmaintained ditches increase sediment delivery to streams. Runoff from agricultural fields and farming activities increase fine sediment and pollutant delivery to streams. Removal of large wood and logjams during historic timber harvest and subsequent channel clearing or splash dam sluice activities, resulted in increased channel instability and loss of stored sediments. Runoff from land clearing for land conversion, including road building, increases fine sediment delivery to streams. Altered runoff and flow regimes due to land uses cause greater streambank erosion and recapture of stored sediments, thereby increasing sediment loading. Climate change is expected to increase sediment delivery to streams in Western Washington due to intensification of rainfall events and an associated increase in landslides and erosion (Mauger et al. 2015; Beechie et al. 2012).	Continue to improve forest management practices to reduce sediment yields from roads, clearcuts, and from areas prone to landslides. Close and obliterate unneeded roads (Roni et al. 2012; Beechie et al. 2010). Continue to upgrade and improve best management practices for managing sediment yield from all types of land uses. Improve opportunities for public education on ways of controlling sediment. Improve knowledge and understanding about sources of sediment produced in the watershed.	**Road Maintenance and Abandonment Plans:** Complete the development of Road Maintenance and Abandonment Plans on all forest lands, and implement steps for upgrading, maintaining, or decommissioning of roads and road crossings. **Non-forest roads:** Assess conditions of existing non-forest road systems that might contribute sediments, identifying risk levels for sediment contributions, and implement identified remedial measures. **Non-road sediment:** Assess non-road related sediment sources that contribute sediments, identifying risk levels for sediment contributions to adjacent streams, and implement remedial measures. **Protect riparian lands:** Increase protection of riparian lands through regulations, incentives (e.g., conservation easements), land purchases, and education and outreach programs. **Restore riparian forest:** Restore riparian forest characteristics using passive or active management methods. Activities listed for protection of riparian lands also apply here. **Large wood:** Construct engineered logjams or place large wood in appropriate locations of the river to facilitate sediment storage and processing and more natural channel patterns (including bed elevations) and, where appropriate, to recreate stable side channels, backwaters, or stable vegetated islands. **Sediment analysis:** Prepare watershed sediment budget and transport analysis for a sub-basin of concern. Such analysis will provide a landscape perspective for assessing the sediment budget, including rates of sediment supply and transport. Remedial measures can be formulated accordingly.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: FLOW REGIME CHARACTERISTICS (MAGNITUDE, TIMING, FREQUENCY, DURATION, AND RATE OF CHANGE IN FLOW)				
The natural flow regime organizes and defines river ecosystems (Poff et al. 1997). The flow regime is defined by flow magnitude, duration, timing, frequency, and rate of change. The natural ranges of these attributes within the basin shaped the riverine environment and the populations of aquatic species that adapted to these conditions over millennia. **Altered flow regime (high-flow or low-flow aspects):** Conversion of upland mature forests to young, managed stands, combined with an extensive road network, alter the characteristics of the natural flow regime to varying extents. Land conversion in lowland from vegetation clearing and conversions to agriculture, residential areas, commercial and industrial uses, and urbanized areas. These changes decrease canopy cover and interception of rainfall, increase impervious surfaces, and decrease groundwater infiltration and water storage that supplement low flows. The flow regimes in certain rivers have also been altered by dams and reservoirs (Wynoochee and Skookumchuck). Flow regimes are also directly altered by channel incision. Floodplain disconnection alters flow regimes—the same flow magnitudes (Q) that once spread out slow-moving water onto floodplains are confined to deep, fast-moving water constrained within the channel. This also reduces the floodplain function of attenuating downstream flood peaks, thus not just altering flow regimes but also recurrence intervals. For example, urbanization does not change rainfall event, but it will increase the quantity of water entering the channel network due to impervious surfaces. This changes flood frequencies: a flow that naturally had a 0.01% probability of occurring in a given year can occur every year. This then changes flow regimes, which in turn change sediment and wood regimes. Climate change is expected to result in still further changes to the flow regime of the Chehalis Basin (Mauger et al. 2016; Beechie et al. 2012). Intensification of rainfall events are expected to increase peak annual flows significantly in some areas of the basin.	Life history patterns and associated life stage survivals of salmon and other native fish are strongly affected by characteristics of the flow regime in a stream system (Poff et al. 1997). Peak flow intensity, runoff volume and duration, and rate of change in flows during storm events can adversely affect egg to fry survival, emergent fry survival, and juvenile overwintering survival (Schuett-Hames and Adams 2003; Seiler et al. 2004). Diminished low flows in late summer or early fall as a result of changes in the flow regime will generally reduce the number of coho salmon smolts (and probably steelhead smolts) produced from tributary streams (Smoker 1953; Seiler 1999). Diminished low flows in late summer or fall can reduce connectivity and water storage of off-channel habitats and wetlands, reducing habitats for other aquatic species such as Olympic mudminnow and amphibians.	Extensive road networks through managed forests increase rate of runoff, which can produce greater instability of streams. Replacement of mature forests with managed forests of much younger stands increases runoff. Land clearing and land conversion create impervious surfaces in the watershed, altering runoff patterns and rates. Levees that prevent flooding onto the floodplains increase the volume and elevation of flow in the main channel. Channel incision reduces connectivity to floodplains and changes the volume of flow in the channels and increases delivery of water to areas downstream. Water withdrawals from surface water for the purpose of irrigation, domestic, and industrial use reduce low flow volumes. Groundwater pumping to support agricultural or residential uses can also reduce streamflow volumes.	Promote diverse stand age in the managed forest to increase retention of precipitation on the landscape. Reduce the footprint of roads in the managed forest areas of watersheds wherever possible. Restore connections to floodplains that provide for increased flood capacity and storage. Protect channel migration zones (CMZs) to maintain floodplain habitat formation and complex flow pathways. Restore flow regime characteristics by reducing the rate of storm runoff associated with developed areas. Restore riparian and floodplain vegetation communities.	**Channel pattern:** Strategically remove channel constrictions and impediments to meanders to restore channel capacity and develop more natural channel pattern and migration (e.g., by dike removal, use of setback levees, road relocations, lengthening and/or raising bridges, or rebuilding the channel pattern). **CMZ:** Protect and restore active channel migration zone (because it has been reduced by human activities) through regulations, incentives, education programs, or land acquisition. **Decommissioning:** Decommission or remove roads of little use on public lands, or ones whose services can be provided on alternative roads. **Forest maturity:** Manage for an increase in hydrologic maturity (older-age stands) of forested lands to the extent possible using incentives on private lands or through policy change on public lands. **Protect floodplains:** Protect existing riparian and floodplain lands from land conversions or loss of function through regulations, incentives, education programs, land acquisition, or land set-asides. **Restore floodplains:** Restore more natural floodplain characteristics and function by restoring wetlands, ponds, overflow channels, riparian forest, and/or size of floodplains; this includes connectivity of off-channel features. **Road Maintenance and Abandonment Plans:** Complete the development of Road Maintenance and Abandonment Plans on all forest lands, and implement steps for upgrading, maintaining, or decommissioning of roads and road crossings. **Stormwater management:** Update and enforce storm runoff management on agricultural, residential, commercial, or urbanized lands, including all transportation corridors that produce pollutants, promoting greater increases in stormwater infiltration using various methods and greater capacity for stormwater detention or retention. **Water rights:** Purchase water rights as available and dedicate those rights to conservation.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: STREAM CHANNEL CONDITIONS (LARGE AND SMALL STREAMS)				
The river channels in the region have lost structural and habitat diversity compared to their historic condition to varying extents across the basin. Wood loads have been reduced to low levels throughout large portions of the basin (Smith and Wenger 2001; GHLE 2011). These changes have resulted in alterations to channel stability, changes in substrate stability, loss of pool habitat and other habitat types, and substrate sizes (Wendler and Deschamps 1955; Hiss and Knudsen 1993; Sullivan and Massong 1994; Smith and Wenger 2001; GHLE 2011). Smaller streams have been extensively channelized within urban and agricultural areas (Hiss and Knudsen 1993; GHLE 2011). Wood removal can trigger channel incision, which creates new sources of sediment by mining channel bed and destabilizing banks. Incision also increases sediment transport capacity, which has similar effects of a dam—bed coarsening and reduction of spawning gravel. Channel incision as a result of past land uses is widespread in large parts of the basin (Smith and Wenger 2001). Climate change may be exacerbating these issues (Clark 1999), seen in the dramatic increase in peak annual flows in the Newaukum River hydrograph.	The Chehalis Basin has experienced reductions of native fish migration, spawning, incubation, and juvenile rearing habitat quality (manifested in the frequency, stability, and structure of habitats) and quantity (Hiss and Knudsen 1993; Smith and Wenger 2001; Mobrand Biometrics 2003; GHLE 2011). Numerous river segments in the Chehalis Basin have experienced a loss of side channel habitats, which are particularly important for spawning and rearing by young juveniles. Reduced in-channel wood or increased flow can cause increased egg to fry mortality due to channel scour or sediment deposition. Reduced in-channel wood and loss of off-channel habitat can increase mortality of young fry due to loss of refuge habitat. Reduced in-channel wood and floodplain connectivity can increase mortality during summer and winter rearing stages due to loss of high-quality habitats. Reduced in-channel wood and riparian forest can result in reduced food diversity and quantity for juvenile salmon and other native fish. Reduced quality of in-channel habitats can result in declines in fish population performance at all freshwater life stages and over the entire life cycle, thereby reducing the probability of long-term sustainability and performance.	Intensive timber harvest in the early 20th century accompanied by log driving and splash damming resulted in large reductions to in-channel wood and channel incision (Wendler and Deschamps 1955). Removal of large and small logjams within the active channel migration zone has reduced riverine habitat quality and quantity. Stream channel straightening or channelization reduces habitat quantity and quality. Constriction of the active high-flow channel by roads, bridges, levees, or bank armoring reduces habitat quantity and quality. Increases (from various land uses) or decreases (due to a dam) in sediment loading to the stream change habitat-forming processes. Changes in the flow regime, particularly in the frequency, duration, and level of high-flow events, which is caused by various land and water use patterns, reduce habitat-forming processes. Disconnection from the river's floodplain or reductions in the water and/or sediment storage capacity of the floodplain reduces habitat quantity and habitat-forming processes. Gravel mining from the channel or the river bars reduces spawning habitats and modifies natural habitat-forming processes. Timber harvest or clearing within the riparian zone reduces wood recruitment to the river system and reduces nutrient cycling and foodweb productivity. Climate change effects (increasing peak flows in the Newaukum River) may be exacerbating these issues (Clark 1999).	Protect and restore active CMZs and restore meander patterns by reducing channel and flow constrictions and restoring channel migration zones. Restore large wood to the active channel and the active CMZ, and where appropriate, promote stable vegetated islands. Restore more natural flow regime characteristics by stormwater management and increasing forest cover. Restore connections to floodplains that provide for increased sediment storage and flood capacity and storage. Restore more natural flow regime in dammed rivers (Wynoochee and Skookumchuck rivers).	**Channel pattern:** Strategically remove channel constrictions and impediments to migration to restore channel capacity and develop more natural channel patterns (e.g., use of setback levees, road relocations, lengthening and/or raising bridges, or rebuilding the channel pattern). **CMZ:** Protect and restore the active CMZ (because it has been reduced by human activities) through regulations, incentives, education programs, or land acquisition. **Large wood:** Construct engineered logjams or place large wood in appropriate locations of the river to facilitate island formation, sediment storage, and processing and channel patterns (including bed elevations), and promote the formation of side channels, backwaters, or stable vegetated islands. **Invasive species management:** Inventory and manage invasive plant species such as Japanese knotweed and canary reed grass. **Protect riparian lands:** Increase protection of riparian lands through regulations, incentives (e.g., conservation easements), land purchases, and education and outreach programs. **Restore riparian forest:** Restore more natural riparian forest characteristics using passive or active management methods. Activities listed for protection of riparian lands also apply here. **Consider restoration corridor:** Consider a restoration corridor concept for restoration projects to identify channel migration hazards and provide space for a diversity of channel and floodplain habitats.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: LARGE STREAM FLOODPLAIN CONDITIONS				
Loss of floodplain connectivity: Major parts of the floodplains of stream channels in the basin have been disconnected from the active channels within the alluvial valleys due to various types of channel alterations that have occurred over the decades, including channel incision (Smith and Wenger 2001; GHLE 2011). **Floodplain conversion:** Large areas of the floodplains have been converted to agriculture, residential, or urbanized areas. In the process, wetlands have been drained and filled (Clark 1999). Changes to the floodplains reduce their function including elements such as groundwater infiltration and storage, runoff volumes, and the amount and quality of off-channel habitat features used by native aquatic species.	Loss in floodplain function can further degrade in-channel conditions, affecting adult migration, spawning, incubation, and juvenile salmonid habitat quality (manifested in the loss of frequency, stability, and structure of habitats) and quantity. Loss in floodplain connectivity and function can diminish fish food diversity and quantity (Bellmore et al. 2013, 2017; Lestelle et al. 2005). Loss of side channel habitats is most significant for spawning and rearing by young salmon juveniles (Sedell et al. 1984). Loss of off-channel habitats are most important for summer and winter rearing of juvenile coho salmon, though juvenile Chinook salmon can also use these habitats (Lestelle et al. 2005; Lestelle 2007). Floodplain connectivity and seasonal timing affects the quality of habitat and presence of invasive species that affect the survival of stillwater breeding amphibians and native fish such as Olympic mudminnow (Hayes et al. 2019; Mongillo and Hallock 1999). All of these changes reduce fish population performance at various life stages and over the entire life cycle, thereby reducing the probability of long-term sustainability or recovery (citations as listed previously in this column). Loss of floodplain medium-hydroperiod habitats results in loss of breeding and rearing habitat for stillwater-breeding amphibians where these can breed and rear without high impact from invasive predator species.	Intensive timber harvest in the early 20th century accompanied by log driving and splash damming resulted in large reductions to in-channel wood and channel incision (Wendler and Deschamps 1955). Stream channel straightening or channelization can disconnect the active channel from its floodplains. Channel control measures, such as levees, and other types of bank armoring reduce channel migration and disconnect the active channel from its floodplain. Conversion of forested floodplains and floodplain intermediate-hydroperiod pond to agriculture, residential, and urban settings reduce floodplain habitats and functions. Drainage and filling of overflow channels, off-channel ponds, and wetlands and marshes located on the floodplains occur to convert these areas to simplified and/or upland habitats. Loss of floodplain medium-hydroperiod habitats results in loss of breeding and rearing habitat for stillwater-breeding amphibians where these can breed and rear without high impact from invasive predator species.	Restore connections to floodplains that provide for increased sediment storage, flood capacity and storage, and groundwater and hyporheic recharge (Roni et al. 2012). Restore wetland complexes and beaver pond complexes. Protect and restore CMZs and restore meander patterns by reducing channel and flow constrictions. Modify or remove levees, bank armoring, and other infrastructure that disconnects floodplains. Acquire floodplain lands and restore ecological functions of those lands. Create medium-hydroperiod pond to encourage stillwater amphibian breeding	**Transportation infrastructure:** Improve or remove transportation infrastructure within floodplains to restore channel and floodplain function and connectivity. **Protect floodplains:** Protect existing riparian and floodplain lands from land conversions or loss of function through regulations, incentives, education programs, land acquisition, or land set-asides. **Restore floodplains:** Restore floodplain characteristics and function by restoring wetlands, ponds, overflow channels, riparian forest, and/or size of floodplains; this includes connectivity of off-channel features. **Beaver management:** Develop and implement as warranted beaver management measures. Beaver activity is consistent with achieving floodplain, channel, and habitat characteristics, though private property protection and riparian protection (during re-establishment phase) may warrant active management of beaver. **CMZ:** Protect and restore active the CMZ (because it has been reduced by human activities) through regulations, incentives, education programs, or land acquisition. **Invasive species management:** Inventory and identify management measures for invasive plant species such as Japanese knotweed and canary reed grass. **Restore riparian:** Restore riparian forest characteristics using passive or active management methods. Activities listed for protection of riparian lands also apply here. **Consider restoration corridor:** Consider a restoration corridor concept for restoration projects to identify channel migration hazards and provide space for a diversity of channel and floodplain habitats.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: RIPARIAN CONDITIONS				
Loss of riparian function: Riparian areas have been impacted to varying degrees throughout the basin by a wide variety of land use activities, which include timber harvest, land clearing, and land development. These activities have removed or altered the riparian plant communities, modified riparian soil conditions, and other associated land and water features, as well as modified natural ecological cycles, all of which affect riparian functions (Hiss and Knudsen 1993; Smith and Wenger 2001).	The ecological health of streams is closely linked to the watershed landscape by the biotic and physical-chemical properties of the riparian zone (Naiman et al. 2005; this citation applies to all following text also). Riparian forests affect stream and shoreline shading, influencing stream temperature, dissolved oxygen, and plant species composition (e.g., invasive species)—all of which affect salmonid and other aquatic species performance and habitat use. Riparian zones affect water quality by trapping suspended and fine sediments and pollutants. Riparian zones slow water velocities during high flows. Riparian zones stabilize streambanks and help maintain channel stability and bank cover for fish. Riparian zones add leaf matter, insects, and wood to the stream, providing nutrients, food, and structure to stream ecosystems. All of these functions directly and indirectly affect salmon and other aquatic species.	Timber harvest has occurred widely across the basin, including riparian areas, over the past 150 years, although only limited removal of trees is allowed within riparian forests in present day. Land conversion and vegetation removal has occurred within the riparian corridors of rivers across the basin for agriculture, residential, road systems, and urban areas. Streambank protection practices have been widely used to protect private property and infrastructure and have reduced riparian areas. The growth and spread of invasive plant species such as Japanese knotweed and reed canary grass has affected the growth and survival of native vegetation within the riparian corridor and can choke seasonal or small channels within the corridor.	Promote mature riparian forests by expanding widths where possible or by use of active management practices (e.g., thinning, planting). Manage Japanese knotweed and reed canary grass. Manage beaver populations to limit their adverse effects on riparian corridors while in the process of being restored to more natural conditions.	**Protect riparian lands:** Increase protection of riparian lands through regulations, incentives (e.g., conservation easements), land purchases, and education and outreach programs. **Restore riparian forest:** Restore riparian forest characteristics using passive or active management methods. Activities listed for protection of riparian lands also apply here. **Beaver management:** Develop and implement as warranted beaver management measures. Beaver activity is consistent with achieving floodplain, channel, and habitat characteristics, though private property protection and riparian protection (during re-establishment phase) may warrant active management of beaver. **Invasive Species Management:** Inventory and identify management measures for invasive plant species such as knotweed and reed canary grass.

ISSUES OF CONCERN	RELEVANCE TO INDICATOR SPECIES	CAUSES	SOLUTIONS	STRATEGIES/ACTIONS
ECOSYSTEM COMPONENT: WATER QUALITY				
Degraded water quality (temperature, oxygen, pollutants): Runoff developed lands can be sources of different types of pollutants, including fine sediment and various types of chemicals and heavy metals. Runoff from highways and major roads are particular sources of metals. Loss of forested riparian zones also cause elevated stream temperatures and sometimes reductions in dissolved oxygen, both of which reduce water quality. Low flows and lack of connectivity with floodplains can also increase water temperatures and subsequently reduce dissolved oxygen (Beechie et al. 2012).	Elevated stream temperatures can negatively affect native fish and amphibian population performance by limiting growth, prompting redistribution in search of cool water refuges, or in severe cases, causing direct mortality. Low dissolved oxygen levels in late summer and early fall when flows are at seasonal lows can adversely affect population performance by limiting growth or causing direct mortality. Increased sedimentation reduces habitat quality and can cause increased mortality or stress in certain life stages. Small amounts of chemical pollutants can adversely affect the physiology or behavior of both juvenile and adult salmon, leading to stress, mortality, reduced homing to spawning areas, or reproductive success.	Removal of forest cover affects the microclimate of stream systems and can elevate water temperatures. Loss of riparian trees along streams can directly lead to elevated water temperatures from solar radiation. Increased water temperatures, combined with low flows and high levels of organic material, can result in diminished dissolved oxygen levels. This condition can be particularly severe in off-channel habitats and wetlands and when flows are extremely low. Runoff from roads, highways, and parking lots is a source of metal and petroleum pollutants. Runoff from residential and agricultural areas is a source of nutrients, herbicides, and pesticides.	Continue to improve forest management plans to promote more diverse stand age across the landscape. Evaluate pre-filled sediment wedges to locally reduce water temperatures. Restore forested riparian corridors. Improve stormwater treatment measures. Improve education of the public on sources of pollutants and how to minimize these sources. Improve conservation and retention in fertilizer applications.	**Protect riparian lands:** Increase protection of riparian lands through regulations, incentives (e.g., conservation easements), land purchases, and education and outreach programs. **Restore riparian forest:** Restore riparian forest characteristics using passive or active management methods. Activities listed for protection of riparian lands also apply here. **Stormwater management:** Update and enforce storm runoff management on agricultural, residential, commercial, or urbanized lands, including all transportation corridors that produce pollutants, promoting greater increases in stormwater infiltration using various methods and greater capacity for stormwater detention or retention.