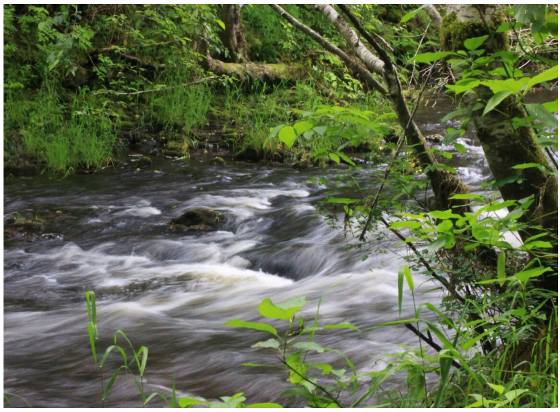
Chehalis Basin Strategy

Aquatic and Terrestrial Mitigation Opportunities Assessment



Prepared by Kleinschmidt Associates for the
Chehalis River Basin Flood Control Zone District

July 2020

ACKNOWLEDGEMENTS

This report was prepared by Kleinschmidt Associates for the Chehalis River Basin Flood Control Zone District, Chehalis, WA. Kleinschmidt acknowledges the significant contributions from a variety of key authors in the preparation of this report. These authors include:

Shane Cherry and Jennifer Norman, HydroGeoLogic, Inc.

Kim Gould and Patrick Hendrix, Stillwater Sciences

Vince Sortman, Biohabitats, Inc.

David Gorman, Ecological Engineering, LLC

PREFACE

The Chehalis River Basin Flood Control Zone District proposes to construct and operate a flood damage reduction facility and to enhance an existing levee structure on the Chehalis River. Federal and state environmental review of the proposed actions will identify potential construction and operational impacts. This Aquatic and Terrestrial Mitigation Opportunities Assessment Report (Report) fulfills a form of due diligence before the project advances to environmental permitting. The purpose of this assessment is to make an early determination on mitigation feasibility by assessing whether sufficient opportunity exists to provide mitigation for anticipated project impacts at a reasonable cost. The assessment provided in the report demonstrates that sufficient opportunity, in terms of multiple locations and different types of mitigation actions presently exists to provide mitigation for anticipated project impacts to aquatic and terrestrial resources. It also provides an initial estimate of the cost of such mitigation using conceptual mitigation designs.

This report is not a mitigation proposal or a conceptual mitigation plan. The information in this report could be used to inform the future development of a formal mitigation proposal during the environmental permitting process.

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ACRONYMS AND ABBREVIATIONS

ASRP	Aquatic Species Restoration Plan
BMP	best management practice
CFCZD	Chehalis River Basin Flood Control Zone District
Chehalis Tribe	Confederated Tribes of the Chehalis Reservation
CWA	Clean Water Act
Corps	U.S. Army Corps of Engineers
DEIS	Draft Environmental Impact Statement
DNR	Washington State Department of Natural Resources
Ecology	Washington State Department of Ecology
EDT	Ecosystem Diagnosis and Treatment model
ESA	Endangered Species Act
FRE	Flood Reduction - Expandable
FPDSI	Fish Passage and Diversion Screening Inventory
GSU	Geospatial Unit
HPA	Hydraulic Project Approval
NOAA Fisheries	National Oceanic and Atmospheric Administration Fisheries
OHWM	ordinary high water mark
QIN	Quinault Indian Nation
RCW	Revised Code of Washington
RM	river mile
SEPA	Washington State Environmental Policy Act
SF	south fork
USFWS	U.S. Fish and Wildlife Service
WDFW	Washington State Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

EXECUTIVE SUMMARY

This Aquatic and Terrestrial Mitigation Opportunities Assessment Report (Report) identifies opportunities to develop mitigation for impacts to aquatic and terrestrial habitats that may result from the Chehalis River Basin Flood Damage Reduction Project proposed by the Chehalis River Basin Flood Control Zone District (CFCZD). The CFCZD engaged the Kleinschmidt team to identify and evaluate mitigation opportunities and assess the types, locations, and quantities of mitigation likely to be required. The mitigation assessment does not constitute a mitigation proposal, but it lays the groundwork for future mitigation plan development that would be performed in coordination with regulatory agencies, tribes, and other stakeholders during a future phase of environmental permitting.

> ### Key Questions
>
> • What are the types, locations, and quantities of mitigation likely to be required to address project impacts to aquatic and terrestrial species and habitats?
>
> • Are there sufficient mitigation opportunities available to address the anticipated mitigation requirements?
>
> • What is the approximate cost for aquatic and terrestrial habitat mitigation?

The Report serves multiple purposes by addressing the following key questions:

- What are the types, locations, and quantities of mitigation likely to be required to address project impacts to aquatic and terrestrial species and habitats?
- Are there sufficient mitigation opportunities available to address the anticipated mitigation requirements?
- What is the approximate cost for aquatic and terrestrial habitat mitigation?

The approach developed to address these questions began with an assessment of project impacts to aquatic and terrestrial species and habitats. The resulting impact summary informed the preliminary assessment of mitigation requirements including an overview of applicable regulations and an estimate of required mitigation types, quantities, and locations. Mitigation needs were used to develop criteria to identify and evaluate mitigation opportunities within the upper Chehalis Basin. This process resulted in an initial pool of approximately 350 candidate mitigation opportunities. From this pool, five mitigation opportunity sites were selected to develop as example mitigation design concepts to illustrate a reach-scale approach to aquatic mitigation that could integrate multiple habitat restoration and enhancement techniques. The example mitigation design concepts were used to develop unit costs for a range of mitigation action types. Those unit costs were applied to the estimated mitigation requirements to generate a preliminary cost estimate for aquatic and terrestrial habitat mitigation.

Project Impact Summary

The Kleinschmidt team developed an estimate of project impacts to serve as a basis for estimating the types, amounts, and locations of mitigation potentially needed to address anticipated project impacts to aquatic and terrestrial habitat. At the present phase of environmental review, the preliminary summary of project impacts described in the SEPA DEIS (Ecology 2020) provided a basis for estimating potential mitigation needs. The impacts portrayed in the SEPA DEIS are described by Ecology as conservative to account for uncertainty inherent to the early planning phase of environmental review and were not subjected to avoidance and minimization measures. Avoidance and minimization of project impacts are required regulatory process steps that would occur as part of any future mitigation planning during project permitting and design refinement. Impact avoidance and minimization has the potential to substantially reduce project impacts and the mitigation required to address them. The Kleinschmidt team developed the mitigation opportunities assessment with the understanding that the resulting mitigation needs would be a conservative high-end estimate of potential mitigation requirements and may be further reduced after avoidance and minimization measures are applied. The estimated project impacts area associated with three project zones:

- Flood Retention Expandable (FRE) facility and Temporary Reservoir
- Downstream of the FRE to the South Fork Chehalis River Confluence (~20 miles)
- Airport Levee Improvements

The preliminary impacts associated with the FRE facility and temporary reservoir included:

- Removal of 90% of the trees within 600 acres of the temporary reservoir area
- Episodic temporary flooding of up to 847 acres (maximum extent of temporary reservoir area at full capacity)
- Water temperature increases of up to 9 degrees F (including the combination of project effects and effects of climate change) related primarily to loss of shade along the river and tributary streams
- Permanent loss of approximately 11 acres of wetlands and 333 acres of wetland buffers located within the 847-acre footprint of the temporary reservoir area
- Permanent elimination of 17 miles of stream channel and 441 acres of stream buffers
- Temporary fish passage interruption during FRE facility construction
- Permanent elimination of 0.3 acres of the Chehalis River channel at the FRE site
- Habitat degradation within approximately 6 miles of the mainstem Chehalis River channel and 11 miles of tributary stream channel within the footprint of the temporary reservoir area

The preliminary estimated aquatic habitat impacts to the 20-mile segment of the main stem Chehalis River extending from the FRE structure site downstream to the South Fork Chehalis River confluence included:

- Water temperature increases of up to 5.4 degrees F (including the combination of project effects and effects of climate change) related primarily to loss of shade along the river and tributary streams within the footprint of the temporary reservoir area;
- Episodic increases in turbidity when water is released from the temporary reservoir after storm events: an unspecified amount of sediment deposited within the temporary reservoir area would be remobilized and flushed downstream after the water level recedes; and
- Changes in the movement of sediment, large wood, and water resulting in unquantified effects on fish habitat.

Impact quantities are preliminary and subject to critical review and revision during ongoing state and federal environmental review and future environmental permitting.

Mitigation Requirements

Mitigation requirements were summarized by characterizing the types, quantities, and locations of mitigation needed to address unavoidable impacts to aquatic and terrestrial species and their habitats. Project impacts directly determine each of these aspects of mitigation. The assessment was informed by state and federal guidance pertaining to aquatic and terrestrial species and their habitats and by consideration of the jurisdictions of federal, state, and local regulatory agencies and tribes. The on-site mitigation area was defined as the FRE facility, the temporary reservoir, and the 20-mile segment of the main stem Chehalis River between the FRE facility and the S.F. Chehalis River confluence. The off-site mitigation area proposed by the Kleinschmidt team included the upper Chehalis Basin upstream of the Skookumchuck River confluence outside of the proposed on-site area.

Mitigation types and quantities were determined based on the types and quantities of project impacts. A key guiding principle for mitigation is to replace the ecological functions and values that would be lost as a result of habitat impacts. The Kleinschmidt team developed a preliminary assessment of the types, quantities, and locations of needed mitigation. The following list of mitigation components is a preliminary illustration of one way that project impacts could be mitigated. There are many combinations of mitigation actions that could be used to replace the ecological functions lost because of project impacts. The preliminary quantities listed below are based on an assessment of ecological functions provided by the habitats that would be impacted and best professional judgment to estimate the intensity of mitigation actions (quantity per mile) necessary to achieve ecological lift in the areas where mitigation could occur. This preliminary list of mitigation components is necessary to illustrate an approach to mitigation and form the basis for addressing the key questions of this analysis.

- Riparian reforestation along 6 miles of main channel and 11 miles of tributary channel (assumes 200 ft buffers on both sides of the channel that add up to 824 acres);
- Conservation of 824 acres including a mixture of uplands and wetlands (assumes that this would be satisfied by riparian reforestation of 824 acres);
- Conservation of 100 acres of forested upland adjacent to or near the temporary reservoir;

- Implementation of 34 cold water thermal refugia enhancements including 4 cold water retention structures (e.g. groundwater interception channels and alcoves) and 30 hyporheic enhancement structures;
- Enhancement of instream habitat in 17 miles of stream and river channel by placement of 50 wood loading structures with substrate enhancement (assume 3 structures per mile) including 30 instream wood and rock placement structures and 15 gravel retention jams;
- Implementation of 4 floodplain reconnection projects for a total of 2 miles of off-channel aquatic habitat and 100 acres of riparian buffer including a mixture of wetlands and uplands); and
- Replacement of 5 fish passage barrier culverts with fully fish-passable stream crossings.

Mitigation Opportunities

The Kleinschmidt team developed a preliminary list of candidate mitigation opportunities representing a range of mitigation action types to address unavoidable impacts to aquatic and terrestrial species and their habitats. The approach to identifying and qualifying candidate mitigation opportunities included four key elements:

- Define the geographic area in which mitigation could occur, including defining on-site and off-site areas.
- Designate and define a range of mitigation action types needed to address project impacts.
- Identify criteria for screening, prioritizing, and selecting candidate mitigation opportunities.
- Summarize the pool of candidate mitigation opportunities organized by mitigation action type and location.

The Kleinschmidt team proposed defining the geographic area in which mitigation could occur to include the upper Chehalis Basin upstream of the Skookumchuck River confluence. On-site and off-site mitigation areas were defined within the upper Chehalis Basin upstream of the Skookumchuck River confluence.

Nine mitigation action types were defined to categorize mitigation opportunities and simplify the process of organizing and quantifying mitigation opportunities. The nine mitigation action types included:

- **Riparian Buffer Expansion** – Establish forest vegetation along channel margins to provide shade and other riparian forest ecological functions.
- **Hyporheic Exchange Enhancements** –Instream and bank modifications to enhance the exchange between surface water and shallow groundwater to create or expand cool water pockets for summer thermal refugia. Several types are proposed based on different landforms.

- **Cold Water Retention Structures** –Features including floodplain channels, backwater alcoves, and channel margin pockets positioned to intercept colder groundwater or hyporheic flow and maintain a cool water pocket to provide thermal refugia.
- **Instream Modifications** – Construction of habitat features within the perennial wetted channel for several purposes such as habitat complexity, creation of cold-water refuge pockets, and spawning gravel retention.
- **Off-channel Modifications** – Off-channel habitat enhancements including side channel and floodplain actions to reconnect, enhance, and expand off-channel habitat.
- **Gravel Retention Jams** – Larger instream structures composed of large wood pieces and rock located and designed to provide hydraulic roughness and promote accumulation and retention of salmonid spawning gravels.
- **Fish Passage** – Fish passage improvements including removal of small dams and replacing fish passage barrier culverts with passable stream crossings.
- **Wetland Enhancement** – Enhancement, restoration, or expansion of wetlands to benefit wildlife species.
- **Upland Forest Conservation** – Conservation and enhancement of specific habitats matching the requirements of focal wildlife species.

The Kleinschmidt team developed a set of criteria used to identify and screen candidate mitigation sites as a desktop exercise that relied on previous site characterization data, previous analysis of geomorphology, LiDAR, and aerial and satellite imagery. The desktop exercise yielded an initial pool of 355 candidate mitigation sites representing opportunities for each of the nine mitigation action types defined for this exercise. The Kleinschmidt team estimated the quantity of mitigation opportunity available for each mitigation action type and determined that the opportunities exceeded estimated potential mitigation needs. The pool of candidate mitigation opportunities was developed to deliberately exceed potential mitigation needs to account for the fact that many candidate opportunities may be screened out during future mitigation plan development due to multiple factors including ability to secure property for mitigation sites by purchase or easement.

Conceptual Design Examples

The Kleinschmidt team prepared five distinct "conceptual design groups" and cost estimates as examples to illustrate an integrated reach-scale approach to combining multiple mitigation techniques to produce high-value properly functioning ecological communities. Each conceptual design group applies multiple conceptual designs to demonstrate how integrating multiple action types can be used at a reach scale to optimize ecological benefits and achieve cost efficiencies. A separate narrative was prepared for each of the five conceptual design group examples. Each narrative is companion to the graphical presentation of the designs and the cost estimates associated with the designs. Planning-level cost estimates were prepared to include design, permitting, land acquisition, construction, construction oversight, and contingency. **Appendix A** contains the conceptual design drawings for the five example conceptual design groups along with supporting unit cost estimating tables. The cost estimates were used to develop unit costs for individual mitigation action types, and those in turn were used to build a preliminary cost estimate for anticipated potential aquatic and terrestrial habitat mitigation needs.

Preliminary Mitigation Cost Estimate

The Kleinschmidt team developed a preliminary planning level cost estimate for potential aquatic and terrestrial habitat mitigation needs. The cost estimate was developed by applying the unit costs developed from the conceptual design examples to the estimated mitigation needs summarized in **Section 3**. The preliminary cost estimate developed by the Kleinschmidt team resulted in an approximate planning-level cost of $86 million for aquatic and terrestrial habitat mitigation. That cost estimate is a conservatively high estimate based on preliminary information and the impact quantities presented in the SEPA DEIS. There are substantial opportunities to reduce project impacts by applying avoidance and minimization during future permitting and design refinement phases. The Kleinschmidt team assumed that avoidance and minimization could reduce project impacts and their associated mitigation requirements by as much as 50 percent. Actual impact reduction will have to be clearly documented during project permitting and concurrently integrated into a future formal mitigation proposal. For planning purposes, the Kleinschmidt team recommends considering the range of $43 to $86 million as a preliminary characterization of potential mitigation costs to address impacts to aquatic and terrestrial species and their habitats.

Conclusions

This Report is focused on addressing three key questions. Each of those questions is discussed below:

Key Question #1: What are the types, locations, and quantities of mitigation likely to be required to address project impacts to aquatic and terrestrial species and habitats?

The Kleinschmidt team based the assessment of mitigation needs on the project impacts presented in the SEPA DEIS (Ecology 2020). Based on the nature of the project impacts, the Kleinschmidt team defined nine mitigation action types that could collectively replace ecological functions lost or impaired by the project impacts. On-site and off-site mitigation areas were delineated, and the area in which mitigation could occur was defined to include the upper Chehalis Basin upstream of the Skookumchuck River confluence. Mitigation quantities were estimated for each impact type based on simple measurements (e.g. impacted stream length, acreage of impacted upland) considering the nature of each kind of impact. The Kleinschmidt team's preliminary assessment of mitigation needs is detailed in **Section 3.3** and summarized in **Table 1**.

Key Question #2: Are there sufficient mitigation opportunities available to address the anticipated mitigation requirements?

Comparison of the estimated needs to the available opportunities demonstrated there are sufficient mitigation opportunities to address the anticipated unavoidable project impacts to aquatic and terrestrial species and their habitats. The Kleinschmidt team identified over 350 possible candidate mitigation sites within the upper Chehalis Basin as described in **Section 4**. Those mitigation opportunities were converted to estimated quantities of each mitigation action type potentially available in each sub-watershed within the designated mitigation area shown on **Figure 3.** Mitigation opportunities were organized by mitigation action type and sub-basin and summarized in **Table 3**. Overall mitigation opportunity exceeded the anticipated need for each of the nine mitigation action types. No formal outreach to property owners by the Kleinschmidt team occurred as part of this preliminary assessment of mitigation opportunities. Actual availability will depend on future coordination and negotiation with property owners. Similarly, any future mitigation proposal will be developed in close consultation and coordination with regulatory agencies, tribes, and stakeholders, and specific mitigation sites and actions will be subject to the review and approval of regulatory agencies in consultation with tribes.

Key Question #3: What is the approximate cost for aquatic and terrestrial habitat mitigation?

The preliminary cost estimate developed by the Kleinschmidt team resulted in an approximate planning-level cost of $86 million for aquatic and terrestrial habitat mitigation. That cost estimate is a conservatively high estimate based on preliminary information available through the ongoing state and federal environmental review process. There are substantial opportunities to reduce project impacts by applying avoidance and minimization during future permitting and design refinement phases. The Kleinschmidt team assumed that avoidance and minimization could reduce project impacts and their associated mitigation requirements by as much as 50 percent. Actual impact reduction will have to be clearly documented during project permitting and concurrently integrated into a future formal mitigation proposal. For planning purposes, the Kleinschmidt team recommends considering the range of $43 to $86 million as a preliminary characterization of potential mitigation costs to address impacts to aquatic and terrestrial species and their habitats.

1 INTRODUCTION

1.1 Introduction

This Aquatic and Terrestrial Mitigation Opportunities Assessment Report (Report) identifies opportunities to develop mitigation for impacts to aquatic and terrestrial habitats that may result from the flood hazard reduction project proposed by the Chehalis River Basin Flood Control Zone District (CFCZD). The proposed flood hazard reduction project includes the Flood Reduction – Expandable (FRE) facility option and levee improvements near the Chehalis Airport. The proposed FRE facility location is in the upper Chehalis Basin near the city of Pe Ell, Washington, and the proposed levees would be located near the Chehalis Airport between the cities of Centralia and Chehalis, Washington. The CFCZD engaged the Kleinschmidt team to identify and evaluate mitigation opportunities and assess the types, locations, and quantities of mitigation likely to be required. The mitigation assessment does not constitute a mitigation proposal, but it lays the groundwork for future mitigation plan development that would be performed in coordination with regulatory agencies, tribes, and other stakeholders during a future phase of environmental permitting.

The Report addresses the following key questions:

- What are the types, locations, and quantities of mitigation likely to be required to address project impacts to aquatic and terrestrial species and habitats?
- Are there sufficient mitigation opportunities available to address the anticipated mitigation requirements?
- What is the approximate cost for aquatic and terrestrial habitat mitigation?

1.2 Purpose and Scope

This Report provides a form of due diligence before the project advances to the next phase of environmental review. The SEPA DEIS characterized anticipated unavoidable project impacts to aquatic and terrestrial habitats without developing a specific assessment of mitigation needs. The primary purpose of this Report is to make an early determination on whether sufficient opportunity exists to provide mitigation for anticipated project impacts and develop a preliminary estimate of what that mitigation would cost.

This mitigation opportunities assessment will be used to support and inform permit applications for local permits (e.g. shorelines, critical areas, land use), U.S. Clean Water Act Sections 401 and 404, Endangered Species Act (ESA) Section 7 consultation, Hydraulic Project Approval, and other related permits.

Although the project will have unavoidable impacts to wetlands, wetland mitigation is not included in the scope of this document and will be developed separately.

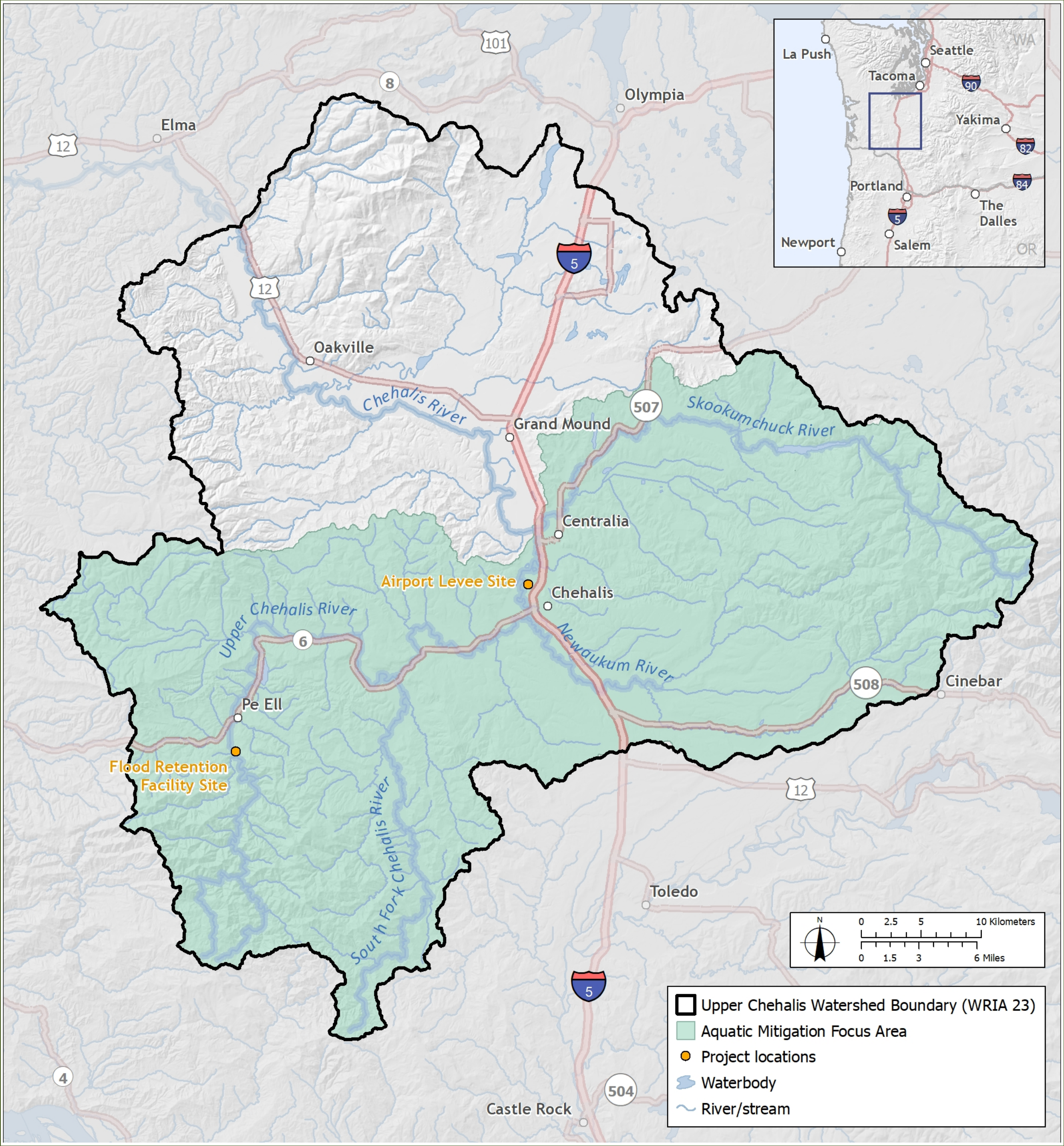
1.3 Background

The CFCZD proposes a new flood hazard reduction project including construction of a new flood retention facility in the upper Chehalis Basin near the city of Pe Ell, Washington. Project elements include levee improvements near the Chehalis Airport, and the FRE facility with a temporary reservoir designed to fill episodically to mitigate flooding during peak flow events (HDR 2017; HDR 2018; CFCZD 2019). The SEPA DEIS published in February 2020 described the proposed project and presented a preliminary assessment of project effects on aquatic and terrestrial species and habitats (Ecology 2020). The Report relied on the DEIS and its appendices as the primary source for the description of the project, characterization of the affected environment, and description of anticipated project impacts. **Figure 1** shows the study area located within the upper Chehalis Basin. The study area was defined to include a reasonable geographic range for mitigation opportunities based on common practice for locating mitigation in accordance with published regulatory guidance (WDFW and Ecology 2000).

1.4 Approach

The mitigation opportunities assessment began with an assessment of project impacts to aquatic and terrestrial species and habitats. A preliminary analysis of project impacts was presented in the Washington State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (DEIS) published by Washington Department of Ecology (Ecology) in February 2020 (Ecology 2020). The resulting impact summary informed the preliminary assessment of mitigation requirements including an overview of applicable regulations and an estimate of required mitigation types, quantities, and locations. Mitigation needs were used to develop criteria to identify and evaluate mitigation opportunities within the upper Chehalis Basin. This process resulted in an initial pool of mitigation opportunities. Five mitigation opportunities were selected to develop example mitigation design concepts to illustrate a reach-scale approach to aquatic mitigation that would integrate multiple habitat restoration and enhancement techniques. The example mitigation design concepts were used to develop unit costs for a range of mitigation action types. Those unit costs were applied to the estimated mitigation requirements to generate a preliminary cost estimate for aquatic and terrestrial habitat mitigation.

Figure 1
Study Area



2 PROJECT IMPACT SUMMARY

2.1 Project Description

The proposed project includes a new flood retention facility and temporary reservoir near the town of Pe Ell, Washington, and levee improvements around the Chehalis Airport in Chehalis, Washington. The proposed project is intended to reduce flood damage in the Chehalis River Basin. The project will not protect communities from all flooding, nor is it designed to stop regular annual flooding from the Chehalis River. **Figure 2** shows the locations of the following major project components:

- FRE flood retention facility
- Temporary reservoir
- Fish passage facilities at the flood retention facility
- Construction using a temporary river bypass tunnel
- Airport levee improvements

The temporary reservoir near Pe Ell that would temporarily store floodwater during major floods and then slowly release retained floodwater when it is safe to do so and over a period of time. Most of the time, the Chehalis River would flow through the structure's low-level outlet works at its normal rate of flow and volume—and allow fish to pass both upstream and downstream. Fish passage at the facility during construction and during post-construction operation is discussed in detail in Section 2.3.3 of the SEPA DEIS (Ecology 2020).

The fish passage facilities at the flood retention facility will allow fish to pass both upstream and downstream during construction using a river bypass tunnel. During normal flows, low-level outlets would remain open to facilitate passage during normal conditions and smaller floods. During major floods, a fish collection and transport system would be implemented to temporarily transport and release migrating fish (trap and haul) when the structure's outlets are closed.

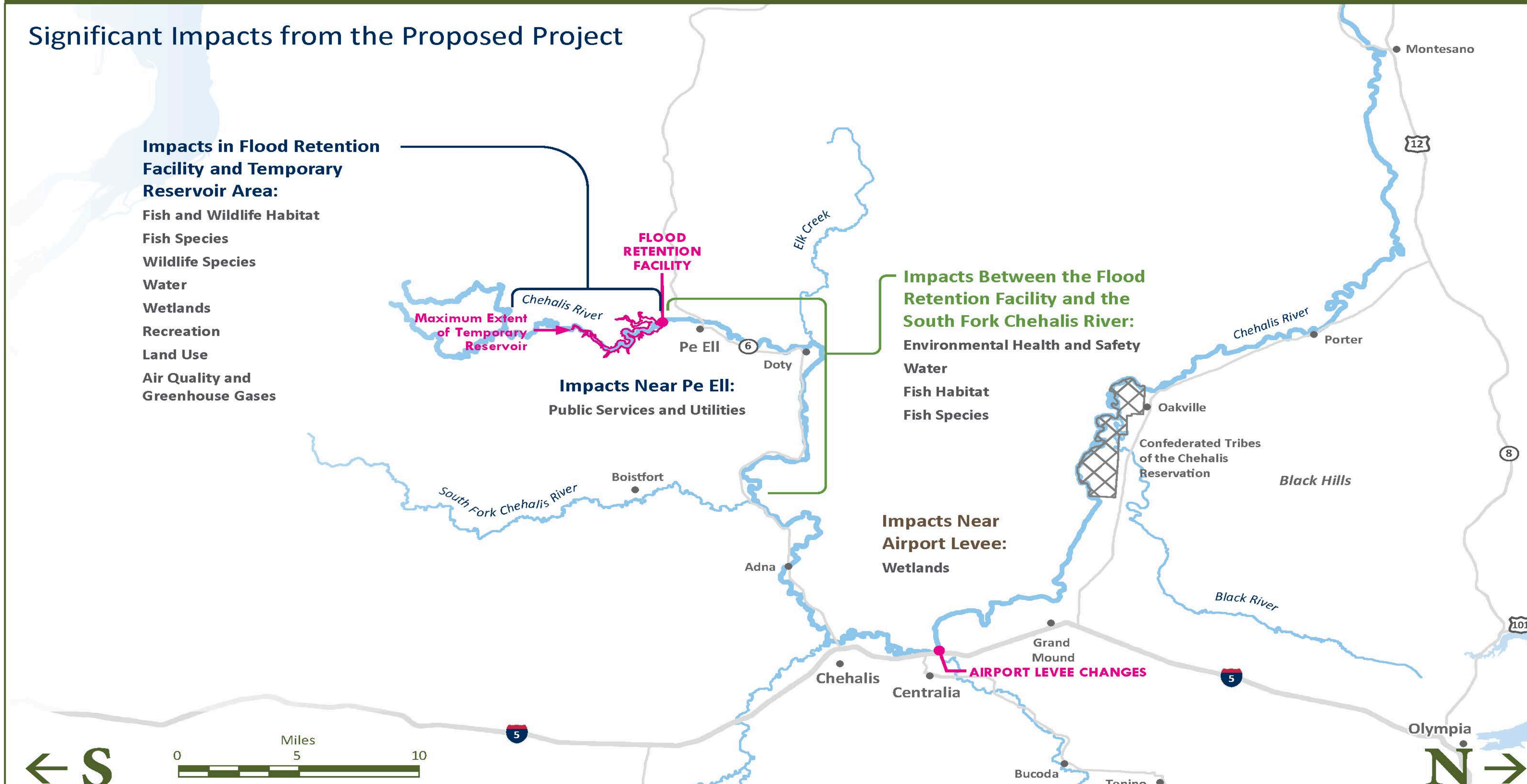
The airport levee improvements are designed to protect the Chehalis-Centralia Airport, local businesses, and area transportation from damage from a 100-year flood. In addition to raising the existing levee around the Chehalis-Centralia Airport, 1,700 feet of Airport Road would be raised to meet the airport levee height along the southern extent of the airport.

2.2 Summary of DEIS Estimates of Impacts

The quantities and types of impacted habitats are the fundamental drivers for the quantities and types of mitigation that will be required. Mitigation quantities are further affected by their location with respect to the impacts as well as whether the mitigation directly replaces the ecological value and functions of the impacted habitats.

Figure 2
Project Elements

Excerpt from Exhibit S-5
Significant Impacts from the Proposed Project



After the SEPA DEIS was published in February 2020, the Kleinschmidt team described and estimated impact quantities in the Critical Mitigation Parameters technical memorandum (Kleinschmidt 2020). The SEPA DEIS (Exhibit S-5) described project impacts related to each project element and organized by zones within the project area. The zones are identified on **Figure 2** and include:

- FRE Structure Site and Temporary Reservoir
- Downstream of the FRE to the South Fork Chehalis River Confluence (~20 miles)
- Airport Levee Improvements

An abbreviated overview of DEIS estimates of project impacts is provided below. Impact quantities published in the February 2020 SEPA DEIS were preliminary and are subject to review and revision. They are reported here for information only and are not endorsed by the Kleinschmidt team or the CFCZD. Actual mitigation needs will be determined during the permitting process in coordination with regulatory agencies based on mitigation sequencing, design and operational refinements to the proposed project, and any new relevant analysis of the affected environment.

2.2.1 DEIS Estimates of Impacts at the FRE Site and Temporary Reservoir

The DEIS identified the following potential aquatic and terrestrial habitat impacts at the FRE structure site and upstream of the FRE within the temporary reservoir area:

- Removal of 90% of the trees within 600 acres of the temporary reservoir area;
- Episodic temporary flooding of up to 847 acres (maximum extent of temporary reservoir area at full capacity);
- Water temperature increases of up to 9 degrees F in the river and stream channels flowing through the footprint of the temporary reservoir. The model-predicted temperature increase would result from the combination of the effects of climate change and project impacts related primarily to loss of shade along the river and tributary streams;
- Permanent loss of approximately 11 acres of wetlands and 333 acres of wetland buffers located within the 847-acre footprint of the temporary reservoir area;
- Permanent elimination of 17 miles of stream channel and 441 acres of stream buffers. ("Permanent elimination" entails habitat degradation and loss of ecological function within approximately 6 miles of the mainstem Chehalis River channel and 11 miles of tributary stream channel within the footprint of the temporary reservoir area.);
- Temporary fish passage interruption during FRE facility construction;
- Permanent elimination of 0.3 acres of the Chehalis River channel at the FRE site; and
- Habitat degradation within approximately 6 miles of the mainstem Chehalis River channel and 11 miles of tributary stream channel within the footprint of the temporary reservoir area.

The DEIS described potential impacts associated with construction activities from the FRE and temporary reservoir and future operation that could include dewatering and increased turbidity, inundation or siltation of redds with increased embryo mortality, adult migration delays during periods of FRE facility operation, and fill of riparian habitat. Episodic temporary flooding effects of FRE operation would affect the Chehalis River and the lower reaches of several creeks, including Big, Browns, Crim, Hull, Lester, and Roger creeks. Key aquatic species present in these reaches include spring Chinook salmon (*Oncorhynchus tshawytscha*), fall Chinook salmon, coho salmon (*O. kisutch*), and winter steelhead (*O. mykiss*). Combined, these species have adults migrating or holding year-round, juvenile rearing and outmigration year-round, and spawning occurring 9 months of the year in the vicinity of the proposed project. Much of the area of the temporary reservoir is currently forested riparian area. Periodic inundation during flood events would affect the plant communities, with the most intense effects occurring at lower elevations. The higher elevation portions of the FRE inundation zone would experience diminishing magnitude, intensity, and frequency of disturbance due to lower frequency, duration, and depth of inundation. Long-term terrestrial habitat impacts may include effects on habitats for three amphibians of concern, several waterfowl and bird species covered under the Migratory Bird Treaty Act, and elk (*Cervus elaphus*) which are also a Washington priority (PHS) species.

2.2.2 DEIS Estimates of Impacts to Chehalis River Downstream of the FRE to the SF Chehalis River Confluence

The DEIS identified the following aquatic habitat impacts extending from the FRE structure site approximately 20 miles downstream to the South Fork Chehalis River confluence:

- Water temperature increases of up to 5.4 degrees F (including conflated project effects and effects of climate change) related primarily to loss of shade along the river and tributary streams within the footprint of the temporary reservoir area.
- Episodic increases in turbidity when water is released from the temporary reservoir after storm events. An unspecified amount of sediment deposited within the temporary reservoir area would be remobilized and flushed downstream after the water level recedes.
- Changes in the movement of sediment, large wood, and water resulting in unquantified effects on fish habitat.

Long-term aquatic impacts are likely to include changes to hydrology, sediment transport, instream wood recruitment and transport, hydraulics, and geomorphology. These changes will likely include a combination of both positive benefits and negative impacts. Such effects to aquatic habitats are challenging to quantify and determine appropriate mitigation quantities. Aquatic impacts may include increased stream temperature leading to increased mortality, increased predation, stream substrate changes from changes in sediment input, changes to channel morphology, and reduced access to floodplain and side channel habitats. Previous studies characterized hydrology, hydraulics, and geomorphology in the project area for both existing and proposed conditions (Watershed GeoDynamics and Anchor QEA 2017; WSE 2019a; WSE 2019b). The DEIS described the approximate area of these aquatic impacts as the Chehalis River channel extending approximately 20 miles downstream of the FRE site to the confluence of the South Fork Chehalis River. The intensity of those effects would diminish with distance downstream.

Long-term impacts must be considered in the context of long-term geomorphic and hydrologic trends not related to the proposed project. Long-term trends in geomorphology, sediment dynamics, and basin hydrology have been characterized in previous studies (Watershed GeoDynamics and Anchor QEA 2017; Mauger et al. 2016; Anchor QEA 2019). Understanding the landscape context is a key part of such an evaluation. Land use in the Chehalis Basin is primarily forestland (87%), with most forested properties in private ownership. In the lower basin, 7% of the land base is in agriculture, with a heavy emphasis on commercial dairy and livestock, and crop farming. Conventional timber and agricultural practices have had an impact on the health of the Chehalis basin, contributing to increased sedimentation and warmer water temperatures.

2.2.3 DEIS Estimates of Impacts Associated with Airport Levee Improvements

The DEIS identified the following impacts associated with the airport levee improvements:

- Elimination of 7 acres of wetlands
- Elimination of 44 acres of wetland buffers

For the proposed airport levee improvements, the DEIS focused on effects on wetlands and did not call out significant effects on aquatic habitats or species resulting from the proposed levee improvements.

2.2.4 Limitations Regarding Preliminary Impact Characterization

The mitigation options presented in this assessment are preliminary and are intended to be refined in consultation with project sponsors, stakeholders and regulatory agency staff. The description of project impacts and approach to mitigation is intended to be consistent with key DEIS findings to the extent possible with the information provided in the DEIS. There are limitations related to aspects of how the DEIS portrays project impacts and mitigation. The DEIS portrayed many of the aquatic and terrestrial habitat impacts in broad qualitative terms making it difficult or nearly impossible to reasonably estimate quantities for separable impact types without additional detail.

Further, the DEIS did not provide parameters for estimating mitigation quantities. Impact quantities and descriptions published in the DEIS were summarized in this technical memorandum for information and planning purposes. Impacts reported in the SEPA DEIS are based on conservative, worst-case assumptions applied to account for uncertainty that is typical at this early stage of project design and environmental review. Impact quantities published in the SEPA DEIS are preliminary and subject to critical review and revision. They are reported here for information only and are not endorsed by the Kleinschmidt team or the Chehalis River Basin Flood Control Zone District.

3 MITIGATION REQUIREMENTS

This Section identifies and describes regulatory jurisdiction over mitigation and presents the framework used by the Kleinschmidt team to develop a preliminary assessment of likely mitigation requirements. The results of the assessment are presented in **Section 3.3** as a description and supporting table showing the approximate types, quantities, and locations of mitigation.

3.1 Regulatory Jurisdiction

Impacts to aquatic and terrestrial habitats are regulated by multiple local, state, and federal agencies with overlapping jurisdiction regarding permitting and mitigation requirements. The following summary identifies agencies and entities that have jurisdiction over mitigation for impacts to aquatic and terrestrial species and their habitats.

U.S. Army Corps of Engineers (Corps): The Corps has jurisdiction over work in Waters of the United States through Clean Water Act (CWA) Section 404. Within the upper Chehalis Basin, Waters of the United States would include the Chehalis River, its tributaries, and associated wetlands. The Corps has authority to require mitigation for unavoidable impacts, including ecological impacts, to Waters of the United States. Corps jurisdiction under CWA Section 404 is triggered by construction of the proposed FRE facility within Waters of the United States.

NOAA Fisheries and USFWS: Under Endangered Species Act (ESA) Section 7, the Corps must consult with NOAA Fisheries and USFWS as part of the CWA Section 404 permitting process to evaluate the potential project effects on federally listed threatened and endangered species. The applicant completes a Biological Assessment (BA), and NOAA Fisheries and USFWS prepare a Biological Opinion (BO) that results in nondiscretionary conditions applied to construction and operation of the project. While NOAA Fisheries and USFWS do not have the authority to directly require mitigation, the ESA consultation considers mitigation as part of the project action, and the mitigation can affect the outcome of the consultation's conclusions regarding the project's potential to jeopardize the continued existence of species or adversely modify critical habitat. NOAA Fisheries and USFWS jurisdiction is triggered by the need for a CWA Section 404 permit and the ESA Section 7 consultation requirement.

Native American Tribes: The U.S. Government recognizes tribal rights to fish and wildlife within each tribe's designated "Usual and Accustomed Areas" as established by treaties between the tribes and the U.S. Government. Two tribal entities are present and have rights within the Chehalis Basin: the Quinault Indian Nation (QIN), and the Confederated Tribes of the Chehalis Reservation (Chehalis Tribe). The Corps engages in a government-to-government consultation with tribes when those rights are potentially affected by a proposed project seeking a CWA Section 404 permit. The consultation typically includes a focused dialog on impacts to aquatic and terrestrial species and the mitigation associated with those impacts. The tribal consultation typically has a strong influence on the nature and extent of the mitigation requirements. In addition to involvement through the Corps permitting process, tribes are co-managers of fisheries with WDFW, and as such tribes are actively involved in the Hydraulic Project Approval (HPA) permitting process administered by WDFW. The Office of the Chehalis Basin (OCB) Board includes tribal representation. Tribal consultation is triggered by the need for a CWA Section 404 permit and the need for a HPA.

WDFW: Washington State Hydraulics Code grants authority to WDFW to issue HPA permits for projects that involve work in Waters of the State of Washington. WDFW has jurisdiction over in-water construction as well as project effects on aquatic and terrestrial species and their habitats. WDFW has the authority to apply conditions when granting an HPA permit including specifying mitigation requirements. Mitigation requirements specified by WDFW are typically developed in close coordination with tribes. WDFW jurisdiction is triggered by construction work within Waters of the State of Washington.

Ecology: Ecology administers CWA Section 401 Water Quality Certification permits in coordination with the Corps and linked to the CWA Section 404 permit as a concurrent requirement. Ecology also has jurisdiction over wetlands that extends beyond the limits of federal wetland jurisdiction. Ecology administers the SEPA process and oversees municipal land use jurisdiction under the State Shoreline Management Act and the Growth Management Act. Ecology jurisdiction is multi-faceted. Jurisdiction under CWA Section 401 is triggered by work within Waters of the State of Washington. Jurisdiction under SEPA is triggered by the scope and scale of the project and its potential to have significant environmental impacts.

Municipal Governments: Municipal governments have jurisdiction over land use, shoreline zones, and critical areas under the State Growth Management Act and the State Shoreline Management Act. Jurisdiction is triggered by land use application requirements and proposed work within shoreline management zones and growth management areas.

3.2 Framework for Determining Mitigation Requirements

The Kleinschmidt team used a framework to identify and evaluate mitigation needs and opportunities. That framework establishes the basis for the geographic focus areas where mitigation would occur, determination of on-site versus off-site mitigation areas, considerations regarding in-kind versus out-of-kind mitigation, the basis for establishing mitigation ratios, and a brief discussion on how ecological functions are used as a primary means of comparing impacts and mitigation. On-site mitigation is defined as mitigation located at or near the site of the project impacts. Off-site mitigation is defined as mitigation that occurs away from the site of the project impacts but typically within the same drainage basin.

Washington state has a well-established preference for on-site and in-kind mitigation for impacts to aquatic habitat. The basis for that preference includes the view that that replacing lost ecological functions near the site of an impact provides a higher level of confidence that impacted wildlife populations and ecological communities will directly benefit from the mitigation in a way that offsets the loss.

Uncertainty associated with temporal losses of ecological functions may be further mitigated by imposing higher mitigation ratios to increase the amount of mitigation relative to the impacts or by requiring monitoring and adaptive management that may result in additional future mitigation actions if deemed necessary.

The preference for on-site in-kind mitigation is not a hard and fast rule, and the joint mitigation guidance (WDFW and Ecology 2000) specifies the conditions under which off-site and/or out-of- kind mitigation would be superior to on-site mitigation. There are situations where opportunities to directly replace lost ecological functions do not exist at or near the site of impact. For these situations, mitigation regulations and guidance allow for mitigation proposals to consider the health of the larger watershed and allow for mitigation that is out-of-kind and/or off-site on a case-by-case basis. Out-of-kind and off-site mitigation may be technically justified in situations where the project sponsor demonstrates that the mitigation would be effective in benefiting the impacted species in the larger context of the watershed. There must be a meaningful and demonstrable ecological connection between the impacts and the proposed mitigation. One approach involves identifying limiting factors for priority species in the basin considering all life cycle stages and proposing mitigation that addresses those limiting factors at locations where those changes would provide superior benefits to the same species and populations.

There is precedent for off-site and out-of-kind mitigation being allowed in cases where the proposed mitigation provided habitat that addressed a demonstrated limiting factor for an endangered and/or threatened species, or a species of concern. Estuarine habitat restoration is a common off-site, out-of-kind mitigation where unavoidable project impacts occur in a watershed where diminished estuarine habitat has been proven to be a limiting factor for salmonid species in that Watershed Resource Inventory Area (WRIA).

Revised Code of Washington (RCW) 75.46 states that mitigation guidance published by the State will support alternative mitigation options that have a low risk to the environment, yet have a high net environmental, social, and economic benefit. The overarching goal is to develop and implement habitat projects that maximize environmental benefits from project mitigation.

Washington State mitigation policy guidance (WDFW and Ecology 2000) supports this degree of flexibility, and states:

"The 1996 State Legislature passed the Aquatic Resources Mitigation Act (RCW 90.74) which stipulates that it is the policy of the state to authorize innovative mitigation measures by requiring state regulatory agencies to consider mitigation proposals for infrastructure projects that are timed, designed, and located in a manner to provide equal or better biological functions and values compared to traditional on-site, in-kind mitigation proposals. For infrastructure projects, the agencies may not limit the scope of

options to be considered in a mitigation plan to traditional on-site, in-kind mitigation proposals. When making regulatory decisions, the agencies shall consider whether the mitigation plan provides equal or better functions and values, compared to the existing conditions, for the target resources or species identified in the mitigation plan and agreed to by the resource agencies. The factors the agencies must consider in making this decision are identified in the Hydraulic Code, the State Water Pollution Control Act, and the Aquatic Resources Mitigation Act. The mitigation policy guidance developed under the Salmon Recovery Act is required to be consistent with those criteria established under the Aquatic Resources Mitigation Act. The Departments of Ecology and Fish and Wildlife are not required to grant approval to a mitigation plan that the Departments find does not provide equal or better biological functions and values within the watershed or bay."

Related within the Chehalis Basin Long Term Strategy but separate from this Aquatic and Terrestrial Mitigation Opportunities Assessment, the Aquatic Species Restoration Plan (ASRP) will implement habitat restoration and enhancement projects throughout the Chehalis Basin. Aquatic mitigation within this assessment is separate from the ASRP, and the ecological benefits generated by the two parallel efforts of mitigation and ASRP will be additive. The Kleinschmidt team reviewed the ASRP and communicated with technical staff working on the ASRP to identify sub-basins within the upper Chehalis Basin where restoration efforts and mitigation efforts may geographically overlap. Mitigation opportunities identified by Kleinschmidt accounted for the extent of restoration work proposed by the ASRP at a sub-basin scale. This approach ensured that sufficient restoration opportunities exist in each sub-basin to support both ASRP and mitigation objectives, and mitigation would not interfere with ASRP implementation.

3.2.1 Considerations for On-site Mitigation

The first preference for mitigation will be for in-kind habitat replacement located on-site within the project zone as close to the site of impact as possible. Project impacts are expected to occur within a 27-mile long segment of the river corridor, which includes seven miles of the Chehalis River within the temporary reservoir and approximately 20 miles of the Chehalis River extending downstream from the proposed FRE to the confluence of the SF Chehalis River. Defining the on-site mitigation area to include this entire 27-mile river segment would afford some flexibility in finding on-site mitigation opportunities. Beyond replacing like functions at the site of impact, mitigation planning will consider basin scale analyses that have previously identified key priorities for each basin and subbasin (CBP 2004; CBP 2009; CBPHWG 2008; GHLE 2011; OCB 2019). On-site mitigation selection will consider the priority issues identified for the subbasin in which the unavoidable impact occurs.

3.2.2 Considerations for Off-site Mitigation

Off-site and out-of-kind mitigation will be considered secondary to on-site in-kind mitigation, and any justification for using off-site and out-of-kind mitigation will follow the criteria for such mitigation specified in published mitigation guidance (WDFW and Ecology 2000). Off-site out-of-kind mitigation will only be considered in clear cases of species betterment: cost savings will not be the basis for rejecting more expensive on-site opportunities that would be feasible, effective, and aligned with basin-wide priorities. The rationale for selecting off-site and/or out-of-kind mitigation will be ecologically based to address limiting factors in a way that will serve the same populations and ecological communities affected by the impacts, such as geographical displacement of an impacted species.

Spring Chinook provide an example of a population that may experience geographical displacement as a result of project impacts. The FRE is expected to impact spring Chinook spawning habitat primarily as a result of periodic inundation and related changes to riverbed substrate upstream of the FRE facility (McConnaha et al. 2017). With the project construction and change in stream geomorphology, there may not be enough suitable area within the on-site project zone where viable spawning habitat could be replaced. However, appropriate stream gradient and substrate conditions are available in other subbasins within the upper Chehalis Basin where spring Chinook spawning has been previously documented (Liedtke et al. 2016). Other locations that could support spring Chinook spawning habitat include Skookumchuck, Newaukum, and South Fork Chehalis Rivers. A sound technical case could be made to implement off-site mitigation in these subbasins by considering the potential benefits to the basin-wide population of spring Chinook.

3.2.3 Geographic Focus Areas for On-site and Off-site Mitigation

The overarching mitigation approach centers on replacing lost habitat functions with similar habitat functions as close to the impact sites as possible and aligned with ecological priorities for the basin. This section describes the rationale that guides the definition of target areas for implementing mitigation.

Understanding the project impacts is key to selecting the appropriate area within which mitigation can be effectively implemented to serve the same populations and ecological communities that are affected by the project impacts. The geographic focus area for mitigation site selection must consider the immediate project impact area and other nearby eco-regions that provide opportunities to replace like functions.

The DEIS identified the geographic range for aquatic mitigation options to include everything upstream of the Newaukum River confluence. The Kleinschmidt team agrees that mitigation should focus on this area but recommends expanding this area to include the Skookumchuck River basin and the Chehalis River upstream of the Skookumchuck River confluence. The justification for this proposed expansion includes three key reasons. First, the airport levee improvements are downstream of the Newaukum River confluence, and riverine mitigation at that site may be more effective in the context of floodplain reconnection. Second, if the amount of mitigation needed for impacts to spring Chinook spawning habitat exceeds available opportunities within the project area, additional spawning habitat for spring Chinook should prioritize areas that currently support or could support a strong population, which include the Newaukum River basin and the Skookumchuck River basin. Lastly, the ASRP has identified the Newaukum River basin as a high priority area, and ASRP restoration efforts might address most of the available aquatic restoration opportunity there. **Figure 3** shows the geographic focus area that portrays the extent of where on-site and off-site mitigation sites may be considered and provides a site count for the number of mitigation sites envisioned within a sub watershed area.

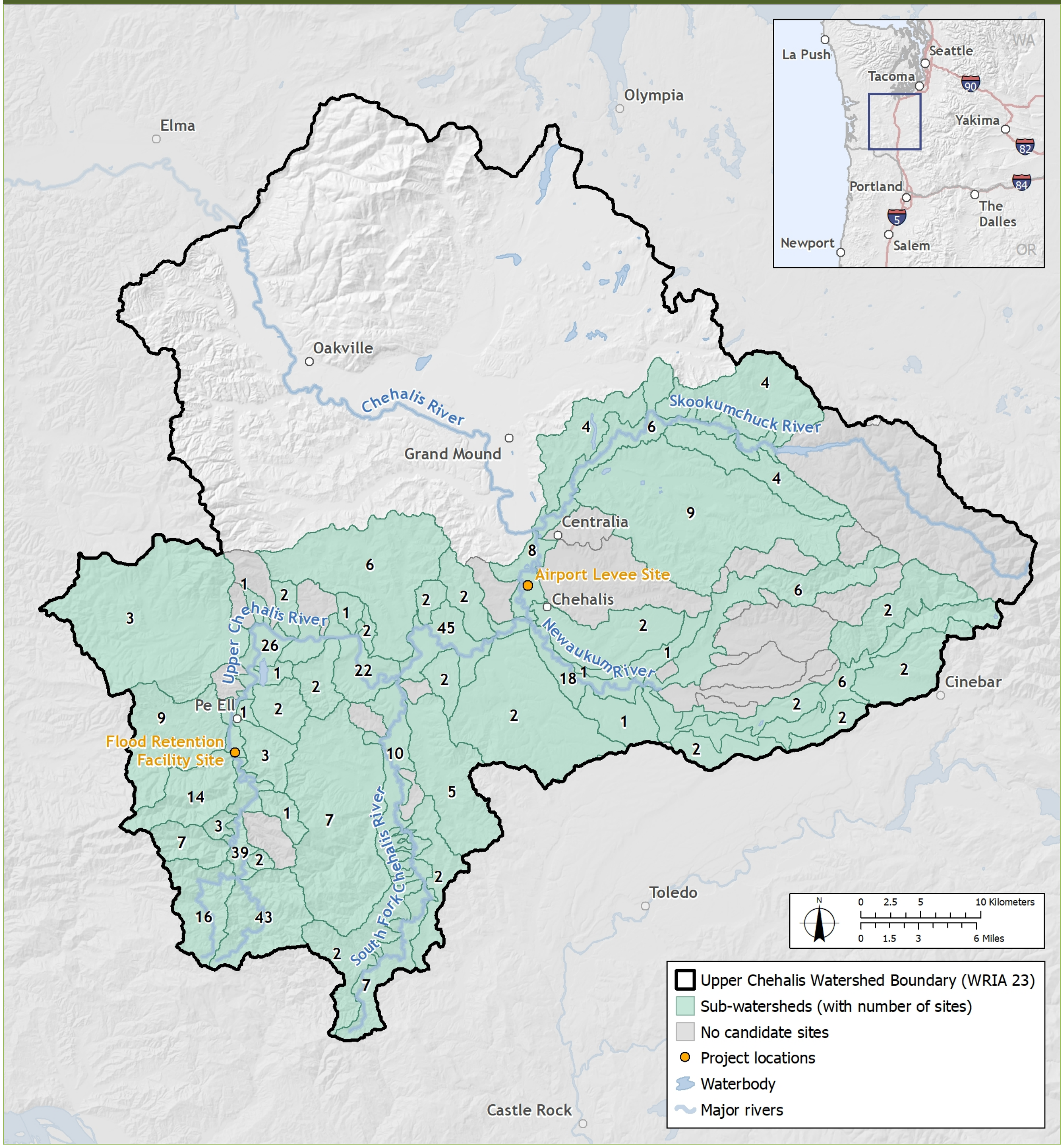
3.2.4 Project Area or On-site Zone

Mitigation requirements may be affected by whether mitigation occurs on-site versus off-site. This section defines the area that would be considered on-site for mitigation planning purposes. The basis for this determination focuses on identifying the portion of the river corridor where project impacts would occur. The proposed project includes the FRE at River Mile (RM) 108 and separate levee improvements planned in the vicinity of the Chehalis-Centralia Airport approximately 35 miles downstream. For the FRE portion of the project, the immediate project area or on-site zone includes the impounded area upstream of the FRE, the FRE facility, and portions of the Chehalis River corridor extending downstream from the FRE. The affected areas upstream and downstream of the FRE would experience diminishing effects with distance. The impounded area would extend from River Mile (RM) 108 to RM 115. Hydrologic changes to the river upstream and downstream of the FRE (RM 108) are predicted to occur from RM 75 to RM 115. Using this rationale, the on-site zone includes the Chehalis River corridor from RM 75 to RM 115 and should be considered for on-site mitigation site selection.

The levee improvements proposed near the Chehalis-Centralia Airport will be located approximately 35 miles downstream of the FRE. For mitigation planning purposes, the on-site zone for impacts associated with the levee improvements will include approximately four miles of the Chehalis River corridor centered on the airport.

Geographic limits of the mitigation site locations should be described in terms of the reaches, areas, and eco-regions identified in the framework used for the ASRP. This will facilitate agency review of the interplay between aquatic mitigation and the proposed benefits of the ASRP. As the candidate site list is refined through screening and prioritization, the candidate mitigation sites will be defined at a finer resolution compared to the reach-scale resolution used in the ASRP.

Figure 3
Initial aquatic habitat candidate site pool locations summed by sub-watershed



Notes:

1. On-site mitigation area was defined to include the proposed FRE site near Pe Ell, the footprint of the temporary reservoir, sub-basins for tributaries that flow through the temporary reservoir, and the 20-mile river corridor between the proposed FRE and the SF Chehalis River confluence.
2. Off-site mitigation area was defined to include the upper Chehalis River Basin upstream of the Skookumchuck River confluence excluding the on-site mitigation area.

3.2.5 Off-site Zone

The off-site zone is the remainder of the Chehalis Basin outside the on-site zone. For mitigation planning purposes, the off-site zone for mitigation site selection was restricted to include only the upper portion of the Chehalis basin including the Skookumchuck River sub-basins and Chehalis River subbasins located upstream of the Skookumchuck confluence. Impacts to spring Chinook salmon spawning within the inundation area may not be fully mitigated on-site if it is determined there are not enough on-site restoration and enhancement opportunities. Off-site areas where mitigation could benefit spring Chinook salmon spawning include the Skookumchuck subbasin, the Newaukum subbasin, and the South Fork Chehalis subbasin (Liedtke et al. 2016). The South Fork Chehalis subbasin has notably high temperatures, so for spring Chinook salmon spawning mitigation to be successful there, the mitigation would need to include a combination of habitat enhancement and temperature mitigation.

3.2.6 Approach to Selecting In-kind versus Out-of-kind Mitigation

Mitigation planning for this project will address federal and state regulatory requirements and generally follow published mitigation guidance (WDFW and Ecology 2000). Conventional mitigation sequencing specifies, in order of preference, avoidance, minimization, on-site mitigation, then off-site mitigation. Avoidance and minimization of impacts is assigned the highest priority before resorting to compensatory mitigation. For unavoidable impacts, compensatory mitigation generally starts with maximizing all feasible on-site in-kind mitigation opportunities that are likely to be effective in the context of the landscape and the effects of the project. In situations where on-site and in-kind mitigation is not feasible or enough to fully address project impacts, additional ecological functions and values may be provided by off-site and out-of-kind mitigation. Off-site and out-of-kind mitigation is usually required to demonstrate that it has a meaningful ecological connection to the impacted priority species and ecological communities in the context of the larger drainage basin with an emphasis on addressing critical or limiting factors.

3.2.7 Mitigation Ratios

Regulatory agencies apply mitigation ratios for a variety of purposes aimed at ensuring no net loss of ecological functions and values. Mitigation ratios typically result in a larger area or amount of mitigation compared to the area or amount of impact. There are several considerations that may apply when specifying mitigation ratios:

How much time will pass between when the impact occurs and when the mitigation is in place and fully functioning (temporal loss)?

- What are the timing, duration, and intensity of the impact? Is it short-term temporary, permanent, or recurring intermittent?
- What is the relative quality of the impacted habitat compared to the mitigation?
- Where is the mitigation located in relation to the site of the impacts?

- Does the mitigation directly replace the same ecological functions and values as those lost as a result of the impact?
- Are there other factors that introduce uncertainty regarding the effectiveness of the mitigation?

A key purpose of this report is to provide general guidance for mitigation ratios to allow for a gross quantification of required mitigation. The ratios included herein are preliminary and are intended to inform mitigation planning specifically by estimating the quantity and type of mitigation necessary to address project impacts. Mitigation ratios are ultimately specified by regulatory agency staff as an integrated component of the permit conditions based on their review of the project impacts and the proposed mitigation measures intended to address them. Preliminary mitigation ratios are not prescriptive for definitive habitat quantification.

There is no set of standardized mitigation ratios for aquatic impacts, unlike the more prescriptive guidance for wetland impacts in Washington state. Terrestrial and aquatic habitat mitigation is developed by comparing impacts and mitigation based on ecological functions and values in the overall watershed context and accounting for uncertainty as described above.

Preliminary mitigation ratios for each combination of mitigation type and impact type will likely include temporal and spatial contexts; temporary or permanent impacts; and other necessary qualification to describe the range of impact types. While prescribed ratios will not be finalized by agencies until they review complete permit applications and issue permits, gaining early agreement on the rationale for determining ratios or potential ranges will help determine the amount and type of mitigation likely to be required including spatial extents and ecosystem qualities. This will also provide a preliminary framework for comparing mitigation options and evaluating the costs and benefits of alternative mitigation strategies.

For aquatic mitigation, state and federal agencies typically require a minimum of a 1:1 habitat replacement ratio provided the replacement habitat quality has equivalent or better functional values compared to the lost habitat and it is appropriately located.

Ratios between 1:1 and 2:1 may be required to offset and account for any uncertainty introduced by selecting out-of-kind, “off-site” mitigation. Higher ratios may also be used to account for uncertainty introduced by multiple factors described at the beginning of this section, but in practice mitigation ratios for impacts to aquatic habitat typically vary between 1:1 and 2:1 (WDFW and Ecology 2000).

3.2.8 Opportunities to Avoid and Minimize Project Impacts

Avoidance and minimization of project impacts is an essential component of mitigation sequencing. Project applicants are required to apply all practicable steps to avoid project impacts and to minimize all unavoidable impacts. The impacts to aquatic and terrestrial species and their habitats as summarized by the SEPA DEIS (Ecology 2020) have not yet been subject to avoidance and minimization measures. Avoidance and minimization measures may substantially reduce the nature, extent, and severity of project impacts. Kleinschmidt team identified a preliminary list of opportunities for avoidance and minimization to reduce project impacts during a future phase of project review:

- Implement a vegetation management plan to minimize loss of riparian vegetation within the temporary reservoir footprint
- Refine the proposed FRE operation plan to minimize the impacts of temporary inundation on riparian vegetation within the temporary reservoir footprint
- Refine the proposed FRE operation plan to include objectives related to flushing sediment that accumulates upstream of the FRE
- Implement a wood management plan to transport large wood pieces past the FRE and minimize the effects of reduced wood loading to the Chehalis River downstream of the FRE
- Optimize the construction schedule to minimize the duration and extent of in-water work
- Apply best management practices (BMPs) during construction activities to minimize impacts associated with construction (e.g. stormwater management, temporary erosion and sediment control, spill prevention and countermeasures)

3.3 Summary of Estimated Mitigation Needs

The Kleinschmidt team developed preliminary mitigation information based on the project's estimated effects on aquatic and terrestrial species and their habitats documented in the SEPA DEIS published by Ecology in February 2020. Compensatory mitigation typically aligns with the locations, types, and extents of project impacts. Links between impacts and mitigation are evaluated in the physical and ecological context of watershed processes and trends. **Table 1** lists the summary of aquatic and terrestrial impacts presented in the SEPA DEIS and shows estimated mitigation needs to address each component of the impacts.

To develop the estimated mitigation quantities, the Kleinschmidt team considered the nature and extent of project impacts to inform the extent of areas and channels that would be enhanced by mitigation. Impacted stream length was matched or exceeded by the length of stream channel that would be enhanced by mitigation. Impacted riparian areas were exceeded by the combined extent of mitigation actions also offering riparian reforestation, wetland enhancement and creation, and upland conservation. The Kleinschmidt team applied best professional judgment to develop assumptions regarding the density of instream wood loading (e.g. 3 structures per mile for 17 miles) and cold-water thermal refugia structures (2 structures per mile for 17 miles). Best professional judgment was informed by consideration of existing habitat conditions within the on-site area as documented in the SEPA DEIS. Some of the impacts are collocated within the same 847-acre temporary reservoir. Similarly, some of the mitigation actions will address multiple impacts at the same locations. The mitigation quantities shown in **Table 1** could be provided by a combination of approximately 40 to 50 mitigation sites accounting for co-located mitigation action types. These could be grouped into 5 to 10 reach scale mitigation projects that each treat 1 to 3 miles of channel.

Table 1
Summary of Estimated Mitigation Needs Compared to Impacts

IMPACT DESCRIPTION	ESTIMATED MITIGATION NEEDED
Removal of 90% of the trees within 600 acres of the temporary reservoir area	• Riparian reforestation along 6 miles of main channel and 11 miles of tributary channel (assume 200 ft forested buffer on both channel banks that ad up to 824 acres).
Episodic temporary flooding of up to 847 acres (maximum extent of temporary reservoir area at full capacity)	• Conservation of 924 acres including a mixture of forested uplands and wetlands (assume this is partially fulfilled by 824 acres of forested riparian buffer supplemented by 100 acres of upland conservation adjacent to the temporary reservoir)
Water temperature increases of up to 9 degrees F related primarily to loss of shade along 6 miles of river and 11 miles of tributary streams within the temporary reservoir	• Riparian reforestation along 6 miles of main channel and 11 miles of tributary channel (assume 200 ft forested buffer on both channel banks that add up to 824 acres). • Implement 34 cold-water thermal refugia enhancements (e.g. 30 hyporheic exchange enhancements and 4 cold-water retention structures) – assume 2 structures per mile for 17 miles
Permanent loss of approximately 11 acres of wetlands and 333 acres of wetland buffers located within the 847-acre footprint of the temporary reservoir area	• Conservation of 924 acres including a mixture of forested uplands and wetlands (assume this is partially fulfilled by 824 acres of forested riparian buffer supplemented by 100 acres of upland conservation adjacent to the temporary reservoir) • 3 acres of wetland creation and enhancement targeting habitats for focal wildlife species • Wetland impacts will be comprehensively addressed in a separate wetland mitigation assessment
Permanent elimination of 17 miles of stream channel and 441 acres of stream buffers. "Permanent elimination" entails habitat degradation and loss of ecological function within approximately 6 miles of the mainstem Chehalis River channel and 11 miles of tributary stream channel within the footprint of the temporary reservoir area.	• Enhance instream habitat in 17 miles of stream and river channel by placement of 50 wood loading structures with substrate enhancement (assume 3 structures per mile for 17 miles). • 35 of the wood loading structures would each include 300 ft of large wood placement, 200 feet of wood toe, 50 ft of boulder weir, and 1 beaver dam analog. • 15 of the wood loading structures would be gravel retention jams each covering 900 linear ft of channel • Riparian reforestation along 6 miles of main channel and 11 miles of tributary channel (assume 200 ft forested buffer on both channel banks that add up to 824 acres)
Permanent elimination of 0.3 acres of the Chehalis River channel at the FRE site	• Replace lost main channel habitat with 1 acre of new channel habitat created by excavating alcoves to intercept cold water from groundwater or hyporheic flow

IMPACT DESCRIPTION	ESTIMATED MITIGATION NEEDED
Temporary fish passage interruption at the FRE facility during construction	• Replace 5 fish passage barrier culverts on local roads within the upper Chehalis Basin with fish passable stream crossings
Water temperature increases of up to 5 degrees F within the 20-mile river corridor between the proposed FRE and the SF Chehalis River confluence. Model-predicted temperature increased result from the combined effects of climate change and project impacts related primarily to loss of shade along the river and tributary streams within the footprint of the temporary reservoir area	• Riparian reforestation along 6 miles of main channel and 11 miles of tributary channel (assume 200 ft forested buffer on both channel banks that add up to 824 acres) • Implement 34 cold-water thermal refugia enhancements (e.g. 30 hyporheic exchange enhancements and 4 cold-water retention structures) – assume 2 structures per mile for 17 miles
Episodic increases in turbidity when water is released from the temporary reservoir after storm events. An unspecified amount of sediment deposited within the temporary reservoir area would be remobilized and flushed downstream after the water level recedes.	• Implement 4 floodplain reconnection projects for a total of 2 miles of off channel aquatic habitat and 100 acres of riparian buffer including a mixture of wetlands and uplands) • 15 gravel retention jams each covering 900 linear ft of channel
Changes in the movement of sediment, large wood, and water resulting in unquantified effects on fish habitat.	• Implement 4 floodplain reconnection projects for a total of 2 miles of off channel aquatic habitat and 100 acres of riparian buffer including a mixture of wetlands and uplands) • Enhance instream habitat in 17 miles of stream and river channel by placement of 50 wood loading structures with substrate enhancement (assume 3 structures per mile for 17 miles)

Notes:

1. Some of the itemized impacts are collocated within the footprint of the temporary reservoir.
2. Some of the mitigation actions would address multiple impacts at the same sites.

4 MITIGATION OPPORTUNITIES

The Kleinschmidt team developed a preliminary list of candidate mitigation opportunities representing a range of mitigation action types to address unavoidable impacts to aquatic and terrestrial species and their habitats. This Section describes the approach to identifying and qualifying candidate mitigation opportunities. Key elements of this process included:

- Defining the geographic area in which mitigation could occur, including defining on-site and off-site areas;
- Designating and defining a range of mitigation action types needed to address project impacts;
- Identifying criteria for screening, prioritizing, and selecting candidate mitigation opportunities; and
- Summarizing the pool of candidate mitigation opportunities.

4.1 Geographic Scope

The proposed geographic scope for aquatic and terrestrial mitigation includes the upper Chehalis Basin upstream of the Skookumchuck River confluence. The area that would be considered on-site for mitigation planning purposes includes the Chehalis River corridor from RM 75 to RM 115 plus the tributaries that flow through the inundation zone upstream of the FRE. The off-site mitigation area would be limited to the remainder of the upper Chehalis Basin upstream of the Skookumchuck River confluence. **Figure 3** shows the proposed geographic extent for selecting candidate mitigation sites.

4.2 Mitigation Action Types

The Kleinschmidt team defined nine mitigation action types to develop and organize a large pool of preliminary candidate mitigation sites. **Table 2** identifies and briefly describes each mitigation action type.

Table 2
Aquatic and Terrestrial Mitigation Action Types

MITIGATION ACTION TYPES	DESCRIPTION
Riparian Buffer Expansion	Expand riparian buffer beyond forest practices requirements, establish forest vegetation along channel margins
Hyporheic Exchange Enhancements	Instream and bank modifications to enhance the exchange between surface water and shallow groundwater to create or expand cool water pockets for thermal refugia. Several types are proposed based on different landforms.
Cold Water Retention Structures	Off-channel features including floodplain channels and backwater alcoves positioned to intercept colder groundwater or hyporheic flow and maintain a cool water pocket to provide thermal refugia.
Instream Modifications	Construction of habitat features within the perennial wetted channel for several purposes such as habitat complexity, creation of cold-water refuge pockets, and spawning gravel retention.
Off-channel Modifications	Off-channel habitat enhancements including side channel and floodplain actions to reconnect, enhance, and expand off-channel habitat.
Gravel Retention Jams	Larger instream structures composed of large wood pieces and rock located and designed to provide hydraulic roughness and promote accumulation and retention of salmonid spawning gravels. These structures may include gravel augmentation in areas with limited gravel budgets.
Fish Passage	Fish passage improvements including removal of small dams and replacing fish passage barrier culverts with passable crossings.
Wetland Enhancement	Enhancement, restoration, or expansion of wetlands to benefit wildlife species.
Upland Conservation and Enhancement	Conservation and enhancement of specific habitats matching the requirements of focal wildlife species.

4.2.1 Riparian Buffer Expansion

Riparian buffer expansions include two types of actions: establishing forested buffers along stream and river margins that currently lack forest vegetation; and conserving existing forests along streams and rivers as a wider buffer than what is required by forest practices rules. Establishing forest buffers along unshaded channel reaches would include developing and implementing an appropriate plant composition schedule and planting plan to establish a mix of native species of trees and shrubs that would develop into a forested buffer over time. Plant establishment may require initial watering, monitoring, and replacement of plants lost to mortality. Permanence of these reestablished forested buffers would be ensured by land acquisition or conservation easements. Conservation of existing forests would occur in locations where such forests could otherwise be removed or modified by timber harvest, agriculture, or land development. Riparian plantings provide some immediate ecological benefits that increase over time as the forest matures and evolves. Full ecological function would require several decades from the time of initial planting.

Riparian buffer expansion would provide the primary long-term means of mitigating impacts to water temperature related to the predicted loss of riparian shade within the temporary reservoir upstream of the FRE. In addition to providing shade, expanded forested riparian areas provide a source for wood recruitment, reduce soil erosion, and mitigate water quality impacts related to runoff from upslope land use activities. Expanding riparian areas would also provide additional habitat for a variety of riparian-dependent plant and animal species.

Conservation of existing forested riparian buffers has the potential to benefit multiple wildlife species including priority species such as western toad (*Anaxyrus boreas*), Dunn's salamander (*Plethodon dunni*), VanDyke's salamander (*P. vandykei*), yellow billed cuckoo (*Coccyzu americanus*), northern spotted owl (*Strix occidentalis caurina*), and marbled murrelet (*Brachyramphus marmoratus*). Riparian areas are often important migratory corridors and conservation of wide buffers may help mitigate impacts to species such as elk that migrate through the project area. Targeted enhancement of existing forested riparian buffers such as large woody material placement could benefit terrestrial-breeding salamanders. Planting currently non-forested riparian buffers would also provide multiple long-term benefits to wildlife as the plantings mature.

Riparian buffer expansion would not require in-water work, and potential impacts to water quality and instream habitat are minimal. Construction activities focus primarily on planting and possible soil amendment and watering to support plant establishment. Delivery of plant material and possibly soil amendment would use existing transportation routes as much as possible, and any new routes required for site access would follow conventional erosion and sediment control requirements in addition to post-maintenance restoration.

The extent of riparian buffer expansion may be up to approximately 850 acres and address up to 17 miles of river and stream channel length based on the extent of riparian impacts described in the SEPA DEIS. The actual impacts and extent of mitigation will be refined through conventional mitigation sequencing (i.e. avoidance and minimization), additional analysis, and negotiation with regulatory agencies during the design and permitting process should the Proposed Action advance to that stage of review.

4.2.2 Hyporheic Exchange Enhancements

Hyporheic exchange enhancements include instream and bank modifications designed to enhance the exchange between surface water and shallow groundwater to create or expand cool water pockets for thermal refugia. An effective application of hyporheic flow enhancement would establish strategically distributed pockets of accessible cold water thermal refugia for aquatic species during times when average water temperatures are detrimental or lethal to salmonid species. Such a strategy could be applied as an early action that provides immediate and sustained benefits during the longer time required to increase the extent of forested riparian zones that shade the drainage network and provide long-term water temperature reduction. Several types are possible based on different channel and floodplain landforms. **Appendix B** contains a white paper describing hyporheic enhancement and its potential applicability within the upper Chehalis Basin as an integrated component of a broader aquatic habitat mitigation strategy.

Thermal mitigation can be achieved in the riverine environment primarily by modifying and capitalizing on existing geographic locations and morphologic features that are already actively providing hyporheic flow exchange or have the capacity to improve exchange. Thermal mitigation opportunities that capitalize on groundwater and cooler surface water sources may also exist at their interface with surface waters, usually on smaller tributaries.

The fluvial geomorphic features that are most conducive to facilitating hyporheic exchange include the following:

- Pool-step systems
- Pool and riffle systems
- Sinuous/meandering channels
- Secondary or side channels
- Paleo channels
- Channel splits and island gravel bars
- Meander point bars

Hyporheic flow exchange may be enhanced to improve thermal diversity and refugia, nutrient cycling, and primary production to mitigate degradation caused by human activities and climate change. Potential enhancement actions listed below are presented as specific to fluvial site characteristics but are very generic in nature. Design and implementation of hyporheic flow enhancement projects will be site-specific.

1. **Gravel bars with side channels:** Install engineered log jams, log weirs, rock weirs, or beaver dam analogs to increase hydraulic head at the upstream end. Decrease mainstem flow through side channel through restrictions or plugs at the upper end of the channel. Excavate deeper channels or pools at the lower end of side channels. Beaver dam analogs may not be applicable on larger streams.
2. **Channel splits with gravel islands:** Install engineered log jams, log weirs, rock weirs, or beaver dam analogs to increase hydraulic head at the upstream end of islands. Decrease mainstem flow through side channels through restrictions or plugs at the upper end of channels. Excavate deeper channels or pools at the lower end of side channels. Beaver dam analogs may not be applicable on larger streams.
3. **Large degree (> 90°) meander bends with long cross-peninsula flow paths:** Install engineered log jams, log weirs, or rock weirs to increase hydraulic head at the upstream end of bends.
4. **Sinuous reaches with point bars:** Enhance floodplain connection and provide gravel augmentation to increase the size of the active hyporheic zone if sediment supply has been limited.

5. **Paleo channels:** Reconnect paleo channels at the downstream end to provide fish access for refugia. Create alcoves near the downstream end of these channels.
6. **Straightened channel reaches that can be re-meandered:** Re-meander channels as appropriate to their geomorphic setting and provide gravel augmentation if needed to increase the size of the hyporheic zone.
7. **Riparian areas adjacent to the ordinary high-water line and lacking woody vegetation:** Replant riparian zones with a diverse assemblage of native woody species that includes red alder (*Alnus rubra*).
8. **Floodplains:** Restore floodplain activation frequency and extent by installing in-channel hydraulic roughness and/or lowering the floodplain within the hyporheic zone through excavation and re-grading.
9. **Incised channels with adjacent disconnected floodplain:** Restore floodplain activation frequency and extent by installing in-channel hydraulic roughness and/or lowering the floodplain within the hyporheic zone through excavation and re-grading. Install roughness elements on the floodplain to reduce floodway flow velocity and encourage overbank deposition of organic material. Install grade control structures to reduce further incision.
10. **Cold water tributaries, seeps, and springs:** Excavate pools between the cold-water source and the mainstem channel and install wood structures or boulders to minimize dilution with mainstem surface water to provide holding areas for fish.

These types of mitigation action would require instream construction. The thermal refugia resulting from this action are intended to function at low flow conditions, so complete avoidance of in-water work is not possible. To the degree possible, work within the ordinary high-water mark (OHWM) would attempt to minimize the amount and duration of in-water work. Construction timing would comply with applicable local in-water construction windows (i.e. “fish windows”). Conventional BMPs for in-water work would be applied during construction including standard erosion and sediment control measures, isolation of in-water work areas, fish salvage, and fish exclusion measures.

Hyporheic exchange enhancements would primarily serve to provide near-term and sustained thermal refugia within the portion of the Chehalis River and its tributaries that would experience water temperature impacts due to the loss of riparian shade. The SEPA DEIS concluded that water temperature impacts would occur within approximately 20 miles of the Chehalis River downstream of the FRE, six miles of the Chehalis River upstream of the FRE, and 11 miles of tributary streams within the temporary reservoir area upstream of the FRE. Hyporheic exchange enhancements would be prioritized on these channel reaches, and opportunities for hyporheic exchange are available in many other parts of the upper Chehalis Basin. The type of action at each site would be selected to align with the geomorphic attributes of that site. Extent of implementation may be limited by opportunities and property access, but the number of sites may be up to one or two per mile within the affected reaches. The actual impacts and extent of required mitigation will be refined through conventional mitigation sequencing (i.e. avoidance and minimization), additional analysis, and negotiation with regulatory agencies during the design and permitting process.

4.2.3 Cold Water Retention Structures

Cold water retention structures are off-channel features including floodplain channels and backwater alcoves positioned to intercept colder groundwater or hyporheic flow and maintain a cool water pocket to provide thermal refugia. Incised channel segments in steeper terrain lack floodplains and have limited lateral hyporheic exchange. In such locations cold water pockets may be enhanced for thermal refugia by intercepting groundwater where it seeps into the channel from adjacent slopes and higher elevation areas. The conceptual approach focuses on identifying locations where colder groundwater is entering the channel but is quickly mixed with the warmer surface water. Thermal refugia may be enhanced in such locations by installing in-water structures or excavating side channels or alcoves to establish sheltered low energy areas along the channel margins where the colder water originates. During low flow conditions typical for the warmest part of the year, such structures would establish and maintain pockets of cooler water that provide thermal refugia for fish. Cold water retention structures would provide immediate and sustained ecological benefits, and the intended ecological function would be fully realized within one or two years after implementation.

4.2.4 Instream Modifications

Instream modifications involve construction of habitat features within the perennial wetted channel for several ecological purposes such as enhancement, restoration, inducement, or creation of habitat-forming processes and habitat elements such as complexity, cover, hydraulic diversity, pool formation, cold-water refuge pockets, and spawning gravel retention. Instream modifications involve placement of large wood within the channel with or without anchoring mechanisms depending on the size of the channel, risk factors, and the intended function of the wood. Additional construction activities may include supplementation of stream gravel to enhance spawning habitat, minor earthwork to embed large wood pieces into the riverbed and banks, site work to provide heavy equipment access, and construction staging. Forested riparian buffers may be established at sites that lack them. Any instream modifications must consider and adequately address boater safety and the safety of recreational users of the river. Broad application of instream modifications may require targeted public outreach to counteract perceptions that wood accumulations should be removed from the river.

Instream modifications are intended to provide multiple benefits to aquatic species with particular focus on salmonids. Large wood structures provide hydraulic diversity, substrate diversity, instream cover, high flow refugia, pool formation, and gravel retention. Some specific instream modifications may be designed to benefit western toad and other still-water breeding amphibians. These would be anticipated to occur in conjunction with other instream habitat enhancements. Potential enhancements that could benefit western toad would be identified through field assessment of site conditions and opportunities.

This type of mitigation action would require in-water construction. Instream modifications are intended to function over a wide range of flows including low flow conditions, so complete avoidance of in-water work is not possible. To the degree possible, work within the Ordinary High-Water Mark (OHWM) would minimize the amount and duration of in-water work. Construction timing would comply with applicable local in-water construction windows (i.e. "fish windows"). Conventional BMPs for in-water work would be applied during construction including standard erosion and sediment control measures, isolation of in-water work areas, fish salvage, and fish exclusion measures.

The SEPA DEIS concluded that impacts to instream habitat would occur within the approximately 20 miles of the Chehalis River downstream of the FRE, 6 miles of the Chehalis River upstream of the FRE, and 11 miles of tributary streams within the temporary reservoir area upstream of the FRE. Instream modification mitigation actions would focus on these channel reaches, but opportunities for instream modifications are also available in many other parts of the upper Chehalis Basin. The type of action at each site would align with the flow regime and geomorphic attributes of that site. Extent of implementation may be limited by property access, but the number of sites may be up to one or two per mile on average within the affected reaches. Density will likely be higher within the 20-mile reach of the mainstem Chehalis River downstream of the FRE. Individual sites would vary in their extent, with instream modifications typically enhancing between 500 and 2000 ft of channel per site. The actual impacts of the Proposed Action and extent of required mitigation will be refined through conventional mitigation sequencing (i.e. avoidance and minimization), additional analysis, and negotiation with regulatory agencies during the design and permitting process. In-stream modifications would provide immediate and sustained ecological benefits, and the intended ecological function would be fully realized within one or two years after implementation. Ongoing river processes may modify such structures over time, and the structures will affect local hydraulics and sediment dynamics.

4.2.5 Off-channel Modifications

Off-channel habitat enhancements include side channel and floodplain actions to reconnect, enhance, and expand off-channel habitat. This mitigation action type typically targets paleo channels (e.g. dry, disconnected relict channel segments on the floodplain) and other lower elevation areas on the floodplain that could receive and convey flow and be made accessible to fish and other aquatic species by enhancing upstream and downstream connections to the main river or stream channel. Forested riparian buffers would be established along off-channel modification actions where existing vegetation lacks forest cover.

Off-channel modifications provide multiple ecological benefits to aquatic and terrestrial species. The benefits provided by individual actions will vary from site to site depending on the water surface elevation and corresponding flow frequency that engages flow in these off-channel features. Generally, greater benefits may be realized at off-channel enhancement sites that engage flow multiple times per year and not just during less frequent flooding events. Off-channel enhancements provide highly productive rearing and foraging habitat, velocity refugia during high flow events, and may be configured to incorporate hyporheic exchange enhancement for thermal refugia, typically at the downstream connection point with the main channel. Some specific off-channel modifications may be designed to benefit western toad and other still-water breeding amphibians. These would be anticipated to occur in conjunction with other off-channel habitat enhancements. The Kleinschmidt team has identified potential off-channel modification sites that correspond with known western toad breeding areas.

Potential enhancements that could benefit western toad would be identified through field assessment of site conditions and opportunities.

Off-channel Modifications would require minimal in-water construction typically limited to the upstream and downstream connections with the main river or stream channel. This action type is often intended to be wetted during moderate to high flow conditions, but ecological benefits are also provided during low flow dry conditions. Perennial flow conditions may be achievable at some sites, especially where the side channel receives perennial flow from springs, tributaries, or hyporheic flow. For many sites it may be possible to conduct all necessary work within the OHWM in dry conditions by timing work to coincide with low flow. This type of action may be integrated with instream modifications for example, by installing a large wood structure near the upstream off-channel connection point to maintain a pool at that location and maintain the high flow connection. Construction timing would comply with applicable local in-water construction windows (i.e. “fish windows”). Conventional BMPs for in-water work would be applied during construction including standard erosion and sediment control measures, isolation of in-water work areas, fish salvage, and fish exclusion measures.

Instream modifications would focus on the 27-miles of channel included within the on-site mitigation area. Opportunities for off-channel modifications are available in many other parts of the upper Chehalis Basin. The type of action at each site would align with the flow regime and geomorphic attributes of that site. This type of action requires a floodplain wide enough to support a side channel feature. Most off-channel modification actions would occur within the 20-mile reach of the main stem Chehalis River downstream of the FRE. Individual sites would vary in their extent with off-channel modifications on larger floodplains typically reconnecting and enhancing up to 2000 ft of side channel habitat. Actions would be smaller along tributary streams. Overall extent of this action type may be up to one per mile within the 20-mile reach of the main stem Chehalis River downstream of the FRE. Off-channel modifications would provide immediate and sustained ecological benefits, and the intended ecological function would be fully realized within three to five years after implementation. Flow events that activate off-channel flow will enhance the development of off-channel habitat elements over time.

4.2.6 Gravel Retention Jams

Gravel retention jams are larger instream structures composed of large wood pieces and rock located and designed to provide hydraulic roughness and promote accumulation and retention of salmonid spawning gravels. Gravel retention jams involve placement of large wood within the channel, with anchoring elements if needed to retain the jam at the selected location. For each site, a sediment transport analysis would be needed to determine if natural gravel transport is enough to form the spawning habitat or if placement of additional spawning gravel would be needed to supplement natural supply. Additional construction activities may include minor earthwork to embed large wood pieces into the riverbed and banks, site work to provide access, and construction staging. Forested riparian buffers may be established at sites that lack them.

Gravel retention jams are a specific type of instream modification intended to enhance spawning habitat. Such structures would provide multiple secondary benefits to aquatic species with focus on salmonids such as hydraulic diversity, substrate diversity, instream cover, high flow refugia, and pool formation. The vertical hydraulic gradient created by gravel deposition upstream of the jam creates an opportunity to integrate hyporheic exchange enhancement into this type of action.

Gravel retention jams would require in-water construction. This type of mitigation action is intended to function over a wide range of flows including low flow conditions, so complete avoidance of in-water work is not possible. To the degree possible, work within the OHWM would minimize the amount and duration of in-water work. Construction timing would comply with applicable local in-water construction windows (i.e. “fish windows”). Conventional BMPs for in-water work would be applied during construction including standard erosion and sediment control measures, isolation of in-water work areas, fish salvage, and fish exclusion measures.

Gravel retention jams would focus on channel reaches with sufficient gradient to deliver and transport spawning gravel. The type of action at each site would align with the flow regime and geomorphic attributes of that site. This mitigation action type would likely range from 4 to 8 individual locations per site. Individual sites would vary in their extent with wood placement typically occupying approximately 200 linear feet of channel and spawning gravel enhancement (either through supplementation or by natural accumulation) affecting up to 900 linear feet of channel. Estimated mitigation quantities are preliminary. The actual impacts of the Proposed Action and extent of mitigation will be refined through conventional mitigation sequencing (i.e. avoidance and minimization), additional analysis, and negotiation with regulatory agencies during the design and permitting process. Gravel retention jams would provide immediate and sustained ecological benefits, and the intended ecological function would be fully realized within one or two years after implementation at locations where gravel augmentation is part of the action. More time may be required to realize full ecological benefits at locations that rely on natural delivery and accumulation of gravel material transported by the river.

4.2.7 Fish Passage

Fish passage improvements include removal of small dams and replacing fish passage barrier culverts with passable crossings. Fish passage improvements focus on restoring access to habitat upstream of the barrier, and the benefits of individual fish passage projects scale with the quantity and quality of habitat available upstream of the barrier. Actions that remove small dams would usually completely remove the in-water structure, however retrofitting, partial removal, or breaching of the dam may be a viable approach in some locations. Fish passage barrier culverts are typically made passable by removal and replacement with a passable structure such as a stream simulation arch culvert, bridge, or equivalent.

Fish passage actions would require in-water construction. To the degree possible, work within the OHWM would minimize the amount and duration of in-water work. Construction timing would comply with applicable local in-water construction windows (i.e. “fish windows”). Conventional BMPs for in-water work would be applied during construction including standard erosion and sediment control measures, isolation of in-water work areas, fish salvage, and fish exclusion measures.

Preliminary analysis indicates that fish passage actions may be used to restore fish access to between 20 and 40 miles of stream channel. Habitat quality and length made available will be different for each project, but site selection during future mitigation planning would prioritize sites with higher quality and greater quantity of aquatic habitat. Fish passage improvements would provide immediate and sustained ecological benefits. While fish passage would be restored immediately when construction is complete, fish use of the newly accessible habitat would increase gradually over time.

4.2.8 Wetland Enhancement for Terrestrial Species

Wetland enhancement activities addressed here would be targeted toward wildlife habitat enhancement, restoration, or creation. Potential mitigation actions include vegetation management, installation of habitat features, water management changes (e.g. disabling or removing drain tile networks, plugging ditches, etc.), grading, and excavation.

In some cases, such activities may also be able to provide compensatory wetland mitigation credit; however, compensatory wetland mitigation is not part of the current scope of work and will be addressed separately as part of the JARPA process. Similarly, wetland buffer mitigation will be addressed separately as part of the wetland regulatory process, but habitat-related mitigation within wetland buffers may be an integrated component of that process. Wetland buffer mitigation credit may also be obtained in conjunction with the previously addressed riparian buffer expansion and in conjunction with upland conservation and enhancement addressed in the following section. Wetland enhancement activities that occur near the proposed airport levee improvements are anticipated to be addressed during the environmental permitting process as mitigation for the 6.63 acres of anticipated wetland impact.

Wetland enhancement near the proposed FRE facility and temporary reservoir would primarily target western toad breeding habitat. Extensive western toad breeding has been documented within the proposed reservoir footprint. Activities that benefit non-wetland western toad habitat are addressed in other sections of this report (instream and off-channel modifications, and upland conservation and enhancement). Wetland enhancement could potentially benefit numerous other native species including other still-water breeding amphibians and priority species such as western pond turtle (*Clemmys marmorata*) and waterfowl.

Other wetland functions and values besides wildlife habitat would be enhanced. Wetland enhancement would be designed with a full suite of benefits in mind including water quality, water storage, and food web support. Impact avoidance and minimization measures would be incorporated into wetland enhancement design to prevent degradation of other ecological functions such as elevating nearby river and stream temperatures.

Western toad breeding habitat includes shallow ponds, lakes, and slow-moving reaches of streams. Potential wetland enhancement activities could include enhancement or expansion of existing habitats. The Kleinschmidt team has identified areas that are known to be used for western toad breeding as potential mitigation sites. These areas would be evaluated for enhancement potential. Potential enhancement activities include vegetative enhancements such as removal of invasive plant species and planting native species that would be compatible with western toad breeding and larval stage development.

Other potential wetland enhancement activities include creation of new western toad breeding habitat near areas known to be occupied by the species. Creation of new western toad breeding habitat could include creation of new wetlands, restoration of areas that were previously wetland, or enhancement of existing wetlands that currently do not provide western toad breeding habitat. New or modified wetland habitats would ideally be designed to hold surface water through July, after which time it may be preferable for them to dry to avoid creating perennial ponds that could become American bullfrog (*Lithobates catesbeianus*) breeding habitat.

Wetland enhancement activities would occur outside the main channel of the Chehalis River and its major tributaries. Creation, restoration, or enhancement of western toad breeding habitat could occur within the river or stream channels, but if that were to occur it would fall under the instream or off-channel modifications sections addressed above. If wetland connectivity to the river or streams requires work within a channel, the work parameters would comply with those described in the applicable preceding sections.

The extent of wetland enhancement activities targeting wildlife habitat has not been precisely quantified yet. Mitigation of wetland impacts is outside the scope of this mitigation opportunities assessment however wetland habitats may be enhanced to provide ecological benefits to terrestrial species impacted by the proposed project. Wetland enhancement specifically targeting wildlife habitat could total up to five acres in aggregate.

The timing of wetland enhancement work could vary, but any disturbance to existing western toad breeding habitat would occur outside the season when spawning, incubation, and larval stages occur. Such work would be coordinated with WDFW to ensure appropriate site-specific timing. For general planning purposes work in existing western toad breeding habitat should be avoided between February and July. Construction of new habitat areas not currently utilized by western toad could occur during whatever time of year is deemed appropriate for site conditions. Timing of instream and off-channel modifications would occur during timing described in the preceding sections.

Construction equipment could include heavy equipment such as excavators or graders. Efforts to limit grading impacts in saturated soils or standing water may occur by using low ground-weight construction equipment or utilizing prefabricated timber or terra mats. Wetland enhancement work would be planned to minimize impacts to existing resources to the greatest extent possible and is not anticipated to deviate from established standards.

Standard BMPs would be employed during wetland enhancement activities. Erosion prevention and sediment control measures would be utilized when work is in or near wetlands or other waters. Exposed soils would be stabilized during and after construction. Filter bags, sediment fences, sediment traps, leave strips or berms, or other measures would be used to prevent movement of soil into wetlands or other waters. Silt fence or other equally effective methods would be used to protect stockpiled soil as appropriate depending on precipitation and duration of stockpiling. Erosion control measures would be inspected and maintained as necessary to ensure continued effectiveness. Areas of temporary wetland impacts would be restored and re-vegetated with ecologically site-specific native species. Other standard BMPs would be employed to protect natural resources including prohibitions pertaining to hazardous materials and fueling activities within 100 feet of wetlands and other waters.

Wetland enhancement for terrestrial species would provide immediate and sustained ecological benefits. Achieving full ecological function may require several years to a few decades as the wetland plant community gets established and matures.

4.2.9 Upland Conservation and Enhancement

Potential upland conservation and enhancement activities include long-term conservation of high-quality upland habitats and enhancement of degraded upland habitats. Depending on site-specific enhancement potential, implementation could include strategic installation of habitat features and vegetation management such as invasive species removal and planting native species. Upland enhancement depends on field-assessed needs and opportunities. In the absence of such surveys, specific enhancement measures have not been developed and upland conservation is the primary focus of upland mitigation at this time.

The previously described component of riparian buffer expansion that consists of conserving wider buffers than those required by current regulations may overlap with upland conservation, both in concept and function. Where possible, conservation of upland habitats will be targeted adjacent to and in conjunction with riparian conservation. That will allow for larger contiguous forested habitats while minimizing detrimental edge effects.

Upland conservation and enhancement activities are intended to mitigate for impacts to a variety of wildlife species that may include native amphibians and reptiles, terrestrial insects, mammals, and birds including the federally listed northern spotted owl and marbled murrelet. Upland conservation and enhancements also target priority upland habitats that may be impacted by the Proposed Action.

The potential for detrimental impacts to occur as a result of upland conservation and enhancement activities is minimal. The work would not involve in-water work, discharge of materials to waterbodies, or other activities likely to affect water resources. If heavy equipment is necessary for upland enhancements, standard BMPs would be applied to avoid and minimize impacts.

Upland conservation and enhancement would provide immediate and sustained ecological benefits. Upland enhancement may require several decades to fully achieve the intended ecological function as newly established plant communities may require a few decades to mature.

4.3 Criteria for Screening, Selection, and Prioritization

An initial pool of candidate mitigation sites was developed using desk-top analysis methods including Geographic Information System (GIS) analysis of dozens of publicly available geodatabases, digital orthophoto interpretation, and LiDAR digital elevation models. Search criteria were informed by the Programmatic EIS, the 2020 DEIS, the ASRP Phase I Draft Plan, local WDFW research, and knowledge of species life history requirements.

The initial candidate site identification process yielded 355 sites for consideration. This initial pool was not intended to include all potential mitigation sites, nor was it intended to represent a mitigation goal. For example, it did not assign site numbers to many miles of riparian habitat adjacent to river and stream channels in the focus area that could be enhanced and/or conserved to mitigate for predicted riparian thermal impacts in the FRE inundation area. Fish passage restoration sites included in the initial pool were not comprehensive; additional known uncorrected public fish barriers exist in the vicinity, and some barriers on private lands may not have been completely assessed or included in these databases.

4.3.1 Initial Search Criteria

- Located within the Upper Chehalis sub-basin (WRIA 23);
- Located in areas known to be used by or possessing the potential to be used by affected species, especially spring Chinook salmon;
- Located within Lewis County;
- Possess identifiable restoration or conservation potential that matches ecological functions expected to be affected by the construction or operation of the project;
- Surrounded by sufficient open space without apparent infrastructure constraints for habitat functions;
- Possess a geomorphic template appropriate for the desired habitat functions (e.g. valley form and catchment area indicating likely groundwater inputs); and
- Desired plan-form physical attributes for mitigation action type (e.g., point bars and meander bends for hyporheic enhancements).

4.3.2 Additional Emphases

- Within the Willapa Hills Ecological Region as defined by the ASRP; and
- Within the on-site area, defined provisionally as the FRE site, Ecosystem Diagnosis and Treatment (EDT) model reaches that intersect the inundation footprint, and the mainstem Chehalis River downstream of the FRE facility site to the South Fork Chehalis confluence. Of the 355 initial candidate sites, approximately half (n=184) were located in this on-site area.

4.3.3 Candidate Site Attributes

Candidate mitigation opportunity sites identified through screening were further assigned specific attributes including:

- Each candidate site was assigned an on-site or off-site location type category based on the descriptions in **Section 4.1** and shown on **Figure 3**.
- ASRP spatial overlap potential, as determined in discussions with the ASRP team. Early action projects identified by the ASRP were screened out of consideration for mitigation opportunities. Geospatial Units (GSUs) identified in the ASRP for particularly intensive treatment were flagged as having high potential for overlap. Note that even in areas with spatial overlap, ASRP and mitigation actions may differ, and not all actions identified in the ASRP may be funded. Thus, ASRP overlap was not used as a mitigation site elimination criterion except in the case of ASRP early action projects.
- Each candidate site was assigned one or more of nine non-exclusive action types: Fish Passage, Riparian Enhancement, Hyporheic Enhancement, Cold-water Retention Structures, Instream Habitat Improvements, Gravel Retention Structures, Wetland Enhancement, Upland Conservation/Enhancement, Off-Channel Modification.
- Each candidate site was labeled with the EDT "GSU" and 12th-field HUC in which it was located and assigned a unique random reference number.

Potential fish passage improvement sites were selected from documented barriers listed in the WSDOT Fish Passage Inventory, WSDOT Fish Passage - Uncorrected Barriers Subject to the Injunction, WDFW Fish Passage and Diversion Screening Inventory (FPDSI) geodatabases. Sites were selected using the following parameters: located within or draining to the reaches downstream on the proposed FRE facility; located below natural barriers; blocking use by anadromous salmonids; not yet corrected; 0 to 33 percent passable. Emphasis was placed on total adult passage barriers with more than 0.25 miles of "Lineal Gain," and those designated as being located on a "Significant Reach." Several of these barriers were also described in the Upper Chehalis Watershed Culvert Assessment (Verd and Wilson, 2003).

4.3.4 Additional Terrestrial, Floodplain, And Wetland Site Types

- In addition to the criteria described above, sites adjacent to the Chehalis River were considered in areas downstream of the City of Chehalis for potential mitigation of wildlife habitat and wetland impacts from the airport levee elements of the project.
- Several upland areas were identified for wildlife habitat mitigation. These areas were intended to address potential impacts to terrestrial birds or amphibian habitat.

4.3.5 Future Considerations

The following future considerations will apply during future mitigation planning including site selection and site-specific design development:

- Project action type that identified for a given site are preliminary: actions may add or removed actions at sites as they are examined more closely and as mitigation needs are refined and negotiated;
- Site selection was not optimized for fish production – future mitigation planning may opt to apply EDT fish productivity results to inform final site selection;
- Selection of sites for thermal benefits may later be optimized for optimal spacing of cold-water refuge sites for warm weather adult migration and holding;
- Infrastructure constraints: Are there infrastructure improvements (e.g. utilities, structures, roads, buildings) on the site that may be inconsistent with mitigation?
- Landowner outreach;
- Cultural resources;
- Refinement of mitigation needs based on the project's development of avoidance and minimization measures; and
- Adaptive management planning.

4.3.6 Illustrative Conceptual Example Sites for Cost Estimation

To test the efficacy of multi-action sites (more than one mitigation type implemented at a single location) the mitigation team selected five prototypical sites from among the many potential sites previously identified during the initial potential site identification and screening process. These five sites were utilized solely for the purpose of developing and assessing the feasibility of implementing multi-action sites and to aid in the development of mitigation unit costs by type. ***These sites are not being proposed as specific mitigation sites and are not to be considered as any form of a mitigation plan.***

To aid in the selection of generalized cost estimation, several illustrative conceptual example sites were selected. These were not intended to be proposed mitigation site: they were instead used to demonstrate how multiple complimentary mitigation action types could be deployed either on a single site or adjacent sites for construction efficiency and to maximize ecological benefits. To narrow the candidate pool for selection of these illustrative examples, the following criterial were applied to derive a subset of 72 sites:

1. Selected sites that were included in Mitigation Scenario #1 as described in the final EDT Mitigation Input technical memorandum dated June 12, 2020 (Kleinschmidt 2020) (n=86). This included the following criteria:
    A. Prioritized selection of sites within on-site GSUs
    B. Avoided sites with ASRP Early Action projects or "high potential" of ASRP overlap
2. Excluded fish passage projects (note: some were later added to example sites)
3. Excluded sites that were only riparian buffers
4. Excluded projects that were amphibian habitat conservation/enhancement buffer only

4.4 Summary of Mitigation Opportunities

The initial pool of potential mitigation site candidates includes approximately 54 miles of riparian buffer expansion, 28,500 feet of warm weather temperature refuge at hyporheic exchange enhancements at riverbends, 18,000 feet of temperature refuge groundwater retention structures, 89,000 feet of instream modifications, 220,000 feet of off-channel modifications, 18,000 feet of spawning gravel retention enhancement, 23 anadromous barrier corrections, 34 wetland enhancement sites, and 10 upland conservation/enhancement locations. This pool of sites is distributed unevenly across 45 GSUs[1]: the majority (64 percent) of sites are located within nine GSUs.

Actual total length of stream and river channel potentially available for compensatory mitigation for some action types may be considerably more extensive than shown here. For example, for this exercise, riparian buffer expansion, instream modification, and off-channel modification sites were primarily identified only in conjunction with other action types: sites could be expanded or added as needed to match impacts. Similarly, sites for gravel retention jams are intended to be illustrative: the actual number and extent of sites could be adjusted as needed.

Table 3 summarizes the initial 355-site mitigation site candidate pool by mitigation action type and GSU. GSU names were provided by ICF EDT GIS data. Displayed quantities of each aquatic habitat action type are assumed typical affected lengths. Upland and fish passage quantities are shown as numbers of sites. Summed lengths[2] were derived by multiplying number of site types by assumed average dimensions from the June 12, 2020 Preliminary Mitigation Input to Ecosystem Diagnosis and Treatment Model memorandum, shown in **Table 4**. In addition to those dimensional assumptions, the following assumptions were applied:

- riparian buffer expansion would include preservation of existing shade-producing trees and restoration (reforesting 100% of effective width on both sides of the channel on streams that currently have minimal shade);
- wood loading for large streams and small streams would match 100% of natural loading rates for treated reaches;
- each gravel retention jam site would include six 50-feet long wood structures per 900-feet long site;
- all mitigation projects involving off-channel reconnection are assumed to also include floodplain reforestation to 100 percent of effective width on both sides of the side channel;
- side channels are assumed to average 0.25 miles of new channel length per site.

[1] Geospatial Units (GSUs) are subdivisions of the drainage basin defined during the process of configuring the EDT model. GSUs provide a means of describing location on the landscape and within the drainage network. GSUs generally correlate with drainage sub-basins.
[2] "Summed lengths" refers to the cumulative total of channel length treated by each aquatic habitat action type.

Table 3
Summary of Initial Mitigation Site Candidate Pool

GSU NAME	NUMBER OF SITES	RIPARIAN BUFFER EXPANSION	HYPORHEIC EXCHANGE ENHANCEMENTS AT RIVERBENDS	GROUNDWATER RETENTION STRUCTURES	INSTREAM MODIFICATIONS	OFF-CHANNEL MODIFICATIONS	GRAVEL RETENTION JAMS	FISH PASSAGE	WETLAND ENHANCEMENTS	UPLAND CONSERVATION/ENHANCEMENT
	Units ->	*Miles*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Barriers*	*Locations*	*Locations*
Absher Creek	1	0	0	0	0	2000	0	0	0	0
Alder Creek (UC)	3	0.99	0	0	0	0	0	0	0	2
Big (UC) Creek	1	0.33	0	250	500	0	0	0	0	0
Bunker Cr	6	0	300	0	500	10000	0	0	0	0
Chehalis Abv Crim MS	39	8.58	2100	2000	10000	0	16200	0	0	4
Chehalis RB Falls to Crim MS	26	0	3600	0	6000	18000	0	4	0	1
Crim Creek (UC)	14	0.66	300	2250	5500	0	1800	0	0	1
Dillenbaugh Creek	2	0	0	0	0	0	0	0	2	0
EF Chehalis MS	43	14.19	300	9500	19500	0	0	0	0	1
Elk Cr	3	0	0	0	0	4000	0	1	1	0
Fronia Creek	1	0	0	0	0	0	0	1	0	0
Garret Creek	1	0	0	0	0	0	0	1	0	0
Hanaford Cr	9	0	0	0	1000	16000	0	0	3	0
Hope Creek	2	0	0	0	0	0	0	2	0	0
Lake (SFC) Cr	5	0	0	0	1000	6000	0	0	1	0
Lower Chehalis: Black to Porter SB	1	0	0	0	0	0	0	0	1	0
Lower Chehalis: Porter to Satsop	1	0	0	0	0	0	0	0	1	0
Lower Newaukum MS	18	3.3	3000	0	5000	18000	0	0	3	0
Lower Newaukum Tribs	1	0	0	0	0	2000	0	0	0	0
Lower SF Chehalis MS	10	1.32	1200	0	2000	12000	0	0	2	0
Lower Skookumchuck	6	1.32	1200	0	2000	6000	0	0	0	0
Mack Creek (UC)	2	0.66	0	0	0	0	0	0	0	1
Marcuson Creek	2	0	0	0	0	4000	0	0	0	0
Middle Chehalis	8	0.33	300	0	500	12000	0	0	1	0
Middle Chehalis: RBF to SF SB	22	5.28	3000	0	5000	16000	0	2	4	0
Middle Chehalis: SF to Newaukum SB	45	5.94	8700	0	14500	36000	0	0	8	0
Mill Creek	2	0	0	0	0	2000	0	1	0	0
NF Newaukum MS	6	0.33	900	0	1500	6000	0	0	0	0
Nicholson Creek	2	0	0	0	0	2000	0	1	0	0
RB Trib 0949	2	0	0	0	0	0	0	2	0	0
RB Trib 2383	1	0	0	0	0	0	0	1	0	0
Rock (UC) Creek	9	0.33	0	0	0	4000	0	6	0	0
SF Newaukum MS	6	1.65	1500	0	2500	2000	0	0	0	0
SF Newaukum Tribs	2	0.33	300	0	500	2000	0	0	0	0
Skookumchuck Tribs	4	0	0	0	0	8000	0	0	1	0
Stearns Cr	2	0	0	0	500	4000	0	0	1	0
Stillman (SFC) Cr	7	0	1500	0	2500	4000	0	0	0	0

GSU NAME	NUMBER OF SITES	RIPARIAN BUFFER EXPANSION	HYPORHEIC EXCHANGE ENHANCEMENTS AT RIVERBENDS	GROUNDWATER RETENTION STRUCTURES	INSTREAM MODIFICATIONS	OFF-CHANNEL MODIFICATIONS	GRAVEL RETENTION JAMS	FISH PASSAGE	WETLAND ENHANCEMENTS	UPLAND CONSERVATION/ENHANCEMENT
Stowe Creek	3	0	0	0	0	6000	0	0	0	0
Thrash Creek (UC)	7	2.31	0	1500	3000	0	0	0	0	0
Tidal Zone	1	0	0	0	0	0	0	0	1	0
Upper SF Chehalis MS	8	0.33	300	0	500	12000	0	0	2	0
Van Ornum Creek	2	0	0	0	0	2000	0	0	2	0
WF Chehalis MS	16	5.28	0	2500	5000	0	0	0	0	0
Willapa Hills Tribs	2	0	0	0	0	2000	0	1	0	0
Upper SF Chehalis Tribs	1	0	0	0	0	2000	0	0	0	0
Grand Total	**355**	53.5	28,500	18,000	89,000	220,000	7,200	23	34	10

Table 4
Assumed Typical Site Quantities for Each Mitigation Action Type

MITIGATION ACTION TYPE	DESCRIPTION	QUANTITY FOR A TYPICAL SITE	UNIT OF EXTENT
Riparian Buffer Expansion	Reforestation of riparian buffers along channel margins	0.33	Length (miles)
Hyporheic Exchange Enhancements	Hyporheic exchange enhancements at selected riverbends	300	Length (feet)
Groundwater Retention Structures	Structures, side channels, or alcoves that intercept groundwater and form cool water pockets for thermal refugia	250	Length (feet)
Instream Modifications	Construction of habitat features within the perennial wetted channel for several purposes	500	Length (feet)
Off-channel Modifications	Off-channel habitat enhancements including side channel and floodplain actions	2000	Length (feet)
Gravel Retention Jams	Large wood and rock structures that provide roughness to retain salmonid spawning gravels.	900	Length (feet)
Fish Passage	Fish passage improvements including replacing fish passage barrier culverts with passable crossings.	1	Each
Wetland Enhancement	Enhancement, restoration, or expansion of wetlands to benefit wildlife species.	2	Area (acre)
Upland Conservation and Enhancement	Conservation and enhancement of specific habitats matching the requirements of focal wildlife species.	10	Area (acre)

Table 5

Comparison of Estimated Mitigation Needs to Opportunities by Action Type

MITIGATION ACTION TYPES	ESTIMATED NEED	ESTIMATED AVAILABILITY
Riparian Buffer Expansion	17 miles	53 miles
Hyporheic Exchange Enhancements	9,000 ft	28,500 ft
Cold-water Retention Structures	1,000 ft	18,000 ft
Instream Modifications	17,500 ft	89,000 ft
Off-channel Modifications	8,000 ft	220,000 ft
Gravel Retention Jams	13,500 ft	18,000 ft
Fish Passage	5 barriers	23 barriers
Wetland Enhancement	1 location (3 acres)	34 locations
Upland Conservation and Enhancement	2 locations (50 acres each)	10 locations (variable size >50 acres)

Notes:

1. Estimated need was determined by combining information from Table 1 and Table 4.
2. Estimated availability was previously reported in Table 4.

5 CONCEPTUAL DESIGN EXAMPLES

The Kleinschmidt Team prepared five distinct “conceptual design groups” and cost estimates as examples to illustrate an integrated reach-scale approach to combining multiple mitigation techniques to produce high-value properly functioning ecological communities. Each conceptual design group demonstrates how integrating multiple action types can be used at a reach scale to optimize ecological benefits and achieve cost efficiencies. A separate narrative was prepared for each of the five conceptual design group examples. Each narrative is companion to the graphical presentation of the designs and the cost estimates associated with the designs. Planning-level cost estimates were prepared to include design, permitting, land acquisition, construction, construction oversight, and contingency. **Appendix A** contains the conceptual design drawings for the five example conceptual design groups along with supporting unit cost estimating tables. The cost estimates were used to develop unit costs for individual mitigation action types, and those in turn were used to build a preliminary cost estimate for anticipated potential aquatic and terrestrial habitat mitigation needs.

5.1 Ecological Mitigation Conceptual Design

To test the efficacy of multi-action sites (more than one mitigation type implemented at a single location) the mitigation team selected five prototypical sites from among the many potential sites previously identified during the initial potential site identification and screening process (See **Section 4**). These five sites were utilized solely for the purpose of developing and assessing the feasibility of implementing multi-action sites and to aid in the development of mitigation unit costs by type. ***As noted in Section 4, these sites are not being proposed as specific mitigation sites and are not to be considered as any form of a mitigation plan.***

Future mitigation planning will be subject to landowner willingness, property availability, and field confirmation of site suitability. Changes to the hydraulics and hydrology of the river will be limited to the boundaries of the mitigation site. The cost estimates have been structured to enable the calculation of typical mitigation action costs on a unit basis and then extrapolated across the mitigation area.

The following mitigation action types were integrated into the conceptual designs:

- Riparian buffer acquisition and enhancement
- Hyporheic exchange enhancement and groundwater thermal refuge creation
- Instream modifications, including gravel retention jams and beaver dam analogs
- Fish passage improvements, including culvert replacements
- Wetland restoration and enhancement
- Floodplain reconnection
- Upland conservation and enhancement

5.1.1 Conceptual Design Group #1 – Mainstem Chehalis River

Conceptual Design Group #1 (see Figure in Appendix A) is a prototypical site located on the mainstem Chehalis River within the 20-mile reach between the proposed FRE and the confluence with the South Fork Chehalis River. The primary feature of the design is the reconnection of 105 acres of floodplain that is currently in agricultural production and is predominantly treeless. Floodplain reconnection will be achieved through a combination of excavating material and addition of instream modifications to increase hydraulic roughness to raise flood water surface elevations. The earthwork will include the preservation of the top one foot of topsoil to promote plant growth. The entire floodplain will be replanted with native grasses and forbs and diverse native woody tree and shrub species, with red alder trees included as a significant component to increase nitrogen fixation. Reconnecting the floodplain will provide additional flood storage, enhanced hyporheic exchange, and will add 105 acres of restored floodplain habitats.

Instream modifications include the addition of 1000 linear feet of large wood along the mainstem riverbanks and an integrated boulder weir just downstream of the enhanced inflow area of the floodplain. The boulder weir will create additional roughness for activating the floodplain more frequently, add hydraulic diversity, and work in conjunction with the large wood to create a non-channel spanning gravel retention jam.

Areas of the mainstem river in this reach that are devoid or deficient in riparian buffer will be planted with diverse native woody tree and shrub species, with red alder trees included as a significant component to increase nitrogen fixation. Approximately 2400 linear feet with a width of 200 feet will be planted for a total of 11 acres of riparian buffer added. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity.

The south end of the project area includes an unnamed tributary culvert that has been identified by the Washington State Salmon Recovery Funding Board as one that impairs fish passage. The conceptual design includes replacement of the culvert with one that is fish passable.

Mitigation Actions Included:

- Floodplain reconnection
- Hyporheic exchange enhancement
- Instream modifications
- Riparian buffer addition
- Fish passage improvement

5.1.2 Conceptual Design Group #2 – Mainstem Chehalis River

Conceptual Design Group #2 is located on the mainstem Chehalis River immediately downstream of and adjacent to Conceptual Design Group #1 and within the 20-mile reach between the proposed FRE and the confluence with the South Fork Chehalis River. At the upper end of the project is the reconnection of

43 acres of floodplain that is currently in agricultural production and is mostly treeless. The floodplain will be reconnected primarily through the excavation of material and addition of instream modifications to increase hydraulic roughness to raise flood water surface elevations. The earthwork will include the preservation of the top one foot of topsoil to promote plant growth. The entire floodplain will be replanted with native grasses and forbs and diverse native woody tree and shrub species, with red alder trees included as a significant component to increase nitrogen fixation. Reconnecting the floodplain will provide additional flood storage, enhanced hyporheic exchange, and will add 43 acres of restored floodplain habitats.

Instream modifications include the addition of 2100 linear feet of large wood along the mainstem riverbanks and an integrated boulder weir just downstream of the enhanced inflow area of the floodplain. The boulder weir will create additional roughness for activating the floodplain more frequently, add hydraulic diversity, and work in conjunction with the large wood to create a non-channel spanning gravel retention jam.

About 1200 feet downstream of the Conceptual Design Group #2 floodplain reconnection and north of the Conceptual Design Group #1 floodplain reconnection is a 900-foot long paleo channel that is disconnected from the mainstem river. The design proposes to reconnect the paleo channel to the mainstem at its downstream end and enhance it through the excavation of 2000 cubic yards of material to selectively widen and deepen the channel. This paleo channel is located adjacent to the floodplain and at the base of an approximately 1500 acres upland area, which is 520 feet above the paleo channel with an average slope of 23%. The upland area discharges groundwater to the paleo channel creating the potential to provide both hyporheic flow and groundwater flow for thermal refugia once it is reconnected to the mainstem.

The conceptual design proposes to create a 1000 linear foot groundwater thermal refugia channel approximately 1700 feet downstream of the paleo channel reconnection. It would be constructed by excavating a gently sloping 20-foot wide channel along the base of the upland area to collect and hold cooler groundwater draining from the steep slope to the north. This channel has the potential to provide groundwater thermal refugia once it is connected to the mainstem.

There is an existing alcove about 0.28 acres in size on the left bank of the mainstem approximately 1100 feet downstream of the proposed groundwater refugia channel. The design proposes to double the size of the alcove and enhance it to provide a larger and more complex thermal refugia, requiring the excavation of nearly 5000 cubic yards of material.

Two hundred feet downstream of the alcove is a paleo channel that cuts across a peninsula formed by a mainstem river meander. The design proposes to enhance the channel as a collector of groundwater and hyporheic water to deliver cooler water to a constructed alcove about 3700 feet farther downstream. The constructed alcove will be 400 feet long and 50 feet wide located on the left bank of the mainstem, requiring 5900 cubic yards of excavation.

The design calls for instream modifications in six locations. At the upstream end of the project reach is a combination of large wood placement and a boulder weir structure to increase roughness and flood water surface elevations to increase the frequency of flood activation of the reconnected floodplain. Downstream of the created groundwater refugia channel is approximately 600 feet of large wood placement on the left bank. Just downstream of the alcove enhancement are two boulder weir structures with large wood placement to increase hydraulic head for enhanced hyporheic exchange to the downstream enhanced paleo channel and the gravel island just downstream of that. Two more boulder weirs with 720 feet of large wood placement along the right bank are called for in the southeast corner of the project site to enhance hyporheic exchange. Total large wood placement along the banks of the mainstem is approximately 2100 feet. Large wood will be included in the boulder weirs, but channel spanning log jams will be avoided for the safety of the boating community. All the instream modifications will act to increase hydraulic diversity and locally increase hydraulic head to enhance hyporheic flow and floodplain reconnection.

Riparian buffers will be added wherever they are lacking within the project area. Approximately 9000 linear feet of 200-foot wide buffer will be added for a total of 43 acres. Fifteen acres of riparian buffer will be added as part of the floodplain reforestation with 28 additional acres added elsewhere. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity.

Mitigation Actions Included:

- Floodplain reconnection
- Hyporheic exchange enhancement
- Groundwater refugia creation
- Alcove creation and expansion
- Paleo channel enhancement
- Instream modifications
- Riparian buffer addition

5.1.3 Conceptual Design Group #3 – Mainstem Chehalis River

Conceptual Design Group #3 is located on the mainstem Chehalis River within the 20-mile reach between the proposed FRE and the confluence with the South Fork Chehalis River. It is immediately downstream of and adjacent to Conceptual Design Group #2 and near the confluence of the mainstem and the South Fork Chehalis River.

The design calls for the construction of a 1-acre groundwater alcove on the left bank of the mainstem. The alcove has been located to accept groundwater from an existing channel that drains from an area approximately 1500 acres upland from the mainstem. The alcove would be constructed through the excavation of 14,500 cubic yards near the confluence of the channel and mainstem and will include a constructed channel to connect the existing channel to the alcove.

The design includes a second groundwater alcove, also on the left bank, about 2300 feet downstream of the first one. Alcove construction is combined with the enhancement of another channel that drains groundwater from an upland area. The groundwater channel enhancement will involve the selective excavation of 1400 linear feet of existing channel to improve its conveyance capacity and to direct its flow to the constructed alcove. Constructed alcove area will be approximately 0.6 acre and will require the excavation of about 6500 cubic yards. The two alcoves will serve as cool water refugia.

Adjacent to the second groundwater alcove and just downstream of the confluence of the mainstem with the South Fork Chehalis River is a 15-acre wetland on the left bank of the mainstem. The hydrology of this wetland appears to be supported by a combination of groundwater from the upland area and mainstem floodwaters. The design calls for enhancement of the wetland through grading and vegetation management. Approximately 5000 cubic yards of material will be moved to create microtopography to diversify the vegetation community and to provide breeding pools for amphibians. Existing vegetation will be managed to decrease the presence and cover of invasive non-native species. The entire site will be planted with native grasses, forbs, shrubs, and trees appropriate for the hydrologic regimes present after grading has been completed. The enhanced wetland will provide critical habitat for wetland dependent species.

Instream modifications include the installation of 2100 linear feet of large wood along three separate sections of mainstem riverbank: two on the left bank and one on the right bank. One boulder weir is called for just upstream of the smaller alcove and a couple of gravel islands with side channels. The boulder weir will also be just downstream of the confluence of the mainstem and the South Fork Chehalis River. Large wood will be included in the boulder weirs, but channel spanning logjams will be avoided for the safety of the boating community. All the instream modifications will act to increase hydraulic diversity and locally increase hydraulic head to enhance hyporheic exchange and floodplain reconnection.

Riparian buffer will be added around both alcoves, along the enhanced groundwater channel, and along both the left and right banks of the mainstem. Approximately 6000 linear feet of 200-foot wide riparian buffer will be added, for a total of 27.5 acres. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity.

Mitigation Actions Included:

- Wetland enhancement
- Hyporheic exchange enhancement
- Groundwater refugia creation
- Alcove creation
- Instream modifications
- Riparian buffer addition

5.1.4 Conceptual Design Group #4 – Upland Conservation and Enhancement

Conceptual Design Group #4 will primarily conserve and enhance 1500 acres of upland that has a strong hydrologic connection to the mainstem. The 1500 acres is the dominant upland area for nearly eight miles of the left bank mainstem within the 20-mile reach between the proposed FRE and the confluence with the South Fork Chehalis River. Its upper elevations are about 520 feet above the mainstem with an average slope of 23% that supply groundwater to the river and the paleo channels, groundwater channels, and alcoves that are part of Conceptual Design Groups #2 and #3. Current land use within the 1500 acres is agriculture and forestry.

This Conceptual Design Group would involve the purchase of the 1500 acres and reforestation of about half of the acreage with a mix of native woody shrub and tree species. The land would be placed into a conservation easement with restrictions on land uses to those that will enhance the upland habitats and hydrologic support of water quality and thermal refugia along the adjacent reach of the mainstem.

In the northwest corner of the 1500 acres is a mainstem tributary culvert that has been identified as one that impairs fish passage. The conceptual design includes replacement of the culvert with one that is fish passable.

Mitigation Actions Included:

- Upland conservation and enhancement
- Fish passage improvement

5.1.5 Conceptual Design Group #5 – South Fork Chehalis River

Conceptual Design Group #5 is located on the South Fork Chehalis River upstream of the confluence with Stillman Creek. This reach of the South Fork contains active and fallow agricultural fields such that much of the channel has no riparian trees/shrubs.

The design calls for the installation of 11 beaver dam analogs (BDA's) to increase hydraulic head to enhance hyporheic flow; reconnect the floodplain; create deep, cold water pools; and diversify riparian hydrology/vegetation. While the BDA's are intended to increase frequent flood flow access to the floodplain, they would be located and installed such that they will not adversely impact structures or other properties. Because the BDA's will most likely not be installed to top of bank, it might be advantageous to excavate some of the riverbanks to create more hydrologic diversity around the proposed "beaver ponds".

Other instream modifications include the installation of about 350 linear feet of large wood toe stabilization on two areas of severely eroding banks. The large wood toe is completely underwater to increase roughness and thus reduce velocities of high flows at the toe of bank where shear stresses are highest, and it provides fish habitat in the pool.

There are two paleo channels on this site that can be excavated to reconnect them to the river as well as deepen and widen them. This will create backwater refugia for small fish as well as floodplain wetlands for hydrologic and vegetative diversity. The agricultural fields next to the straightened reach of river provide the opportunity to create a backwater, oxbow wetland that mimics a paleo channel. This proposed floodplain feature will provide the same ecological benefits as the enhanced paleo channels.

On the opposite side of the river in the straightened reach the agricultural field provides the opportunity to create a broad, floodplain wetland. About two acres of wetland could be created by excavating about 6000 cubic yards from the floodplain. This would diversify the hydrology and riparian plant community. And it may be advantageous to connect this wetland to the proposed "beaver pond".

Riparian buffer will be added along the entire reach of river in the project area as well as around the enhanced paleo channels and floodplain wetland. The riparian buffer plantings will be tailored to the new hydrologic conditions and will include large patches of willows around the ponds to entice American beavers (*Castor canadensis*). Approximately 4000 linear feet of 100-foot to 300-foot wide riparian buffer will be added, for a total of 36 acres. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity as well as terrestrial habitat and carbon source for aquatic insects.

Mitigation Actions Included

- Floodplain reconnection
- Wetland enhancement
- Hyporheic exchange enhancement
- Alcove creation
- Instream modifications
- Riparian buffer addition
- Paleo channel enhancement

6 PRELIMINARY MITIGATION COST ESTIMATE

The Kleinschmidt team developed a preliminary estimate of the cost to implement mitigation for unavoidable impacts to aquatic and terrestrial species and their habitats. The sole purpose of this preliminary cost estimate is to provide a form of due diligence in assessing the potential cost of this mitigation to support early planning. The estimated types, amounts, and locations for mitigation do not constitute a mitigation proposal or plan. Such a plan would have to be developed during the permitting process in consultation and coordination with regulatory agencies, tribes, and stakeholders.

Planning level mitigation unit costs for each mitigation action type were developed using the conceptual design examples described in **Section 5**. The unit costs were applied to the estimated mitigation needs described in **Section 3** and shown in **Table 1**.

6.1 Planning Level Mitigation Unit Cost Development

The Kleinschmidt team used the conceptual design examples as a basis for estimating preliminary unit prices for the mitigation action types defined for this study. Preliminary estimated unit prices were developed by preparing cost estimates for the conceptual designs described above, that incorporated the mitigation action types defined for the project. The mitigation action unit prices are applied to a preliminary estimate of required mitigation quantities to develop a preliminary estimate of overall mitigation costs. A future mitigation plan will combine mitigation action types to provide a range of ecological enhancements that will, in aggregate, mitigate for the ecological impacts associated with the construction and operation of the FRE facility. The conceptual design examples used to develop the unit costs are shown graphically with narrative descriptions in the report appendices. The conceptual design examples on the plans and included in the cost estimation are for illustration purposes, and they do not represent the quantity of mitigation that will be required. **Appendix A** contains the conceptual design drawings for the five conceptual design groups along with supporting unit cost estimating tables.

The conceptual designs in aggregate include each of the mitigation action types currently under consideration. A unit cost for each mitigation action type has been prepared to allow the preparation of a planning level cost estimate for full mitigation of the FRE based on the estimated quantity of each mitigation action type (See Section 6). **Table 6** shows unit prices for a typical application of each of the nine mitigation action types defined and described in **Section 4.2**.

Table 6
Unit Costs for a Representative Typical Application of Each Mitigation Action Type

MITIGATION ACTION TYPE	REPRESENTATIVE TYPICAL COMPONENTS AND DIMENSIONS	UNIT COST
Instream Modifications	• Instream wood placement (large wood) - 300 ft • Instream wood placement (wood toe) - 200 ft • Instream boulder placement (boulder weir) – 50 ft • Beaver Dam Analogs – 1 each	$ 296,500
Hyporheic Exchange Enhancements	• Instream wood and rock placement – 300 ft	$ 163,000
Cold-water Retention Structures	• Groundwater thermal channel – 250 ft • Alcove creation – 1 acre	$ 289,250
Off-channel Modifications	• Floodplain reconnection – 16 acres • Paleo channel reconnection – 2,000 ft • Alcove enhancement/expansion – 1 acre	$ 4,830,000
Wetland Creation and Enhancement	• Wetland enhancement – 2 acres • Wetland creation – 1 acre	$ 528,000
Upland Conservation	• Upland conservation – 10 acres	$ 350,000
Gravel Retention Jams	• Instream wood placement – 900 ft	$ 163,000
Riparian Buffer Expansion	• Riparian reforestation – 0.33 mi (16 acres)	$ 816,000
Fish Passage Barrier Removal	• Culvert replacement on local road	$ 244,000

The conceptual designs are based on sites within the mainstem Chehalis Basin and the South Fork Chehalis Basin that were determined to have potential as candidate mitigation sites based on the analysis of aerial imagery. These sites selected for conceptual design were determined to be reasonably representative of conditions that would be encountered during future mitigation site selection for full design. No site visits or ground surveys were conducted to select the sites or support the conceptual design process. Therefore, the conceptual designs and the associated cost estimates are suitable for planning purposes only.

Preparation of the conceptual design cost estimates based on limited site data necessitated the application of multiple assumptions regarding construction approach and requirements. The assumptions that were used to provide a more realistic evaluation of the activities and quantities required to construct the mitigation actions represented on the designs and described in the associated narratives are listed below. Cost estimation assumptions that are specific to each mitigation action are presented in the cost summary tables below.

Conceptual Design Cost Estimation Assumptions

1. All mitigation actions that occur on private land will require the purchase of the land to implement the action.
2. Only the land directly required to implement a mitigation action will be included in the cost estimate.

3. Real estate costs per acre are based on a statistical analysis of existing land prices in Lewis County, Washington for 31 agricultural and forestry parcels for sale during the first quarter of 2020, combined with ASRP land cost information obtained from WDFW. The value used was rounded up to the nearest one thousand dollars from the average cost per acre from all parcels.
4. A unit price of $10,000 per acre was applied for all land costs in this estimate.
5. Full purchase of land will be required. For purchased lands, regulatory agencies may also require a conservation easement or similar deed restriction to establish permanent protection of the mitigation. No additional cost is applied for the placement of a conservation easement on purchased land.
6. Floodplain reconnection will require both excavation and added instream roughness elements.
7. Excavation for floodplain reconnection will require soil excavation of between 3-5 feet.
8. Excess earthwork material will be disposed of either on-site or very nearby with a short haul distance.
9. All areas of floodplain reconnection will require topsoil preservation involving stockpiling, redistribution, and grading.
10. All areas of floodplain reconnection will be planted with a diverse mix of native grasses, forbs, shrubs, and trees.
11. Fish barrier culverts will be replaced with bottomless culverts or bridges that meet Washington Department of Fish and Wildlife (WDFW) fish passage standards.
12. Existing alcoves to be enhanced will require excavation of material.
13. Alcove creation will require excavation of material.
14. Constructed alcoves will require excavation of material to down to or nearly to the adjacent channel invert elevation, for a depth of 4-8 feet.
15. Instream modifications will include the addition of boulders and large wood in various quantities and configurations.
16. Instream modifications on stream reaches used for recreation will not be channel spanning but will be limited to about 30% of the channel width.
17. Instream modifications will be placed to enhance floodplain reconnection, gravel sequestration, hyporheic exchange, hydraulic diversity, and fish cover.
18. Large wood installations will result in spacing of large wood pieces 8 feet on center.
19. Large wood will be ballasted with rock and soil.
20. Boulder weirs will consist of a double row of boulders keyed into the stream banks.
21. Boulders used in boulder weirs and other instream structures and modifications will average 2.75 feet in diameter based on placement in larger streams.
22. All work that disturbs streambanks will require seeding and erosion control.
23. Wetland enhancement will require some minimal excavation and grading.
24. Paleo channels will require selective excavation to widen and deepen them and establish connection to the main channel.
25. Paleo channels will preferentially be reconnected at the downstream end.

26. Groundwater thermal channels will require excavation to an average depth of 5 feet to connect the groundwater source to the mainstem.
27. Groundwater channel enhancement will require selective excavation to widen and deepen them.
28. Beaver dam analogs will include rootwads spaced 8 feet on center with footer logs.
29. Beaver dam analogs will require excavation, grading, and soil salvage.
30. Beaver dam analogs will require seeding, mulching, coir matting, and related erosion control measures.

Unit Cost Sensitivities

Table 7 ranks cost items according to their magnitude and variability. Unit costs shaded in red are typically the largest and most variable cost items. Those shaded in orange are moderate, and those shaded in green are lowest and least variable. High variability costs, especially grading quantities, can have a dominant effect on cost variations between alternative mitigation sites. As site selection advances, these costs may be used to inform site selection and ranking criteria that can help achieve cost efficiency.

Table 7
Unit Cost Sensitivities

COST ITEM	HEADING
Contingencies	Contingency cost is high due to the high level of uncertainty at the conceptual design stage
Topsoil Removal and Stockpile	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Bulk Soil Excavation	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Soil Hauling and Disposal	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Topsoil Placement and Final Grading	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Grading and Excavation	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Topsoil Import and Final Grading	Grading items are highly variable from site to site and usually amount to the largest cost items that drive overall cost
Land	Land costs have high variability demonstrated by experience with other recent restoration projects in the basin
Install Large Wood (wood pieces)	Cost will vary depending on size of channel
Install Boulder Weir (boulders)	Cost will vary depending on size of channel
Install Large Wood (toe wood)	Cost will vary depending on size of channel
Install Beaver Dam Analog	Cost will vary depending on size of channel
Seeding and Erosion Control	Cost will vary depending on size of channel, for example flow diversion and dewatering costs scale with channel size and flow
Reforestation	Cost could vary depending on availability of desired species
Replace Existing Culvert	Cost will vary depending on size of channel
Invasive Plant Control/Management	Cost will vary depending on density and extent of invasive plants
Engineering, Permitting, Construction Oversight	Cost will vary depending on the size of the project
Mobilization and Demobilization	
Seeding	

6.2 Preliminary Mitigation Cost Estimate

The estimated mitigation needs described in **Section 3** and shown in **Table 1** form the basis for the preliminary cost estimate. Estimated mitigation needs are presented as total quantities for each mitigation action type defined in **Section 4.2**. Unit prices developed in **Section 6.1** for each mitigation action type were applied to the estimated mitigation quantities to develop an overall estimated mitigation cost. The resulting summary of estimated mitigation costs is shown in **Table 8**. Costs for planning, design, and contingencies are embedded within the unit costs, so they are not called out separately in the cost summary table.

The preliminary cost estimate developed by the Kleinschmidt team resulted in an approximate planning-level cost of $86 million for aquatic and terrestrial habitat mitigation. That cost estimate is a conservatively high estimate based on preliminary information and the impact quantities presented in the SEPA DEIS (Ecology 2020). There are substantial opportunities to reduce project impacts by applying avoidance and minimization during future permitting and design refinement phases. The Kleinschmidt team assumed that avoidance and minimization could reduce project impacts and their associated mitigation requirements by as much as 50 percent. Actual impact reduction will have to be clearly documented during project permitting and concurrently integrated into a future formal mitigation proposal. For planning purposes, the Kleinschmidt team recommends considering this range of $43 to $86 million as a preliminary characterization of potential mitigation costs to address impacts to aquatic and terrestrial species and their habitats.

Table 8
Estimated Mitigation Costs

MITIGATION ACTION TYPE	COMPONENTS AND DIMENSIONS	UNIT COST	QUANTITY	TOTAL
Instream Modifications	• Instream wood placement (large wood) - 300 ft • Instream wood placement (wood toe) - 200 ft • Instream boulder placement (boulder weir) – 50 ft • Beaver Dam Analogs – 1 each	$ 296,500	35	$10,377,500
Hyporheic Exchange Enhancements	• Instream wood and rock placement – 300 ft	$ 163,000	30	$4,890,000
Cold-water Retention Structures	• Groundwater thermal channel – 250 ft • Alcove creation – 2 acres	$ 527,250	4	$2,109,000
Off-channel Modifications	• Floodplain reconnection – 16 acres • Paleo channel reconnection – 2,000 ft • Alcove enhancement/expansion – 1 acre	$ 4,637,000	4	$18,548,000
Wetland Creation and Enhancement	• Wetland enhancement – 2 acres • Wetland creation – 1 acre	$ 528,000	1	$528,000
Upland Conservation	• Upland conservation – 10 acres	$ 350,000	10	$3,500,000
Gravel Retention Jams	• Instream wood placement – 900 ft	$ 163,000	15	$2,445,000
Riparian Buffer Expansion	• Riparian reforestation – 0.33 mi (16 acres)	$ 816,000	51.5	$42,024,000
Fish Passage Barrier Removal	• Culvert replacement on local road	$ 244,000	5	$1,220,000
			Total:	**$85,641,500**

7 CONCLUSIONS

This Aquatic and Terrestrial Mitigation Opportunities Assessment focused on addressing three key questions and providing sufficient analysis and discussion to inform and support the answers. Each of those questions is addressed below:

Key Question #1: What are the types, locations, and quantities of mitigation likely to be required to address project impacts to aquatic and terrestrial species and habitats?

The Kleinschmidt team based the assessment of mitigation needs on the project impacts presented in the SEPA DEIS (Ecology 2020). Based on the nature of the project impacts, the Kleinschmidt team defined nine mitigation action types that could collectively replace ecological functions lost or impaired by the project impacts. On-site and off-site mitigation areas were delineated, and the area in which mitigation could occur was defined to include the upper Chehalis Basin upstream of the Skookumchuck River confluence. Mitigation quantities were estimated for each impact type based on simple measurements (e.g. impacted stream length, acreage of impacted upland) considering the nature of each kind of impact. The Kleinschmidt team's preliminary assessment of mitigation needs is detailed in **Section 3.3** and summarized in **Table 1**.

Key Question #2: Are there sufficient mitigation opportunities available to address the anticipated mitigation requirements?

Comparison of the estimated needs to the available opportunities demonstrated there are sufficient mitigation opportunities to address the anticipated unavoidable project impacts. The Kleinschmidt team identified over 350 possible candidate mitigation sites within the upper Chehalis Basin as described in Section 4. Those mitigation opportunities were converted to estimated quantities of each mitigation action type potentially available in each sub-basin within the designated mitigation area shown on **Figure 3.** Mitigation opportunities were organized by mitigation action type and sub-basin and summarized in **Table 3**. Overall mitigation opportunity exceeded the anticipated need for each of the nine mitigation action types. No formal outreach to property owners by the Kleinschmidt team occurred as part of this preliminary assessment of mitigation opportunities. Actual availability will depend on future coordination and negotiation with property owners. Similarly, any future mitigation proposal will be developed in close consultation and coordination with regulatory agencies, tribes, and stakeholders, and specific mitigation sites and actions will be subject to the review and approval of agencies in consultation with tribes.

Key Question #3: What is the approximate cost for aquatic and terrestrial habitat mitigation?

The preliminary cost estimate developed by the Kleinschmidt team resulted in an approximate planning-level cost of $86 million for aquatic and terrestrial habitat mitigation. That cost estimate is a conservatively high estimate based on preliminary information and the impact quantities presented in the SEPA DEIS (Ecology 2020). There are substantial opportunities to reduce project impacts by applying avoidance and minimization during future permitting and design refinement phases. The Kleinschmidt team assumed that avoidance and minimization could reduce project impacts and their associated mitigation requirements by as much as 50 percent. Actual impact reduction will have to be clearly documented during project permitting and concurrently integrated into a future formal mitigation proposal. For planning purposes, the Kleinschmidt team recommends considering this range of $43 to $86 million as a preliminary characterization of potential mitigation costs to address impacts to aquatic and terrestrial species and their habitats.

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Appendix A
Conceptual Design Examples and Unit Cost Estimate Tables

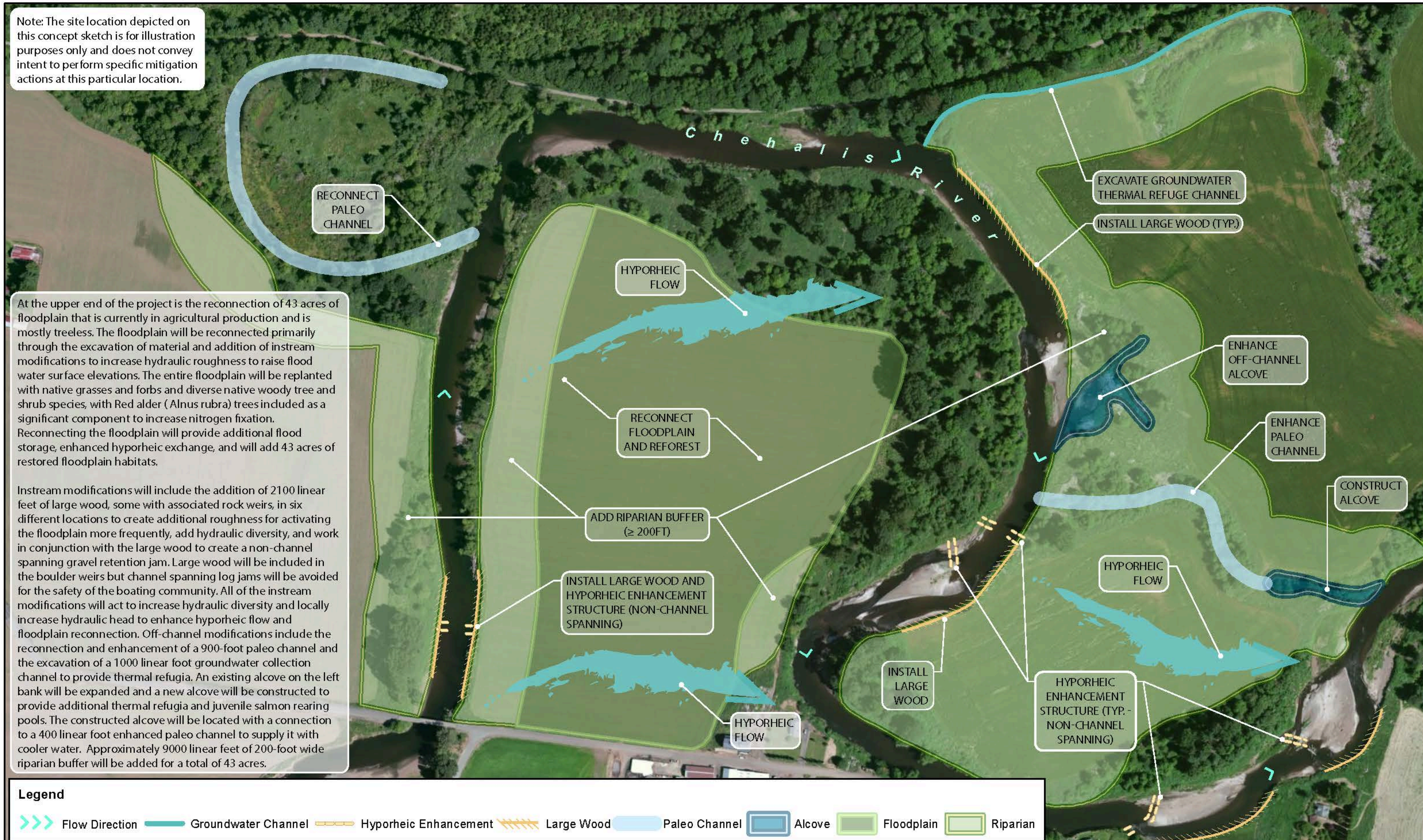
CONCEPTUAL DESIGN EXAMPLES

Chehalis Mitigation Conceptual Design - #1

Main Stem - Chehalis River *Lewis County, WA*

0 350 700 Feet

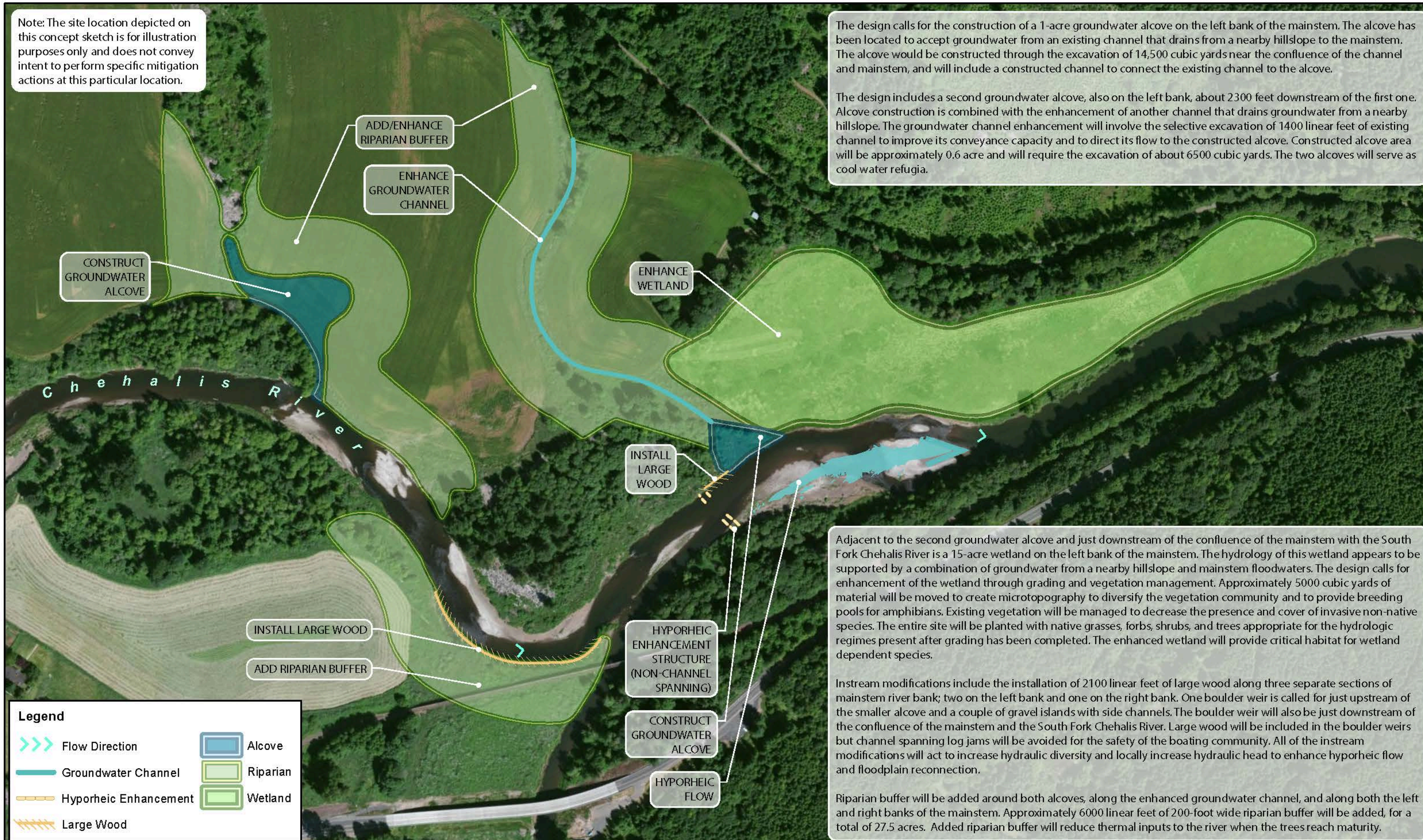
1 inch = 350 feet



Chehalis Mitigation Conceptual Design - #2

Main Stem - Chehalis River *Lewis County, WA*

0 300 600 Feet
1 inch = 300 feet
N



The design calls for the construction of a 1-acre groundwater alcove on the left bank of the mainstem. The alcove has been located to accept groundwater from an existing channel that drains from a nearby hillslope to the mainstem. The alcove would be constructed through the excavation of 14,500 cubic yards near the confluence of the channel and mainstem, and will include a constructed channel to connect the existing channel to the alcove.

The design includes a second groundwater alcove, also on the left bank, about 2300 feet downstream of the first one. Alcove construction is combined with the enhancement of another channel that drains groundwater from a nearby hillslope. The groundwater channel enhancement will involve the selective excavation of 1400 linear feet of existing channel to improve its conveyance capacity and to direct its flow to the constructed alcove. Constructed alcove area will be approximately 0.6 acre and will require the excavation of about 6500 cubic yards. The two alcoves will serve as cool water refugia.

Adjacent to the second groundwater alcove and just downstream of the confluence of the mainstem with the South Fork Chehalis River is a 15-acre wetland on the left bank of the mainstem. The hydrology of this wetland appears to be supported by a combination of groundwater from a nearby hillslope and mainstem floodwaters. The design calls for enhancement of the wetland through grading and vegetation management. Approximately 5000 cubic yards of material will be moved to create microtopography to diversify the vegetation community and to provide breeding pools for amphibians. Existing vegetation will be managed to decrease the presence and cover of invasive non-native species. The entire site will be planted with native grasses, forbs, shrubs, and trees appropriate for the hydrologic regimes present after grading has been completed. The enhanced wetland will provide critical habitat for wetland dependent species.

Instream modifications include the installation of 2100 linear feet of large wood along three separate sections of mainstem river bank; two on the left bank and one on the right bank. One boulder weir is called for just upstream of the smaller alcove and a couple of gravel islands with side channels. The boulder weir will also be just downstream of the confluence of the mainstem and the South Fork Chehalis River. Large wood will be included in the boulder weirs but channel spanning log jams will be avoided for the safety of the boating community. All of the instream modifications will act to increase hydraulic diversity and locally increase hydraulic head to enhance hyporheic flow and floodplain reconnection.

Riparian buffer will be added around both alcoves, along the enhanced groundwater channel, and along both the left and right banks of the mainstem. Approximately 6000 linear feet of 200-foot wide riparian buffer will be added, for a total of 27.5 acres. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity.

Chehalis Mitigation Conceptual Design - #3

Main Stem - Chehalis River *Lewis County, WA*

Chehalis Mitigation Conceptual Design - #4

Main Stem - Chehalis River *Lewis County, WA*

Conceptual Design Group #5 is located on the South Fork Chehalis River upstream of the confluence with Stillman Creek. This reach of the South Fork contains active and fallow agricultural fields such that much of the channel has no riparian trees/shrubs.

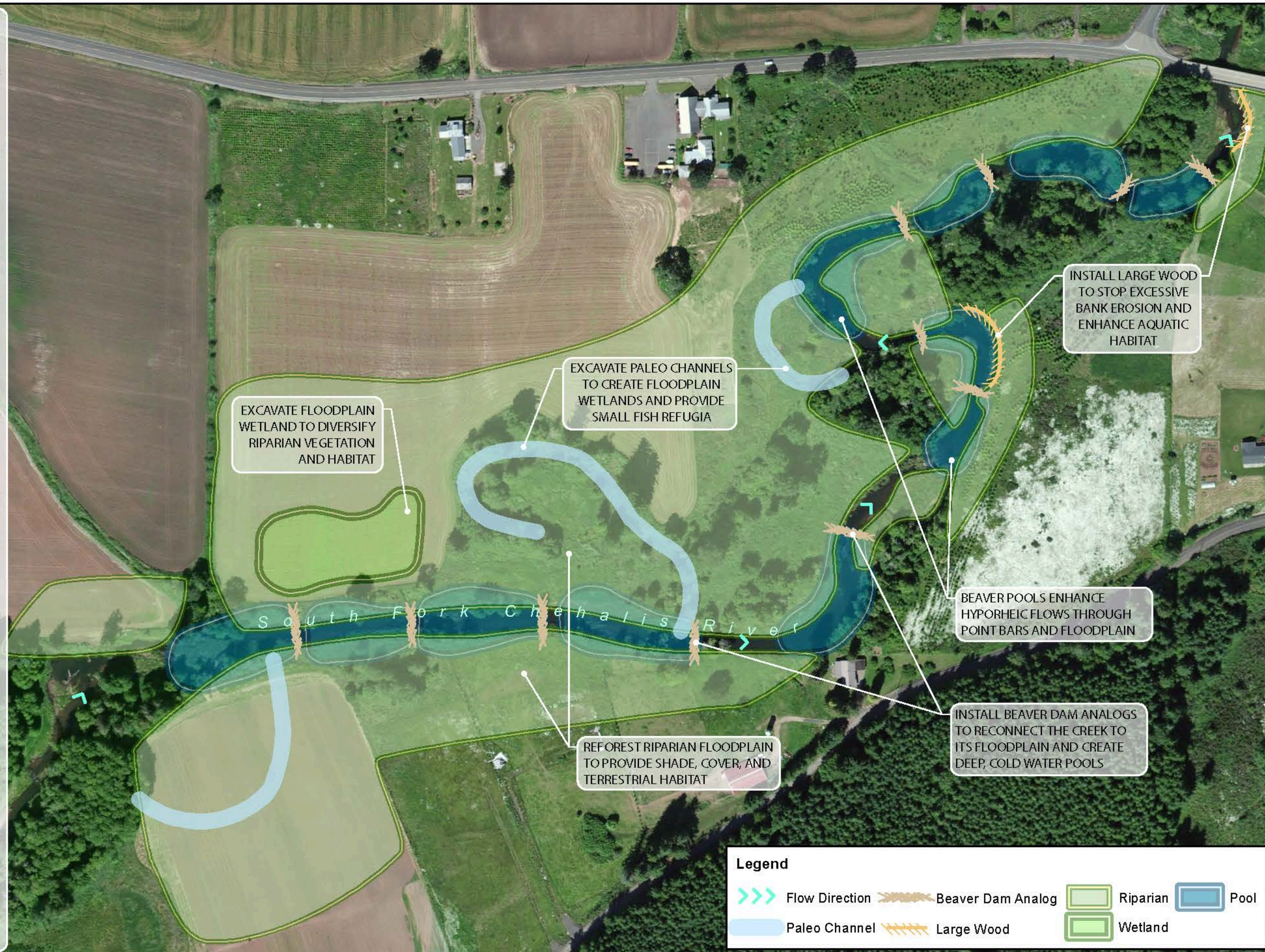
The design calls for the installation of 11 beaver dam analogs (BDA's) to increase hydraulic head to enhance hyporheic flow; reconnect the floodplain; create deep, cold water pools; and diversify riparian hydrology/vegetation. While the BDA's are intended to increase frequent floodflow access to the floodplain, they would be located and installed such that they will not adversely impact structures or other properties. Because the BDA's will most likely not be installed to top of bank, It might be advantageous to excavate some of the river banks to create more hydrologic diversity around the proposed "beaver ponds".

Other instream modifications include the installation of about 350 linear feet of large wood toe stabilization on two areas of severely eroding banks. The large wood toe is completely underwater to increase roughness and thus reduce velocities of high flows at the toe of bank where shear stresses are highest and it provides fish habitat in the pool.

There are two paleo channels on this site that can be excavated to reconnect them to the river as well as deepen and widen them. This will create backwater refugia for small fish as well as floodplain wetlands for hydrologic and vegetative diversity. The agricultural fields next to the straightened reach of river provide the opportunity to create a backwater, oxbow wetland that mimics a paleo channel. This proposed floodplain feature will provide the same ecological benefits as the enhanced paleo channels.

On the opposite side of the river in the straightened reach the agricultural field provides the opportunity to create a broad, floodplain wetland. About two acres of wetland could be created by excavating about 6000 cubic yards from the floodplain. This would diversify the hydrology and riparian plant community. And it may be advantageous to connect this wetland to the proposed "beaver pond".

Riparian buffer will be added along the entire reach of river in the project area as well as around the enhanced paleo channels and floodplain wetland. The riparian buffer plantings will be tailored to the new hydrologic conditions and will include large patches of willows around the ponds to entice beavers. Approximately 4000 linear feet of 100-foot to 300-foot wide riparian buffer will be added, for a total of 36 acres. Added riparian buffer will reduce thermal inputs to the river when the trees reach maturity as well as terrestrial habitat and carbon source for aquatic insects.



Chehalis Mitigation Conceptual Design - #5

South Fork - Chehalis River *Lewis County, WA*

0 225 450 Feet

1 inch = 225 feet

UNIT COST ESTIMATE TABLES

LEGEND	
	High cost driver
	Moderate cost driver

ABBREVIATIONS
cy = cubic yard
sf = square foot
lf = linear foot

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
INSTREAM MODIFICATIONS	Construction of habitat features within the perennial wetted channel for several purposes	
Instream Wood Placement	Light installation of large wood to create hydraulic roughness and diversity, provide cover for fish, and to retain groundwater seeps for thermal refugia	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
INSTALL LARGE WOOD INSTREAM	l		1. Trees with intact root wads will be used
Mobilization and Demobilization	lump sum	2,000	2. Trees will be installed 8 feet on center
Install Large Wood	each	400	3. Trees will be ballasted with rock and soil
Seeding and Erosion Control	sf	1	4. Disturbed areas will be seeded and receive erosion control treatments
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per liner foot of large wood installation	linear foot	$125.00	

MITIGATION ACTION TYPE	DESCRIPTION
Instream Wood Placement	Heavy installation of large wood with footer logs to create hydraulic roughness and diversity, provide cover for fish, and to retain groundwater seeps for thermal refugia

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
INSTALL WOOD TOE INSTREAM	l		1. Trees with intact root wads will be used
Mobilization and Demobilization	lump sum	2,000	2. Trees will be installed 8 feet on center
Install Wood Toe	linear foot	400	3. Trees will be ballasted with rock and soil
Seeding and Erosion Control	sf	1	4. Disturbed areas will be seeded and receive erosion control treatments
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per liner foot of wood toe installation	linear foot	$790.00	

MITIGATION ACTION TYPE	DESCRIPTION
Instream Boulder Placement	Install large boulders to create hydraulic roughness and diversity, hydraulic backwater to enhance hyporheic exchange and floodplain reconnection

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
CHANNEL MODIFCATIONS			1. Boulder weirs will consist of two rows of boulders
Mobilization and Demobilization	lump sum	2,000	2. Boulders will average 2.75 feet in diameter
Install Boulder Weir (boulders)	each	370	3. Boulders will be keyed into the bank
ITEM SUB-TOTAL			4. Boulder weir will not be channel spanning
Contingencies	%	40	5. Boulder weir will typically be combined with instream wood placement
Engineering, Permitting, Construction Oversight	%	20	
Land	acre	10,000	
Unit cost per liner foot of boulder installation	linear foot	$240.00	

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
INSTREAM MODIFICATIONS Continued	Construction of habitat features within the perennial wetted channel for several purposes	
Beaver Dam Analogs	Construct beaver dam analogs to simulate benefits of beaver dams and encourage beaver activity	

Item Description	Units	Unit Cost ($)
CHANNEL MODIFCATIONS		
Mobilization and Demobilization	lump sum	2,000
Install Large Wood (toe wood)	lf	400
Install Beaver Dam Analog	each	15,000
Grading and Excavation	cy	20
Seeding and Erosion Control	sf	1
ITEM SUB-TOTAL		
Contingencies	%	40
Engineering, Permitting, Construction Oversight	%	20
Land	acre	10,000
Unit cost per each beaver dam analog	each	$89,000.00

MITIGATION ACTION ASSUMPTIONS

1. Rootwads will be placed 8 feet on center with footer logs and rock ballast
2. Topsoil will be salvaged and replaced
3. Disturbed areas will be seeded with permanent native seed mix
4. Disturbed areas will receive mulch with coir matting on channel banks
5. Site will undergo finished grading
6. Surplus material will be hauled to onsite or very nearby disposal location

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
Hyporheic Exchange Enhancements	Hyporheic exchange enhancements to provide thermal refugia for aquatic organisms	
Instream Wood and Rock Placement	Place non-channel-spanning wood and rock structures instream to increase hyporheic exchange	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
INSTALL HYPORHEIC EXCHANGE ENHANCEMENT			1. Trees with intact root wads will be used
Mobilization and Demobilization	lump sum	2,000	2. Trees will be installed 8 feet on center
Install Large Wood	each	400	3. Trees will be ballasted with rock and soil
Install Boulder Weir	each	370	4. Disturbed areas will be seeded and receive erosion control treatments
Seeding and Erosion Control	sf	1	5. Boulder weirs will consist of two rows of boulders
ITEM SUB-TOTAL			6. Boulders will average 2.75 feet in diameter
Contingencies	%	40	7. Boulders will be keyed into the bank
Engineering, Permitting, Construction Oversight	%	20	8. Boulder weir will not be channel spanning
Land Purchase	acre	10,000	9. Boulder weir will typically be combined with instream wood placement
Unit cost per each hyporheic installation	each	$163,000.00	

MITIGATION ACTION TYPE	DESCRIPTION	
FISH PASSAGE BARRIER REMOVAL	Remove small dams and replace culverts that are fish barriers	
Culvert Replacement	Replace existing culvert with fish passable culvert	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
REPLACE FISH BARRIER CULVERT			1. Existing culvert is on a small tributary to mainstem
Mobilization and Demobilization	lump sum	2,000	2. Replacement culvert will meet WDFW fish passage standards
Replace existing culvert	each	150,000	3. Countersunk or bottomless arch culvert will be used
ITEM SUB-TOTAL			4. Minimal channel restoration included
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per each culvert replaced	each	$244,000.00	

MITIGATION ACTION TYPE	DESCRIPTION	
RIPARIAN BUFFER EXPANSION	Expansion and enhancement of riparian buffer beyond forest practices requirements	
Riparian Buffer Expansion	Plant trees and shrubs and place riparian zone in a conservation easement	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
INSTALL/ENHANCE RIPARIAN BUFFER			1. Riparian width = 200 feet
Mobilization and Demobilization	lump sum	2,000	2. Entire width and length is devoid of woody vegetation
Plant Trees and Shrubs	acre	25,000	3. Planting density is medium
ITEM SUB-TOTAL			4. Invasive vegetation management will be minimal
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per acre riparian buffer expansion	acre	$51,000	

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
OFF-CHANNEL MODIFICATIONS	Off-channel habitat enhancements including side channel and floodplain actions	
Floodplain Reconnection	Reconnect floodplain through excavation; associated rock and wood structures are priced separately	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
FLOODPLAIN RECONNECTION			1. Excavation depth = 3-5 feet
Mobilization and Demobilization	lump sum	2,000	2. Topsoil removal, stockpile, and replacement to a depth of 1-foot
Top Soil Removal and Stockpile	cy	5	3. Installation of large wood along stream banks
Bulk Soil Excavation	cy	15	4. Installation of boulder weir
Soil Hauling and Disposal	cy	5	5. Reseed entire site
Top Soil Placement and Final Grading	cy	5	6. Reforest entire site
Seeding	acre	2,000	7. Land purchase will be required
Reforestation	acre	25,000	
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per acre of reconnected floodplain	acre	$263,000.00	

MITIGATION ACTION TYPE	DESCRIPTION
Paleo Channel Reconnection	Reconnect existing paleo channels to provide thermal refugia and juvenile salmonid rearing habitat

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
PALEO CHANNEL RECONNECTION			1. Channel width is 20 feet
Mobilization and Demobilization	lump sum	2,000	2. Channel will be selectively widened and deepend through excavation
Grading and Excavation	cy	20	3. Excess material will be hauled to an onsite or very nearby disposal location
Final Grading	cy	5	4. Disturbed areas will undergo erosion control treatment and seeding
Seeding and Erosion Control	sf	1	
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per linear foot of reconnected paleo chan	linear foot	$118.00	

MITIGATION ACTION TYPE	DESCRIPTION
Alcove Enhancement/Expansion	Enlarge and enhance existing alcoves to serve as juvenile salmonid rearing habitat and thermal refugia

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
ALCOVE ENHANCEMENT/EXPANSION			1. Existing alcove area will be doubled
Mobilization and Demobilization	lump sum	2,000	2. Alcove will be expanded through excavation
Bulk Soil Excavation	cy	15	3. Mean excavation depth is 5 feet
Soil Hauling and Disposal	cy	5	4. Disturbed areas will undergo erosion control treatment and seeding
Seeding and Erosion Control	sf	1	5. Excess material will be hauled to an onsite or very nearby disposal location
ITEM SUB-TOTAL			6. Land purchase will be required
Contingencies		40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per acre of alcove enhancement/expansion	acre	$193,000.00	

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
WETLAND CREATION AND ENHANCEMENT	Enhance and restore existing wetlands	

Wetland Enhancement

Enhance existing wetlands to expand hydrologic diversity and improve the native vegetative community

Item Description	Units	Unit Cost ($)
WETLAND ENHANCEMENT		
Mobilization and Demobilization	lump sum	2,000
Grading and excavation	cy	20
Topsoil Import and Final Grading	cy	40
Invasive Plant Control/Management	acre	10,000
Revegetation	acre	25,000
Seeding and Erosion Control	sf	1
ITEM SUB-TOTAL		
Contingencies		40
Engineering, Permitting, Construction Oversight	%	20
Land Purchase	acre	10,000
Unit cost per acre of wetland enhancement	acre	$105,000.00

MITIGATION ACTION ASSUMPTIONS

1. Wetland area will be graded to enhance hydrologic diversity
2. Wetland area will receive initial invasive plant control and management
3. Area will be revegetated with native grasses, forbs, shrubs, and trees as appropriate
4. Land purchase will be required

Wetland Creation

Create wetlands to expand hydrologic diversity and native vegetative community

Item Description	Units	Unit Cost ($)
WETLAND CREATION		
Mobilization and Demobilization	lump sum	2,000
Grading and excavation	cy	20
Topsoil Import and Final Grading	cy	40
Invasive Plant Control/Management	acre	10,000
Revegetation	acre	25,000
Seeding and Erosion Control	sf	1
ITEM SUB-TOTAL		
Contingencies	%	40
Engineering, Permitting, Construction Oversight	%	20
Land	acre	10,000
Unit cost per acre of wetland creation	acre	$318,000.00

MITIGATION ACTION ASSUMPTIONS

1. Topsoil will be salvaged and replaced
2. Topsoil or compost will be imported to supplement existing topsoil
2. Wetland area will receive initial through 2 years invasive plant control and management
3. Area will be revegetated with native grasses, forbs, shrubs, and trees as appropriate
4. Area will undergo erosion control treatment, including seed, mulch, and coir matting for channel banks
5. Land purchase will be required

MITIGATION ACTION TYPE	DESCRIPTION	
UPLAND CONSERVATION	Conserve and enhance existing upland forest	

Upland Conservation

Place conservation easement on uplands and enhance the vegetative community

Item Description	Units	Unit Cost ($)
UPLAND CONSERVATION AND RESTORATION		
Mobilization and Demobilization	lump sum	4,000
Invasive Plant Control/Management	ac	10,000
Revegetation	ac	25,000
ITEM SUB-TOTAL		
Contingencies		30
Engineering, Permitting, Construction Oversight	%	10
Land Purchase	acre	10,000
Unit cost per acre of upland conserved and enhanced	acre	$35,000.00

MITIGATION ACTION ASSUMPTIONS

1. Existing forest cover is 50%
2. Non-forested areas will undergo invasive species removal and management
3. Non-forested areas will be planted with diverse woody species
4. Land will be placed in a conservation easement
5. Land purchase will be required

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
GRAVEL RETENTION JAMS	Construct large rock and wood structures	
Gravel Retention Jams	Construct large non-channel-spanning wood and rock structures instream primarily to provide roughness to retain salmonid spawning gravels	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
CHANNEL MODIFCATIONS			1. Trees with intact root wads will be used
Mobilization and Demobilization	lump sum	2,000	2. Trees will be installed 8 feet on center
Install Large Wood (LWD pieces)	each	400	3. Trees will be ballasted with rock and soil
Install Boulder Weir (boulders)	each	370	4. Disturbed areas will be seeded and receive erosion control treatments
Seeding and Erosion Control	sf	1	5. Boulder weirs will consist of two rows of boulders
ITEM SUB-TOTAL			6. Boulders will average 2.75 feet in diameter
Contingencies	%	40	7. Boulders will be keyed into the bank
Engineering, Permitting, Construction Oversight	%	20	8. Boulder weir will not be channel spanning
Land	acre	10,000	9. Boulder weir will typically be combined with instream wood placement
Unit cost per each gravel retention jam	each	$163,000.00	

MITIGATION ACTION TYPE	DESCRIPTION	MITIGATION ACTION ASSUMPTIONS
COLDWATER RETENTION STRUCTURES	Excavate pools and channels between cold water sources and the mainstem	
Groundwater Thermal Channel	Construct new channels that intersect existing stream channel and cooler groundwater for thermal refugia and juvenile rearing habitat	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
GROUNDWATER REFUGE CHANNEL			1. Channel width is 40 feet
Mobilization and Demobilization	lump sum	2,000	2. Channel will be gently sloping from groundwater source to condfluence with maintem
Grading and Excavation	cy	20	3. Channel will be excavated along the base of the slope supplying groundwater
Topsoil Import and Final Grading	cy	40	4. Excess material will be hauled to an onsite or very nearby disposal location
Seeding and Erosion Control	sf	1	5. Land purchase will be required
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per linear foot of groundwater thermal channel	linear foot	$205.00	

MITIGATION ACTION TYPE	DESCRIPTION	
Alcove Creation	Construct alcoves off of mainstem that intercept groundwater to serve as juvenile salmonid rearing habitat and thermal refugia	

Item Description	Units	Unit Cost ($)	MITIGATION ACTION ASSUMPTIONS
ALCOVE CREATION			1. Alcove will be constructed along mainstem near confluence with groundwater discharge
Mobilization and Demobilization	lump sum	2,000	2. Alcove will require excavation of 4-8 feet across its area
Bulk Soil Excavation	cy	15	3. Excess material will be hauled to an onsite or very nearby disposal location
Soil Hauling and Disposal	cy	5	4. Land purchase will be required
Seeding and Erosion Control	sf	1	
ITEM SUB-TOTAL			
Contingencies	%	40	
Engineering, Permitting, Construction Oversight	%	20	
Land Purchase	acre	10,000	
Unit cost per acre of alcove creation	acre	$238,000.00	

Appendix B
Hyporheic Flow Enhancement White Paper

HYPORHEIC FLOW ENHANCEMENT

1 Abstract

This paper explores and evaluates the possible use of hyporheic flow enhancement to mitigate elevated water temperatures affecting aquatic species in the upper Chehalis River Basin. The Chehalis Flood Control Zone District engaged the Kleinschmidt consulting team to prepare a mitigation assessment to guide planning for mitigation to address unavoidable impacts to aquatic and terrestrial resources resulting from construction and operation of flood hazard mitigation measures including a Flood Reduction Only – Expandable (FRE) facility and levee improvements. Early in the mitigation planning process, project impacts on water temperatures were identified as a high-priority project impact that would be particularly challenging to address in the context of a watershed impaired by elevated water temperature as a pre-project baseline condition. The Kleinschmidt team identified hyporheic flow enhancement as a potential innovative mitigation technique to address project impacts on water temperature. The analysis documents examples of hyporheic flow enhancement and discusses the feasibility and potential benefits of incorporating hyporheic flow enhancement as a component of a comprehensive aquatic habitat mitigation plan.

Stream temperatures in Western Washington have been increasing for decades as a result of land use activities that include forestry, agriculture, flood control, water diversions, and development. Native salmon and trout species are particularly dependent on water temperature for survival. Protecting cold-water aquatic life from existing and anticipated future thermal stress will require significant watershed management actions that include expansion and preservation of woody riparian vegetation, transfer of water rights to instream flow during low flow periods, floodplain reconnection, utilization of groundwater inflow areas, and the enhancement of hyporheic zones. The hyporheic zone is defined as the saturated interstitial areas beneath the stream bed and into the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (White 1993). In floodplain rivers with lateral hyporheic zones that are larger than the surface area of the stream channel, interstitial volume available to conduct hyporheic flow can be greater than the surface water volume (Edwards, 1998). Hyporheic flow is biogeochemically distinct from groundwater and serves many valuable functions in dynamic freshwater systems, including instream thermal regulation and nutrient cycling in support of primary biomass production. Because benefits would be realized within one year of enhancement, hyporheic flow projects as early actions could provide readily implementable thermal refuge for sensitive aquatic species while additional, more long-term, actions (such as riparian planting to increase shade) are implemented in the watershed. Enhancement of hyporheic flow exchange has the potential to increase the migration, spawning, and rearing success of native anadromous salmonids and increase primary production that supports the aquatic food chain. Thermal mitigation can be achieved in the riverine environment by modifying and capitalizing on existing

geographic locations and morphologic features that are already actively providing hyporheic flow exchange or have the capacity to improve exchange. An effective application of hyporheic flow enhancement would be to establish strategically distributed pockets of accessible cold water thermal refugia for aquatic species during times when average water temperatures are detrimental or lethal to aquatic species. Such a strategy could be applied as an early action that provides immediate and sustained benefits during the longer time required to increase the extent of forested riparian zones that shade the drainage network and provide long-term water temperature reduction. While this analysis initially focused on the water temperature benefits of hyporheic flow enhancement, research has revealed a broad and complex suite of ecological benefits provided by hyporheic flow. In conclusion, hyporheic flow enhancement could be used strategically as an integrated component of an aquatic mitigation plan providing multiple ecological benefits in addition to thermal refugia.

2 Introduction

Stream temperatures in Western Washington have been increasing for decades as a result of land use activities that include forestry, agriculture, flood control, water diversions, and development. Some water bodies, including the Chehalis River, have experienced water temperature increases that have exceeded water quality criteria for aquatic species, thereby impacting the migration, spawning, and rearing of native anadromous fish species. Climate change is expected to exacerbate the warming trend primarily by decreasing late summer flows and increasing heat transfer from warmer air to stream water. In many of Washington's streams and lakes, the duration of periods that cause stress to salmon because of warmer temperatures and migration barriers is projected to at least double and perhaps quadruple by the 2080s (Mantua et al. (2010)). The expanded warm water duration is expected to have the greatest impact to late summer and early fall spawning. Increased water temperatures can be lethal for salmon and other cold-water species.

Protecting cold water aquatic life from existing and anticipated future thermal stress will require significant watershed management actions that include expansion and preservation of woody riparian vegetation, transfer of water rights to instream flow during low flow periods, floodplain reconnection, utilization of groundwater inflow areas, and the enhancement of hyporheic zones. This discussion is focused on enhancement of the hyporheic zone and hyporheic flow exchange because it is an early action that can provide readily implementable thermal refuge for sensitive aquatic species while additional, more long-term, actions can be incorporated into the watershed.

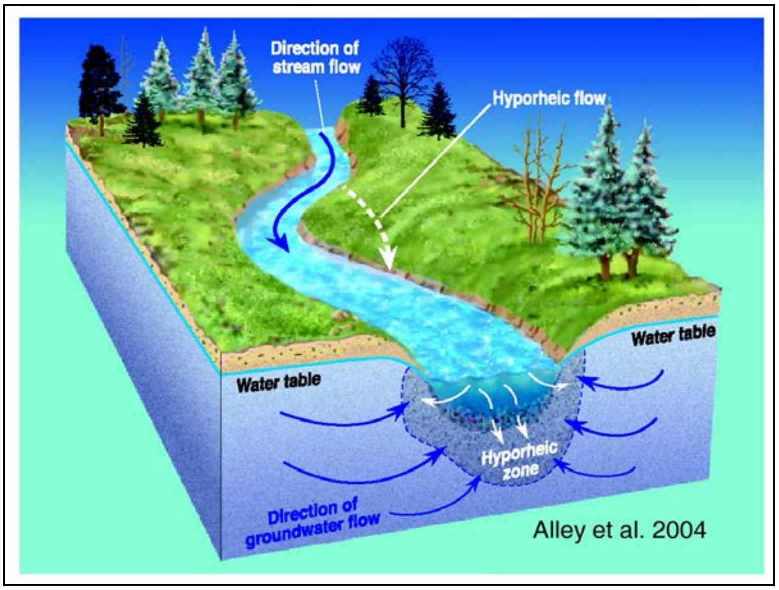
The hyporheic zone is defined as the saturated interstitial areas beneath the stream bed and into the stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (White 1993). The word "hyporheic" is composed of the Latin words "hypo", meaning below, and "rheic", meaning flow. The hyporheic zone is the volume of native porous materials, including sand and gravel, that undergoes an exchange of flow between the shallow groundwater and surface water (Figure 1). The flow of water through this zone is referred to as hyporheic flow. Hyporheic flow is biogeochemically distinct from groundwater. Hyporheic flow serves many valuable functions in dynamic freshwater systems, including instream thermal regulation and nutrient cycling in support of primary biomass production. These two primary functions will be treated separately here with an emphasis on thermal regulation. Enhancement of hyporheic flow exchange has the potential to increase migration, spawning, and rearing success of native anadromous salmonids and increase primary production that supports the aquatic food chain.

3 Overview of Hyporheic Zone Functions and Processes

3.1 Definition of the Hyporheic Zone

An important and defining element of the hyporheic zone is the presence of surface water because of its influence on both thermal exchange and biogeochemical processes, or the flow of chemical elements and compounds between living organisms and the physical environment. There is an important distinction between surface water, groundwater, and hyporheic water in defining the influence of the hyporheic zone. In the context of the riverine environment, “Surface water” is water that is contained within the river channel with sources that include direct rainfall, surface runoff, and groundwater inflow. “Groundwater” is subsurface water that has not entered a channel or other surface water body. “Hyporheic water” is subsurface water within close proximity to a river channel that contains a significant proportion of surface water resulting from direct exchange between the channel and the underlying and adjacent saturated interstitial areas. Defining the hyporheic zone by surface water content within the interstitial areas associated with a stream channel provides a framework for understanding the thermal exchange and biogeochemical processes between the channel and the hyporheic zone. The hyporheic zone can also be defined in more strictly biological terms. Hyporheic fauna, known as the hyporheos, are often distinguished by life history characteristics or adaptations to life within sediment intersticies (Edwards, 1998).

Figure 1
Hyporheic Zone



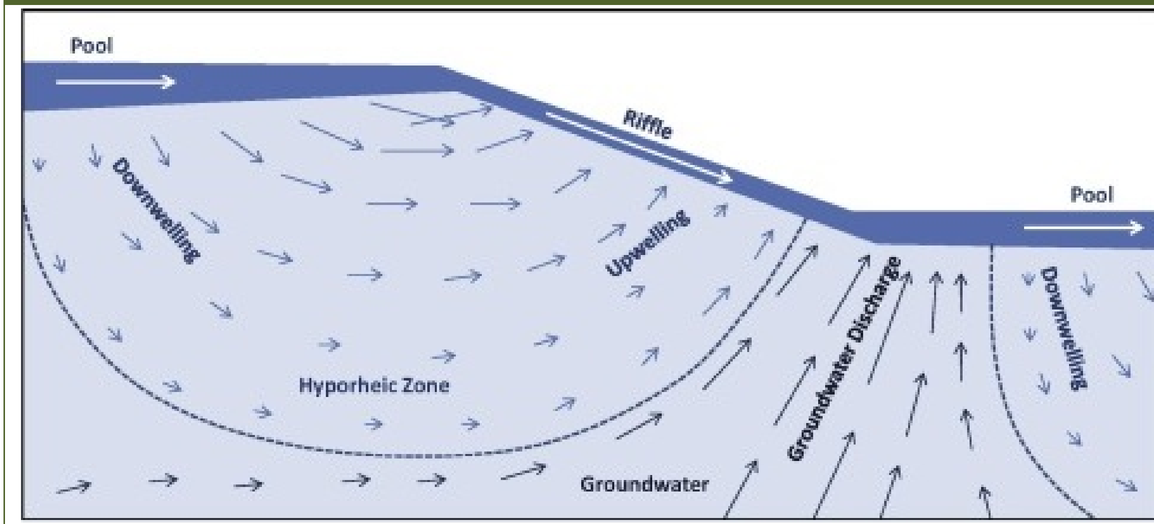
Hyporheic zones in alluvial rivers are dominant links between the riparian forest and the stream channel. The porous, hydraulically conductive sediments characteristic of alluvial rivers of the Pacific coastal ecoregion support extensive hyporheic zones. Hyporheic zones are hotspots of biological diversity that contain intensive physical and chemical gradients. Hyporheic zone processes can dominate surface water quality (Edwards, 1998). Rivers with extensive hyporheic zones retain and process nutrients with greater efficiency than rivers without. Organic matter elimination can be two times greater in rivers with intact hyporheic zones. Upwelling nutrients from hyporheic zones influence primary production within surface communities and accelerate the recovery of surface production from floods and other disturbances (Edwards, 1998).

3.2 Hydrology and Hydraulics

Understanding the hydrology and hydraulics of hyporheic flow exchange is necessary to better understand the natural formation of hyporheic zones, how human activity can impact them, and what measures can be taken to enhance them. The hydrology of the hyporheic zone, defined by the exchange of water between the stream channel and the adjacent porous materials (such as sand, gravel, and cobble), controls the rate and extent of biogeochemical processes, nutrient cycling, and thermal exchange. Depending on the extent of alluvium within a river valley and the strength of processes driving hyporheic flow, the hyporheic zone may extend vertically up to tens of meters and horizontally hundreds of meters to more than a kilometer (Stanford and Ward 1988). In floodplain rivers with lateral hyporheic zones that are larger than the surface area of the stream channel, interstitial storage volume available to conduct hyporheic flow can be greater than the surface water storage volume. Stanford and

Ward (1988) estimated hyporheic flow volumes along a floodplain reach of the Flathead River in Montana to be 2,400 times greater than channel volume. Generally, downstream flow rate in the channel is much larger than the rate of flow through the hyporheic zone, but it is possible for the volume of water stored within the hyporheic zone to be much greater than the volume of water present in the channel.

Figure 2
Hyporheic Zone Hydraulics in a Pool-Riffle Stream Reach (profile view)



Flow through the hyporheic zone can be estimated using Darcy's law, described as:

$Q = (K)A(\Delta h/\Delta l)$

Where:

Q = Discharge of water through sediment (m^3/s)

A = Cross sectional area of flow (m^2)

K = Hydraulic conductivity of the sediment through the hyporheic zone (m/s)

Δh = Hydraulic head between two points under consideration (m)

Δl = Distance between the two points under consideration (m)

Hyporheic flow is primarily dependent on the hydraulic conductivity of the sediment and the hydraulic head on the sediment. Hydraulic conductivity is a measure of flow resistance, and is a function of sediment particle size, shape, and grading (particle size distribution). Sediment particle sizes range from boulders in the high energy reaches of mountain streams to silts and clays in the lower energy reaches and estuaries. Grading can range from well graded with greater pore space and higher hydraulic conductivity to poorly graded with lesser pore space and lower hydraulic conductivity. The high porosity of alluvium in the Pacific coastal ecoregion creates large interstitial volume and high flow velocities, which are optimal traits for hyporheic flow (Edwards, 1998).

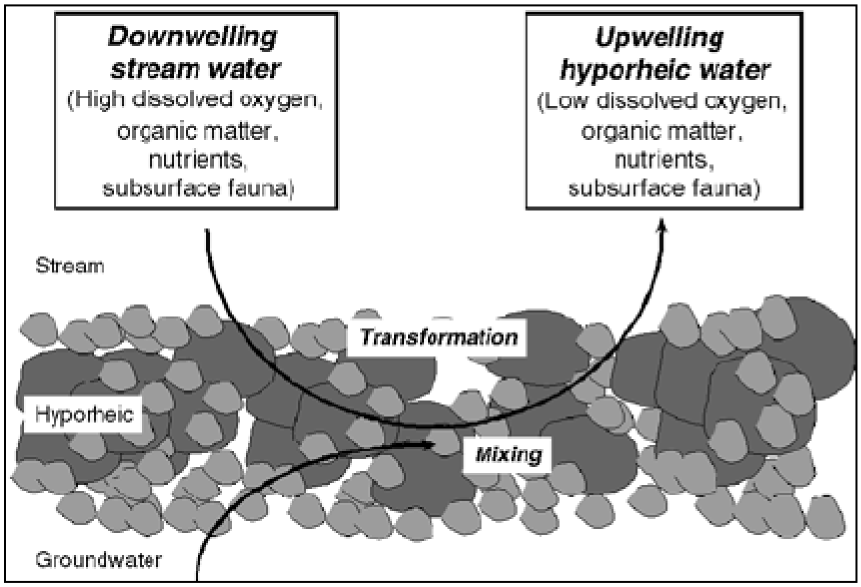
Total hydraulic head in an open channel, such as a stream, is a combination of static and dynamic head. Static head is measured as pressure created by the horizontal depth of water between two points. Dynamic head is measured as the pressure created by the momentum of water in motion. Hydraulic head is the driving force of hyporheic exchange. In the Darcy equation, division of the hydraulic head by the distance over which it is measured gives the hydraulic gradient. The greater the hydraulic gradient is the higher the hyporheic flow will be for a given hydraulic conductivity.

Hydraulic conductivity and hydraulic head are the controlling factors in the *rate* of flow through the hyporheic zone. The *volume* of flow is a function of the area of flow, with rate multiplied by area equaling flow. Efforts to increase hyporheic flow should include increasing hydraulic head on the hyporheic zone, increasing hydraulic conductivity of the sediments, and/or increasing the cross-sectional flow area.

3.3 Biogeochemical Processes

Hyporheic flow exchange is the driving force of biogeochemical processes within the hyporheic zone that have a profound effect on nutrient cycling and biological activity within streams (Figure 3). A biogeochemical cycle is a natural pathway by which essential elements of living matter are circulated. The hyporheic zone is an ecotone, or a region of transition between two biological communities, that provides a biogeochemical link between the riparian forest and the stream channel. The influence of hyporheic biogeochemical processes on water quality and primary production of organic matter stems from the combination of an enormous, highly reactive surface area and long periods of sediment and water contact (Edwards, 1998). The surface area available for biological activity within hyporheic zone sediments of alluvial rivers can be much greater than the surface area of the channel. Stanford and Ward (1988) estimated hyporheic habitat volume to be 2,400 times greater than channel habitat volume along a floodplain reach of the Flathead River, Montana.

Figure 3
Hyporheic Exchange Nutrient Cycling



Nutrient cycling in the hyporheic zone is enhanced by a process of transient storage that increases the residence time of water and expands the contact time between solutes and the hyporheos, or the collective organisms that inhabit the hyporheic zone. Essential elements of living matter that are cycled through the hyporheic zone include oxygen, nitrogen, carbon, phosphorus, carbon dioxide, and methane. Oxygen is supplied to the hyporheic zone by the downwelling of oxygenated stream water and from photosynthesis occurring in the algal communities of the hyporheos. Algal communities are more concentrated in areas of upwelling adjacent to riparian areas in the Pacific Northwest that include a red alder (*Alnus rubra*) component of the woody vegetation due to the higher concentration of dissolved nitrogen from nitrogen fixation. Primary production in the streams of Western Washington and Oregon can be limited by low nitrogen levels. In relatively undeveloped forested portions of watersheds, the primary source of nitrogen is nitrogen fixation through the symbiotic relationship between red alder trees *(Alnus rubra*) and *Frankia alni*, an actinomycete, filamentous, nitrogen-fixing bacterium. Red alder is a common riparian zone tree in the Pacific Northwest that fixes nitrogen within the hyporheic zone. Downwelling of hyporheic water from a forest containing red alder trees supplies nitrogen in support of the base of the food chain that ultimately provides food for juvenile salmonids.

Carbon is typically supplied to the stream and its hyporheic zone as inputs of organic matter from the riparian zone. This organic carbon serves as a food source for non-photosynthetic microorganisms living on the sediment surfaces known as the epilithon. Epilithic bacteria within this community rapidly take up and metabolize dissolved organic matter, thereby serving as the primary driver of carbon cycling.

3.4 Hyporheos Ecology

Bacteria and protozoans readily colonize rocks and sediments near hyporheic upwelling and downwelling in the benthic zone. The benthic zone is the ecological region within a water body that includes the sediment surface and shallow subsurface layers. Benthic microbe populations are primarily responsible for organic matter decomposition and oxygen consumption. Respiration within the hyporheic zone is a major fraction of total river metabolism (Grimm and Fisher 1984, Edwards and Myer 1987, Pusch and Schwoerbel 1994). Organic matter deposited by the stream and dissolved in hyporheic water is the food source for the community of microorganisms living on the surface of sediment particles. This community of microorganisms, known as the epilithon, is ubiquitous on surface sediments. It is composed of layers of bacteria, fungi, protozoans, and meiofauna (Karlstrom 1978). Meiofauna are small benthic invertebrates that include herbivores and omnivores that feed on the epilithon microbes and are a primary source of food for juvenile fish. Current understanding of the abundance, distribution, community structure, productivity, and trophic structure of subsurface communities is limited (Edwards, 1998).

Hyporeheos ecology and productivity is supported by the nutrient cycling that is driven by hyporheic flow exchange. The food web within the hyporheic zone is fully dependent on the supply of particulate and dissolved organic matter delivered to it from outside the zone (allochthonous material). Much of the organic matter, including from leaves and wood, delivered to the hyporheic zone is carried and deposited by higher, bank full flow events. However, in alluvial reaches of pacific coastal streams, buried wood from previous channel migrations is often abundant and lasts for centuries. Large amounts of slowly decomposing buried wood provide a continuous source of food to hyporheic fauna despite the low return frequencies of fresh inputs (Edwards, 1998). Downwelling water in the hyporheic zone delivers organic material, carbon, micronutrients and oxygen to the epilithon. The dissolved oxygen contained in downwelling surface water is necessary for the aerobic metabolism of the organic material.

Upwelling water in the hyporheic zone supplies nitrogen to the epilithon where nitrogen fixing Red alder (*Alnus rubra*) trees are a component of the riparian woody vegetation. Red alder fixes nitrogen well in excess of its needs, creating a reservoir of nitrogen adjacent to the stream and into the hyporheic zone. In upper basins of Pacific coastal ecoregion rivers, where primary production is limited by the availability of nitrogen, the input of nitrogen from hyporheic zones significantly influences primary and secondary production and invertebrate grazing in the stream. Epilithic algae are concentrated at sites of upwelling hyporheic water where standing stocks of epilithic chlorophyll in backchannels are seven times greater than in downwelling zones (Edwards, 1998).

3.5 Hyporheic Thermal Exchange

Pacific Northwest streams are critical to the migrating, spawning, and rearing life stages of native Anadromous fish, including salmon and steelhead trout (*Oncorhynchus sp.*), bull trout (*Salvelinus confluentus*) smelt (*Thaleichthy pacificus*), and Pacific lamprey (*Entosphenus sp.)*. Salmon, steelhead, and

Bull trout are cold water fishes with multiple life stages that are sensitive to, and greatly affected by, stream temperatures. Moreover, water temperature in Pacific Northwest mountain streams regulates virtually every biotic component of the aquatic ecosystem (Thompson, 2005).

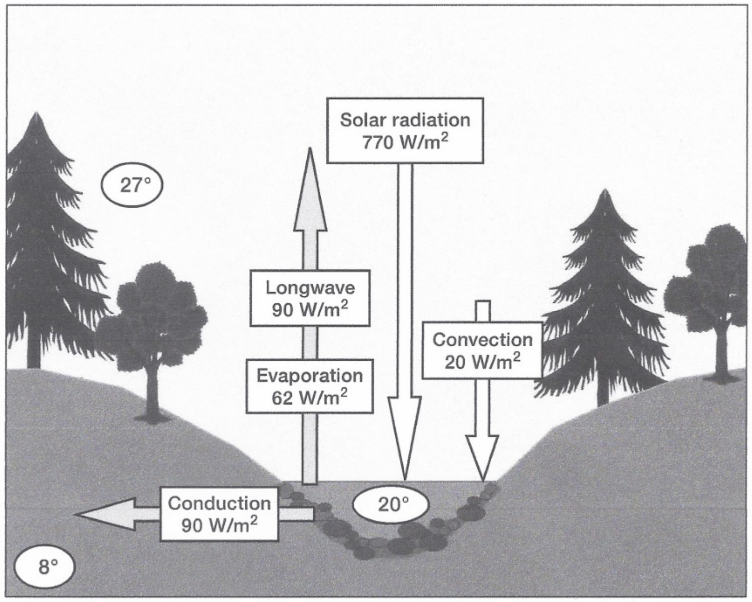
Stream water temperature is a function of multiple heat inputs and losses. A simplified heat budget of a stream is shown in Figure 4 below (Thompson, 2005). White arrows indicate heat transfer to the stream, and grey arrows indicate heat loss from the stream. Temperatures inside the ovals represent typical temperatures of the air, stream, and ground that can be experienced during late summer in the Pacific Northwest. All heat exchange figures are in units of Watts per square meter (W/m^2). Thermal inputs in order of descending magnitude include direct solar radiation, convection from air to water, and hyporheic exchange. Thermal losses in order of descending magnitude include longwave radiation, hyporheic exchange, and evaporation. In this simplified heat budget, heat lost to the hyporheic zone is 90 W/m^2, or approximately 11% of all heat inputs per square meter.

Solar radiation is the dominant source of heat input to streams, with its thermal contribution between one and two orders of magnitude greater than the contribution from convection. The simplified heat budget presented in Figure 4 is representative of the magnitude of heat inputs to a stream that lacks shade from an intact riparian forest. Due to the dominance of solar radiation as a source of thermal inputs to streams, the most effective means of reducing thermal stress for aquatic life is to decrease solar radiation inputs by increasing the level of shading. Hyporheic flow exchange can remove some, but not all, of the heat from stream water resulting from solar inputs.

When water leaves the stream channel and comes into contact with the cooler substrate, it loses heat through conduction, the process of heat transfer from warmer to cooler bodies of matter. The quantity of heat transferred is a function of the temperature difference between the stream and the substrate and the length of time of contact. High hyporheic flow rates will result in greater total heat loss for a given temperature differential between the stream and substrate. However, high flow rates will result in a lower temperature drop between downwelling stream water and upwelling hyporheic water due to the shorter contact time.

Low hyporheic flow rates will result in greater temperature drops between the stream and hyporheic flow for a given temperature differential due to the longer time of contact. However, low flow rates will result in smaller total heat loss and smaller quantities of water cooled.

Figure 4
Simplified Heat Budget of a Stream (Thompson, 2005).



The thermal reduction associated with hyporheic flow exchange is of interest in the Pacific Northwest because it has the potential to reduce stream temperatures and improve migration, spawning, and rearing habitat for salmonid fishes. Although the heat loss in the hyporheic zone may be a significant portion per unit area of the total heat added to a stream through solar radiation and convection, it is not effective over the full length of a stream because most hyporheic flow exchange occurs at very specific geomorphic features. Heat inputs can occur the full length of a stream, but the effect of solar radiation varies with changes in shade from riparian vegetation, orientation of the channel, and topography. Geomorphic features that support hyporheic exchange include pool-step systems, pool and riffle systems, sinuous and meandering channels, secondary or side channels, paleo channels (subsurface channel deposits), channel splits and island gravel bars, and meander point bars.

The results of a study of the influence of hyporheic flow on water temperature in the Clackamas River in Oregon during the summer of 2006 suggests that hyporheic exchange will cool the average temperature of larger rivers only a fraction of a degree. Hyporheic flow may only comprise a fraction of 1% of total river flow, and that fraction varies with stream flow. Hyporheic flow is most impactful and beneficial at lower river flows because it is a larger fraction of total river flow and lower river flows generally coincide with the highest water temperatures of the year. It is therefore difficult for hyporheic exchange to exert a significant effect on overall stream temperature, because any hyporheic buffering present is diluted by larger surface water discharges (Burkholder, *et al*. 2008). However, hyporheic exchange can produce small patches of cooler water that increase thermal heterogeneity within the river channel and can provide thermal refugia (up to 4°C cooler) for aquatic species that are stressed by conditions in the mainstem channel (Fernald *et al*., 2006 and Arscott *et al*., 2001). This local refuge benefit can be of critical importance to fish survival and is the focus of this paper in regards to mitigation value.

3.6 Hyporheic Zone Distribution

The distribution of hyporheic zones in a drainage basin varies with the physical processes that control sediment production, routing, and discharge. The interaction of geologic, geomorphic, and hydrologic processes determines the location, volume, and shape of sediment accumulation in the channel network, the shape and particle size distribution of the substratum, and the magnitude and location of head differentials necessary to drive water through a porous medium (Edwards, 1998). There can be great variability in the size, location, and flow exchange rates between different drainage basins and different reaches within a drainage basin.

Drainage basin factors that control hyporheic zone formation include bedrock geology, basin hydrology, and channel gradient. All of these factors have both temporal and a spatial variability within a drainage basin. Basin geology will have a strong influence on the characteristics of the sediment, including size and texture. Basin hydrology and channel gradient (hydraulics) will drive the transport, sorting, and placement of sediments.

In mountain streams, the steeper upper reaches will typically provide high hydraulic heads to drive hyporheic flow but will often have a bedrock substrate, constrained valleys, and insufficient sediment to facilitate hyporheic exchange. As stream channel gradients decrease in the downstream direction, hydraulic head decreases but sediment deposits increase. The lowest reaches of a stream may contain high volumes of sediment but very low hydraulic head. Hydraulic conductivity of sediments also generally decreases in the downstream direction, with very high conductivity in the boulder substrate of the upper basin and very low conductivity in the silt and clay substrate of the lower basin. The middle reaches of mountain streams are therefore likely to have the best combination of hydraulic head and sediment hydraulic conductivity to facilitate hyporheic exchange.

Hyporheic exchange appears to be significantly influenced by the geomorphic type of stream reach in a drainage basin. Colluvial reaches, or those with significant inputs of colluvium (unconsolidated material that accumulates at the base of slopes), are often steeper gradient reaches with significant hydraulic head, but the sediment tends to be poorly sorted with a low hydraulic conductivity. Colluvial reaches can be expected to have a lower rate of hyporheic exchange than alluvial reaches. Bedrock reaches contain a high proportion of solid rock substrate with very low hydraulic conductivity and therefore support only small areas of hyporheic exchange. Alluvial reaches contain high volumes of sediment transported and sorted by water combined with sufficient hydraulic head to produce conditions most favorable for hyporheic exchange (Edwards, 1998). Within the Chehalis River Basin, alluvial reaches are present both upstream and downstream of the proposed FRE site and likely support hyporheic exchange. Bedrock reaches are more prevalent upstream of the FRE site, and extensive alluvial reaches dominate the river morphology for tens of miles downstream with localized exceptions.

4 Chehalis River Basin Thermal Impacts

Within the state of Washington, water quality standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Listed streams in the Upper Chehalis River Basin are designated as Class A with a temperature criterion of 18°C. Temperature in a Class A waterbody shall not exceed 18°C due to human influences (DOE, 2001).

High stream temperatures are a known concern in the upper Chehalis Basin. Data collected by the Washington Department of Ecology's (Ecology) Ambient Monitoring Program at ten stations between October 1991 and September 1998 were compiled and descriptive statistics generated (Table 1). Months with exceedances of the temperature criterion are shaded pink in Table 1. Ecology has documented exceedances of temperature criteria at long-term monitoring stations in nearly all years since 2001. Chehalis Basin streams affected include Mainstem Chehalis River, Black River, South Fork Chehalis River, Dillenbaugh Creek, Lincoln Creek, Newaukum River, Salzer Creek, Scatter Creek, and Skookumchuck River (DOE, 2001).

Table 1
Temperature Statistics of the Upper Chehalis River Basin (DOE, 2001).

MONTH	NUMBER OF SAMPLES	MEAN TEMPERATURE (°C)	MEDIAN TEMPERATURE (°C)	MAXIMUM TEMPERATURE (°C)	SAMPLES OVER THE CRITERIA (%)
January	29	5.1	4.9	9.1	0
February	29	5.1	5.0	9.7	0
March	29	8.3	8.2	11.3	0
April	29	10.0	10.0	12.8	0
May	29	14.1	14.5	18.1	0.1
June	29	16.3	16.2	24.5	17
July	29	18.9	18.5	22.2	62
August	29	16.9	17.0	19.8	24
September	29	13.6	13.6	18.4	<0.1
October	29	9.4	9.4	13.1	0
November	29	7.2	7.4	10.1	0
December	29	5.4	4.9	10.5	0

Temperatures are expected to continue to rise in the Chehalis Basin due to climate change and future human activities. Historical human activities, including urban and residential development, agriculture, and logging, have degraded riparian vegetation in the Chehalis River Basin, contributing to warmer stream temperatures in some locations (DOE, 2001). Stream temperatures have tremendous influence over the adult migration, spawning, egg incubation, smolt and juvenile rearing, and adult holding of salmonids. Table 2 below provides preferred spawning temperatures by species.

Table 2

Selected water temperatures for spawning by Pacific Northwest salmonids. For the purpose of water temperature criteria protective of spawning salmonids, these references are assumed to be Daily Average Temperatures (DAT). Source: Table 4 in EPA Region 10 (2001).

SPECIES	SELECTED SPAWNING TEMPERATURE RANGE °F (°C) (DAT)	CITATION
Steelhead *(Oncorhynchus mykiss)*	50-55 (10-12.8)	Bell 1991
Spring Chinook salmon *(O. tshawytscha)*	39.9-64 (4.4-17.8)	Olson and Foster 1955, cited in ODEQ 1995
Fall/summer Chinook salmon *(O. tshawytscha)*	41-56.1 (5-13.4)	Raleigh et al. 1986, cited in ODEQ 1995
Coho salmon *(O. kisutch)*	50-55 (10-12.8)	Bell 1991
Pink salmon *(O. gorbuscha)*	46.4-55.4 (8-13)	Independent Scientific Group, 1996
Chum salmon *(O. keta)*	46.4-55.4 (8-13)	Independent Scientific Group, 1996
Sockeye salmon *(O. nerka)*	36.1-46.4 (2.3-8)	Brannon 1987
Anadromous coastal cutthroat trout *(O. clarkii)*	42.9-62.9 (6.1-17.2) 39.9-48.9 (4.4-9.4)	Beschta et al. 1987; Trotter 1989
Potamodromous coastal cutthroat trout *(O. clarkii)*	>41-42.8 (>5-6)	Trotter 1989
Westslope cutthroat trout *(O. clarkia lewisi)*	44.9-55.0 (7.2-12.8)	Beschta et al. 1987; Trotter 1989
Rainbow/redband trout *(O. mykiss)*	Up to 68 (20) 50-55 (10-12.8)	Hicks 1999 (literature review) Behnke 1992
Bull trout *(Salvelinus confluentus)*	peak: <44.6 (<7) cessation: >50 (>10)	Geotz 1989; Pratt 1992; Kraemer 1994; Fraley and Shepard 1989; James and Sexauer 1997; Wydoski and Whitney 1979
Mountain whitefish *(Prosopium williamsoni)*	37.4-41 (3-5)	Brown 1952, 1972; Breder and Rosen 1966; Bruce and Starr 1985; Hildebrand and English 1991

Despite the variations in observed spawning temperatures, the Independent Scientific Group (1996) states that the optimal temperature for anadromous salmonid spawning is 50°F (10°C) and that stressful conditions for anadromous salmonids begin at temperatures greater than 60.08°F (15.6°C,) with lethal effects occurring at 69.8°F (21°C) (EPA Region 10). As shown in Table 1, the water temperatures in the Upper Chehalis River Basin currently exceed preferred spawning temperatures during the time period of May through September.

Future human activity in the Basin, combined with the altered hydrology and thermal regimes resulting from climate change, is expected to cause an increase in stream temperatures. The Chehalis River Basin Flood Control Zone District is proposing to construct a flood retention facility (FRE) and associated temporary reservoir near Pe Ell, Washington, on the Chehalis River and make changes to the Chehalis-Centralia Airport levee to reduce flood damage in the Chehalis-Centralia area. Based on computer model results, river temperatures would increase both within the temporary reservoir area and downstream of the FRE facility. The combination of trees removed during construction and trees that die in response to episodic inundation during operation of the FRE would cause the river temperature to increase due to decreased shading. The increase would be as much as 5.4°F (3°C) in the reservoir area and immediately downstream and as much as 9°F (5°C) within the temporary reservoir at Crim Creek. Farther downstream, the increases in temperature would be less and are estimated to end about 20 miles downstream of the facility (DOE 1). The magnitude of the expected temperature increase is sufficient to eliminate optimal spawning temperatures in the Mainstem Chehalis River for potentially 20 miles downstream of the proposed facility for the entire year, and extend stressful spawning conditions to the months of April and October. A temperature increase of 3°C would also create lethal conditions for salmonids for 7 months of the year in the Mainstem Chehalis River reach downstream of the FRE.

5 Thermal and Hyporheic Flow Mitigation

Cold-water refugia protect salmonids from extreme water temperatures and also permit them to behaviorally thermoregulate to conserve energy when water temperatures are suboptimal. In stream reaches that have warmed above levels optimal for salmonids, fish persist by using cold-water refugia (Berman and Quinn 1991, Li et al. 1994, Neilson et al. 1994, McIntosh et al.1995a, Torgersen et al. 1999, King 1937, Mantelman 1958, Gibson 1966, as cited in McCullough1999) (EPA Region 10). Salmonids will migrate to cooler water when stream temperatures are less than optimal.

Thermal refugia are distinct geographic areas within a riverine system, separated from the main stream flow, with water temperatures noticeably different than the main flow and more optimal to critical life stages of aquatic organisms during periods of seasonally extreme water temperatures. Thermal refugia include warmer zones during the cold of winter and cooler zones during the heat of the summer. Warm summer stream temperatures that are suboptimal for salmonid life stages and other aquatic fauna have been trending upward for decades and are expected to be exacerbated by climate change. Stream temperatures have been increasing far more rapidly than salmonid populations can adapt, resulting in significant impact to reproduction and survival. Cold-water refugia is becoming a critical means of providing thermal mitigation for rising stream temperatures.

Based on EPA guidance, the Oregon Department of Environmental Quality developed a more specific definition: "*Cold-Water Refugia* means those portions of a water body where, at times during the diel temperature cycle, the water temperature is at least 2°C colder than the daily maximum temperature of the adjacent well-mixed flow of the water body." (OAR 340-041-0002 [10]) (EPA Region 10 2).

Alluvial valleys are more likely to have reach-scale cold-water refuges formed by hyporheic processes, whereas bedrock canyons primarily may be limited to tributary sources (EPA Region 10-2). Cold-water refugia is found near groundwater seeps, tributary confluences, and areas of hyporheic flow exchange where mixing with main channel surface water is limited (e.g. side channels, backwater areas, and pools sheltered by in-stream structure). Although hyporheic flow can be greater than surface flow, the volume of hyporheic flow exchange between the channel and its substrate is typically much less than the overlying surface flow. Once fully diluted by the surface flow, upwelling hyporheic water will have a negligible effect on average stream temperature. Limited mixing of inflowing cool water with main channel surface flow is critical for producing cool-water refugia by avoiding thermal dilution by the main flow.

Thermal mitigation can be achieved in the riverine environment primarily by modifying and capitalizing on existing geographic locations and morphologic features that are already actively providing hyporheic flow exchange or have the capacity to improve exchange. Thermal mitigation opportunities that capitalize on groundwater and cooler surface water sources may also exist at their confluence with mainstem surface water.

The fluvial geomorphic features that are most conducive to facilitating hyporheic exchange include the following:

1. Pool-step systems
2. Pool and riffle systems
3. Sinuous/meandering channels
4. Secondary or side channels
5. Paleo channels
6. Channel splits and island gravel bars
7. Meander point bars

All of these features are prevalent within the Chehalis Basin and the Willapa Hills Subbasin, however some features are more conducive to modification for the purpose of enhancing hyporheic flow for thermal mitigation. Geomorphic features that are most conducive for hyporheic flow enhancement for thermal mitigation are listed below. Pool-step systems are smaller features within the landscape that are more difficult to access, due to steeper and more rugged terrain, and should be considered a lower priority for consideration as mitigation sites. Pool and riffle systems can provide hyporheic exchange on a small scale and are more likely to be accessible for modification than pool-step systems, but they should also be considered a lower priority for consideration as mitigation sites compared to other opportunities that can provide larger-scale benefits.

5.1 Thermal Mitigation Site Characteristics

The fluvial geomorphic features that can provide significant hyporheic exchange, can be readily modified for enhancement of hyporheic flow, and are more likely to be accessible for construction of enhancements include the following. All of these sites are also readily discernible on aerial imagery. Larger sites should be prioritized over smaller sites.

1. Gravel bars with side channels
2. Channel splits with gravel islands
3. Large degree (> 90°) meander bends with long cross-peninsula flow paths
4. Sinuous reaches with point bars
5. Paleo channels
6. Straightened channel reaches that can be re-meandered

5.2 Nutrient Mitigation Site Characteristics

Primary production in the streams of Western Washington and Oregon can be limited by low nitrogen levels. In relatively undeveloped forested portions of watersheds, the primary source of nitrogen is nitrogen fixation through the symbiotic relationship between red alder trees (Alnus rubra) and Frankia alni, an actinomycete, filamentous, nitrogen-fixing bacterium. Red alder is a common riparian zone tree in the Pacific Northwest that fixes nitrogen within the hyporheic zone. Downwelling of hyporheic water from a forest containing red alder trees supplies nitrogen in support of the base of the food chain that ultimately provides food for juvenile salmonids. Wherever the riparian zone and its red alder component has been reduced within the watershed, the base of the aquatic food chain has been reduced, thereby diminishing secondary production. The primary site characteristic that can provide nutrients to the stream, can be readily modified for enhancement (red alder tree planting), and is likely to be accessible for modification is listed below.

1. Riparian areas adjacent to the ordinary high water line and lacking woody vegetation

5.3 Floodplain Mitigation Site Characteristics

Stream channel incision reduces, and in some cases eliminates, frequent interaction between the stream and its floodplain. Regular activation of the floodplain is one of the means by which the hyporheic zone is recharged with stream water for later release as cooler and more nutrient rich hyporheic water back into the channel. Restoring the floodplain connection can enhance the hyporheic flow and its associated thermal and nutritional benefits. Examples of actions that help to restore the floodplain reconnection include the addition of step structures to the channel using native wood and rock materials, lowering the floodplain elevation, or both. Another floodplain enhancement that could increase hyporheic zone recharge and create additional aquatic thermal refuge is the excavation of channels and alcoves into the floodplain. The primary site characteristics that can provide mitigation through floodplain reconnection are listed below. Incised channels may be difficult to identify through examination of aerial imagery.

1. Floodplains that are lacking flood vulnerable structures and any significant woody vegetation (to avoid removing riparian forest)
2. Incised channels with adjacent disconnected floodplain
3. Paleo channels that can be reconnected to the mainstem.

5.4 Other Thermal Mitigation Site Characteristics

Groundwater and surface water can also provide thermal refugia at their confluence with mainstem surface water. Site characteristics that are likely to be potential thermal refugia mitigation opportunities are listed below.

1. Surface water tributaries with mean water temperatures at least 2°C lower than main stem surface water temperatures. Surface water tributaries are often mapped and easily identifiable from aerial imagery and field investigations. Temperature differentials are readily measurable with inexpensive data loggers.
2. Groundwater seeps, springs, and upwelling areas with mean water temperatures at least 2°C lower than main stem surface water temperatures. Groundwater sources of inflow to surface water can be estimated based on geomorphological assessments at the basin, subbasin, and segment level. More detailed analysis using remote sensing techniques, such as aerial photography, LiDAR, and thermal infrared imaging combined with ground truthing may be necessary to more accurately delineate and define potential groundwater supported thermal refugia.

5.5 Hyporheic Flow Exchange Enhancement Measures

Hyporheic flow exchange can be enhanced to improve thermal diversity and refugia, nutrient cycling, and primary production to mitigate degradation caused by human activities and climate change. Potential enhancement actions listed below are presented as specific to fluvial site characteristics but are very generic in nature. Design and implementation of hyporheic flow enhancement projects will be site specific.

1. **Gravel bars with side channels**: Install engineered log jams, log weirs, rock weirs, or beaver dam analogs to increase the hydraulic head at the upstream end. Decrease mainstem flow through the side channel through restrictions or plugs at the upper end of the channel. Excavate deeper channel or pool at the lower end of the side channel. Beaver dam analogs may not be applicable on larger streams.
2. **Channel splits with gravel islands**: Install engineered log jams, log weirs, rock weirs, or beaver dam analogs to increase the hydraulic head at the upstream end. Decrease mainstem flow

through the side channel through restrictions or plugs at the upper end of the channel. Excavate deeper channel or pool at the lower end of the side channel. Beaver dam analogs may not be applicable on larger streams.

3. **Large degree (> 90°) meander bends with long cross-peninsula flow paths**: Install engineered log jams, log weirs, or rock weirs to increase the hydraulic head at the upstream end of the bend.
4. **Sinuous reaches with point bars:** Enhance floodplain connection and provide gravel augmentation to increase the hyporheic zone if sediment supply has been limited.
5. **Paleo channels:** Reconnect paleo channels at the downstream end to provide fish access for refugia. Create alcove near downstream end.
6. **Straightened channel reaches that can be re-meandered:** Re-meander channel appropriate to geomorphic setting and provide gravel augmentation if needed to increase the hyporheic zone.
7. **Riparian areas adjacent to the ordinary high water line and lacking woody vegetation:** Replant riparian zone with diverse assemblage of native woody species to include red alder (Alnus rubra).
8. **Floodplains:** Restore floodplain activation frequency and extent by installing in-channel hydraulic roughness and/or lowering the floodplain within the hyporheic zone through excavation and grading.
9. **Incised channels with adjacent disconnected floodplain:** Restore floodplain activation frequency and extent by installing in-channel hydraulic roughness and/or lowering the floodplain within the hyporheic zone through excavation and grading. Install grade control structures to reduce further incision.
10. **Cold water tributaries, seeps, and springs:** Excavate pools between the cold water source and the mainstem channel that minimize dilution with mainstem surface water to provide holding areas for fish.

Figure 5
Example Chehalis River Hyporheic Flow Exchange Mitigation Downstream of Pe Ell, Washington.

6 Hyporheic Flow Project Examples

Five example projects were identified and described to illustrate applications of hyporheic flow enhancement in rivers and streams in the Pacific Northwest region. The following project descriptions are taken directly and unedited from the abstracts of the reports prepared by the technical contributors for each of these projects.

6.1 Floodplain Restoration Increases Hyporheic Flow in the Yakima River Watershed, Washington

A parameterized groundwater model was used to study the effects of floodplain restoration on hyporheic flow in Gap to Gap region of Yakima Basin, Washington during steady and transient states. The attributes of hyporheic flow pathlines generated from the particles adjacent to Yakima River were compared for pre- and post-restoration periods. It was noticed that at two transects along the Yakima River where levee setback occurred, there was change in the directions of hyporheic pathlines. The change in the directions of the pathlines resulted in wider area of coverage and likely surface water and groundwater interactions. Statistical tests conducted to compare the lengths of the hyporheic pathlines for pre- and post-restoration conditions, showed that restoration in the form of levee setback resulted in increase in the length of pathlines after floodplain restoration. Model simulations during transient state showed that the longest pathlines during both pre- and post-restoration (pre: 398.19 m and post:

460.57 m) occurred in relatively drier periods. Overall, this study supported the hypothesis that flood plain restoration efforts in the form of levee setback should improve the hyporheic flow in the floodplain regions. The improved hyporheic flow and river reconnection to greater floodplain area should improve the ecosystems conditions that support more opportunities for enhanced biogeochemical processing, improved water quality, and restoration of habitat to occur (Harsh et al. 2018).

Key Applications to Chehalis Basin Mitigation:

- Removing artificial constraints (in this example, levee setback) and floodplain reconnection can increase the extent of hyporheic exchange.
- Largest increases occurred during drier periods.

6.2 Thornton Creek Hyporheic Process Restoration: Design and Performance of an Engineered Streambed

Stream restoration designed specifically to enhance hyporheic processes has seldom been contemplated. To gain experience with hyporheic restoration, an engineered streambed was built using a gravel mixture formulated to mimic natural streambed composition, filling an over-excavated channel of Thornton Creek in Seattle, Washington to a minimum depth of 90 cm. Specially designed plunge-pool structures, built with subsurface gravel extending down to 2.4 m, promoted greatly enhanced hyporheic circulation, path length, and residence time. Hyporheic process enhancement was verified using intra-gravel temperature mapping to document the distribution and strength of upwelling and downwelling zones, computation of vertical water flux using diurnal streambed temperature patterns, estimation of hyporheic zone cross section using sodium chloride tracer studies, and repeat measurements of streambed sand content to document evolution of the engineered streambed over time. Results showed that vertical water flux in the vicinity of plunge-pool structures was quite large, averaging 89 times the pre-construction rate, and 17 times larger than maximum rates measured in a pristine stream in Idaho. Upwelling and downwelling strengths in the constructed channel were larger and more spatially diverse than in the control. Streambed sand content showed a variety of response over time, indicating that rapid return to an embedded, impermeable state is not occurring.

Key Applications to Chehalis Basin Mitigation:

- This project demonstrated on a small scale that hyporheic flow conditions could be engineered effectively into a stream restoration project
- Hyporheic flow enhancements were persistent over time and did not degrade as a result of fine sediment accumulation or embeddedness.

6.3 Bird Track Springs Fish Habitat Enhancement Project Environmental Assessment

To address limited habitat conditions for native fish within the project area, the US Forest Service and the Bonneville Power Administration have proposed actions for the Bird Track Springs reach of the Grand Ronde River in Oregon that would re-establish natural river-floodplain connections and processes. Natural processes within this reach of the Grande Ronde River (GRR) include multiple channel networks created through forcing mechanisms of large wood, ice, beaver, and rock. To meet the purpose and need described above, the following types of activities are proposed within the Bird Track Springs project area (USFS et al., 2018):

- Improve channel geometry to reduce width-to-depth ratios through large wood placement, channel fill, and bar construction.
- Place large wood structures throughout the mainstem channel to provide habitat and channel control.
- Place floodplain wood and plant native shrubs to reduce overland velocities and trap ice.
- Increase channel/floodplain interactions by removing topographical features that inhibit overland flows (historical railroad grade).
- Increase connectivity of existing channel scars (swales) and enhance fish cover.
- Re-meander channel in appropriate locations to reconnect to floodplains and existing swale networks while improving channel form and function.
- Improve alcove connectivity to mainstem and enhance fish cover.
- Enhance and protect existing functional juvenile fish-rearing habitats.
- Improve connectivity of spring-fed side channels, wetlands, and alcoves to provide additional summer and winter rearing habitats.
- Plant native vegetation to improve riparian and floodplain conditions and to shade the stream.
- Reduce risk of erosion to highway embankments and ice damage through strategic placement of log structure treatments, rock, and graded features.

Key Applications to Chehalis Basin Mitigation:

- This is a large-scale project example that will restore complex physical and ecological interactions between the river and its floodplain. This is a good project to monitor for insights regarding multiple benefits of restoration actions that affect hyporheic exchange.

6.4 Opportunities and Limitation of Hyporheic Restoration in a 4th Order Semi-Arid Floodplain: A Case Study of Meacham Creek, Oregon

Persistent societal interest in improving water quality and recovering imperiled, native, aquatic species has expanded the scope of stream restoration to include the hyporheic zone as a focus. Despite the lack of detailed studies, hyporheic restoration is often invoked as a means to achieve multiple objectives including moderation of water temperature, delay of seasonal flows and increasing the localized volume of floodplain water. The ongoing Meacham Creek case study monitors changes as a result of stream restoration of the hyporheic zone of a 4th order, alluvial floodplain in northeast Oregon. Active and passive restoration of 2.5 km of Meacham Creek has altered the creek from a single-threaded, incised and bedrock-dominated channel to a perched, alluvial channel that seasonally exchanges overbank flows with the surrounding floodplain. Our results suggest that the stream restoration effort on Meacham Creek has increased the volume of annual hyporheic storage and created a more diverse distribution of flowpath lengths within the restoration site. Furthermore, our monitoring indicates that hyporheic process response to stream restoration, analogous to other geomorphic processes, conforms to a systematic hierarchy where nested flow paths range in length and residence time from meters and hours at the habitat scale to tens of meters and months at the floodplain scale. We assert that scale-explicit and measurement-focused restoration planning has a greater likelihood of meeting the stated objectives and result in improved water quality and encourage recovery of many native aquatic species (O'Daniel et al., 2014).

Key Applications to Chehalis Basin Mitigation:

- Demonstrated success enhancing hyporheic exchange on a 2.5-mile river reach
- Example of effectively integrating hyporheic enhancement into a multi-faceted, multi-objective ecological restoration effort
- The longer hyporheic flow paths that have residence times of months will store colder water entering the hyporheic zone in the winter and spring that is then released to the stream during the summer hotter months.

6.5 Influence of hyporheic flow and geomorphology on temperature of a large, gravel-bed river, Clackamas River, Oregon

The hyporheic zone influences the thermal regime of rivers, buffering temperature by storing and releasing heat over a range of time scales. We examined the relationship between hyporheic exchange and temperature along a 24-km reach of the lower Clackamas River, a large gravel-bed river in northwestern Oregon (median discharge = 75·7 m^3/s; minimum mean monthly discharge = 22·7 m^3/s in August 2006). With a simple mixing model, we estimated how much hyporheic exchange cools the river during hot summer months. Hyporheic exchange was primarily identified by temperature anomalies, which are patches of water that demonstrate at least a 1°C temperature difference from the main channel. Forty hyporheic temperature anomalies were identified through field investigations and thermal-infrared radiometry (TIR) in summer 2006. The location of anomalies was associated with specific geomorphic features, primarily bar channels and bar heads that act as preferential pathways for hyporheic flow. Detailed field characterization and groundwater modelling on three Clackamas gravel bars indicate residence times of hyporheic water can vary from hours to weeks and months. This was largely determined by hydraulic conductivity, which is affected by how recently the gravel bar formed or was reworked. Upscaling of modelled discharges and hydrologic parameters from these bars to other anomalies on the Clackamas network shows that hyporheic discharge from anomalies comprises a small fraction (<<1 %) of mainstem discharge, resulting in small river-cooling effects (0·012°C). However, the presence of cooler patches of water within rivers can act as thermal refugia for fish and other aquatic organisms, making the creation or enhancement of hyporheic exchange an attractive method in restoring the thermal regime of rivers (Burkholder et al., 2008).

Key Applications to Chehalis Basin Mitigation:

- During warm summer months, hyporheic exchange contributes to formation and persistence of thermal refugia.
- Hyporheic exchange makes little difference in the overall temperature of the main river flow.
- Hyporheic flow and associated thermal refugia zones were linked to identifiable geomorphic features.

7 Summary

Recent research clearly demonstrates that the hyporheic zone plays a central role in controlling instream thermal diversity, nutrient cycling, and primary production. In addition to beneficial effects on water temperature, enhancement of hyporheic flow exchange has the potential to increase the migration, spawning, and rearing success of native anadromous salmonids and enhance the aquatic food chain. Hyporheic flow enhancement, using a suite of techniques, provides viable options for aquatic habitat mitigation measures to increase thermal diversity and refugia, enhance nutrient cycling, and support the aquatic food chain. Fluvial geomorphic features that can provide significant hyporheic exchange, can be readily modified for enhancement of hyporheic flow, and are more likely to be accessible for construction of enhancements include the following:

- Gravel bars with side channels
- Channel splits with gravel islands
- Large degree (> 90°) meander bends with long cross-peninsula flow paths
- Sinuous reaches with point bars
- Straightened channel reaches that can be re-meandered
- Riparian areas adjacent to the ordinary high water line and lacking woody vegetation
- Floodplains that are lacking flood vulnerable structures and any significant woody vegetation (to avoid removing riparian forest)
- Incised channels with adjacent disconnected floodplain
- Paleo channels that can be reconnected to the mainstem.

Project examples demonstrate the effectiveness of successful hyporheic enhancement efforts. Key observations from those examples include:

- Hyporheic enhancement works best when it is an integrated component of a comprehensive restoration strategy. Specific restoration sites integrate multiple physical and ecological processes and components.
- Large-scale hyporheic enhancement is possible with levee setbacks and floodplain reconnection efforts.
- Engineered and constructed hyporheic zones can be effective at a small scale.

Hyporheic flow enhancement may be applied most effectively as a strategic component of a comprehensive aquatic habitat mitigation plan. For mitigation of temperature impacts, hyporheic enhancement would be most effective for providing thermal refugia. Due to the small ratio of hyporheic flow to surface water flow, this approach would not produce a meaningful reduction in the overall temperature of the water body. But for salmonids in warm rivers, thermal refugia can greatly increase their probability of survival. By providing thermal refugia, hyporheic enhancement provides immediate benefits to aquatic species during the time it would take for riparian reforestation to mature and provide long-term temperature mitigation.

Other potential opportunities to enhance thermal refugia in the Chehalis Basin include modification of groundwater sources that contribute flow directly to the river and its tributaries. Groundwater sources that may produce water that is significantly cooler than mainstem surface water include cold water tributaries, seeps, and springs. These features can be modified to improve their function as thermal refugia through the excavation of pools between the cold water source and the stream channel to minimize the dilution of the cooler water by the warmer surface water and to provide holding areas for fish.

8 Hyporheic Video

Please see the video at this link for an overview of the value of the hyporheic zone:

https://www.youtube.com/watch?v=cGEXjbEP0YA&feature=youtu.be

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