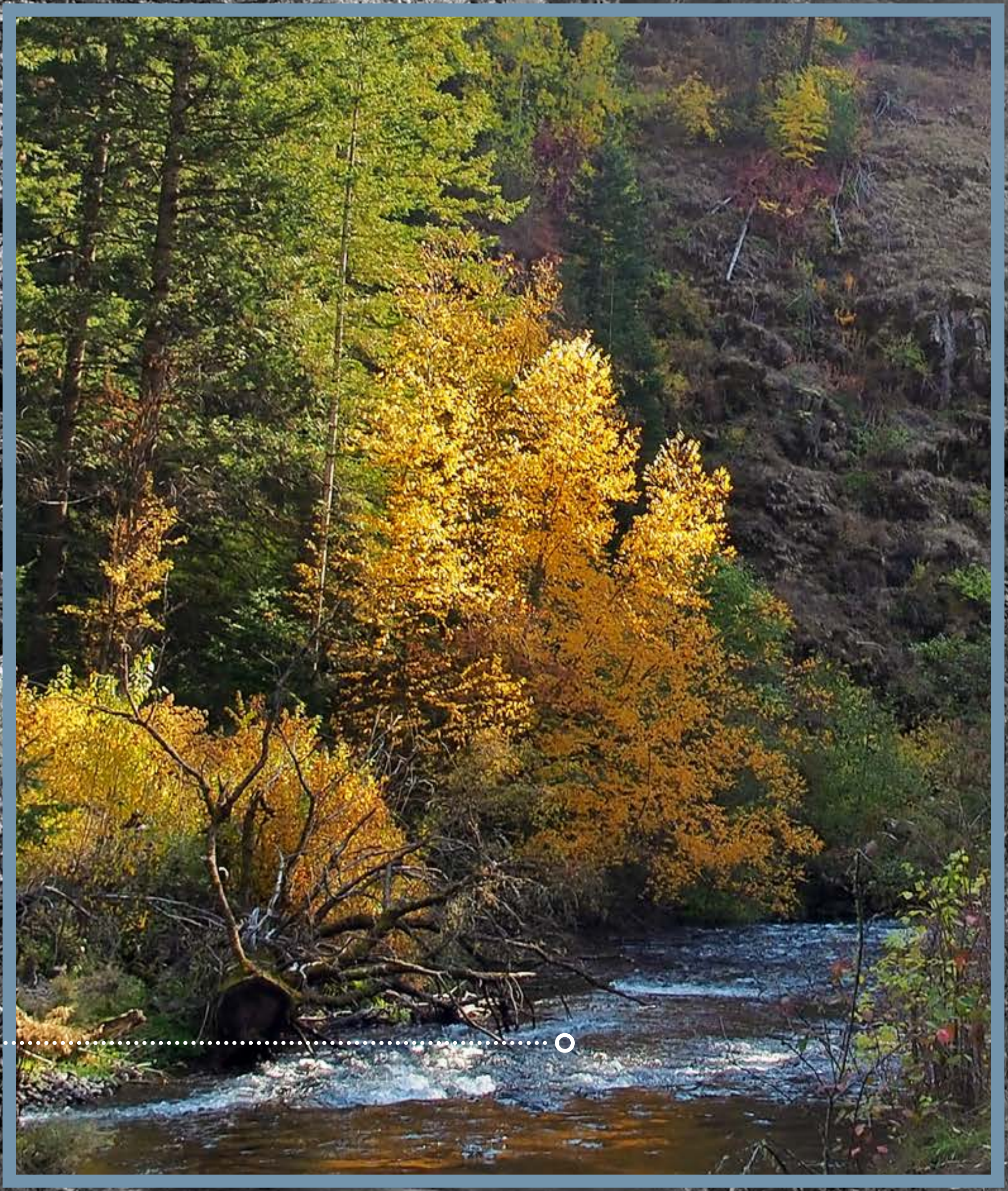
UPPER WALLA WALLA RIVER

ASSESSMENT & ACTION PLAN



Confederated Tribes of the Umatilla Indian Reservation

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Upper Walla Walla Assessment & Action Plan

Acknowledgements

Confederated Tribes of the Umatilla Indian Reservation

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is a federally recognized union of the Cayuse, Umatilla, and Walla Walla Tribes established through the 1855 Treaty of Walla Walla. At the signing of the treaty with the United States, the Tribes ceded 6.4 million acres of homeland located on the Columbia River Plateau in what is now northeastern Oregon and southeastern Washington. For thousands of years the Tribal economy was based on subsistence as people traveled throughout the homeland to harvest and gather food. Tribal people maintain a strong connection to the traditional culture of fishing, hunting, and gathering foods important to the tribal community, which is emphasized with their adoption of the First Foods mission and application of the Umatilla River Vision (Jones et. al. 2008). The upper Walla Walla river, a tributary to the Columbia River, flows from a watershed that supports and provides these important First Foods and is a priority area for protection and enhancement of water and fisheries resources.

Contributors

A collaborative approach was taken to incorporate ecological and fisheries recovery goals with local management and use. The common goal was to create an action plan for improving watershed conditions and natural riverine processes in the Upper Walla Walla Watershed. Contributions to the assessment and planning process were provided through a technical and scientific level of input and review led by the CTUIR. This Action Plan was prepared using available data collected by a broad group of partners and compiled by a team of technical scientists and habitat restoration specialists from Ecosystem Sciences, LLC, Rio ASE, LLC, Mount Hood Environmental and with substantial support from CTUIR and fellow co-managers Washinton Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW). Technical analysis was completed using data and content provided by CTUIR, Walla Walla Basin Watershed Council, WDFW, ODFW, and other project partners. No field data were collected by the project team, who reviewed, analyzed, and synthesized the previously collected and readily available data represented in this report. Not all the data that was used or created in the technical memos is illustrated in this main document. The maps and information illustrated are a representation of the full suite of data, included in the appendices.

■ *South Fork Walla Walla River*

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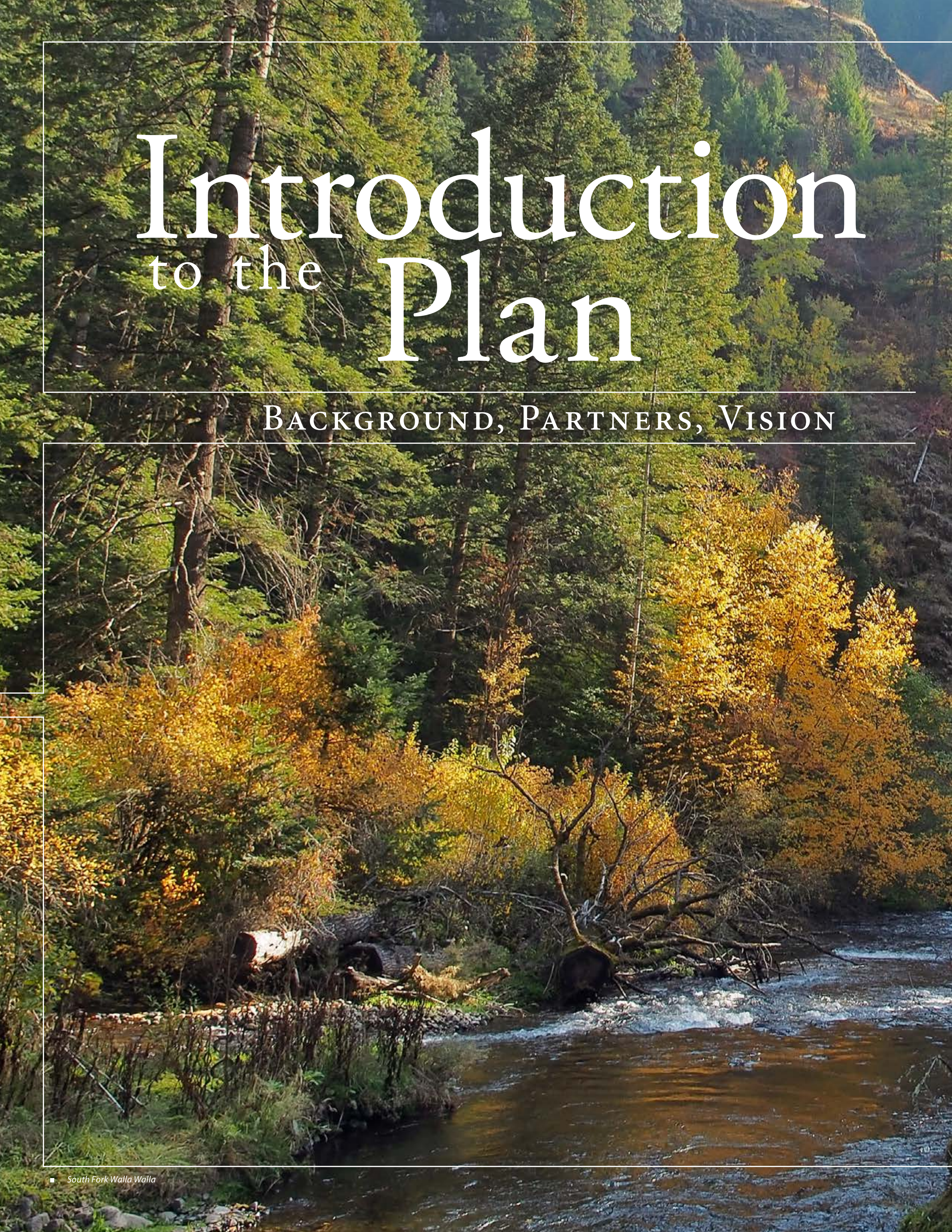
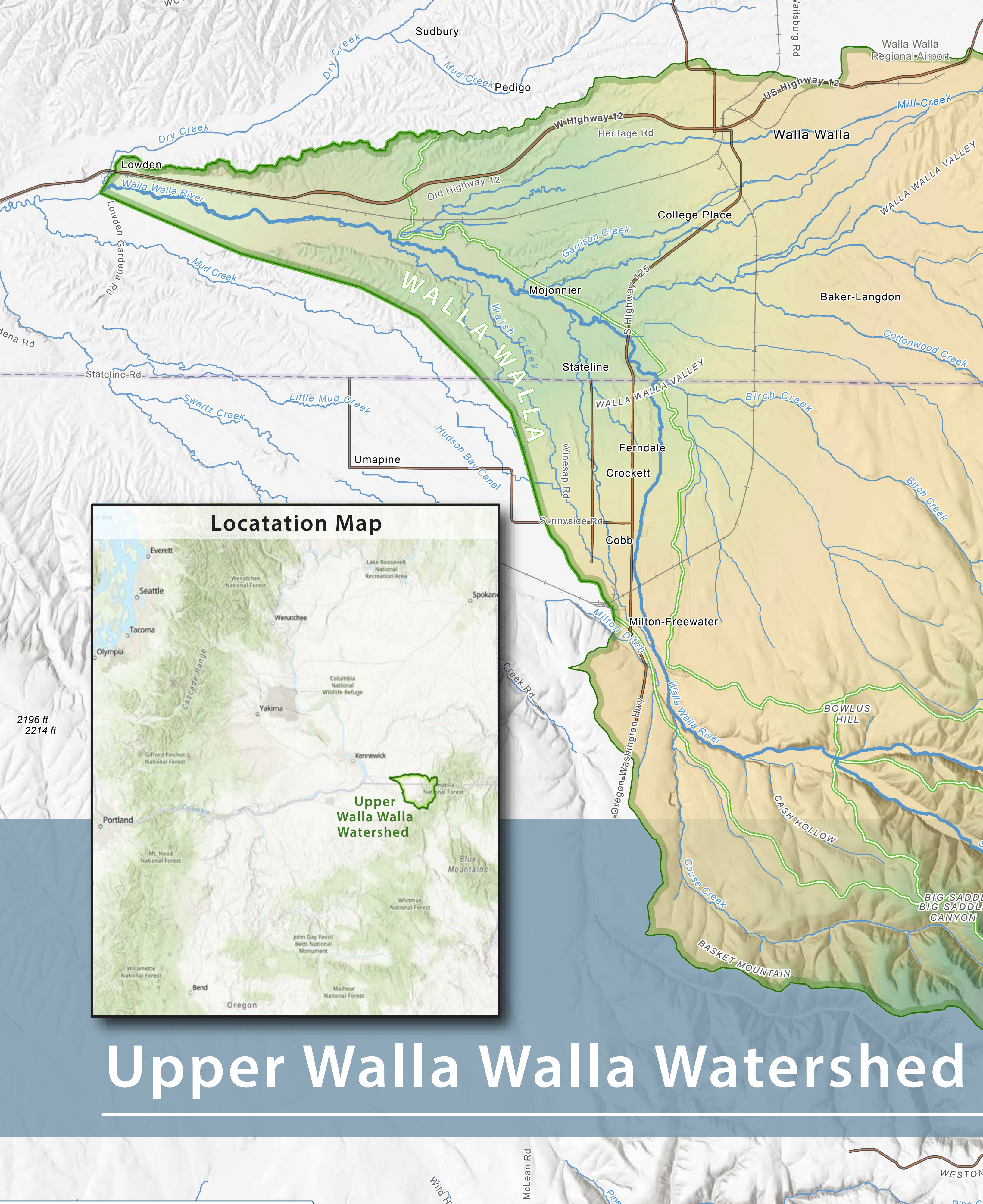
Introduction to the Plan

Background, Partners, Vision



South Fork Walla Walla

A scientifically defensible, floodplain-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, biological assessment of historical, current, and desired conditions in the upper Walla Walla River. This project uses a scientifically robust, efficient, and effective approach to assess watershed function and process, identify restoration and conservation opportunities, identify actions to address impairment, and strategize implementation. The goal of restoration is to collaboratively establish a functional and resilient watershed that supports the First Foods including sustainable and harvestable fish populations. This document establishes a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to achieve the stated restoration goal.



Upper Walla Walla Watershed

Harbert
Kibler
Tracy
Mill Creek
Spring Creek
Dry Creek
Burnt Fork
GRIFFIN PEAK
Five Points
BLACKSNAKE RIDGE
BISCUIT RIDGE
DEADMAN PEAK
BUCK
Thomas
KLICKER MOUNTAIN
Blue Creek
LAIRD GULCH
GREEN RIDGE
4680 ft
TABLE ROCK
Russell Creek
Reser Creek
Kooskooskie
RAILROAD CANYON
3690 ft
PARADISE RIDGE
Mill Creek
BROKEN RIDGE
MILK SHAKES
Russell Creek
North Fork Cottonwood Creek
Cottonwood Creek
SADDLE MOUNTAIN
HENRY CANYON
Webb Creek
INDIAN RIDGE
LOW RIDGE
PINE RIDGE
LITTLE MEADOWS
4491 ft
Birch Creek
BIG MEADOWS
North Fork Walla Walla River
5779 ft
YELLOW JACKET POINT
CUP GULCH
PATERSON RIDGE
NORTH FORK WALLA WALLA
North Fork Walla Walla River
THE HORSESHOE
BLALOCK MOUNTAIN
South Fork Walla Walla River
RODGERS RIDGE
BOX CANYON
5691 ft
SOUTH FORK WALLA WALLA
SWEDE CANYON
BOULDER RIDGE
LOW RIDGE
Elbow Creek
Burnt Cabin Gulch
Couse Creek
0
1
2
Miles
4
0
2.5
5
Kilometers
10
N
MOUNTAIN
Tollgate
4610 ft
COYOTE
BIG SINK

The Upper Walla Walla Watershed is a physically diverse landscape containing a variety of land forms and natural resources that support a wide range of valuable land uses and fish and wildlife populations.

The CTUIR developed this scientifically defensible floodplain-based and strategic habitat restoration plan. It is founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. CTUIR and fellow co-managers (ODFW and WDFW) worked with federal and local agencies, and other stakeholders. This project uses a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations.

The focal fish species of the assessment and action plan consist of the following:

- Middle Columbia River summer steelhead (ESA-listed Threatened)
- Columbia River bull trout (ESA-listed Threatened)
- Spring Chinook salmon
- Pacific lamprey

This plan establishes a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the technical team assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes, and conditions.

The plan is primarily focused on the alluvial channel and floodplain of the Walla Walla River from the confluence with Dry Creek near Lowden, Washington, to the headwaters of the North and South Forks of the Walla Walla River in northeastern Oregon. The primary study area includes approximately 70 miles of stream and the associated floodplain of those stream segments. Secondarily, a reconnaissance-level assessment of the upland conditions of the study area was completed using remote sensing data and a geographic information system (GIS). The secondary study area includes the catchment area of the primary study area for analysis of upland and tributary processes that influence the primary study area and is approximately 885 square miles.

This was a collaborative process with the CTUIR and several other stakeholders,with frequent and open communications.

The Action Plan was developed from and supported by a series of Technical Reports. These reports are included in the appendices of this plan for reference.

CTUIR River Vision and Touchstones

The CTUIR have a traditional and cultural connection to the foods provided by the earth. Specifically, people of the CTUIR rely on the availability of First Foods (water, salmon, deer, cous, and huckleberry, in the traditional serving order) as a foundation for their culture, economy, and religion (Karson 2006; Quaempts et al 2018). In 1996, the CTUIR Fisheries Department initiated the Walla Walla River Fish Habitat Enhancement Project to protect, enhance, and restore functional floodplain, channel, and watershed processes to provide sustainable and healthy habitat for aquatic and riparian First Foods species. Similarly, the CTUIR Department of Natural Resources adopted a mission based on First Foods with a vision to assess, manage, restore, and monitor upland and riverine habitat capable of providing First Foods that sustain the continuity of the Tribe’s culture. The River Vision (Jones et al 2008) and Upland Vision (Endress et al 2019) identify multiple, intertwining physical and biological touchstones that together form the foundation for a healthy, dynamic and resilient environment.

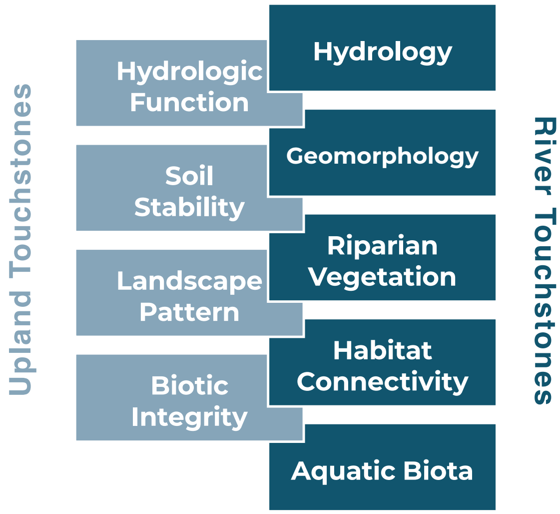


Figure 2. The project will be based on the CTUIR River Vision (Jones et al. 2008) and Upland Vision Touchstones (Endress et al. 2019).

The Upland Vision Touchstones include Hydrologic Function, Soil Stability, Landscape Pattern, and Biotic Integrity (Endress et al 2019). The River Vision Touchstones include water quantity and quality (hydrology), geomorphology, connectivity, riparian vegetation, and aquatic biota (Jones et al 2008). Water in the form of rain and melting snow flows over the landscape picking up nutrients, minerals, and soil, supporting both vegetation that stabilizes and erosion that destabilizes the surface. The shape of the earth's surface as expressed by the variability in water, vegetation, and soil is defined as the landscape pattern. The change in the landscape pattern over time defines the geomorphology of the area. Different plants and animals have evolved to thrive in this variable landscape taking advantage of the connectivity between different habitats and the transfer of nutrients, sediment, energy, and organisms within them. The interconnections between the upland and river vision touchstones are central to the proper function of the entire ecosystem.

Recognizing these interactions, and the focus of this effort toward the Walla Walla River and its floodplain, this Plan incorporates analysis of watershed-scale upland touchstones and reach-scale river touchstones. Additionally, salmon are considered keystone and indicator species whose health can be used to represent the overall ecological condition of a stream (Hyatt and Godbout 1999; Cederholm et al 2000). It can therefore be assumed that conditions supporting healthy salmon (individuals and/or population) will similarly support a healthy ecosystem overall.

River Vision Touchstones

Hydrology - Clean, cold water of adequate quantity is not only a First Food, but is required to support Salmon and other native aquatic species.

Geomorphology - Channel and floodplain form are shaped as a balance between water flow and sediment with influences from other physical characteristics, such as valley width and slope. Diverse and complex floodplain forms provide the platform for functional floodplain processes and healthy fish habitat.

Connectivity - A functional river and floodplain is supported by connectivity of surface water and shallow groundwater. The movement of nutrients, sediment, and biota is dependent on connected flowpaths in the surface and subsurface environments.

Riparian Vegetation - Native vegetation in the riparian area and floodplain influence system stability, water quality and provide habitat in several ways. Live trees and shrubs that depend on water for growth and nutrients can provide shade and stability to the channel. Large woody material can be an important structural feature for habitat complexity and cover.

Aquatic Biota - The aquatic food web includes a range of biota from primary production organisms to a variety of fish species at higher trophic levels. The health and persistence of biota respond to the functionality of physical characteristics in the watershed and can be viewed as the result of the riverine and floodplain conditions.

The mission of the CTUIR Fisheries Program is to provide sustainable harvest opportunities for salmon by protecting, conserving, and restoring native aquatic populations and their habitats. In support of this, the Habitat Program mission is to protect, enhance, and restore functional floodplain, channel, and watershed processes to provide sustainable and healthy habitat for aquatic First Food species.

Setting and Context

The forested headwaters, located along the western face of the Blue Mountains, contain timber resources along with complex wildlife habitats. The lower and western portions of the watershed consist of grasslands, upland pasture, and moderately wide and fertile floodplains along the Upper Walla Walla and its tributaries that provide farming and ranching opportunities.

The Walla Walla Watershed has been part of the homeland for the three Tribes of the Confederated Tribes of the Umatilla Indian Reservation, Cayuse, Umatilla, and Walla Walla, since time immemorial. The Tribes moved across the Columbia Plateau in an annual cycle of travel from areas of hunting, fishing, and gathering to celebration and trading camps. They would hunt, fish and gather roots and berries in various areas and seasons based on availability. This cycle would take them to the lower watershed areas and along the Columbia and Snake rivers in the winter and spring and to the headwaters along the foothills of the Blue Mountains and far beyond in the summer and fall. The Walla Walla river provided a conduit for travel, and the diverse resources of the watershed were available for subsistence hunting, fishing and gathering.

Beginning in the 1800's, Euro-American explorers and traders arrived in the Columbia River Basin in search of the plentiful furs and other natural resources. The Oregon Trail was established through the Tribes' homeland and the United States government encouraged settlers to move to the developing Oregon Territory. By the 1850's tension between immigrants and Tribes had escalated to a level that the government pursued the development of a treaty.

After much negotiation, the Treaty of June 9, 1855 was signed between the United States and members of the Walla Walla, Cayuse, and Umatilla Tribes and ratified in 1859. The Umatilla Indian Reservation was created at that time and 6.4 million acres of land were ceded to the United States. The Confederated Tribes of the Umatilla Indian Reservation was eventually formed and rights were reserved for fishing, hunting, gathering foods and medicine, and grazing livestock in the ceded area.

European settlers continued to move into the Walla Walla River Subbasin through the late 1800's as they found the area to be productive and accessible land for ranching and farming. The area along the floodplain of the Walla Walla river and its tributaries provided accessible and fertile land for ranching and agriculture.

Purpose

Land management activities have taken a toll on ecological conditions and natural geomorphic processes. Over the past 150 years, activities such as grazing, timber harvest, conversion of land to agricultural production and floodplain and stream channel manipulation have had detrimental effects on habitat. Over the years reductions in habitat quality and quantity have resulted in impacts to key fish species, including the extirpation of spring Chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*). To improve and restore habitat conditions, activities have been planned and implemented for decades, but generally in isolated and opportunistic ways. The purpose of this Plan is to leverage and tier off of existing recovery and subbasin plans, providing improved data and analysis as well as identifying and prioritizing actions to improve and restore the functions that create and maintain healthy aquatic habitat and biota.

Limiting factors and treatments have been generally defined in the Walla Walla Subbasin Plan (NPCC 2004), the Middle Columbia Steelhead Recovery Plan (NOAA 2009), the Recovery Plan for the Coterminous United States Population of Bull Trout (*Salvelinus confluentus*; USFWS 2015), and several other local planning documents.

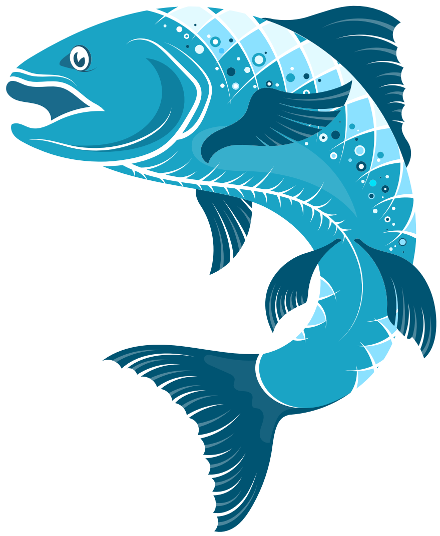


Figure 3. Focal fish species of the assessment and action plan include Chinook salmon, steelhead, bull trout and pacific lamprey.

These planning documents have typically focused on remediating specific limiting factors through identifying often isolated restoration measures with anticipation of fish habitat uplift without an understanding of larger scale watershed processes across time and space and at multiple scales. A comprehensive inventory and assessment of the hydrologic, geomorphic, aquatic, and riparian conditions of the watershed including historic, present and future conditions is needed to inform and develop a process-based restoration approach that addresses root causes of limiting factors (ecological concerns) and results in long-term improvements to watershed and fluvial processes and sustainable ecological processes.

This information is consolidated into this single document that detailsthe strategic approach to address root causes of degradation within a watershed context, specifically beneficial to focal fish species and their aquatic habitat. The watershed assessment, provided data resources, prioritization strategy and adaptive management plan generated from this effort will be beneficial to stakeholders engaging in implementation, both in communicating with private landowners but also aligning restoration approach and actions with the watershed co-manager's missions, recovery plans, and conservation funding agencies.

Data and Resources

Technical analysis was completed using data and content provided by CTUIR, Walla Walla Basin Watershed Council, WDFW, ODFW, and other project partners. No field data were collected by the project team, who reviewed, analyzed, and synthesized the previously collected and readily available data represented in this report.

Co-Managers

The directives of relevant watershed co-manager's mission statements are presented below for reference.

Confederated Tribes of the Umatilla Indian Reservation (CTUIR) Department of Natural Resources Program

To protect, restore, and enhance the first foods - water, salmon, deer, cous, and huckleberry - for the perpetual cultural, economic, and sovereign benefit of the CTUIR. We will accomplish this utilizing traditional ecological and cultural knowledge and science to inform:

1) population and habitat management goals and actions; and

2) natural resource policies and regulatory mechanisms.

In support of the CTUIR Department of Natural Resources mission statement, the Fisheries Habitat Program goal and objectives:

1) To protect, enhance, and restore functional floodplain, channel, and watershed processes to provide sustainable and healthy habitat for aquatic species of the First Foods order.

2) Develop comprehensive and scientifically defensible restoration strategies based on the most recent and best available scientific information (Includes prioritizing actions and geographic areas).

3) Maintain and apply an updated knowledge of floodplain, channel and watershed function as it relates to healthy aquatic conditions and fish populations.

4) Build and maintain cooperative and coordinated relationships with other key agencies and stakeholders in order to maximize project efficiency, effectiveness and success.

Oregon Department of Fish and Wildlife (ODFW)

To protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations.

Washington Department of Fish and Wildlife (WDFW)

To preserve, protect, and perpetuate fish, wildlife, and ecosystems while providing sustainable fish and wildlife recreational and commercial opportunities.

Technical Team, Co-Managers, Stakeholders and Collaboration

The project was performed in collaboration with state co-managers, Federal and local agencies, and other stakeholders. The state co-managers include the ODFW and the WDFW.

A communication plan was designed for this project and used to facilitate the development of the Assessment and Action Plan. The communication plan aligns with and supports the Vision, Goals and Objectives established for the project. The communication plan helped the project team determine the appropriate level of engagement and communication, map appropriate strategies, and share information.

Stakeholders were a key source of data and the ultimate recipient of the communications messaging. Stakeholder groups and their respective roles are described below. Key personnel per group was a vital part of defining the collaboration process.

CTUIR - Project Lead and point of contact with all stakeholder groups

Core Project Team - Lead for all project technical assessments, managed products and deliverables, lead internal meetings and technical meetings in collaboration with CTUIR Project Lead. The team of technical scientists and habitat restoration specialists included Rio ASE, LLC, Ecosystem Sciences, LLC, and Mount Hood Environmental.

Co-Managers
- CTUIR
- ODFW
- WDFW

Technical Advisors - The project developed an efficient partitioning of technical groups to avoid overlap, or involvement in areas without technical expertise or oversight. Technical input from advisory groups was an important part of the Action Plan development.

Landowners / Public - CTUIR maintains an outreach component to the public, local landowners and other stakeholders to inform, engage and solicit feedback on all projects. Two public meetings were held in March, 2023 and August, 2024 to disseminate information from the assessment and Plan and to seek feedback prior to finalization.

Vision, Goals, Objectives

CTUIR, core project team and co-managers were responsible for developing the Vision, Goals, and Objectives (Figure 4). These principals guide the project, communications, and outcomes. The Vision, Goals and Objective for this project are described on the following pages.

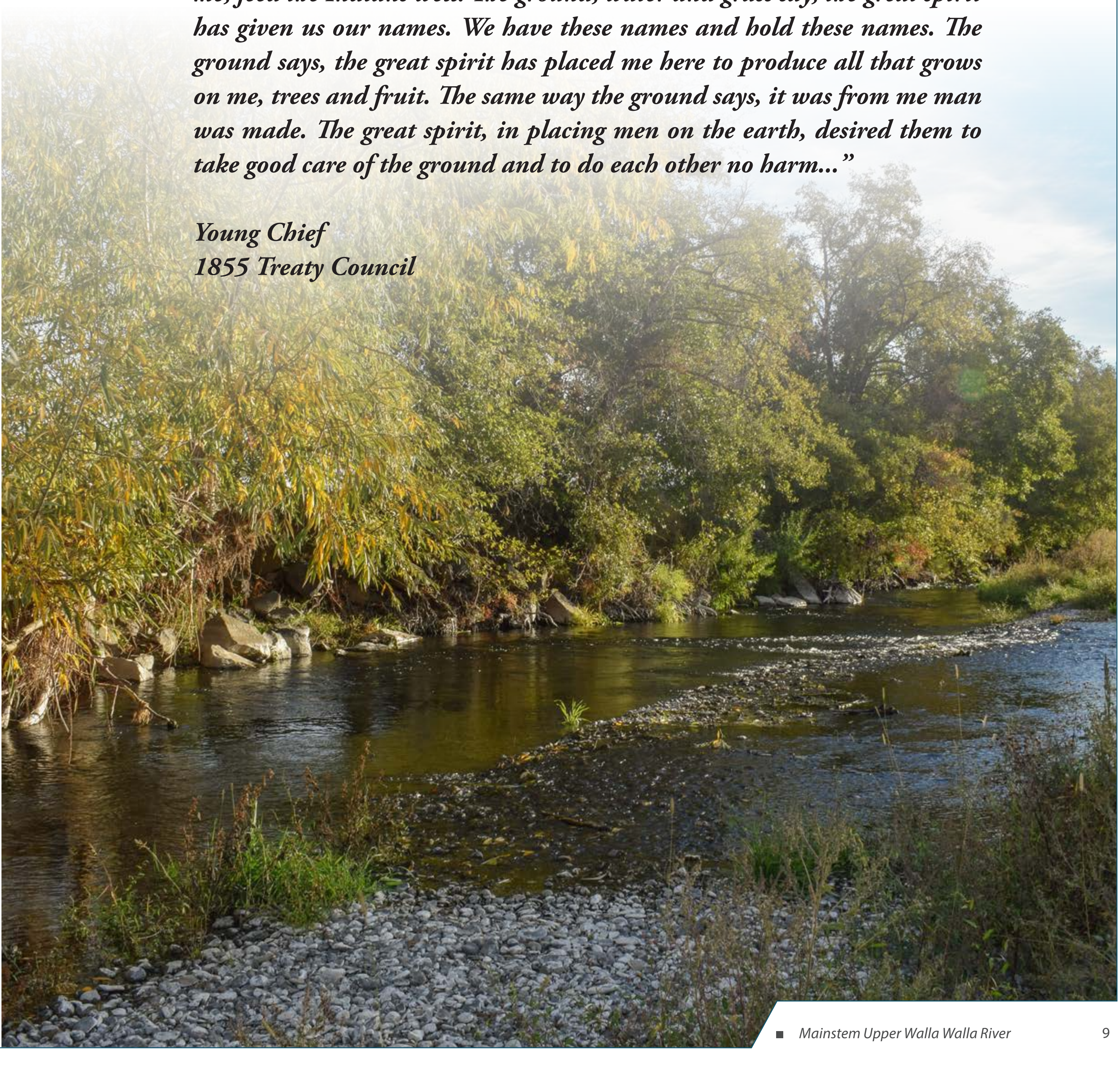
A vision is a brief but powerful statement that acts as a driving force for achievement of a project. A good vision statement is succinct, which makes it easy for leaders to communicate and stakeholders to understand.

Goals are the targets for the project, and are needed to achieve and fulfill the vision. A goal is a brief, clear statement of an outcome to be reached. The primary difference between visions and goals is action. A vision provides direction for the goals. Goals are action-oriented that produce results and drive project success.

Objectives define the actions that must be taken. Objectives are targets that are realistic, specific, and measurable. Objectives help achieve project goals over time and work to ensure that the actions are directed toward overall goals. Objectives define the steps to take to achieve goals. By fulfilling an objective, the project progresses toward goals and ultimately, the vision.

"I wonder if the ground has anything to say? I wonder if the ground is listening to what is said? I wonder if the ground would come alive and what is on it? Though I hear what the ground says. The ground says, it is the great spirit that placed me here. The great spirit tells me to take care of the Indians, to feed them alright. The great spirit appointed the roots to feed the Indians on. The water says the same thing. The great spirit directs me, feed the Indians well. The ground, water and grass say, the great spirit has given us our names. We have these names and hold these names. The ground says, the great spirit has placed me here to produce all that grows on me, trees and fruit. The same way the ground says, it was from me man was made. The great spirit, in placing men on the earth, desired them to take good care of the ground and to do each other no harm..."

Young Chief
1855 Treaty Council



Vision

TO ESTABLISH THE UPPER WALLA WALLA RIVER AS A HEALTHY AND FUNCTIONAL ECOSYSTEM

An ecosystem that supports multiple uses for cultural and nutritional subsistence, species conservation, agriculture, recreation, and public safety such that the Walla Walla River sustainably supports harvestable focal species populations in balance with the needs of the local community. These values are expressed through the CTUIR Upland Vision[1] and River Vision[2] touchstones, and are complementary to conservation and restoration strategies supported by local and regional stakeholders.

1. First Foods Upland Vision (Endress B. A., 2019).
2. River Touchstones (Jones K. L., 2008).

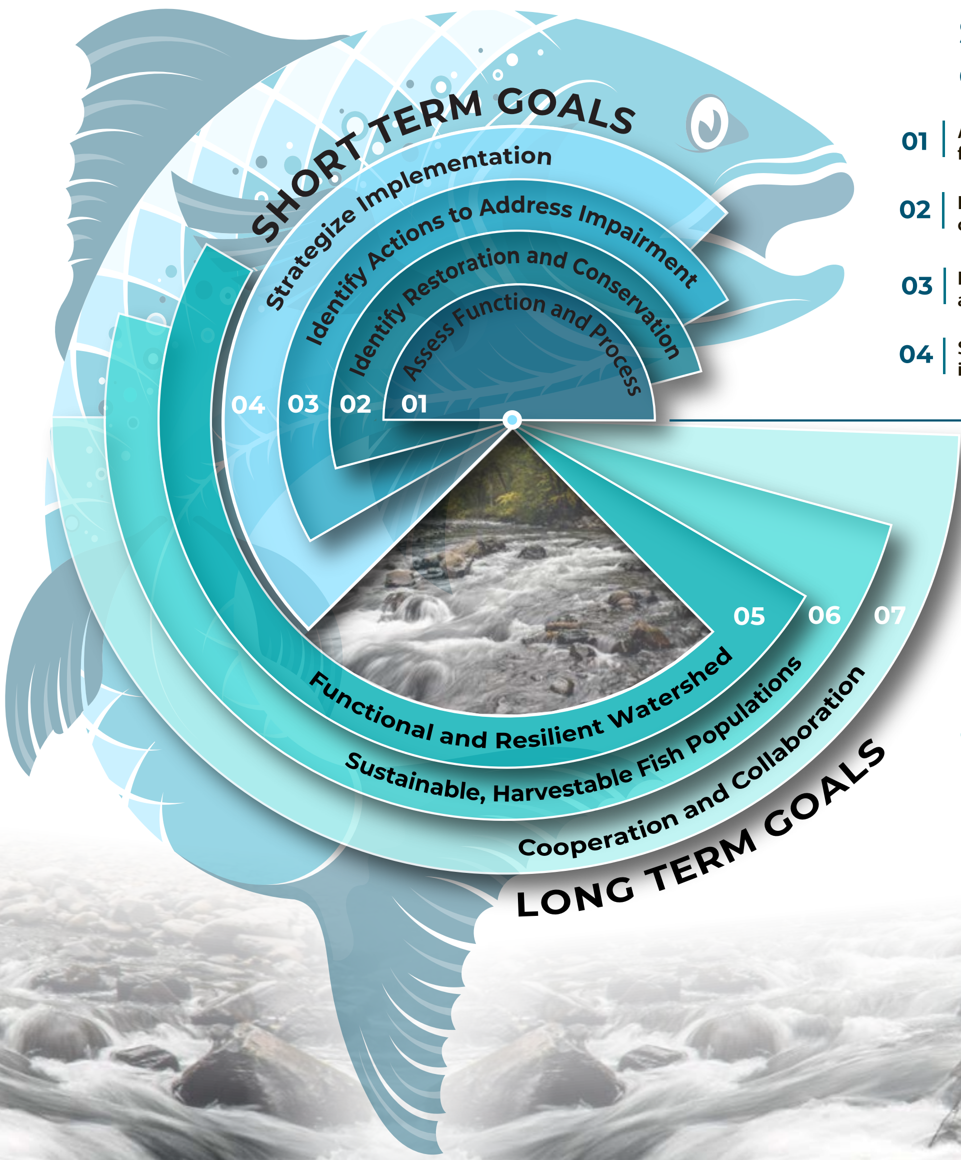
UPLAND VISION
Touchstones

Upland Vision[1] touchstones ensure healthy, resilient and dynamic upland ecosystems capable of providing First Foods that sustain the continuity of the Tribe's culture.

RIVER VISION
Touchstones

River Vision[2] touchstones support a healthy, dynamic river system that can sustain production of First Foods, with an emphasis on Water and Salmon.

Goals & Objectives



SHORT TERM

	GOALS	OBJECTIVES
01	Assess watershed function and processes	Scientifically robust assessments of watershed function
02	Identify restoration and conservation opportunities	Prioritized areas for restoration and conservation
03	Identify actions to address impairment	Develop actions that support restoration to achieve multi-species uplift
04	Strategize implementation	Design a 20-year strategic plan for restoration implemetation

LONG TERM

	GOALS	OBJECTIVES
05	Functional and resilient watershed	Implement actions in priority areas to restore function
06	Sustainable and harvestable fish populations	Enable projects that achieve multi-species uplift
07	Cooperation and collaboration	Establish shared goals and understanding of healthy watershed conditions

Figure 4. Vision, Goals, Objectives

Watershed Assessment

Geology and Geomorphology, Soils, Land Cover and Land Use, Sediment, Hydrology, Fish Use and Population, Climate, Fish habitat Capacity

The Upper Walla Walla Watershed Assessment included approximately 1,111 square kilometers of the watershed and 114 stream kilometers that were divided into 21 distinct geomorphic reaches within the main stem, North Fork and South Fork Walla Walla River upstream of the confluence with Dry Creek near the town of Lowden, Washington.

Upper Walla Walla

This chapter summarizes multiple watershed-scale attributes, evaluating their existing conditions and impacts affecting upland and aquatic ecosystems. The combination of these attributes defines the character of the river system, influences its evolution and resilience over time, and creates habitat supporting the first foods necessary to sustain CTUIR culture. These attributes were also used to delineate individual geomorphic reaches for more detailed analysis and development of restoration targets and treatments summarized later in this document.

The Upper Walla Walla Watershed is diverse both in its physical features and its historical evolution. The South Fork and the North Fork of the Walla Walla River originate on the forested slopes of the Blue Mountains in southeastern Washington and Northeastern Oregon. The Blue mountains are comprised primarily of basalt bedrock with relatively shallow soils that contribute to flashy runoff and high erosion rates on the surface, and enable deep groundwater recharge through the highly fractured bedrock. The narrow canyons of the North Fork and South Fork join forming the mainstem Walla Walla River. Where the mainstem departs the confined upper watershed the historical river was able to spread out, branch into multiple channels, dissipate energy, and deposit sediment. A broad alluvial fan formed. The conifer forest of the headwaters similarly transitions to more and more deciduous trees and shrub/scrub landcover on the broad alluvial fan surface of the lower watershed. Likewise, groundwater recharge from the upper watershed contributes to gaining reaches of the mainstem river in the lower watershed where the basalt geology shifts to gravel deposits of the broad alluvial valley.

The diverse physical character of the watershed has been influenced by human impacts of the years. Historical land use by the Cayuse, Umatilla, and Walla Walla Tribes, consisted primarily of annual cycles of travel between the uplands of the Blue Mountains in the summer and fall to the lower watershed areas in the winter and spring following food sources and preferable climate patterns. Land use impacts were minimal.

Beginning in the 1880's European settlers moved into the area introducing large-scale farming, ranching, timber harvesting, roads, irrigation diversions, levees, and other impacts associated with rural development. These practices started relatively small, but quickly grew to take over much of the lower watershed. Floodplains provided available flat ground upon which to raise crops, build roads and infrastructure, and create new communities. The river was mechanically modified to accommodate this new development, and large portions of the river were straightened, channelized, leveed, and riprapped.

On the following pages is a summary of watershed-scale conditions within the Upper Walla Walla. Below is an association of each watershed scale condition accompanied by the associated touchstone.

River Vision Touchstones and Associated Watershed-Scale Conditions

Riparian Vegetation - Land Use and Land Cover / Soils / Climate

Aquatic Biota - Fish Habitat Capacity / Climate / Fish Use, Population and Access / Land Use and Land Cover

Connectivity - Land Use and Land Cover / Climate / Fish Use, Population and Access

Hydrology - Hydrology / Land Use and Land Cover / Climate

Geomorphology - Geomorphology and Geology / Sediment / Soils / Land Use and Land Cover / Climate

Geomorphology and Geology

Upper Walla Walla Watershed

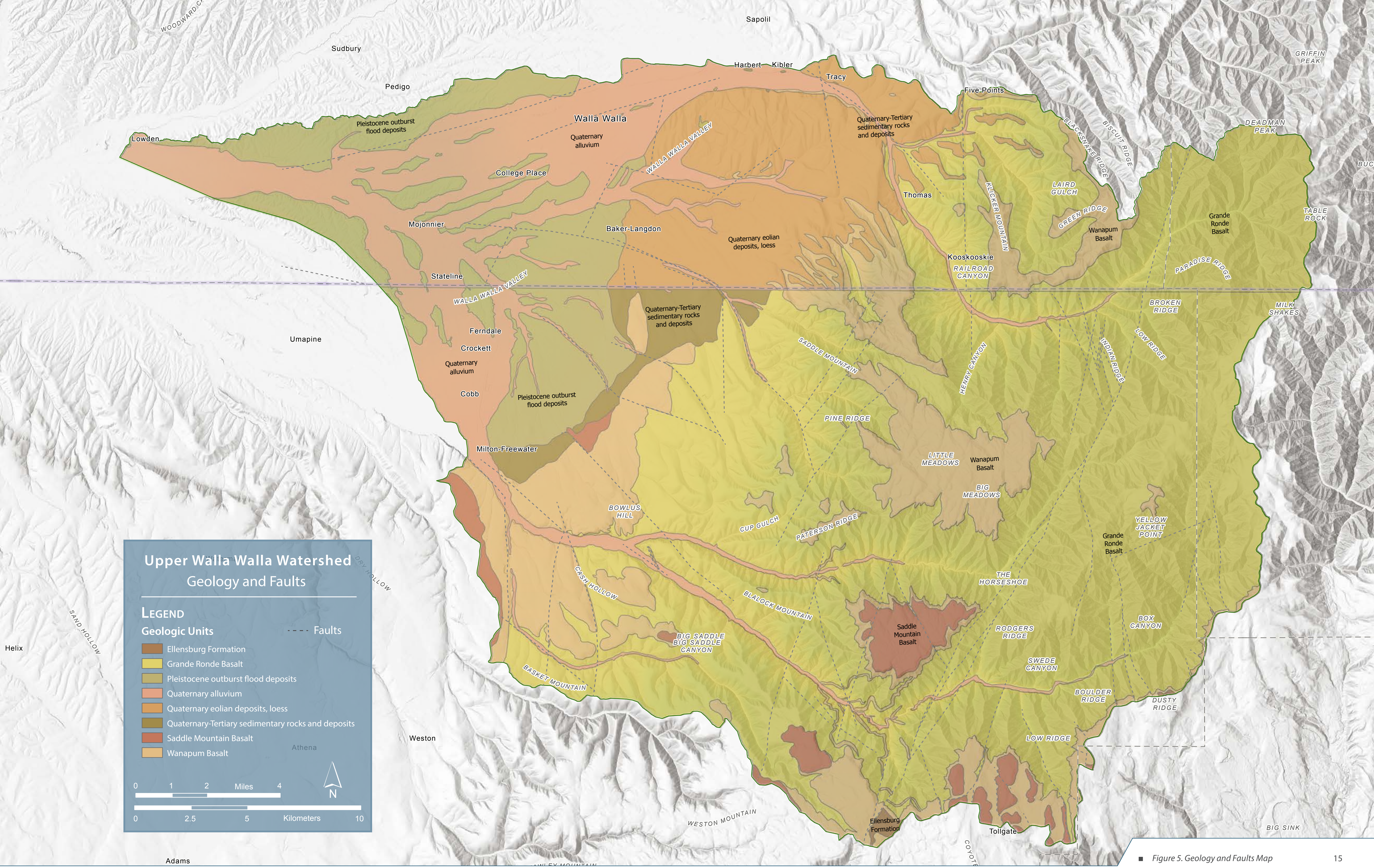
From the basalt cliffs of the uplands to the fertile floodplains of the valley, the geology and geomorphology of the Walla Walla River Basin provide the foundation for landscape processes that shape the integrated Upland and River Vision Touchstones.

The watershed is primarily underlain by the Columbia River Basalt Group (CRBG), which formed between 17 and 6 million years ago and consists of thick basalt layers stacked like a "layer cake." The Grande Ronde Basalt is the oldest and thickest of CRBG units in the basin and consists of multiple, relatively thin flows with low silica content and is known for its dark, fine-grained texture. The Wanapum Basalt, which overlies the Grande Ronde Basalt, is composed of several flows, which are less extensive and exposed primarily in areas where erosion has removed the overlying Saddle Mountains Basalt, revealing a more varied topography with cliffs and rocky outcrops. As a result, dense fractures in this formation allow for significant groundwater storage and flow. The Saddle Mountains Basalt caps the basalt sequence and consists of thinner flows with a more complex composition, including more silica-rich basalts and occasional interbedded sediments. It is less widespread than the underlying basalts but can be found in scattered outcrops and is often associated with elevated topography that serves as a protective layer, reducing erosion of the softer underlying units. These formations dominate the upper landscape, creating steep hillsides and rugged cliffs, especially in the headwaters of the South Fork and North Fork Walla Walla River.

The geomorphology of the South Fork and North Fork are characterized by steep, rugged terrain shaped by a combination of tectonic uplift, which has raised the land, and stream erosion, which has carved the river valleys. The elevations in these areas range from approximately 457 meters to over 1,800 meters, with steep slopes frequently exceeding gradients of 30%. The headwaters are primarily covered with shallow, rocky soils derived from volcanic ash and basalt. Basalt outcrops are common on the steep hillsides, where erosion has exposed the columnar jointing and stratified layers of the basalt flows. Faulting and tectonic uplift have also influenced the course and incision of the river. Fault zones, such as the Hite Fault, create weaknesses in the rock, allowing the rivers to cut deeply into the landscape. These geologic and geomorphic characteristics of the upper watershed influence both soil formation and hydrology by providing channels for groundwater flow through the fractures in the rock that are important to aquifer recharge. Faults and folds influence groundwater flow and sediment transport, while the varying topography and soil types determine the suitability of land for different uses.

As the Walla Walla River descends from the uplands into the lower elevations near Milton-Freewater, the landscape transitions into broad alluvial plains and gently sloping terrain that contrasts sharply with the rugged headwaters. In the valley bottoms and floodplains, deposits of sand, gravel, and silt, transported by the Walla Walla River and its tributaries, overlay the basalt bedrock.

Overlying the basalt in some areas are sedimentary deposits including those from catastrophic, regional, glacial outburst floods during the last ice age. These deposits are more easily eroded than the underlying basalt, but more resistant to erosion than other wind and floodplain deposits. Wind-blown deposits, which also originated ruing the last ice age, can reach thicknesses of several meters and, along with the floodplain sediments, contribute to the thick and fertile soils in the valley. These soils sustain a rich agricultural landscape that has traditionally been used for growing crops that are essential for sustaining the First Foods.



Upper Walla Walla Watershed
Geology and Faults
Legend
Geologic Units
Faults
Ellensburg Formation
Grande Ronde Basalt
Pleistocene outburst flood deposits
Quaternary alluvium
Quaternary eolian deposits, loess
Quaternary-Tertiary sedimentary rocks and deposits
Saddle Mountain Basalt
Wanapum Basalt
0 1 2 Miles 4
0 2.5 5 Kilometers 10
N
Walla Walla
Quaternary alluvium
Pleistocene outburst flood deposits
Quaternary-Tertiary sedimentary rocks and deposits
Quaternary eolian deposits, loess
Wanapum Basalt
Grande Ronde Basalt
Saddle Mountain Basalt
Ellensburg Formation
Walla Walla Valley
Sapolil
Sudbury
Pedigo
Lowden
Harbert
Kibler
Tracy
Five Points
College Place
Mojonnier
Baker-Langdon
Thomas
Kooskooskie
Stateline
Umapine
Ferndale
Crockett
Cobb
Milton-Freewater
Helix
Weston
Athena
Adams
Tollgate
Woodward C
Griffin Peak
Deadman Peak
Blacksnake Ridge
Biscuit Ridge
Laird Gulch
Green Ridge
Klicker Mountain
Table Rock
Railroad Canyon
Paradise Ridge
Broken Ridge
Milk Shakes
Low Ridge
Indian Ridge
Henry Canyon
Saddle Mountain
Pine Ridge
Little Meadows
Big Meadows
Bowlus Hill
Cup Gulch
Paterson Ridge
Yellow Jacket Point
The Horseshoe
Cash Hollow
Dry Hollow
Blalock Mountain
Sand Hollow
Big Saddle
Big Saddle Canyon
Rodgers Ridge
Box Canyon
Swede Canyon
Boulder Ridge
Dusty Ridge
Basket Mountain
Low Ridge
Weston Mountain
Big Sink
Coyote

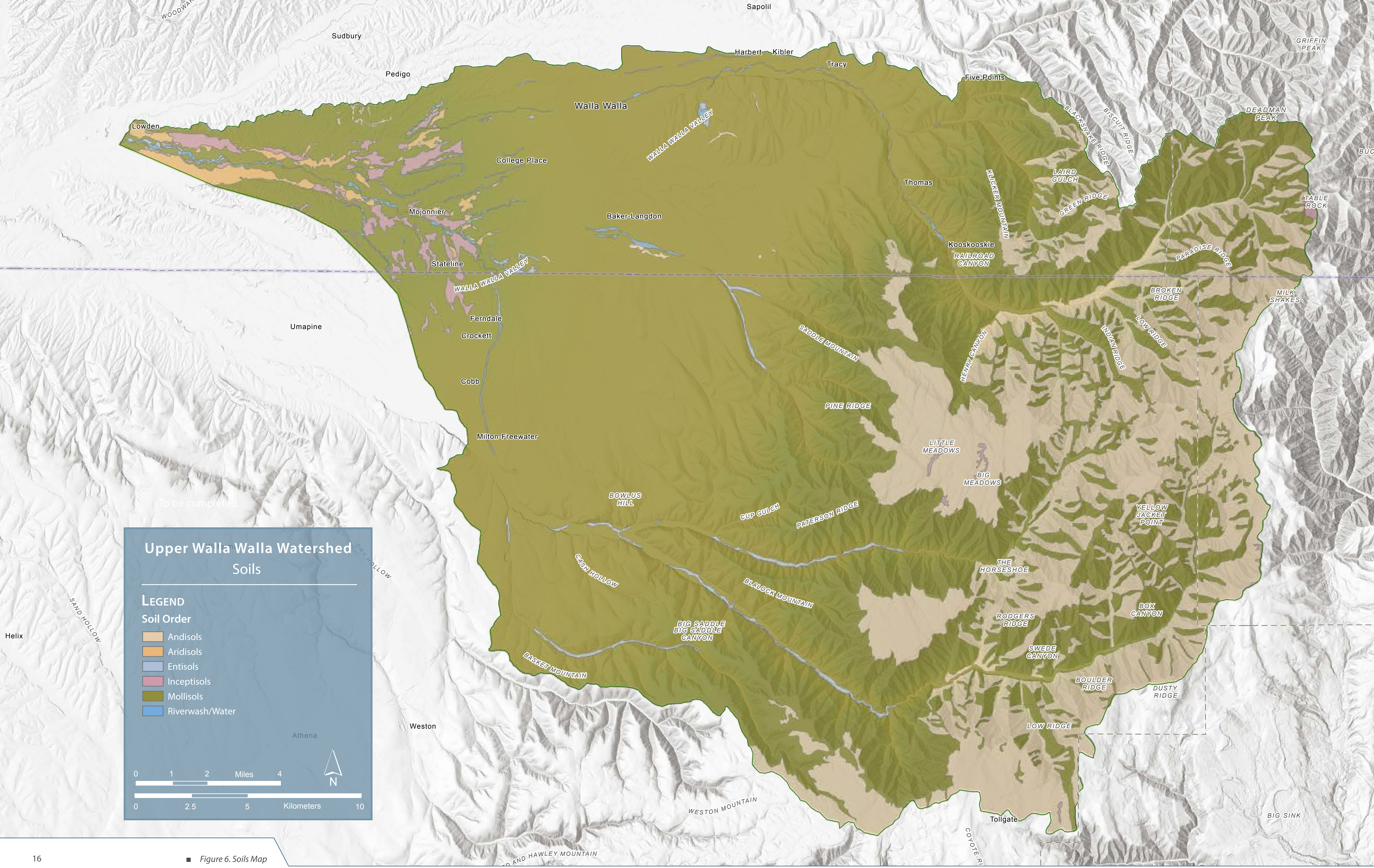


Figure 6. Soils Map

Soils

Upper Walla Walla Watershed

The soils of the Upper Walla Walla Watershed are primarily a mix of volcanic ash, basalt-derived materials, and sedimentary deposits, leading to a range of soil types that vary in texture, fertility, and drainage capabilities, which are integral to the ecological health and cultural values emphasized in the Upland Vision Touchstone framework.

Following the general landscape patterns in geology and topography, the uplands and lowlands are composed of functionally different soil characteristics. In the lower watershed near Milton-Freewater, deep, fertile soils classified as Mollisols are formed from loess and alluvial deposits. These soils have a high organic matter content, neutral to slightly alkaline pH, and excellent structure, allowing for extensive root growth and high water retention. The soil thickness, often several meters deep, supports robust agricultural productivity for crops like wheat, vineyards, and orchards. Mollisols' ability to retain moisture and nutrients makes them highly effective for cultivation, but they are also susceptible to erosion and compaction, particularly on sloped fields or with improper tillage practices. Effective management, such as no-till farming and cover cropping, is essential to preserve their structure and prevent degradation.

In contrast, soils in the upper watershed are classified as Andisols, which are shallow soils developed from volcanic ash, pumice, and basalt. These soils are light, porous, and characterized by high water-holding capacity due to the presence of clay minerals. However, Andisols are typically less than a meter deep and rest on fractured basalt bedrock, which limits their ability to support deep-rooted plants and results in rapid surface runoff during precipitation events. Their texture varies from sandy to gravelly loams, with lower organic matter and nutrient content compared to Mollisols.

These conditions create challenging environments for vegetation, favoring drought-resistant grasses, shrubs, and coniferous forests such as Ponderosa pine and Douglas fir. The steep slopes and thin soil layers increase susceptibility to erosion, landslides, and reduced water infiltration, particularly during heavy rainfall or snowmelt.

Effective management of these contrasting soil types is crucial for the overall health of the watershed. Practices like controlled grazing, reforestation, and erosion control in the uplands not only help stabilize soils but also enhance water retention and support the River Vision's goals by reducing sediment loads and regulating the flow of clean water into downstream areas. The interconnectedness of upland and river systems highlights the need for integrated management strategies that balance agricultural productivity with habitat restoration and conservation. By protecting the soil health and ecological integrity of both the fertile lowland Mollisols and the fragile upland Andisols, the Upland and River Vision Touchstones provide a comprehensive framework to sustain the cultural and ecological values of the CTUIR and ensure the long-term resilience of the Walla Walla Basin.

Land Cover and Land Use

Upper Walla Walla Watershed

The Upper Walla Walla Watershed is characterized by a diverse range of natural and human-influenced landscapes that reflect its geographical, ecological, and socio-economic characteristics.

Upstream of Milton-Freewater, the rugged Blue Mountains shape the Upper Walla Walla watershed with steep slopes, narrow valleys, and complex geology dominated by Columbia River Basalt. The shallow Andisols, formed from volcanic ash and basalt, support coniferous forests of Ponderosa pine, Douglas fir, and grand fir, historically managed for timber production and now increasingly focused on recreation and wildlife habitat conservation. Logging has been a significant industry, but land use practices have shifted towards sustainable management, reforestation, and controlled grazing to reduce erosion and maintain ecological health. These upland areas, with their cool climate and seasonal snowpack, play a critical role in water retention and contribute to the hydrological balance of the watershed, aligning with the Upland Vision Touchstone's goals of protecting soil stability, water quality, and ecosystem resilience.

As the watershed transitions downstream near Milton-Freewater, the landscape opens into gently rolling hills and broad floodplains, ideal for extensive agricultural use. Fertile Mollisols and alluvial soils, formed from loess and river sediments, support dryland farming, irrigated agriculture, and livestock grazing. This area is renowned for producing wheat, barley, peas, and, more recently, high-quality wines from the expanding vineyards in the Walla Walla Valley.

The shift towards more intensive irrigated agriculture has increased water demand, impacting groundwater levels and surface water flow. Balancing agricultural productivity with the protection of riparian zones, which are crucial for water quality and wildlife habitat, is central to the River Vision Touchstone's focus on integrating sustainable agricultural practices with ecological restoration.

Urban and residential development, particularly around Walla Walla and Milton-Freewater, has been gradually expanding, driven by the growth of the wine industry and tourism. This development increases pressure on water resources and land stability, highlighting the need for careful planning to balance growth with conservation. The watershed also provides numerous recreational opportunities, such as hiking, fishing, camping, and hunting, with the Blue Mountains serving as a popular destination for outdoor activities.

Conservation efforts are crucial throughout the watershed, particularly in restoring critical habitats for endangered fish species like Chinook salmon, steelhead, and bull trout. The Walla Walla River and its tributaries are vital for sustaining aquatic First Foods, including salmon and trout, which depend on cool, clean water and complex stream habitats. Habitat restoration projects aim to enhance riparian zones and improve water quality, supporting both ecological and cultural values.

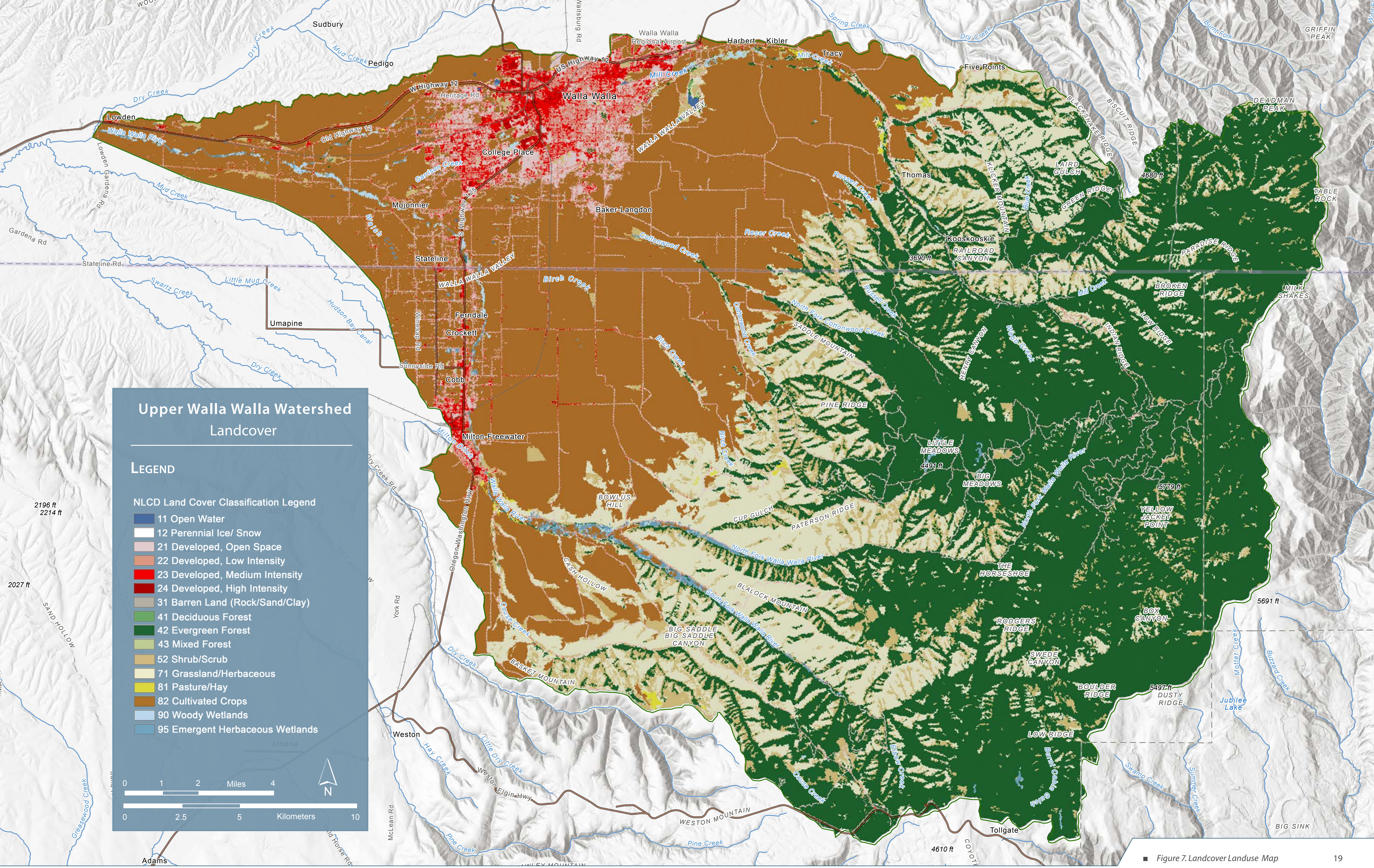


Figure 7. Landcover Landuse Map

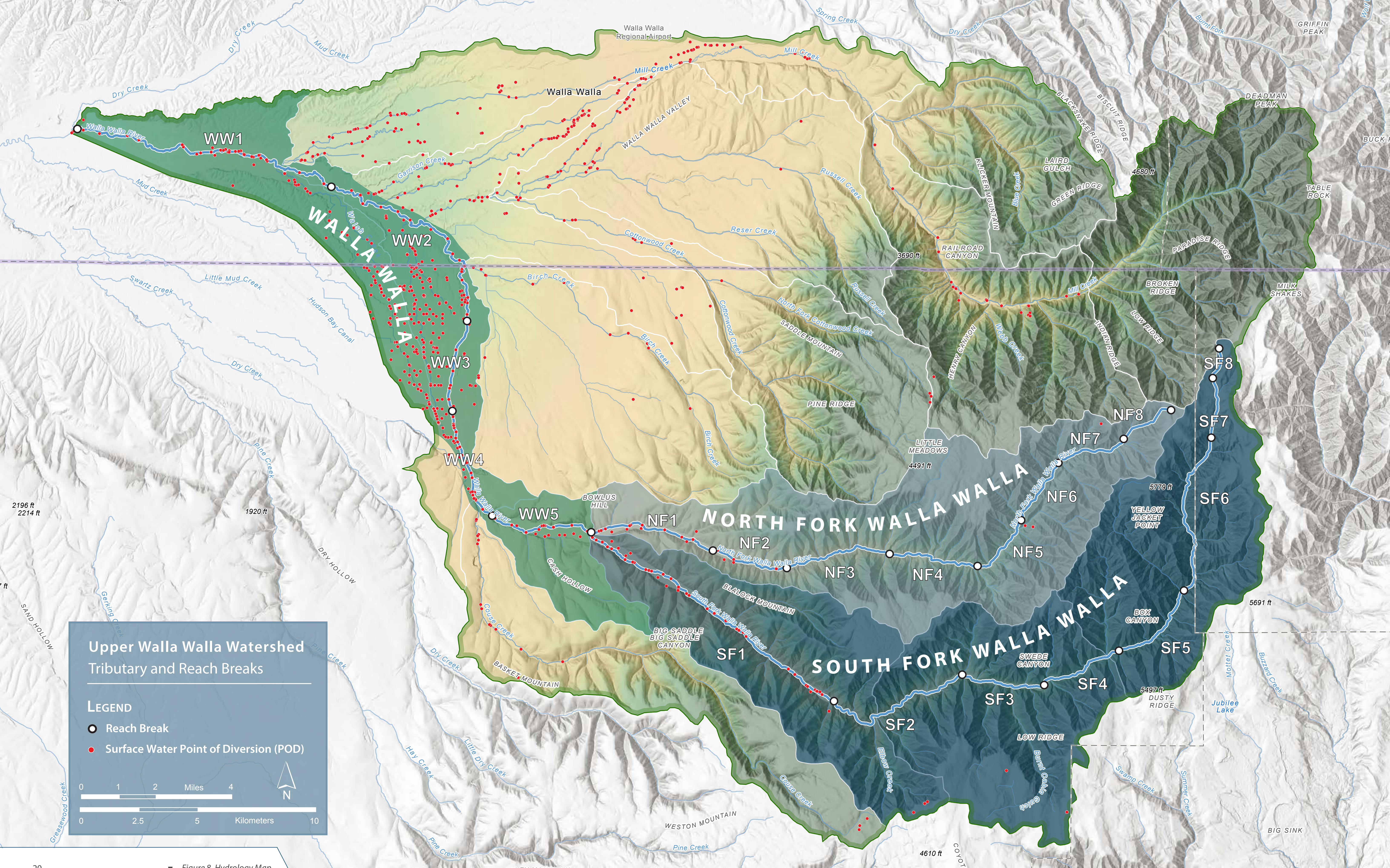


Figure 8. Hydrology Map

Hydrology

Upper Walla Walla Watershed

Surface water hydrology in the upper Walla Walla River is dominated by snowmelt, with the South Fork often contributing nearly double the discharge of the North Fork (Figure 9). The highly fractured basalt geology overlain by alluvial gravels also stores and contributes groundwater to the system. Up to 2.0 cms (70cfs) of discharge is gained from groundwater and springs between RKM 13 on the South Fork (Reach SF1) and the downstream project extent. Irrigation withdrawals on the other hand significantly reduce surface water flows, especially downstream of Milton-Freewater where the valley opens onto a broad alluvial fan that has been converted from floodplain to agriculture and rural development. Channel straightening, confinement, and levee construction have been used to protect infrastructure on the floodplain. The resulting channel confinement has increased the erosive force of the river while reducing floodplain storage and energy dissipation. Several distributary channels were historically used to divert water from the Walla Walla and recharge the groundwater (acting as an artificial floodplain), but occasional floods periodically overwhelm the system resulting in broad-scale flooding and erosion.

Because much of the water in the system originates in the headwaters and most irrigation withdrawals are in the lower valley, the upper reaches of the project area are generally meeting recommended ecological base flows required for fish passage and habitat needs for key species and life stages (Walla Walla River Bi-State Flow Study 2019). Conversely, reaches lower in the system (especially downstream of Milton-Freewater) are functioning at generally less than 25% of their recommended ecological base flows (Figure 10). Groundwater contributions help offset irrigation losses in Reaches NF1 and WW5.

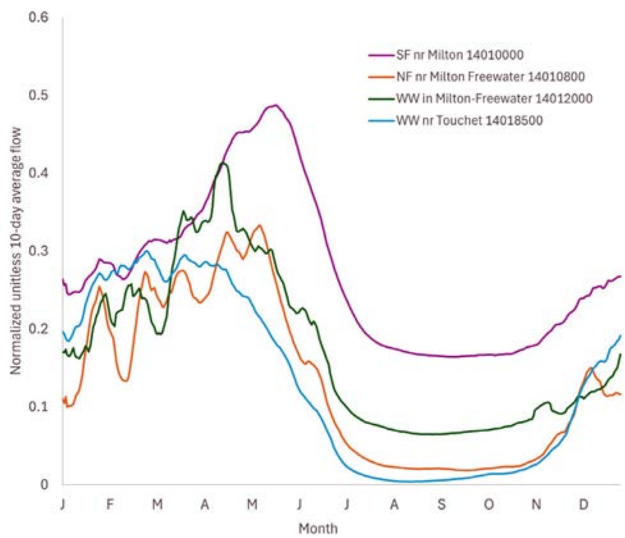


Figure 9. Relative timing and magnitude of streamflow at gage locations.

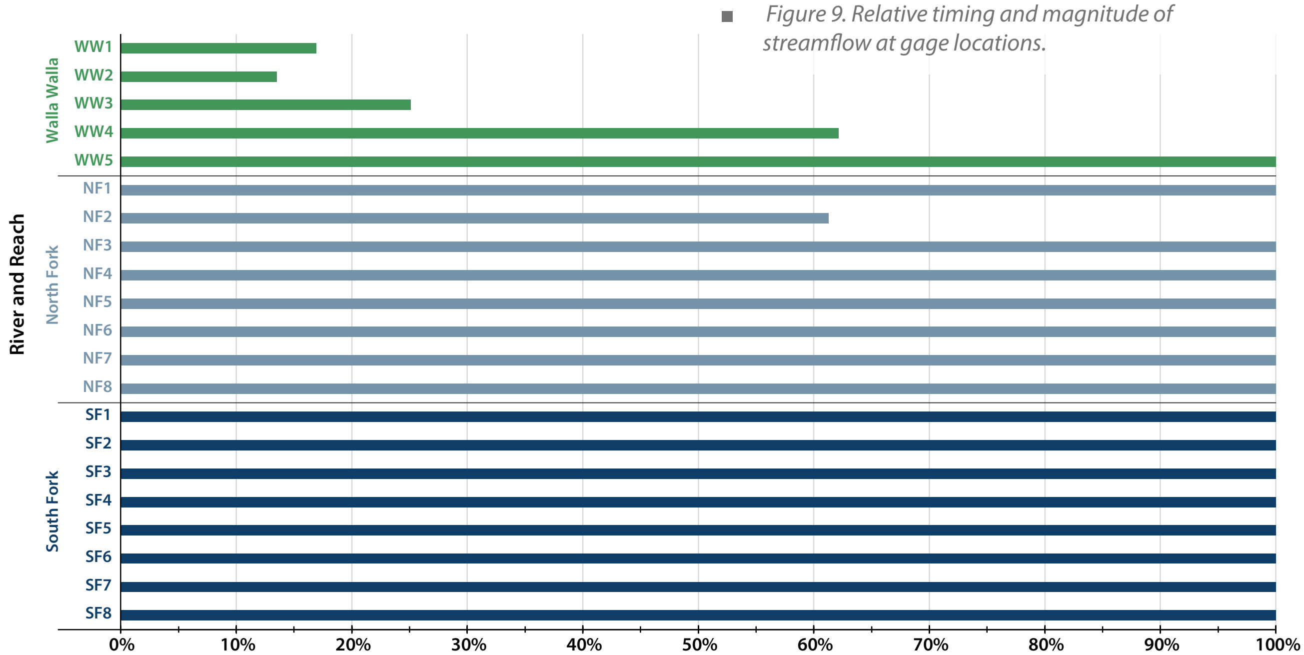


Figure 10. Estimated Baseflow (July-September) as a percent of Ecological Flow

Fish Use, Population Status and Access

Upper Walla Walla Watershed

Spring-run Chinook Salmon Extirpated in the late 1950s, spring-run Chinook salmon historically occupied the mainstem Upper Walla Walla River, the North and South Fork Walla Walla River, Mill Creek, and many Upper Walla Walla River tributaries. Reintroduction of the species occurred in the South Fork and Mill Creek in the early 2000s and hatchery augmentation continues through the ʔImtwaha Fish Hatchery, established in 2021 on the South Fork Walla Walla River. Today, Chinook salmon can be found in the mainstem Upper Walla Walla River, the South Fork Walla Walla River, and Mill Creek. While reintroduction efforts were successful in the watershed, contemporary abundance estimates of Chinook salmon in the Walla Walla River watershed continue to fall short of conservation goals.

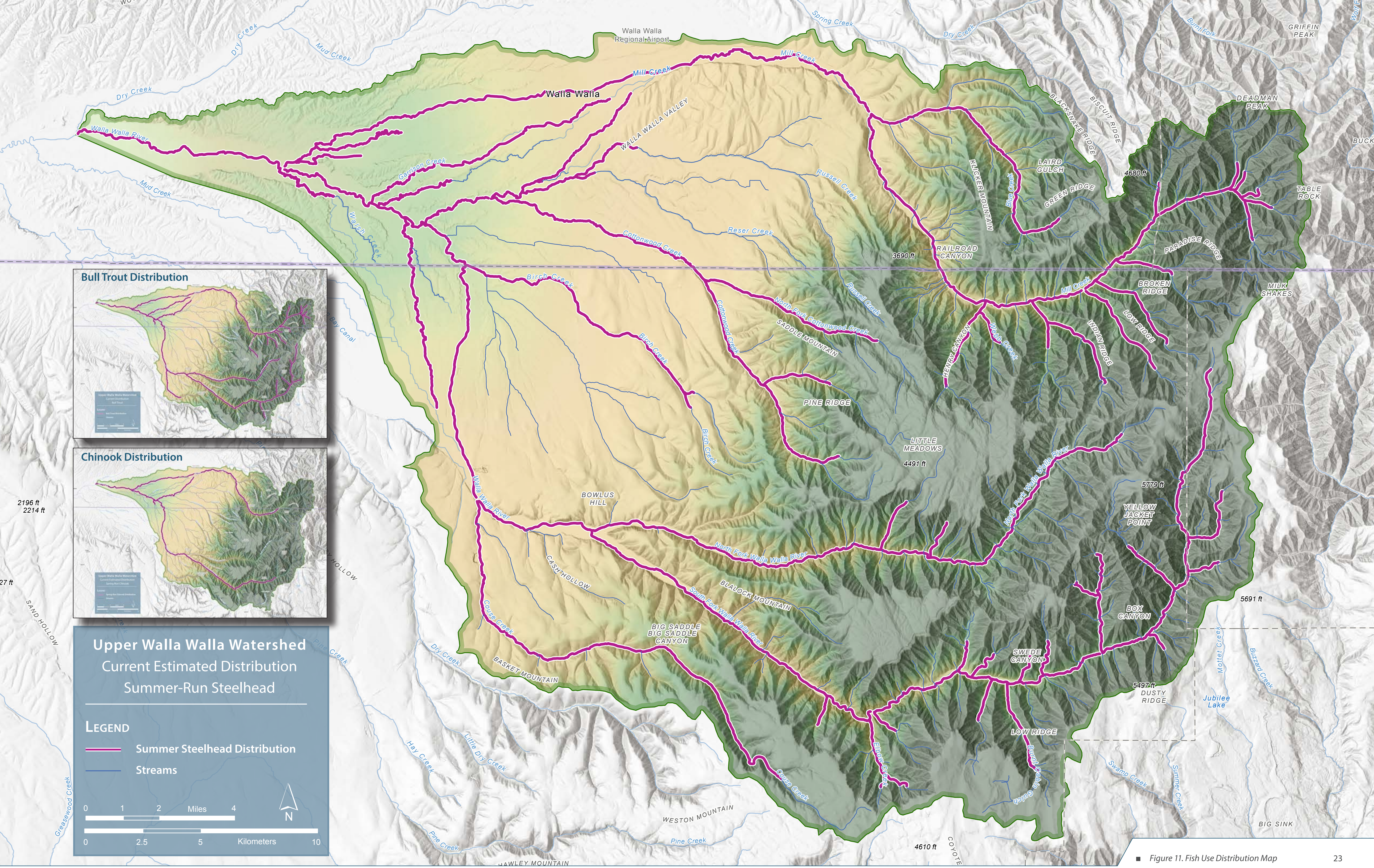
Middle Columbia River Summer Steelhead Steelhead occupy much of their historic range in the Upper Walla Walla River watershed but in limited or depressed capacities and are currently listed as threatened under the Endangered Species Act (ESA). Agricultural, urban, and forestry development in the early 1900's significantly impacted steelhead distributions and connectivity in the watershed. Implementation of adult fish passage infrastructure on several diversion dams in the 1980's improved steelhead connectivity in the watershed but degraded habitat continues to inhibit spawning and rearing throughout the watershed. The contemporary steelhead abundance estimates in the Upper Walla Walla River watershed is less than historical abundances, and the 10-year geometric mean (2011-2019) of upstream migrating adults at the Nursery Bridge Dam suggests a declining trend in abundances.

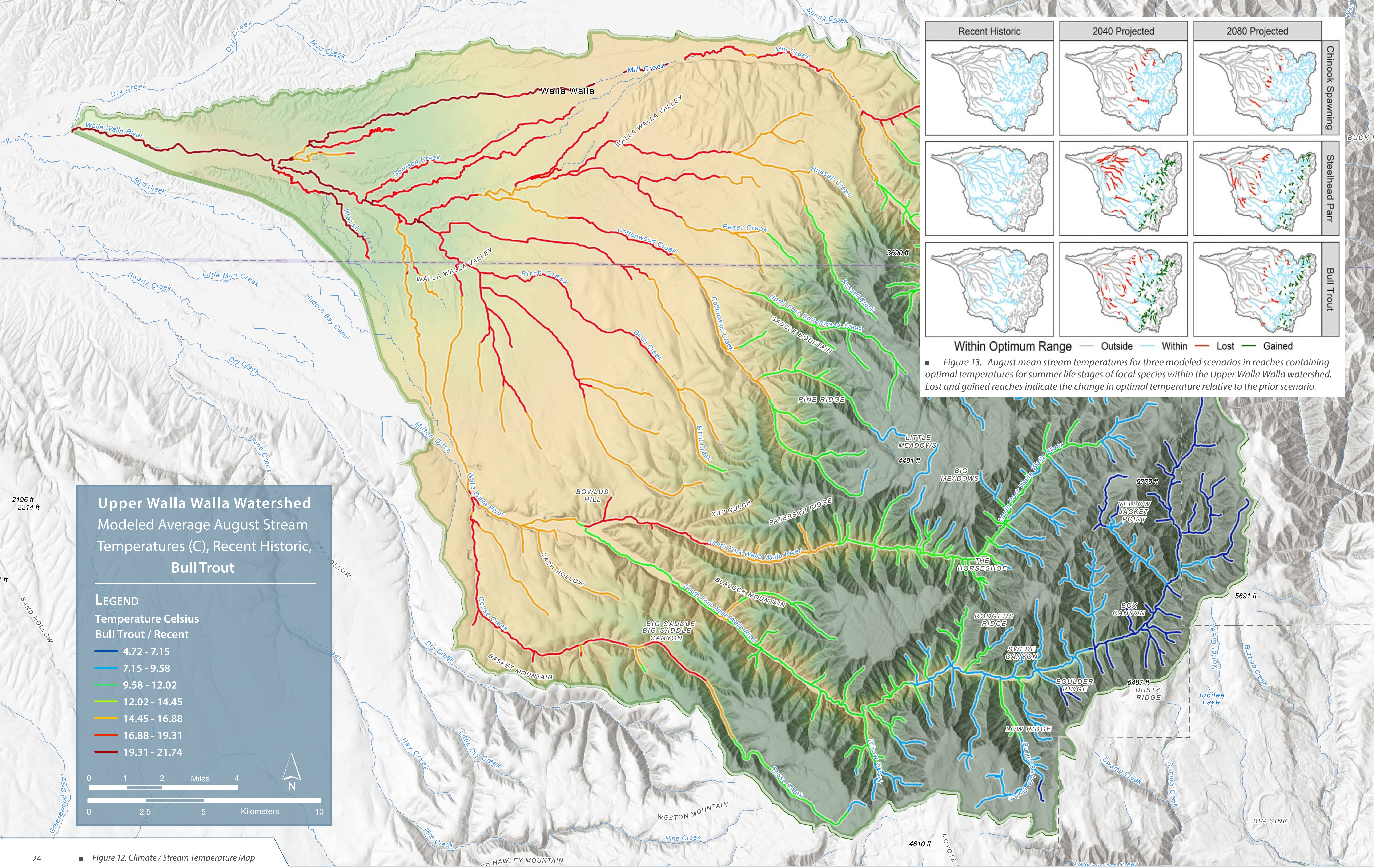
Columbia River Bull Trout Bull trout in the Upper Walla Walla River watershed exhibit both fluvial and resident life histories. Fluvial bull trout exhibit substantial seasonal movement throughout the Upper Walla Walla watershed (as well as into the Columbia River) depending on rearing and reproductive needs. Resident bull trout are often confined by thermal conditions to headwater habitat for most, or a portion, of their life.

Historic bull trout abundances and spatial extents are poorly documented, but it is assumed both have been reduced and negatively impacted by habitat degradation and anthropogenic impacts in the watershed. Bull trout are currently listed as threatened under ESA. Contemporary spatial extents for bull trout in the Upper Walla Walla River watershed consist of Mill Creek, North Fork Walla Walla, South Fork Walla Walla, and the mainstem Walla Walla. While contemporary bull trout abundance estimates in upper portions of the watershed suggest a stable population size, it is believed the population has been reduced compared to historical estimates.

Pacific Lamprey Pacific lamprey once occurred throughout much of the Upper Walla Walla River watershed, however they now appear to be extirpated from their entire historic range. While no quantitative data is available, tribal accounts from the South and North Fork of the Upper Walla Walla River and Skiphorton Creek suggest lamprey were abundant in the watershed. The last documented lamprey in the Upper Walla Walla River watershed was in 1997. Reintroduction of Pacific Lamprey is proposed for the Walla Walla through supplementation efforts focused on larval outplanting.

Limiting Factors Population productivity and distribution of focal species in the Upper Walla Walla River watershed has been impacted by agriculture, irrigation and water management, timber harvest, and urbanization. These land-use practices have led to several interrelated limiting factors for fish including degraded riparian habitat, increased water temperatures, excess sedimentation, simplified river morphology, modified timing and magnitude of flows, loss of North American beaver, degraded water quality, and physical barriers to movement. These factors adversely impact access to and the quality of habitat and food sources for focal species. While fish ladders have been installed to improve fish passage, dams on the mainstem Walla Walla River and Mill Creek have contributed to limited distributions of focal species within the watershed, and the extirpation of Chinook salmon in the 1950s. Today, there are three diversion structures within the watershed that can impede fish movement at low flows.


Upper Walla Walla Watershed
Current Estimated Distribution
Summer-Run Steelhead
Legend
Summer Steelhead Distribution
Streams
0 1 2 Miles 4
0 2.5 5 Kilometers 10
N
Bull Trout Distribution
Chinook Distribution
Walla Walla
Walla Walla Regional Airport
Walla Walla River
Mill Creek
Dry Creek
Mud Creek
Garrison Creek
Walsh Creek
Walla Walla Valley
Russell Creek
Reser Creek
Cottonwood Creek
North Fork Cottonwood Creek
Birch Creek
Saddle Mountain
Pine Ridge
Little Meadows
4491 ft
3690 ft
Railroad Canyon
Klicker Mountain
Blue Creek
Laird Gulch
Green Ridge
Blacksnake Ridge
Biscuit Ridge
Spring Creek
Burnt Fork
Griffin Peak
Deadman Peak
Table Rock
4680 ft
Paradise Ridge
Milk Shakes
Broken Ridge
Low Ridge
Indian Ridge
Henry Canyon
North Fork Walla Walla River
5779 ft
Yellow Jacket Point
Box Canyon
5691 ft
Swede Canyon
5497 ft
Dusty Ridge
Low Ridge
Jubilee Lake
Mottet Creek
Buzzard Creek
Swamp Creek
Summer Creek
Big Sink
Bowlus Hill
Cash Hollow
Blalock Mountain
South Fork Walla Walla River
Big Saddle
Big Saddle Canyon
Couse Creek
Basket Mountain
Elbow Creek
Burnt Cabin Gulch
Weston Mountain
Pine Creek
4610 ft
Hawley Mountain
Little Dry Creek
Hay Creek
Greasewood Creek
Sand Hollow
2196 ft
2214 ft



■ *Figure 13. August mean stream temperatures for three modeled scenarios in reaches containing optimal temperatures for summer life stages of focal species within the Upper Walla Walla watershed. Lost and gained reaches indicate the change in optimal temperature relative to the prior scenario.*

■ *Figure 12. Climate / Stream Temperature Map*

Climate

Upper Walla Walla Watershed

Warming temperatures associated with climate change are expected to affect the watershed in a variety of ways. A combination of moist maritime and dry continental climates creating a climate pattern with warm dry summers and cool damp winters. Low elevation areas are particularly susceptible to winter rain, rain-on-snow events, and early spring thaw contributing to flood flows. Due to orographic lift, the higher elevation areas of the watershed receive significantly more precipitation, primarily as snow in the winter.

The spring snowmelt-dominated hydrology is likely to transition to a rain-and-snow hydrology adding a secondary peak discharge associated with rain in the fall. Additionally, lower snowline elevations will result in more frequent rain-on-snow events throughout the winter increasing the likelihood of more frequent high- magnitude floods. With generally less snow and warmer temperatures, snowmelt and spring peak discharge are anticipated to occur earlier in the season, along with reduced low flows and higher stream temperatures in the summer. Snowmelt provides most of the streamflow in the Walla Walla River during the dry, summer months.

Stream Temperature Stream temperature is a critical component of the hydrology of the Upper Walla Walla River watershed, directly affecting the fish community and the connectivity of their habitat. In the Pacific Northwest, summer months are anticipated to become progressively more stressful for cold-water species as stream temperatures increase with warming air temperatures, which is likely to shift and reduce suitable habitat for many species. To determine whether summer stream temperature is a potential limiting factor for fish population productivity within the Upper Walla Walla River watershed, recent historic and future projected summer stream temperature scenarios were compared to life-stage specific temperature thresholds for focal species.

Understanding potential stream temperature limitations on habitat availability and suitability can help prioritize restoration actions (e.g., riparian planting, improved grazing practices, etc) to mitigate future impacts of a warming climate.

Recent historic (2002-2011) and projected (2040 & 2080) August mean stream temperature predictions (i.e., NorWest) were used in combination with established life-stage specific temperature thresholds for focal species to evaluate potential habitat limitations within the upper Walla Walla River watershed. To accomplish this, the August mean stream temperature predictions were used to quantify the amount of stream habitat exceeding optimum, maximum, and acute temperature thresholds relative to focal species' distributions (i.e., StreamNet) within the Upper Walla Walla watershed during summer months.

Under the recent historic stream temperature scenario, significant amounts of each species domains are outside of optimum thresholds with smaller amounts of habitat exceeding maximum thresholds, including the parr and spawning life-stages for Chinook salmon (Table 1). A small amount of Chinook salmon spawning and bull trout habitat also exceed acute thresholds under the recent historic scenario. As stream temperatures increase through the 2040 and 2080 projected scenarios, greater amounts of habitat exceed optimum, maximum and acute thresholds for each species and life-stage, reducing potential species' distributions to upper portions of the watershed. This constrains available habitat further and could create substantial thermal barriers downstream, preventing species from reaching habitat with suitable temperatures. A theoretical scenario where current stream temperatures cool by 1°C suggests that restoration actions aimed at mitigating climate change impacts, could provide relatively moderate gains in suitable habitat for each focal species.

Life Stage	2040 Projected	2080 Projected
Chinook salmon spawning	-3.8	-13.2
Chinook salmon parr	-18.4	-7.4
Steelhead parr	-24.6	-42.8
Bull trout	19.3	29.9
Pacific lamprey	5.8	24.7

■ *Table 1. Cumulative Length (km) of Optimal Temp Lost(-)/Gained(+)*

Habitat Capacity

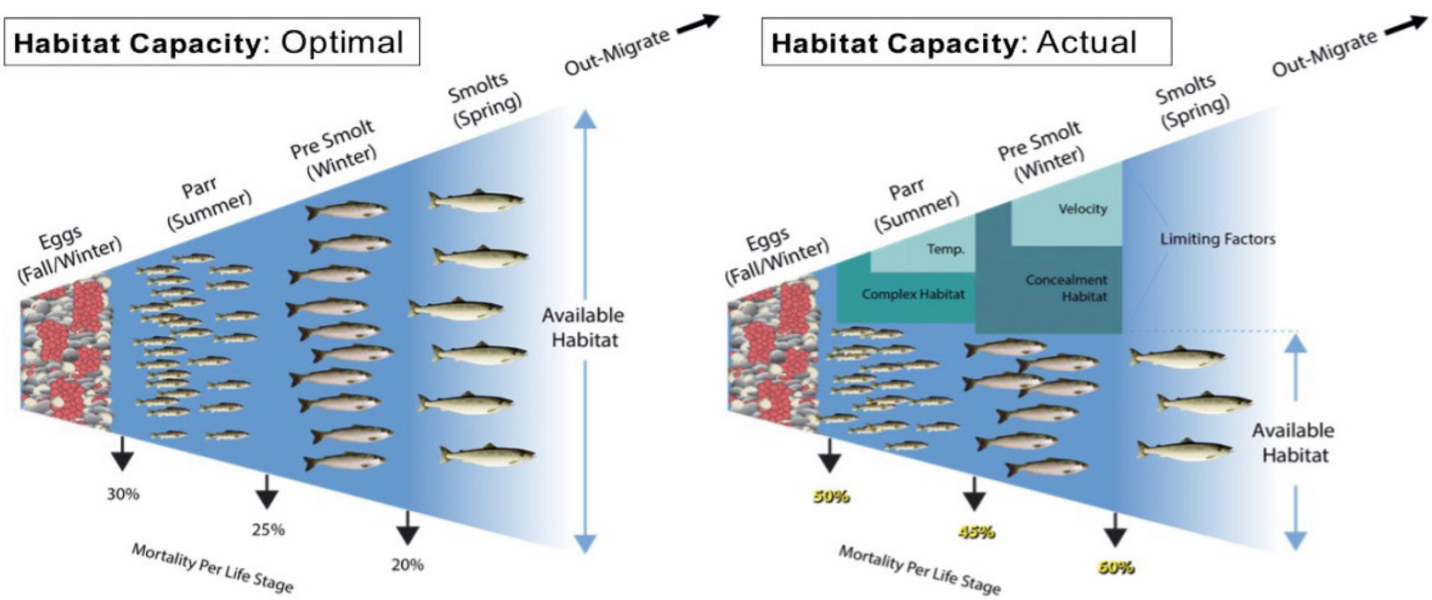
Understanding life-stage specific bottlenecks for salmon and steelhead populations is paramount in developing restoration or rehabilitation strategies that optimize benefits for specific species and life-stages. To determine restoration actions that have the greatest potential for recovery of Endangered Species Act-listed salmonids in the Upper Walla Walla River watershed, a novel approach for estimating habitat carrying capacity for multiple life-stages of Chinook salmon and steelhead relative to adult escapement recovery goals was employed. This quantitative approach identified population bottlenecks, helping guide restoration actions to alleviate limiting factors for specific species and life-stages.

Habitat capacity deficits resulting from limitations in habitat quantity and/or quality were assessed for three life stages of Chinook salmon and steelhead: 1) spawning (redds), 2) juvenile summer rearing (parr), and 3) juvenile winter rearing (presmolts). First, the capacity required to meet adult abundance escapement goals was estimated for each of the life stages using a Generalized Capacity Model framework. Next, the currently available habitat capacity was estimated using a quantile random forest (QRF) model approach applied at each life stage.

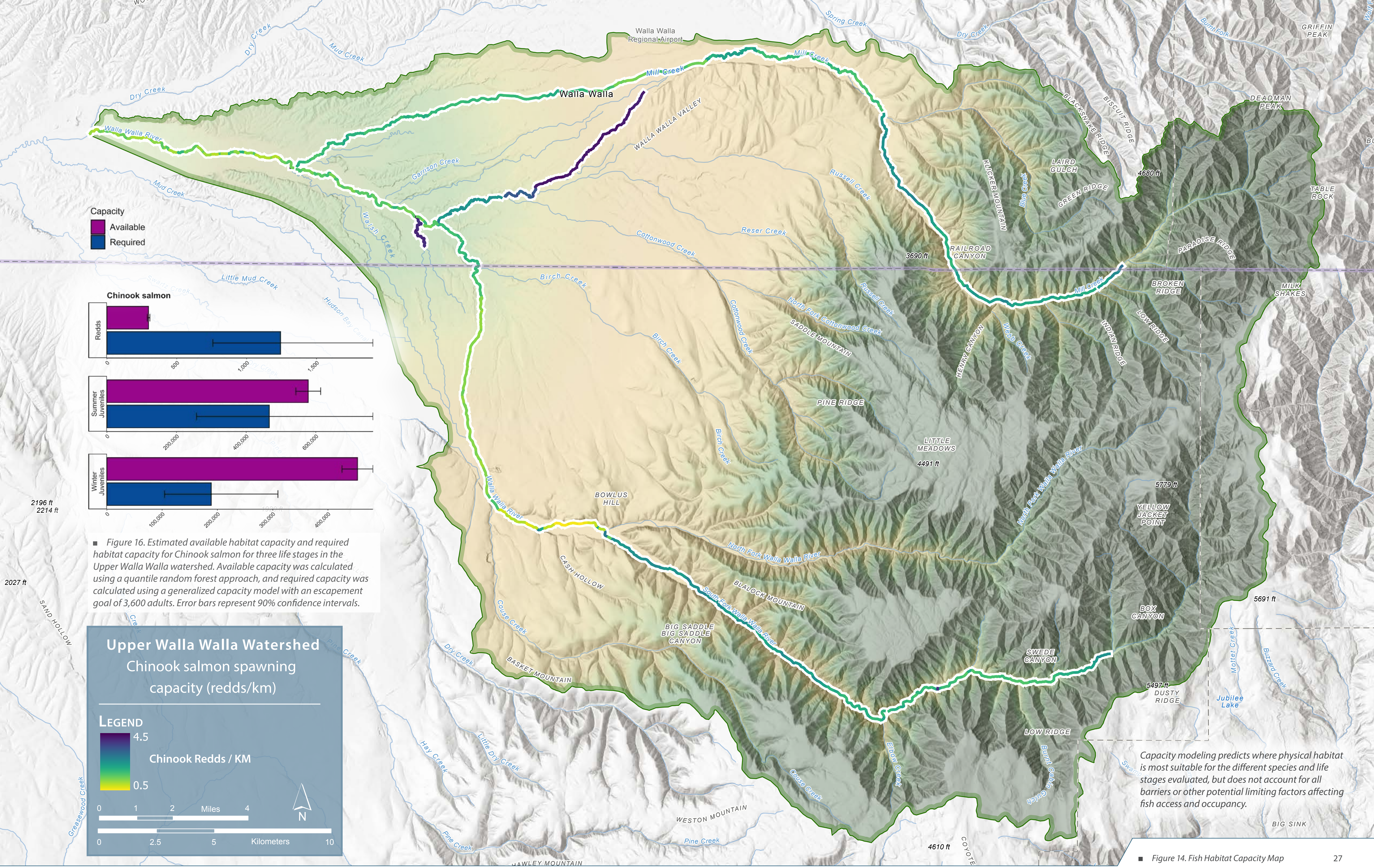
Finally, capacity limitations were quantified by subtracting required capacity from available capacity, providing an estimate of (potential) capacity deficit by species and life stage.

Results from the habitat capacity assessment identified that sufficient juvenile rearing habitat, during summer and winter months, is likely available for Chinook salmon to support an escapement recovery goal of 3,600 adults. However, there does not appear to be sufficient Chinook salmon spawning habitat available. It is estimated that the watershed would need to support an estimated 1,242 redds to recover 3,600 adults; a 317% increase from the estimated available capacity of 298 redds. For steelhead, there is sufficient juvenile rearing habitat, during winter months, to support an escapement recovery goal of 3,400 adults. However, available spawning and summer rearing habitat is insufficient. It is estimated that habitat in the watershed would need to support an estimated 2,017 redds to recover 3,400 adults; an 87% increase from the estimated available capacity of 1,079 redds. It is estimated that 1,355,743 parr would be required to achieve escapement recovery goals; a 33% increase from the estimated available capacity of 1,016,587 parr.

Reference Appendix H for additional species and life stage capacity modeling results.



■ *Figure 15: Schematics conceptualizing habitat capacity scenarios. The scenario on the left has no limiting factors, while the scenario on the right has significant limiting factors resulting in reduced habitat capacity and production.*



■ *Figure 16. Estimated available habitat capacity and required habitat capacity for Chinook salmon for three life stages in the Upper Walla Walla watershed. Available capacity was calculated using a quantile random forest approach, and required capacity was calculated using a generalized capacity model with an escapement goal of 3,600 adults. Error bars represent 90% confidence intervals.*

Capacity modeling predicts where physical habitat is most suitable for the different species and life stages evaluated, but does not account for all barriers or other potential limiting factors affecting fish access and occupancy.

South Fork, North Fork and Mainstem Upper Walla Walla

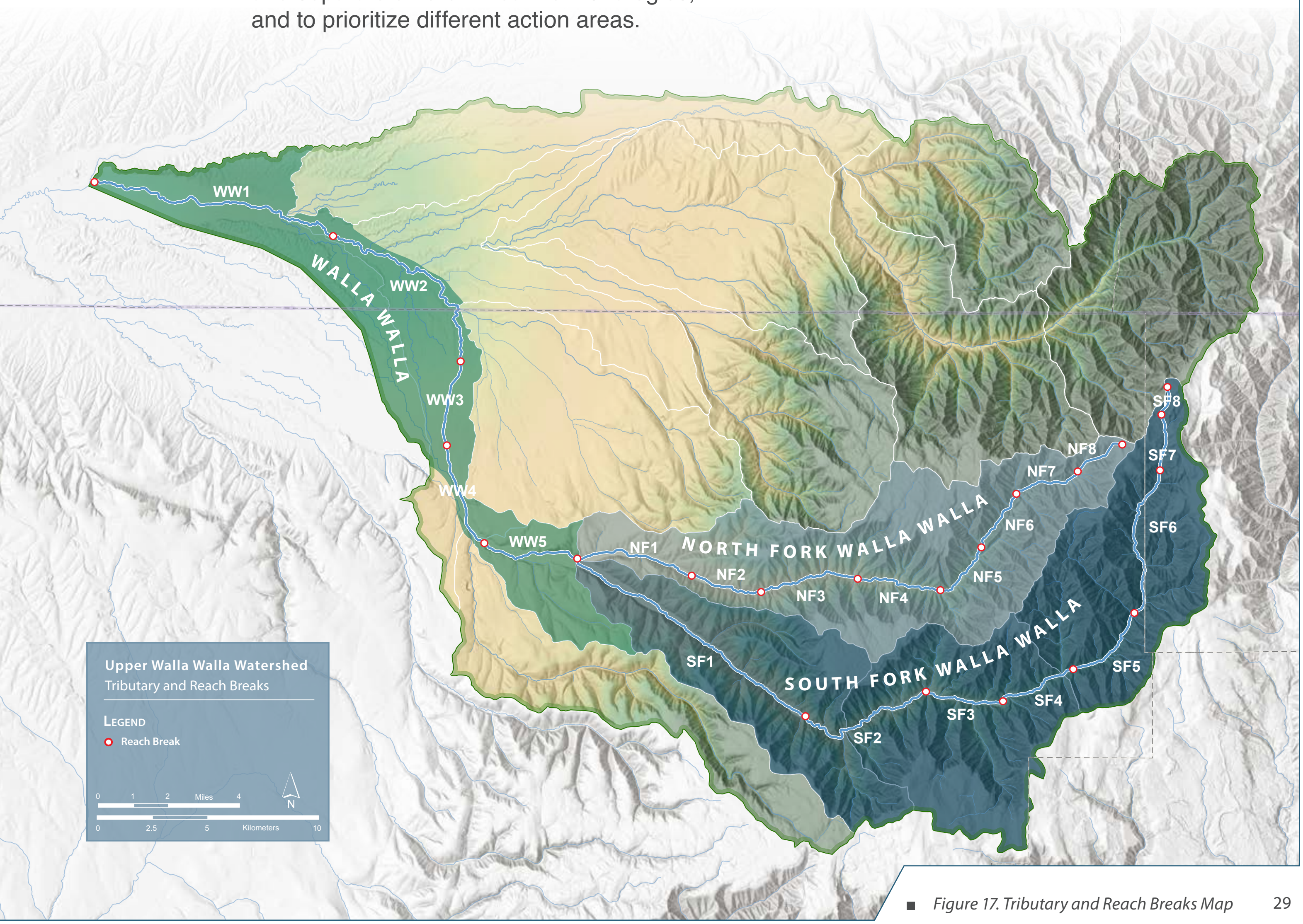
Reach Assessments

South Fork Walla Walla

The 114 stream kilometers evaluated within this assessment have been divided into 21 distinct geomorphic reaches. In each reach, assessments of hydrology and hydraulics, geomorphology, riparian, and fish habitat suitability were conducted to gain a more thorough understanding of the current conditions and potential restoration opportunities.

The conditions in a river change from the headwaters downstream to the lower watershed. In a reach assessment, the channel and associated floodplain are divided into segments called "reaches" based on their similar forms and functional characteristics to facilitate an accurate and meaningful evaluation of the river. In that way each reach can be individually assessed for impacts and restoration opportunities and all the reaches can be collectively compared to characterize the relative level of impairment, to identify and separate different treatment strategies, and to prioritize different action areas.

Various changes to the form and function of the upper Walla Walla River have occurred over many decades. Some of these changes have been natural, others were caused by human activities. Some of the changes have created benefits, others have caused harm. A reach assessment is a tool by which scientific data and analyses can help identify and define the amount of change that has occurred and quantify the level of benefit versus impact, especially regarding sensitive and/or endangered species.



■ *Figure 17. Tributary and Reach Breaks Map*

Tributaries and Reach Assessment

Upper Walla Walla Main, North Fork, and South Fork Walla Walla River

Salmon, steelhead, and bull trout are sensitive and/or endangered species currently occupying the upper Walla Walla River. These fish are often considered keystone species whose health and abundance are emblematic of the environment they occupy. Evaluating the physical characteristics of a reach and the habitat and use by keystone species is an informative tool for understanding impacts and potential restoration needs within the river at a reach scale.

The Upper Walla River Reach Assessment is a critical piece of the overall action plan serving as the basis for a 20-year strategic approach to process-based stream and floodplain restoration and conservation to assist in the recovery of focal fish species. The Reach Assessment specifically evaluates hydraulic habitat suitability, areas of erosion and deposition, flood inundation potential, riparian shade, and many in-stream metrics like pools, riffles, large woody material, and floodplain extent to quantify current river function relative to established benchmarks to determine the level of impairment, target conditions, and restoration opportunities. The following pages summarize those results for each reach within the three valley segments evaluated (mainstem, North Fork, and South Fork Walla Walla River).

Not all the data that was used or created in the technical memos is illustrated in this main document. The maps and information illustrated are a representation of the full suite of data, included in the appendices. Detailed assessment methods, results, and conclusions are included in the appendices of this document.

Figure 18 and 19: Highly confined reach with large grade control structure at the Eastside Rd bridge.

Figure 20: Unconfined reach.

Reach Map Data Layers

Reach assessments include several geospatial data layers containing groups of point, line, or area (polygon) features representing a particular class or type of real-world entities. The reach data layers included in the following pages illustrate the pertinent characteristics that were assessed for the action plan. This page describes each data layer that is shown on the following reach maps.

Hydraulic Habitat Suitability

Modeling analysis, for a given river reach and a given flow, a suitable habitat availability for target aquatic species.

Erosion and Deposition

Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.

Flood Inundation

Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/bathymetric LiDAR survey.

Riparian Shade

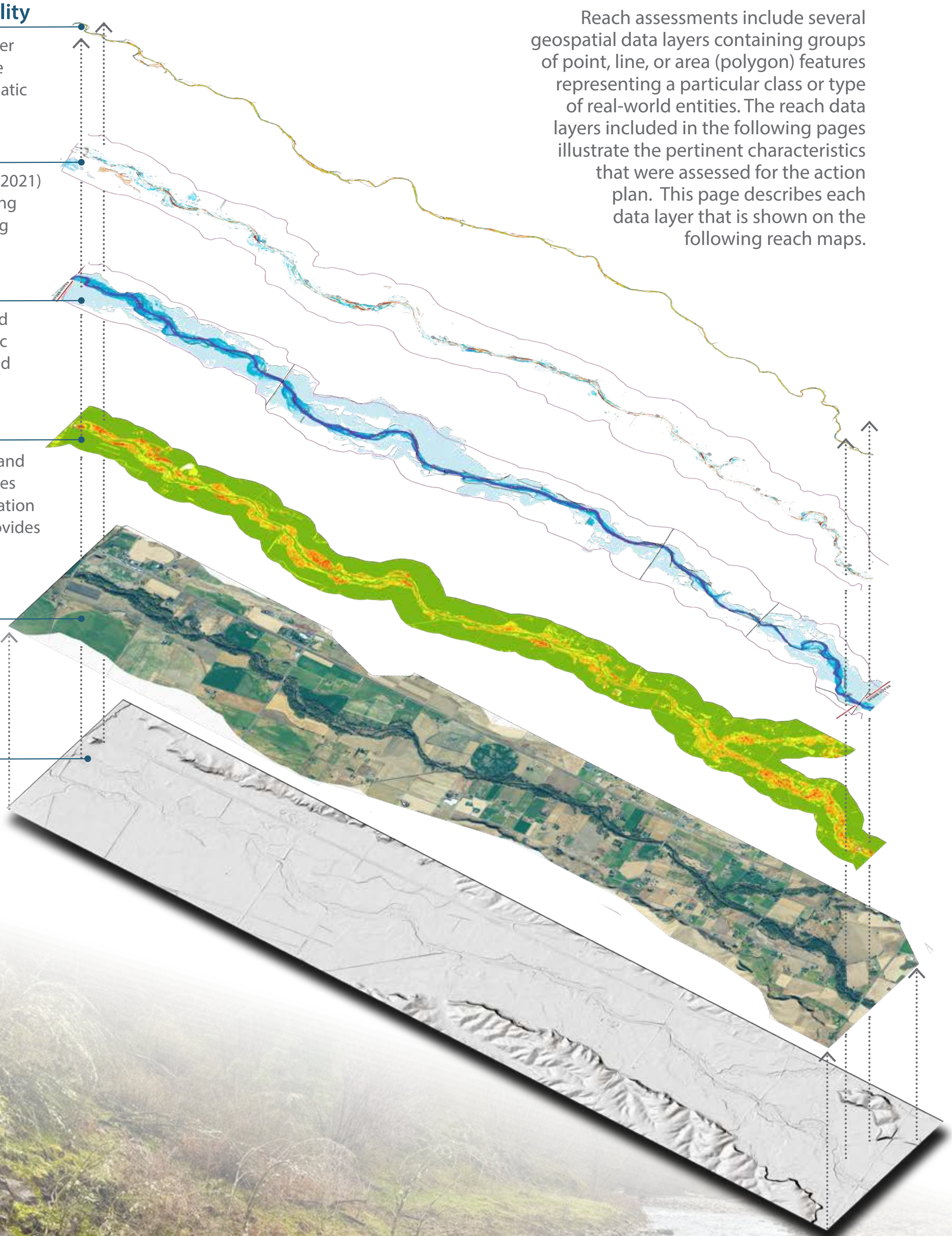
Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Aerial Imagery

2021 high resolution aerial imagery base.

Lidar Terrain

Highlights natural land forms, uses land digital elevation model (DEM) to display the different regions, elevation, and physiography.



■ *Figure 21. Reach Data Layers Diagram*

Walla Walla River Mainstem

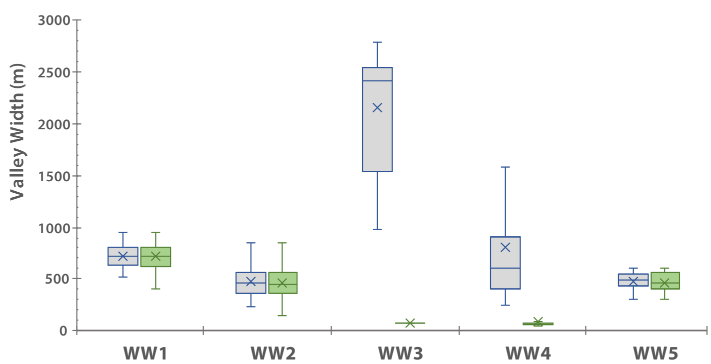
38.5 KM Reach Length   RKM 44.1 to 82.6

Walla Walla Mainstem extends approximately 38.5 river kilometers (RKM) from the confluence with Dry Creek near the town of Lowden Washington at RKM 44.1, upstream to the confluence of the North Fork and South Fork at RKM 82.6. There are five geomorphic reaches along this distance, ranging in length from 4.1 kilometers (WW3) to 13.1 kilometers (WW1).

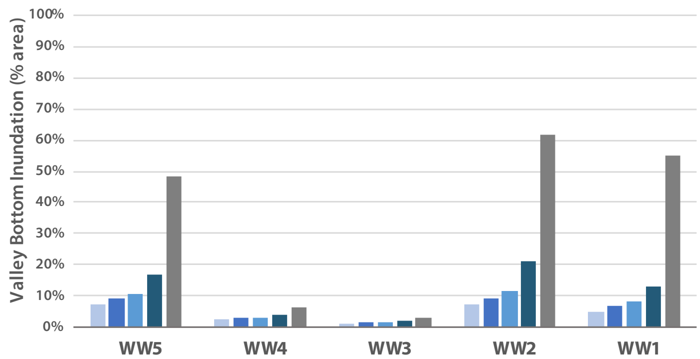
The river and floodplain conditions in the Walla Walla mainstem have been highly altered as a result of rural residential development along the valley bottom. The historically broad floodplain has been disconnected by levees, and the sinuous often multi-threaded channel has been confined and straightened into a single thread. These changes have resulted in long, uniform, riffles, very few pools, and increased erosion and channel incision. Grade controls, like the concrete structure at the Eastside Road and multiple boulder weirs, have largely arrested channel incision, but excess stream energy has significantly widened banks such that the width-to-depth ratio is 2 to 4x the desired target.

Similarly, the amount of in-stream wood providing habitat structure and cover is 2 to 7x below the desired target. High in-stream velocity also reduces Chinook salmon spawning suitability to only those reaches upstream of the concrete grade control structure at Eastside Road in Milton-Freewater. All reaches are within the deciduous riparian vegetation zone.

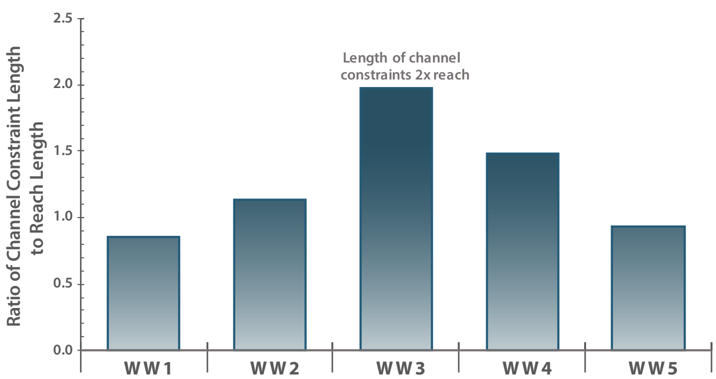
There were negligible changes in reach-scale hydraulic characteristics like channel depth, velocity, shear stress, sediment transport, etc. following the 2020 flood of record, but there were notable changes in bank erosion and channel migration. In other words, the channel moved during the 2020 flood, but the characteristics in both the old and new location are very similar.



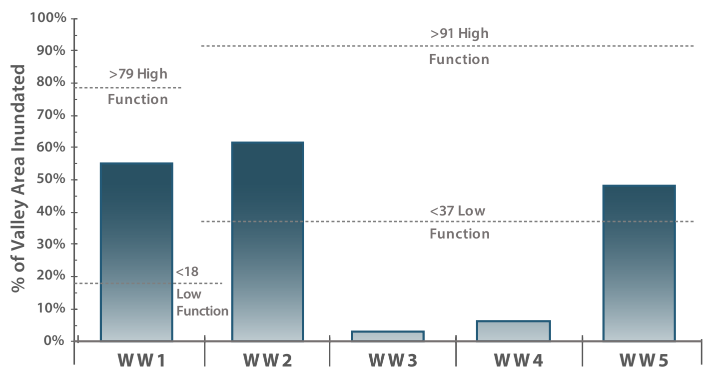
■ *Valley Width - Natural / Confined*



■ *Valley Bottom Inundation*

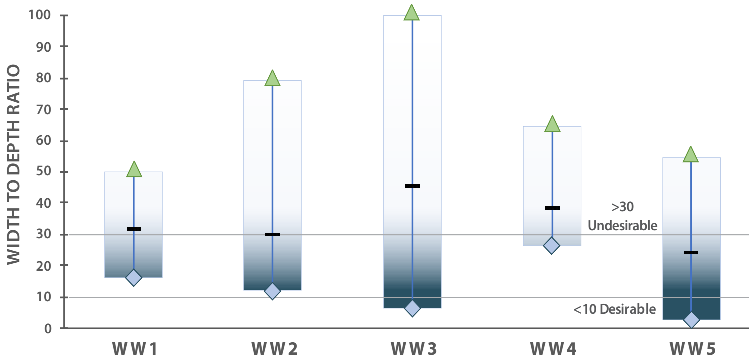


■ *Artificial Floodplain Disconnection Ratio*

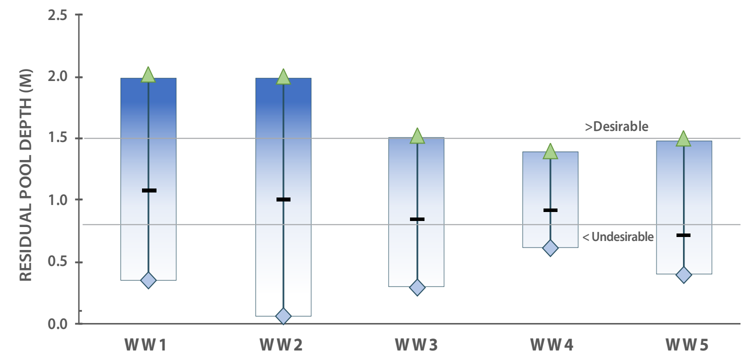


■ *Valley Area Inundated by 100 yr Flow and Function*

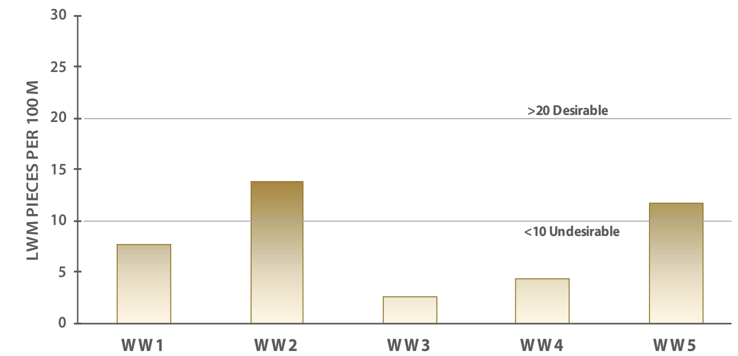
■ *Walla Walla Mainstem*



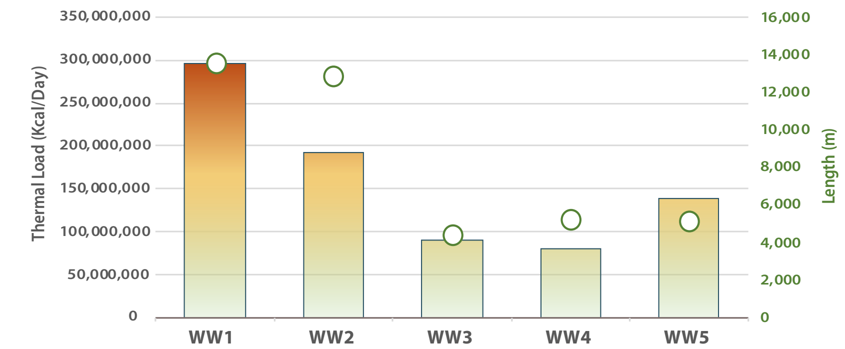
Riffle Width to Depth Ratio ◇ Min — Avg △ Max



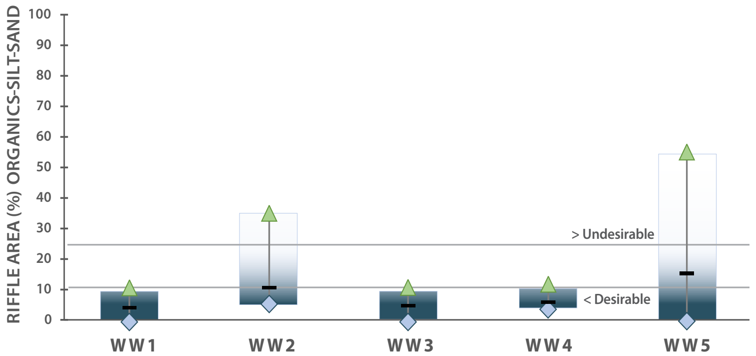
Residual Pool Depth ◇ Min — Avg △ Max



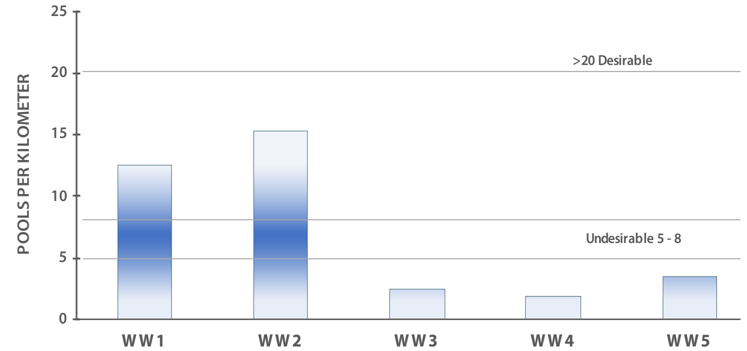
Large Wood Material Piece Frequency LWM per 100 m



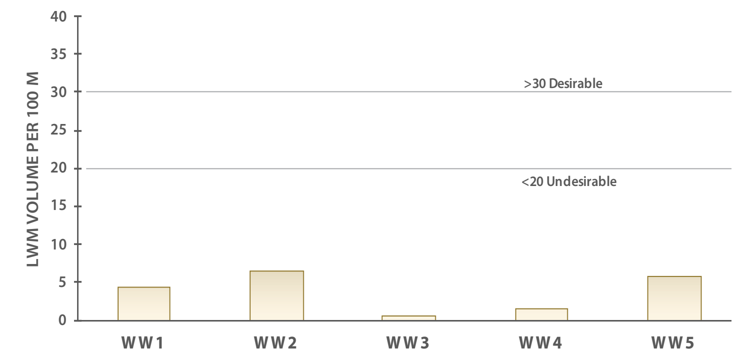
Riparian Shade - Thermal Load (Kcal/Day) Thermal Load (Kcal/Day) Reach Length (m)



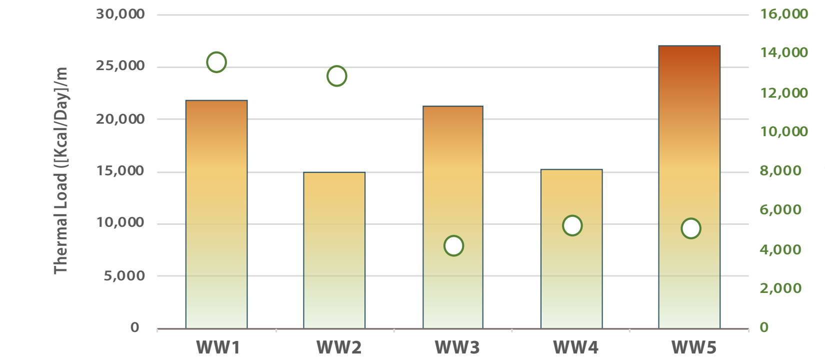
Riffle Area (%) Organics - Silt - Sand ◇ Min — Avg △ Max



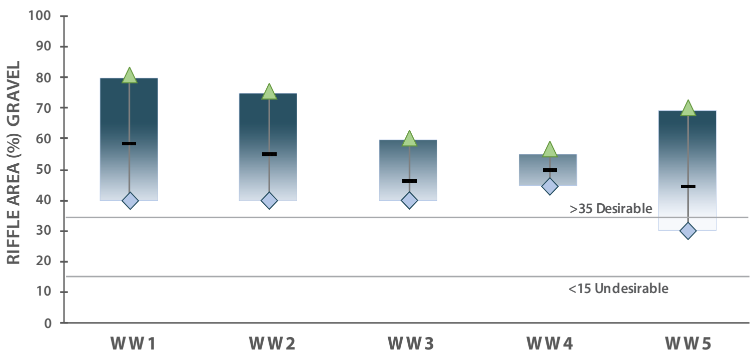
Pool Frequency per Kilometer Pools per km



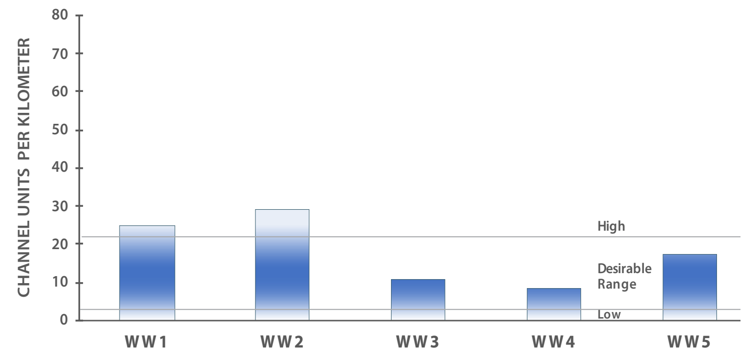
Large Wood Material Volume Frequency LWM Volume (m3) per 100 m



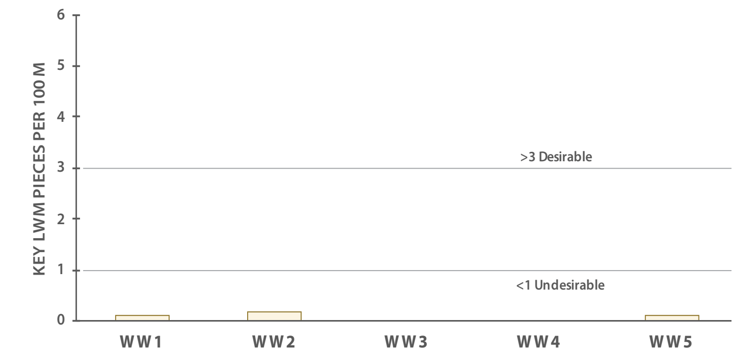
Riparian Shade - Thermal Load per Meter Thermal Load per Meter Reach Length (m)



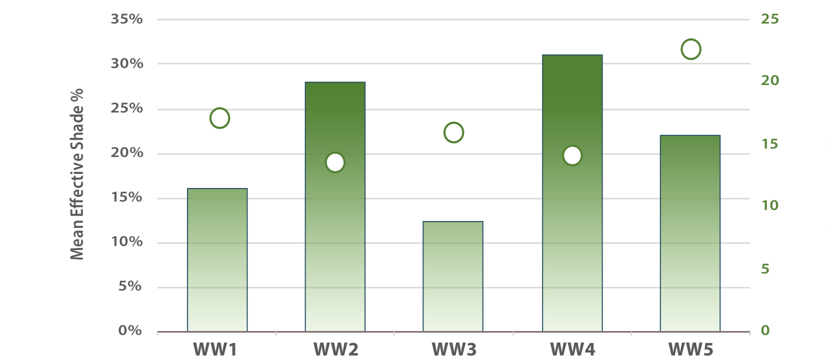
Riffle Area (%) Gravel



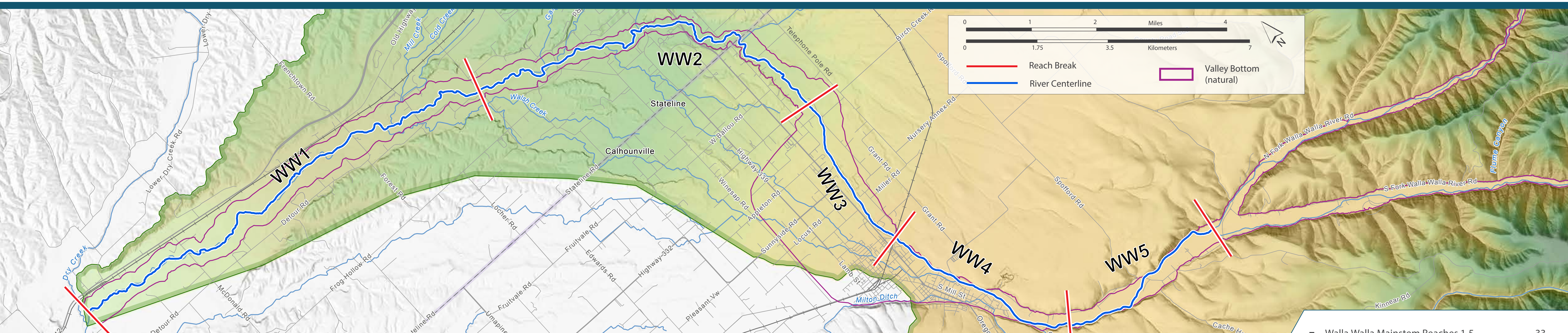
Channel Unit Frequency Channel Units per km



Large Wood Material Key Piece Frequency Key LWM per 100 m



Riparian Shade - Mean Effective Shade % Mean Effective Shade % Mean Channel Width

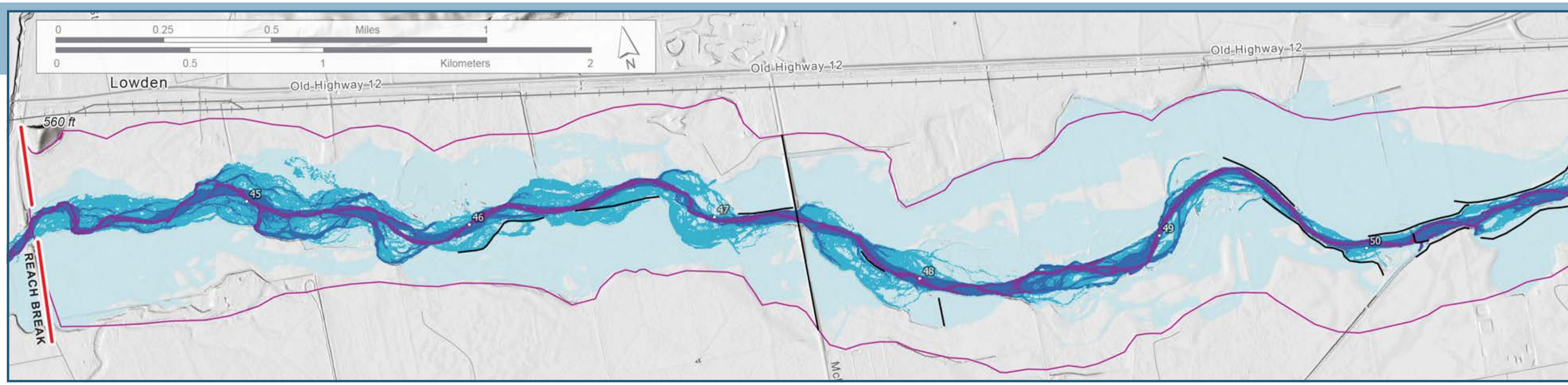


Reach WW1

13.1 KM Reach Length RKM 57.2 to 44.1

Hydraulic Modeling Inundation Extents

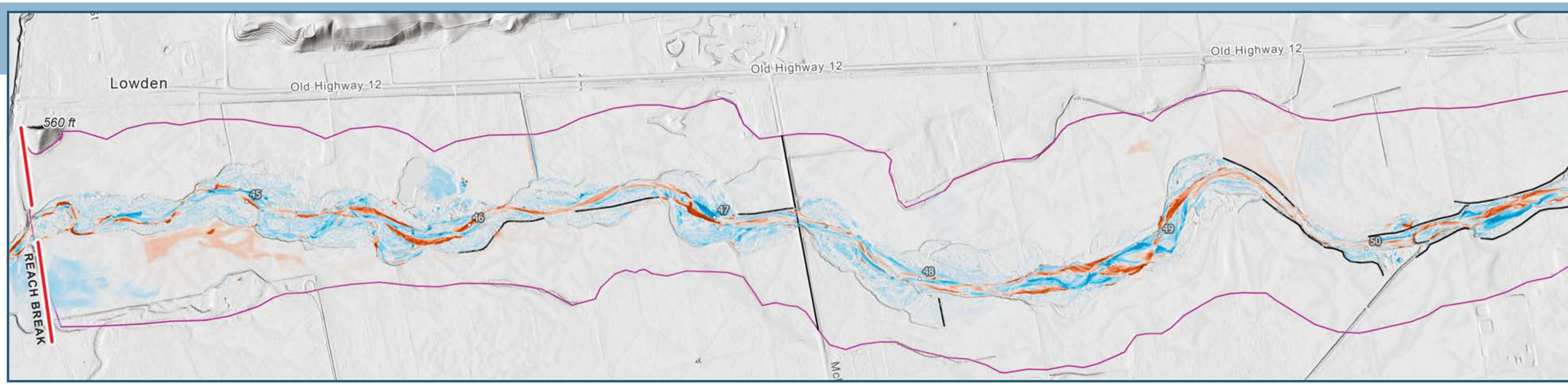
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

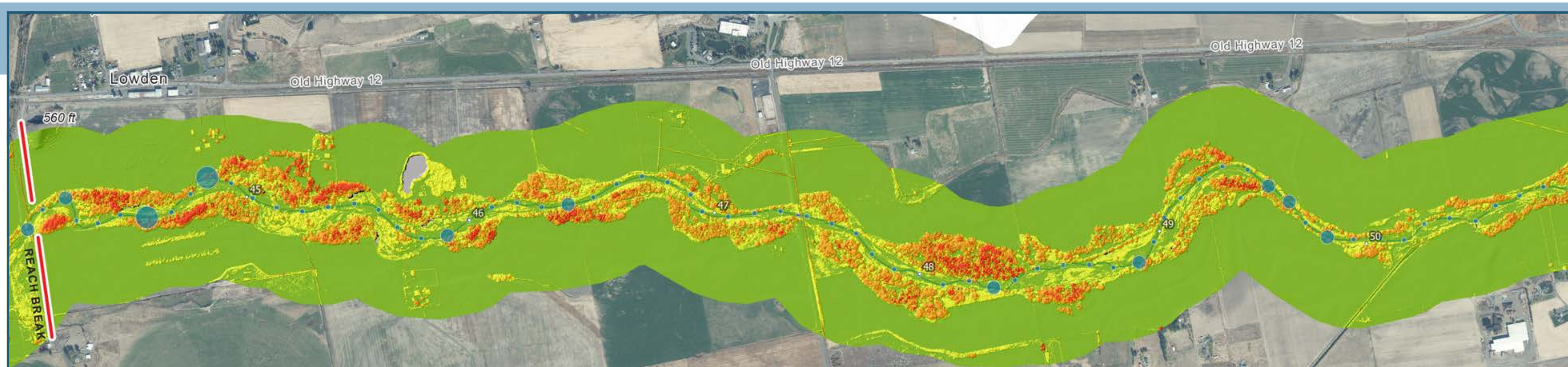
Effective Stream Shade

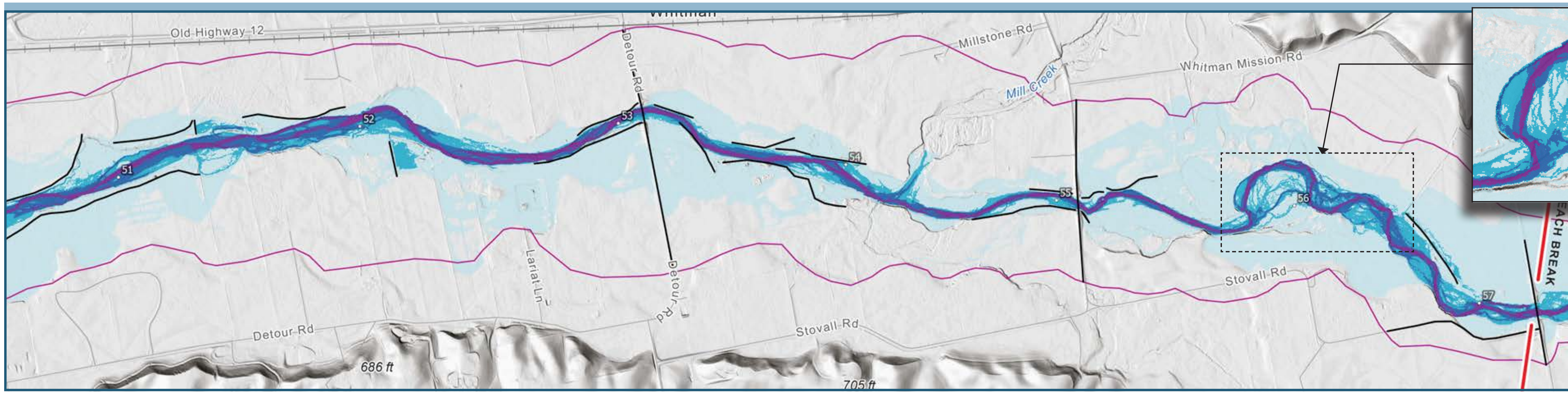
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

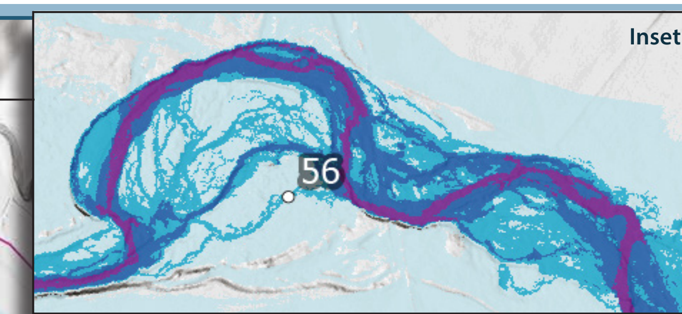
Thermal Load: **21,875** (Kcal/m)

Effective Shade **16%**

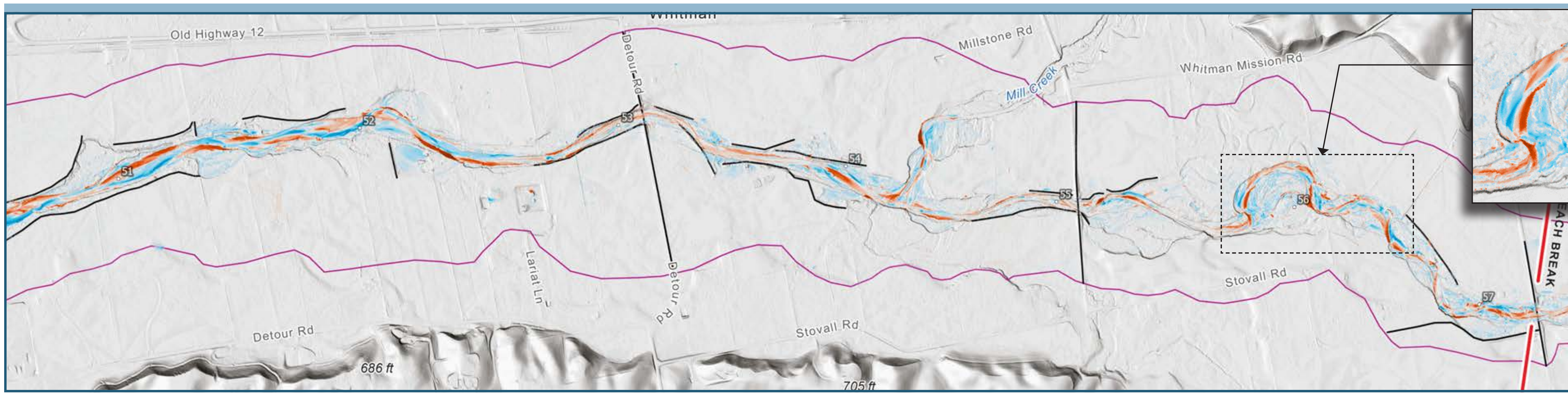
System Potential **4%**

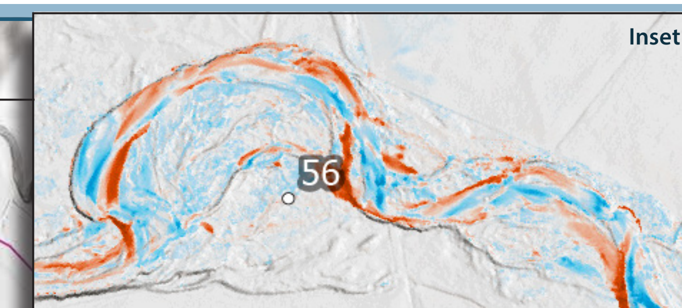




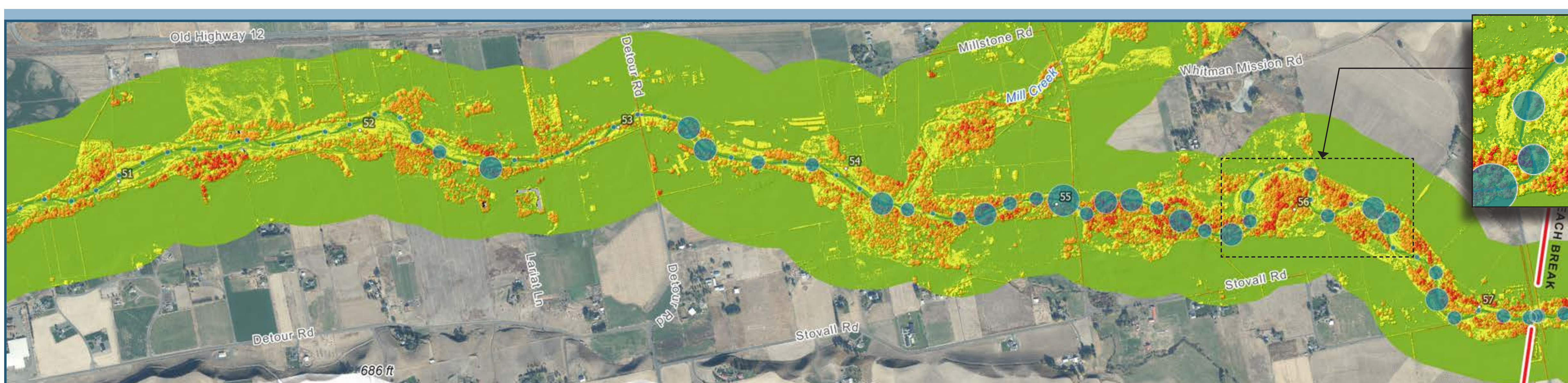


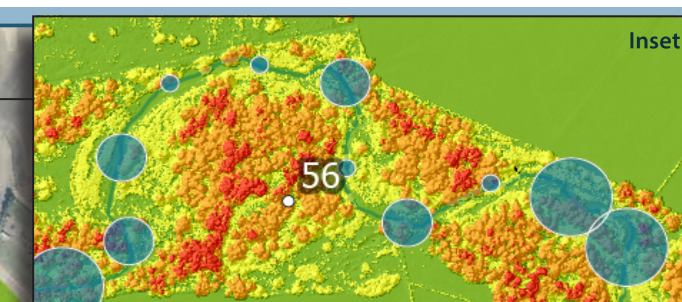
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Reach WW1

HYDRAULIC HABITAT SUITABILITY

13.1 KM Reach Length RKM 57.2 to 44.1

HHS
Chinook Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

HHS
Chinook Winter Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

HHS
Steelhead Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

HHS
Steelhead Spawning Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

HHS
Steelhead Winter Composite, 2021

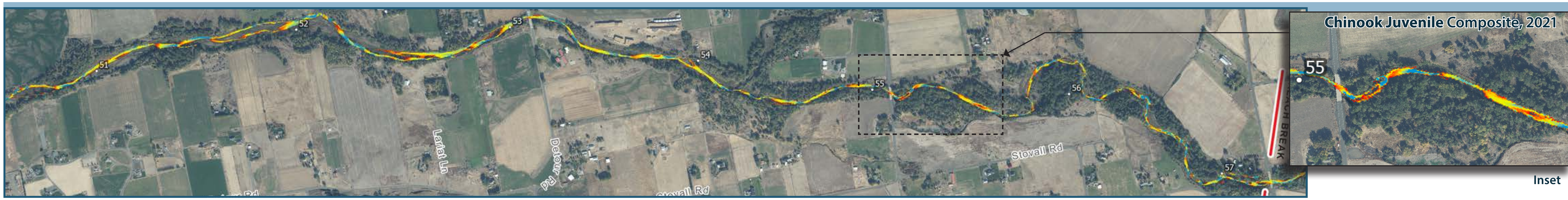
Highly Suitability

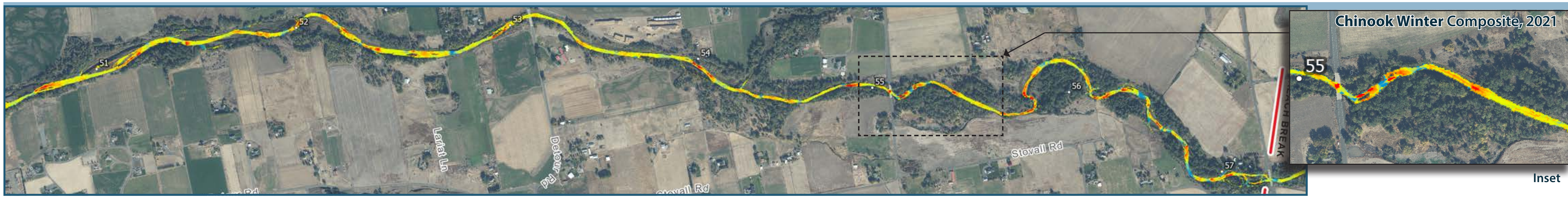
Moderate Suitability

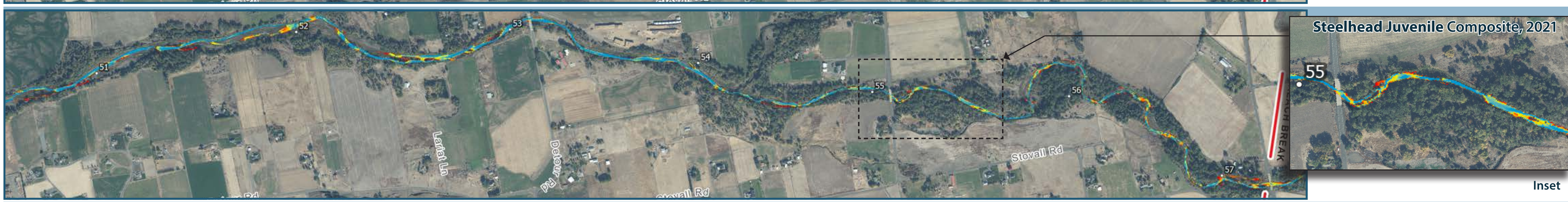
Low Suitability

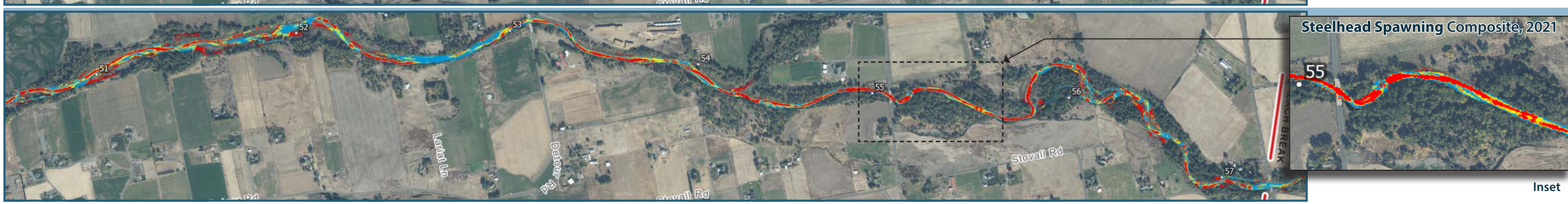
Reference Appendix I for details on the methods and results, including all species and life-stages modeled.

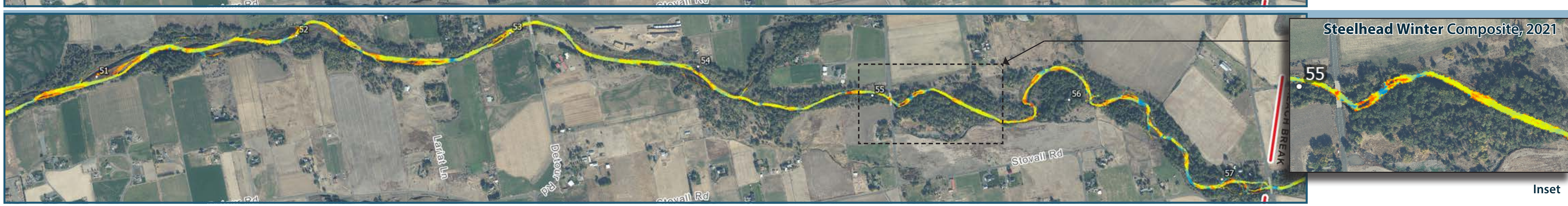
Reach WW1









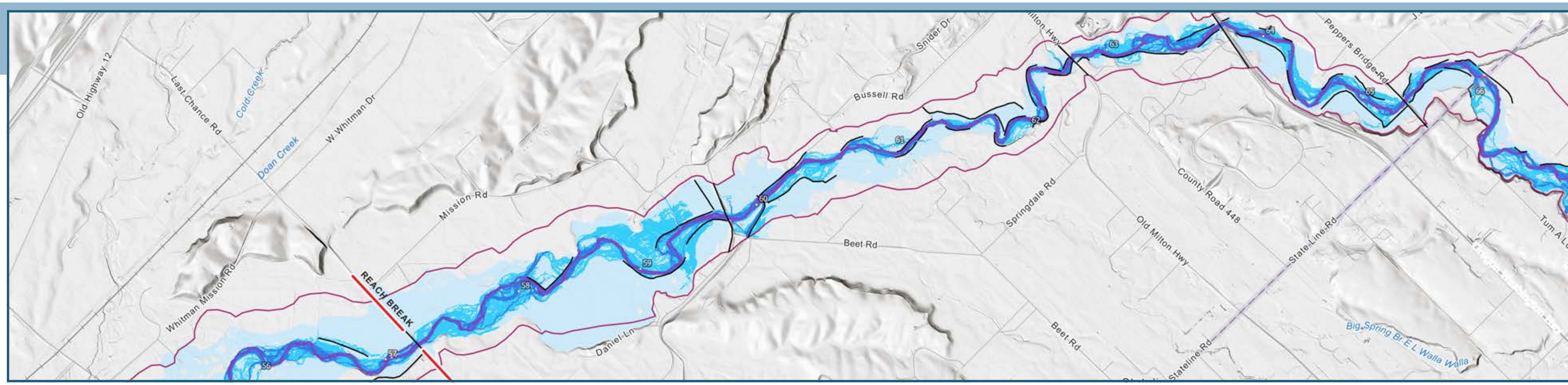


Reach WW2

11.5 KM Reach Length   RKM 68.7 to 57.2

Hydraulic Modeling Inundation Extents

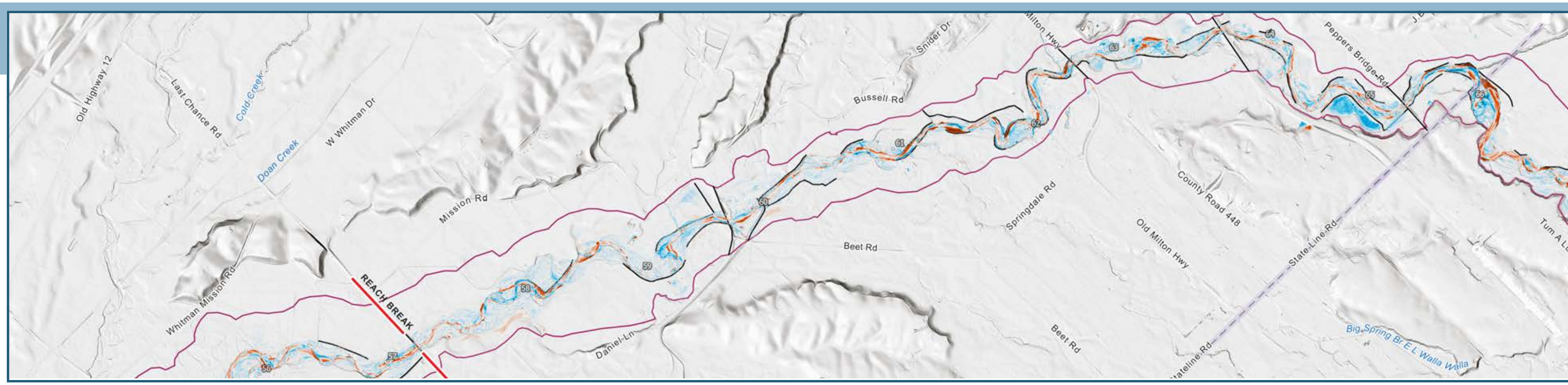
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

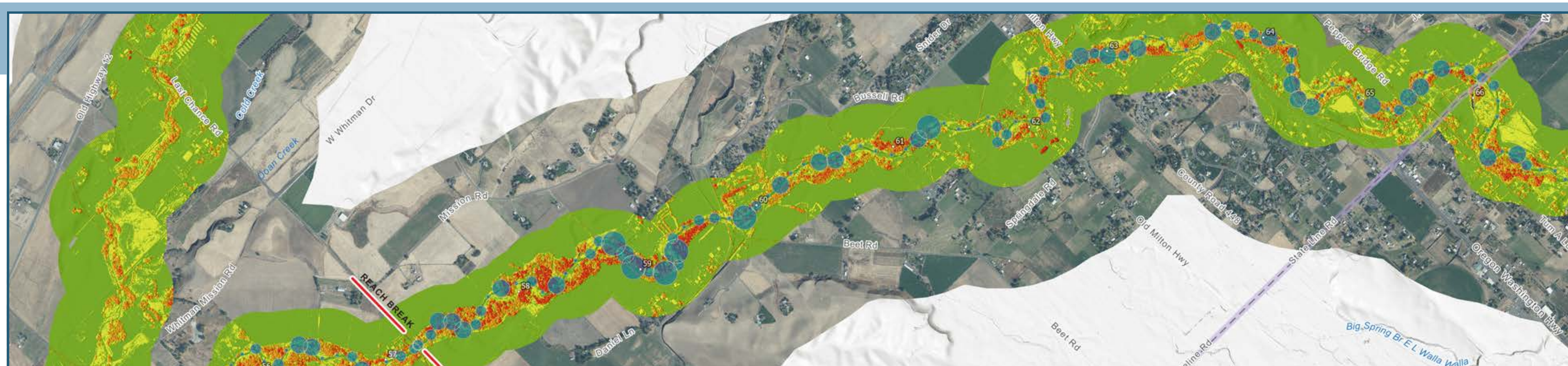
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

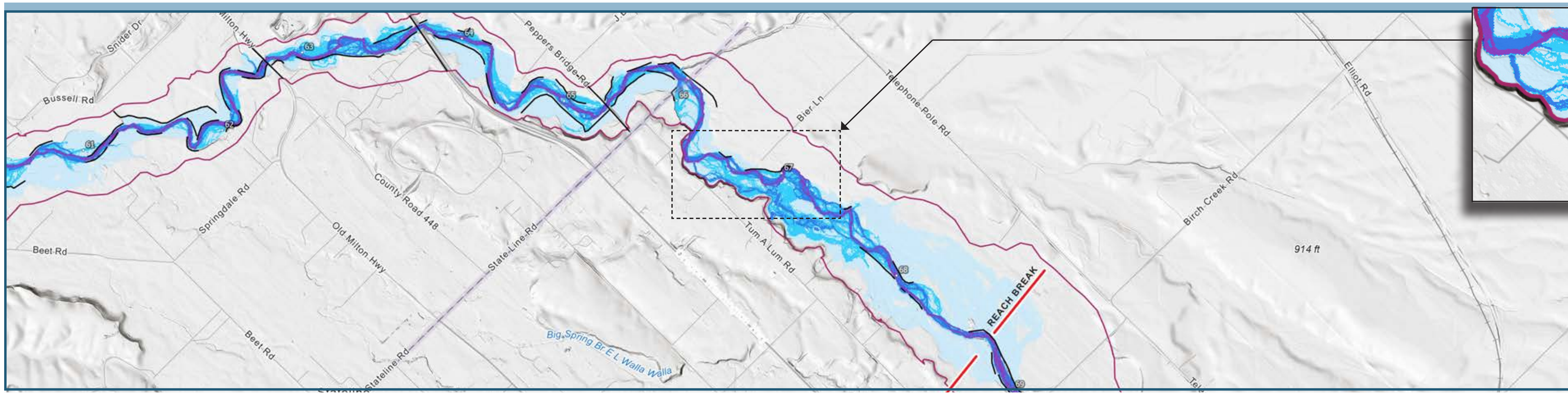
Thermal Load:
14,927 (Kcal/m)

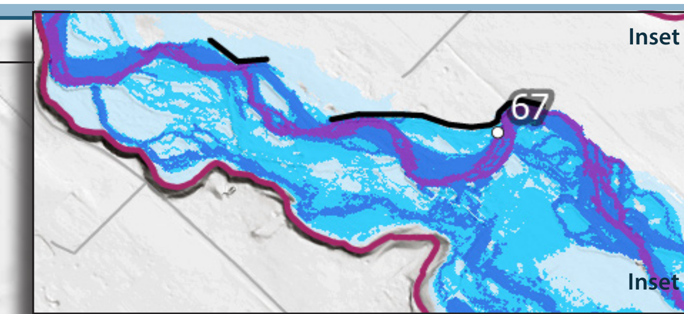
Effective Shade **28%**

System Potential **5%**

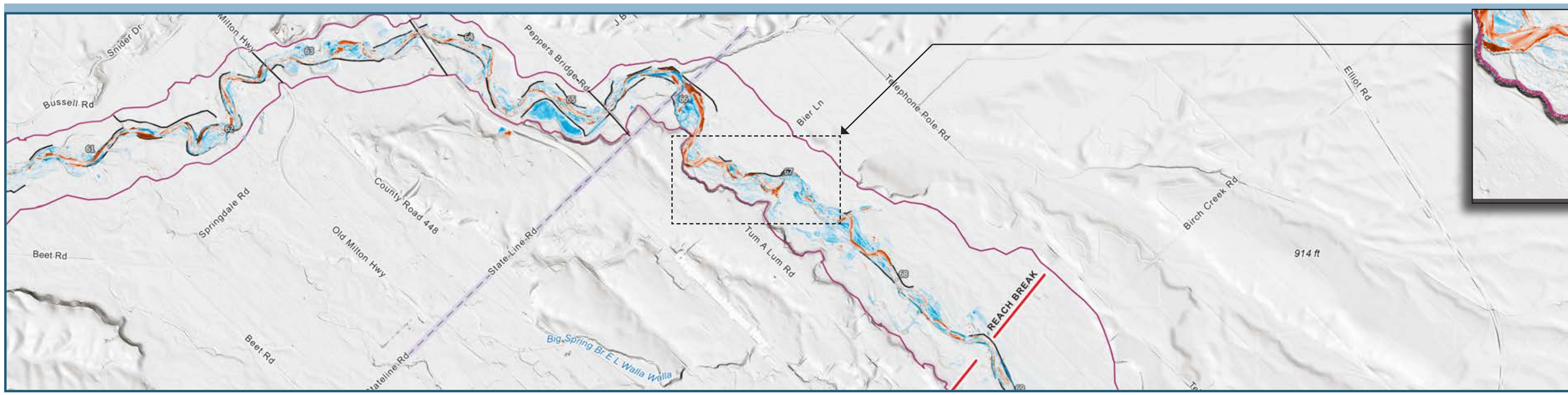


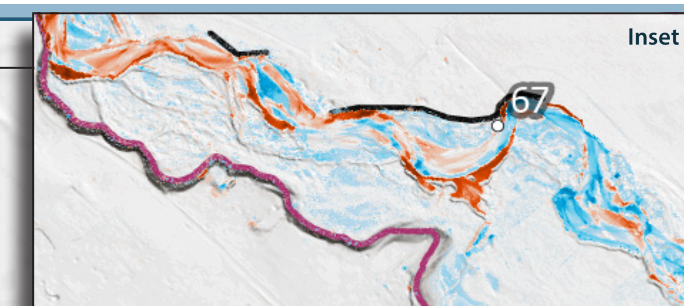
Reach WW2



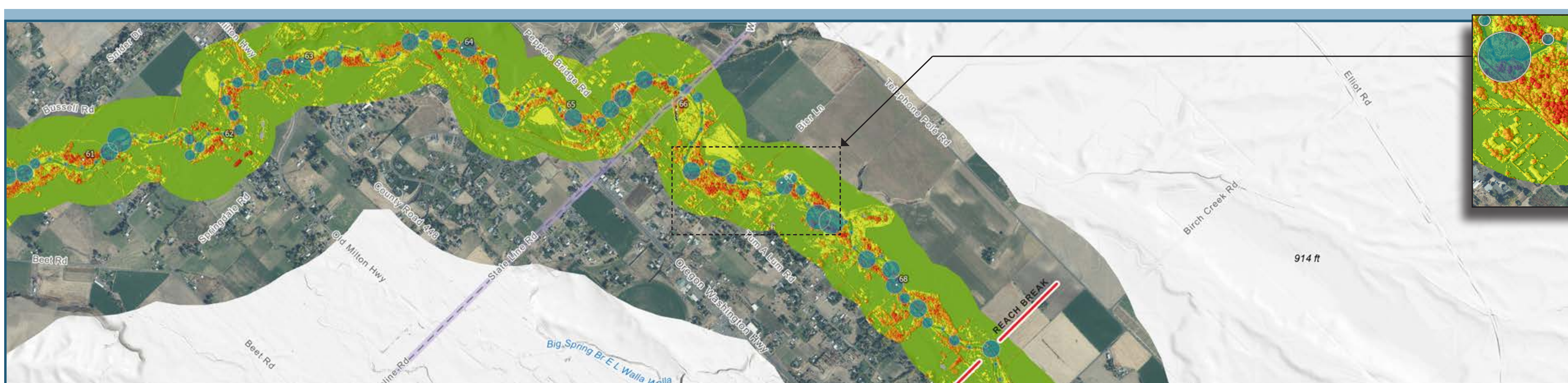


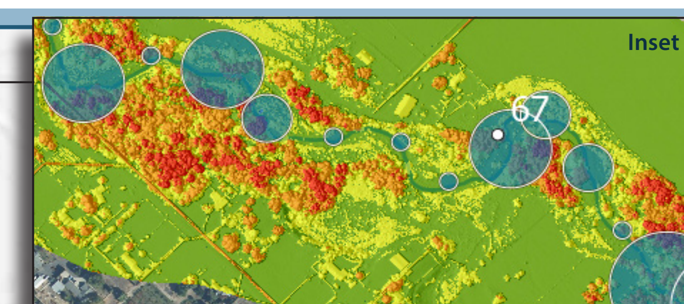
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

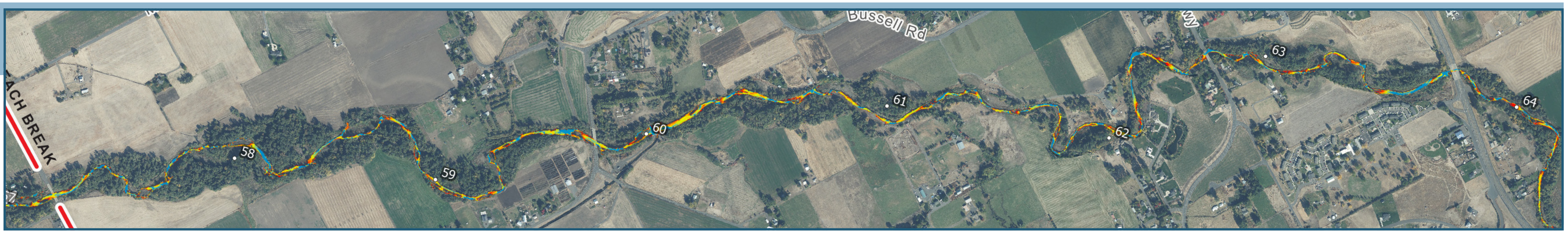
Reach WW2

HYDRAULIC HABITAT SUITABILITY

11.5 KM Reach Length RKM 68.7 to 57.2

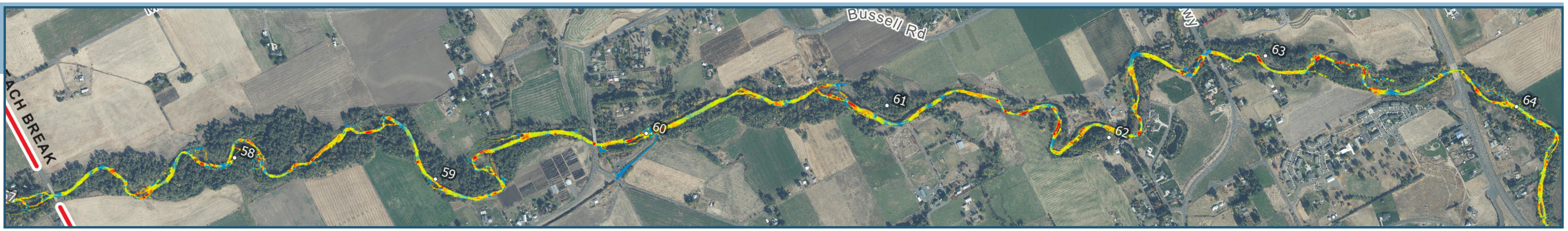
HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



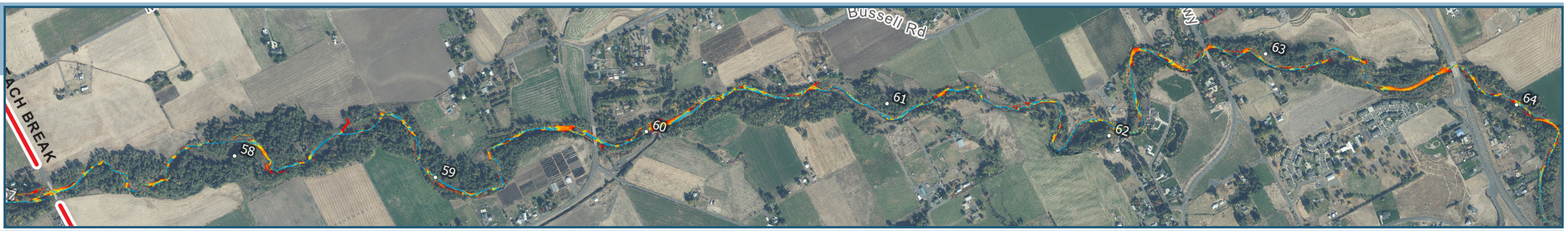
HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



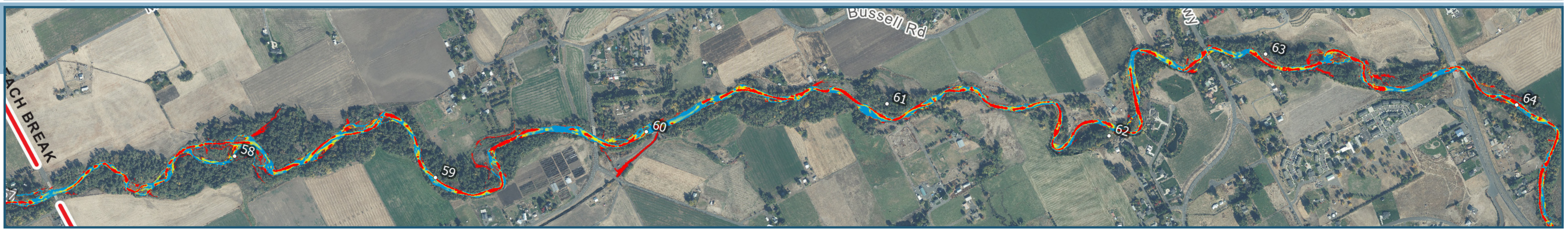
HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



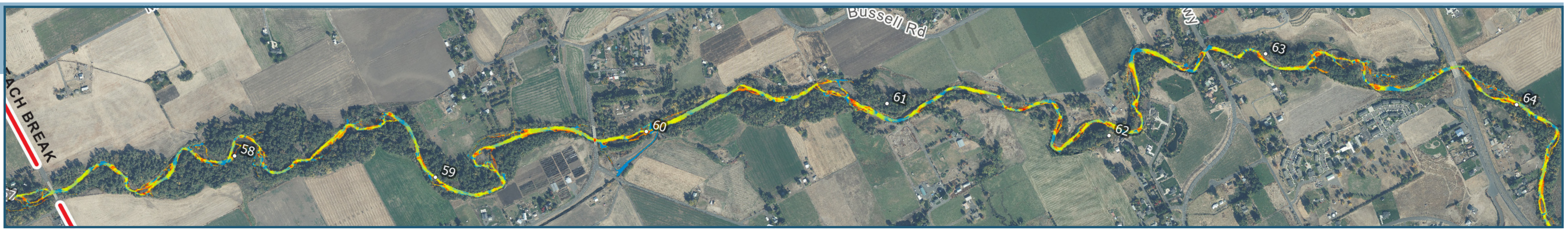
HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

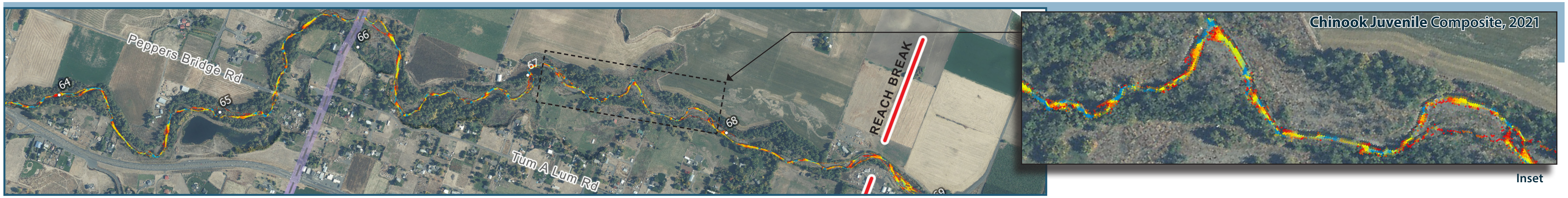


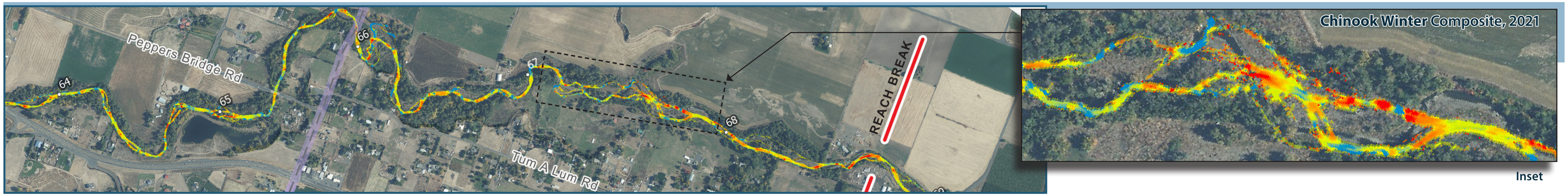
HHS
Steelhead Winter Composite, 2021

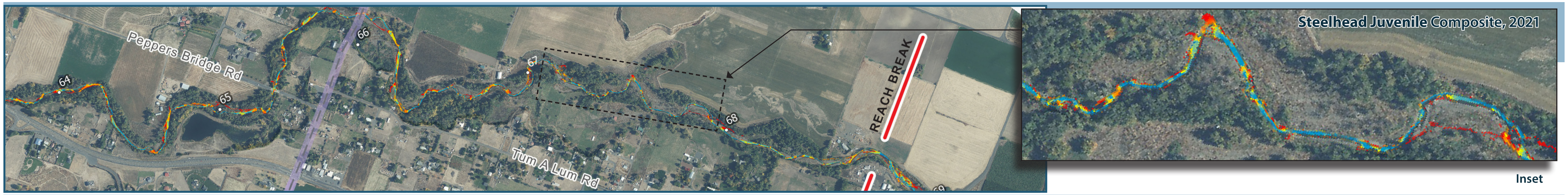
Highly Suitability
Moderate Suitability
Low Suitability

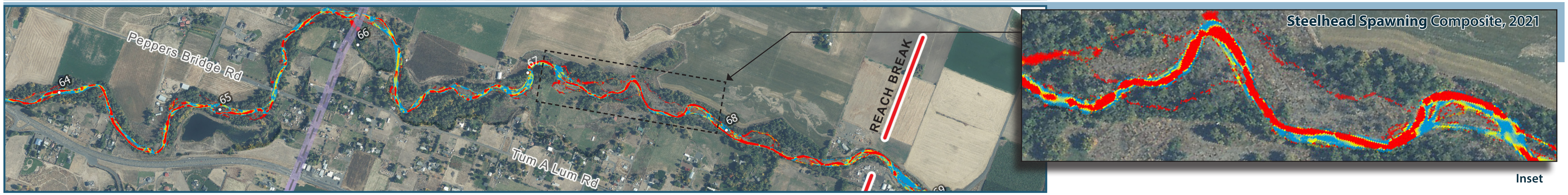


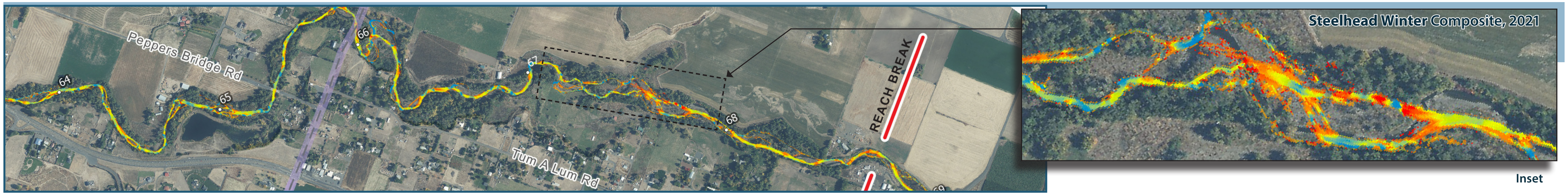
Reference Appendix I for details on the methods and results, including all species and life-stages modeled.









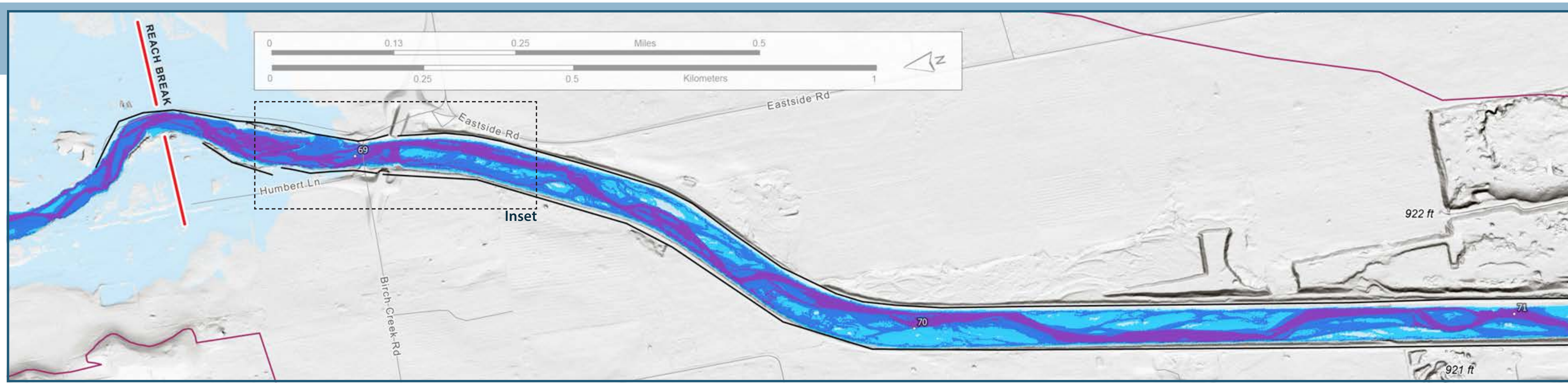


Reach WW3

4.1 KM Reach Length RKM 72.8 to 68.7

Hydraulic Modeling Inundation Extents

- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

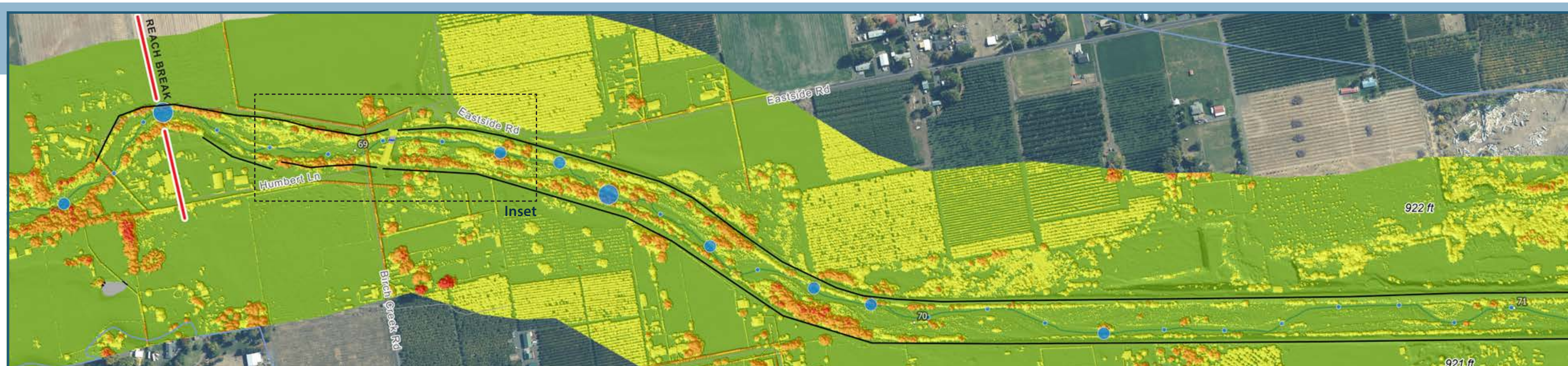
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

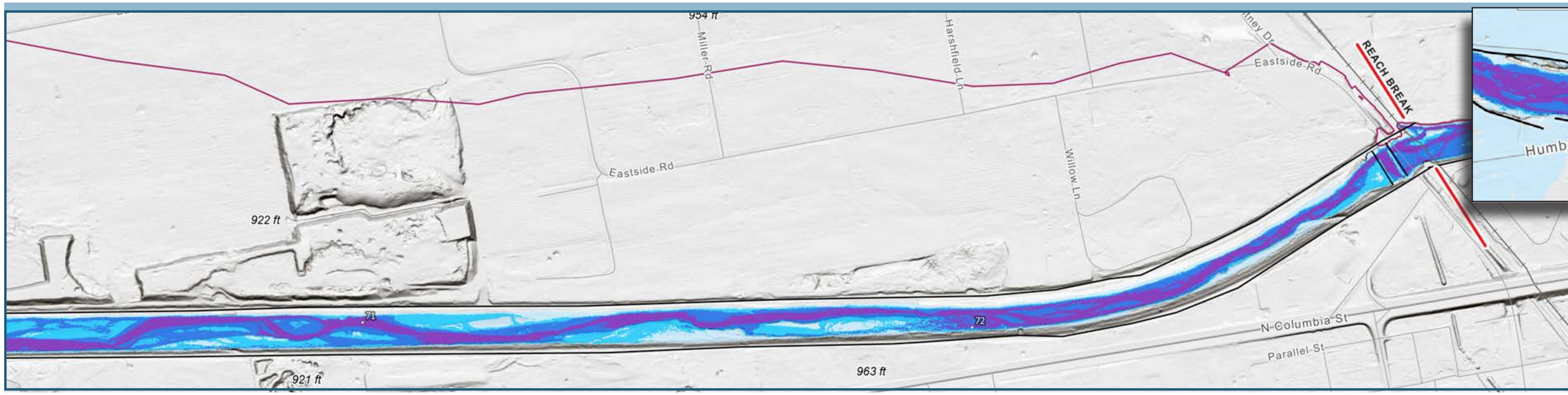
Thermal Load:
21,345 (Kcal/m)

Effective Shade **12%**

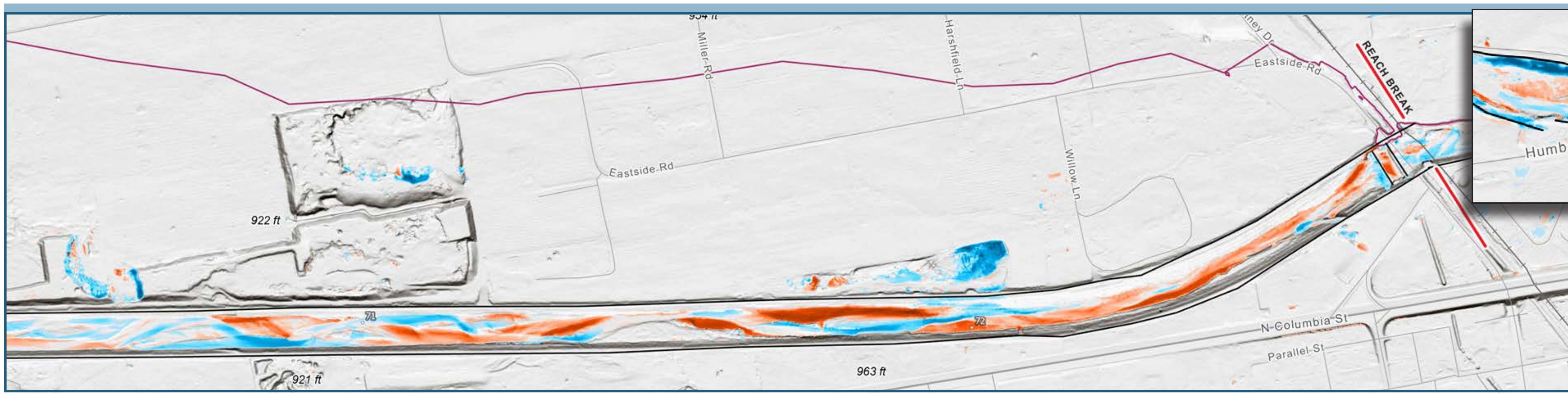
System Potential **0%**



Reach WW3



Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.

Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

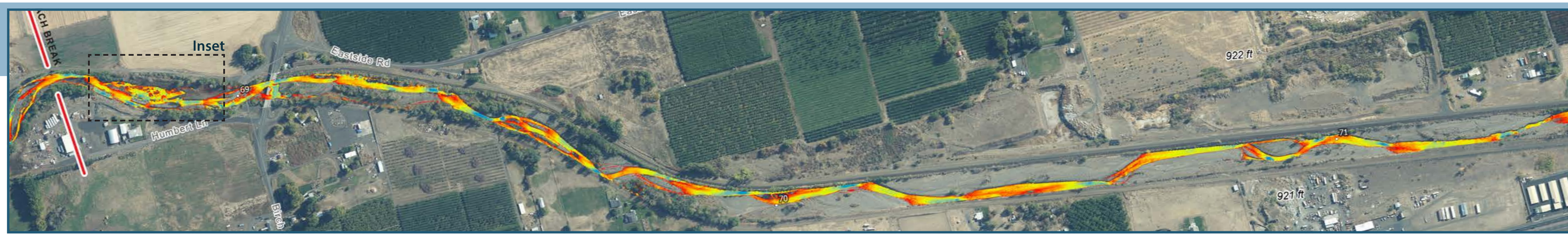
Reach WW3

HYDRAULIC HABITAT SUITABILITY

4.1 KM Reach Length RKM 72.8 to 68.7

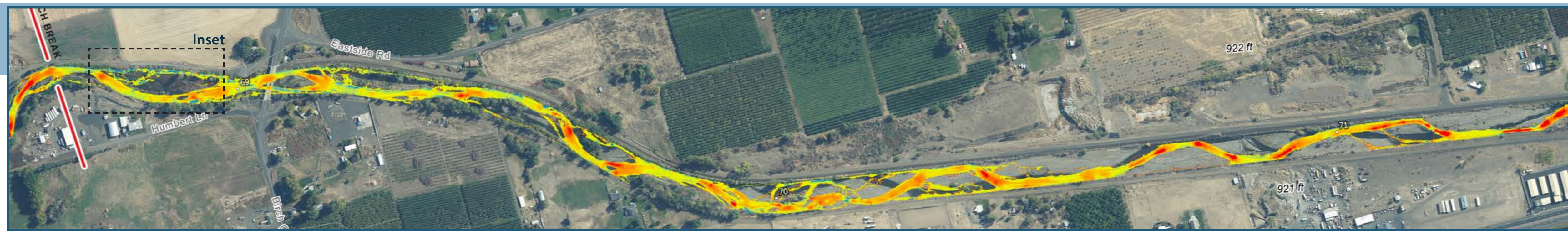
HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Juvenile Composite, 2021

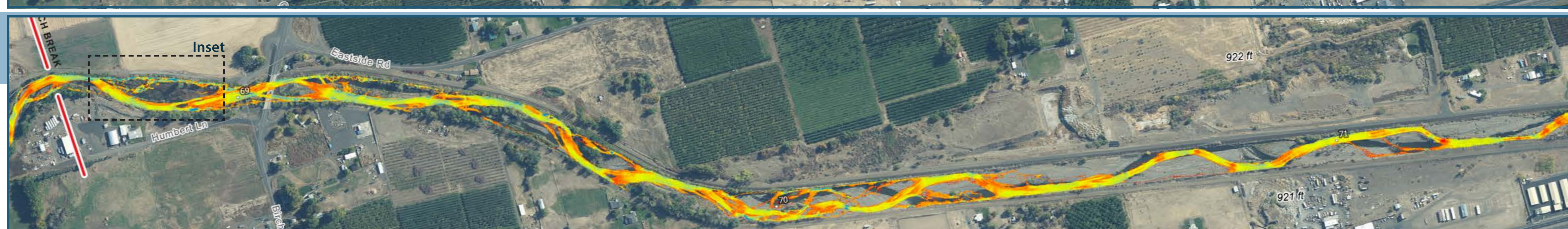
Highly Suitability
Moderate Suitability
Low Suitability

HHS
Steelhead Spawning Composite, 2021

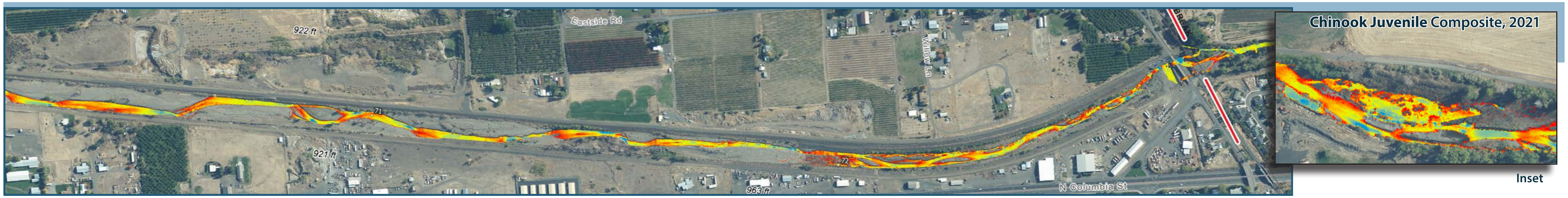
Highly Suitability
Moderate Suitability
Low Suitability

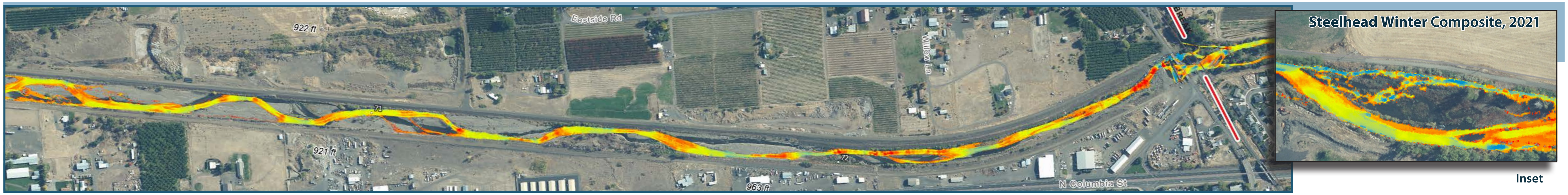
HHS
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



Reference Appendix I for details on the methods and results, including all species and life-stages modeled.



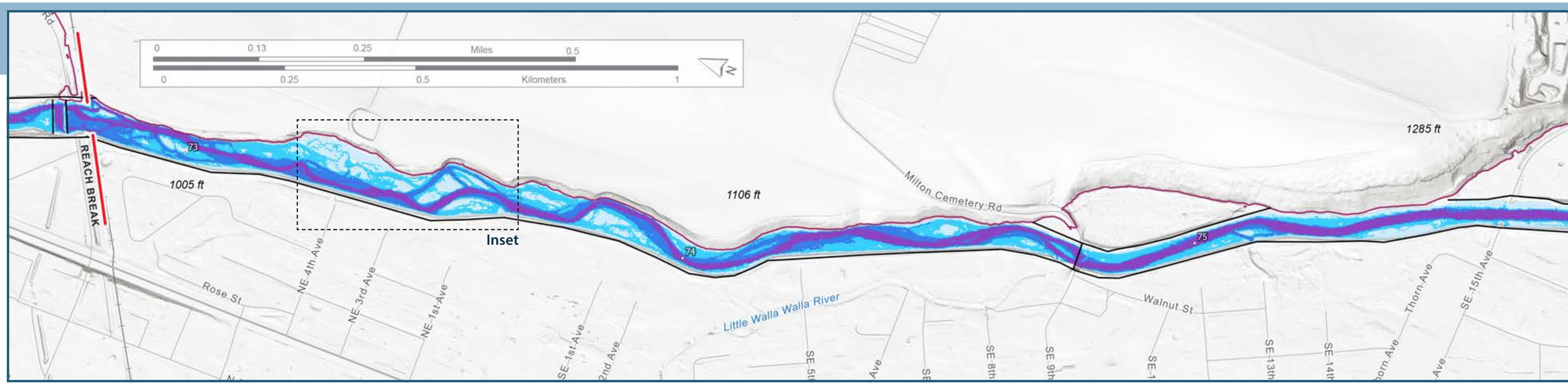


Reach WW4

5.1 KM Reach Length RKM 77.9 to 72.8

Hydraulic Modeling Inundation Extents

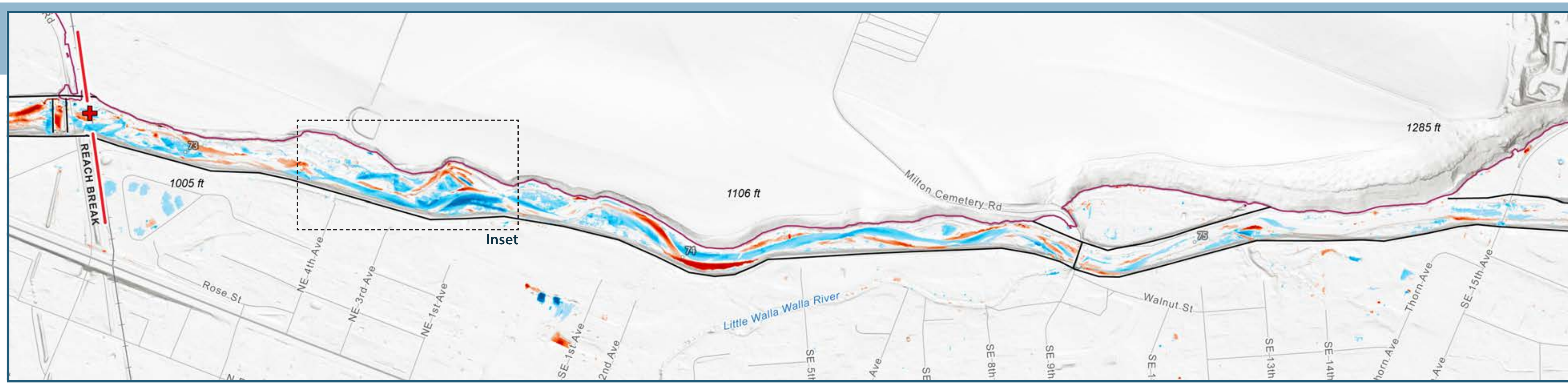
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

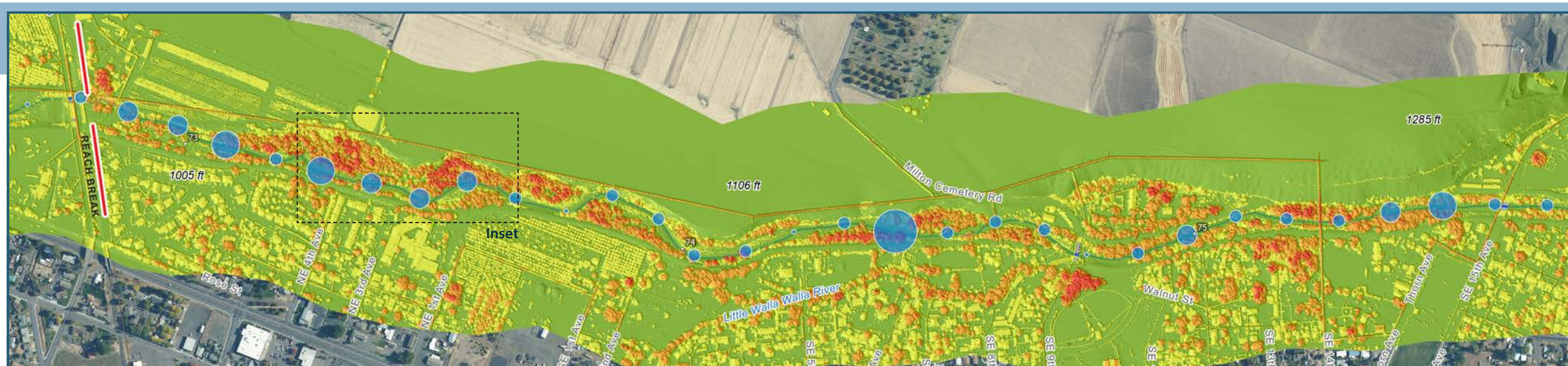
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

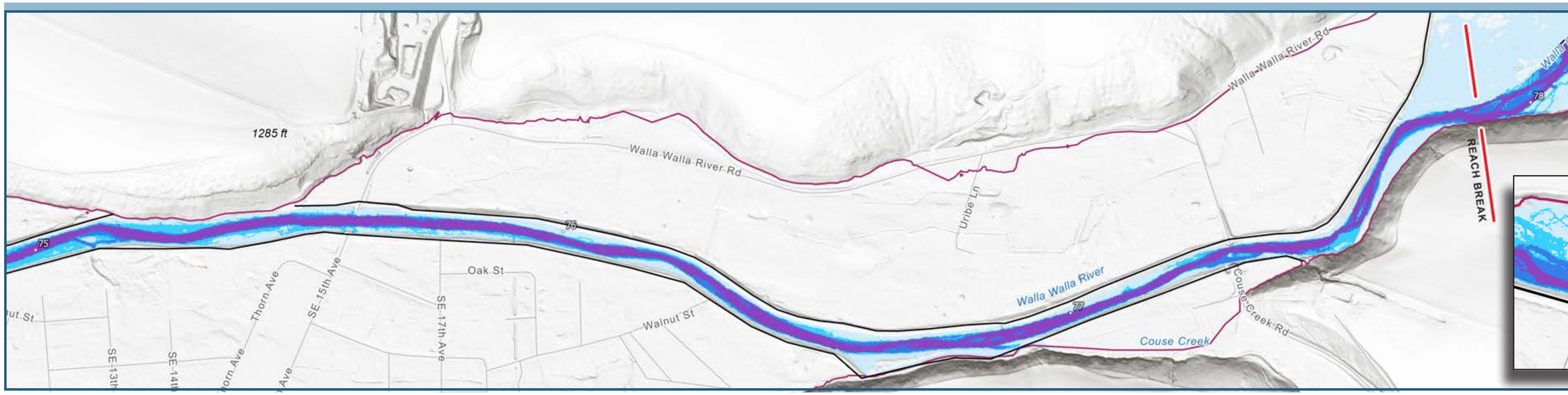
Thermal Load: **15,249** (Kcal/m)

Effective Shade **31%**

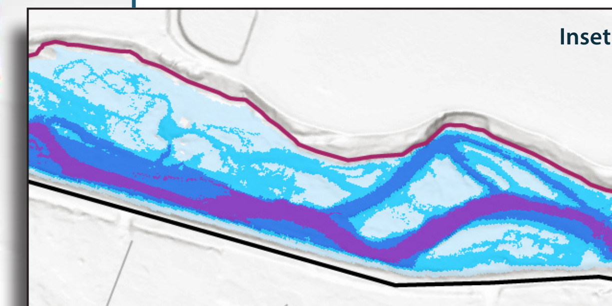
System Potential **4%**

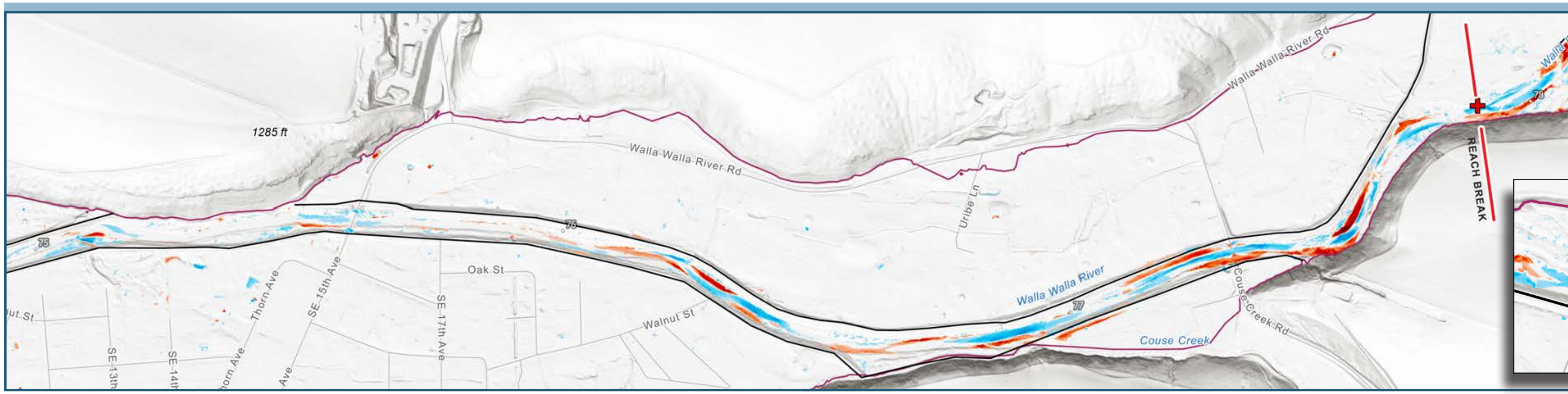


Reach WW4

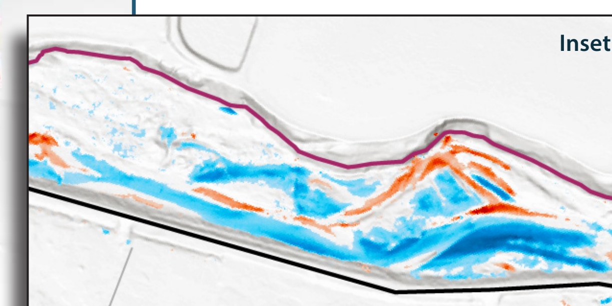


Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.

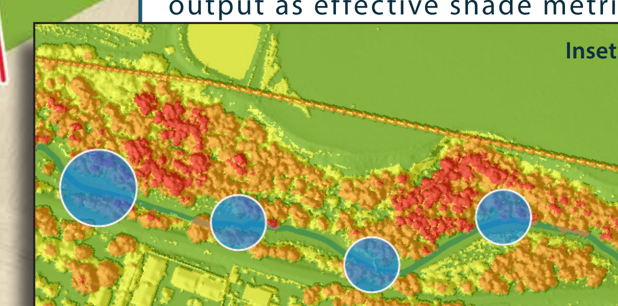




Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.



Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.



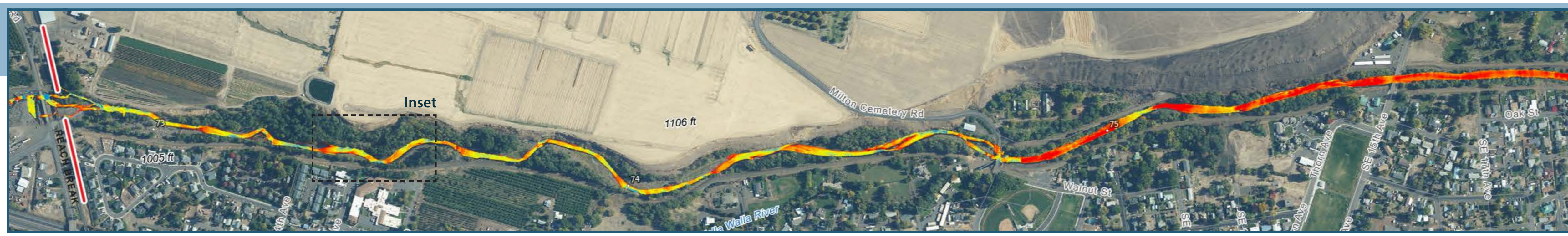
Reach WW4

HYDRAULIC HABITAT SUITABILITY

5.1 KM Reach Length RKM 77.9 to 72.8

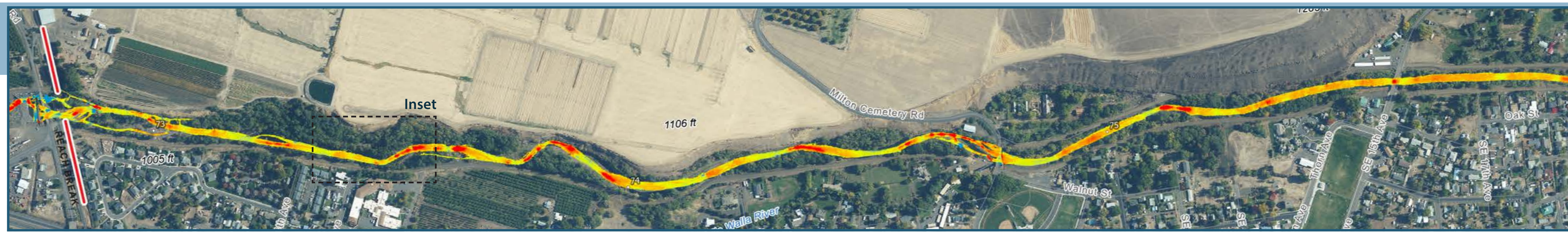
HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



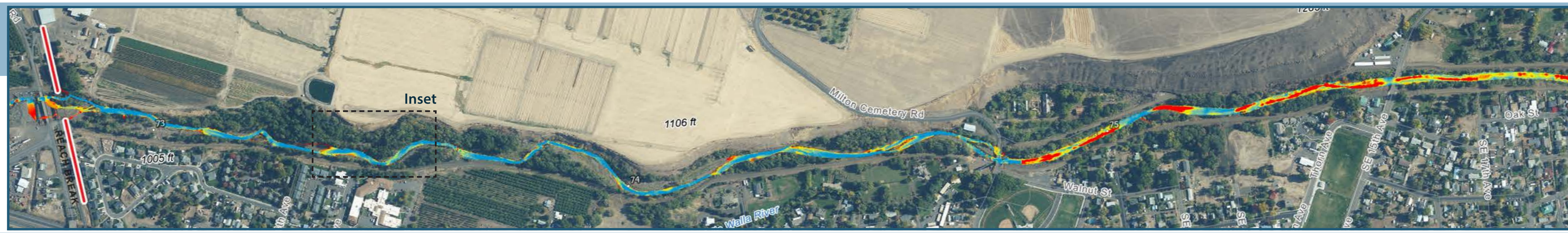
HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

Reference Appendix I for details on the methods and results, including all species and life-stages modeled.

Reach WW4

Inset

Inset

Inset

Inset

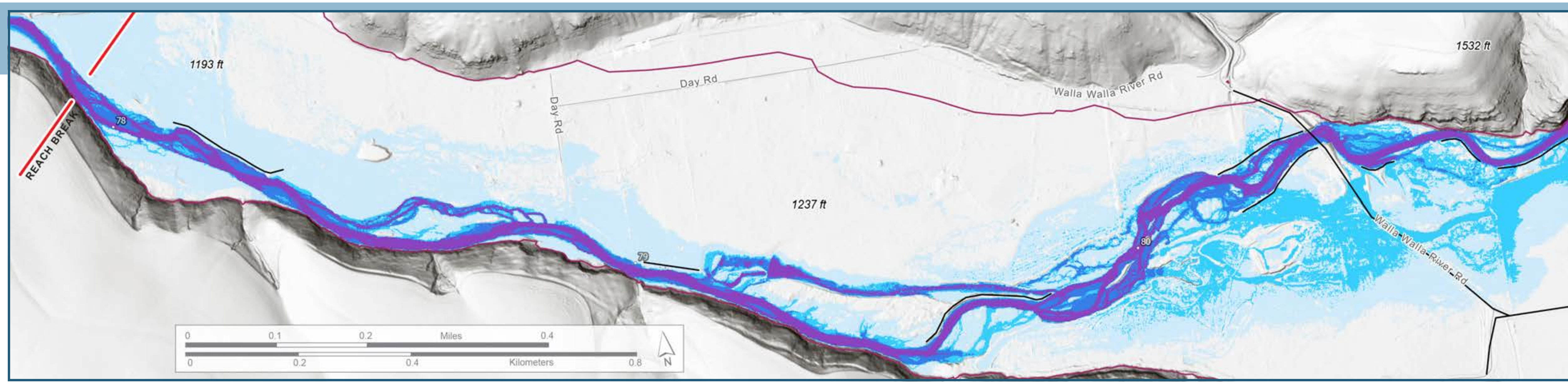
Inset

Reach WW5

4.7 KM Reach Length RKM 82.6 to 77.9

Hydraulic Modeling Inundation Extents

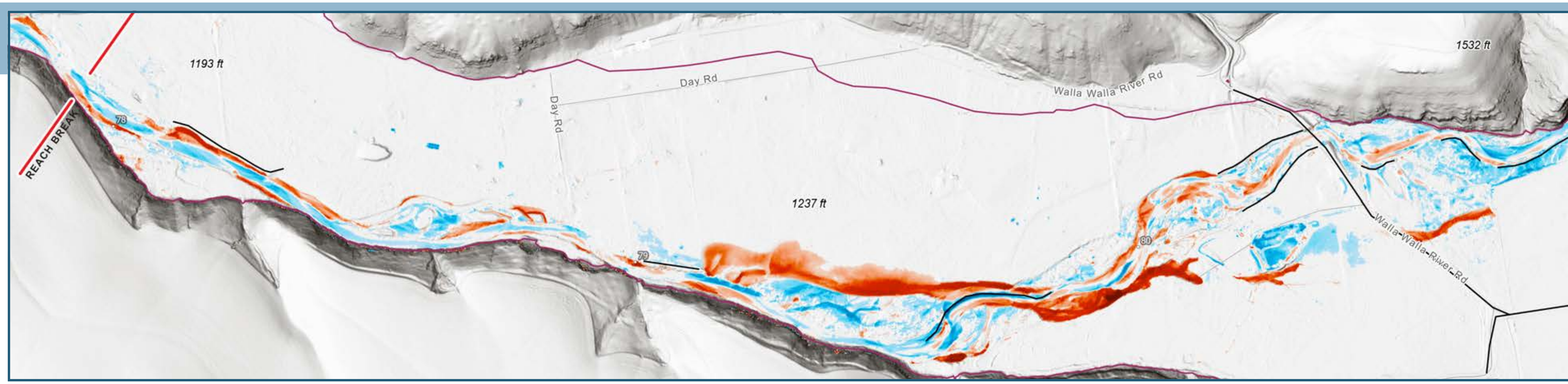
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

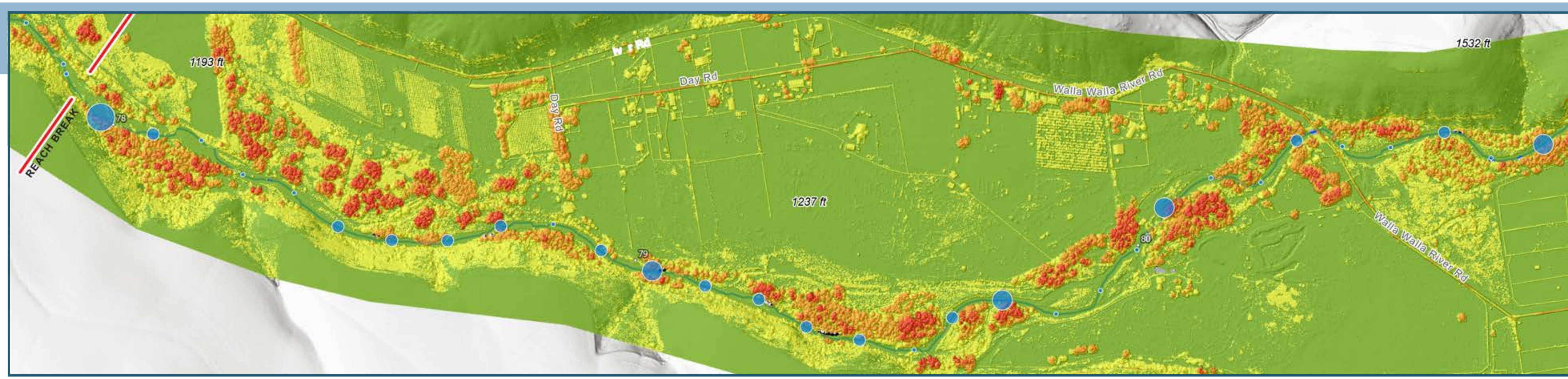
Effective Stream Shade

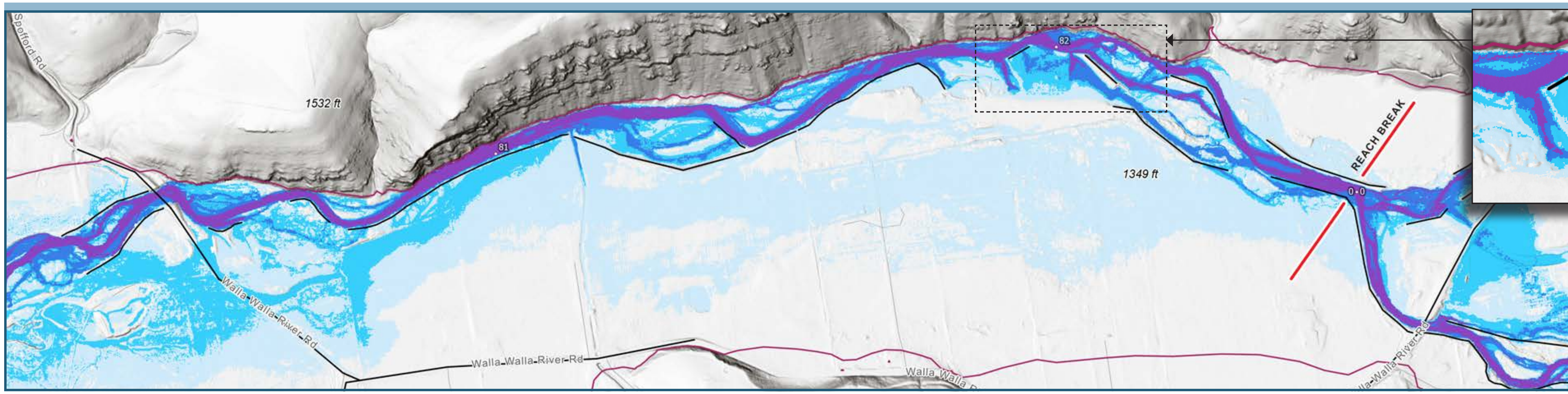
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

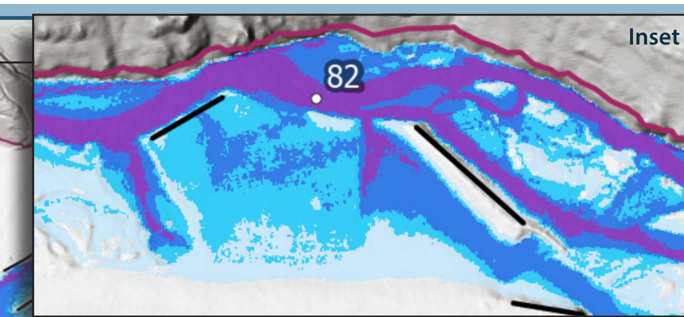
Thermal Load:
27,082 (Kcal/m)

Effective Shade **22%**

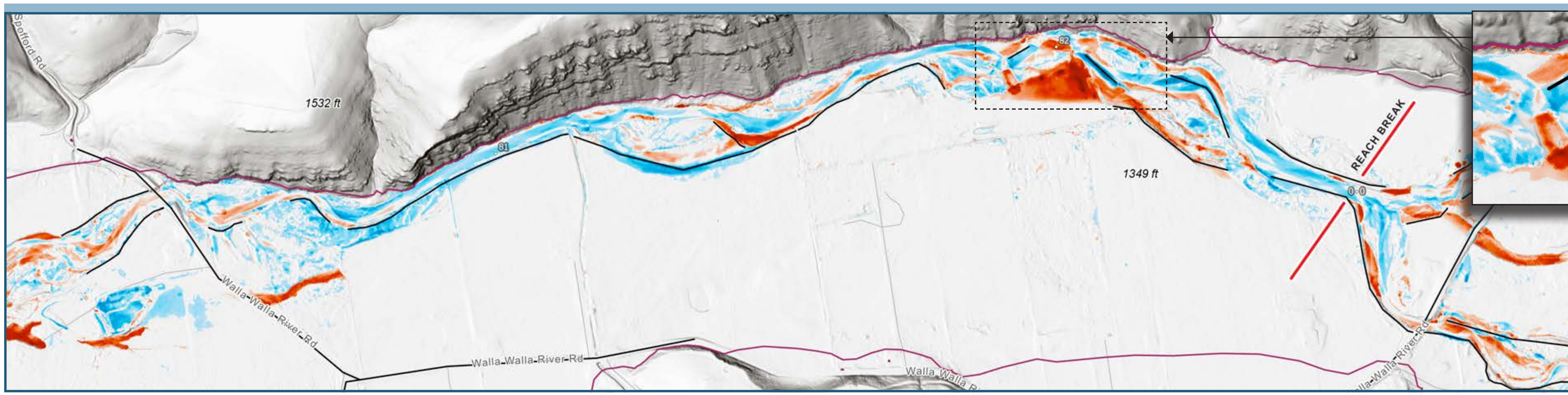
System Potential **8%**

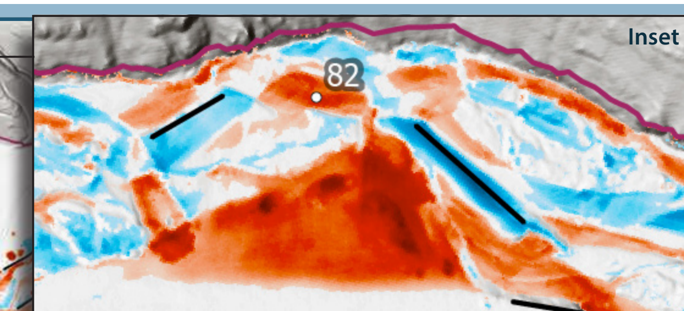






Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.

Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Reach WW5

HYDRAULIC HABITAT SUITABILITY

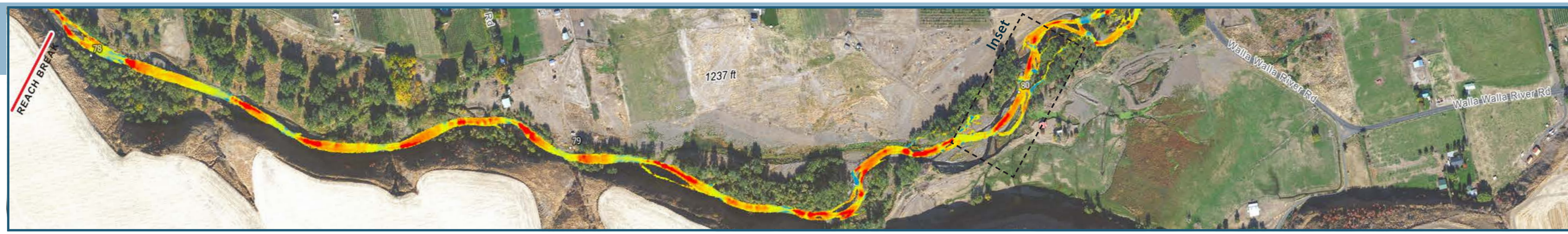
4.7 KM Reach Length RKM 82.6 to 77.9

HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

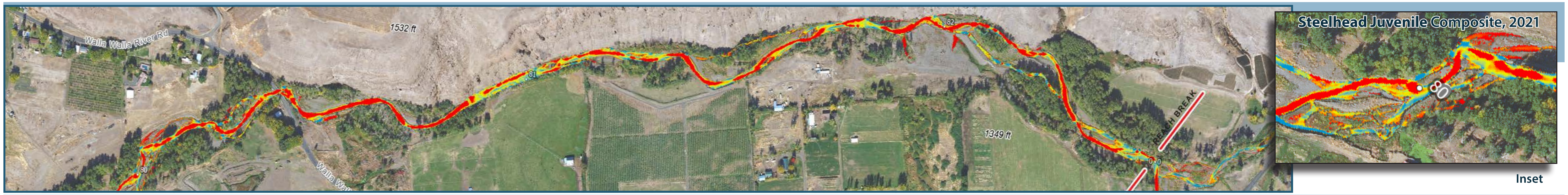
HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

Reference Appendix I for details on the methods and results, including all species and life-stages modeled.



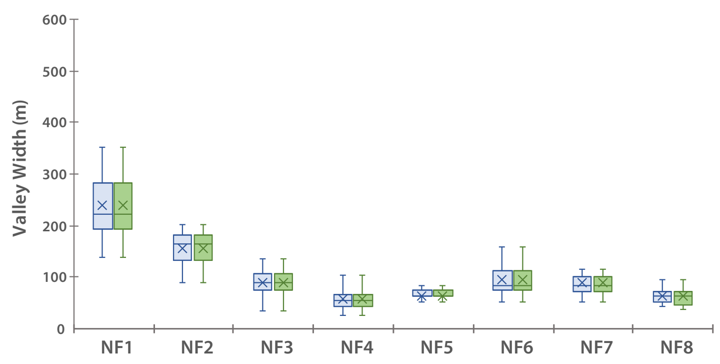
■ North Fork Walla Walla River

North Fork Walla Walla River

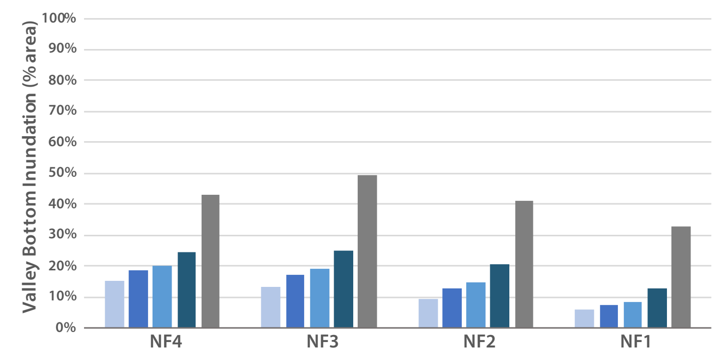
27.9 KM Reach Length   RKM 0.0 to 27.9

The North Fork (NF) of the Walla Walla River extends approximately 30.5 RKM from the confluence with the South Fork to its headwaters in the National Forest. There are eight geomorphic reaches along this distance, ranging in length from 2.6 kilometers (NF8) to 5.7 kilometers (NF1).

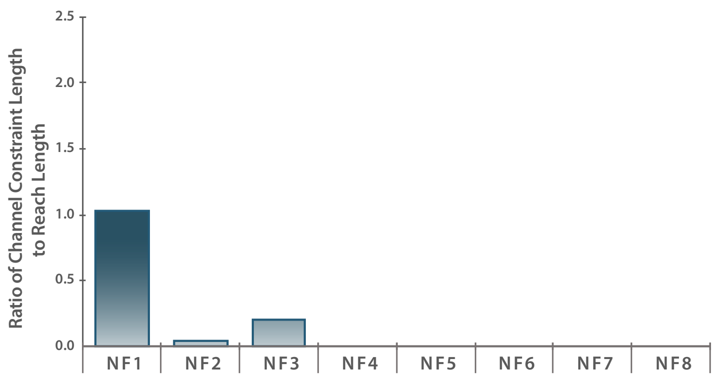
The lower NF Walla Walla is a primarily single-thread channel with low sinuosity, a moderate gradient, and is partially confined naturally by basalt valley walls in the upper reaches (NF3-NF8) and artificially by a discontinuous series of levees, revetments, and road embankments within Reaches NF1 and NF2. Within Reach NF1, less than 15% of the natural valley bottom remains connected to the active floodplain. These channel and floodplain alterations have simplified the channel character, reduced the frequency of pools, and concentrated flood flows within the banks increasing the frequency and magnitude of erosion and channel incision, especially in Reach NF1. Upstream of Reach NF1, the channel becomes increasingly steep and confined by basalt valley walls. Relatively few human impacts have directly altered channel form and process in Reaches NF3-NF8 with the exception of road construction upstream to RKM 14.1. The small size and steep gradients of the NF Walla Walla are such that it is generally only suitable for steelhead spawning while supporting rearing for both Chinook salmon and steelhead. Riparian vegetation transitions from deciduous to mixed, to conifer upstream of NF4. Following the 2020 flood of record, there were negligible changes to the reach-wide hydraulic characteristics of the channel like channel depth, velocity, shear stress, sediment transport, etc., but there were significant changes in channel location and alignment associated with large-scale erosion and deposition, primarily in Reaches NF1 and NF2. Portions of the river were completely abandoned and new channel segments were formed.



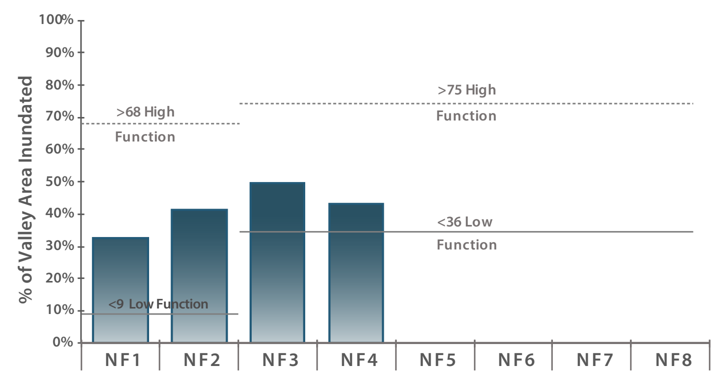
■ *Valley Width - Natural / Confined*



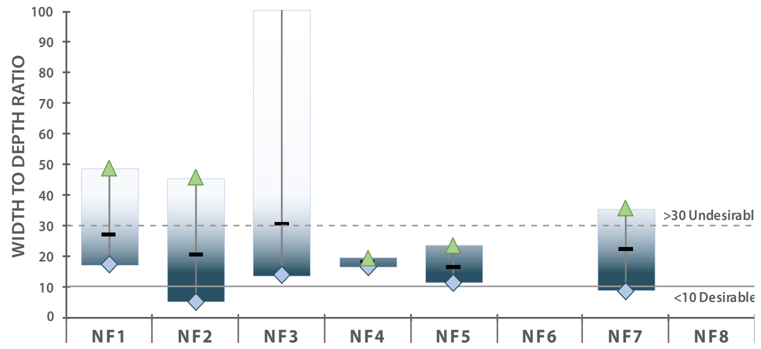
■ *Valley Bottom Inundation*



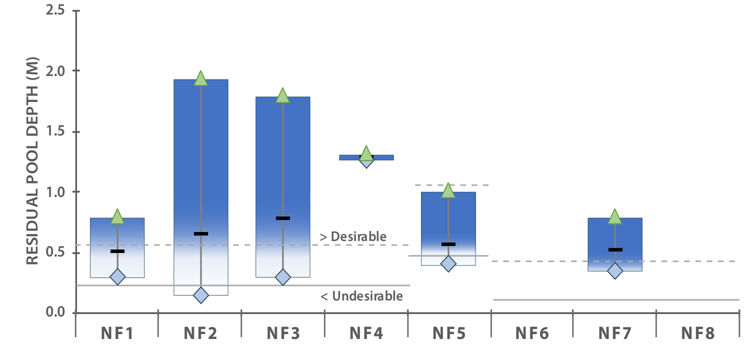
■ *Artificial Floodplain Disconnection Ratio*



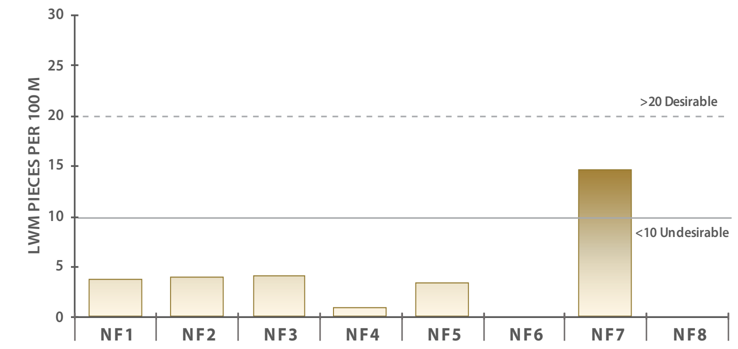
■ *Valley Area Inundated by 100 yr Flow and Function*



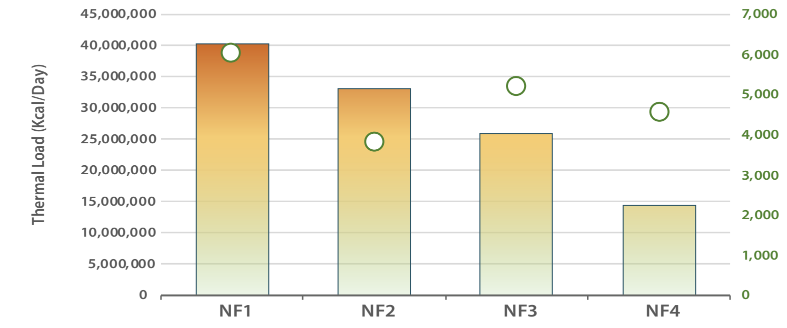
■ *Riffle Width to Depth Ratio* ◇ Min – Avg ▲ Max



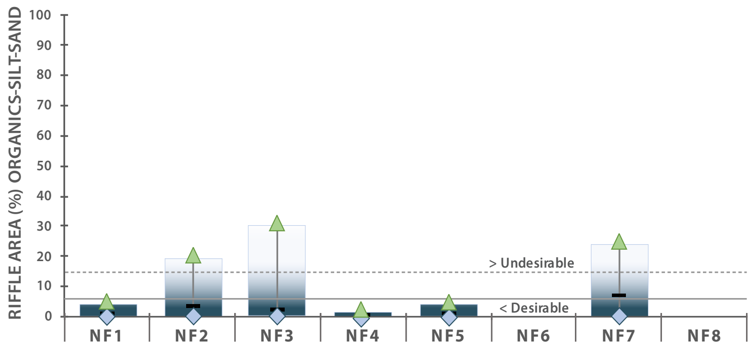
■ *Residual Pool Depth* ◇ Min – Avg ▲ Max



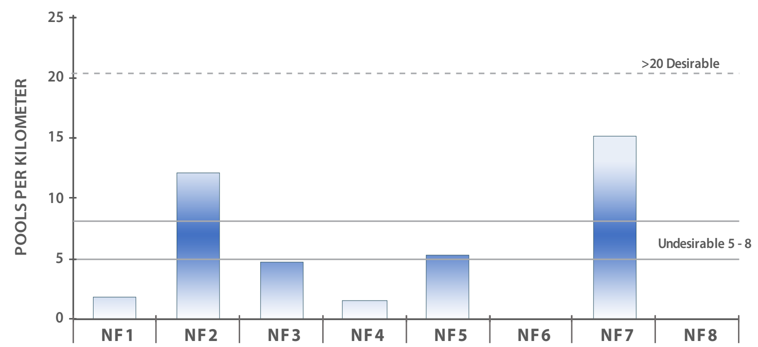
■ *Large Wood Material Piece Frequency* LWM per 100 m



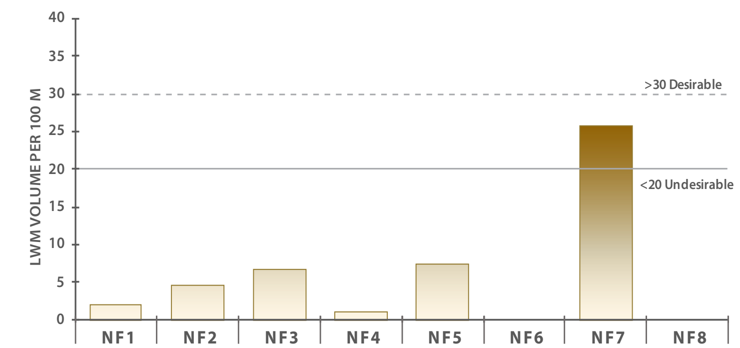
■ *Riparian Shade - Thermal Load (Kcal/Day)* Thermal Load (Kcal/Day) Reach Length (m)



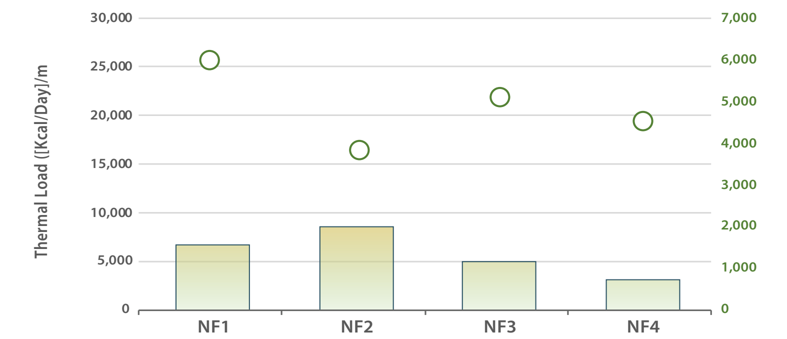
■ *Riffle Area (%) Organics - Silt - Sand* ◇ Min – Avg ▲ Max



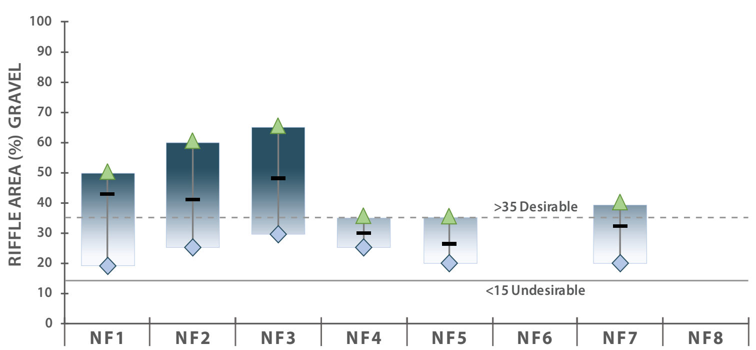
■ *Pool Frequency per Kilometer*



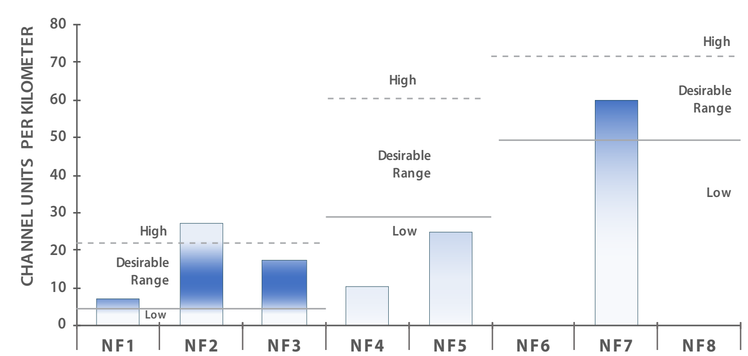
■ *Large Wood Material Volume Frequency* LWM Volume (m3) per 100 m



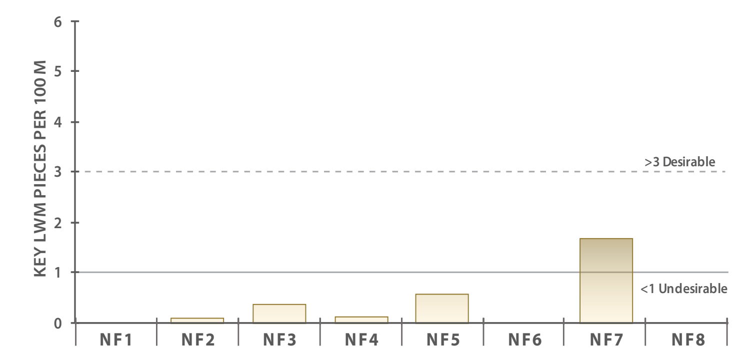
■ *Riparian Shade - Thermal Load per Meter* Thermal Load per Meter Reach Length (m)



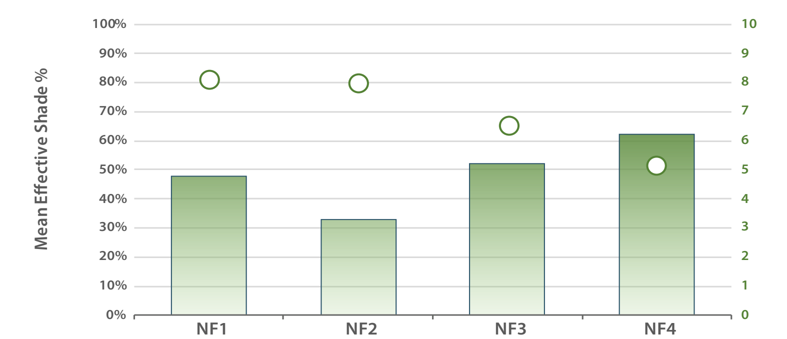
■ *Riffle Area (%) Gravel* ◇ Min – Avg ▲ Max



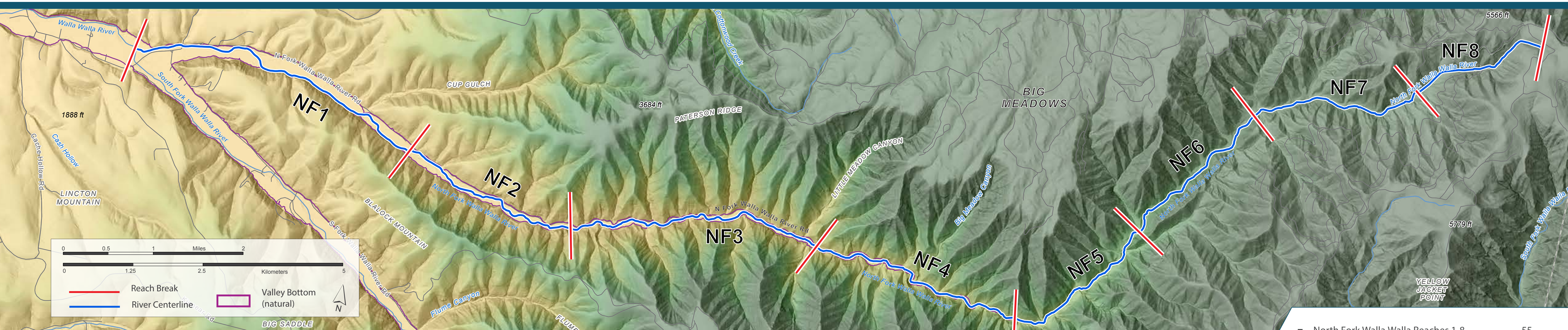
■ *Channel Unit Frequency*



■ *Large Wood Material Key Piece Frequency* Key LWM per 100 m



■ *Riparian Shade - Mean Effective Shade %* Mean Effective Shade % Mean Channel Width

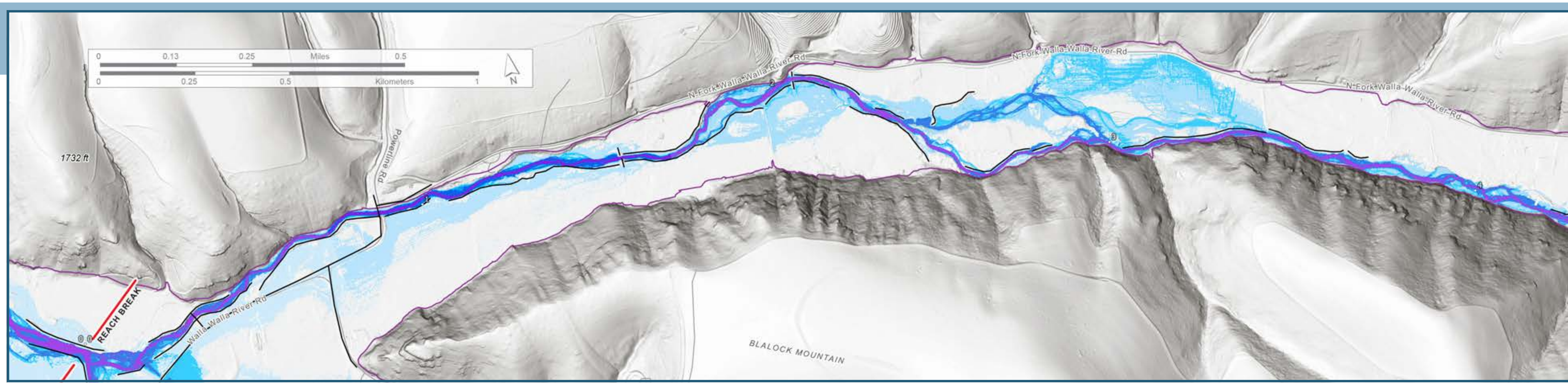


Reach NF1

5.7 KM Reach Length   RKM 0 to 5.7

Hydraulic Modeling Inundation Extents

- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

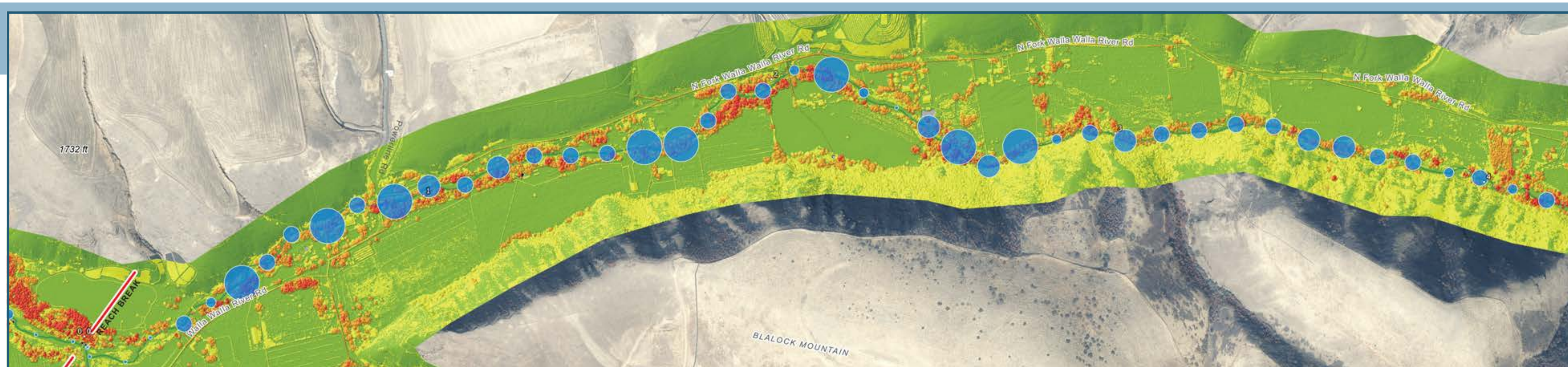
Effective Stream Shade

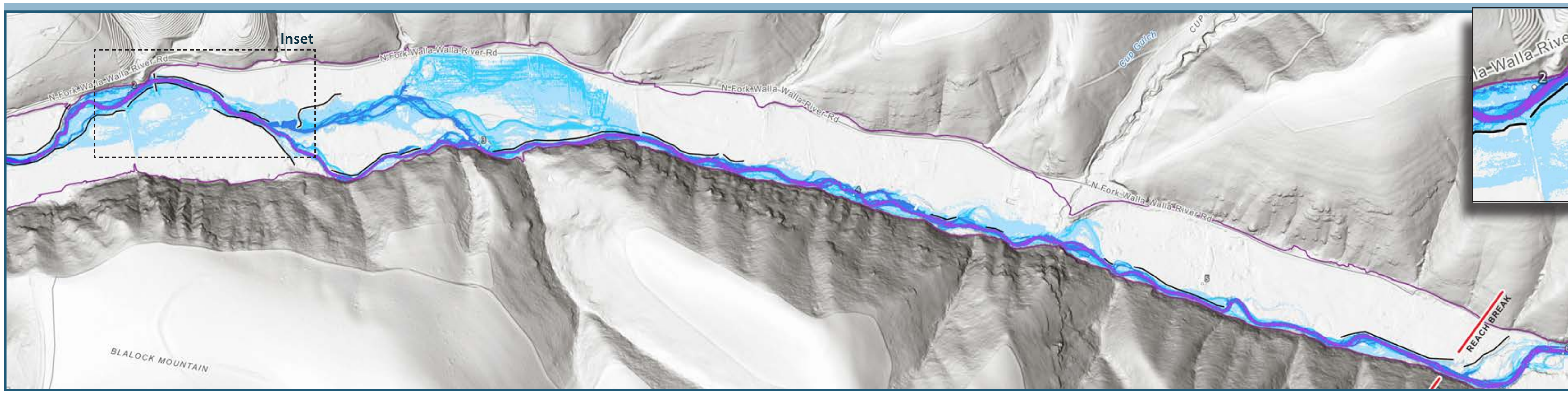
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

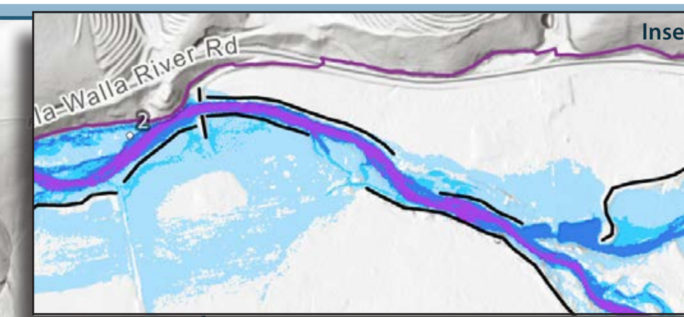
Thermal Load: **6,699** (Kcal/m)

Effective Shade **48%**

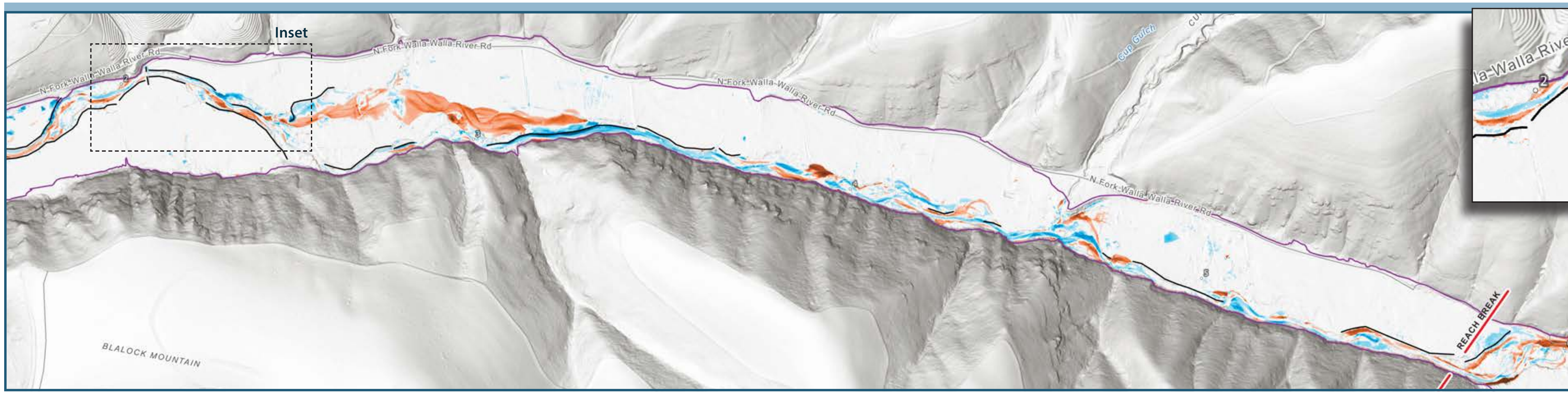
System Potential **7%**

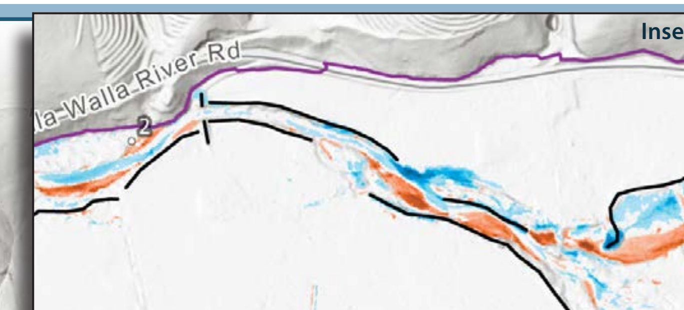




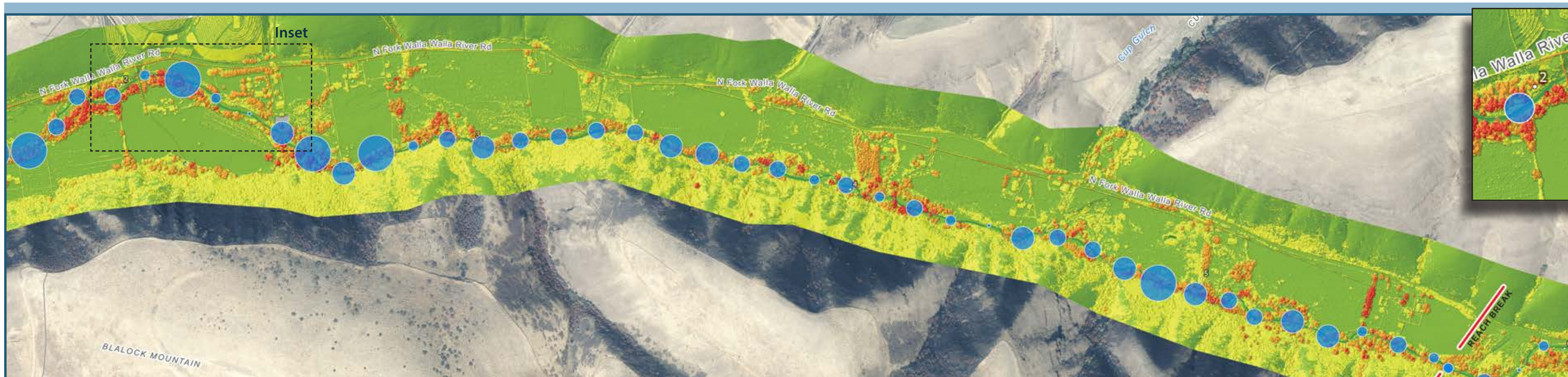


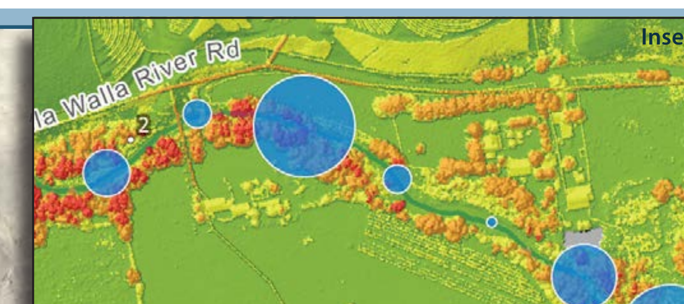
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Reach NF1

HYDRAULIC HABITAT SUITABILITY

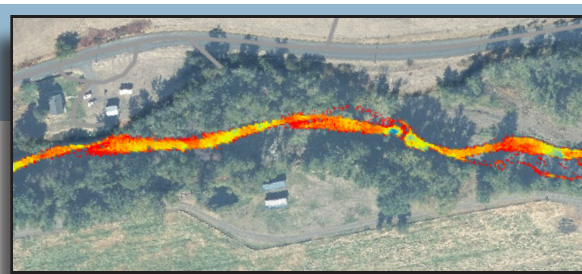
5.7 KM Reach Length RKM 0 to 5.7

HHS
Chinook Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



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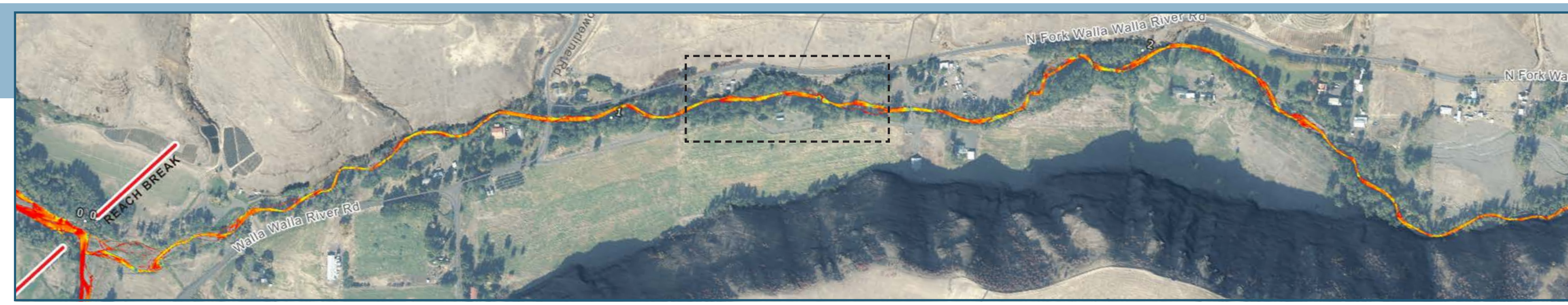
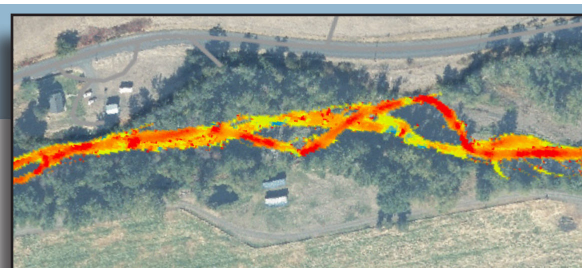


HHS
Chinook Winter Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



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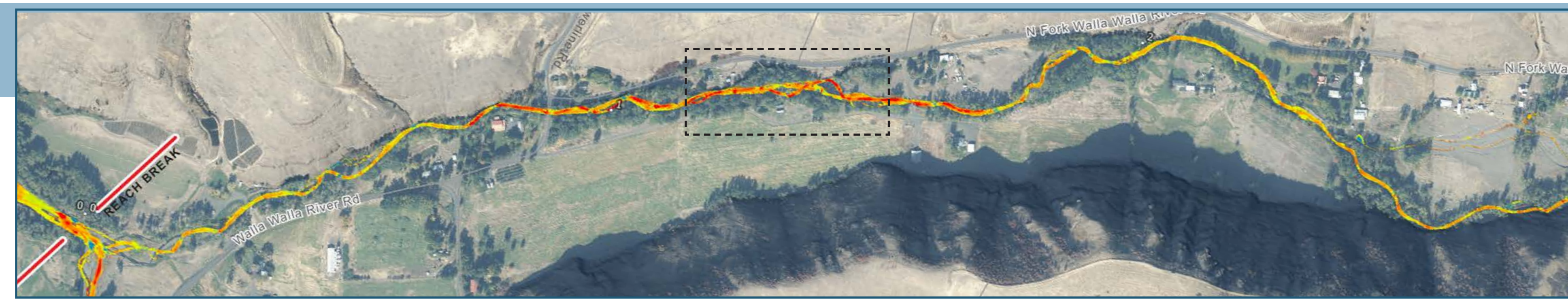
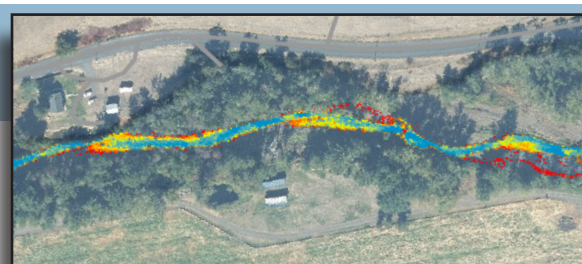


HHS
Steelhead Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



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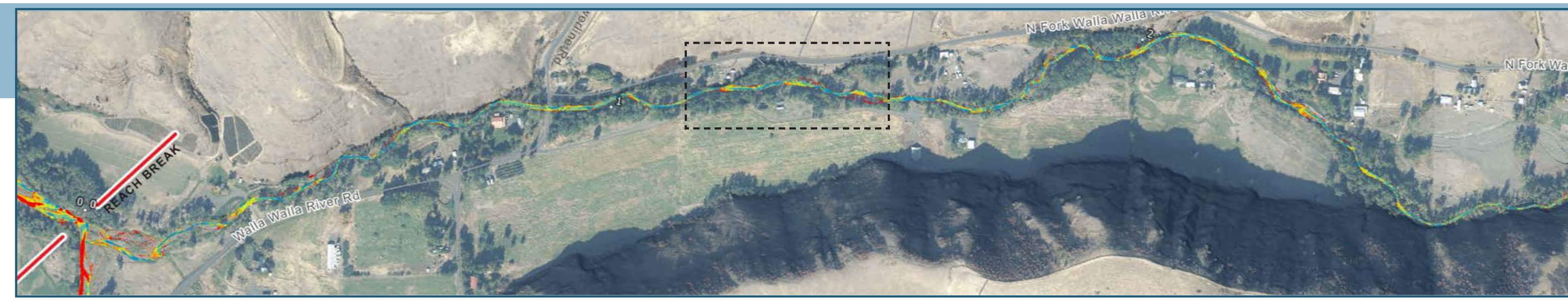
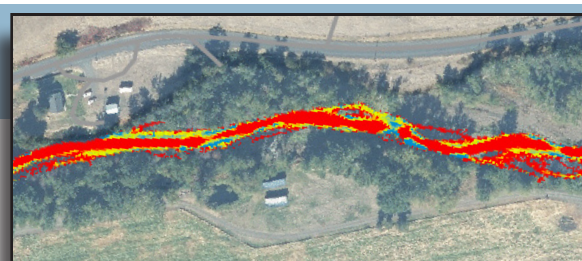


HHS
Steelhead Spawning Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



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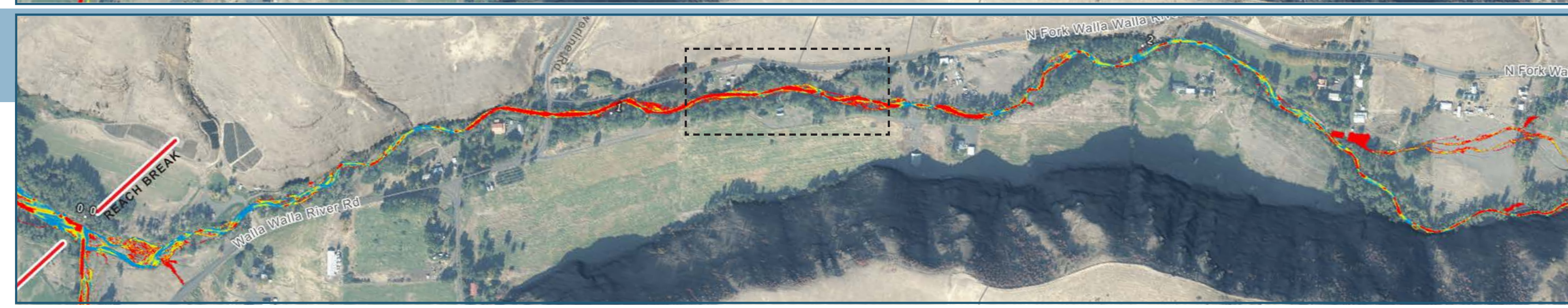
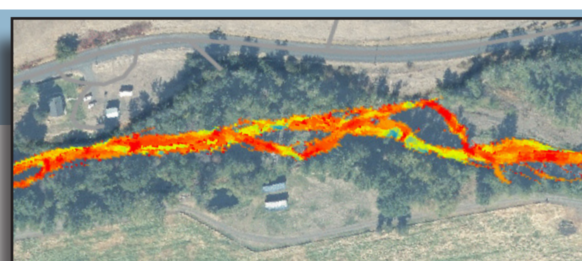


HHS
Steelhead Winter Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



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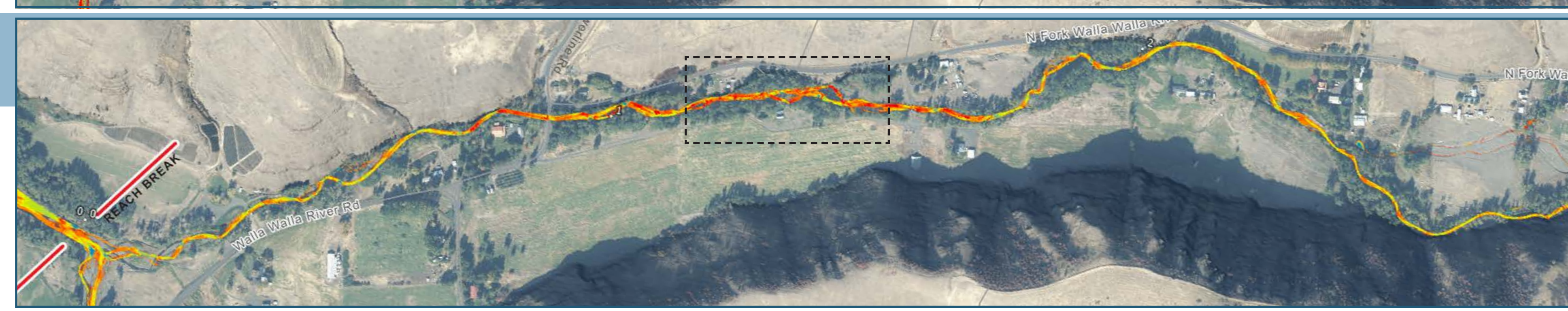
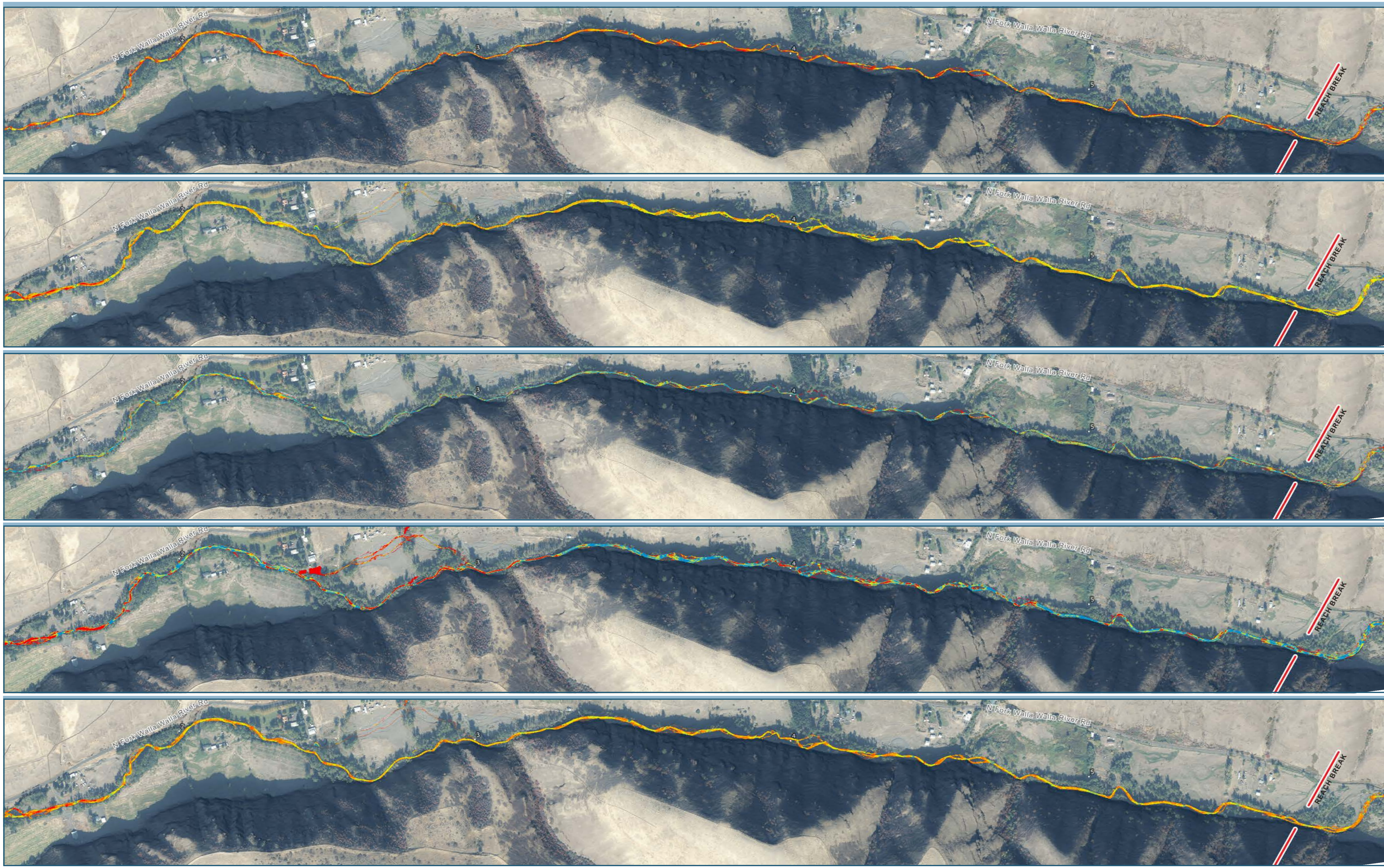


Reference Appendix I for details on the methods and results, including all species and life-stages modeled.

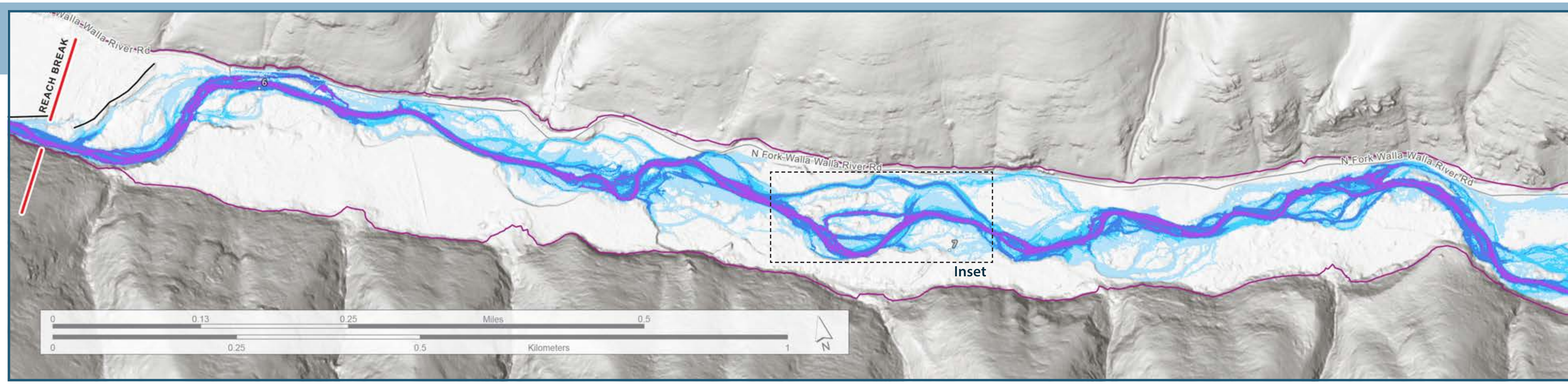


Reach NF2

3.5 KM Reach Length RKM 5.7 to 9.2

Hydraulic Modeling Inundation Extents

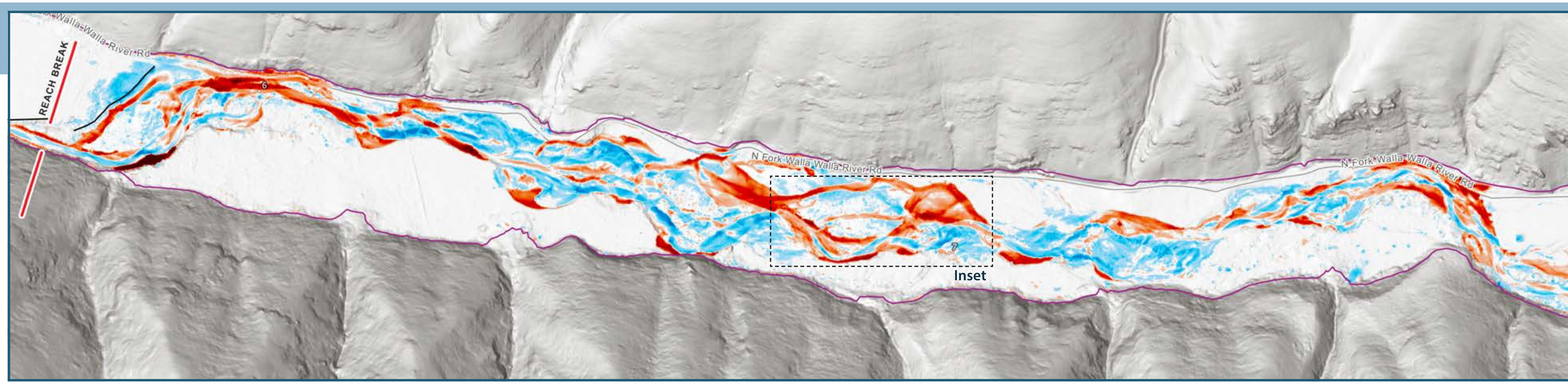
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

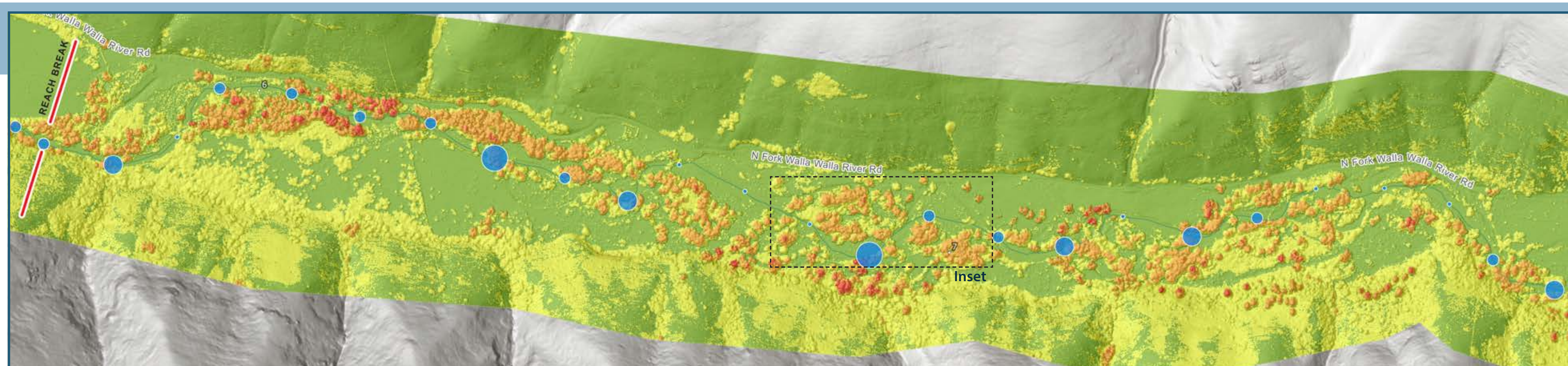
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

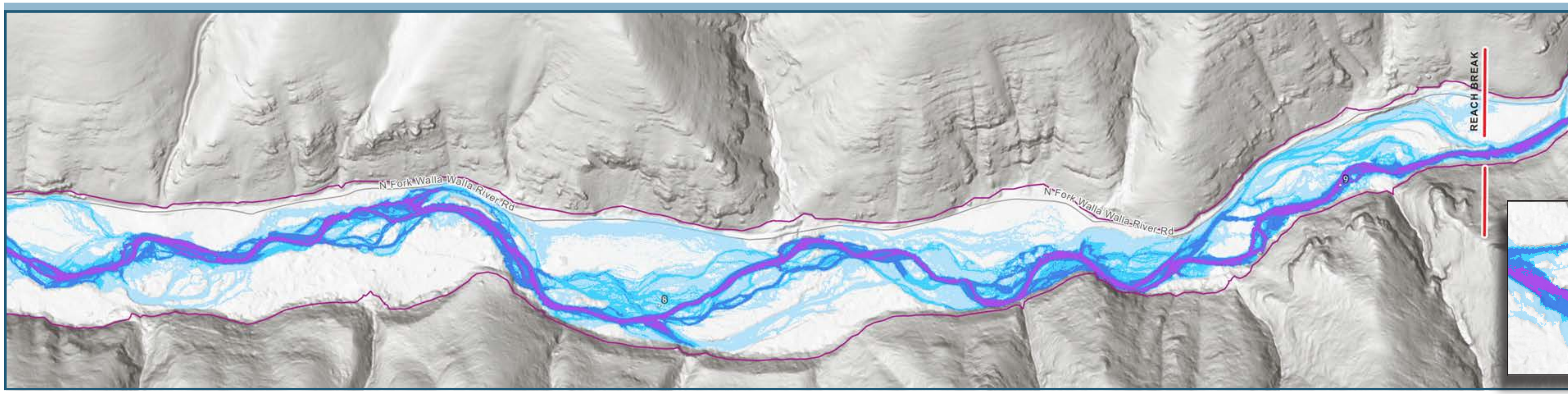
Thermal Load: **8,616** (Kcal/m)

Effective Shade **33%**

System Potential **3%**

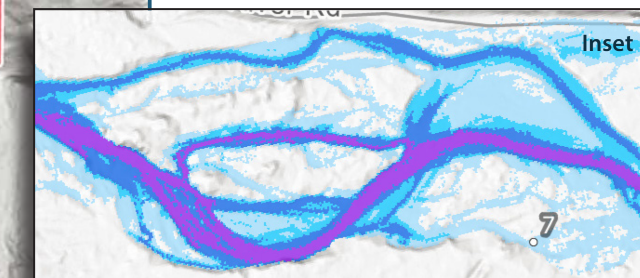


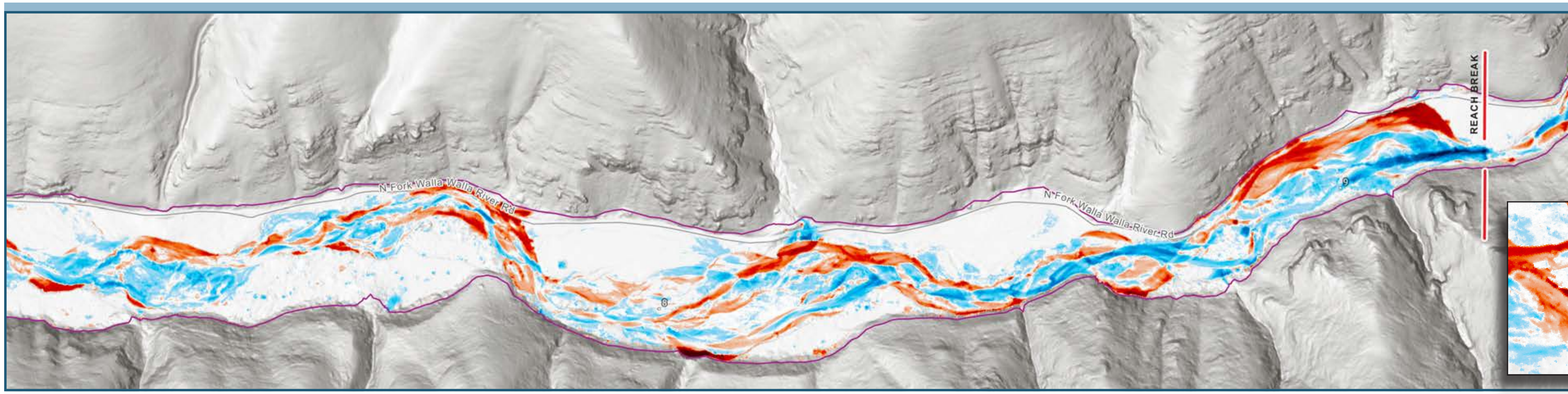
Reach NF2



Hydraulic Modeling Inundation

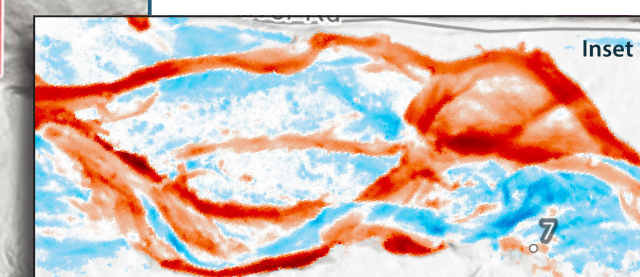
Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/bathymetric LiDAR survey.

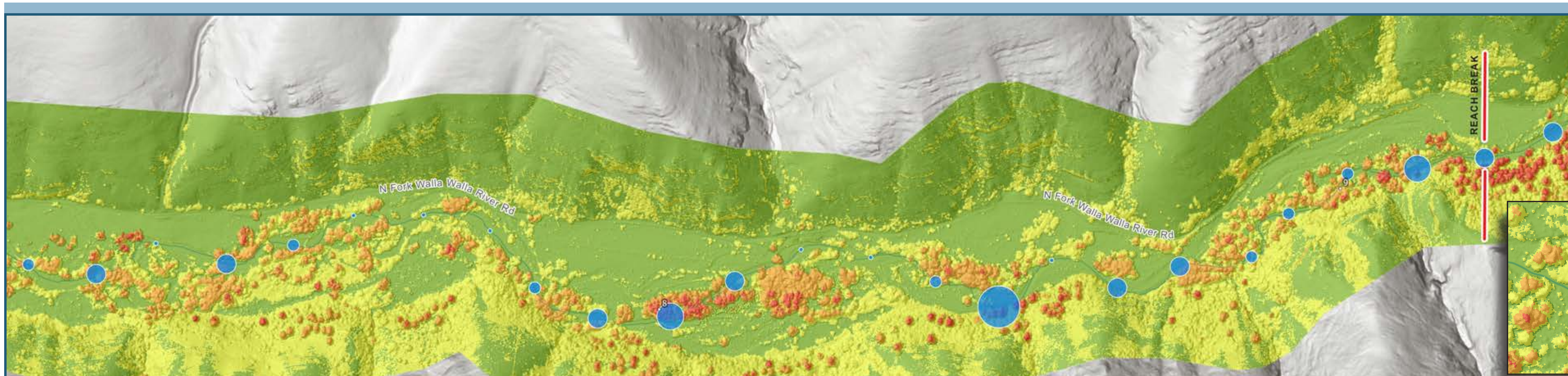




Channel Deposition and Erosion

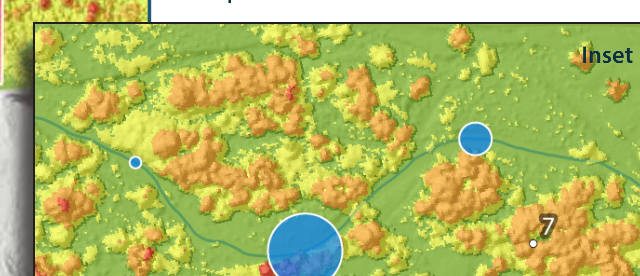
Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis

Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.



Reach NF2

HYDRAULIC HABITAT SUITABILITY

3.5 KM Reach Length   RKM 5.7 to 9.2

HHS
Chinook Juvenile Composite, 2021

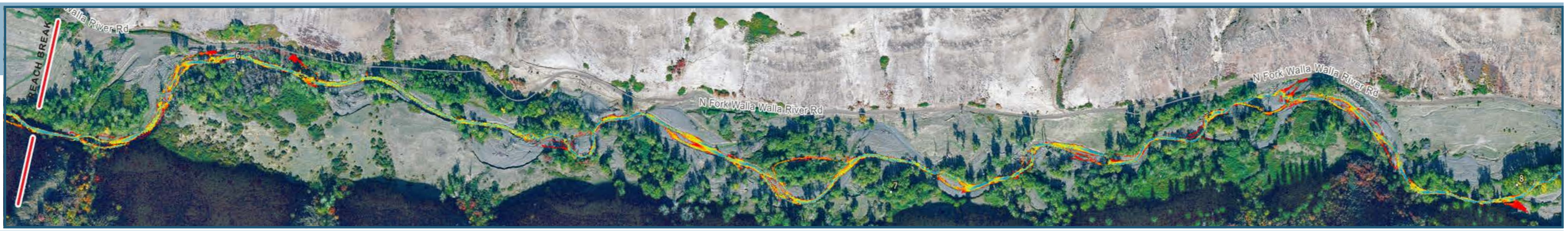
Highly Suitability
Moderate Suitability
Low Suitability

HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

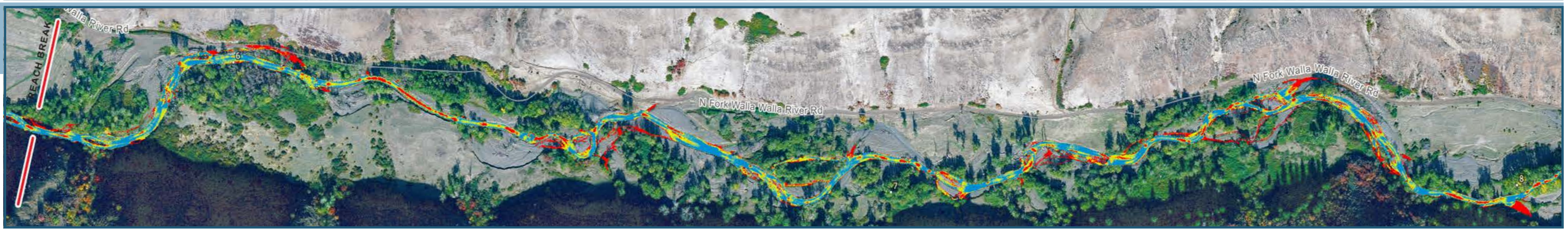
HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

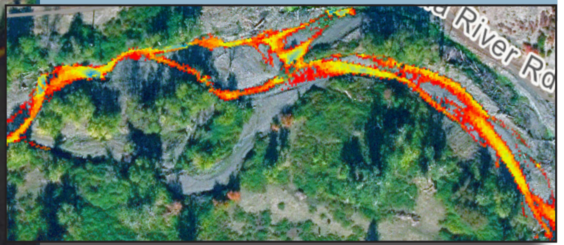


HHS
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

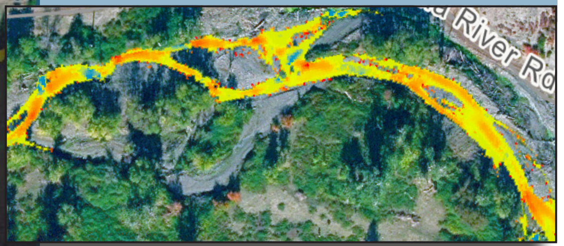
Reach NF2

Chinook Juvenile Composite, 2021



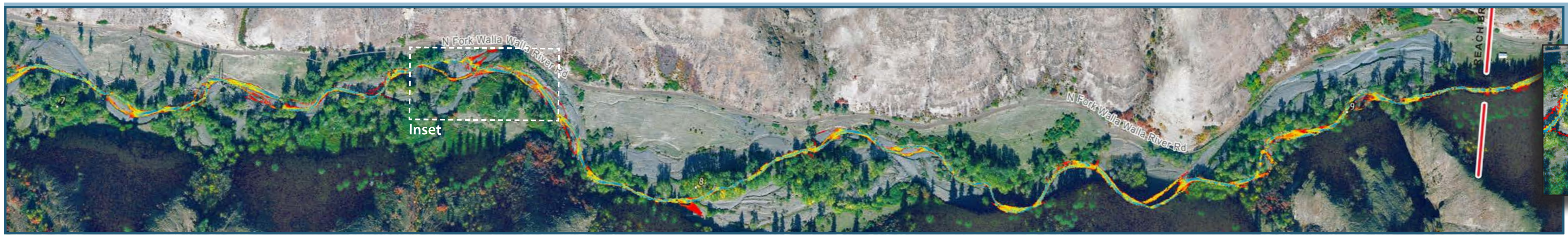
Inset

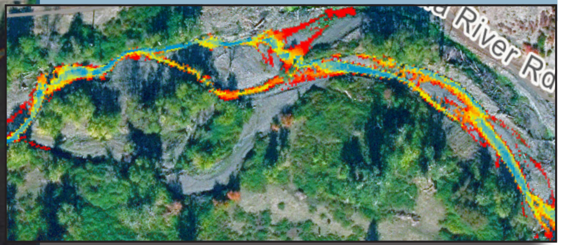
Chinook Winter Composite, 2021



Inset

Steelhead Juvenile Composite, 2021





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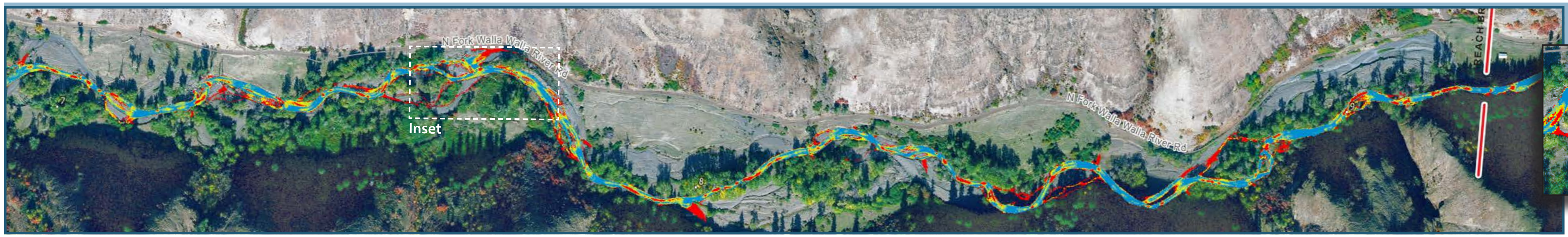
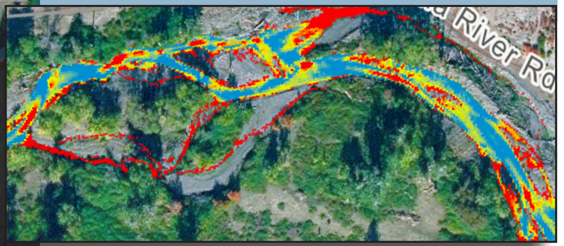
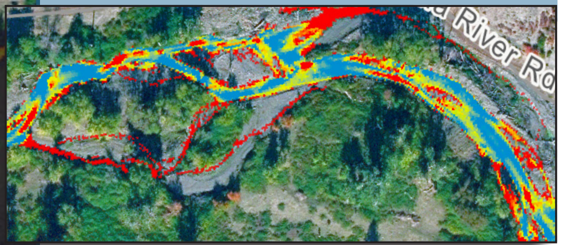
Steelhead Spawning Composite, 2021





Inset

Steelhead Winter Composite, 2021



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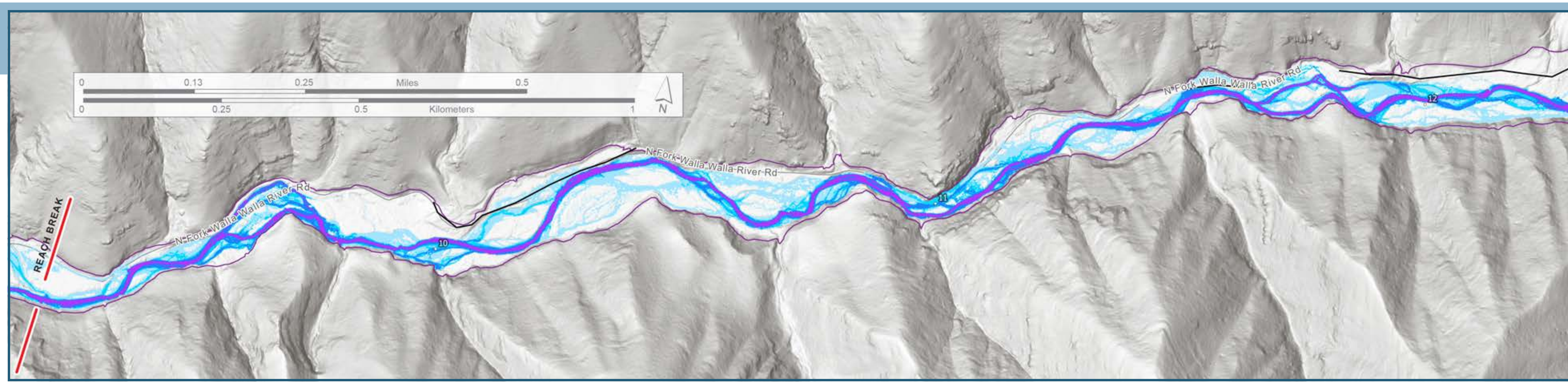
Reach NF3

4.9 KM Reach Length RKM 9.2 to 14.1

Hydraulic Modeling Inundation Extents

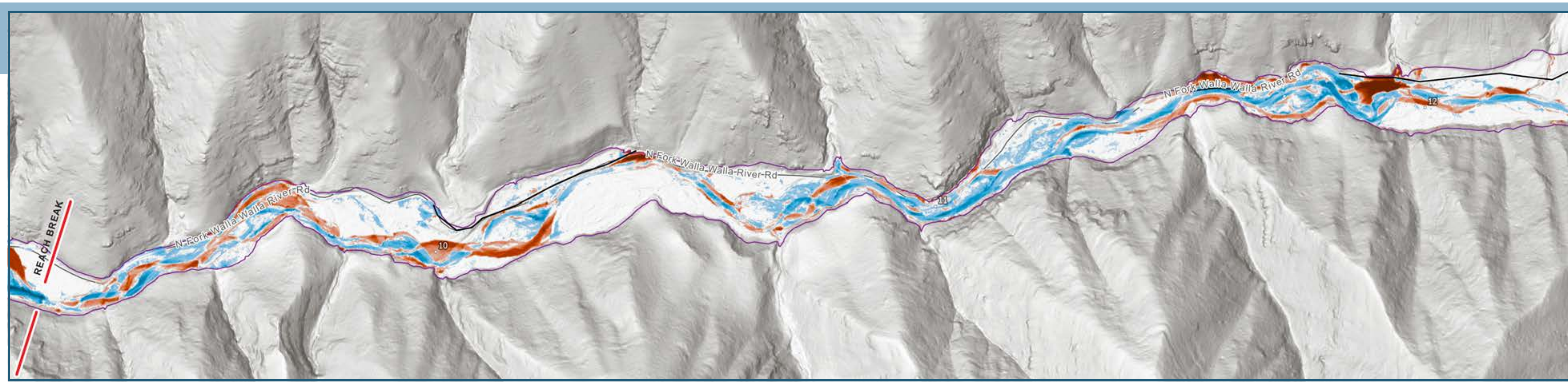
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

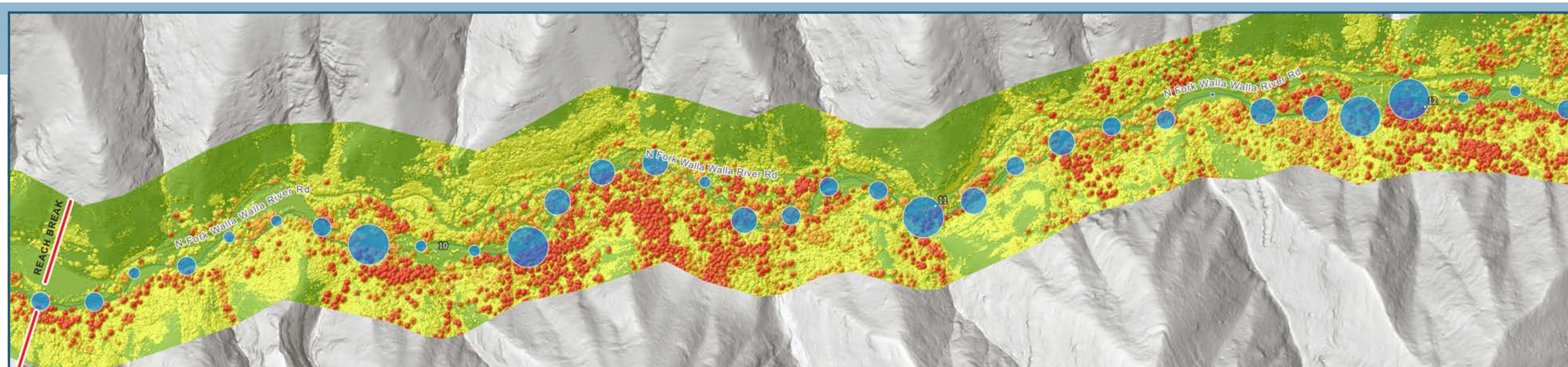
Effective Stream Shade

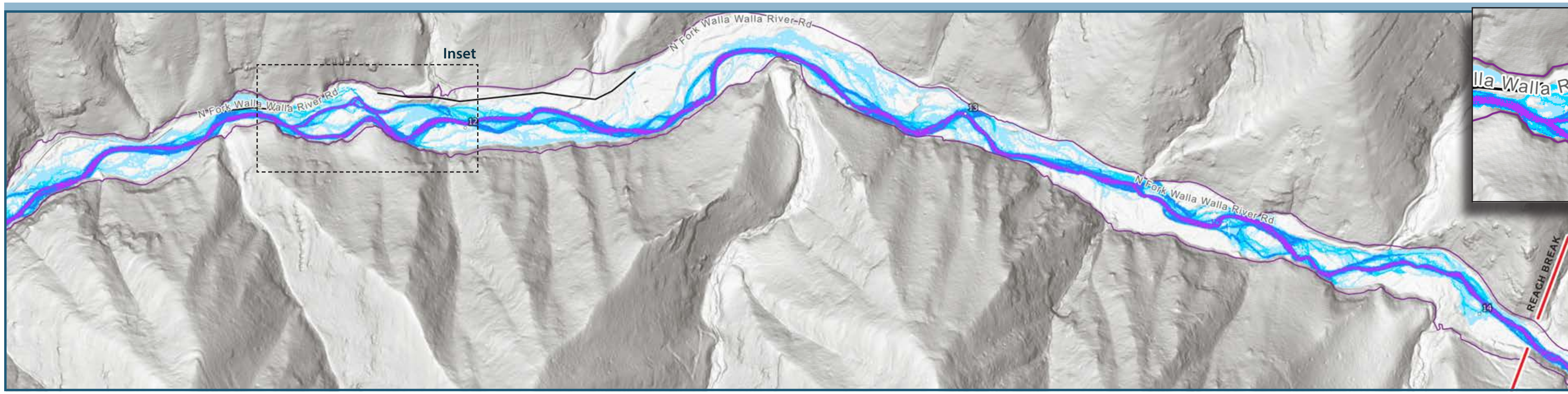
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

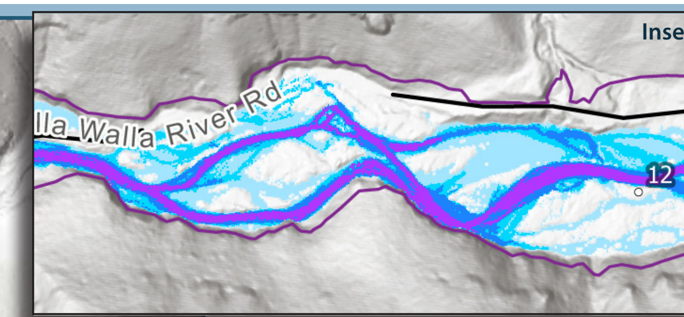
Thermal Load: **5,004** (Kcal/m)

Effective Shade **52%**

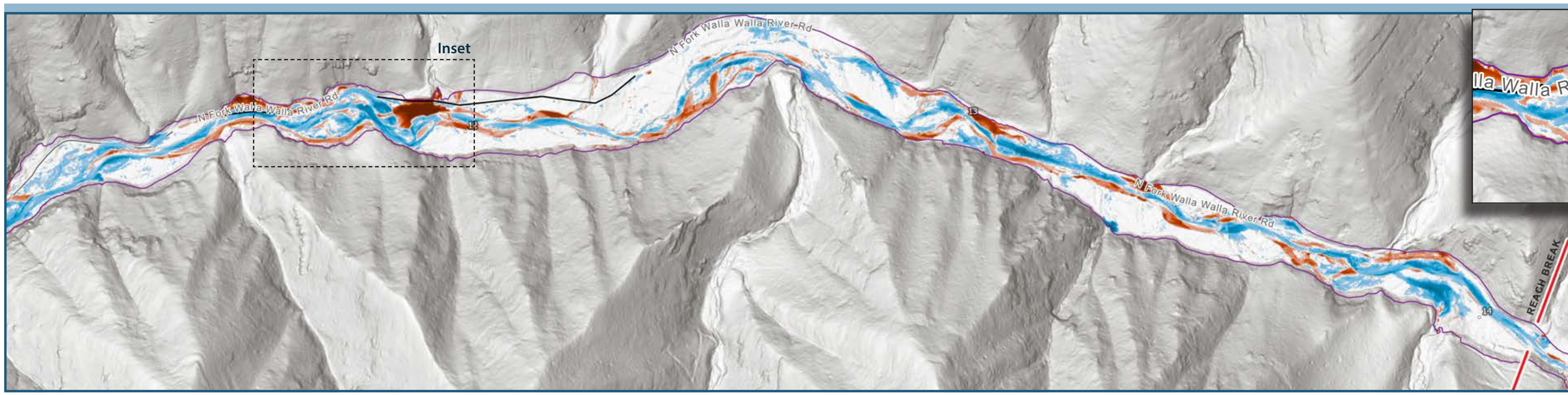
System Potential **0%**

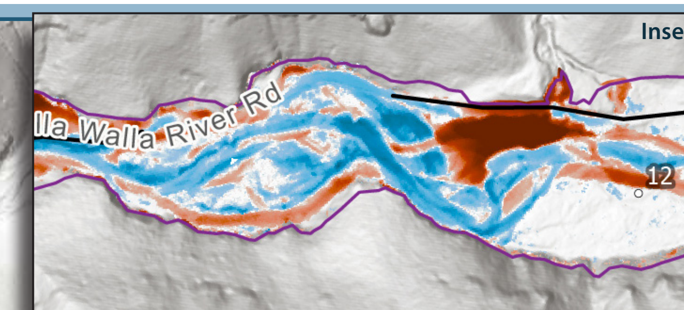




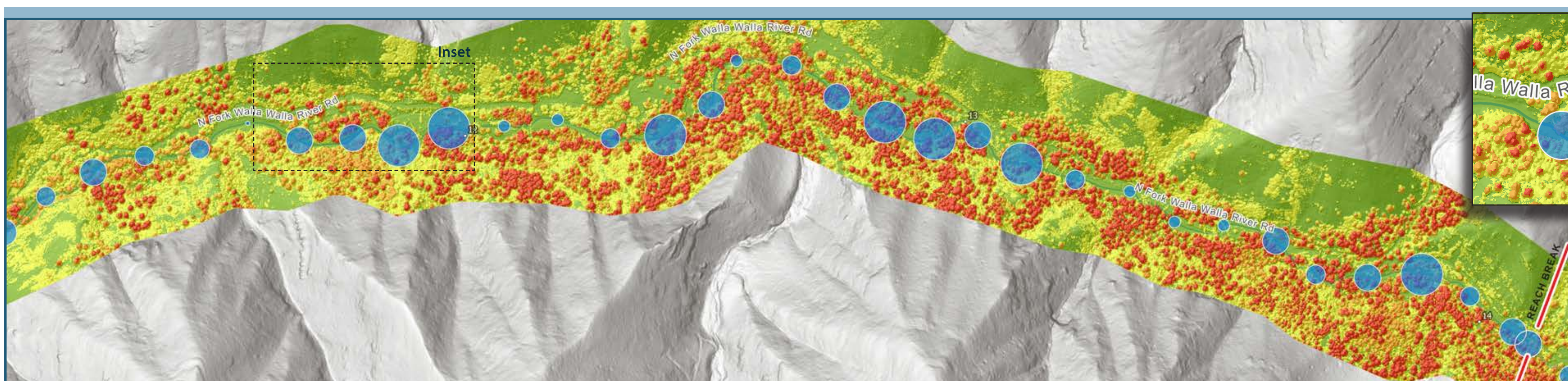


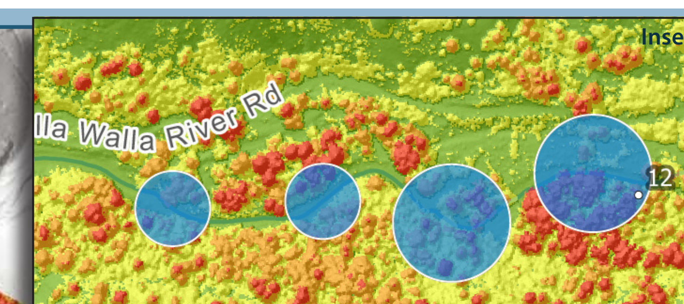
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Reach NF3

HYDRAULIC HABITAT SUITABILITY

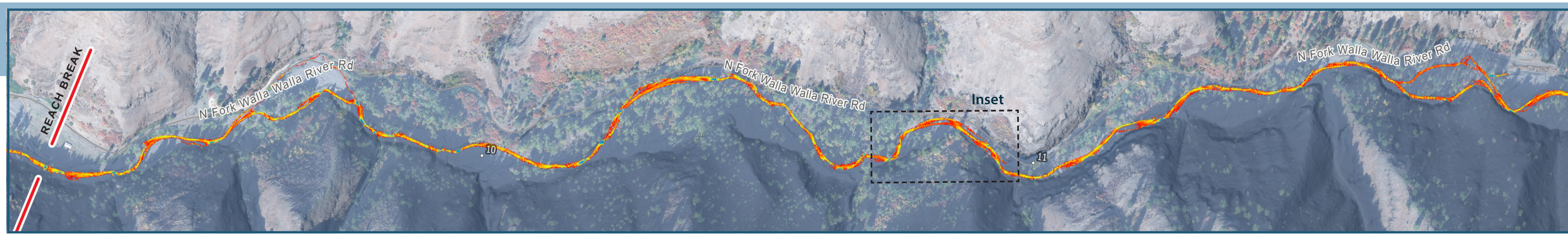
4.9 KM Reach Length   RKM 9.2 to 14.1

HHS
Chinook Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



HHS
Chinook Winter Composite, 2021

Highly Suitability

Moderate Suitability

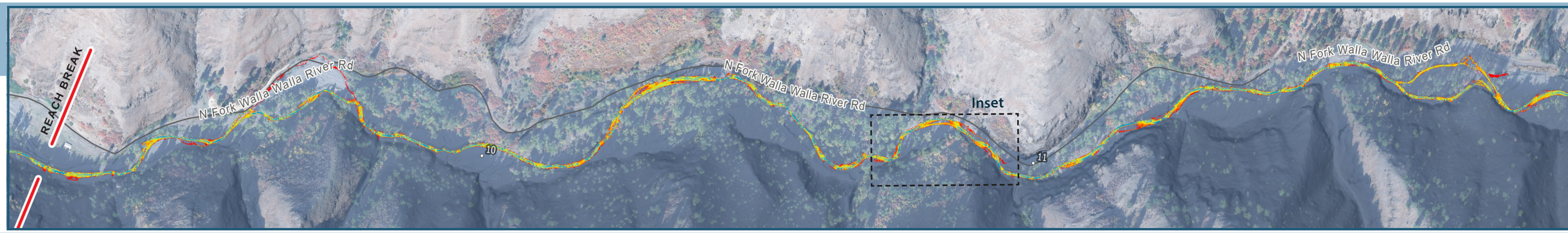
Low Suitability

HHS
Steelhead Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

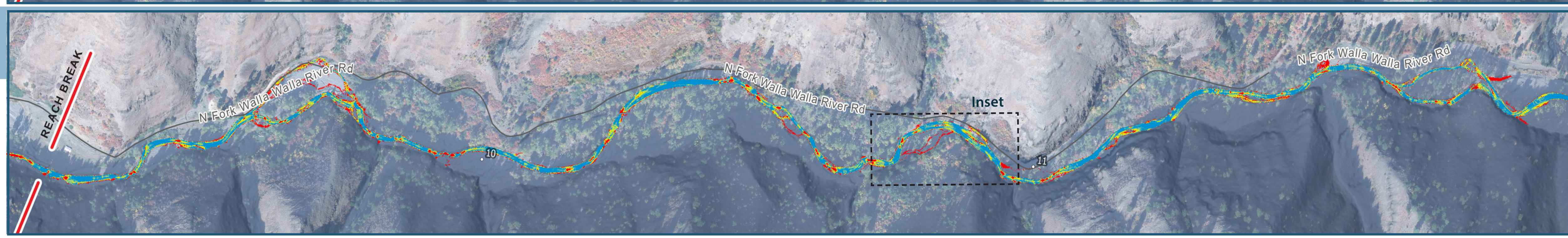


HHS
Steelhead Spawning Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability



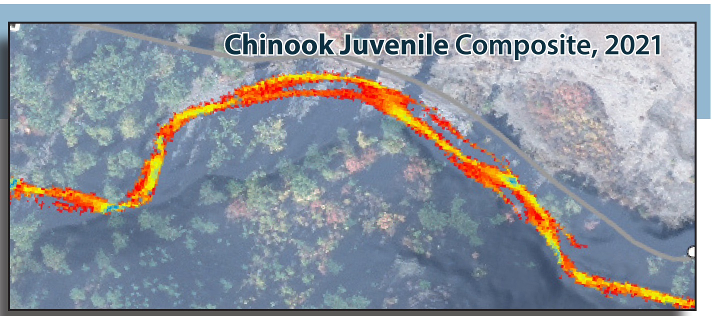
HHS
Steelhead Winter Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

Reference Appendix I for details on the methods and results, including all species and life-stages modeled.



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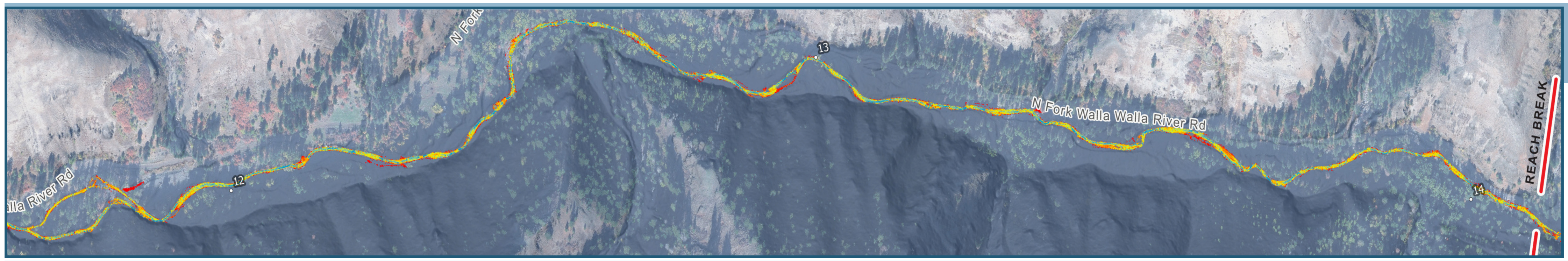

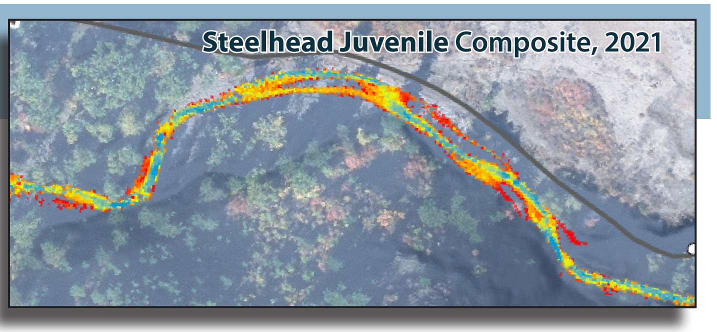

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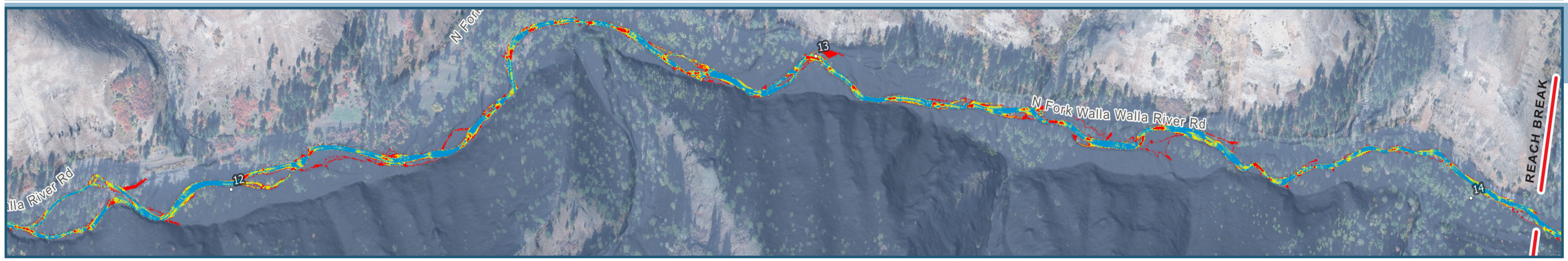

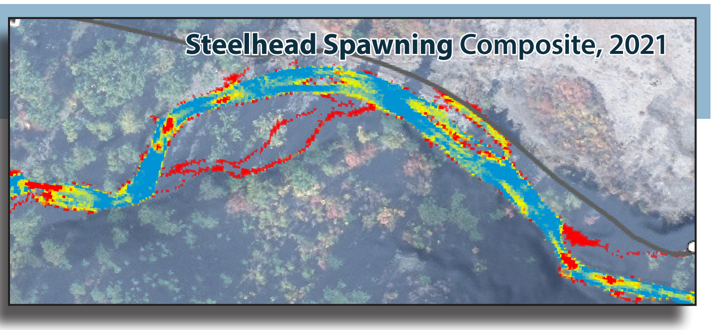

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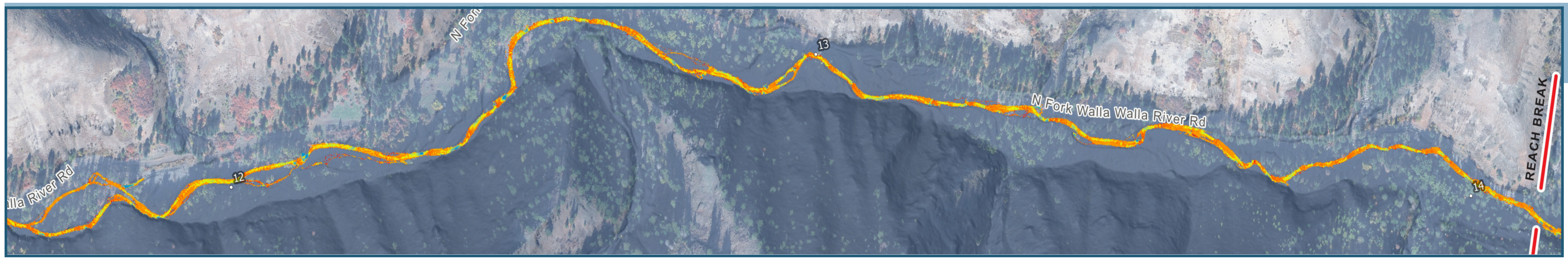


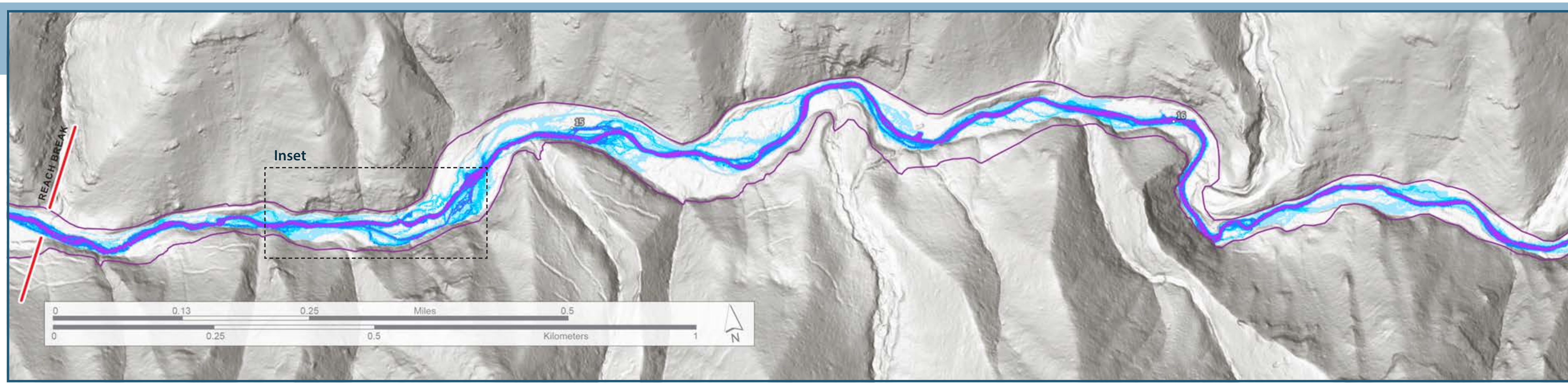
Inset

Reach NF4

4.2 KM Reach Length RKM 14.1 to 18.3

Hydraulic Modeling Inundation Extents

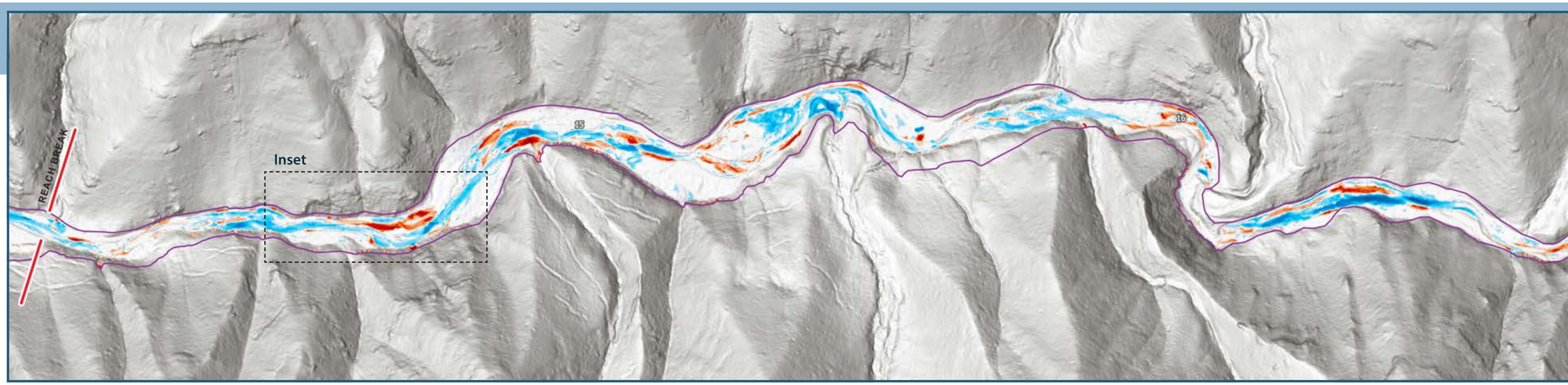
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

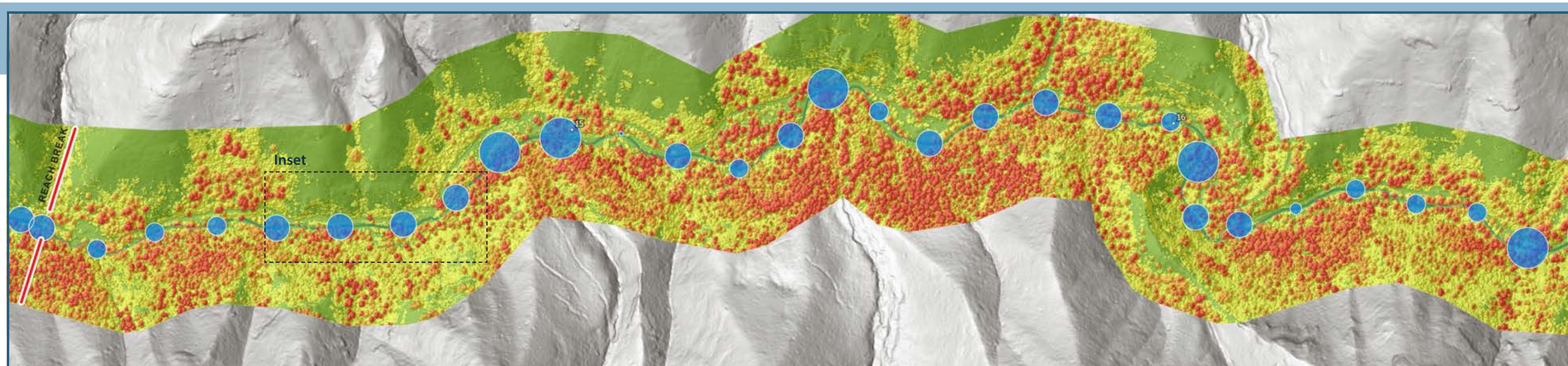
Effective Stream Shade

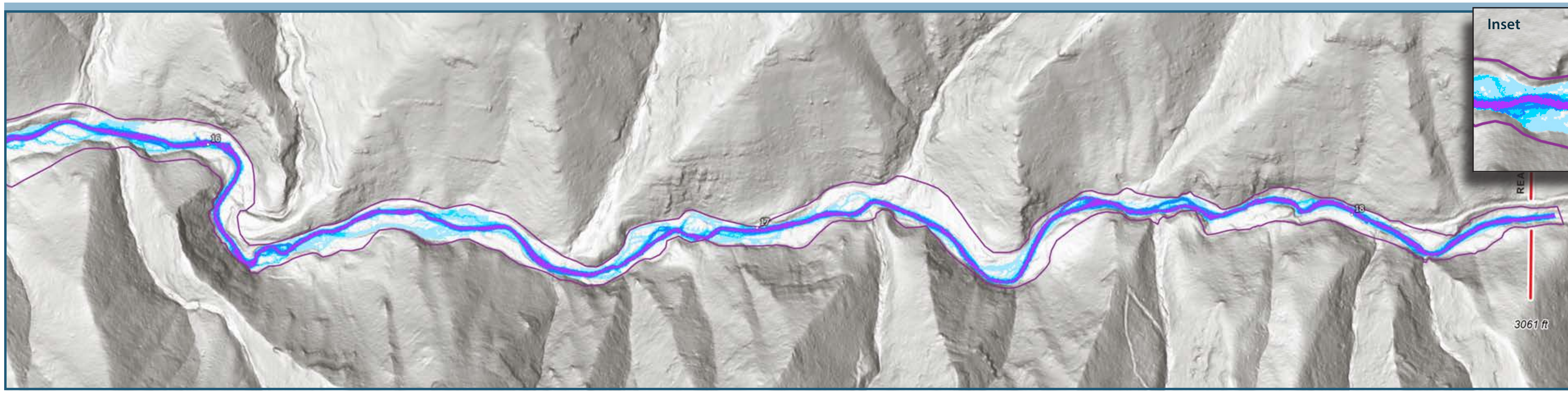
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

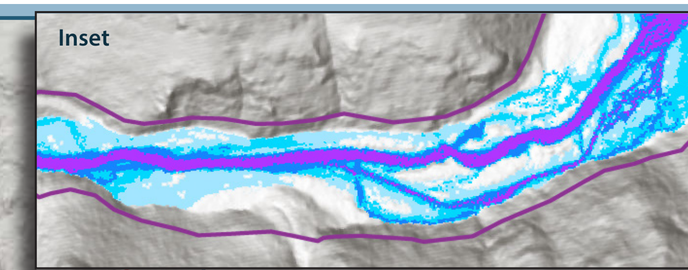
Thermal Load: **3,172** (Kcal/m)

Effective Shade **62%**

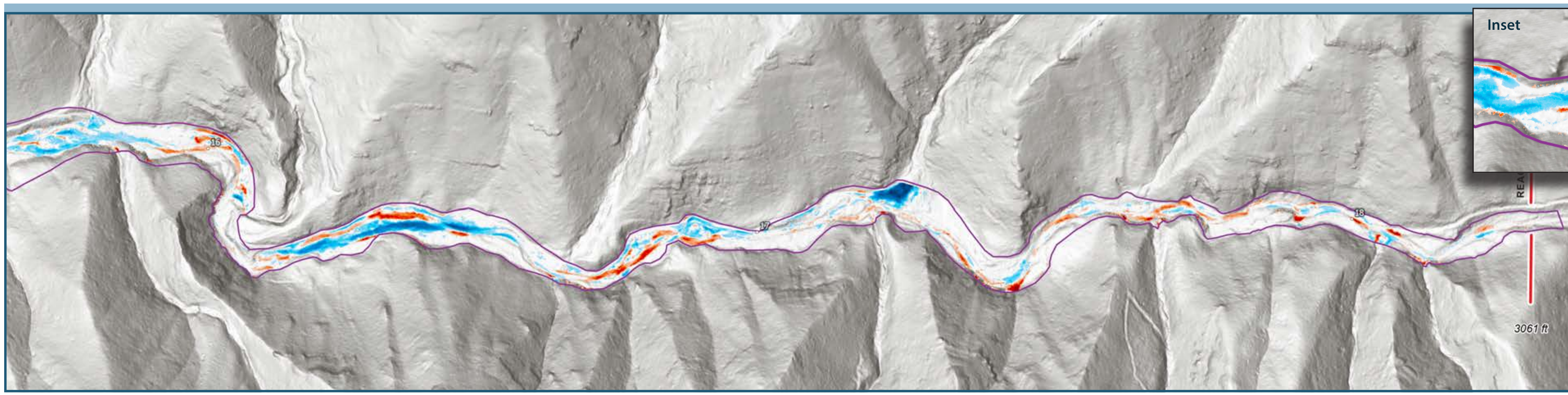
System Potential **4%**

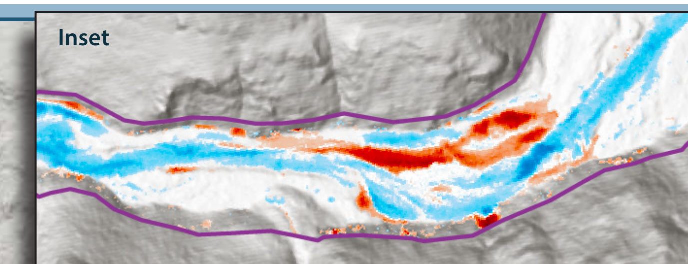




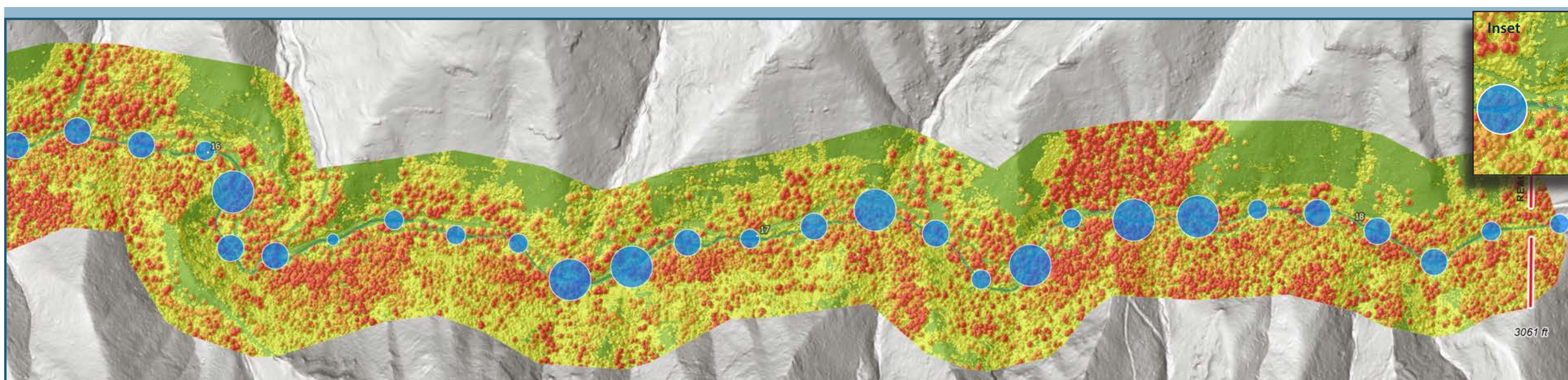


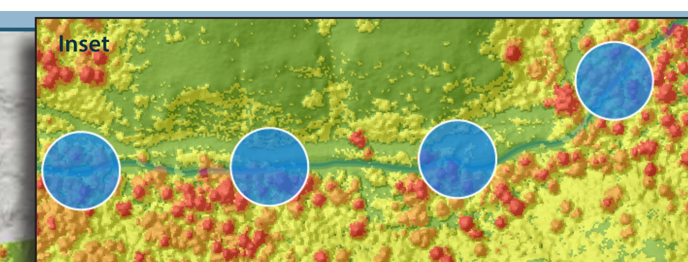
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.





Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream’s surface and also provides shade output as effective shade metric.

Reach NF4

HYDRAULIC HABITAT SUITABILITY

4.2 KM Reach Length RKM 14.1 to 18.3

HHS

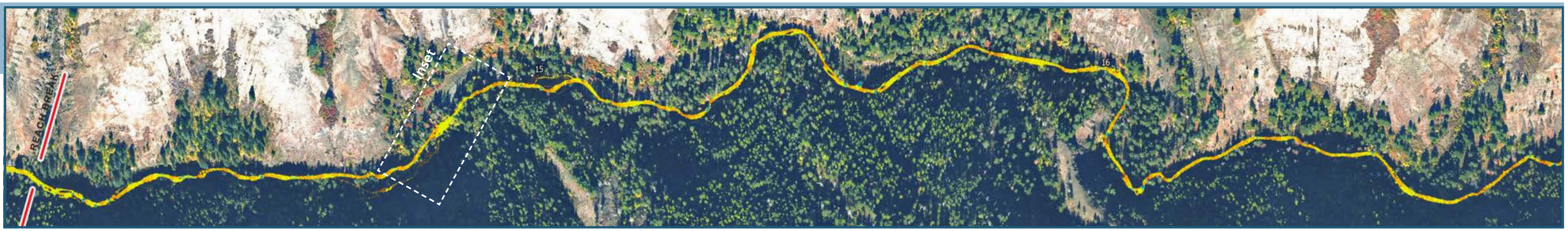
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS

Chinook Winter Composite, 2021

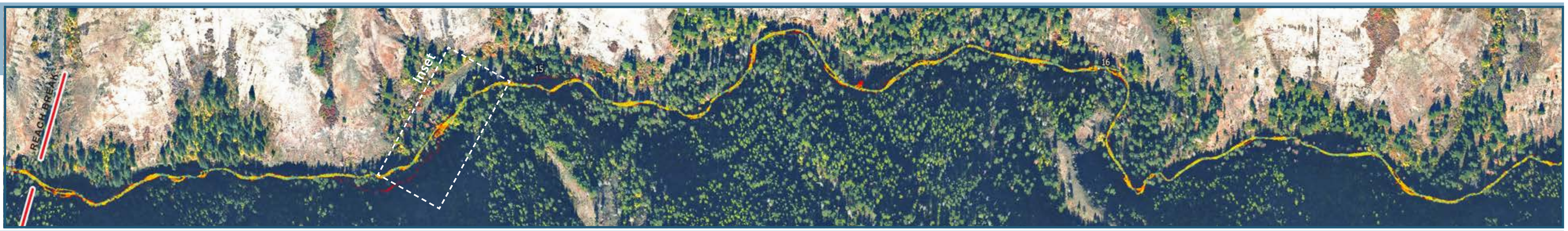
Highly Suitability
Moderate Suitability
Low Suitability



HHS

Steelhead Juvenile Composite, 2021

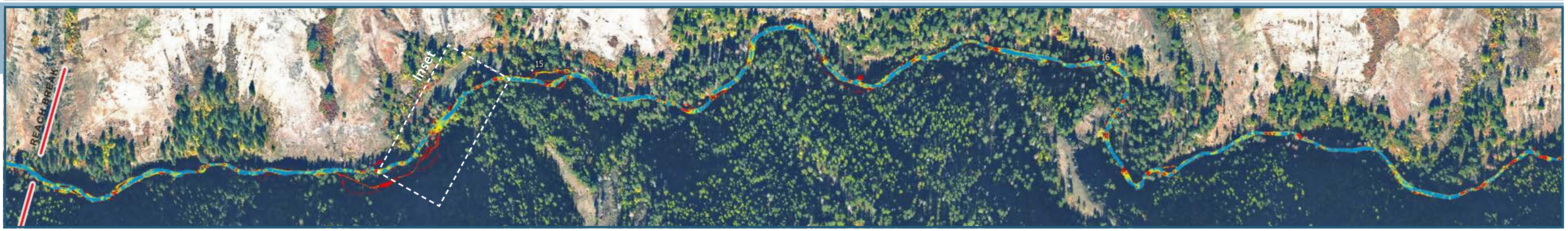
Highly Suitability
Moderate Suitability
Low Suitability



HHS

Steelhead Spawning Composite, 2021

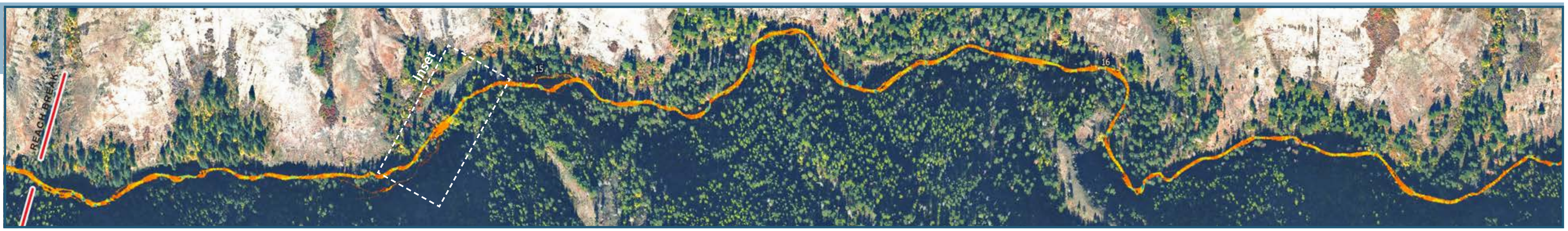
Highly Suitability
Moderate Suitability
Low Suitability



HHS

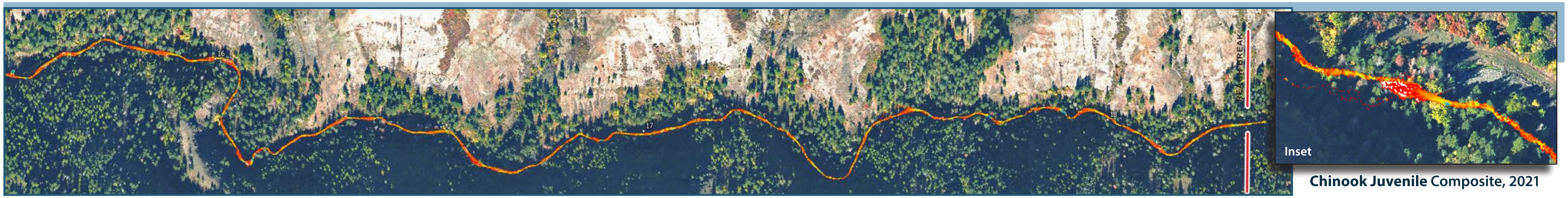
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

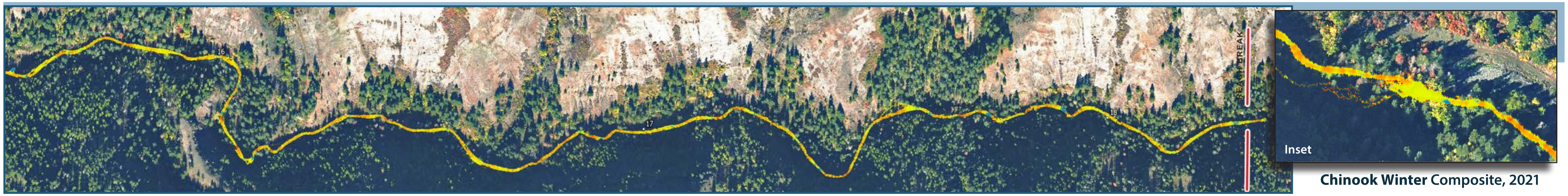


Reference Appendix I for details on the methods and results, including all species and life-stages modeled.

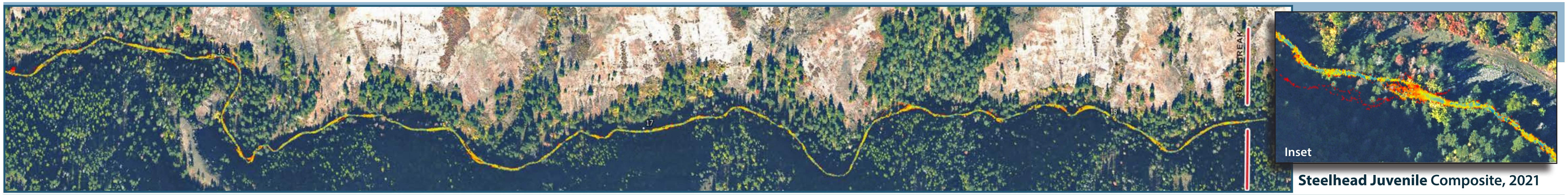
Reach NF4



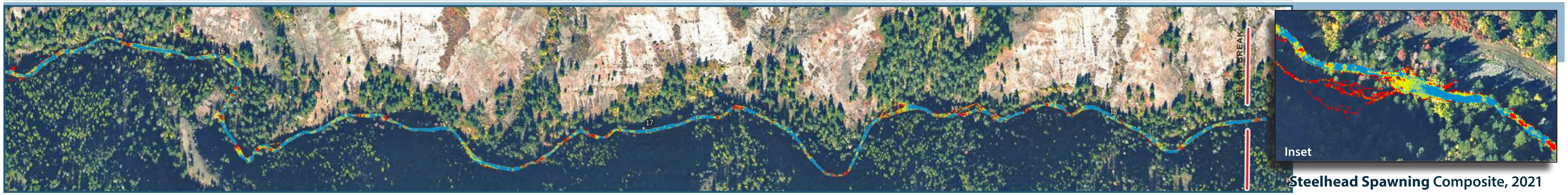
Chinook Juvenile Composite, 2021



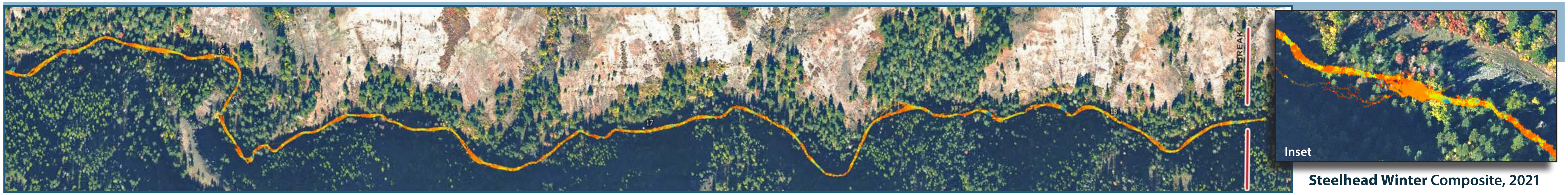
Chinook Winter Composite, 2021



Steelhead Juvenile Composite, 2021



Steelhead Spawning Composite, 2021



Steelhead Winter Composite, 2021

■ South Fork Walla Walla River

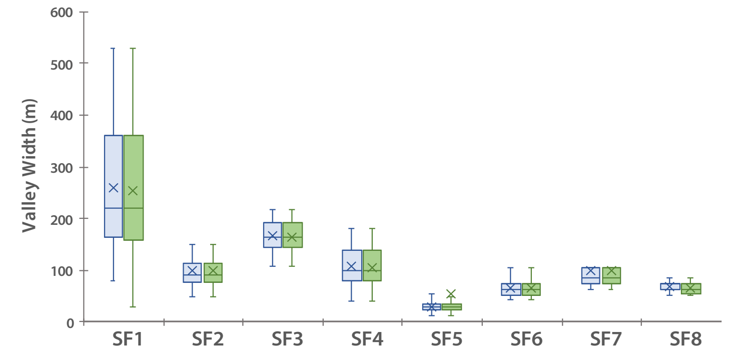
South Fork Walla Walla River

44.6 KM Reach Length RKM 0.0 to 44.6

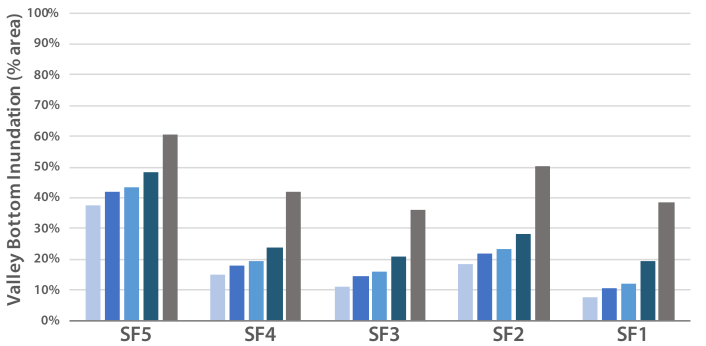
The South Fork (SF) of the Walla Walla River extends approximately 44.6 RKM from the confluence with the North Fork to its headwaters in the National Forest. There are eight geomorphic reaches along this distance, ranging in length from 1.4 kilometers (SF8) to 13.3 kilometers (SF1).

The SF Walla Walla can be divided into two segments: Reach SF1 which has been highly altered by human development, and all other reaches upstream, which have been minimally impacted. While Reach SF1 is naturally partially confined by basalt valley walls, the floodplain has been further disconnected by a series of levees, roads, bridges, and bank revetments. Channel straightening and confinement in Reach SF1 has converted a once multi-thread channel with numerous pools and large woody debris, into a primarily single-thread channel with relatively uniform bed character lacking habitat diversity. Less than 8% of the natural valley bottom remains connected to the active floodplain in Reach SF1. As with the Mainstem and SF Walla Walla, valley confinement and channel straightening have focused the stream's energy largely within the banks increasing the frequency and magnitude of channel incision and bank erosion.

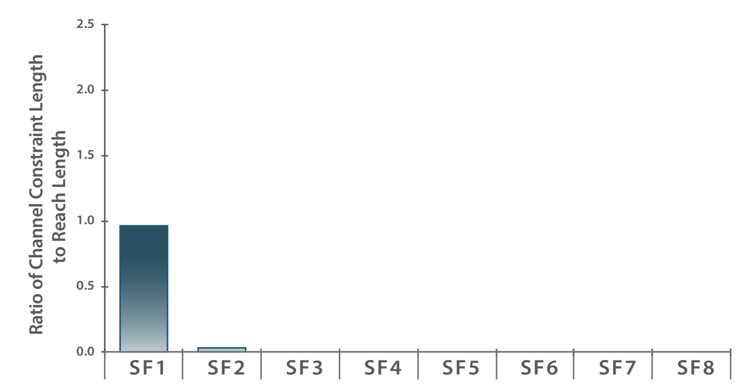
Relatively few human impacts have directly altered channel form and process upstream of Reach SF1 with the exception of road construction upstream to RKM 14.2. Velocity and depth within the SF are generally suitable for Chinook salmon and steelhead spawning with only moderate to poor rearing suitability. Riparian vegetation transitions from deciduous to mixed within NF1 and again to conifer in NF2 and all reaches upstream. Following the 2020 flood of record, there were negligible changes to the reach-wide hydraulic characteristics of the channel like depth, velocity, shear stress, sediment transport, etc., but there were significant changes in channel form including large-scale erosion, sediment deposition, and channel relocation. The area near the confluence of the NF and SF experienced an especially high degree of change (both in the NF and the SF). New channels and flood paths formed during the flood were largely filled and mechanically recontoured, forcing the river back to its confined, pre-flood path.



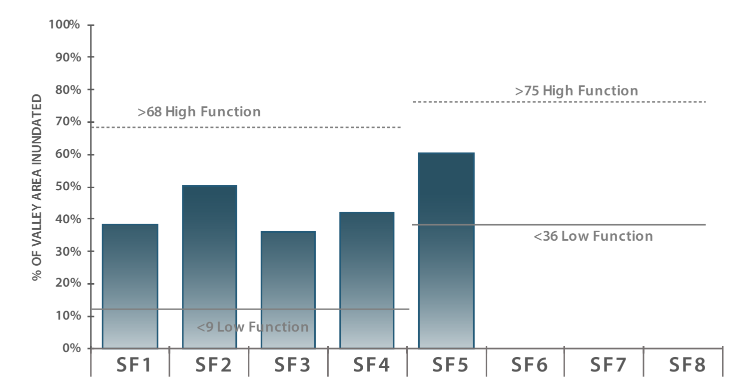
■ *Valley Width - Natural / Confined*



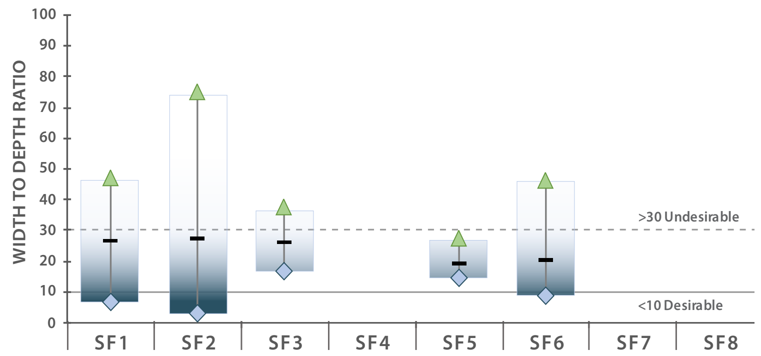
■ *Valley Bottom Inundation*



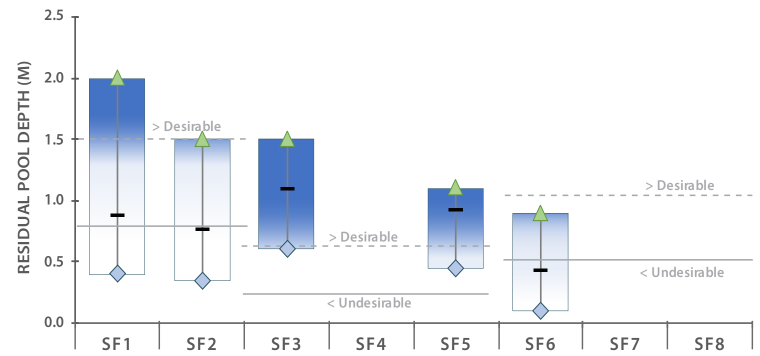
■ *Artificial Floodplain Disconnection Ratio*



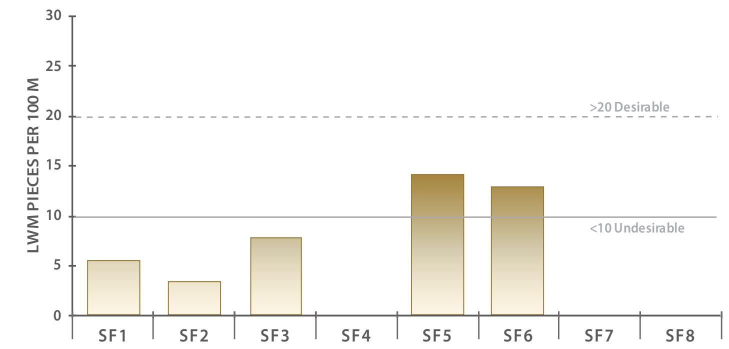
■ *Valley Area Inundated by 100 yr Flow and Function*



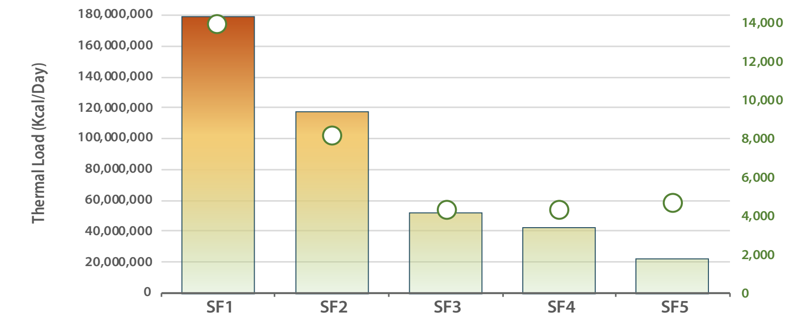
■ *Riffle Width to Depth Ratio* ◇ Min – Avg △ Max



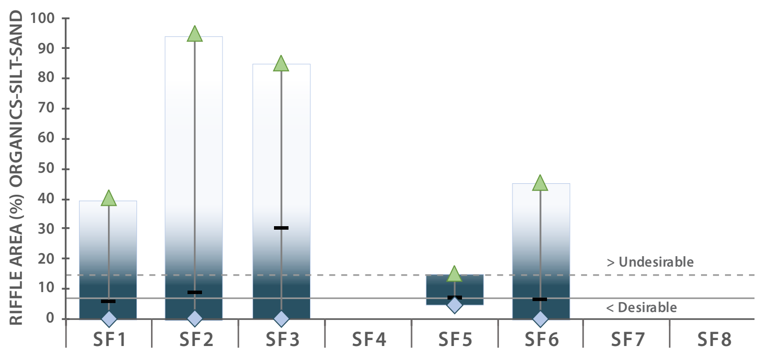
■ *Residual Pool Depth* ◇ Min – Avg △ Max



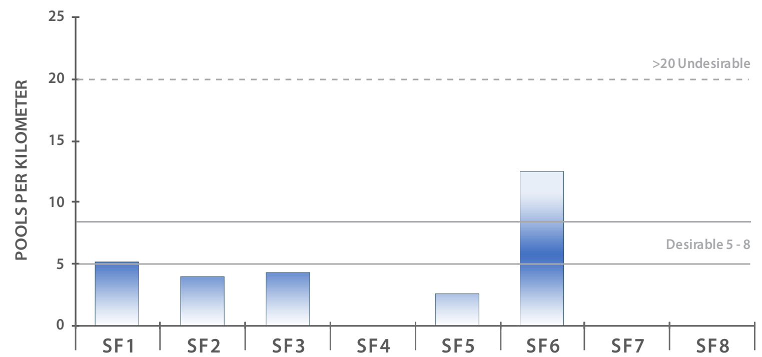
■ *Large Wood Material Piece Frequency* LWM per 100 m



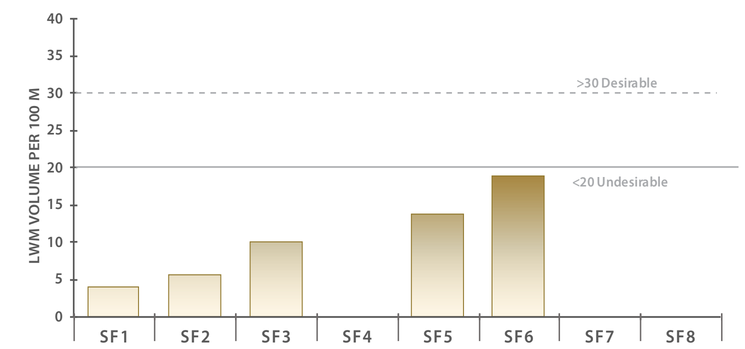
■ *Riparian Shade - Thermal Load (Kcal/Day)* Thermal Load (Kcal/Day) ○ Reach Length (m)



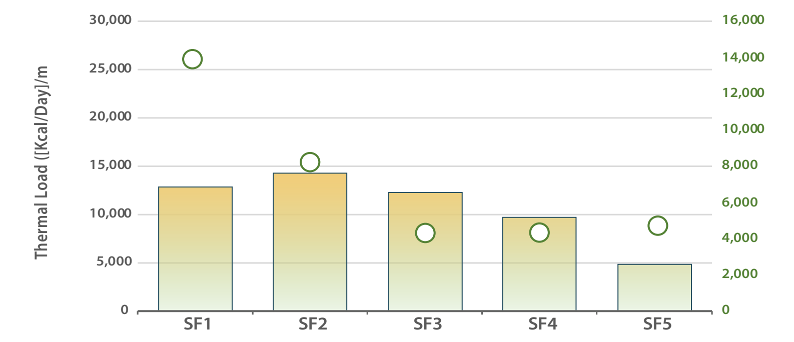
■ *Riffle Area (%) Organics - Silt - Sand* ◇ Min – Avg △ Max



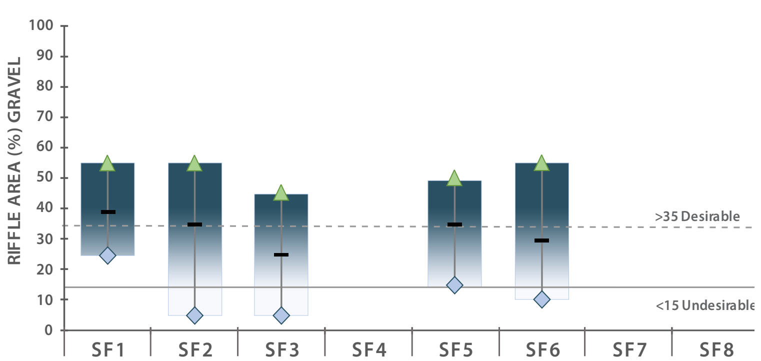
■ *Pool Frequency per Kilometer*



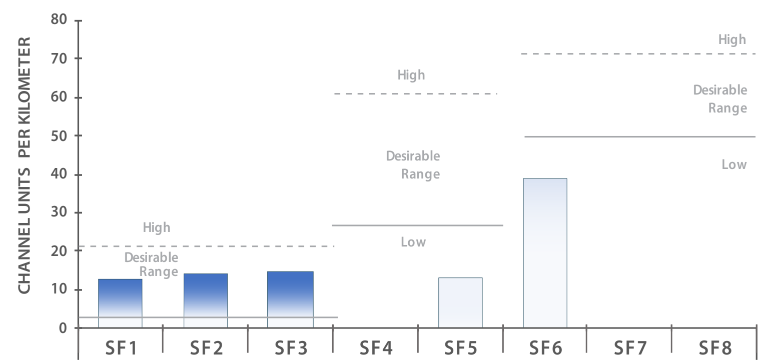
■ *Large Wood Material Volume Frequency* LWM Volume (m3) per 100 m



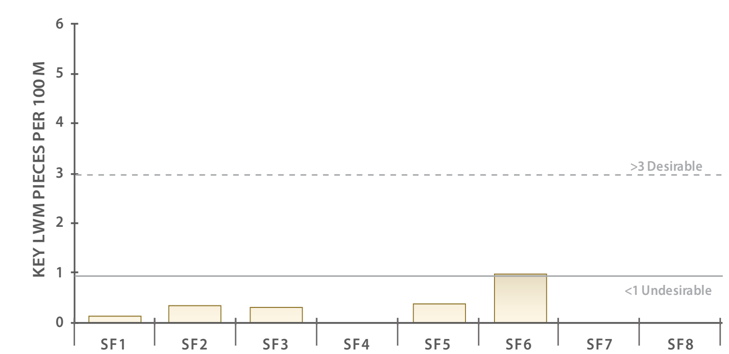
■ *Riparian Shade - Thermal Load per Meter* Thermal Load per Meter ○ Reach Length (m)



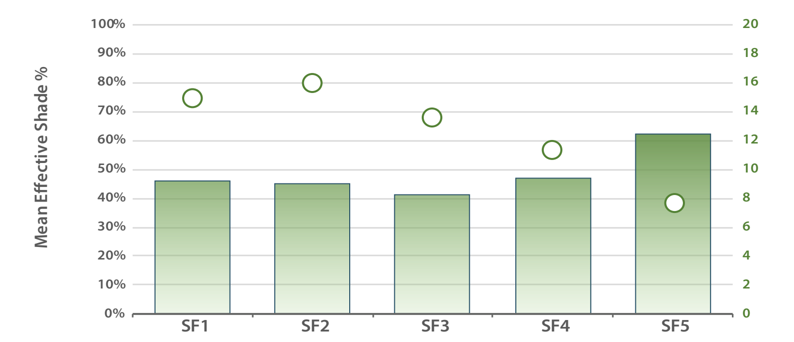
■ *Riffle Area (%) Gravel* ◇ Min – Avg △ Max



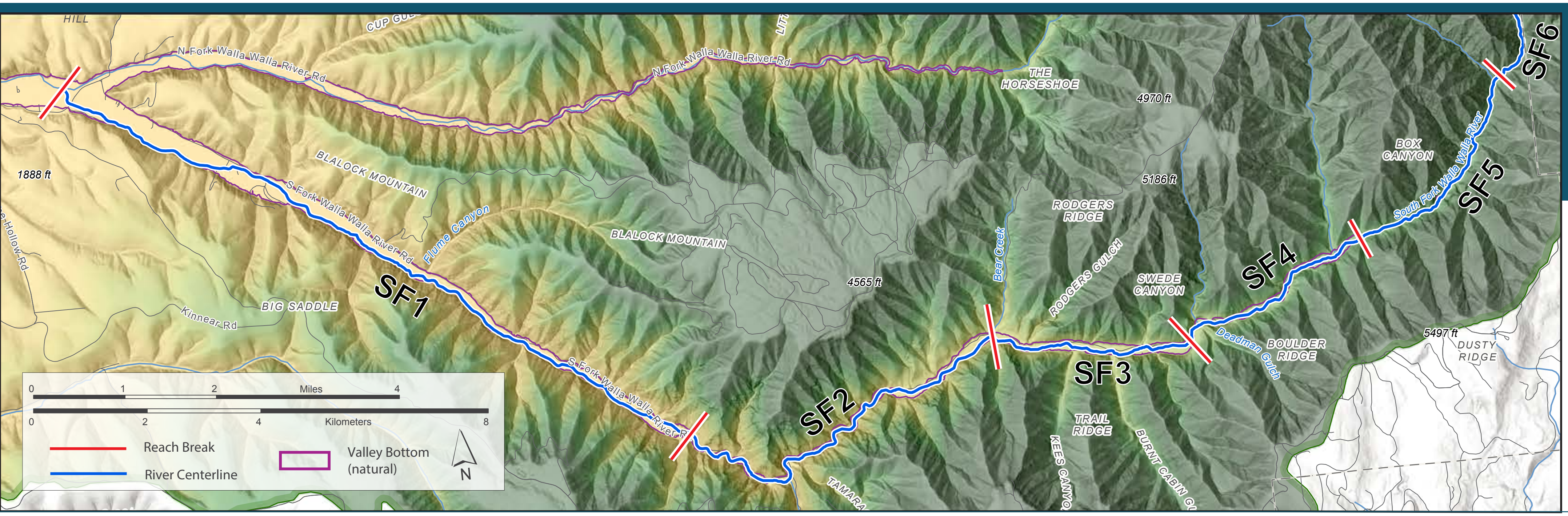
■ *Channel Unit Frequency*

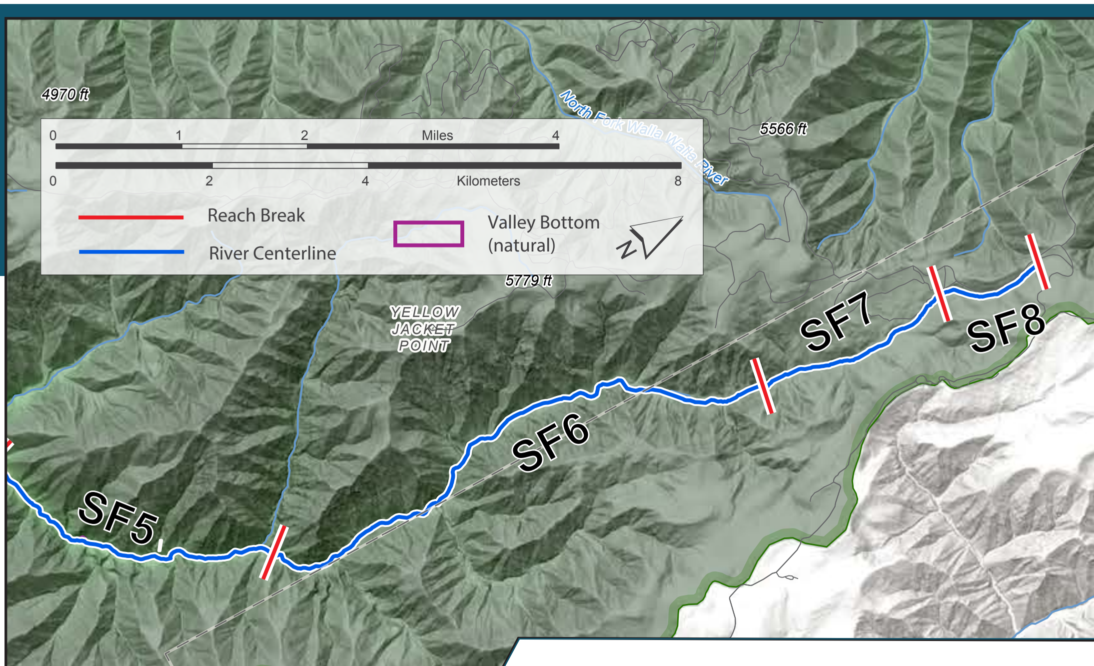


■ *Large Wood Material Key Piece Frequency* Key LWM per 100 m



■ *Riparian Shade - Mean Effective Shade %* Mean Effective Shade % ○ Mean Channel Width

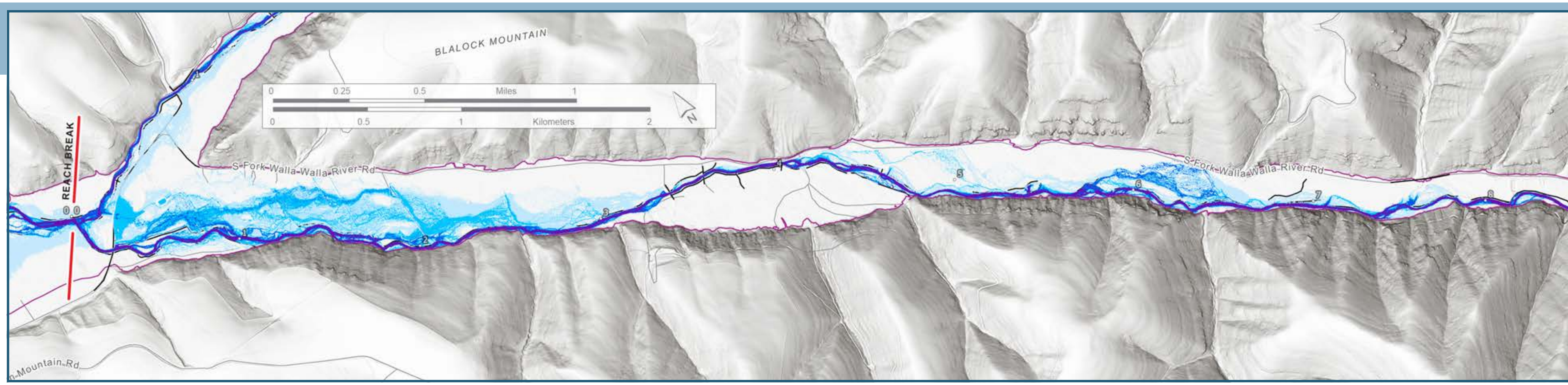




Reach SF1

Hydraulic Modeling Inundation Extents

- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

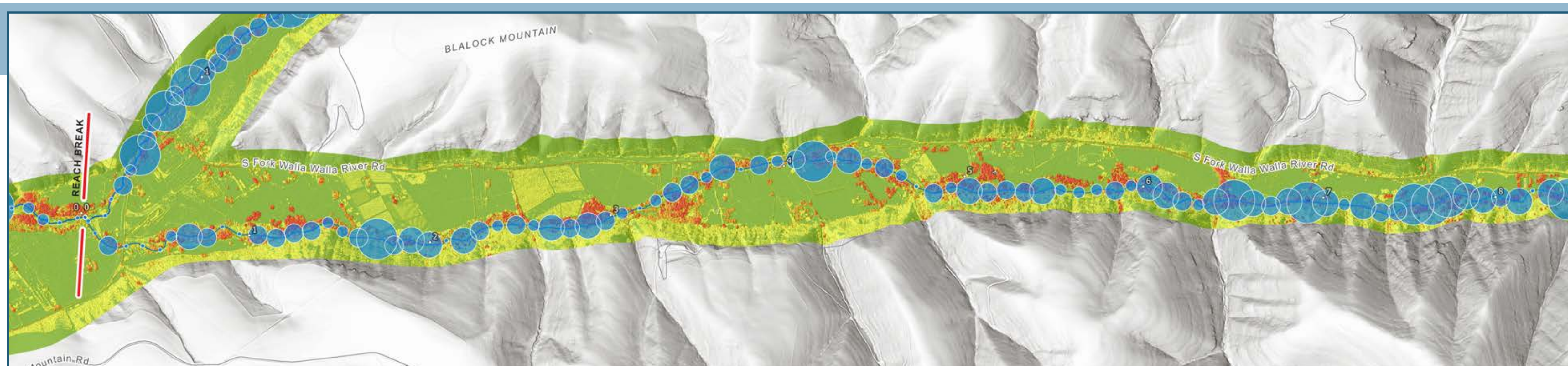
Effective Stream Shade

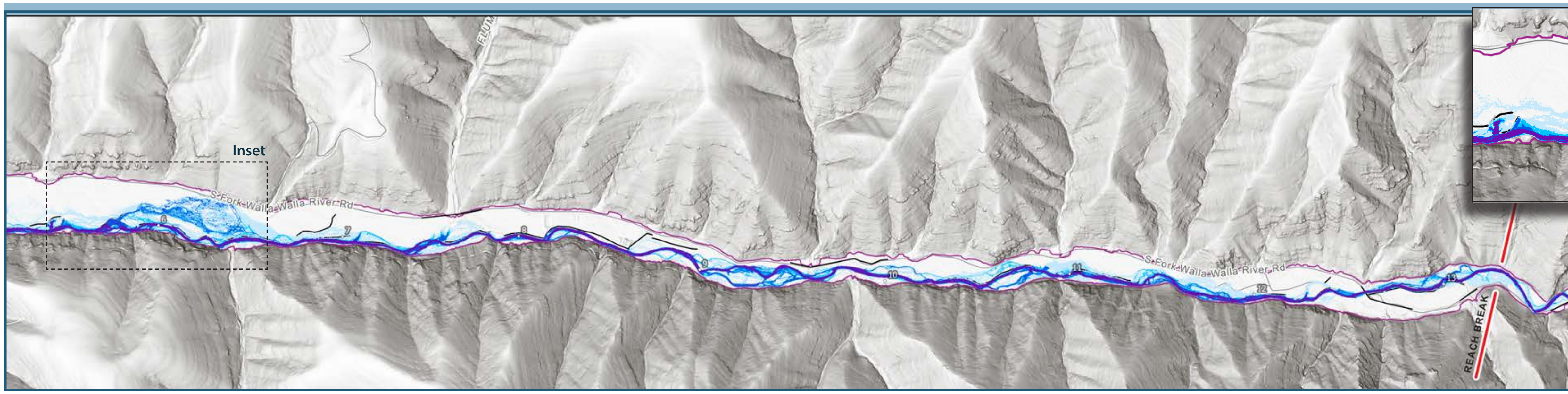
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

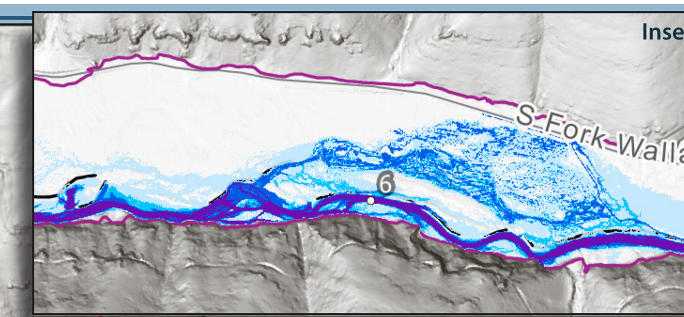
Thermal Load: **12,842** (Kcal/m)

Effective Shade **46%**

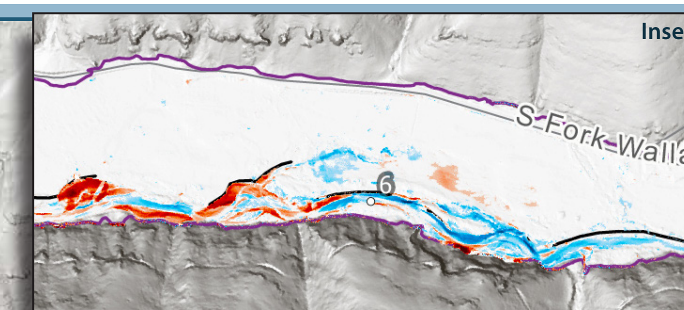
System Potential **17%**



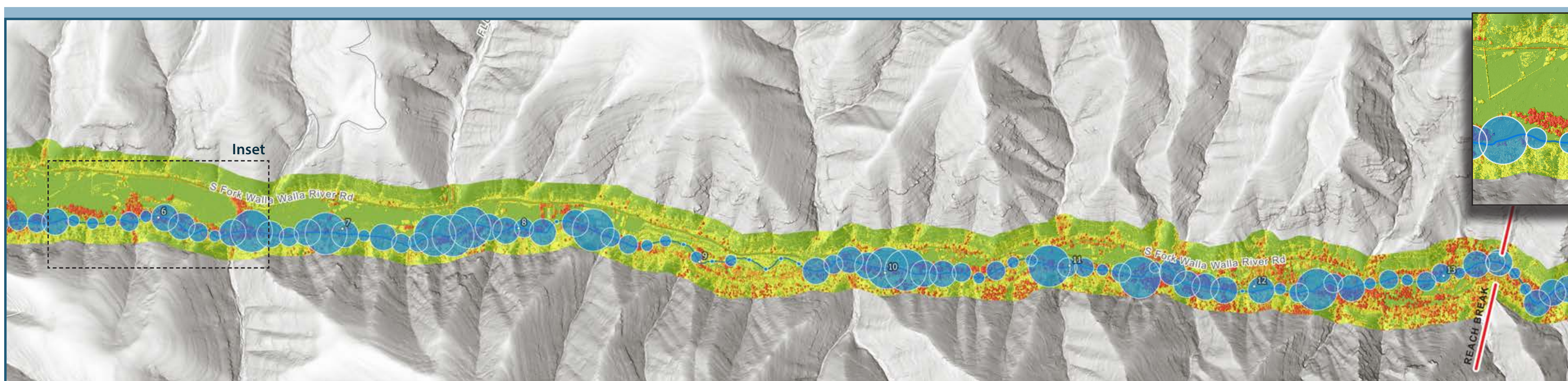


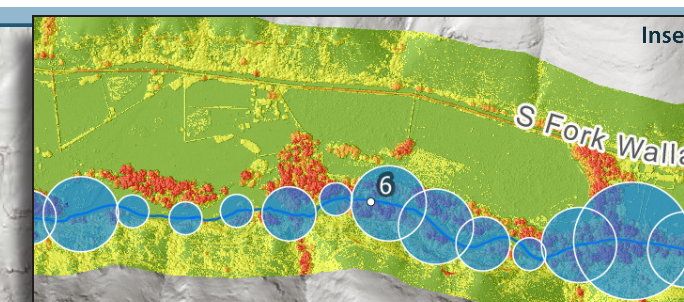


Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

Reach SF 1

HYDRAULIC HABITAT SUITABILITY

13.3 KM Reach Length   RKM 0.0 to 13.3

HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

HHS
Steelhead Juvenile Composite, 2021

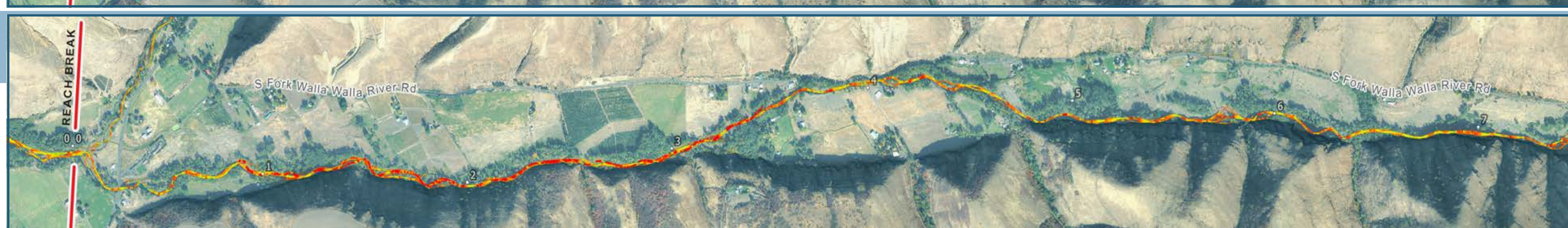
Highly Suitability
Moderate Suitability
Low Suitability

HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

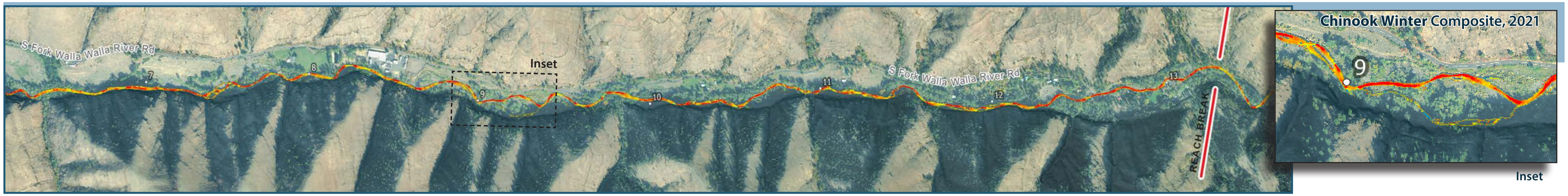
HHS
Steelhead Winter Composite, 2021

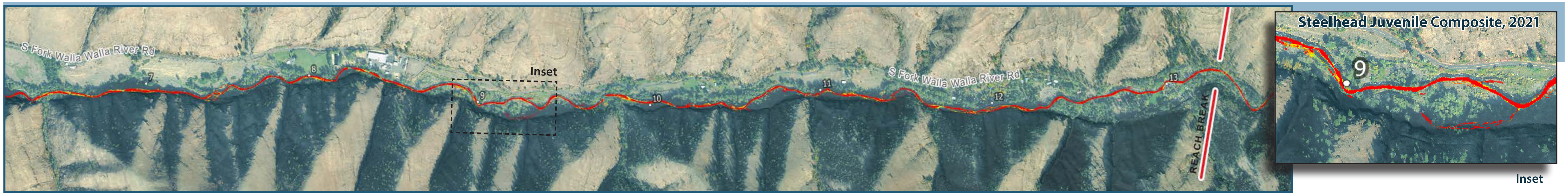
Highly Suitability
Moderate Suitability
Low Suitability

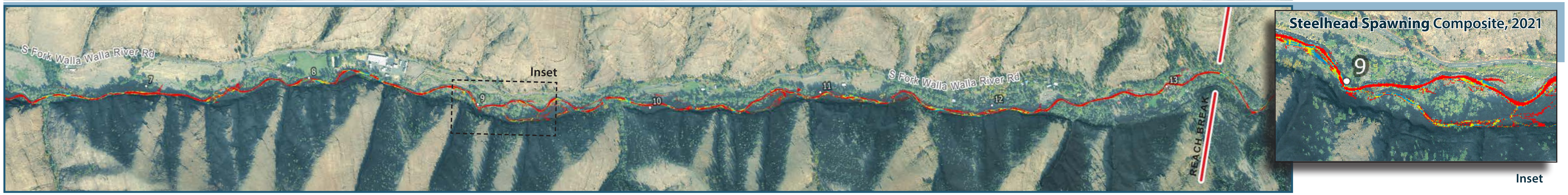


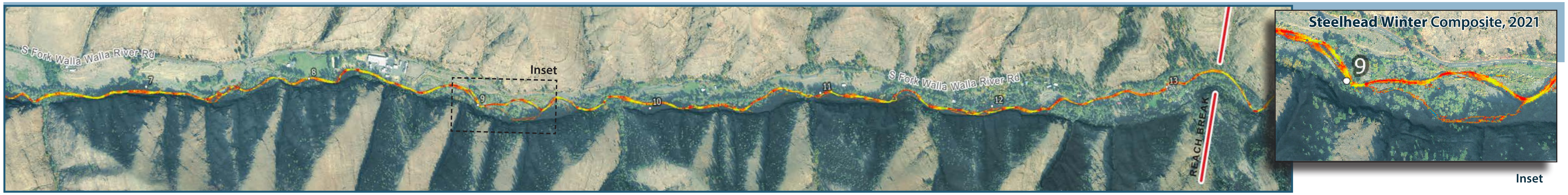
Reference Appendix I for details on the methods and results, including all species and life-stages modeled.

Reach SF1









Reach SF2

7.5 KM Reach Length RKM 13.3 to 20.8

Hydraulic Modeling Inundation Extents

- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

5 (Deposition)

-5 (Scour)

- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

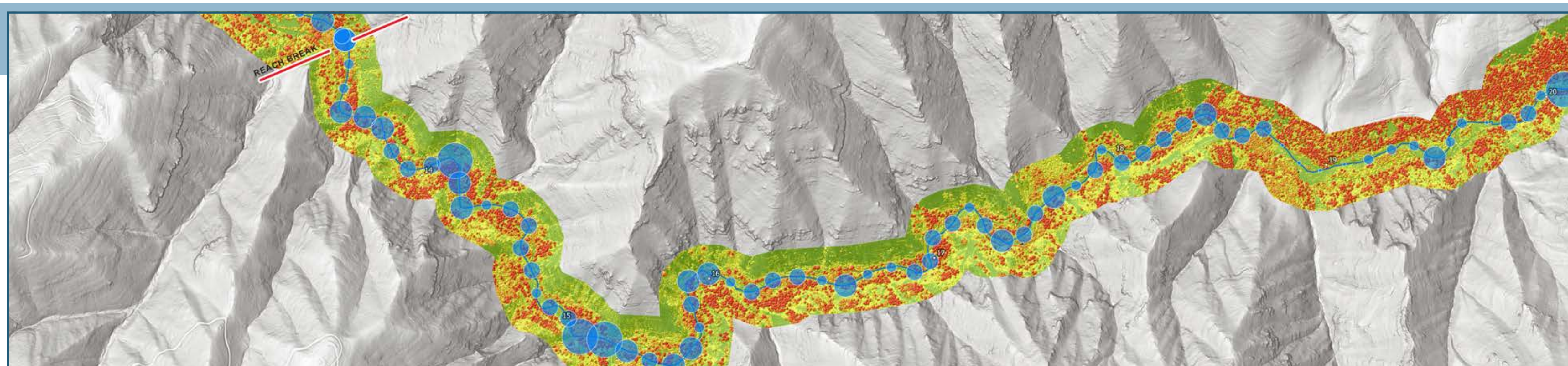
Effective Stream Shade

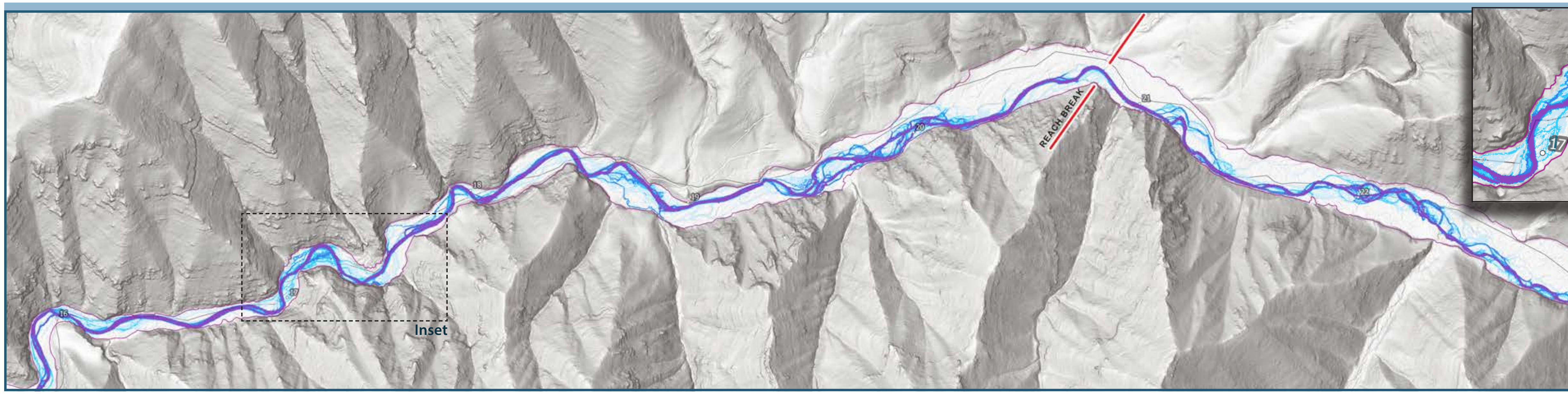
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

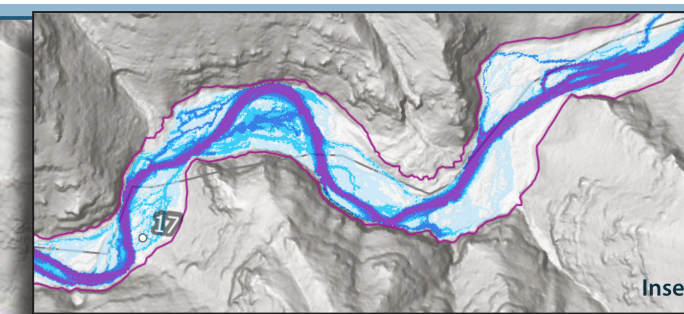
Thermal Load: **14,344** (Kcal/m)

Effective Shade **45%**

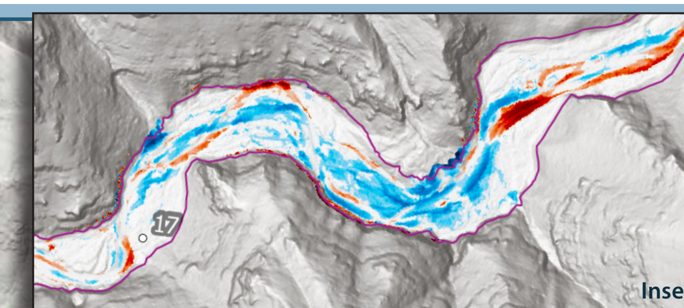
System Potential **11%**



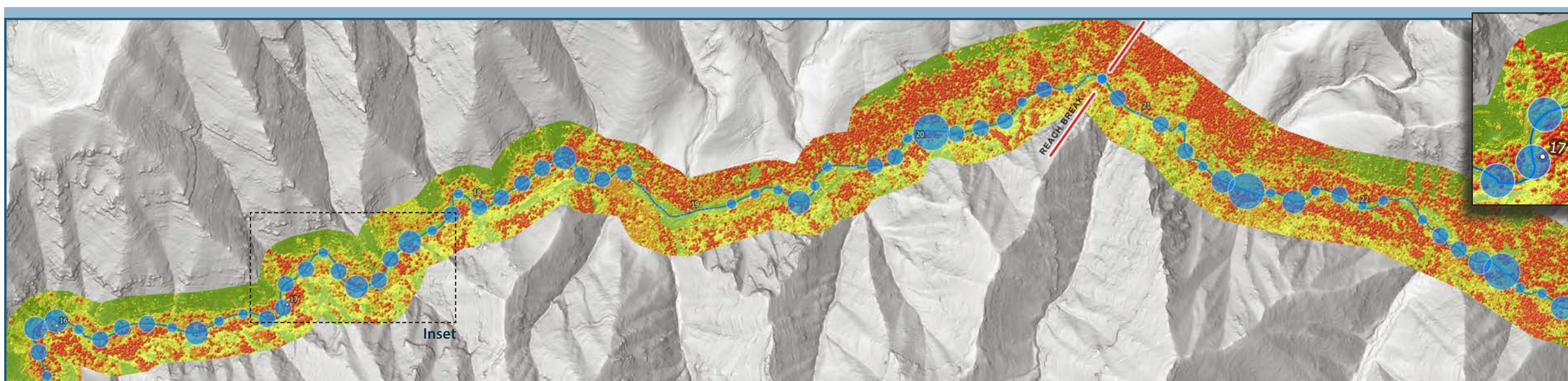


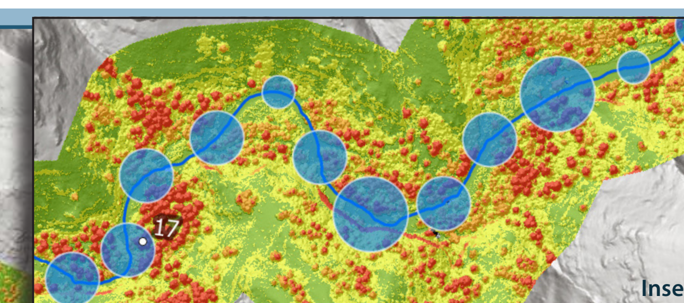


Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

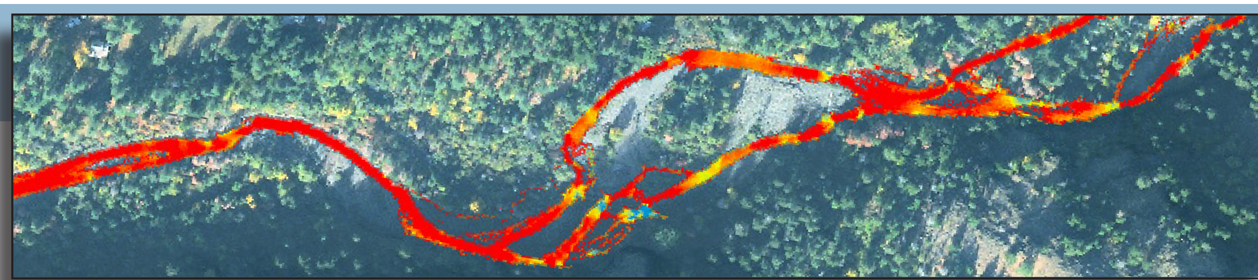
Reach SF2

HYDRAULIC HABITAT SUITABILITY

7.5 KM Reach Length RKM 13.3 to 20.8

HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



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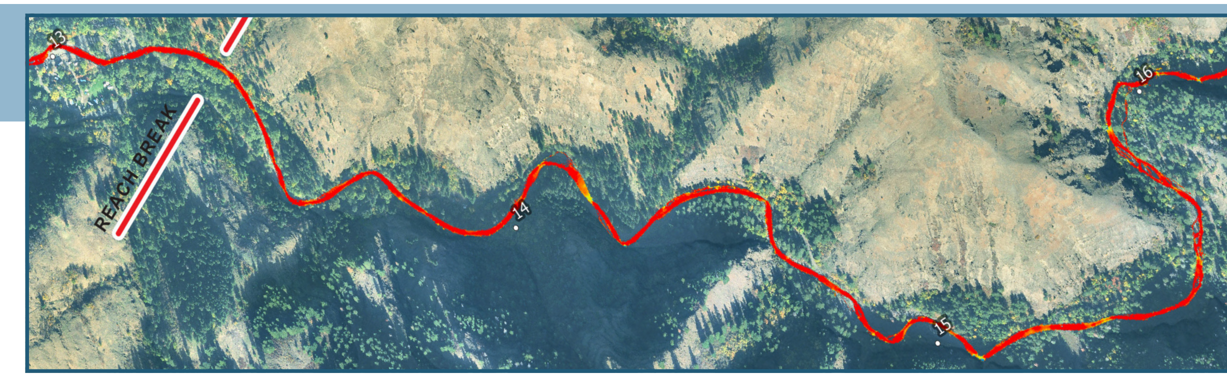
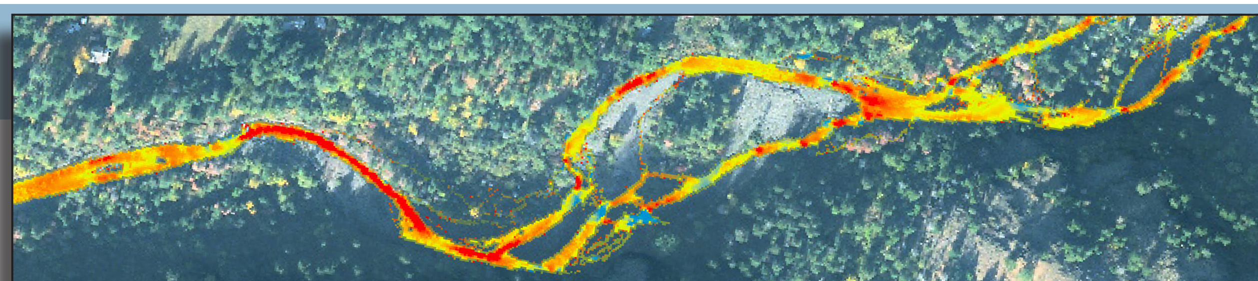


HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



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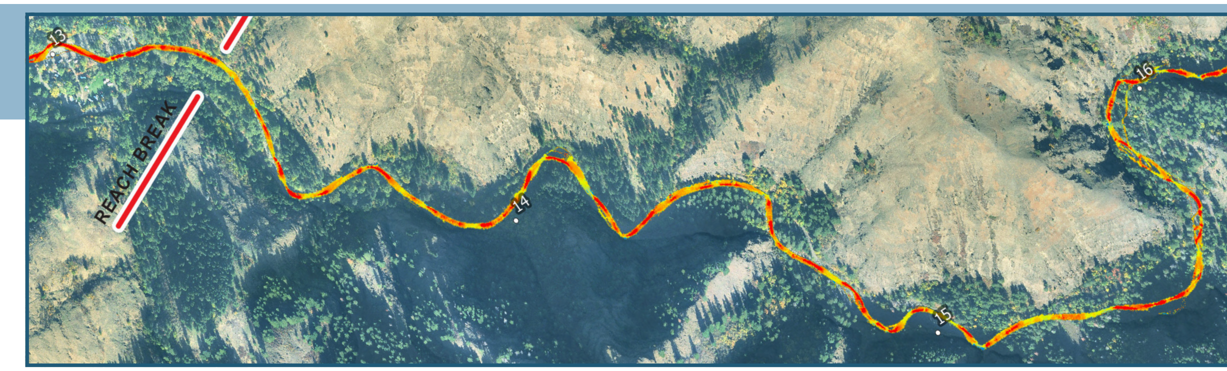
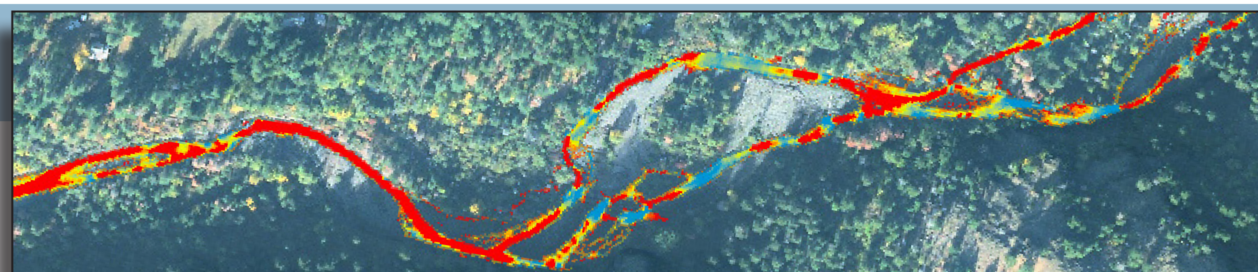


HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



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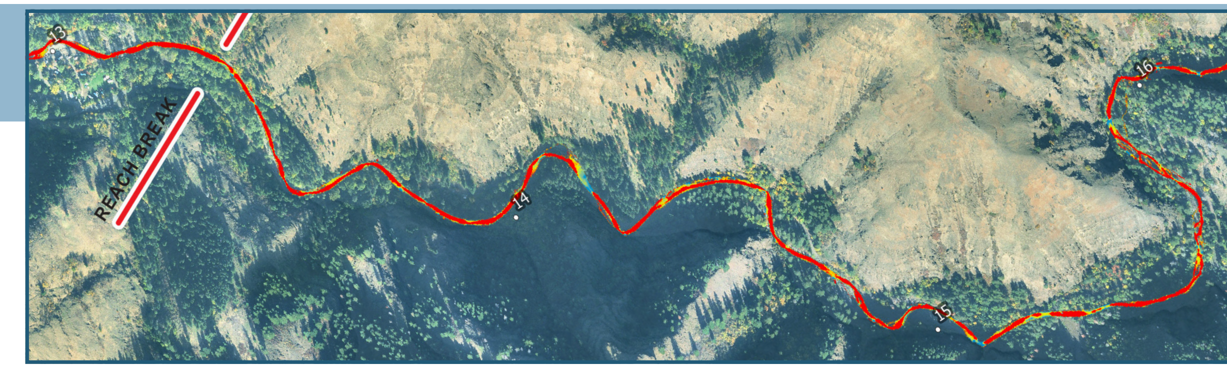
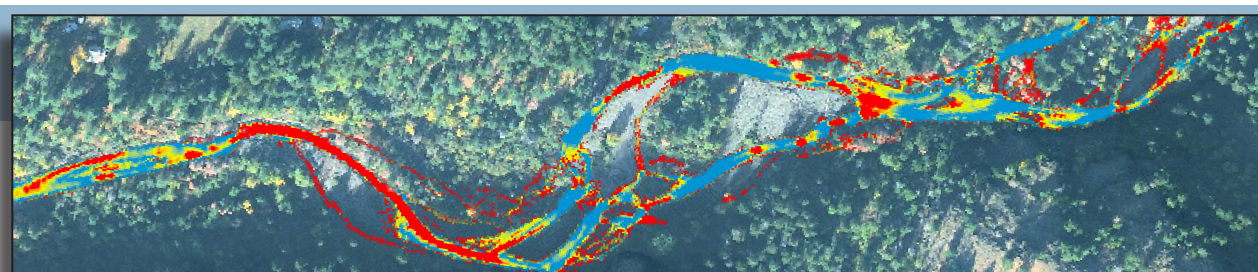


HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



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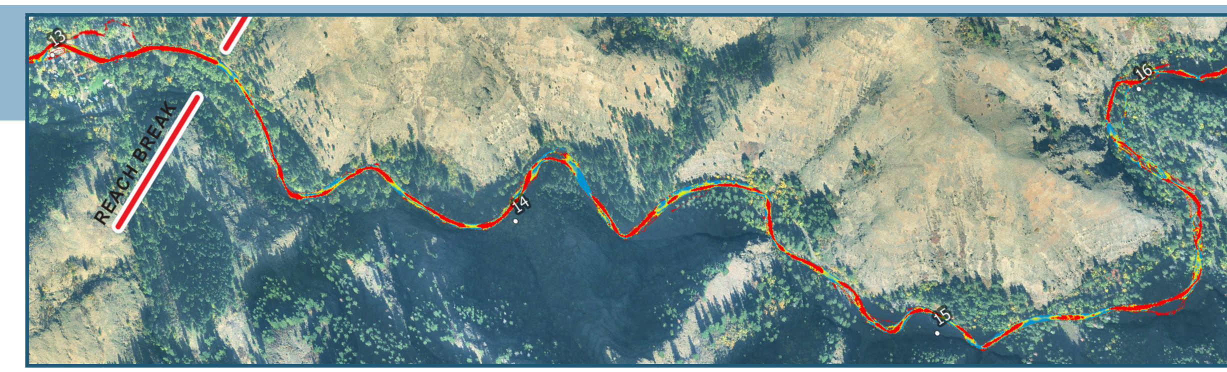
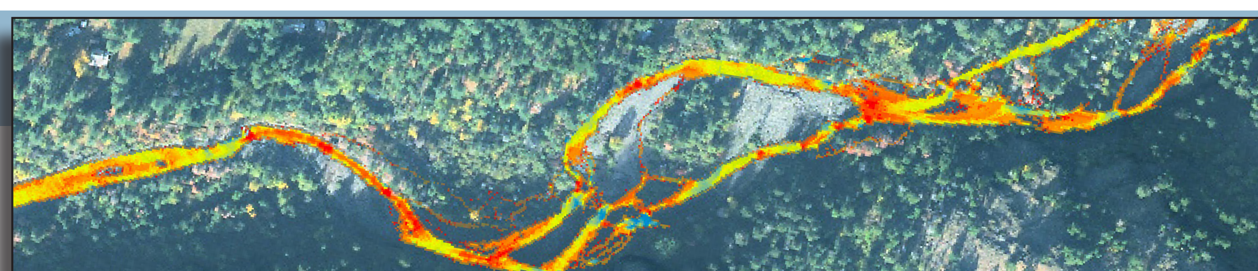


HHS
Steelhead Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



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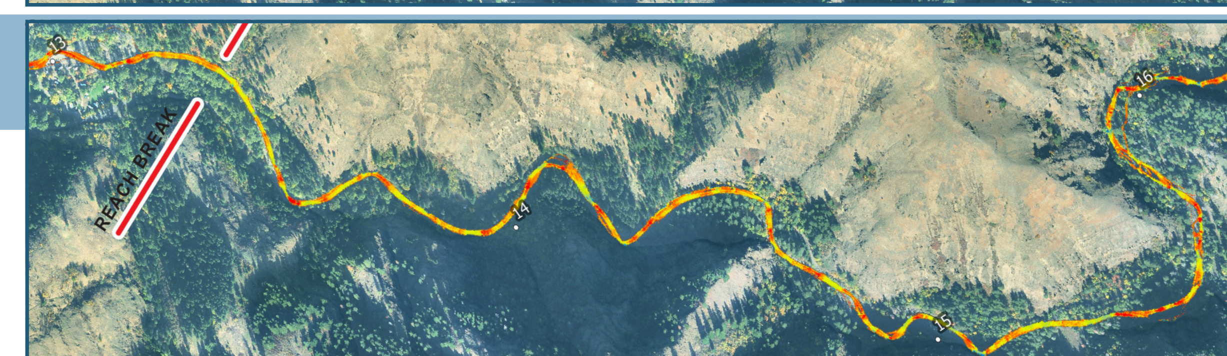
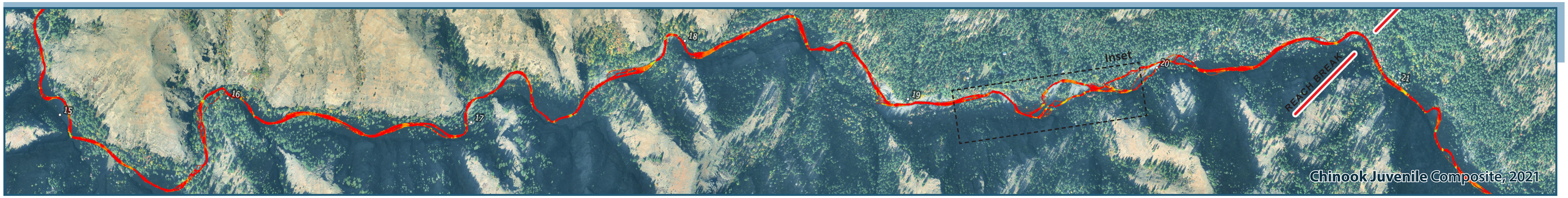
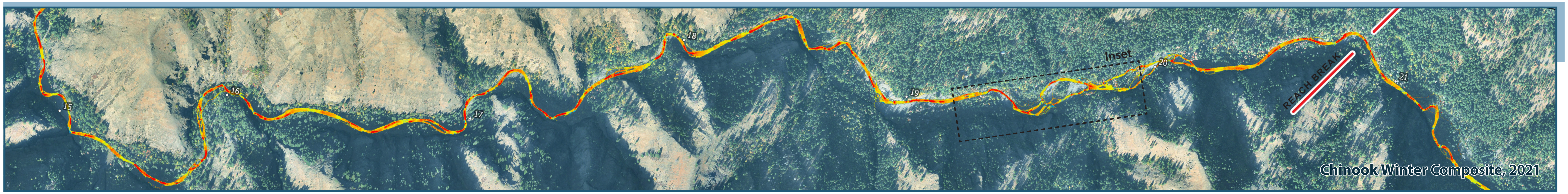
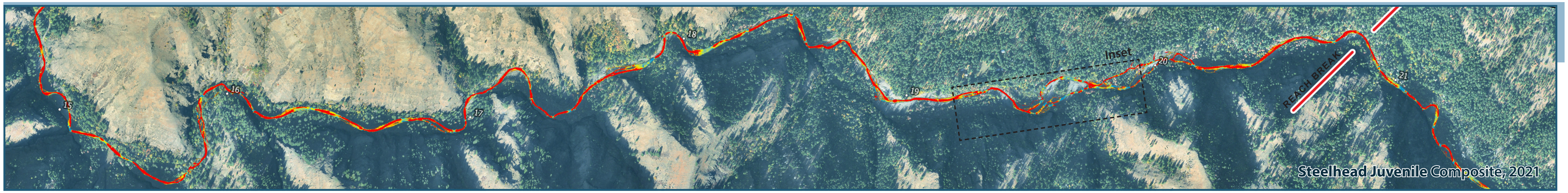
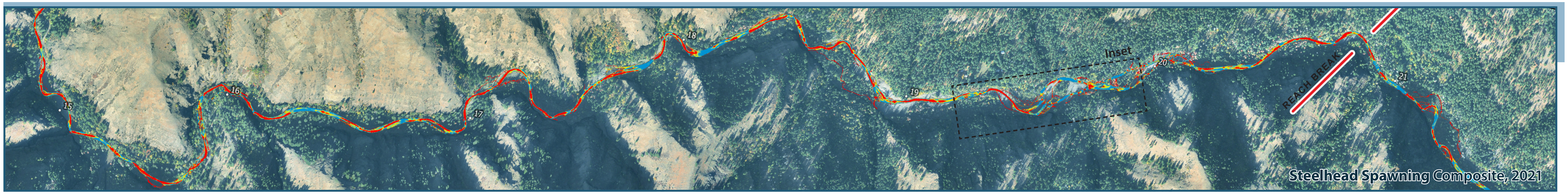


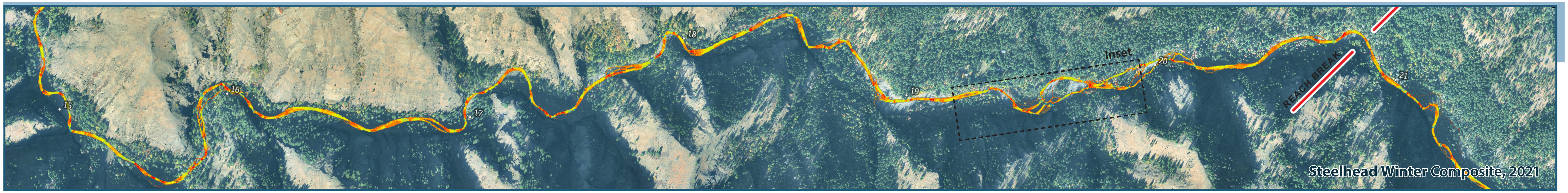
Reference Appendix I for details on the methods and results, including all species and life-stages modeled.









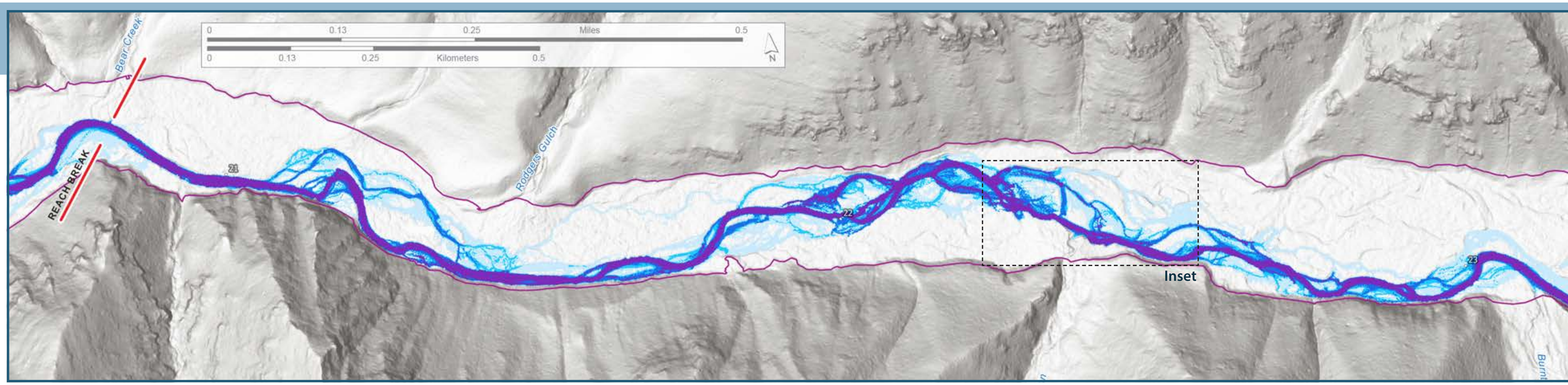


Reach SF3

3.8 KM Reach Length **RKM 20.8 to 24.6**

Hydraulic Modeling Inundation Extents

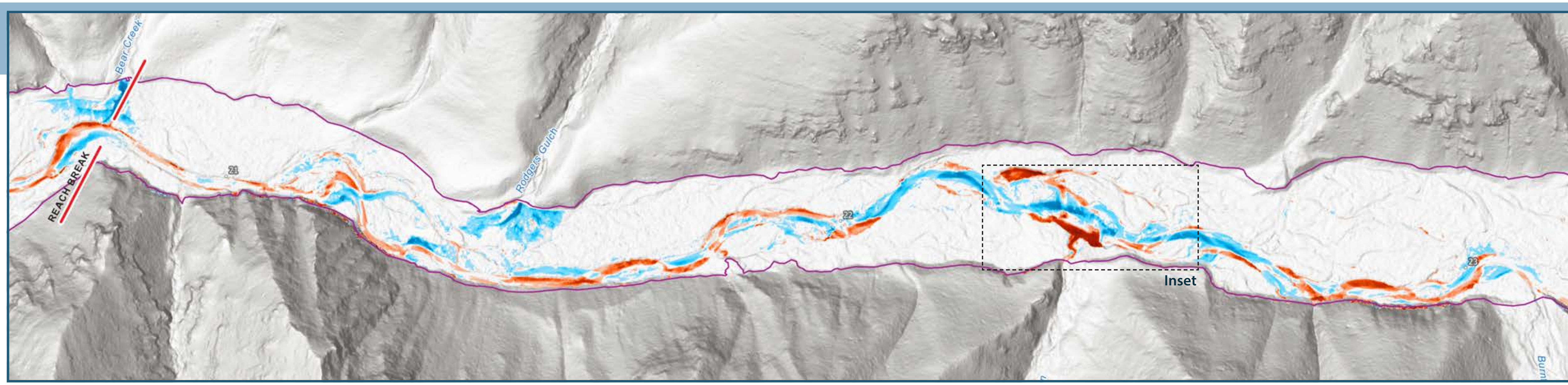
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

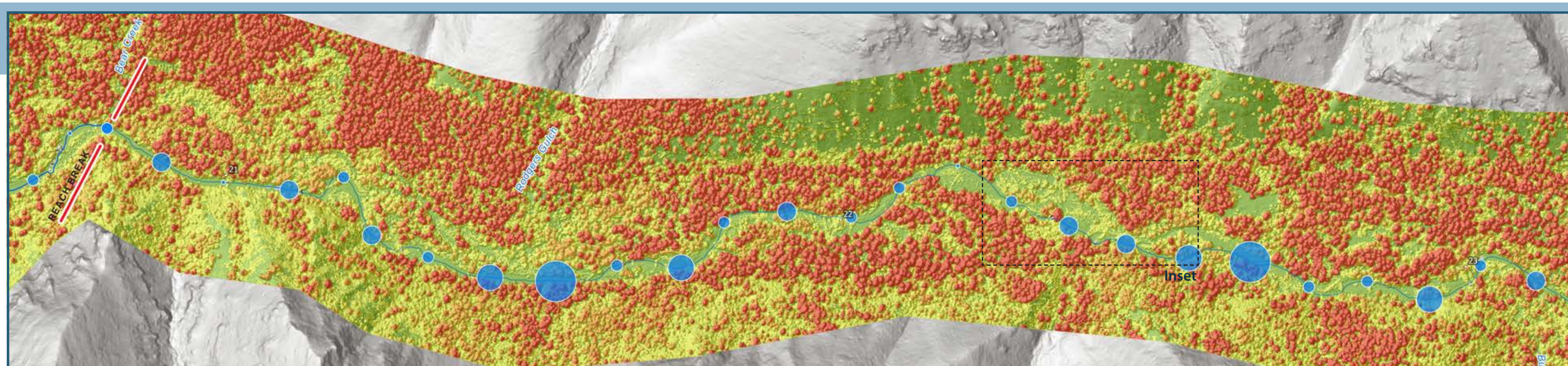
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

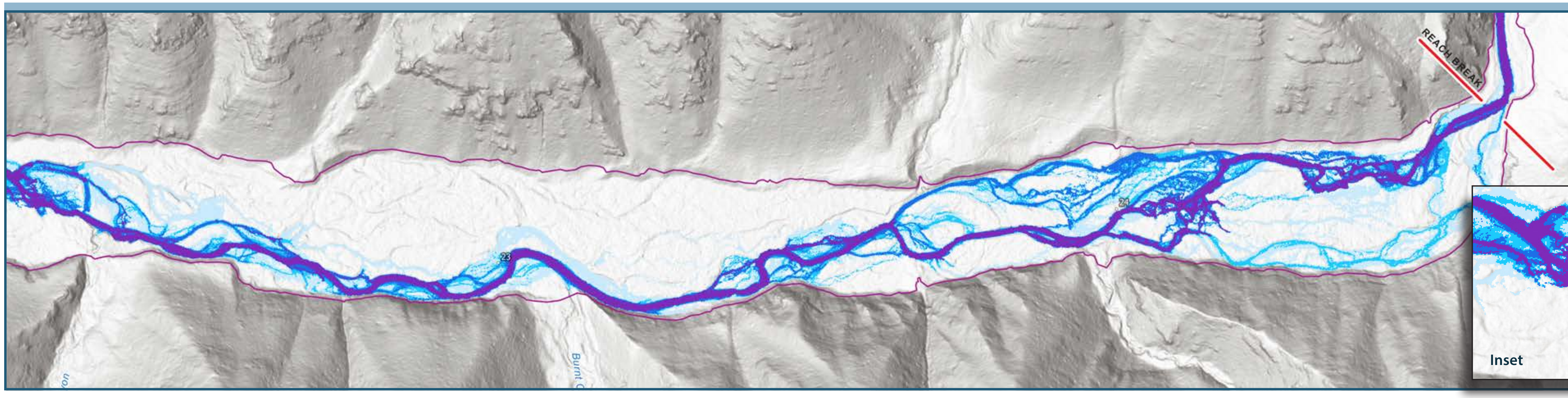
Thermal Load: **12,318** (Kcal/m)

Effective Shade **41%**

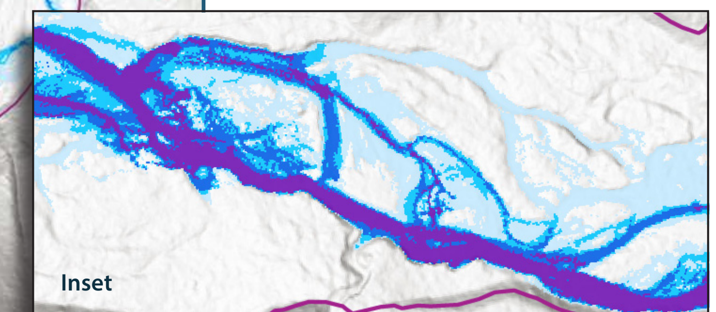
System Potential **5%**

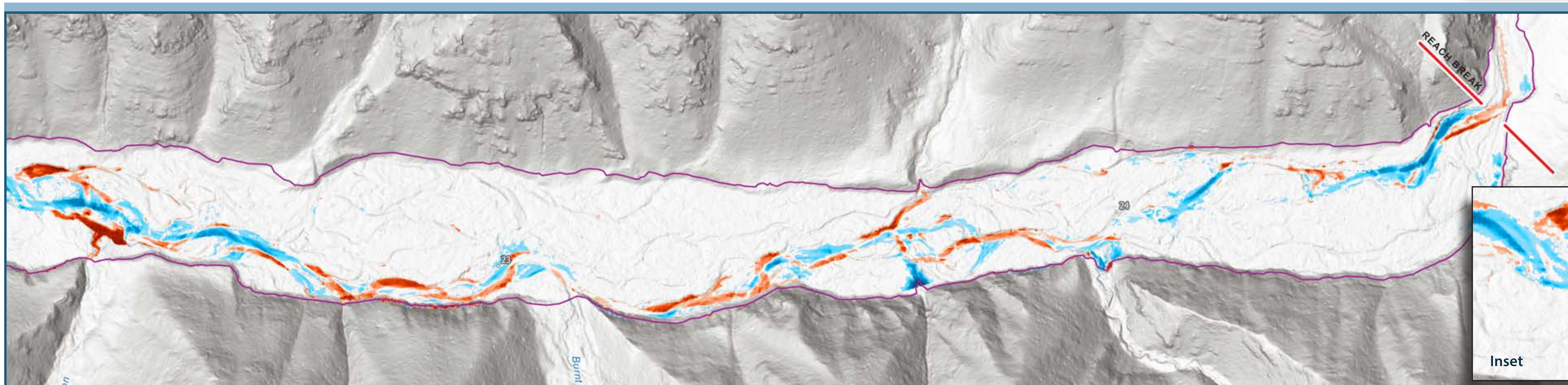


Reach SF3

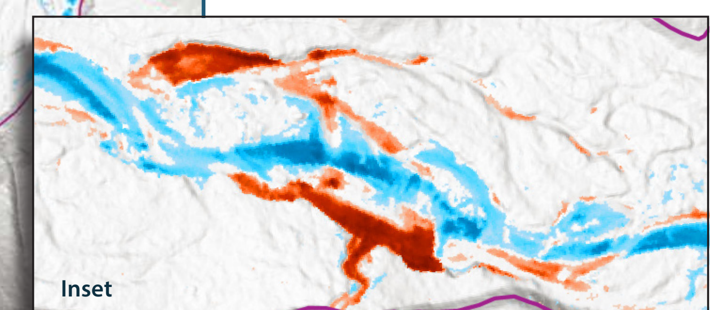


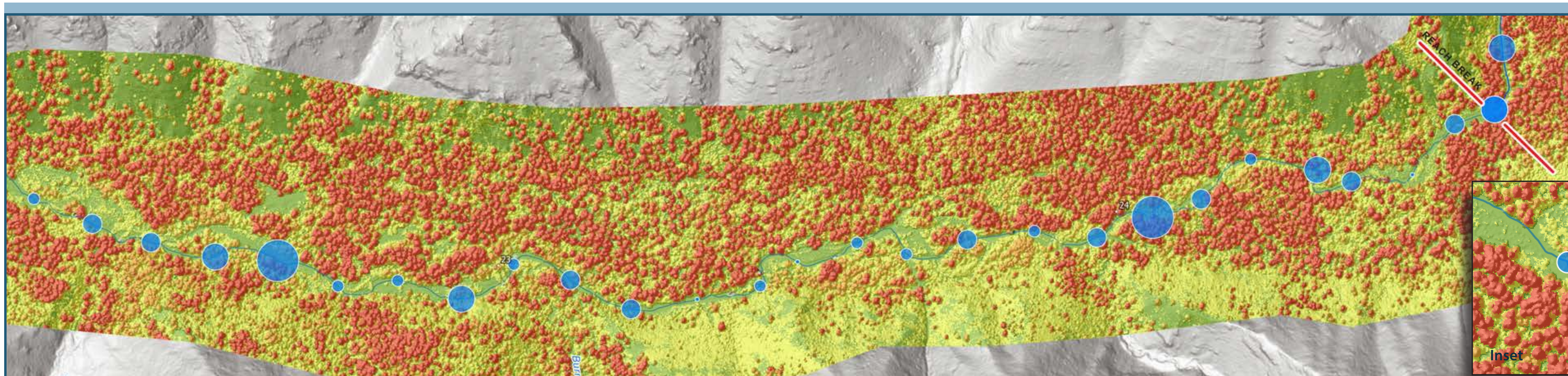
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



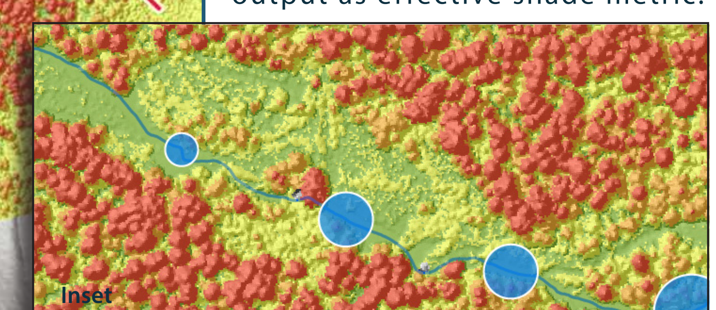


Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

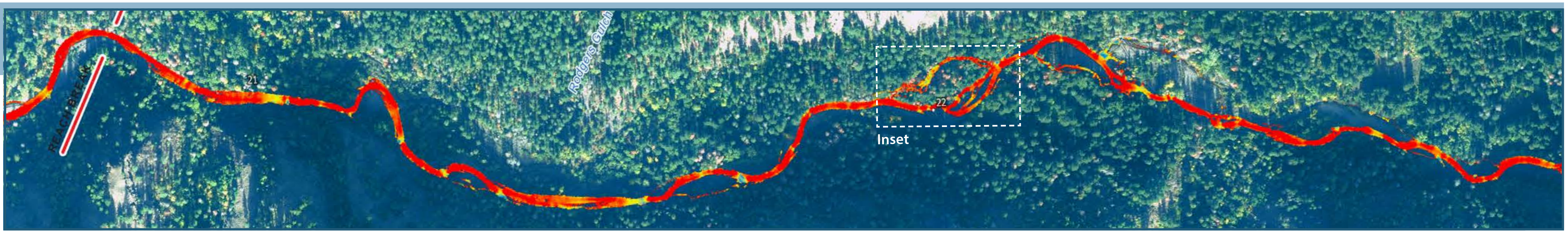


HHS
Chinook Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

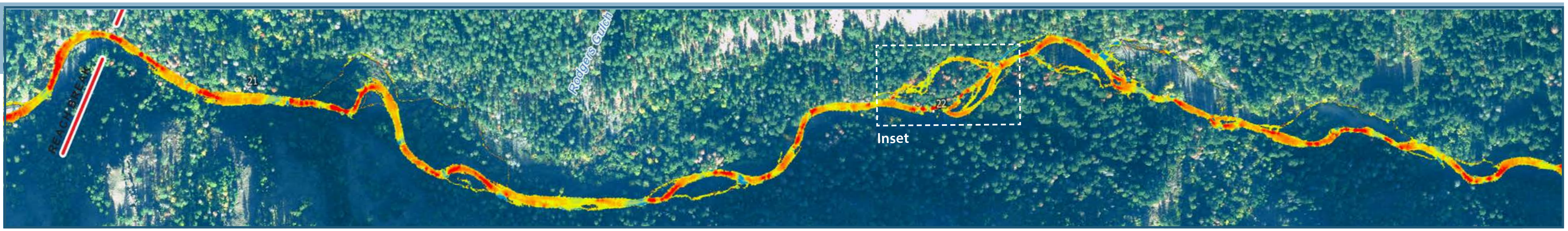


HHS
Chinook Winter Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

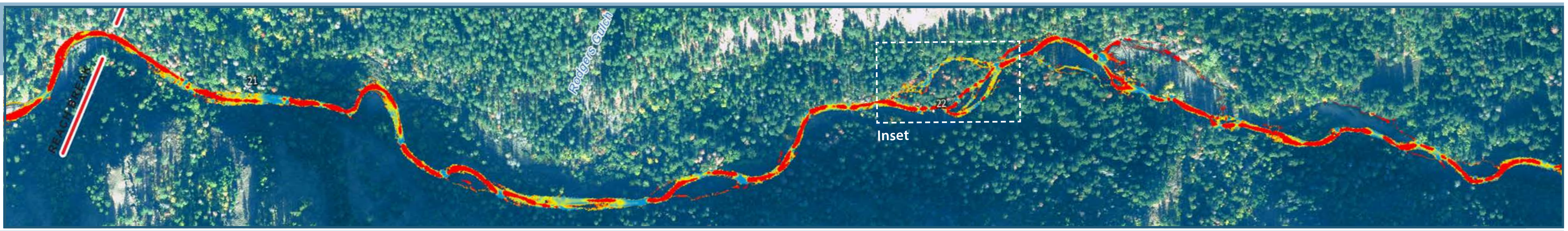


HHS
Steelhead Juvenile Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

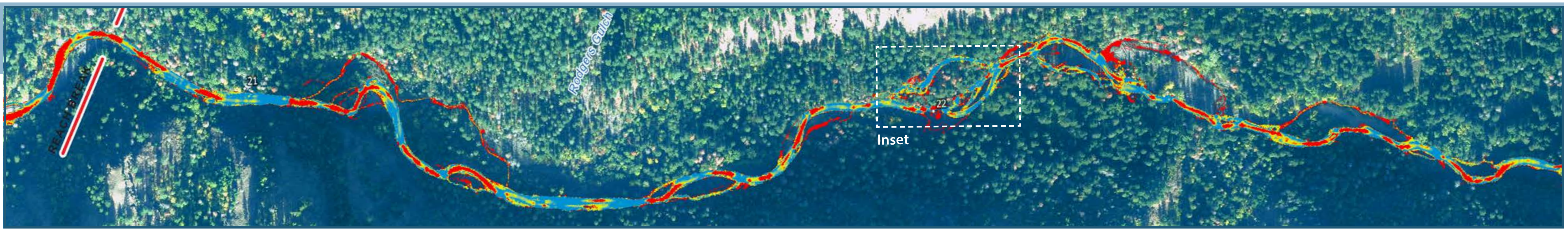


HHS
Steelhead Spawning Composite, 2021

Highly Suitability

Moderate Suitability

Low Suitability

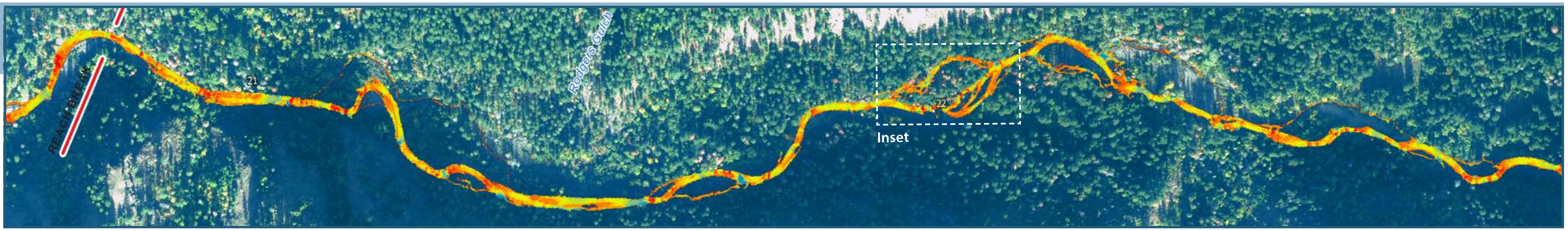


HHS
Steelhead Winter Composite, 2021

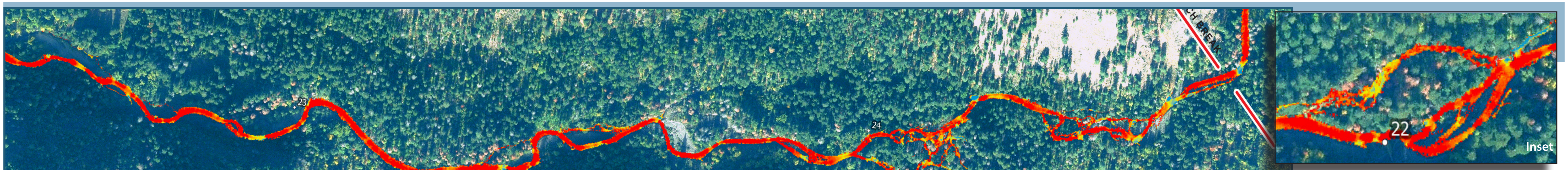
Highly Suitability

Moderate Suitability

Low Suitability



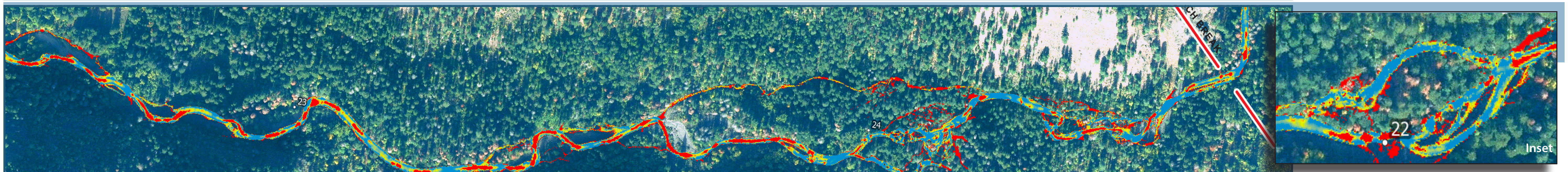
Reference Appendix I for details on the methods and results, including all species and life-stages modeled.



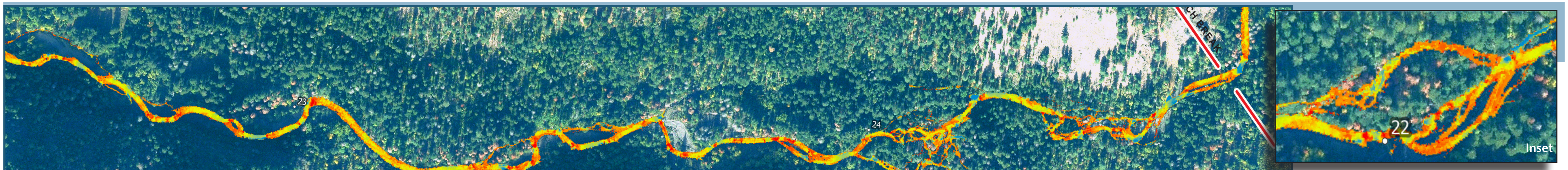
Chinook Juvenile Composite, 2021

Chinook Winter Composite, 2021

Steelhead Juvenile Composite, 2021



Steelhead Spawning Composite, 2021



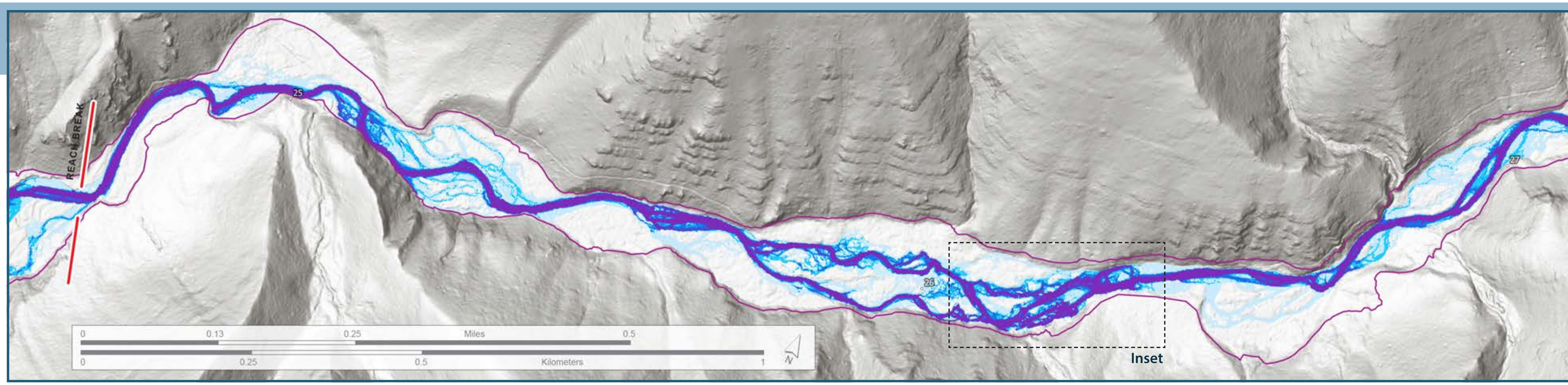
Steelhead Winter Composite, 2021

Reach SF4

3.9 KM Reach Length RKM 24.6 to 28.5

Hydraulic Modeling Inundation Extents

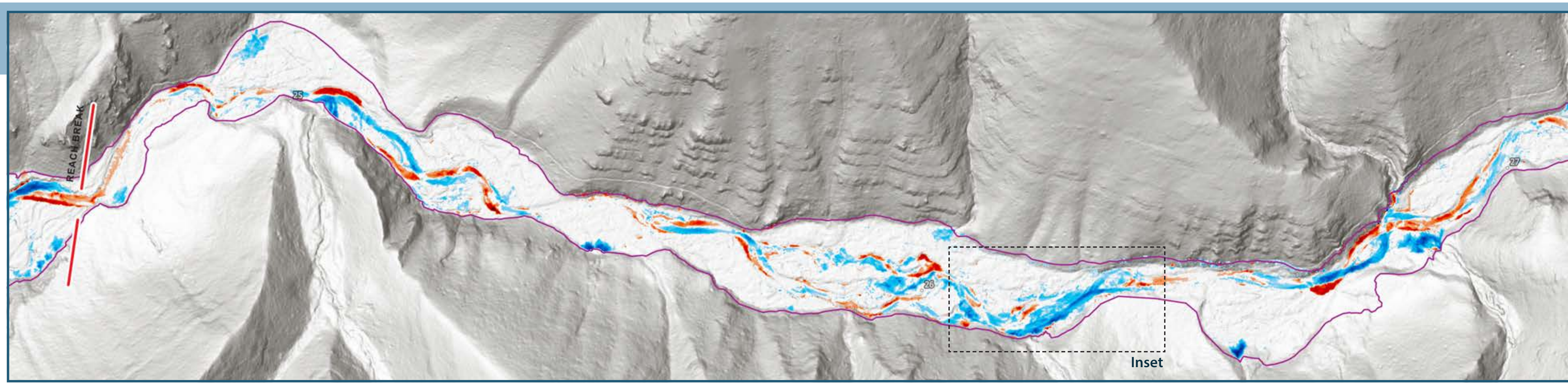
- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Channel Deposition and Erosion

2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)



Riparian Shade Analysis

Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

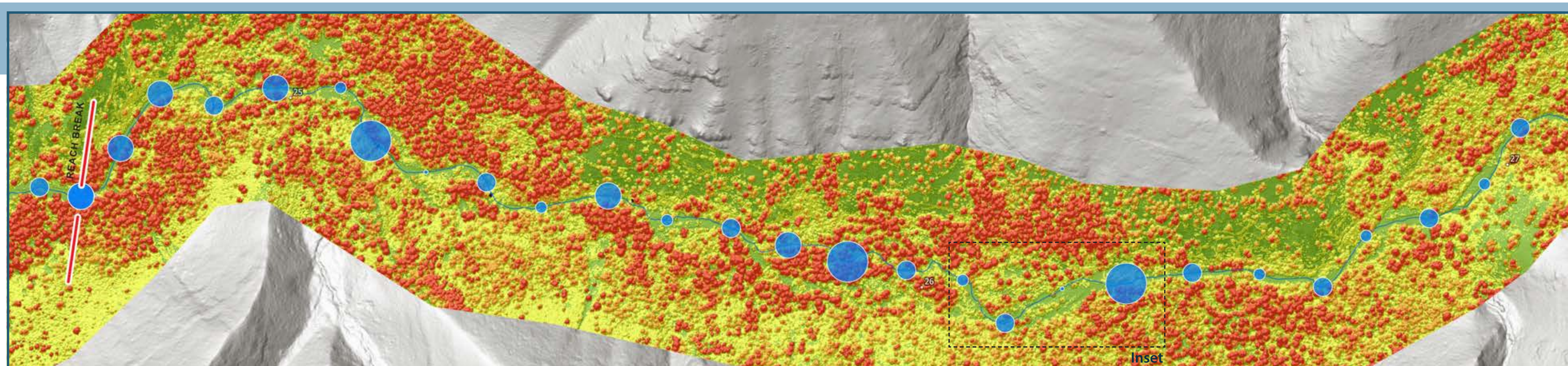
Effective Stream Shade

- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

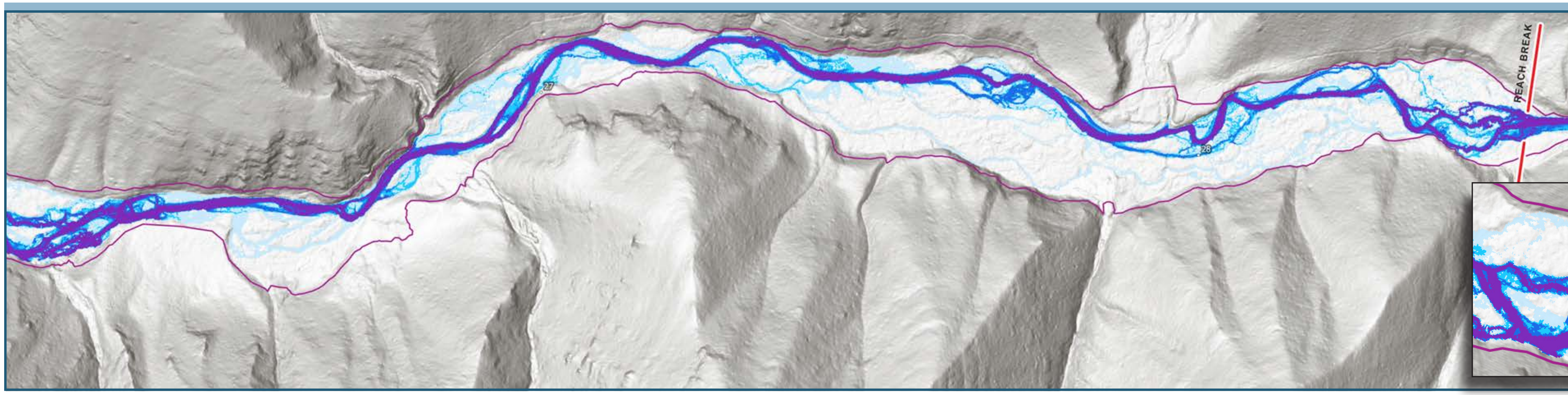
Thermal Load: **9,856** (Kcal/m)

Effective Shade **47%**

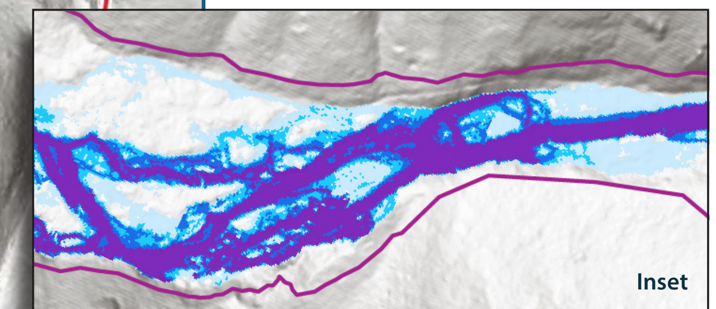
System Potential **9%**

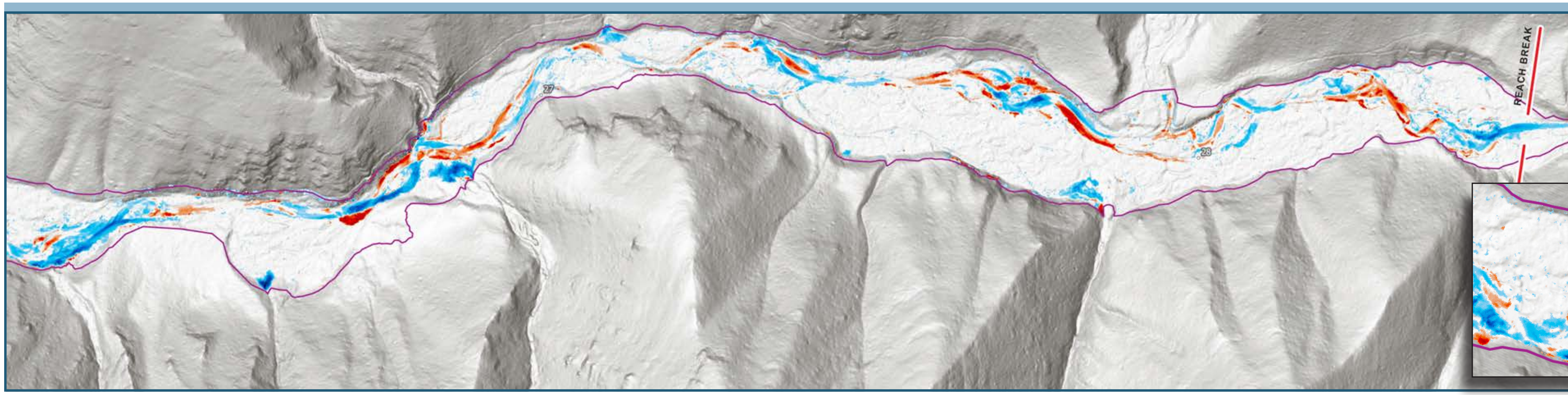


Reach SF4

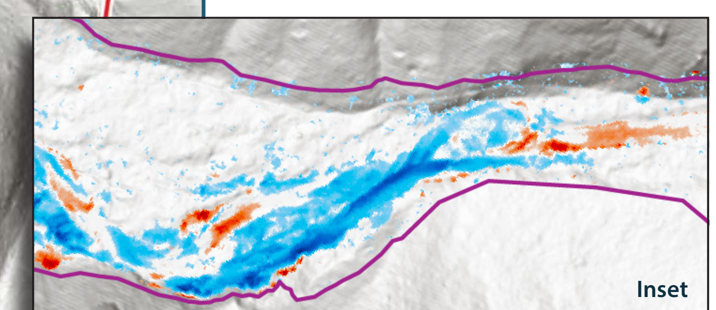


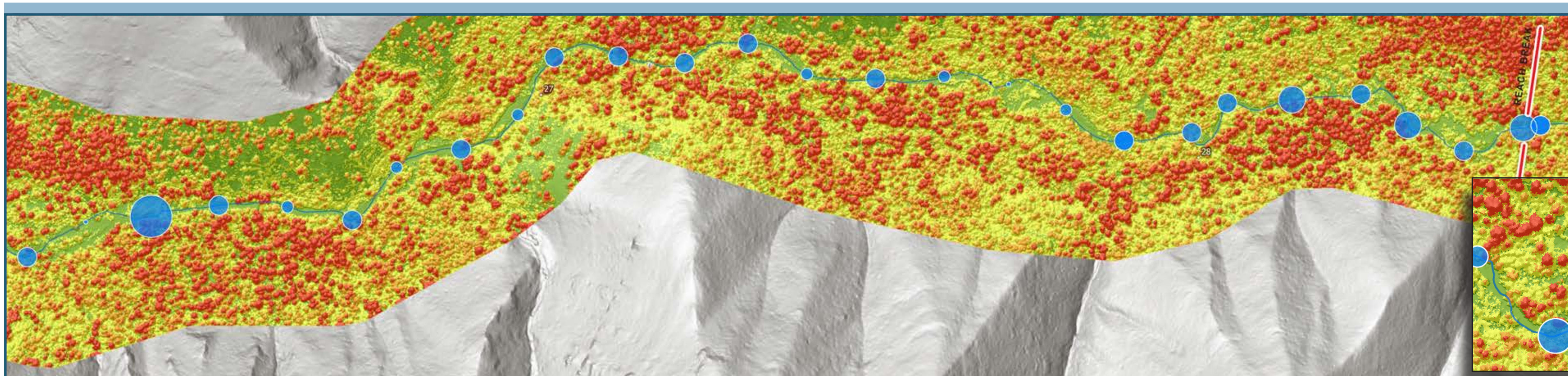
Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



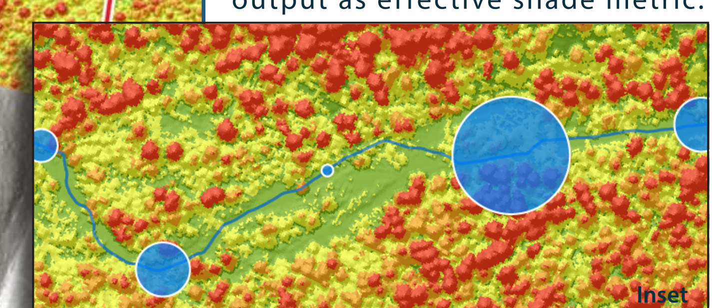


Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.





Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.



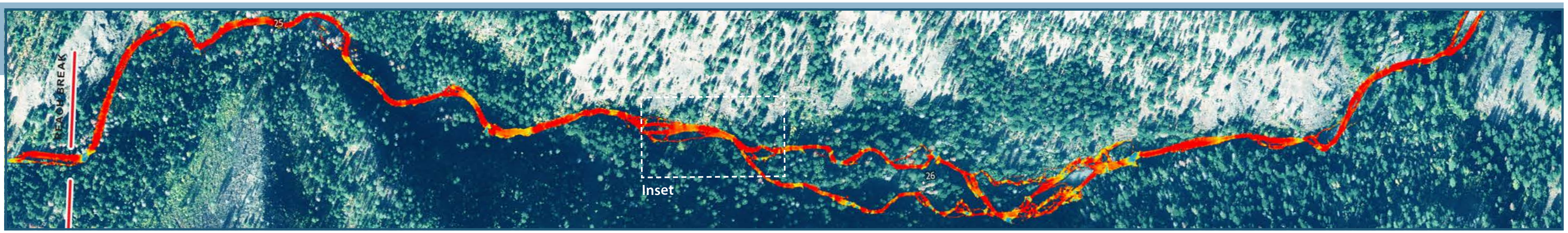
Reach SF4

HYDRAULIC HABITAT SUITABILITY

3.9 KM Reach Length RKM 24.6 to 28.5

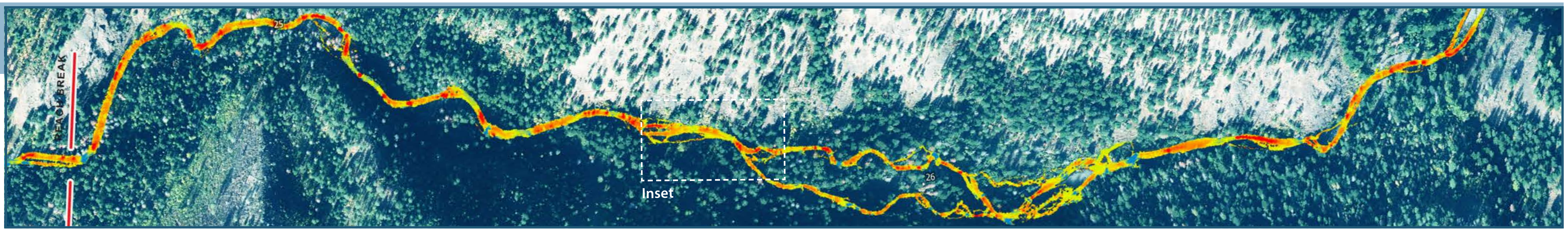
HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



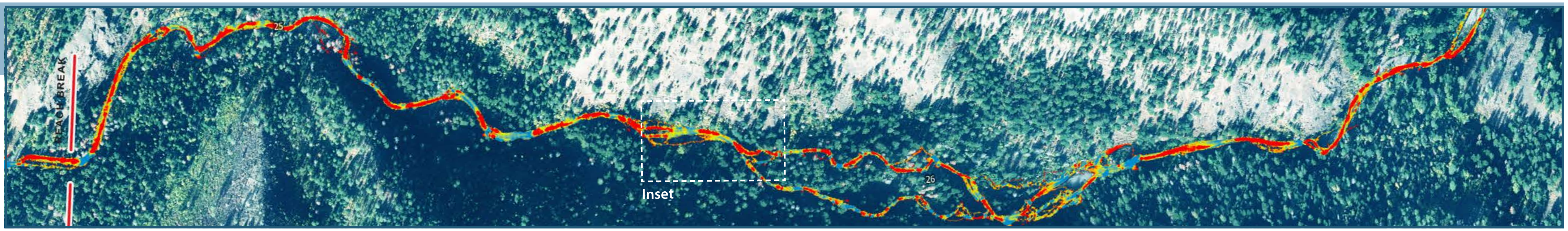
HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



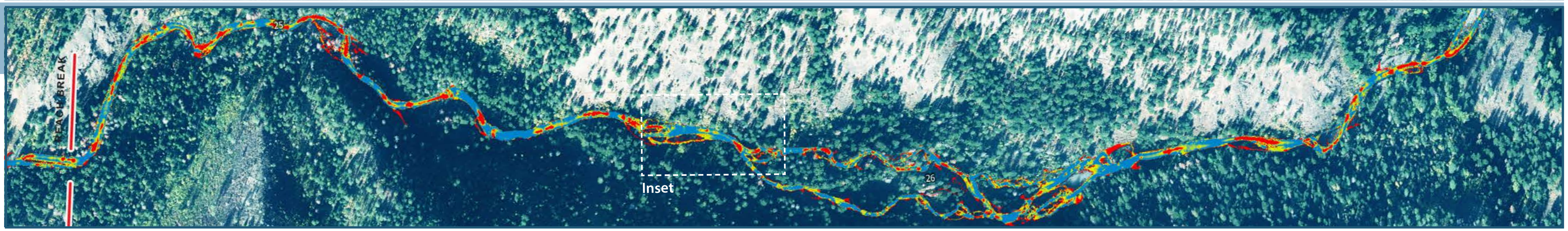
HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



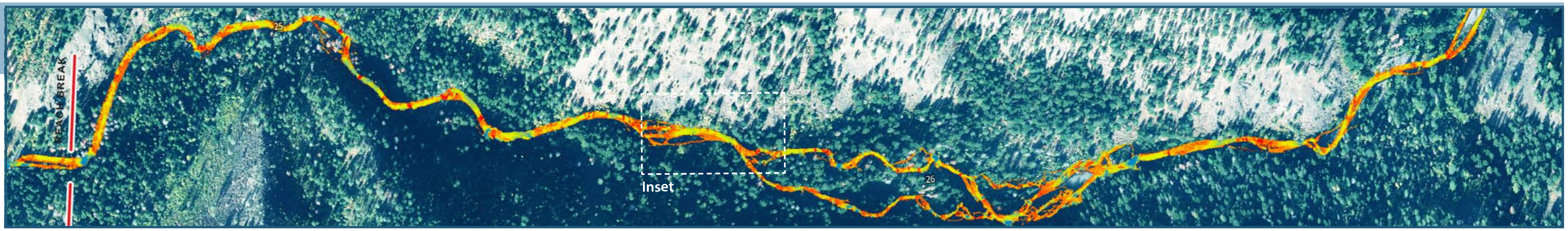
HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability

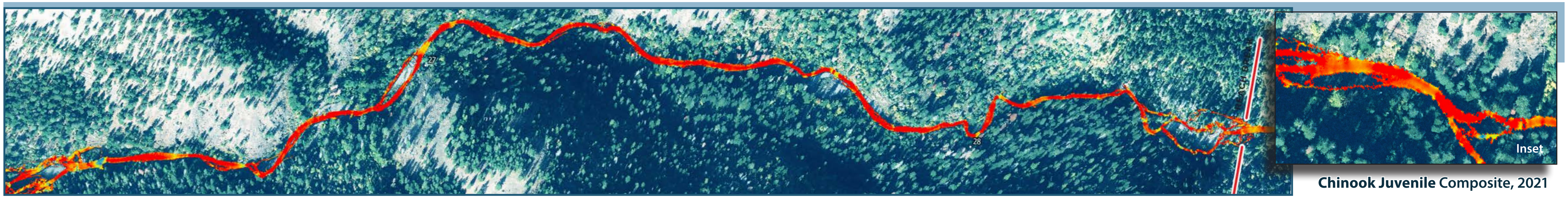


HHS
Steelhead Winter Composite, 2021

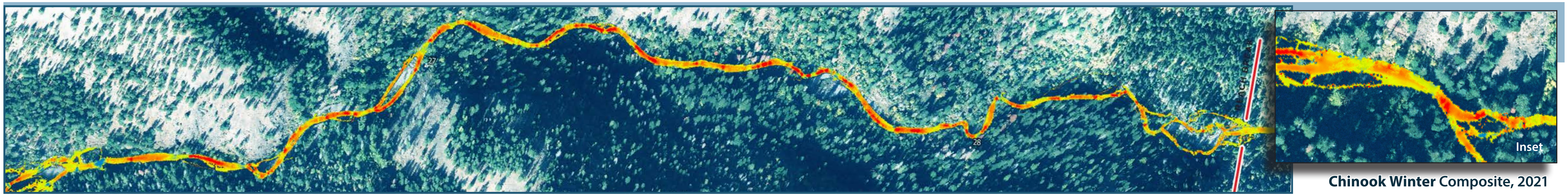
Highly Suitability
Moderate Suitability
Low Suitability



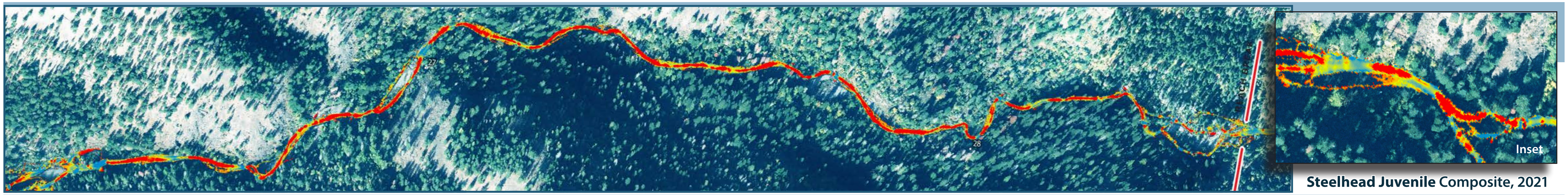
Reach SF4



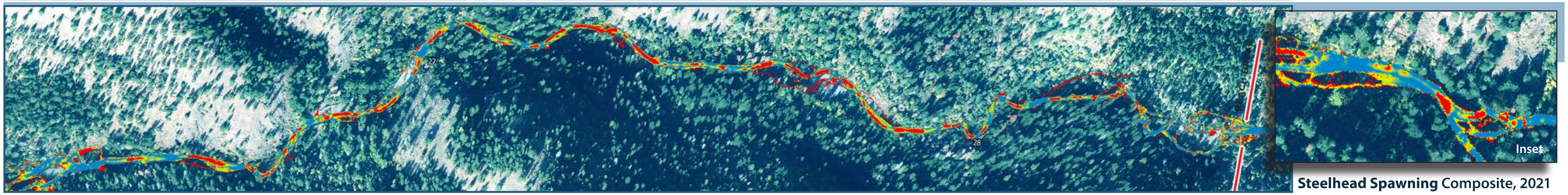
Chinook Juvenile Composite, 2021



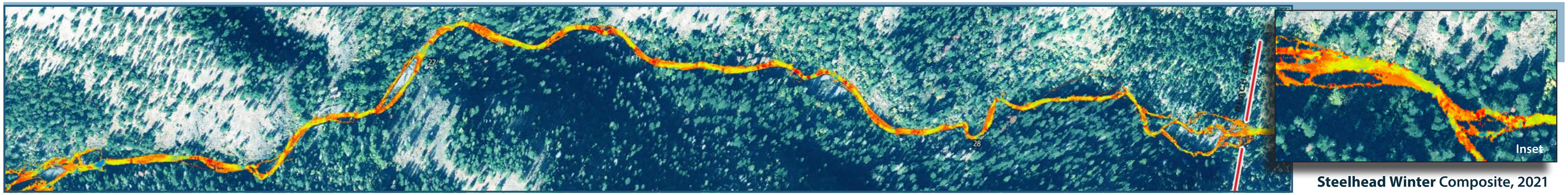
Chinook Winter Composite, 2021



Steelhead Juvenile Composite, 2021



Steelhead Spawning Composite, 2021

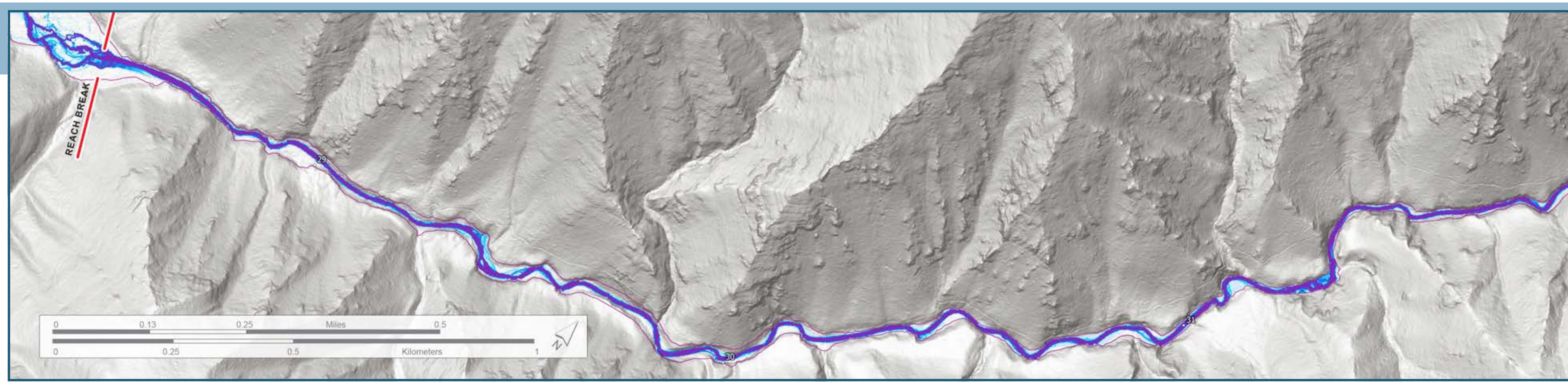


Steelhead Winter Composite, 2021

Reach SF5

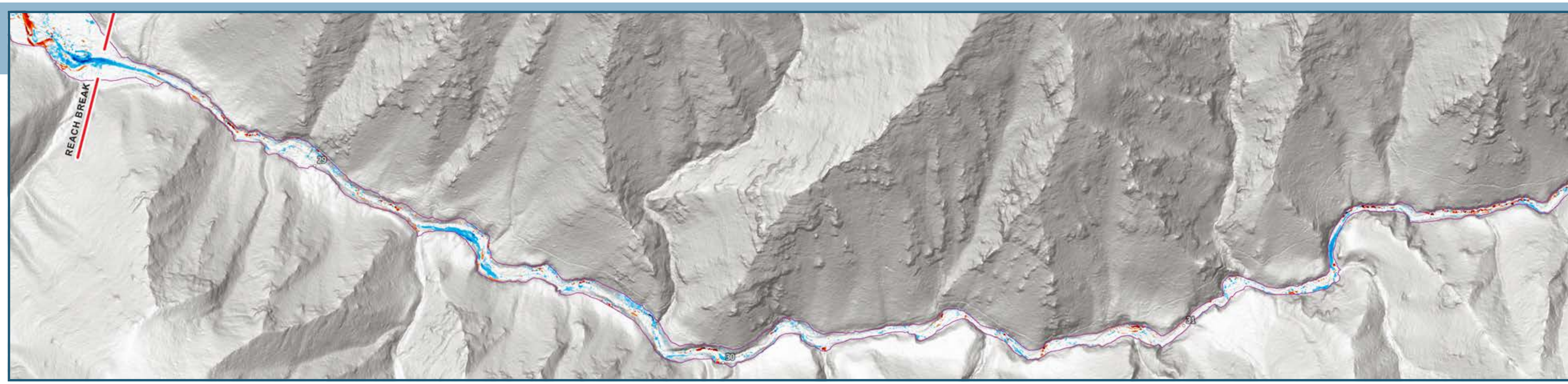
4.3 KM Reach Length   RKM 28.5 to 32.8

Hydraulic Modeling Inundation Extents



- Low Flow Inundation Extents
- 1.5-yr Flood Inundation Extents
- 5-yr Flood Inundation Extents
- 100-yr Flood Inundation Extents
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

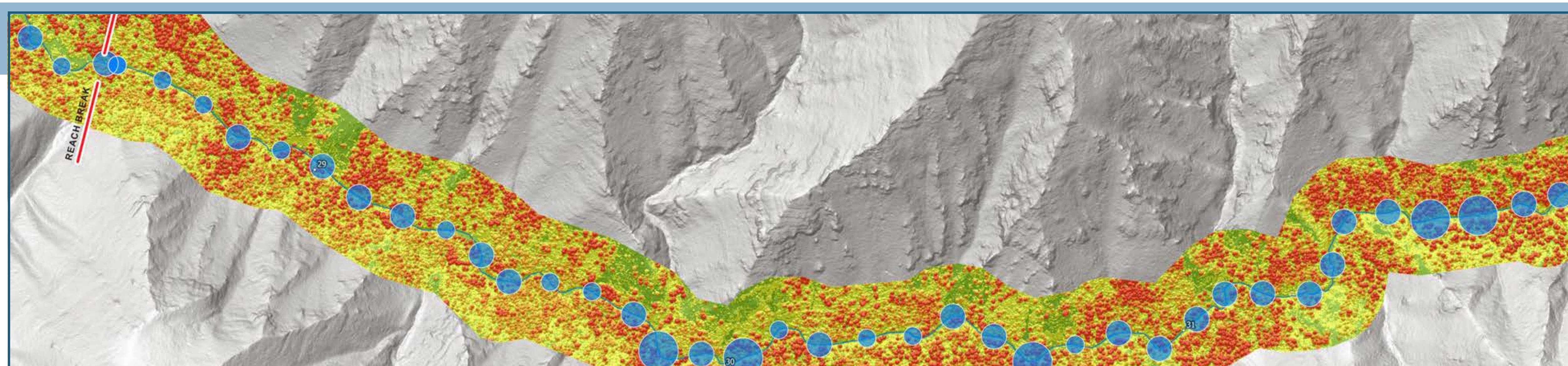
Channel Deposition and Erosion



2019 -2021
Elevation change (ft)

- 5 (Deposition)
- -5 (Scour)
- Geomorphic Reach Breaks
- Constraints
- Valley Bottom (natural)

Riparian Shade Analysis



Vegetation Height (m)

- 0
- 0 - 1 m
- 1 - 10 m
- 10 - 22 m
- >22 m

Effective Stream Shade

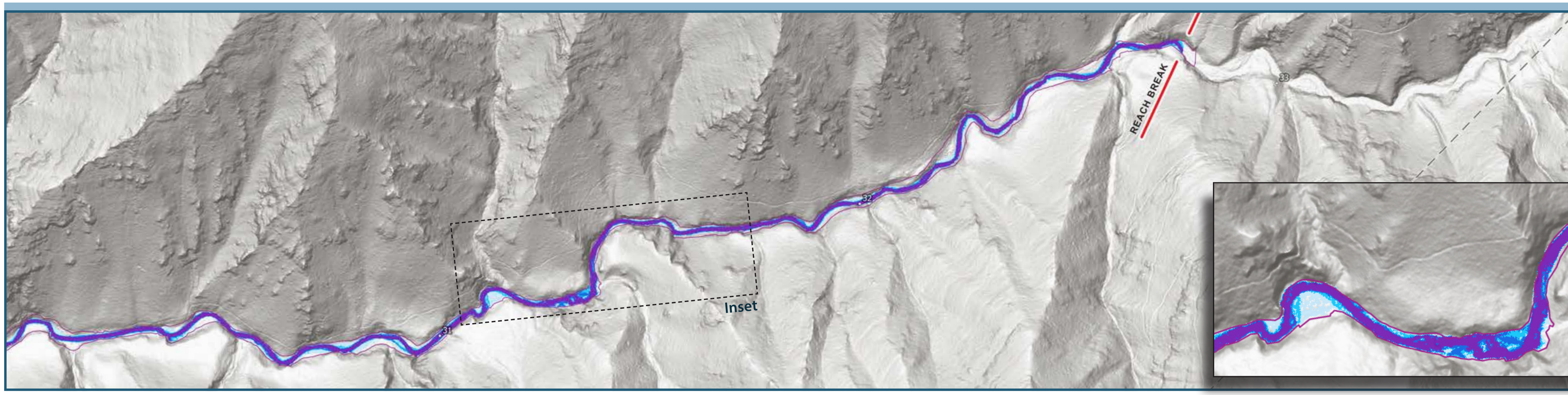
- 0 - 20%
- 20 - 40%
- 40 - 55%
- 50 - 75%
- 75 - 95%

Thermal Load: **4,881** (Kcal/m)

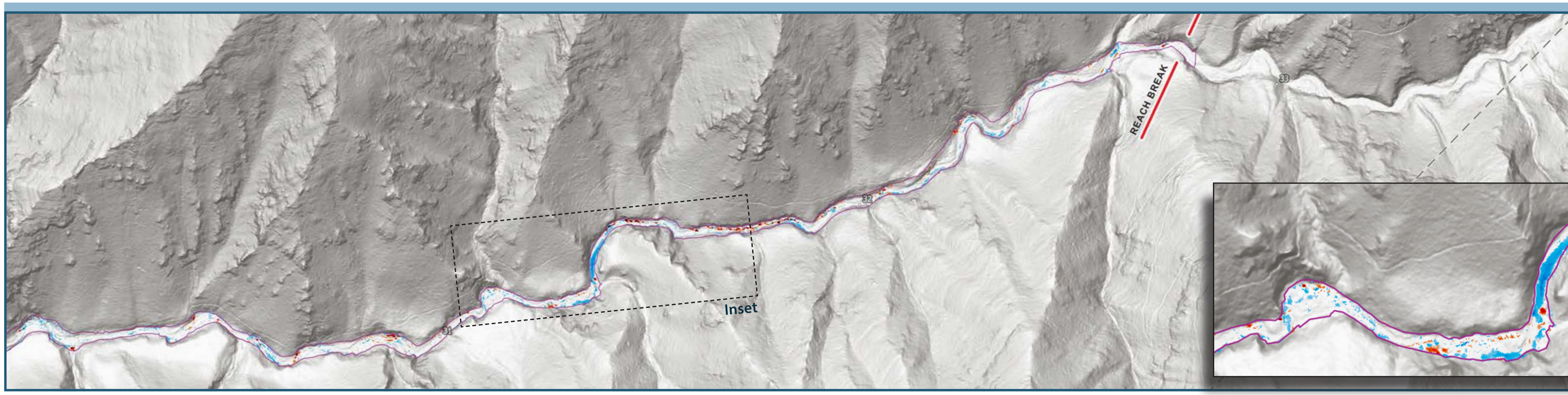
Effective Shade **62%**

System Potential **4%**

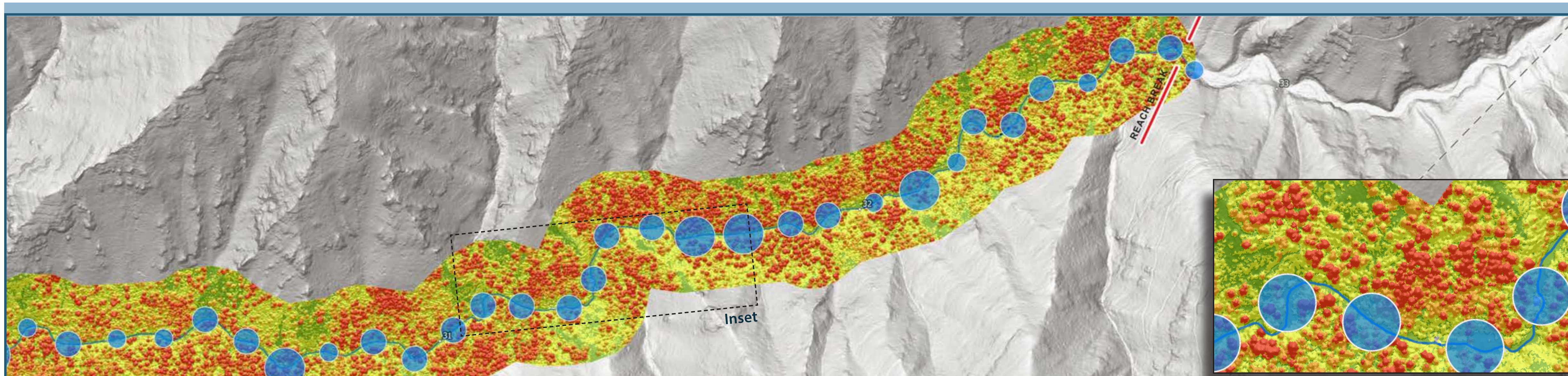
Reach SF5



Hydraulic Modeling Inundation Extents - Various discharge predicted flood depths derived from 2D hydraulic modeling produced from detailed topo/ bathymetric LiDAR survey.



Channel Deposition and Erosion Pre-flood (2019) and post-flood (2021) LiDAR difference model illustrating areas of physical change resulting from the 2020 flood of record.



Riparian Shade Analysis - Lidar derived vegetation height and solar routing model that calculates potential and received solar radiation at a stream's surface and also provides shade output as effective shade metric.

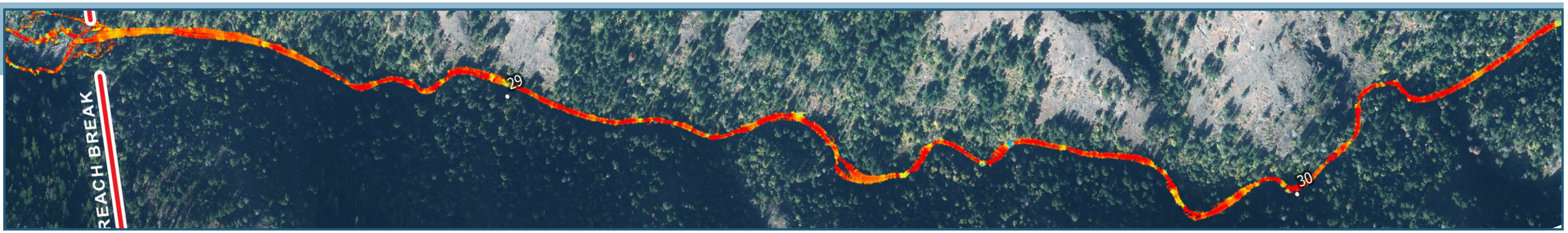
Reach SF5

HYDRAULIC HABITAT SUITABILITY

4.3 KM Reach Length RKM 28.5 to 32.8

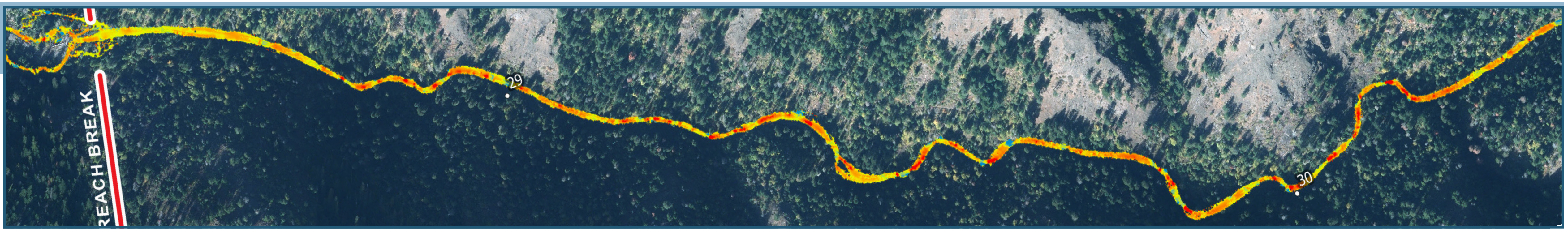
HHS
Chinook Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



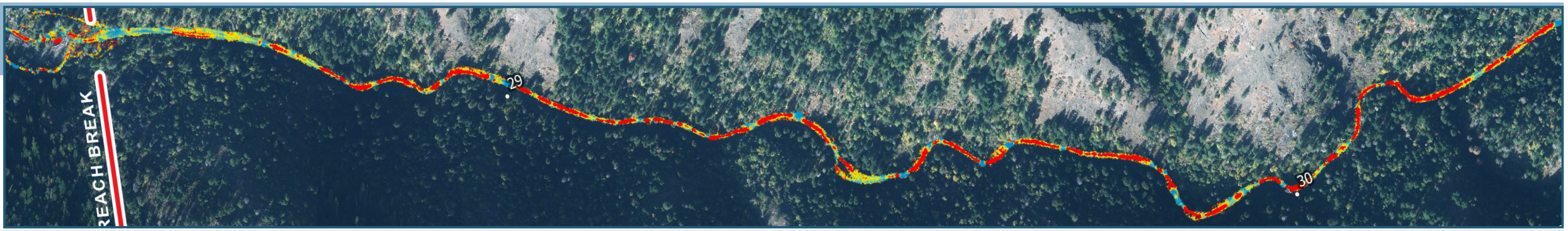
HHS
Chinook Winter Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



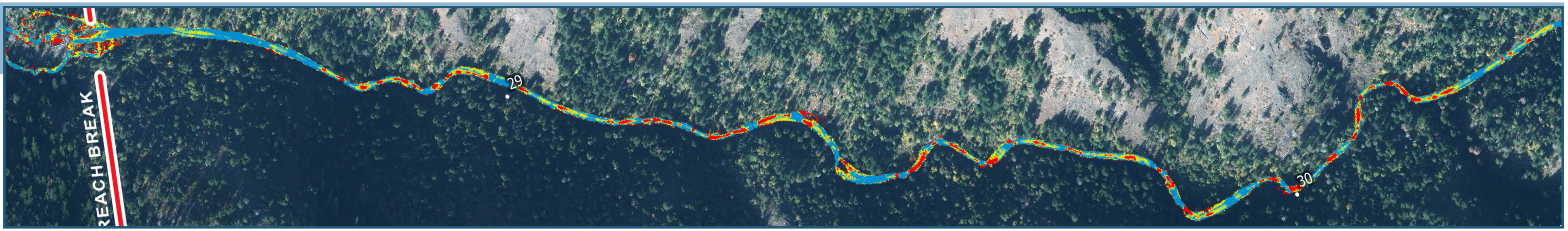
HHS
Steelhead Juvenile Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



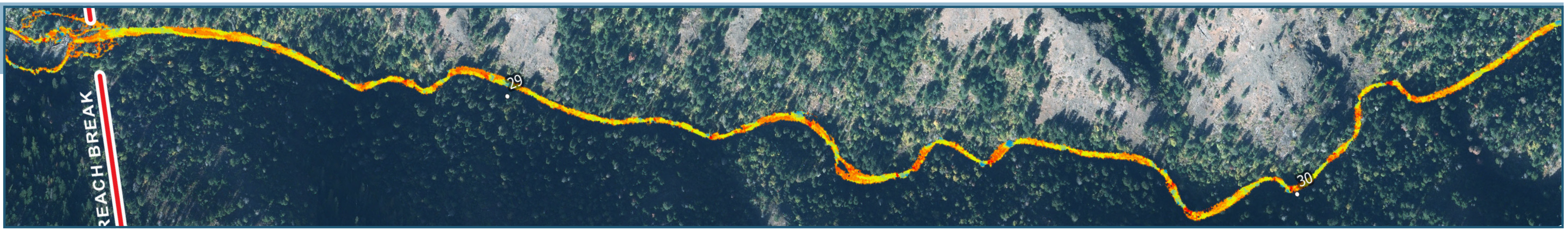
HHS
Steelhead Spawning Composite, 2021

Highly Suitability
Moderate Suitability
Low Suitability



HHS
Steelhead Winter Composite, 2021

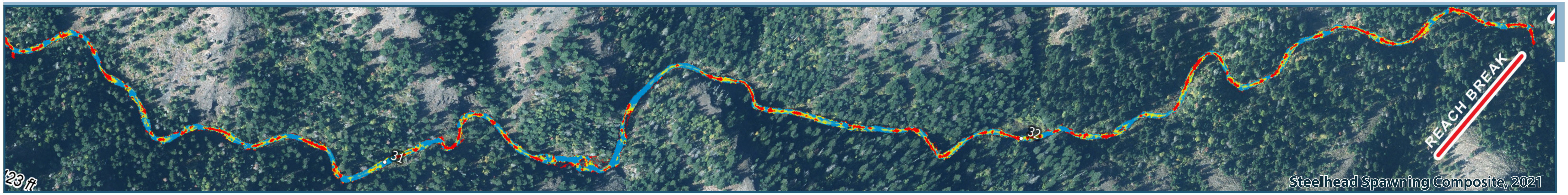
Highly Suitability
Moderate Suitability
Low Suitability

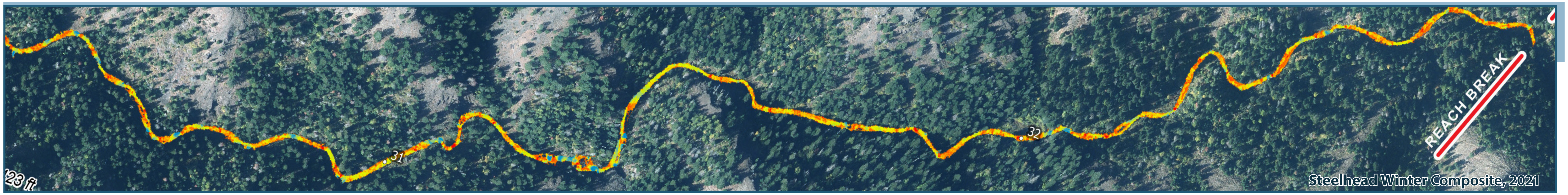



31
32
REACH BREAK
Chinook Juvenile Composite, 2021


31
32
REACH BREAK
Chinook Winter Composite, 2021


31
32
REACH BREAK
Steelhead Juvenile Composite, 2021


31
32
REACH BREAK
Steelhead Spawning Composite, 2021


31
32
REACH BREAK
Steelhead Winter Composite, 2021

South Fork, North Fork and Mainstem Upper Walla Walla

Functional Assessments

North Fork Walla Walla

The Functional Assessment approach is based on evaluating functions in the five River Vision Touchstone categories: Hydrology, Geomorphology, Connectivity, Riparian Vegetation, and Aquatic Biota.

The approach is based on evaluating functions in the five River Vision Touchstone categories (Jones et al., 2008): Hydrology, Geomorphology, Connectivity, Riparian Vegetation, and Aquatic Biota (Table 2). These functional categories represent the primary watershed- and reach-scale processes responsible for determining the health of stream ecosystems. Each category is comprised of one or more functional parameters that are used to quantify or describe the status of each category. The parameters are evaluated through the use of functional metrics (Table 2 and Table 3) that are calculated from all of the relevant available data, measured in accessible reaches, or modeled at the watershed and reach scales. The metrics are quantifiable attributes that are associated with one or more parameters and can be used to directly or indirectly evaluate the status and trend of stream function.

Functional assessments of the geomorphic reaches are used to determine aquatic habitat conditions and restoration opportunities within the upper Walla Walla River watershed. Information from the Watershed and Reach Assessments is used to score the Functional Metrics on a scale from 0.0 (absent/non-functional) to 1.0 (abundant/fully functional).

Touchstone Functional Category	Functional Parameter	Functional Metric
Hydrology	Base flow	Ecological Flow Attainment (%)
	Water Quality	Mean August Stream Temperature
Geomorphology	Channel Structure	Residual Pool Depth
		Riffle Width:Depth Ratio
	Channel Complexity	Pool Frequency
		Channel Unit Frequency
	LWD Transport and Storage	LWM Piece Frequency
		LWM Key Piece Frequency
		LWM Volume Frequency
	Bed Material Characterization	Riffle Area Organics and Sand (%)
		Riffle Area Gravel (%)
Connectivity	Floodplain Connectivity	Inundated Area Ratios (% of Valley Bottom)
		Artificial Floodplain Disconnection (% of Reach Length)
	Longitudinal Connectivity	Instream Barrier Burden
Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment
	Shade	System Effective Shade Potential Attainment
Aquatic Biota	Habitat Availability	Multispecies Habitat Suitability Index

■ ***Table 2.*** *Reach-based functional assessment categories and metrics for the CTUIR River Vision Touchstones.*

The data were evaluated relative to performance standards based on regional benchmarks, properly functioning conditions defined for salmon recovery planning in the Columbia River Basin, or literature values. For many environmental attributes in general, performance standards are nonexistent, ambiguous, and not applicable to the spatial scale of interest; therefore, literature values and professional judgment are commonly used to score the relative functionality of stream conditions. Functional Parameter values are calculated as the average Functional Metric scores, Functional Category values are calculated as the average Functional Parameter scores, and overall reach functionality is estimated as the average of Functional Category scores.

This approach helps identify the fundamental drivers of overall reach functionality and fosters comparability of functionality among reaches (Langhans et al., 2013).

Within each geomorphic reach of the project area, the Functional Metrics are scored on a scale from 0% (absent/non-functional) to 100% (abundant/fully functional) based on benchmark values.

- **Metrics with continuous values** (e.g., % of a reach meeting ecological flow targets) use the calculated value as the metric score. For example, a reach with 80% of its length meeting the ecological flow target is scored as 0.80.

Functional Metric	Functional Metric Description
Ecological Flow Attainment (%)	% of reach length meeting ecological flow target (WDOE, 2021; Stillwater Sciences, 2013); based on Rio ASE hydrology analysis
Mean August Stream Temperature	% of reach length (mean of species/life stage) below the optimum temperature threshold; based on MHE analysis of NORWEST recent historic temperature scenario
Residual Pool Depth	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Riffle Width:Depth Ratio	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Pool Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Channel Unit Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
LWM Piece Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
LWM Key Piece Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
LWM Volume Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Riffle Area Organics and Sand (%)	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Riffle Area Gravel (%)	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001)
Inundated Area Ratios (% of Valley Bottom)	Ratio of 1% annual chance flood area to the valley bottom area; based on Rio ASE modeling and analysis
Artificial Floodplain Disconnection (% of Reach Length)	Ratio of the length of artificial confinement features to the reach length; based on Rio ASE analysis
Instream Barrier Burden	Cumulative fish passage barrier burden; based on CTUIR analysis
Vegetative Height Potential Attainment	% of the analysis area within a reach meeting the vegetative height potential (ODEQ, 2005); based on Ecosystem Sciences analysis
System Effective Shade Potential Attainment	% of the analysis area within a reach meeting the effective shade potential (ODEQ, 2005); based on Ecosystem Sciences analysis
Multispecies Habitat Suitability Index	Mean hydraulic habitat suitability index value for species/life stage in the reach; based on modeling and analysis by Rio ASE and MHE

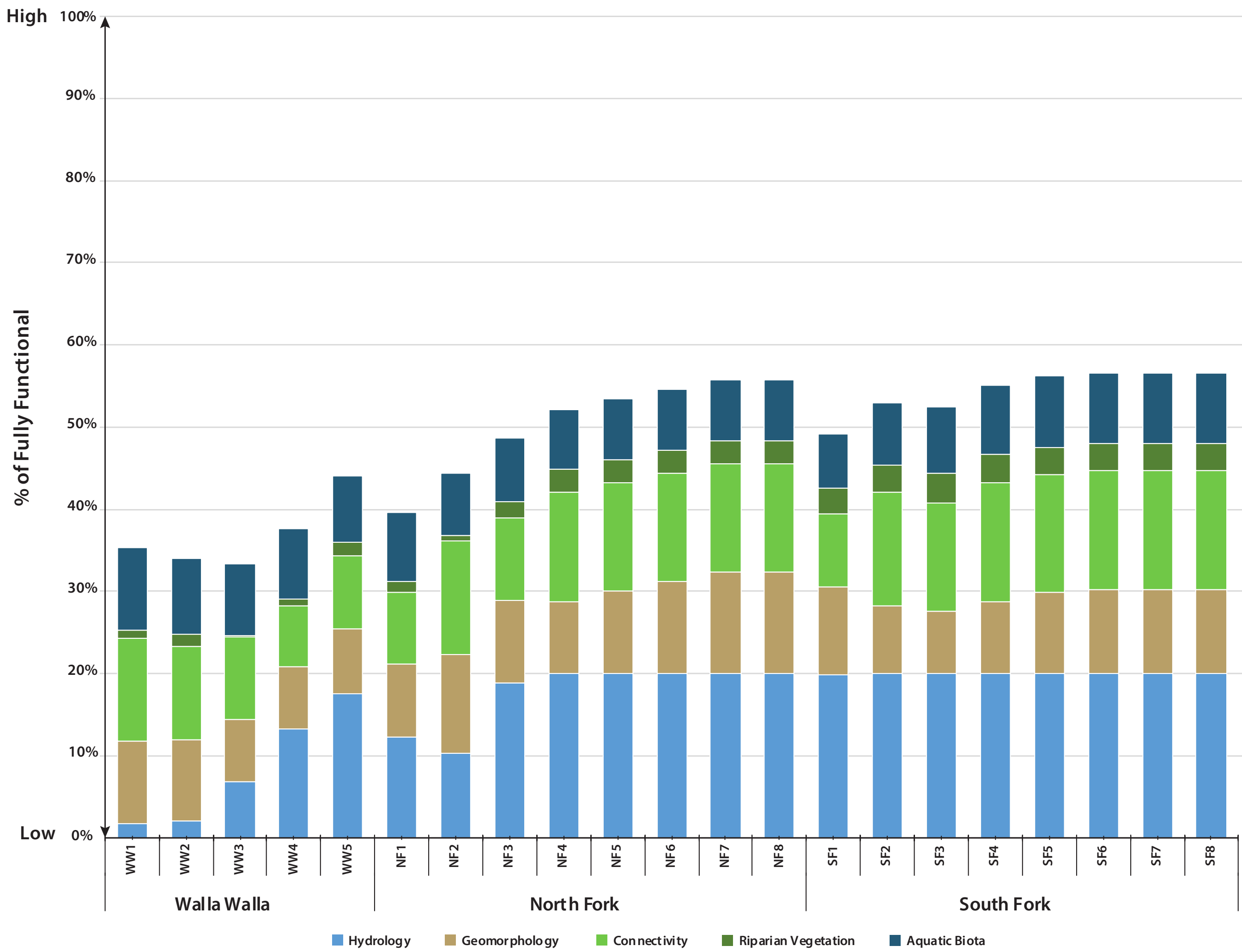
■ ***Table 3.*** *Reach-based functional metric descriptions.*

- **Metrics based on discrete data** (e.g., stream survey data using the ODFW (2017) protocol) are scored based on benchmarks for these data (Foster et al. 2001) that are adapted to the scale 0.0 to 1.0. The scale is divided into quartiles (0.0-0.25, 0.26-0.50, 0.51-0.75, 0.76-1.0) and the midpoint value of each quartile is used as the score for that metric value falling within that range. For example, a reach with an average Width:Depth ratio <=10 is scored as 0.88 (the mid-point of the upper quartile).

Missing Data Handling

All of the available and relevant data are being used to quantify the metrics. However, some of the reaches have no available data because, 1) stream surveys by WWBWC were not completed in all reaches, and 2) the Lidar data acquisition did not include the upper reaches of the North Fork and South Fork.

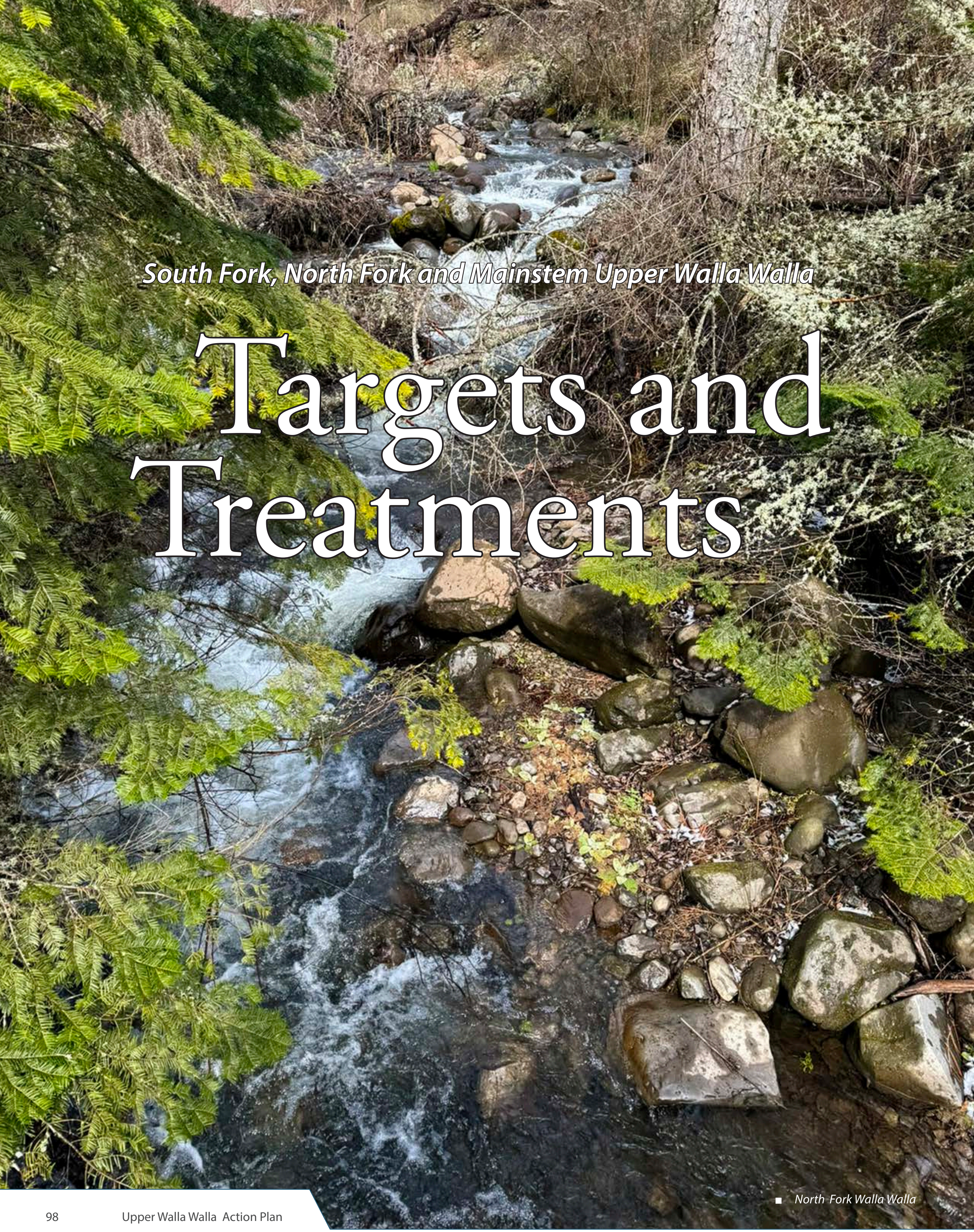
The reaches with missing data were included in the functional assessment and reach prioritization. For reaches with no WWBWC survey data, the lowest value from adjacent reaches (upstream or downstream) was used, and for reaches with no Lidar data the value from the adjacent downstream reach was used.



■ ***Figure 22.*** *Touchstone Functional Category Relative % of Total Reach Function*

South Fork, North Fork and Mainstem Upper Walla Walla

Targets and Treatments



■ *North Fork Walla Walla*

Targets

Targets include desirable physical conditions to improve reach-scale geomorphic function and habitat. Measured existing vs. desirable (target) and undesirable benchmark conditions are quantified for each valley segment in the Reach Assessment section of this document (Main Stem p. 32-33; North Fork p. 54-55; South Fork p. 72-72).

Additional information regarding assessment methods, results, and conclusions can also be found in Appendices B and E. The restoration targets are intended to address habitat limiting factors that have been identified in the watershed as summarized below (organized by priority).

Category	Description	Target
High water temperature (primarily from May – October) affects fish directly and affects fish indirectly by reducing dissolved oxygen content. High temperatures have been known to preclude fish movement/migration.	Areas with the upper Walla Walla watershed that exceed optimum temperatures are predicted to increase from 21% of the species domain currently to 33% and 38% under projected 2040 and 2080 climate scenarios, respectively	Chinook spawning: 7.2-14.5°C Chinook summer parr: 10-16°C Steelhead summer parr: 10-18°C Bull trout (all): 10.2-16°C Pacific lamprey (all): 10-17°C
	The Chinook salmon spawning life stage is predicted to be the most negatively impacted by warming scenarios	
Altered River Morphology	Lack of slow-water off-channel habitat and floodplain connectivity (especially important for juvenile rearing and high-flow refugia)	Valley area inundated by 100yr flow: WW1: >79% WW2-5: >91% NF1-2 and SF1-4: >68% NF3-8 and SF5-8: >75%
	Lack of pools, especially deep pools with cover	Pool frequency per km: >20
	Other barriers to movement (culverts, diversions, grade control structures, levees)	No barriers to movement longitudinally or laterally
Altered Water Flows	Irrigation withdrawals reduce available water limiting fish access to tributaries and proximal off-channel habitat while also increasing in-stream temperature	Reach WW5 minimum flow requirements* August - 76 cfs January - 97 cfs
Lack of Riparian Habitat	Deciduous zone below target tree height and density	22m tall trees with 80% density across floodplain
	Mixed zone below target tree height and density	25m tall trees with 80% density across floodplain
	Conifer zone below target tree height and density	24m tall trees with 80% density across floodplain
Sedimentation	Resulting in substrate embeddedness effecting spawning and egg incubation	Riffle area % gravel: >35%
Lack of Large Woody Material	Affecting cover and habitat-forming hydraulic structure	>20 pieces per 100m
Chemical Water Pollution	Chlorinated pesticides, polychlorinated biphenyls (PCBs) and low levels of lead and mercury; also high pH	No 303(d) listings or TMDL exceedance
Unscreened Surface Water Diversions	Unscreened surface water diversions (and screed diversions not meeting state criteria); primarily on tributaries to the upper Walla Walla (not included in this assessment)	All surface water diversions screed and meeting state criteria

■ ***Table 4. Habitat Limiting Factors and Targets***

**Note - From the Walla Walla River Bi-State Flow Study, 2019 Flow Study Update; Monthly minimum flow targets are identified in Table 2 of Appendix 1-A.*

Species	Limiting Factors Per Life Stage	Target
Chinook Salmon	Redds are most limiting	1,242 redds
	There is more available summer and winter juvenile rearing capacity than required to meet existing adult escapement goals (3,600 Chinook salmon) representing healthy and harvestable abundance levels.	Meeting target
Steelhead	Redds and summer juvenile rearing capacity are both limiting	2,017 redds 486,712 winter juveniles
	Available winter juvenile rearing capacity exceeds required capacity to meet existing escapement goals (3,400 steelhead) representing healthy and harvestable abundance levels	Meeting target

■ ***Table 5. Habitat Capacity Deficits***

**Note - Although physical habitat may be suitable for certain species and life-stages, other factors may preclude fish use (i.e. temperature, barriers, or other limiting factors). Just because there is available habitat capacity does not mean that capacity is being fully utilized. See Appendix H for more details.*

All process-based and form-based restoration should be designed to work with and restore river and floodplain processes to ensure long-term project success.

Treatments

The overall restoration goal for the Walla Walla River is to improve channel and floodplain form and function by restoring natural processes that can create and maintain diverse, dynamic, and complex physical habitat suitable for freshwater life stages of Middle Columbia River summer steelhead, Columbia River bull trout, Spring Chinook salmon, Pacific lamprey, and other native aquatic and riparian species.

Restoration can be accomplished using process-based and form-based restoration techniques. Process-based restoration techniques generally rely on removing impediments to natural channel process and/or installing features that will restore or augment natural channel processes, but generally allows the river to "do the work" as much as possible. With form-based restoration on the other hand, habitat is directly and immediately created via excavation, structure placement, and/or other mechanical means. Form-based restoration often results in greater initial impact (i.e. more construction) but also produces results more quickly. Any restoration, form-based or process-based, should be completed such that the final project will work with existing natural processes in the future. Process-based restoration is commonly used to change the trajectory of the channel in a more positive direction and typically results in forms and features early in their evolution requiring time to mature. For example, removing a levee and allowing the channel to migrate and reactivate relict floodplain may take many years to fully restore pre-disturbance conditions. Form-based restoration on the other hand is commonly used to completely reset the channel, and in some cases also the floodplain. Form-based restoration targets form features late in their evolution, while restoring processes previously unavailable to the system due to past impacts.

■ ***Figure 23.*** *Meander beltwidth determined by 2x the maximum meander amplitude*

For example, a channel that has been historically straightened and confined may be reconstructed in a more sinuous planform with excavated side channels and floodplain. Although this is a form-based restoration approach, the resulting product will be able to evolve following a new trajectory according to the natural processes that were restored.

Process-Based Restoration Examples Suitable to the Upper Walla Walla

- Remove levees, revetments, culverts, bridges, irrigation diversions, and other restraints artificially confining the channel and/or floodplain where feasible

- Within primary channels: Add large woody material jams (bank and apex jams) within the channel and floodplain to initiate a hydraulic response by 1) obstructing and distributing flow laterally to promote channel migration and creation of flow splits, and 2) by roughening the channel to dissipate stream energy and encourage sediment deposition at riffles, improving floodplain connection over time.

- Within existing or proposed secondary channels: Allow for and/or reintroduce beaver where allowable. Where beavers are not present or to expedite restoration, add beaver dam analogues, post-assisted log structures, woody material, boulders, and other natural (or emulating natural) channel obstructions to initiate a hydraulic response by increasing roughness, dissipating flow energy, and promoting sediment deposition to encourage lateral channel movement and/or distribution.

- On the banks and floodplain: Plant riparian vegetation to promote bank and floodplain soil structure, hydraulic roughness, shade and nutrient cycling as well as long-term large woody material recruitment. Increased plant and woody material density provides roughness that may prevent undesirable avulsions (new-channel paths).

Form-Based Restoration Examples Suitable to the Upper Walla Walla

- Channel realignment and construction to recreate more appropriate channel forms (sinuosity and multi-thread channels).

- Riffle construction for grade control including raising the channel bed to overcome prior incision and reconnect the floodplain.

- Floodplain grading – It is always preferable to reconnect relict floodplains by removing confining structures and/or by raising the streambed. Where it is infeasible to raise the channel bed sufficiently to reconnect the floodplain, or where infrastructure or other constraints preclude reactivation of the floodplain, an inset floodplain may be excavated such that the prior floodplain is abandoned as an upland terrace. The size of the floodplain (inset or otherwise) should be sufficient to enable the full meander beltwidth of the channel defined by 2x the maximum meander amplitude (Figure 23).

Specific actions to address spawning and rearing habitat capacity deficits:

- Implement rehabilitation actions within lower-quality habitats to increase available capacity (i.e. increased quality)

    - Spawning habitat – Treatments should aim to increase stream complexity, cover, and riffle-pool interfaces with fine to coarse gravels. Proximity to pool is important for adult cover.

    - Summer rearing habitat – create deeper pools and runs, increase channel unit frequency (i.e. channel complexity) increase cover (i.e. large woody material), and include a variety of substrate sizes (sediment sorting associated with channel and hydraulic complexity). Increasing overall channel complexity by incorporating side channels, off-channel areas, and island complexes can increase the frequency and scale of target characteristics.

    - Fry and early parr life stages – improved connectivity to and availability of slow-water, off-channel habitat (side channels, beaver complexes, floodplains).

- Improve connectivity to the available stream network in tributaries, headwaters, and off-channel areas by removing access barriers (i.e. increased quantity).

Specific Treatment Recommendations

For all reaches, consider road decommissioning and range/forest management to reduce grazing impacts and fire severity in upland areas (outside of the floodplain).

Nearly all the treatment recommendations address multiple functional categories, parameters, and/or metrics. Most also indirectly address the Aquatic Biota functional category.

WW1 and WW2

- *Addresses Geomorphology functional category and Floodplain Connectivity functional parameter:* Establish an appropriate meander beltwidth (approximately 300m) where stream/floodplain function and riparian vegetation will be allowed, while agricultural and rural development land uses will occur outside the beltwidth.

- *Addresses LWM, Vegetation Height, and Shade functional metrics*: Improve temperature and reduce fine sediment production by planting native riparian vegetation along banks and floodplain within the defined meander beltwidth.

- *Addresses Connectivity functional parameters*: Remove levees, bank revetments, and other impediments to channel migration, floodplain activation, and side channel formation.

- *Addresses Geomorphology functional categories*: Add woody material jams within the channel, along the bank, and in the active floodplain to obstruct and bifurcate flow increasing hydraulic and habitat complexity, reducing velocity, scouring pools, and sorting sediment.

WW3 and WW4

- *Addresses Geomorphology functional categories and Connectivity functional parameters*: Where feasible, restoration should focus on removing or setting back levees to reestablish an appropriate meander beltwidth and floodplain. Due to the extreme constraints within these reaches, it is anticipated that levee removal or setback may not be immediately feasible. Therefore, in the interim, restoration should focus on creating a suitable migration corridor for fish while providing shade and areas of isolated habitat where feasible.

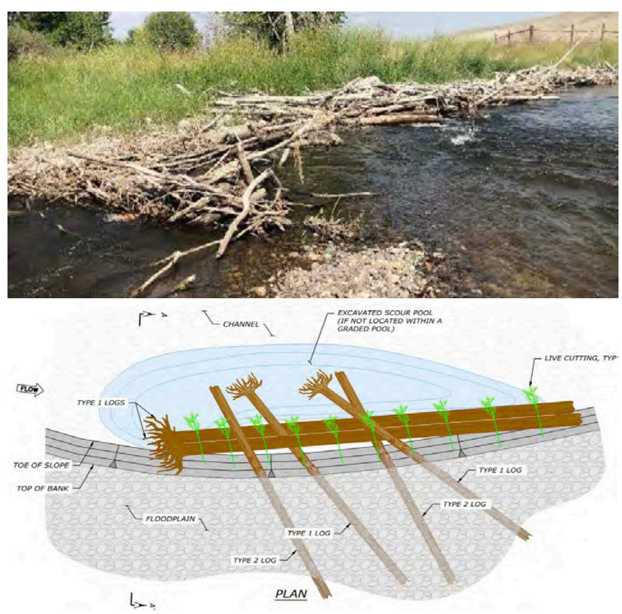
- *Addresses channel structure, channel complexity, and bed material functional parameters*: Work with the US Army Corps of Engineers and local sponsors to develop a study and implementation plan for ecosystem restoration to address poor habitat connectivity, excess stream power, low geomorphic function, poor habitat suitability, and high in-stream temperatures. Channel and floodplain function is poorest in the upper half of WW3 (immediately below the concrete grade control structure at Eastside Road) where incision is most pronounced. The lower half of WW3 and WW4 have developed a modest inset floodplain with slightly improved geomorphic, riparian ,and aquatic biota function.

- *Addresses LWM, Vegetation Height, and Shade functional metrics*: While planting riparian vegetation may not be permissible on the levees themselves, planting riparian vegetation within the levees on the inset floodplain where present will provide shade and woody material recruitment while also creating a roughened channel margin versus the hydraulically smooth levee surface.

- *Addresses Geomorphology functional categories:* Install woody material jams and/or boulder clusters where feasible along the margins of the channel to promote hydraulic diversity, provide roughness, and reduce in-stream velocity.

WW5, NF1, and SF1

- *Addresses Geomorphology functional category and Floodplain Connectivity functional parameter:* Establish an appropriate meander beltwidth (approximately 175m [WW5]; 75m [NF1]; 120m [SF1]) where stream/floodplain function and riparian vegetation will be allowed, while agricultural and rural development land uses will occur outside the beltwidth. The area of 2020 flood impact (scour and deposition) defines the



■ ***Figure 24.*** *Treatment: Large Wood Material (LWM) Habitat Structure* active floodplain and represents the area in which future impacts are most likely to occur.

- *Addresses LWM, Vegetation Height, and Shade functional metrics:* Improve temperature and reduce fine sediment production by planting native riparian vegetation along banks and floodplain within the defined meander beltwidth.

- *Addresses Connectivity functional parameters:* Remove levees, bank revetments, and other impediments to channel migration, floodplain activation, and side channel formation.

- *Addresses Geomorphology functional categories:* Add woody material jams within the channel (Figure 24), along the bank, and in the active floodplain to obstruct and bifurcate flow increasing hydraulic and habitat complexity, reducing velocity, scouring pools, and sorting sediment.

- *Addresses Geomorphology functional categories and Connectivity functional parameters*: Excavate new side channels and/or connect abandoned side channels (especially those abandoned by or temporarily activated by the 2020 flood) to increase off-channel habitat.

NF2 and SF2

These reaches are already relatively dynamic and complex and lack the majority of infrastructure impacting the channel and constraining restoration when compared to downstream reaches. Restoration actions should seek to reestablish an active floodplain across the entire valley width.

- *Addresses Geomorphology functional categories:* Within the primary channel, add woody material jams within the channel, along the bank, and in the active floodplain to obstruct and bifurcate flow increasing hydraulic and habitat complexity, reducing velocity, scouring pools, and sorting sediment.

- *Addresses Geomorphology functional categories*: Within secondary channels, add beaver dam analogues (Figure 25), post-assisted log structures, woody material, boulders, and other natural (or emulating natural) channel obstructions to increase roughness, dissipate flow energy, promote sediment deposition, and encourage lateral channel movement and/or distribution.

■ ***Figure 25.*** *Treatment: Floodplain spanning structure designed to emulate a relic beaver dam*

- *Addresses channel structure, channel complexity, and bed material functional parameters:* Where road access permits and the valley is narrow (e.g. NF2 RKM 7.8 and RKM 9.2), consider emulating debris flows, avalanches, and/or rock fall by constructing a robust riffle and valley-spanning grade control to create a new, dynamic, response reach, active floodplain, and beaver complex.

- *Addresses LWM, Vegetation Height, and Shade functional metrics:* Within the mixed deciduous-conifer riparian vegetation zone, promoting sediment deposition and bar formation will encourage natural recruitment of deciduous riparian vegetation.

NF3-8 and SF3-8

These reaches are already dynamic and complex and completely upstream of any direct impacts associated with human infrastructure. Restoration actions should seek to add roughness and complexity to the system in the form of woody material, rock, and beaver. Helicopter placement of wood and rock is recommended.

- *Addresses Geomorphology functional categories:* Within naturally confined reaches (or subreaches), robust structure will be required to overcome concentrated stream forces. Objectives in these areas are to roughen the bed and banks, reduce in-stream velocity, promote sediment deposition where possible, and maintain fish passage.

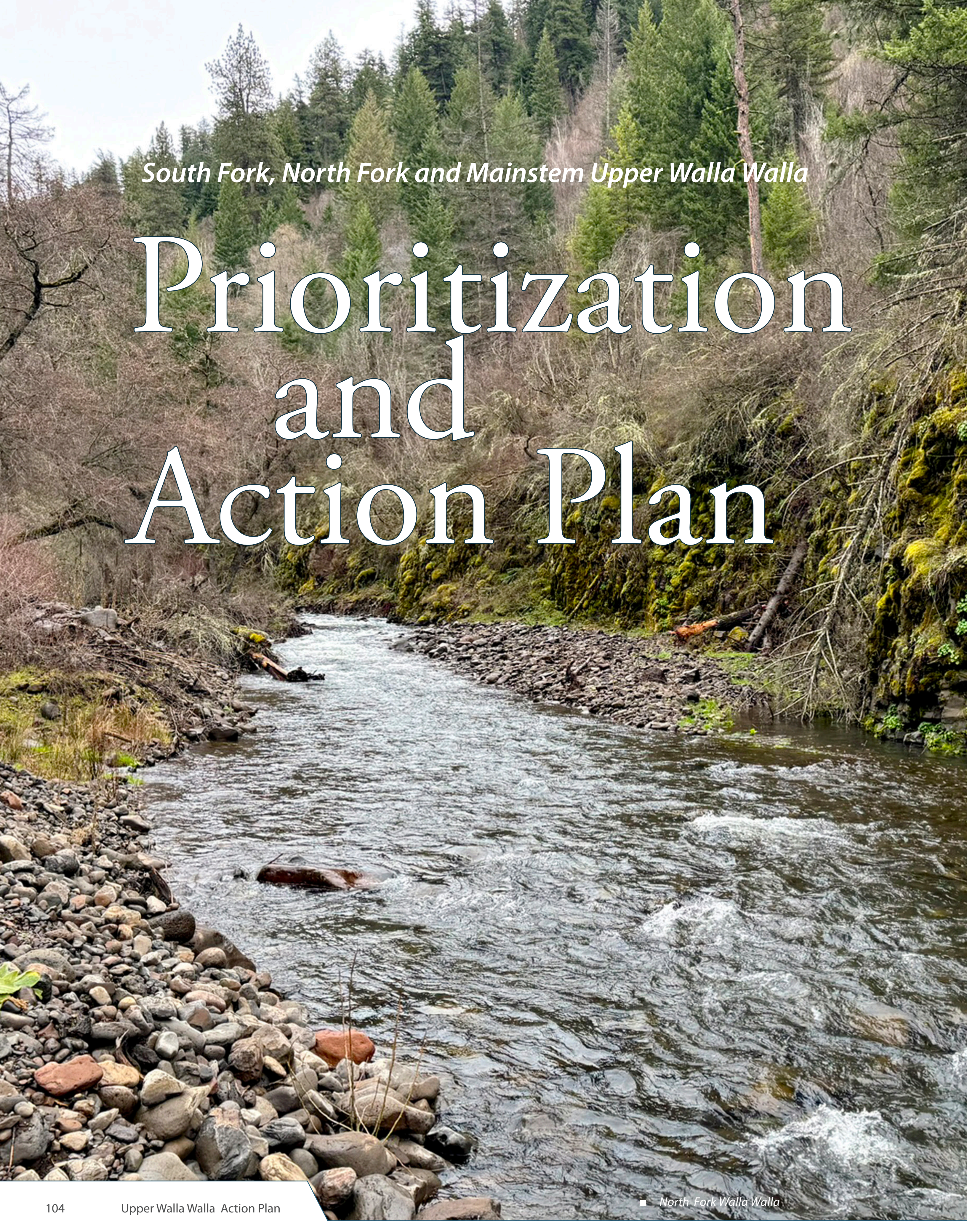
- *Addresses Geomorphology, functional categories and Floodplain Connectivity functional parameters:* Within unconfined reaches (or subreaches), structure should be placed to bifurcate and laterally distribute flow promoting more complex and diverse habitat types. Promote beaver colonization within these reaches.

Treatment Type References

Included in Appendix K of this Action Plan is a suite of representative treatment types and applications.

South Fork, North Fork and Mainstem Upper Walla Walla

Prioritization and Action Plan



■ *North Fork Walla Walla*

Treatments identified for each reach can be prioritized based on metrics derived primarily from the CTUIR River Vision Touchstones: Hydrology, Geomorphology, Connectivity, Riparian Vegetation, and Aquatic Biota. These five touchstones plus the addition of a Social category (requested to be added by the co-managers) were divided into 13 prioritization criteria, also largely based on the definition of each Touchstone from the River Vision, and then 20 prioritization metrics coinciding with the data available from each project reach (Table 6). All of the assessment results were considered in this process and recommended treatment are discussed in the previously section. The prioritization matrix is an objective approach without additional interpretation. Treatment applications and descriptions have also been described in the previous sections.

	Prioritization Category (River Vision Touchstones)	Prioritization Criteria	Prioritization Metric
River Vision Touchstones	**Hydrology (Water)**	Baseflow	Ecological Flow Attainment
			Mean August Stream Temperature (% of reach below threshold)
			Proportion of Life Stages Over Max 2040 Modeled August Stream Temp
	Geomorphology	Channel Structure	Residual Pool Depth
			Riffle Width:Depth Ratio
			Entrainment Potential 2-yr Q
		Channel Complexity	Pool Frequency
			Channel Unit Frequency
		LWM Transport and Storage	LWM Piece Frequency
			LWM Key Piece Frequency
			LWM Volume Frequency
		Bed Material Characterization	Riffle Area Organics and Sand (%)
			Riffle Area Gravel (%)
	Connectivity	Floodplain Connectivity	Valley Inundated Area % (100-y:Valley Bottom)
			Artificial Floodplain Disconnection (% of Reach Length)
		Longitudinal Connectivity	Instream Barriers Burden
	Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment
		Shade	System Effective Shade Potential Attainment
	Aquatic Biota	Habitat Suitability	Multispecies Habitat Suitability Index
		Habitat Capacity	Multispecies Habitat Capacity Deficits
	Social	Site Access Constraints	
		Parcel Density	

■ *Table 6. Prioritization Criteria and Metrics Table*

Hydrology

Water quality and quantity as well as hydrologic processes (hydraulics) must be adequate to support the sustainable production of First Foods. Base flows occurring primarily in the summer and early fall months are commonly the most impactful to fish and riparian/upland vegetation collectively comprising all of the First Foods. Baseflow hydrology has been evaluated based on the percentage of each reach attaining recommended minimum flows (i.e. Ecological Flow Attainment) (Stillwater Sciences 2013). Additionally, baseflow (i.e. summer) water quality has been evaluated based on stream temperature thresholds for key aquatic species. This evaluation was conducted using modern temperature data and modeled water temperature for the year 2040 based on climate change scenarios (see Appendix J).

- **Hydrology** - *Prioritize high-functioning reaches to ensure restoration occurs first where flow and in-stream temperature are suitable for target species.*

Geomorphology

The shape of the river and how it changes over time creates and maintains habitat for aquatic and riparian organisms including macroinvertebrate insects, salmon, willow shrubs, and cottonwood trees. Typically, the more complex and diverse the shapes and structure of the channel and floodplain, the higher quality and quantity habitat. Channel structure and complexity have been evaluated based on pool depth, pool frequency, channel width-to-depth ratio, sediment transport potential, and overall channel unit frequency (e.g. variability between different channel types like pools, riffles, runs, and glides). Additionally, large woody material (LWM) within a river corridor often contributes to the formation and maintenance of habitat diversity (e.g. scour pools, split flows, islands, undercut banks, and cover), therefore the frequency of LWM pieces and key pieces (those over 60cm diameter and over 10m long) has also been evaluated. Finally, the percentage of riffle organics and sand versus gravel has been evaluated as a key metric impacting salmon spawning.

- **Geomorphology** - *Prioritize low-functioning reaches to focus restoration efforts on those areas with the greatest potential uplift.*

Connectivity

Target fish species are migratory and require habitat connectivity to fulfill their various freshwater life stages. Connectivity is evaluated longitudinally based on known barriers to up/down stream movement (e.g. dams, vertical drops, excessive velocity, etc.) and laterally based on known barriers between the stream and surrounding floodplain (e.g. levees, obstructed side channels, etc).

- **Connectivity** - *Prioritized reaches with the greatest amount of disconnected habitat and therefore the greatest uplift potential.*

Riparian Vegetation

Vegetation growing within the riparian area provides structure and nutrients for the stream and floodplain as well as shade to limit high stream temperatures during warm summer months. Taller vegetation implies more mature riparian habitat, greater canopy cover, and increased large woody material recruitment potential. Actual vegetation height derived from LiDAR topography was compared against targets for riparian vegetation height as summarized in Appendix E. Similarly, the effective shade from the existing riparian vegetation was calculated from LiDAR vegetation models to identify areas with the most and the least percent shade cover, which were consolidated into reach-averaged values.

- **Riparian Vegetation** - *Prioritize reaches with the lowest amount of riparian vegetation (height and shade) to focus restoration in areas with the greatest uplift potential.*

Aquatic Biota

Target aquatic species including Chinook salmon, steelhead, and bull trout have been used as indicator species for the sake of evaluating aquatic biota. It has been assumed that where conditions for these indicator species are high quality, so too is the quality for the other aquatic biota associated with them. Physical conditions for the key species were evaluated based on habitat suitability modeling and habitat capacity modeling. Habitat suitability compares known stream depth and velocity preferences per species and life-stage against hydraulic modeling results of depth and velocity predicted (per reach) at the time of year associated with occupancy of a given species and life-stage. Likewise, habitat capacity modeling uses thousands of data points from hundreds of stream sites over many years to predict which suite of conditions provides the most habitat capacity for different species and life-stages. Measurements of these specific conditions can then be used to accurately predict habitat capacity potential within a given area. Appendix H summarizes the methods and results of the habitat suitability and capacity modeling. Results from both models have been averaged per reach and converted to a percentage.

- **Aquatic Biota** - *Prioritize reaches with the lowest habitat suitability and capacity to focus restoration in the areas with the greatest uplift potential.*

Social

In addition to the technical metrics described above, prioritizing stream and floodplain restoration is also dependent on social constraints such as site access and landowner willingness. Site access was evaluated based on perceived constraints or limitations to stream and floodplain restoration primarily associated with existing, certified levees protecting very large amounts of infrastructure. Landowner willingness was evaluated based on the density of parcels within a given reach, assuming more parcels means more landowners, and more landowners reduces the potential for agreement and cooperation between all. Stream and habitat restoration is voluntary, so agreement among stakeholders is essential.

- **Social** - *Prioritize reaches with the fewest social constraints to focus restoration in the areas with the greatest potential for a project to advance successfully through design and implementation.*

The scoring of each metric described above was conducted based on reach-averaged results. Scoring was divided between 0% (absent/dysfunctional) and 100% (abundant/fully functional) as summarized in Table 7.

Where data were missing or unavailable for a specific metric within a given reach, the lowest value from adjacent upstream and downstream reaches was used for metrics derived from habitat surveys and the actual value from the adjacent downstream reach was used for topographic LiDAR derived metrics.

The percentage scores were then converted to values of 1 (low = 0-50%), 2 (moderate = 50-90%) and 3 (high = 90-100%). The sum of each metric score was then tabulated for each criterion, and the sum of each criterion score tabulated to generate the final score per each of the six total prioritization categories. The total prioritization score is summarized per category and overall in Figure 26.

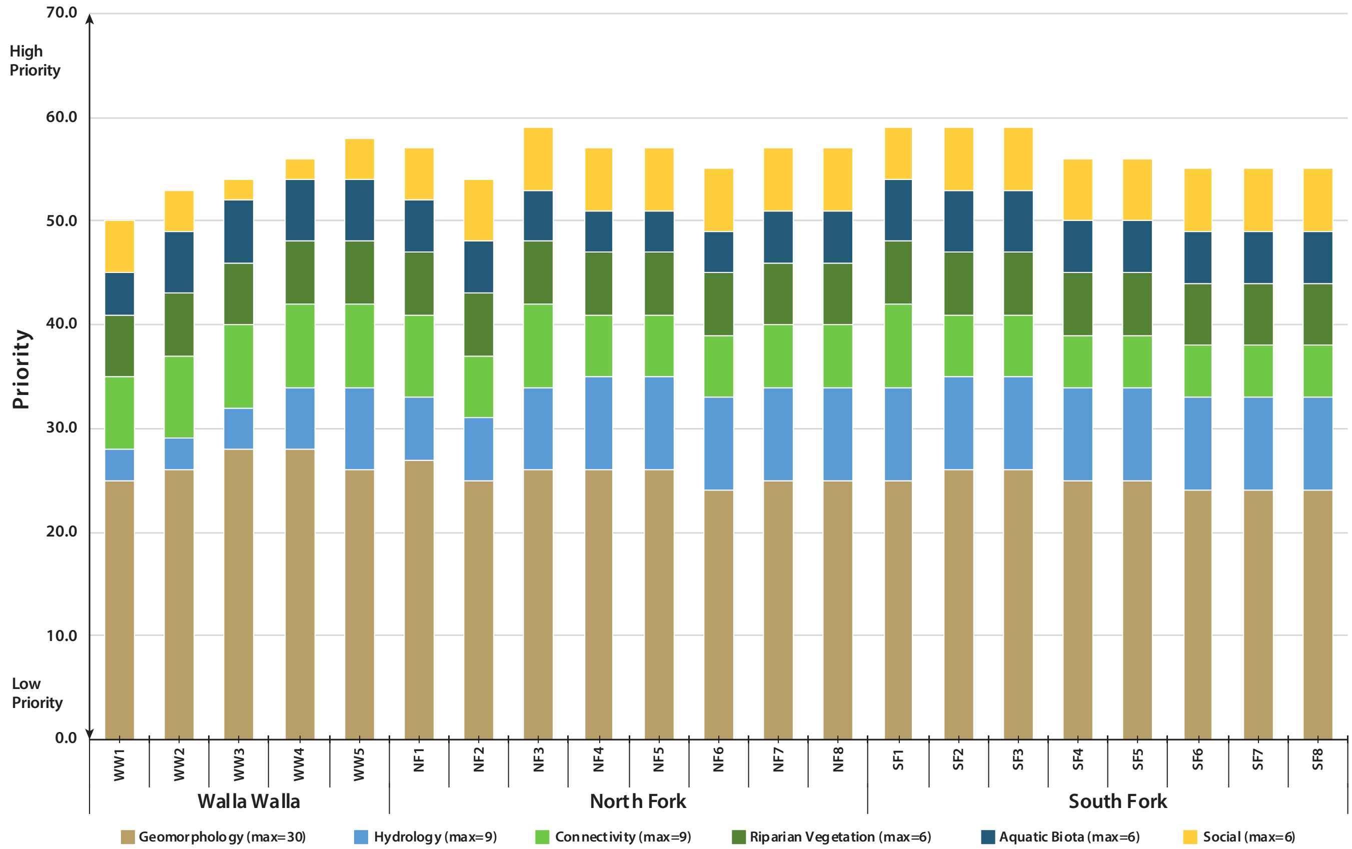
Functional Metric	Metrics are scored on a continuous scale from 0% to 100%, using the performance standards as guide.			
	absent/dysfunctional			abundant/fully functional
	0 – 25%	26-50%	51-75%	76-100%
Ecological Flow Attainment (% of reach length)	calculated %	calculated %	calculated %	calculated %
Mean August Stream Temperature (% of reach BELOW threshold)	calculated %	calculated %	calculated %	calculated %
Proportion (%) of Life Stages Over Max 2040 Modeled August Stream Temp	calculated %	calculated %	calculated %	calculated %
Residual pool depth[1]	< 50% desirable value	50 - 75% desirable value	76 - 100% desirable value	>= desirable value
Width to depth ratio[1]	>= undesirable value (30)	20 to 30	10 to 20	<= desirable value (10)
Entrainment Potential 2-yr Q[2]	calculated %	calculated %	calculated %	calculated %
Pool frequency (channel widths between pools)[1]	>20 or <5	14 to 20	8 to 14	5 to 8
Channel unit frequency (number of geomorphic units per km)[1]	0 - 25% of fully functional	26 - 50% of fully functional	51 - 75% of fully functional	100%-76% of target: Channel width : units/km <3 m: 48-220 3-5 m: 70-120 5-6 m: 60-80 6-8 m: 48-70 8-15 m: 28-60 15-23 m: 6-16 23-30 m: 4-28 >30 m: 4-22
LWM piece frequency (per 100 m)[1]	<10	10 to 15	15 to 20	>=20
Key LWM piece frequency (per 100 m)[1]	<1	1 to 2	2 to 3	>3
LWM volume frequency (m^3 per 100 m)[1]	<20	20 to 25	25 to 30	>=30
Riffle area (%) organics and sand[1]	>= undesirable value (15 or 25)	18 to 15, or 11 to 15	12 to 18, or 8 to 11	<= desirable value (12 or 8)
Riffle area (%) gravel[1]	<= undesirable value (15)	15 to 25	25 to 35	>= desirable value (35)
Valley Inundated Area % (100-y:Valley Bottom)[2]	WW unconfined: < 18	18 to 49	49 to 79	> 79
	WW partly confined: < 37	37 to 64	64 to 91	> 91
	NF/SF partly confined: < 9	9 to 39	39 to 68	> 68
	NF/SF confined: < 36	36 to 56	56 to 75	> 75
Artificial Floodplain Disconnection (Length ratio of reach)[2]	> .50	.20 to .50	.20 to .10	< .10
Instream Barriers Burden			<= 0.99	> 0.99
Vegetative Height Potential Attainment[2]	calculated %	calculated %	calculated %	calculated %
System Effective Shade Potential Attainment[2]	calculated %	calculated %	calculated %	calculated %
Multispecies Habitat Suitability Index[2]	calculated %	calculated %	calculated %	calculated %
Habitat Capacity	calculated %	calculated %	calculated %	calculated %

■ ***Table 7. Metrics Scoring Table***

Notes:

1. Metrics derived from habitat surveys (ODFW 2017)

2. Metrics derived from LiDAR or LiDAR developed hydraulic modeling



■ *Figure 26. Prioritization Category Scores per reach*

Glossary

Term	Definition
Action	Proposed activities to improve selected physical and ecological processes that may be limiting the productivity, abundance, spatial structure or diversity of the focal species. Examples include removing or modifying passage barriers to reconnect isolated habitat, planting appropriate vegetation to reestablish or improve the riparian corridor along a stream that reconnects channel-floodplain processes, placement of large wood to improve habitat complexity, cover and increase biomass.
Active channel	The portion of an alluvial stream considered a short-term geomorphic feature subject to change by prevailing discharges; its upper limit is defined by a break in the relatively steep bank slope of the active channel to a more gently sloping surface beyond the channel edge. The break in slope normally coincides with lower limit of perennial vegetation so that the two features, individually or in combination, define the active-channel reference level.
Aggradation	The raising or elevating of a bottomland surface through the process of alluvial deposition; conceptually it is the vertical component of accretion and is most frequently applied to sediment deposition on a channel bed, bar or other near-channel surfaces, flood plain, or, less often, low-lying alluvial terrace.
Alluvial deposit	alluvium
Alluvium	A general term for detrital deposits made by streams on river beds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time.
Anthropogenic	Caused by human activities.
Armoring	The winnowing of fine particles from the uppermost bed sediment of a stream channel, resulting in a bed-surface layer of generally gravel to boulder sizes that are resistant to scour; because armoring occurs at specific flow rates, the armor layer may be susceptible to removal by higher flow and sedimentation during lower flow.
Avulsion	A rapid change in the course or position of a stream channel, especially by incision (erosion) of lowland alluvium, to bypass a meander and thereby shorten channel length and increase channel gradient; avulsion commonly occurs during floods but also can occur by normal processes of lateral migration of a stream channel during non-flood discharges.
Bank	A sloping margin of a natural, stream-formed, alluvial channel that confines discharge during non-flood flow; within the earth sciences, designation of a right or left bank is done when looking in the downstream direction.
Bankfull discharge	The flow rate when the stage (height) of a stream is coincident with the uppermost level of the banks -- the water level at channel capacity, or bankfull stage. Thus, the concept of bankfull discharge, which often approximates the mean annual flood for perennial streams, includes the flood plain as a unique, identifiable geomorphic surface, all higher surfaces of alluvial bottomlands being terraces, and acknowledgement that bankfull discharge occurs only when stream stage is at flood-plain level.
Bank material	The sediment of which the mostly sloping sides, or banks, of a stream channel are formed; like bed material, it is generally reflective of the size range of the total sediment load of the stream, may be partly residual, but for regime channels is mostly indicative of the suspended-load transported by streams during non-flood periods.
Bar	In-channel sediment of relatively coarse bed material, typically coarse sand through cobbles in size, that is generally deposited during the recession of a high flow and is mostly exposed during periods of low flow.

Term	Definition
Bed	The bottom surface of a water course, generally of a stream channel, upon which water and sediment move during periods of discharge.
Bed load	The sediment that is moved by saltation, rolling, or sliding on or near the stream bed, essentially in continuous contact with it. Also considered as the sediment discharged as bed load.
Bed material	The sediment of which the mostly horizontal bed of a stream channel is formed; it is generally reflective of the size range of the total sediment load of the stream, in many cases may be partly residual, but is mostly indicative of the bed-load sizes transported by the stream.
Bedrock	The solid rock that underlies gravel, soil or other superficial material and is generally resistant to fluvial erosion over a span of several decades, but may erode over longer time periods.
Benthos diversity	A measure of the diversity and production of the benthic macroinvertebrate community; also used to describe the diversity of the physical structure along a streambed (i.e., benthos habitat diversity).
Cfs	Cubic feet per second; a measure of water flows
Channel forming flow	Sometimes referred to as the effective flow or ordinary high water flow and often as the bankfull flow or discharge. For most streams, the channel forming flow is the flow that has a recurrence interval of approximately 1.5 years in the annual flood series. Most channel forming discharges range between 1.0 and 1.8 years. In some areas it could be lower or higher than this range. It is the flow that transports the most sediment for the least amount of energy, mobilizes and redistributes the annually transient bedload, and maintains long-term channel form.
Channel morphology	The physical dimension, shape, form, pattern, profile and structure of a stream channel.
Channel planform	The two-dimensional longitudinal pattern of a river channel as viewed on the ground surface, aerial photograph or map.
Channel units	Morphologically distinct areas within a channel segment that are on the order of at least one to many channel widths in length and are defined by distinct hydraulic and geomorphic conditions within the channel (i.e. pools, riffles, and runs). Channel unit locations and overall geometry are somewhat stage dependent as well as transient over time, and observers may yield inconsistent classifications. To minimize the inconsistencies, channel units are interpreted in the field based on the fluvial processes that created them during channel forming flows, then mapped in a geographic information system (GIS) to provide geospatial reference.
Control	A natural or human feature that restrains a streams ability to move laterally and/or vertically.
Critical shear stress	The lowest required value of shear stress applied by flowing water to initiate motion of individual particles of specified size (diameter) along the bed of a stream.
Degradation	The lowering of a bottomland surface through the process of erosion; conceptually it is the opposite of the vertical component of aggradation and is most frequently applied to sediment removed from a channel bed or other low-lying parts of a stream channel.
Discharge	The movement downstream per unit length of channel of a volume of water; water discharge is given in volume per unit time, typically cubic meters per second. As a sedimentology term, discharge is the movement of a mass of sediment per unit length of channel in a specified time interval; technically it is expressed in watts per meter, but informally it is viewed as mass per unit time. Owing to theoretical considerations, the term sediment-transport rate is preferred to that of sediment discharge.
Diversity	Genetic and phenotypic (life history traits, behavior, and morphology) variation within a population. Also refers to the relative abundance and connectivity of different types of physical conditions or habitat.
Ecosystem	An ecologic system, composed of organisms and their environment. It is the result of interaction between biological, geochemical and geophysical systems.
Extirpation	The loss of a local or regional population, with the species continuing to survive elsewhere.
Fine sediment	Sand, silt and organic material that have a grain size of 2.0 mm or less.
Flood	Any climatically controlled, relatively high streamflow that overtops the natural or artificial banks in any reach of a stream, thereby being of geomorphic significance; where a flood plain exists, a flood is any flow that spreads over or inundates the floodplain.

Term	Definition
Floodplain	The portion of relatively smooth land bordering a stream, built of sediment carried by the stream and deposited in slackwater beyond the influence of the swift current of the channel; the level of the floodplain is generally about the stage of the mean annual flood, and therefore one and only one floodplain level can occur in a limited reach of valley bottom land.
Fluvial	Pertains to the action of a river or stream; included are stream processes (fluvial processes), fluvial landforms, such as fluvial islands and bars, and biota living in and near stream channels. Common usage is often extended by geomorphologists to hydrologic processes on hillslopes.
Fluvial process	A process related to the movement of flowing water that shape the surface of the earth through the erosion, transport, and deposition of sediment, soil particles, and organic debris.
Geomorphic reach	An area containing the active channel and its floodplain bounded by vertical and/or lateral geologic controls, such as alluvial fans or bedrock outcrops, and frequently separated from other reaches by abrupt changes in channel slope and valley confinement. Within a geomorphic reach, similar fluvial processes govern channel planform and geometry resulting from streamflow and sediment transport.
Geomorphology	A composite science in the study of landforms, including investigations into the processes that cause and alter the landforms.
GIS	Geographical information system. An organized collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
Gradient	The rate of elevation change between two specified sites of horizontal distance measured along the thalweg of the channel; it is generally expressed as a non-dimensional number.
Hydrology	The cycle of water movement from the atmosphere to land, surface-water, and ground-water bodies, including movement among land and water bodies, before returning to the atmosphere.
Indicator	A variable used to forecast the value or change in the value of another variable; for example, using temperature, turbidity, and chemical contaminants or nutrients to measure water quality.
Instability	As a descriptor of geomorphic processes and landforms, refers to a condition of imbalance between inflows and outflows of matter through or over a landscape feature. As a geomorphic concept, instability is often expressed as some state of dynamic- or quasi-equilibrium, signifying that geomorphic processes and landforms are almost always in a condition of dis-equilibrium and are almost always adjusting to regain relative stability; an objective if applying the term is to determine the degree to which a process or landform deviates from stability or equilibrium.
Large woody material (LWM)	Large downed trees or parts of trees that are transported and deposited by the river during high flows and are often deposited on gravel bars or at the heads of side channels as flow velocity decreases. The trees can be downed through river erosion, wind, fire, landslides, debris flows, or human-induced activities. Synonymous with large woody debris (LWD).
Limiting factor	Any factor in the environment that limits a population from achieving complete viability with respect to any Viable Salmonid Population (VSP) parameter.
Loess	Wind-blown deposit often of glacial origin consisting of primarily silt and fine sediment.
Meander	One of a series of regular, sharp, freely developing, and sinuous curves, bends, loops, turns, or windings in the course of a stream; the process of stream meandering is a means of channel-gradient adjustment through sorting of stored sediment by erosion at the outside of a bend and deposition, as a point bar, at the inside of the bend.
Pool	A relatively deep, low velocity reach of quiescent flow between upstream and downstream riffles, or rapids, at which the flows are ordinarily more rapid and turbulent.
Pool-riffle sequence	A succession of one or more combinations of pools and riffles along the channel in the downstream direction; during flood the normally low water velocities in pools and higher water velocities at riffles are reversed, causing scour and removal of accumulated sediment from pooled reaches and deposition of bed sediment on riffles.
Reach	An uninterrupted part of a stream channel between two points; generally the two points are where readily recognizable tributary inflows occur, but can also include features such as meander bends, gorges, or a significant change in geology.
Restoration	The attempt to recreate the adjusted physical and biological conditions that were present prior to alteration by human activity; a goal of restoration, therefore, is to minimize and eliminate the effects of human-induced alterations, thus promoting stable landforms, bioproductivity, and species diversity.
Riffle	A short, relatively shallow and coarse-bedded length over which the stream flows at ordinarily higher velocity and greater turbulence than it does through upstream and downstream pooled reaches where cross-sectional areas of the channel are greater, bed material is smaller, and velocities and turbulence are less.

Term	Definition
Riparian area	An ecological term referring to that part of the fluvial landscape inundated or saturated by flood flows; it consists of all surfaces of active fluvial landforms up through the flood plain including channel, bars, shelves, and related riverine features such as oxbow lakes, oxbow depressions, and natural levees. Particularly in arid and semiarid (water-deficient) environments, the riparian zone may support plants and other biota not present on adjacent, drier uplands.
Riverine	That characteristic by which a feature or process pertains to or is formed by a river.
River mile (RM)	Miles measured in the upstream direction beginning from the mouth of a river or its confluence with the next downstream river.
Salmonid	Fish belonging to the family Salmonidae, including steelhead trout and salmon.
Saltation	The process by which sediment, generally of sand size and coarser, bounces along the stream bed by the impact of the flow of water or of other moving particles.
Sediment	Detached fragmental material that originates from either chemical or physical weathering of rocks and minerals and is transported by, suspended in, or deposited by water or air or is accumulated in beds by other natural agencies.
Sediment yield	Sediment-transport rate per unit area, generally from watersheds or drainage basins larger than the field scale; erosion studies, however, may consider sediment yield from smaller areas of the hillslope or plot scale.
Shear	A strain, or change in shape or volume of a body resulting from stress; as applied to fluvial processes and sediment transport, it typically refers to the stress that is exerted on sediment particles by a moving fluid – air, water, and ice.
Shear stress	That portion of stress acting tangentially as a tearing action (as opposed to that portion that acts as a normal stress) to a plane or surface; thus, a sediment particle resting on a channel bed is affected by the shear stress created by water moving on the bed.
Side channel	A distinct channel with its own defined banks that is not part of the main channel, but appears to convey water perennially or seasonally/ephemerally. May also be referred to as a secondary channel.
Sinuosity	A non-dimensional ratio, generally expressed in meters per meter or kilometers per kilometer, of the length of the channel thalweg to the length of the stream valley, measured between the same points.
Slope	Any inclined surface of the earth. As a geomorphic measurement, slope is the inclination, generally measured in degrees departure from horizontal or expressed as a non-dimensional number (meters per meter), of any surface of the earth's landscape (including sub-aqueous surfaces); for application to models of hillslope soil loss, steepness is often used synonymously with slope.
Stability	A condition of approximate balance between inflows and outflows of matter through or over a landscape feature. As a geomorphic concept, stability generally is regarded as being an integration of processes affecting a system and thus has time-independence; the term often is used synonymously with (dynamic or quasi) equilibrium.
Subwatershed	A subwatershed (or sub-watershed) represents the drainage area within a larger defined watershed; synonymous with sub-basin.
Terrace	A relatively stable, planar surface formed when the river abandons its floodplain. It often parallels the river channel, but is high enough above the channel that it rarely, if ever, is covered by over-bank river water and sediment. The deposits underlying the terrace surface are primarily alluvial, either channel or overbank deposits, or both. Because a terrace represents a former floodplain, it may be used to interpret the history of the river.
Thalweg	The line within a stream channel connecting the lowest points at all locations along the channel.
Tributary	A stream feeding, joining, or flowing into a larger stream or lake.
Valley segment	An area of river within a watershed sometimes referred to as a subwatershed that is comprised of smaller geomorphic reaches. Within a valley segment, multiple floodplain types exist and may range between wide, highly complex floodplains with frequently accessed side channels to narrow and minimally complex floodplains with no side channels. Typical scales of a valley segment are on the order of a few to tens of miles in longitudinal length.
Viable salmonid population	An independent population of Pacific salmon or steelhead trout that has a negligible risk of extinction over a 100-year time frame. Viability at the independent population scale is evaluated based on the parameters of abundance, productivity, spatial structure, and diversity.
Watershed	A drainage divide or a "water parting", but common usage of the term has been altered to signify a drainage-basin area contributing water to a network of stream channels, a lake, or other topographic lows where water can collect.

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Additional references are included in each of the Technical Reports found in the Appendices of this Action Plan.

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Upper Walla Walla

Watershed Action Plan

Confederated Tribes of the Umatilla Indian Reservation

Appendix A

Upper Walla Walla Assessment

LANDSCAPE PATTERN AND SOIL STABILITY

Technical Report

September 2024

Technical Report

Rio Applied Science and Engineering

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Landscape Pattern Technical Report

Date: September, 2024

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1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations. The focal fish species of the assessment and action plan consist of the following:

1. Middle Columbia River summer steelhead (ESA-listed Threatened)
2. Columbia River bull trout (ESA-listed Threatened)
3. Spring Chinook salmon
4. Pacific lamprey

The final restoration action plan establishes a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions.

This Appendix provides an overview of landscape characteristics and upland touchstones that support the maintenance of ecosystems, species, and associated ecological processes and interactions within the Upper Walla Walla Assessment watershed. Landscape Patterns and Soils Stability are focal upland touchstones considered within this Appendix, which is structured by general summaries of the following characteristics at the watershed scale: Geology and Geomorphology, Soils and Sediment, Climate and Hydrology, and Land Use and Land Cover. Interactions among these landscape-scale processes and upland touchstones support continued natural production of First Foods for utilization by the CTUIR community.

The Walla Walla Basin is a sub-basin of the Columbia River and is bisected by the Oregon/Washington state line. The Walla Walla River originates on the western slope of the Blue Mountains in the southeastern part of the basin. The North and South Forks of the Walla Walla River converge upstream of the town of Milton-Freewater and flow generally westward across alluvial deposits confined by steep basalt valleys. Downstream of Milton-Freewater, the Walla Walla River flows north and west through farms and pastures and rural development. The lower portion of the basin is characterized as a wide alluvial fan of distributary channels, where spring creeks emerge and provide cool stream flow to the river in the summer. The downstream project extent is defined by the confluence with Dry Creek near Lowden, Washington. The Walla Walla River confluence with the Columbia River is just downstream from where the Snake River and Yakima Rivers enter the Columbia River.

2.0 METHODS AND DATA SOURCES

The Upper Walla Walla basin consists of a total of fifteen 12-digit Hydrologic Unit Code (HUC) subwatersheds (Table 2-1; Figure 2-1). Landscape patterns associated with Upland Vision touchstones are summarized at the HUC 12 scale. Above Milton-Freewater, The South Fork Walla Walla (SFWW) River and North Fork Walla Walla (NFWW) River are main the source waters contributing the Walla Walla (WW) River (Figure 2-2)

Table 2-1: HUC12 Level Subwatersheds in the Walla Walla Watershed

HUC12 Code	HUC 12 Name	Area (Km^2)
170701020704	Cash Hollow-Walla Walla River	21
170701020203	Blue Creek	51
170701020105	Couse Creek	64
170701020103	Lower South Fork Walla Walla River	69
170701020101	Upper South Fork Walla Walla River	71
170701020102	Middle South Fork Walla Walla River	72
170701020702	Cottonwood Creek	73
170701020204	Lower Mill Creek	74
170701020202	Middle Mill Creek	83
170701020201	Upper Mill Creek	87
170701020703	Birch Creek	90
170701020701	Russell Creek	96
170701020704	Garrison Creek-Walla Walla River	96
170701021102	Mud Creek-Walla Walla River	108
170701020104	North Fork Walla Walla River	116

Spatial data sets were obtained from various public sources and analyzed in ESRI's ArcPro GIS software using the NAD 1983 UTM Zone 11N projected coordinate system. Geologic information and spatial data were obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Washington State Department of Natural Resources (WADNR) as well as published maps from the US Geological Survey. Soils data were obtained from the SSURGO (Soil Survey Geographic Database), managed by the Natural Resources Conservation Service (NRCS). Precipitation data were obtained from the PRISM Climate Group, Oregon State University. Land Use and Land Cover were obtained from the USGS, National Land Cover Database (NLCD) Data Set.

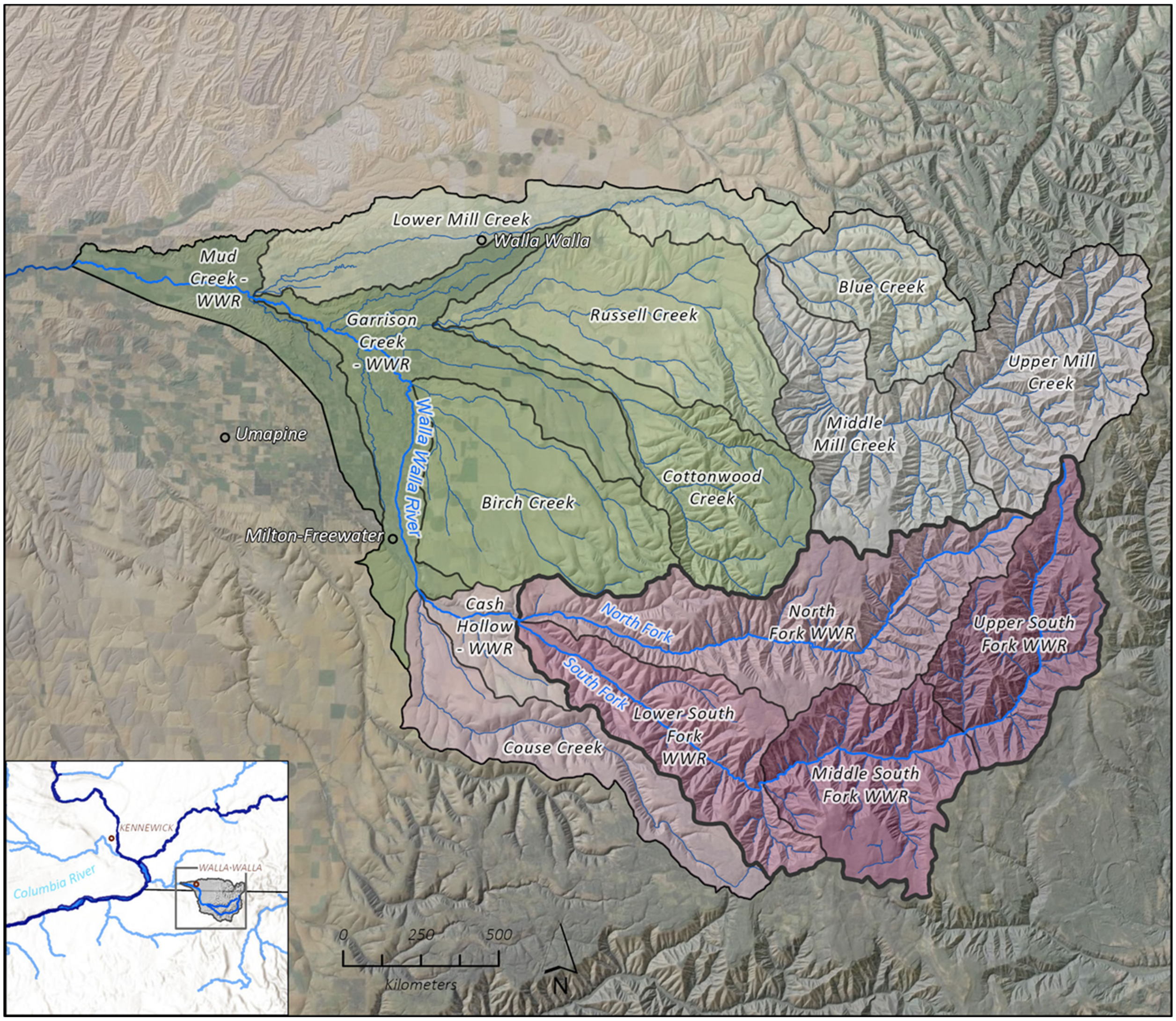

Figure 2-1: Overview Map of HUC12 Level Sub watersheds in the Walla Walla Watershed

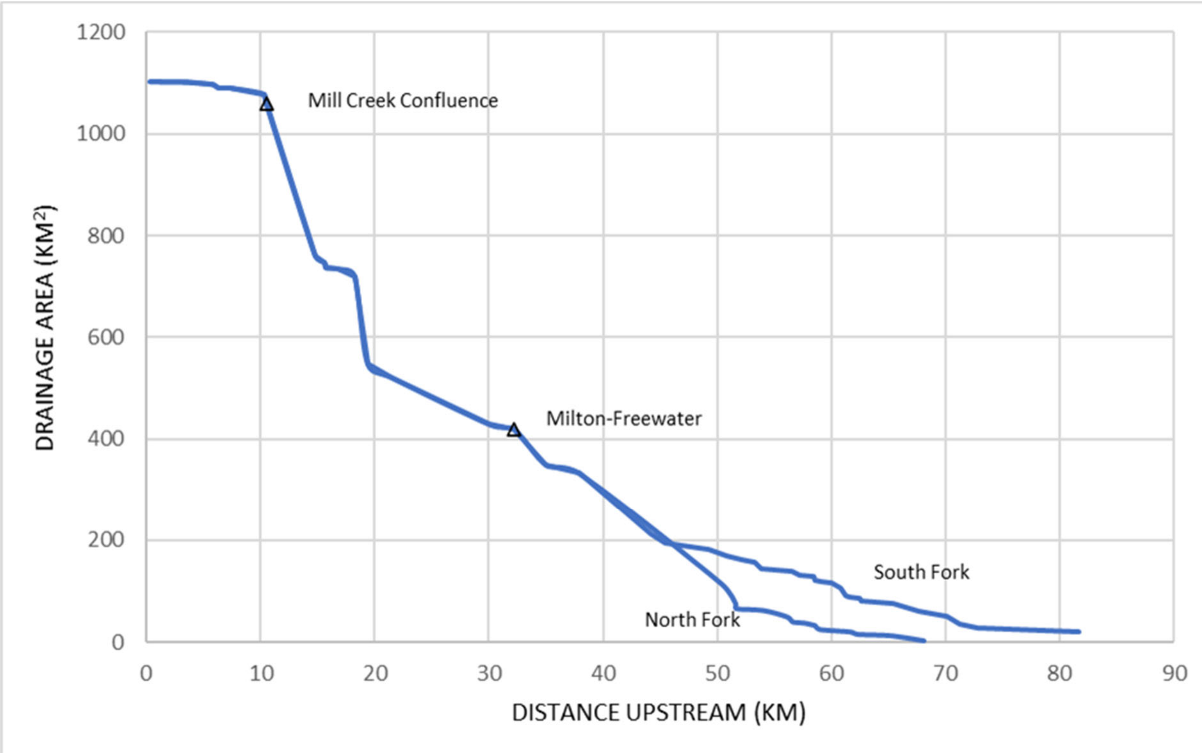

Figure 2-2: Drainage area contributions along the length of study area streams. Two main tributaries – SFWW River and NFWW River – contribute to the Walla Walla (WW) River above Milton-Freewater.

3.0 GEOLOGY AND GEOMORPHOLOGY

The geology and geomorphology of the Upper Walla Walla watershed play a pivotal role in shaping its ecological functions, habitat distribution, and resource availability, which are central to the Upland and River Visions touchstones. This section delves into the geological history and geomorphic processes that define the watershed's landscape, critical for understanding water resources, soil stability, and ecosystem dynamics, as well as for informing sustainable land use and conservation strategies.

The region's landscape is underpinned by a dynamic interplay of volcanic activity, tectonic forces, erosion, and climatic influences over time. The Columbia River Basalt Group (CRBG), comprising multiple thick basalt flows, forms the foundational geology, creating steep hillsides and rugged canyons in the upper watershed. Above these basalt formations, wind-blown loess and alluvial sediments blanket the lower elevations, contributing to the fertile soils that are vital for the area's agricultural productivity. Tectonic activities, such as faulting and uplift, have significantly sculpted the topography, producing distinct features like deep river valleys and prominent basalt outcrops. This section provides a comprehensive overview of these geologic and geomorphic processes, offering insight into the controls on landscape patterns, soil stability, and their implications for the sustainable management of the watershed.

3.1 GEOLOGIC HISTORY AND BEDROCK LITHOLOGY

The geology of the Upper Walla Walla Watershed contains bedrock formations that include sedimentary, volcanic, and metamorphic rocks that can be generally categorized into two distinct lithologies: Miocene basalt members of the CRBG, which underlie approximately 65% of the watershed and Quaternary alluvium and fine-grained surficial deposits, which mainly occur in the lower 35% or the of watershed (Figure 3-1; Table 3-1).

Table 3-1: Distribution of lithology

Lithology	Watershed Area (%)	Geologic Unit	Watershed Area (%)
Unconsolidated Deposits	33.6%	Pleistocene outburst flood deposits	10.7%
		Quaternary alluvium	14.7%
		Quaternary eolian deposits, loess	8.2%
Sedimentary Rocks	1.7%	Quaternary-Tertiary sedimentary rocks and deposits	1.6%
		Miocene sedimentary rocks	0.1%
Columbia River Basalt Group	64.7%	Saddle Mountain Basalt	2.1%
		Wanapum Basalt	13.4%
		Grande Ronde Basalt	49.2%

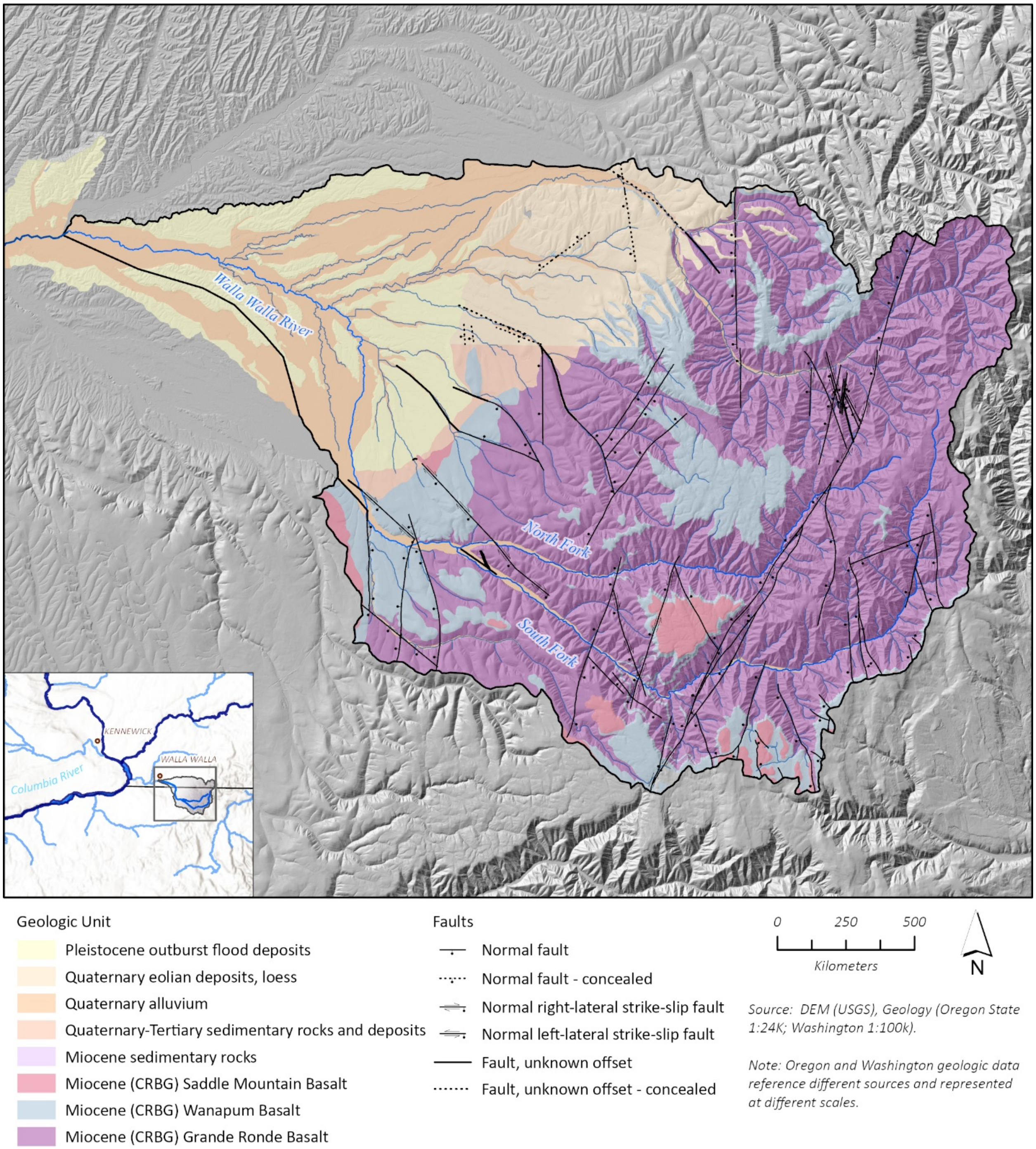

Figure 3-1: Geologic Map of Upper Walla Walla study basin

The CRBG originated from multiple volcanic eruptions during the Miocene (17 and 6 million years ago), which produced extensive lava flows that covered the region. These flows created distinct geophysical formations that resemble layers in a cake, eventually filling the Walla Walla area with up to 3.2 kilometers (2 miles) of Columbia River basalts (Orr and Orr, 2006; Barry et al., 2013). These flows are highly resistant to erosion and form the bedrock in many areas, particularly in the Blue Mountains (Tolan et al., 2019). Three major basalt formations—Saddle Mountains, Wanapum, and Grande Ronde—are present, with the Grande Ronde flows accounting for over 85% of the Columbia River Basalt Group (Newcomb, 1965; Tolan et al., 2019). Basalt flow thicknesses range from 5 to 150 feet, and sedimentary deposits, or paleosols, are found between some layers, indicating soil formation during periods between volcanic activity (Tolan et al., 1989).

The Grande Ronde Basalt is the most voluminous and extensive unit of the CRBG in the Walla Walla region, accounting for over 85% of the total volume of the CRBG. This formation consists of multiple thin, fine-grained flows with low silica content, and is characterized by its dark, dense texture. In the Milton-Freewater area, the Grande Ronde Basalt forms the primary bedrock and significantly influences the topography, providing a foundation for overlying geologic formations. Its layers are highly fractured, making it an essential component of the region’s groundwater system by facilitating the movement and storage of water in the aquifer.

Overlying the Grande Ronde Basalt is the Wanapum Basalt, which includes several members such as the Priest Rapids, Roza, and Frenchman Springs flows. While less voluminous than the Grande Ronde Basalt, these flows are crucial in shaping the local landscape, often forming cliffs and rocky outcrops where erosion has exposed them. The fractured nature of the Wanapum Basalt also contributes to groundwater recharge and flow, making it an important aquifer.

The youngest unit, the Saddle Mountains Basalt, caps the basalt sequence in the region and consists of thinner, more compositionally diverse flows. This formation, although less extensive, is significant for its role in protecting underlying units from erosion and contributing to the area's elevated topography.

Above these basalt layers, sedimentary deposits, including sandstones, siltstones, and conglomerates, are prominent in valleys and lower elevations. These deposits, often reworked by fluvial processes, are more easily eroded, contributing to sediment production in the watershed. Wind-blown loess and alluvial sediments, deposited during the Pleistocene, form deep, fertile soils that are crucial for agriculture, particularly in the lower elevations near Milton-Freewater. These sediments support a diverse agricultural landscape and play a vital role in groundwater recharge

3.2 REGIONAL TECTONICS AND STRUCTURAL GEOLOGY

Tectonic forces have profoundly influenced the topography and geomorphology of the Walla Walla subbasin. Movements of continental plates have caused folding, faulting, and uplifting, creating the southern portion of the subbasin and forming the uplifted basalt plateau that ranges from 915 to 1,800 meters in elevation and dips westward (Newcomb, 1965; Bryce and Omernik, 1997). In the lowlands, gentle slopes result from the gradual subsidence of the Earth’s crust due to the weight of these thick basalt flows. Over these basalts, wind-blown sediments deposited during the Pleistocene glacial periods create fertile soils that, while similar to the Palouse Hills, feature distinct terraced foothills (Tolan, et al., 2009).

Key tectonic structures, including the Walla Walla Syncline, Hite Fault, and Wallula Fault Zone, define regional deformation patterns (Figure 3-1). These structures—comprising thrust, normal, and strike-slip faults—influence topography, sediment transport, and geological stability. The Hite Fault, a major structural feature, has shaped the drainage patterns of the North and South Forks of the Walla Walla River, promoting the development of steep, incised valleys. This thrust fault has experienced significant vertical displacement, contributing to the uplift of the Blue Mountains and displaying evidence of recent tectonic activity during the more recent, late Quaternary period.

The Wallula Fault Zone, southwest of the Upper Walla Walla watershed, affects the broader structural framework and topography, playing a crucial role in shaping the area's landscape. This fault zone, potentially active and capable of generating moderate to strong earthquakes (magnitudes 5.0–7.0), continues to influence the region through ongoing deformation and possible fault reactivation. The Wallula Fault Zone and associated structures create aligned ridges and valleys, guiding surface water flow and affecting groundwater movement, which is crucial for sustaining springs and baseflows in the region's rivers and streams.

The Walla Walla Syncline, a broad fold trending northwest-southeast, is composed of layered basalt flows from the CRBG. This syncline directs surface water flow along its axis and influences the distribution of sedimentary deposits, forming extensive alluvial fans and terraces in the lower watershed near Milton-Freewater and Walla Walla. These tectonic features also impact groundwater flow and the alignment of river channels, often directing streams along fault lines or creating barriers that alter drainage patterns. These faults and folds control sediment delivery and accumulation, contributing to the formation of steep valleys in the upper watershed and broad alluvial plains at lower elevations.

Glacial activity and catastrophic flooding during the last ice age further shaped the subbasin's topography. Massive floods, caused by the periodic breaching of an ice dam on the Clark Fork River in Montana, stripped away surface soils and deposited distinct layers of silt, sand, and gravel, such as those seen in the Touchet Beds of the lower Walla Walla Valley (Orr and Orr, 1996; O'Connor et al., 2021). Observations of Touchet Beds exposed in the lower Walla Walla River suggest it is relatively erosion-resistant compared with other alluvial sediments throughout the lower valley. The interplay of tectonic and geomorphic processes continues to influence the hydrology, soil stability, and resource distribution across the Walla Walla subbasin, affecting both natural ecosystems and human land use.

3.3 GEOMORPHOLOGY

The Walla Walla subbasin features diverse topography, from low-relief plateaus and rolling hills, to steep, high-relief breaks and deeply entrenched valleys with narrow streams (Nesser, 1997). These landforms were shaped by a series of high-magnitude geologic events, including catastrophic prehistoric flooding, volcanic activity, and tectonic movements.

The geomorphology of the headwaters is also shaped by faulting and tectonic uplift, which have influenced the course and incision of the river. Fault zones, such as the Hite Fault, create weaknesses in the rock, allowing the rivers to cut deeply into the landscape. The steep valleys and canyons of the South Fork and North Fork have been shaped by a combination of tectonic uplift, which has raised the land, and fluvial erosion, which has carved the river valleys. These canyons can be as much as 450 meters deep, with narrow, V-shaped profiles that reflect the power of the rivers to transport material and erode the landscape.

Basalt outcrops on these steep slopes are exposed where the overlying soils have been stripped away by erosion or where the slope has been cut by streams and rivers. These outcrops are characterized by their columnar jointing and stratified appearance, which results from the cooling and contraction of the basalt. The outcrops contribute to the ruggedness of the terrain and create areas of high relief with minimal soil cover, supporting only sparse vegetation. The presence of these outcrops can also influence local hydrology, as water percolates through fractures and joints, providing baseflow to streams and springs. The basaltic bedrock generally influences the pattern of stream erosion and sediment transport. Within the river corridor, basalts in the upper reaches contribute gravel and coarser sediments to the river corridor, whereas more recent surficial deposits that dominate the lower relief topography provide a source of mainly silt and finer material.

3.4 HYDROGEOLOGY

As described above, multiple fault systems, including the Hite Fault, Wallula Fault Zone, and others associated with the structural deformation of the CRBG, have shaped the landscape patterns of the Walla Walla. These faults can act as both barriers and conduits for groundwater movement, depending on their orientation, nature, and the types of rock they cut through. In some areas, faults create vertical pathways that allow water to move between otherwise isolated aquifer layers, enhancing the overall recharge and flow dynamics of the basin. In contrast, fault zones that are sealed or impermeable can isolate aquifers, leading to variations in groundwater quality and availability.

In the Walla Walla Basin, many faults cut through the basalt layers of the CRBG, creating discontinuities that can reduce the connectivity between aquifers. For example, the Wallula Fault Zone is a complex system of faults that can compartmentalize the aquifers within the basalt flows, leading to significant differences in groundwater levels on either side of the fault.

Conversely, faults can enhance groundwater flow when they create zones of increased permeability. This occurs when faulting fractures the rock, creating pathways for water to move more easily through the otherwise low-permeability basalt. The Hite Fault, for instance, has been identified as a significant structural feature that influences groundwater movement in the northern part of the basin. Where the fault intersects the basalt flows, it can channel groundwater from higher elevations in the Blue Mountains toward the lower valley areas. This fault-controlled flow can contribute to localized areas of higher recharge and increased groundwater availability.

3.5 SUMMARY

The geology and geomorphology of the Upper Walla Walla watershed are critical to its ecological health and resource management, as highlighted by the Upland and River Vision

Touchstones. The region's landscape is dominated by the CRBG, consisting of extensive Miocene basalt flows that form the foundational bedrock and create the steep, rugged topography of the upper watershed. This bedrock influences surface water and groundwater dynamics, with faults such as the Hite Fault and Wallula Fault Zone playing key roles in shaping drainage patterns and groundwater flow. Overlying these basalts, wind-blown loess and alluvial deposits in the lower elevations contribute to fertile soils, essential for agriculture. The region's tectonic activity has led to the formation of deep valleys and complex structural features that impact soil stability and hydrology. Effective management of these geological and geomorphic processes is essential for maintaining soil integrity, water quality, and ecosystem resilience, ensuring the sustainability of both upland and riparian areas in line with the Upland and River Vision Touchstones.

4.0 SOILS AND SEDIMENT

The Upland Vision Touchstone emphasizes the importance of fertile soils in sustaining the health of upland ecosystems, which in turn nourish the First Foods that are central to CTUIR cultural traditions. This section provides a watershed-scale discussion of the geological history and geomorphic processes in the Upper Walla Walla, which is essential for assessing the region's water resources, soil stability, and ecosystem dynamics, as well as for guiding sustainable land use and conservation efforts.

On the slopes of the Blue Mountains, loess and residuum weathered from basalt are the chief soil materials with limited organic layers. The soil is rocky and shallow to moderately deep. Slope aspect has played an important role on soil development via interactions among solar radiation, water retention, and vegetation. The soils that mantle the south-facing slopes in the valleys of the Blue Mountains consist of weathered basalt and a small amount of loess and are seldom more than 40-cm deep over solid basalt. North-facing slopes are generally mantled by a larger percentage of loess than are the south slopes, and the soil is about a 30-cm deeper (Figure 4-1). Regardless of aspect, well drained soils on steep slopes erode very rapidly once the surface layer of duff is removed. As a result, the upper portions of the watershed have limited soil development. Most soils covering the bottom lands and low terraces have formed from material washed from adjacent uplands and deposited as alluvium on nearly level to gently sloping stream bottoms and flood plains.

4.1 SOIL CHARACTERISTICS AND LANDSCAPE PATTERNS

Volcanic soils, influenced by the CRBG, are dark, fertile, and well-drained, enhancing agricultural potential. The soil pH is generally neutral to slightly alkaline, suitable for a wide range of crops. However, steep slopes are prone to erosion, requiring effective land management to maintain soil health and prevent topsoil loss. Overall, the region’s unique geology and climate create productive soils for agriculture. The soils of the upper Walla Walla watershed are a diverse mix of volcanic ash, basalt-derived materials, and sedimentary deposits, resulting in varied textures, fertility, and drainage properties. Sandy loams, silt loams, and clay loams dominate the upper watershed, known for their good drainage and moderate water retention. Volcanic ash contributes to soil fertility by adding lightness and essential nutrients, promoting healthy vegetation growth.

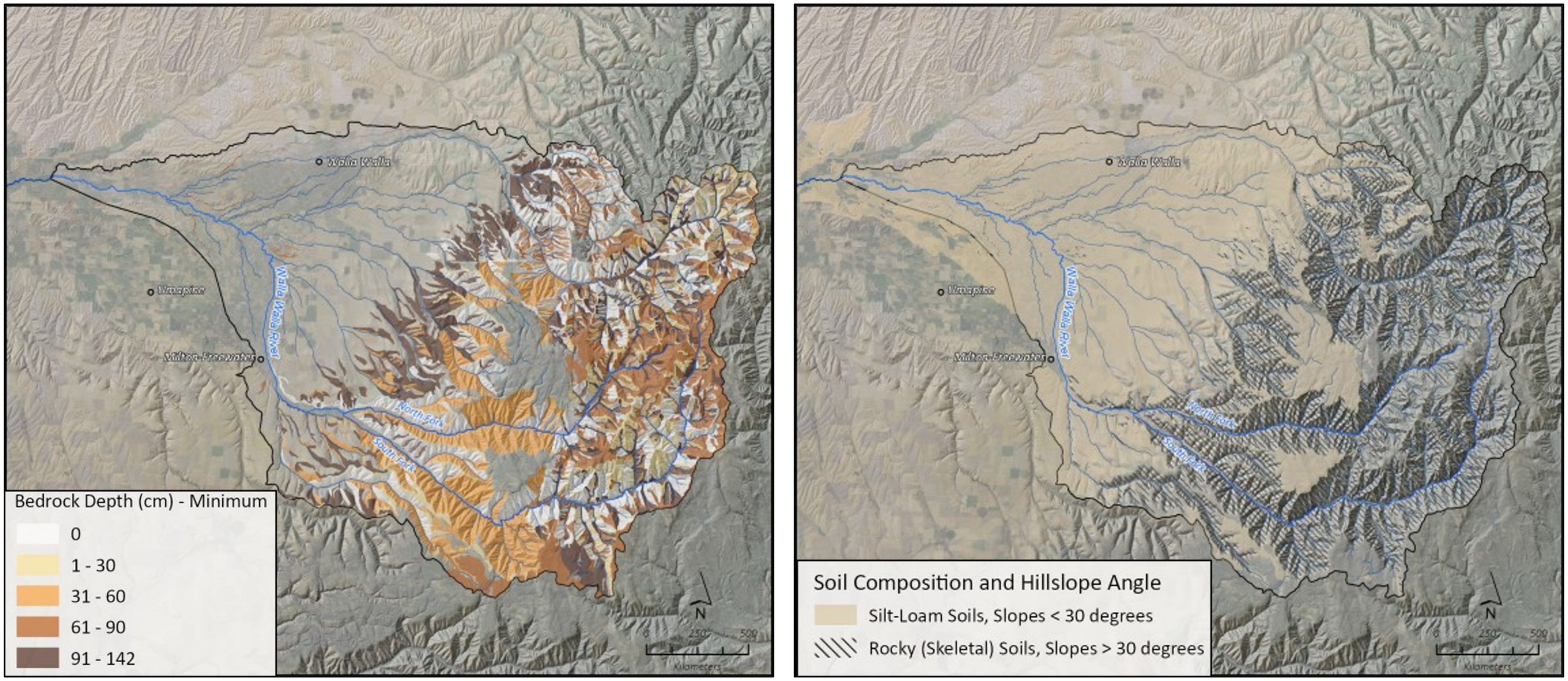

Figure 4-1: Soil thickness (depth to bedrock), composition, and slope angles. The map on the left shows the minimum depth (cm) to bedrock and the map on the right shows the distribution of steep and rocky hillslopes in the upper watershed. Taken together, these two maps illustrate the landscape patterns that influence soil stability and sediment available for delivery to streams. Both maps also highlight the distinct physiographic differences between the upper and lower portions of the Upper Walla Walla.

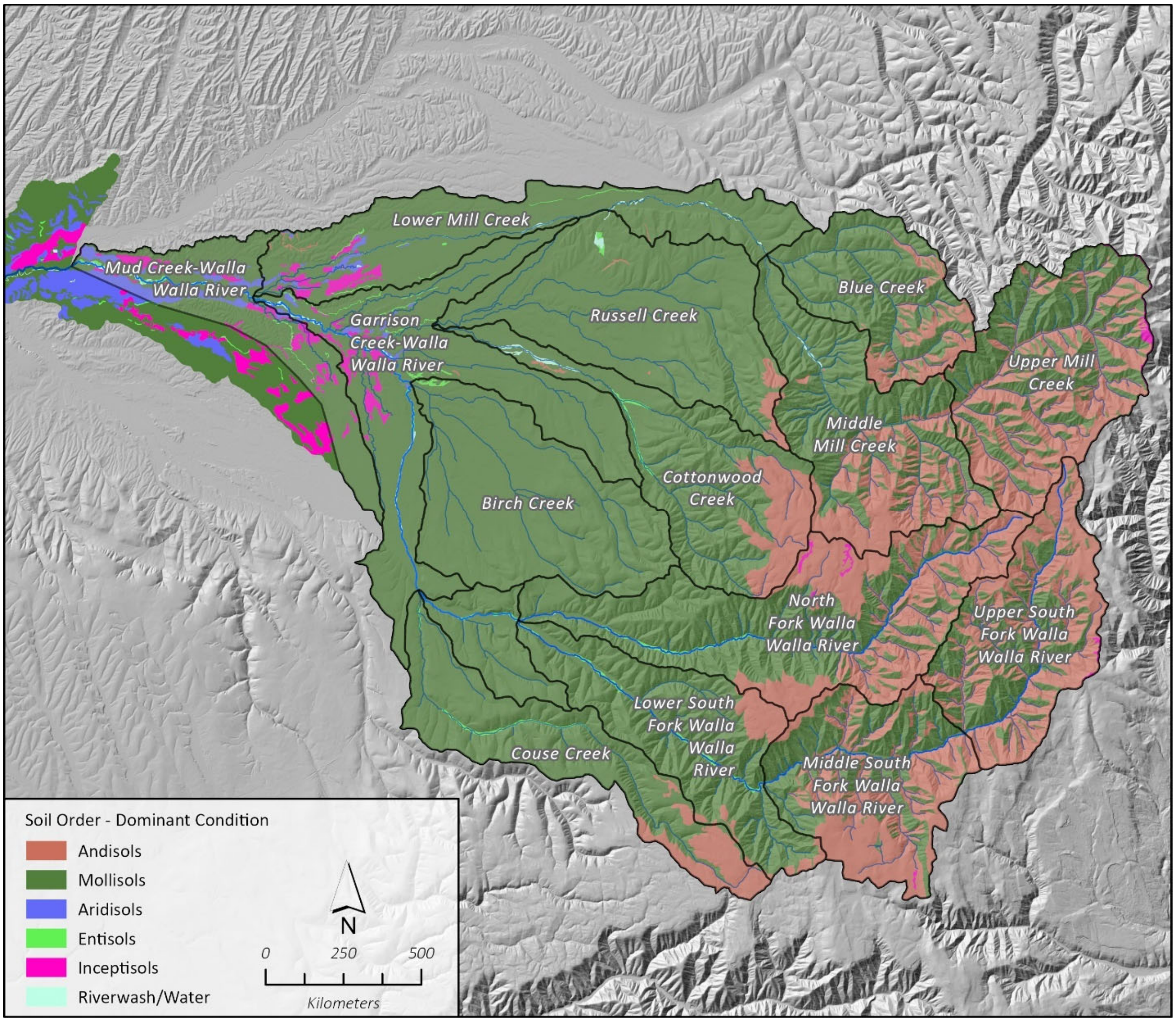

Figure 4-2: Spatial distribution of soil orders

Mollisols dominate the lower and mid-elevation areas of the Walla Walla watershed, particularly in valleys and alluvial plains, where their high organic matter content and deep, soft texture make them highly fertile and suitable for agriculture, including crops such as wheat, vineyards, and orchards. However, their intensive use increases susceptibility to erosion. Implementing sustainable practices like cover cropping and reduced tillage is crucial for preserving soil structure and fertility, aligning with the Upland Vision's emphasis on sustainable land use and soil health.

In the higher elevations, Andisols, derived from volcanic ash, have a porous structure with high water-holding capacity, supporting native vegetation and traditional First Foods like camas. Despite their fertility, these soils are often shallow and prone to erosion on steep slopes, particularly during heavy rainfall events. Conservation measures, such as reforestation and vegetative buffers, are essential to maintaining soil stability and health, in accordance with the Upland Vision's focus on soil conservation and ecological sustainability. The volcanic ash deposits, including those from eruptions of Mount Mazama and Mount St. Helens, contribute to the region's andic soil properties, characterized by high porosity, low bulk density, and significant organic matter content, supporting coniferous forests with species such as Ponderosa pine and Douglas fir.

The South Fork Walla Walla River watershed features steep, rugged terrain with elevations ranging from 450 to 1,800 meters. Soils here, primarily loamy skeletal materials like sandy loams and gravelly loams derived from volcanic ash and basalt, are typically shallow, well-drained, and have a high erosion potential on steeper slopes. The combination of steep topography and a dense road network exacerbates erosion and landslide risks, particularly in areas affected by logging and road construction. Conservation practices, including road decommissioning and reforestation, are critical to mitigating these impacts and maintaining soil and watershed health.

In contrast, the North Fork Walla Walla River watershed has a more diverse topography, with a mix of steep, forested slopes and gentler, rolling uplands. Soils here are deeper and more developed than in the South Fork, with fertile alluvial deposits along the river and valley bottoms that improve water retention and support a variety of vegetation, including riparian habitats. The lower road density and less intensive logging in the North Fork result in relatively lower erosion rates and better soil stability compared to the South Fork.

Balancing sustainable management practices across both upland and river systems is essential for preserving the interconnected health and resilience of the entire watershed. While Mollisols in the lowlands support high agricultural productivity, they are vulnerable to erosion without proper management. Conversely, Andisols in the uplands are more susceptible to runoff and require targeted strategies to maintain soil stability and hydrological function. This integrated approach is vital for sustaining the ecological integrity and cultural resources of the Walla Walla Basin.

4.2 SEDIMENT GENERATION AND SUPPLY

At the watershed scale, suspended sediment constitutes more than 90% of the Walla Walla River total sediment load (Mapes, 1969). Adaptation of these quantified sediment yields, along with measured incision volumes and aggradation rates from multiple literature sources, Beechie et al. (2008) suggested that sediment loads are adequate to achieve aggradation rates of 0.03–0.10 m per year and that with the support of beaver-related restoration, historically incised channels could be reconnected to floodplains within 50 to 100 years (Beechie et al. 2008).

In the upper Walla Walla watershed, sediment supply is heavily influenced by the steep terrain and varying soil stability. The headwaters, particularly the South Fork and North Fork areas, are primary sediment sources due to their steep slopes, thin soils, and frequent basalt outcrops (Figure 4-1). Erosion and landslides are common in these areas, especially during heavy rain or snowmelt, as the shallow Andisols and fractured basalt bedrock provide limited stability (Figure

4-1; Figure 4-2). These upper reaches contribute significant amounts of coarse sediment to the river system, especially in the form of gravel and boulders.

In contrast, the lower watershed acts as a sediment sink. The gentler slopes and broad floodplains allow for the deposition of finer sediments, such as silt and sand, transported from upstream. Deep, fertile alluvial soils accumulate in these lower areas, supporting extensive agricultural activities. Here, sediment deposition is essential for maintaining the productivity of the farmland, while the flat terrain reduces the risk of erosion compared to the upper watershed. Overall, the upper watershed serves as a primary sediment source, while the lower watershed functions as a sediment sink, balancing the region's sediment dynamics.

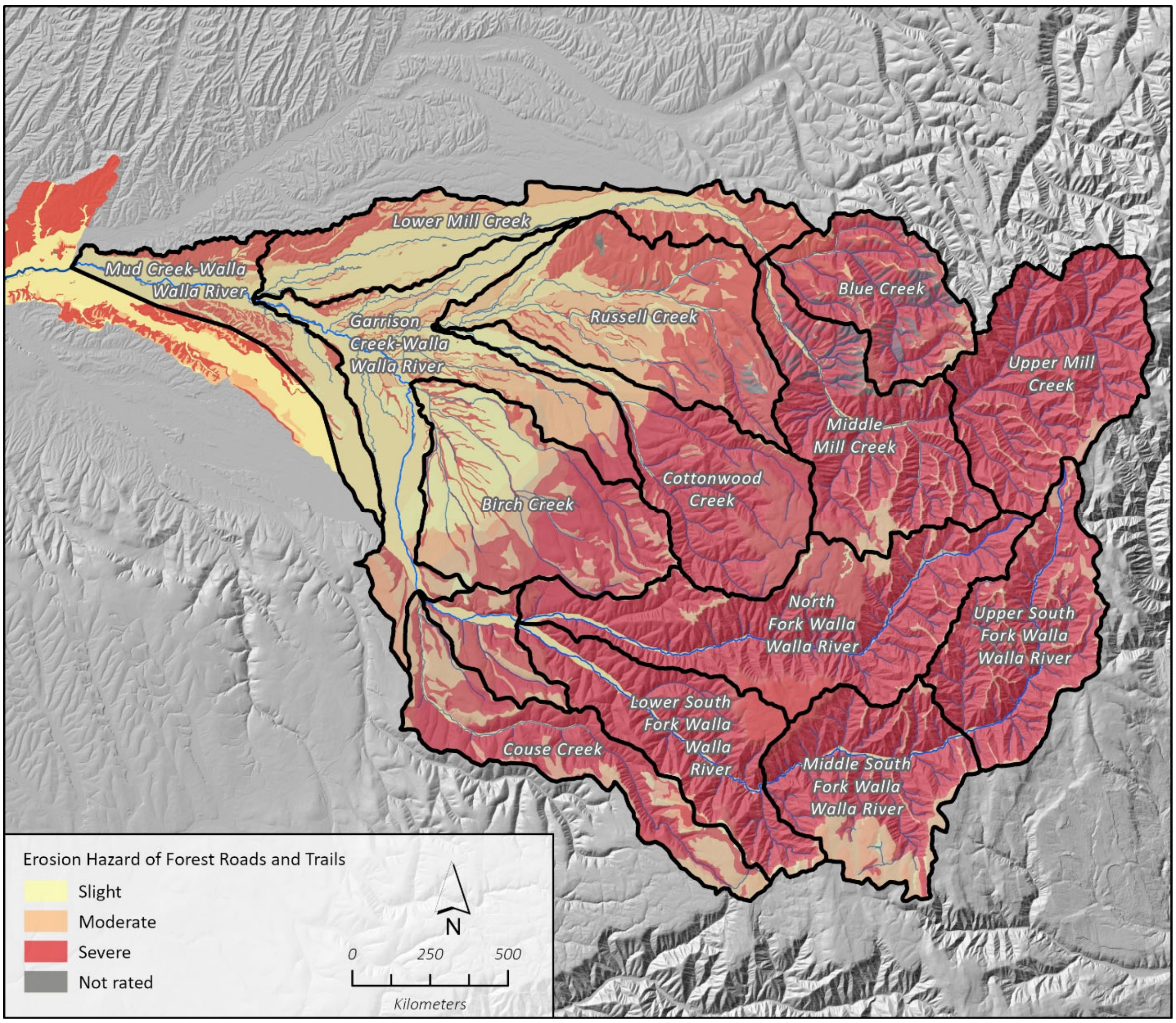

Figure 4-1: Soil Erosion Hazard

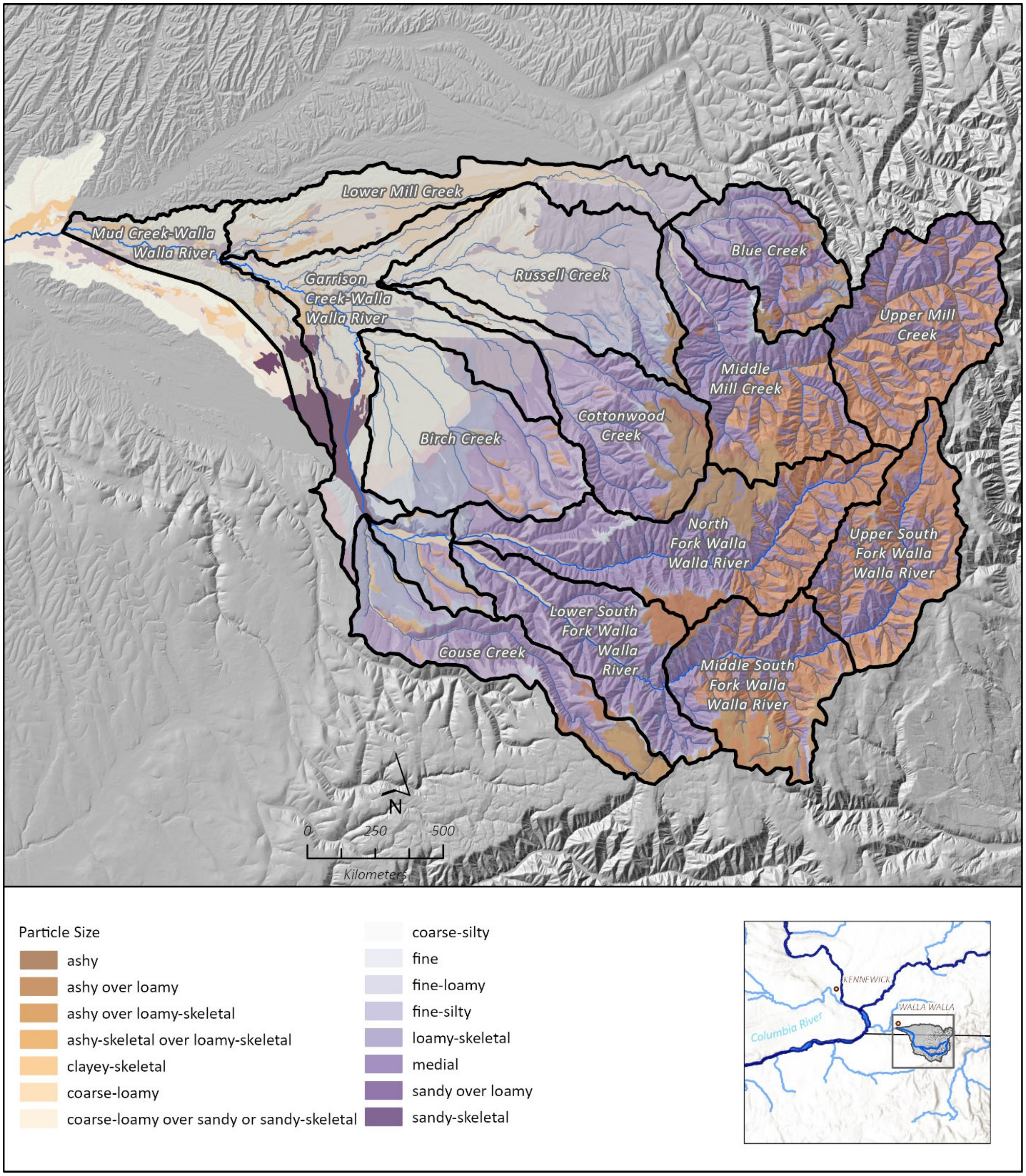

Figure 4-2: Soil size distributions

4.3 SUMMARY

The geology and geomorphology of the Upper Walla Walla watershed significantly influence soil characteristics, slope stability, and sediment delivery to streams, all of which are integral to the ecological functions and cultural values emphasized by the Upland and River Vision Touchstones. In the upper watershed, steep slopes and thin, rocky Andisols derived from volcanic ash and basalt are highly susceptible to erosion and landslides, particularly during intense rainfall or snowmelt. The unstable nature of these soils, combined with fractured bedrock, makes these areas major sources of sediment, including gravel and boulders, which are transported downstream. Tectonic activity, such as movement along the Hite Fault, can trigger mass wasting events that further contribute to sediment loads in streams, impacting water quality and aquatic habitat (Beechie et al., 2008; Tolan et al., 2009). These dynamics underscore the need for effective land management practices in the uplands to maintain slope stability and minimize sediment delivery to waterways.

In contrast, the lower watershed serves as a sediment sink, where gentler slopes and broad floodplains promote the deposition of finer sediments such as silt and sand. These deep, fertile Mollisols, formed from loess and alluvial deposits, support extensive agricultural activity but are also vulnerable to erosion if not managed properly. The interplay between upland erosion and downstream sediment deposition highlights the critical role of integrated watershed management. Sustainable practices like reforestation, controlled grazing, and the establishment of riparian buffers are essential to reduce erosion, stabilize soils, and manage sediment transport effectively (Beechie et al., 2008; Reidel et al., 2002). Such strategies are vital for protecting soil health, maintaining water quality, and supporting both agricultural productivity and ecological resilience in the Walla Walla Basin, aligning with the broader goals of the Upland and River Vision Touchstones.

5.0 CLIMATE AND HYDROLOGY

In the Upland and River Vision Touchstones framework, climate and watershed hydrology play a crucial role in sustaining the ecological health and availability of First Foods in the Upper Walla Walla, as seasonal precipitation and snowmelt drive surface water and recharge groundwater, supporting the interconnected upland and riparian ecosystems essential for cultural and ecological resilience. This section provides a general summary of the hydrological patterns and processes in the Upper Walla Walla and implications of climatic shifts and agricultural demands on future water availability.

5.1 HISTORIC HYDROCLIMATE CONDITIONS

The Upper Walla Walla region experiences a semi-arid to temperate climate, with seasonal variations driven by its location in the rain shadow of the Cascade Mountains. Winters are typically cold and moderately wet, while summers are hot and dry (winter temperatures average slightly above freezing, 0°C and summer temperatures average 23°C (Table 5.1)). Precipitation is concentrated in the late fall, winter, and spring months, with winters bringing both rain and snow, especially at higher elevations. Average annual precipitation is approximately 50 cm, with much of it occurring during the winter months (Table 5.2).

Rainfall patterns in the Upper Walla Walla are heavily influenced by elevation and topography. The lower elevations receive less precipitation, averaging around 40 cm annually, while the higher elevations, such as the Blue Mountains, can receive significantly more, up to 100 cm per year (Figure 5-1). Snowfall is a key contributor to the region's water supply, particularly in the upland areas where snowmelt feeds streams and rivers during the warmer and dryer months of the year. Summer months are typically very dry, with less than 15% of annual precipitation occurring from June to August.

Table 5.1: Historical Temperatures

Time Period	Annual Avg. Temp (°F)	Winter Avg. Temp (°F)	Spring Avg. Temp (°F)	Summer Avg. Temp (°F)	Fall Avg. Temp (°F)
1900-1950	50.2	35.1	48.3	70.5	49
1951-2000	50.8	35.5	49	71	49.5
2001-2020	51.5	36	50.2	72.5	50
2021-Present	52	36.3	50.5	73	50.5

Table 5.2: Historical Precipitation

Time Period	Annual Precipitation (cm)	Percent Rain (%)	Percent Snow (%)	Winter Precipitation (%)	Spring Precipitation (%)	Summer Precipitation (%)	Fall Precipitation (%)
1900-1950	47	60	40	40	25	10	25
1951-2000	48	63	37	38	27	12	23
2001-2020	50	65	35	35	30	12	23
2021-Present	51	67	33	36	29	13	22

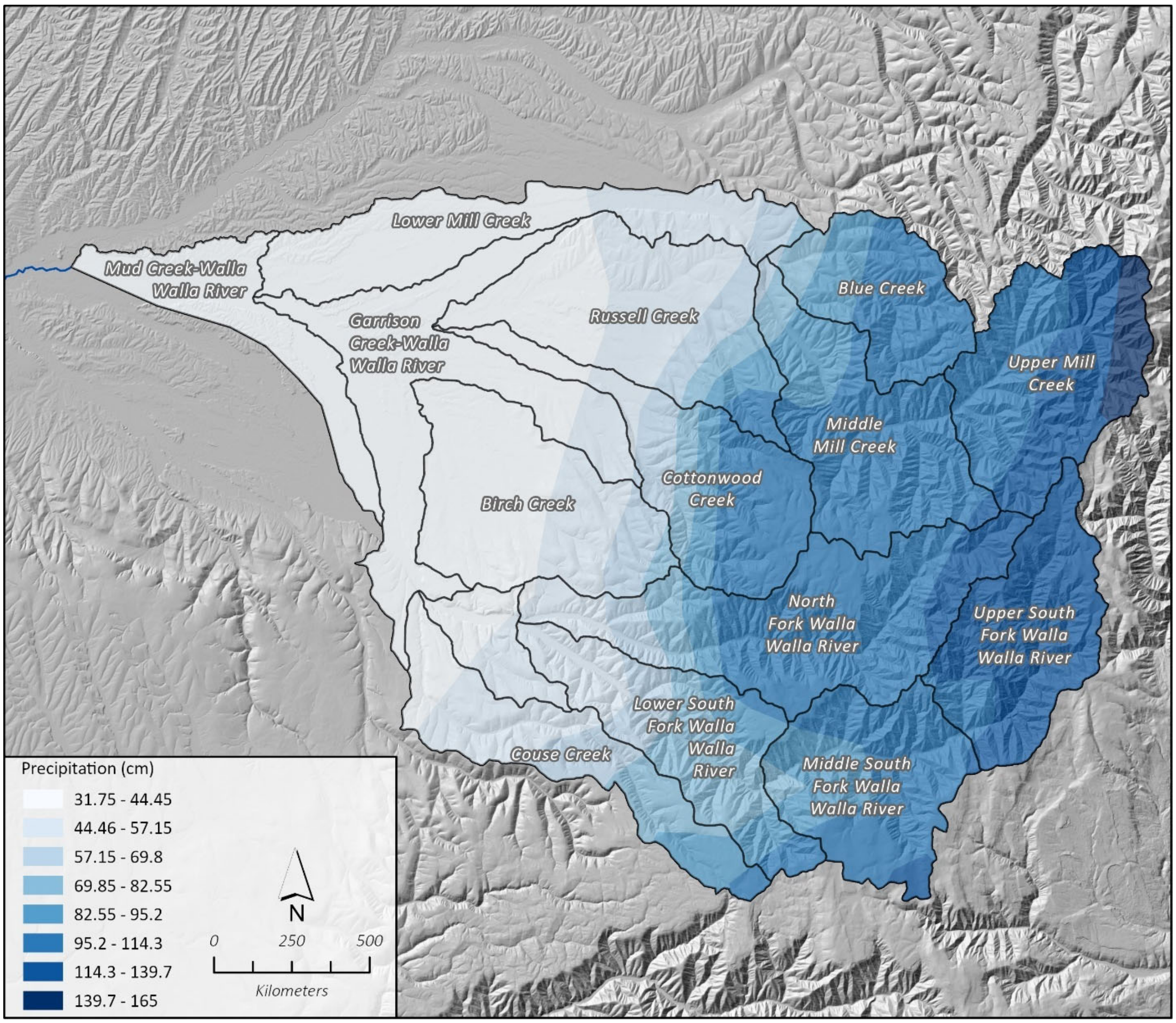

Figure 5-1. Spatial Patterns of Precipitation

5.2 GROUNDWATER WATER RESOURCES

Groundwater resources in the Upper Walla Walla watershed are vital for supporting both ecological health and cultural values, as outlined in the Upland and River Vision Touchstones. The region's groundwater is primarily stored in two types of aquifers: basalt aquifers associated with the CRBG and highly productive alluvial aquifers in the valley bottoms. The CRBG aquifers consist of multiple basalt flows, such as the Grande Ronde and Wanapum basalts, interspersed with sedimentary interbeds that create distinct permeable zones, known as interflow zones, which facilitate groundwater movement. These fractured and permeable layers provide pathways for groundwater flow, particularly in the interbedded sedimentary deposits, which can store significant volumes of water and sustain baseflows in the Walla Walla River and its tributaries during dry periods (Burns et al., 2012; Tolan et al., 2009).

Groundwater recharge in the upper watershed is primarily driven by precipitation, snowmelt, and stream infiltration. Recharge rates vary based on soil type and topography, ranging from 2 to 8 cm annually. In the upland areas, shallow Andisols and fractured basalt bedrock can limit infiltration capacity, making these regions susceptible to surface runoff and erosion (Figure 4-; Figure 5-2). Sustainable land management practices, such as reforestation, controlled grazing, and maintaining vegetative cover, are crucial to enhancing groundwater recharge and preventing erosion that could disrupt water quality and availability.

In the lower watershed, alluvial aquifers, composed of unconsolidated deposits of sand, gravel, silt, and clay, play a significant role in supporting the region's extensive irrigation and municipal water needs. These aquifers are highly porous and permeable, with hydraulic conductivity often exceeding 30 meters per day in coarser gravel and sand layers. This allows for rapid groundwater movement and high well yields, with some wells producing between 500 and 1,000 gallons per minute, depending on location and depth (Washington State Department of Ecology, 2005). However, the high permeability of these aquifers also makes them vulnerable to contamination from agricultural runoff, particularly from nitrates and pesticides. Nitrate levels exceeding the U.S. EPA's maximum contaminant level of 10 mg/L have been reported in several monitoring wells in agricultural zones, posing risks to drinking water safety and long-term aquifer health (Harter et al., 2002; Vaccaro et al., 2009).

Recent changes in water use, driven by agricultural expansion, urban growth, and climate variability, have increased pressure on these groundwater resources (Figure 5-3). The region has experienced more frequent and severe droughts, leading to reduced surface water availability and increased reliance on groundwater for irrigation and municipal use. This has resulted in declining groundwater levels, with some areas showing drops of 3 to 5 meters over the past few decades (Washington State Department of Ecology, 2005). Changes in snowpack levels in the Blue Mountains have also affected seasonal runoff patterns, reducing spring and summer streamflows, which exacerbates water shortages during the growing season and impacts the timing and quantity of water available for both irrigation and ecological needs (Burns et al., 2012; Tolan et al., 2009).

To ensure the sustainability of groundwater resources, adaptive management strategies are needed, including efficient irrigation practices, enhanced monitoring of water quality and quantity, and collaborative efforts among agricultural, urban, and environmental stakeholders. These measures are crucial for maintaining the long-term viability of the region's groundwater systems, supporting both cultural and ecological values, and aligning with the goals of the Upland and River Vision Touchstones.

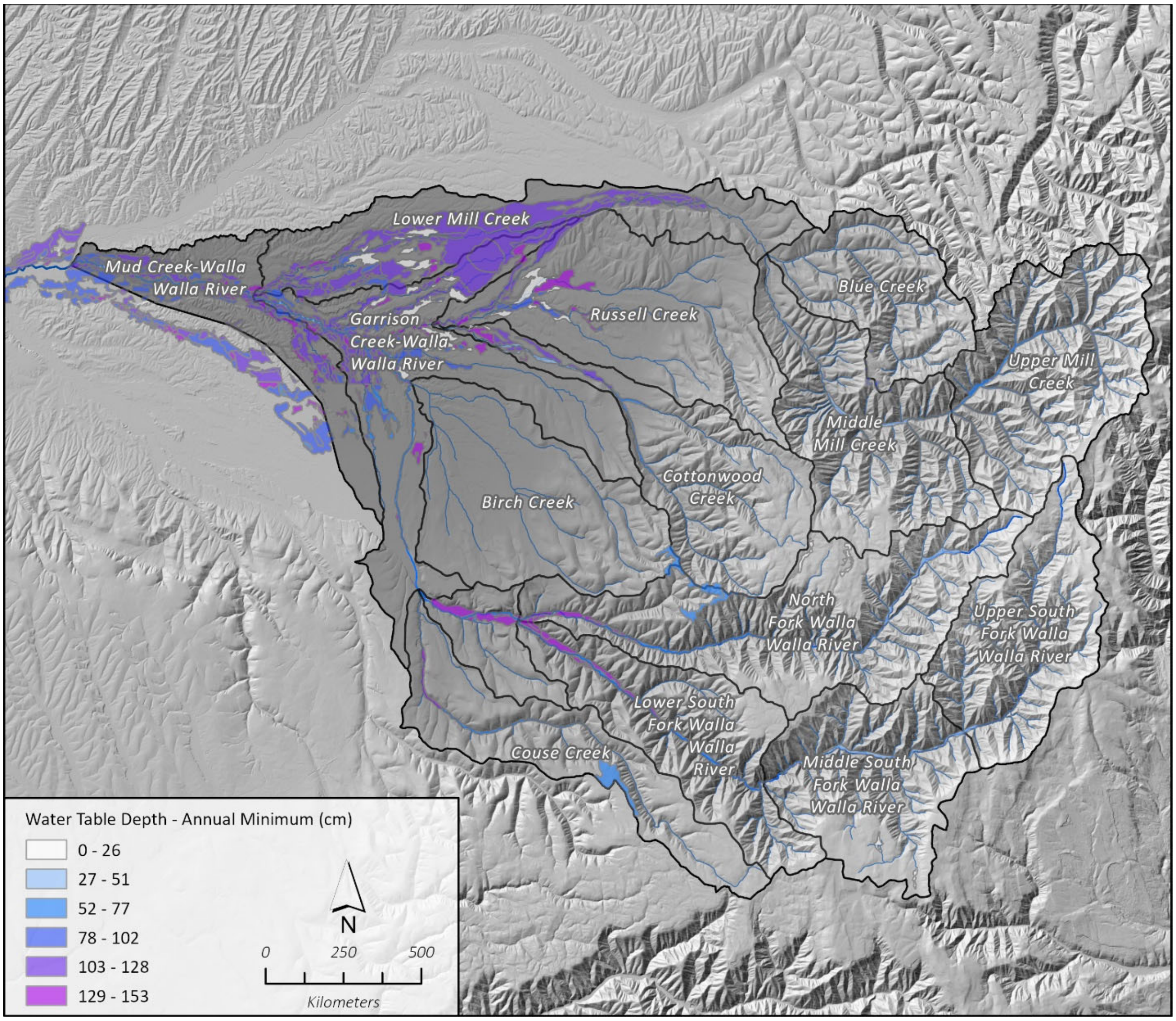

Figure 5-2: Annual minimum depth from the surface to the water table. Alluvial sediments in valley bottoms in the upper watershed allow for perennial groundwater storage and flow. In the lower watershed, depth to the water table is greater because of deeper and more permeable soils (e.g., Figure 4-).

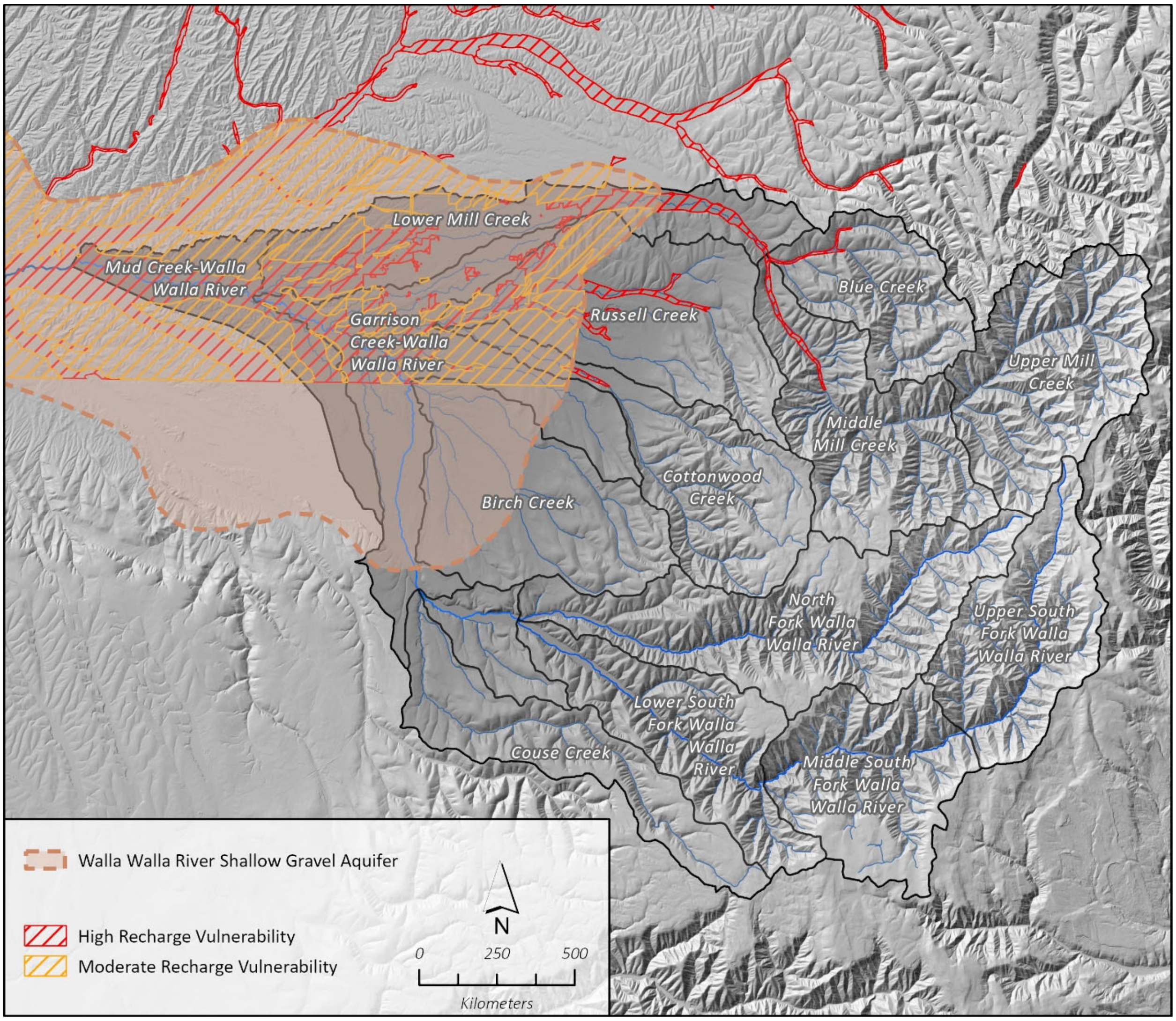

Figure 5-3. Walla Walla alluvial aquifer and recharge vulnerability

5.3 SUMMARY

The climate and hydrology of the Upper Walla Walla watershed are critical to sustaining both ecological health and cultural values, as emphasized in the Upland and River Vision Touchstones. The region's semi-arid to temperate climate, characterized by cold, wet winters and hot, dry summers, influences water availability through seasonal precipitation and snowmelt. These hydrological patterns are vital for recharging groundwater and supporting interconnected upland and riparian ecosystems. However, shifts in climate, such as reduced snowpack and altered precipitation patterns, pose significant challenges to water availability, impacting both natural habitats and agricultural needs. Groundwater, primarily stored in basalt and alluvial aquifers, is essential for maintaining baseflows in the Walla Walla River and its tributaries, particularly during dry periods. Effective management practices that enhance groundwater recharge and limit over-extraction are necessary to support these water resources.

The watershed’s geological structure, with its complex fault systems, significantly influences groundwater movement, recharge, and quality. The basalt aquifers, characterized by interflow zones that facilitate groundwater flow, and the highly productive alluvial aquifers in the valley bottoms, are key sources of water for agriculture and municipal use. However, declining groundwater levels due to over-extraction, combined with contamination risks from agricultural runoff, threaten the sustainability of these resources. To address these challenges, adaptive management strategies that integrate sustainable irrigation practices, land use planning, and water quality monitoring are essential. Collaborative efforts involving agricultural, urban, and environmental stakeholders will be crucial for ensuring the long-term resilience and sustainability of the Upper Walla Walla watershed’s water resources in the face of growing demands and climate variability.

6.0 LAND USE AND LAND COVER

6.1 HISTORIC PATTERNS

The Upper Walla Walla Watershed is characterized by a diverse range of natural and human-influenced landscapes that reflect geographical, ecological, and socio-economic characteristics. The watershed is primarily known for its agricultural activities, which include dryland farming, irrigated agriculture, and livestock grazing (Table 6-1). The fertile soils and favorable climate conditions make it ideal for producing wheat, barley, peas, and, more recently, vineyards, particularly in the Walla Walla Valley.

Table 6-1: Land Use and Land Cover

Land Use/Land Cover	Description	Percent of watershed (%)
Agriculture	Primarily dryland farming (wheat, peas) and irrigated crops (grapes, orchards).	45
Rangeland	Grazing of livestock, particularly on grasslands and foothills.	25
Forested Areas	Dominated by coniferous forests, mostly in higher elevations.	15
Urban Areas	Small urban development around Walla Walla and surrounding communities.	5
Wetlands/Riparian Zones	Riparian areas along rivers and streams, important for biodiversity and habitat.	3
Conservation Lands	Lands managed for ecological restoration and wildlife conservation.	5
Recreation Areas	Public lands for hiking, camping, and other recreational activities.	2

The upper elevations of the watershed are dominated by forested areas, primarily managed for timber production, recreation, and wildlife habitat conservation (Figure 6-1). These forests include a mix of coniferous species, such as Ponderosa pine, Douglas fir, and Grand fir, with logging being a historically significant industry. There are small urban and residential developments within the watershed, with the city of Walla Walla being the most significant urban center. These areas are expanding gradually, influenced by the growth of the local wine industry and tourism.

The watershed provides numerous recreational opportunities, including hiking, fishing, camping, and hunting. The Blue Mountains, which are part of the watershed, are a popular destination for outdoor activities, drawing visitors from the region. Significant portions of the watershed are dedicated to conservation efforts, aimed at protecting critical habitats for fish and wildlife. The Walla Walla River and its tributaries are crucial for the survival of endangered fish species like the steelhead and bull trout, leading to extensive habitat restoration projects.

The watershed is a vital source of water for agricultural irrigation, municipal use, and ecological sustainability. Groundwater and surface water management are critical issues due to the competing demands and periodic drought conditions. Managing these competing interests is a key challenge for ensuring the long-term sustainability of the watershed's natural resources.

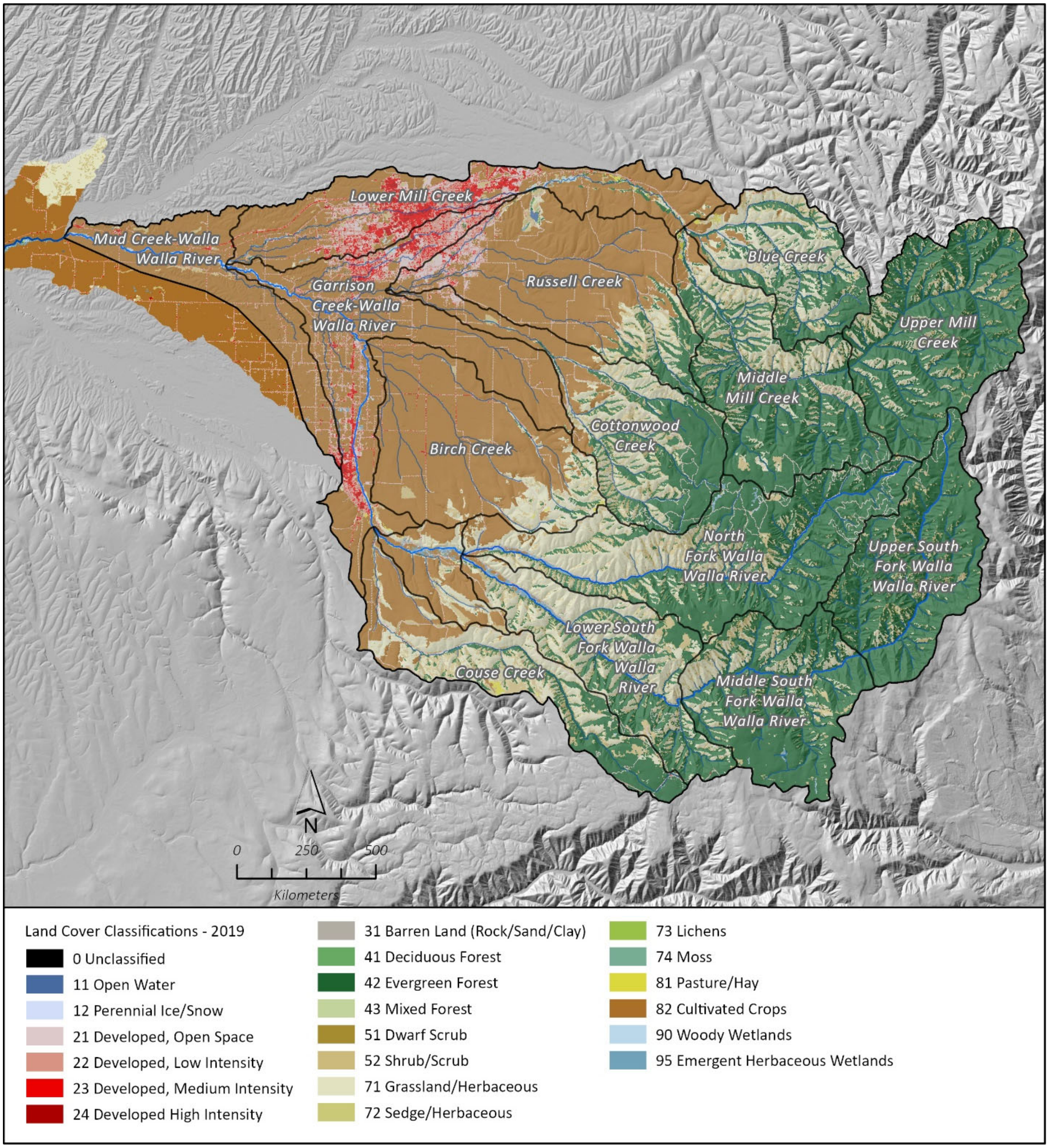

Figure 6-1: Spatial distribution of Land Cover

6.2 FUTURE CONSIDERATIONS

Water resources in the Upper Walla Walla watershed are crucial for supporting both ecological functions and agricultural demands, as outlined in the Upland and River Vision Touchstones. Climate change and future agricultural needs are expected to place additional stress on these resources, necessitating proactive management strategies.

Climate variability has further complicated water management. Increased frequency of droughts and variable snowpack levels in the Blue Mountains have led to reduced streamflows and heightened reliance on groundwater during dry periods (Halofsy and Peterson, 2017). Climate models predict more frequent and severe droughts in the Pacific Northwest, leading to reduced surface water availability and increasing reliance on groundwater for both agricultural and municipal needs. This can decrease groundwater recharge rates, particularly in the upland areas where shallow soils and fractured basalt bedrock already limit infiltration. Reduced recharge can lower groundwater levels, affecting baseflows in the Walla Walla River and its tributaries, which are vital for maintaining aquatic habitats and supporting fish populations like steelhead and bull trout (Isaak et al., 2017). The Blue Mountains, which provide much of the watershed’s snowmelt, are experiencing changes in snowpack dynamics due to warmer winter temperatures. Reduced snowpack and earlier snowmelt alter the timing and volume of water entering the groundwater system, potentially leading to lower summer baseflows in streams that rely on groundwater discharge (Elsner et al., 2010). This affects the River Vision’s goal of maintaining cool, clean water for culturally significant aquatic species and the overall health of riparian ecosystems.

The Walla Walla Valley has seen an increase in high-value crops like vineyards and orchards, some of which require more water compared to traditional dryland farming. This trend is likely to continue, increasing demand for groundwater resources, particularly during dry growing seasons. Over-extraction of groundwater could further lower aquifer levels, impacting streamflows and riparian habitats downstream (WWBWC, 2017). As agricultural demand grows, there is potential for conflicts between water use for irrigation and the need to maintain instream flows for ecological and cultural purposes. Managing this competition requires balancing water allocations through measures such as water banking, efficiency improvements, and policies that prioritize instream flows during critical periods (Washington State Department of Ecology, 2019).

To address these challenges, integrated management approaches are necessary. Enhancing natural recharge through practices such as reforestation, wetland restoration, and improved soil health can help increase groundwater reserves. Adopting water-efficient irrigation technologies and developing collaborative water-sharing agreements among stakeholders are essential for ensuring the resilience of the watershed’s water resources.

Overall, climate change and increased agricultural demand are expected to strain groundwater resources in the Upper Walla Walla watershed. Proactive management strategies, guided by the Upland and River Vision Touchstones, are critical for sustaining both ecological health and agricultural productivity in the face of these challenges.

7.0 SUMMARY

The Upland Vision Touchstone highlights the crucial role of fertile soils in supporting healthy upland ecosystems, which are essential for sustaining First Foods integral to the cultural traditions of the CTUIR. The interaction between geology, geomorphology, and hydrology shapes the landscape, influencing both the Upland and River Vision Touchstones. The rugged terrain of the upper watershed, characterized by steep slopes, basalt outcrops, and shallow Andisols, creates diverse microhabitats vital for native plant species such as camas and huckleberries and provides essential habitat for wildlife like deer and elk. These upland areas are key for water infiltration and groundwater recharge, supporting the broader hydrological health of the watershed.

The River Vision Touchstones focuses on maintaining healthy riparian and aquatic ecosystems, which are shaped by the geomorphic and hydrologic characteristics of the river system. In the headwaters, the steep slopes and narrow canyons create high-energy stream environments that influence water flow and sediment transport, forming complex habitats critical for aquatic First Foods like salmon and steelhead (Table 7-1). Conversely, in the lower river valleys, gentler topography and alluvial soils create sediment sinks that support diverse riparian vegetation, essential for nutrient cycling and water quality (Table 7-1). Effective management practices such as erosion control, reforestation, and habitat restoration must incorporate these geological and geomorphic factors to enhance the watershed's resilience and ensure the continued availability of culturally significant resources.

Table 7-1: Summary of Watershed Characteristics

	Upper Watershed (Upstream of Milton-Freewater)	**Lower Watershed (Downstream of Milton-Freewater)**
Terrain	Steep, rugged hillslopes and narrow valleys	Gentle slopes, broad valleys, and floodplains
Elevation Range	457 - 1,800 meters (1,500 - 6,000 feet)	150 - 300 meters (500 - 1,000 feet)
Topography	High-relief, V-shaped valleys	Low-relief, rolling hills, and flat floodplains
Dominant Soil Type	Thin, rocky soils (Andisols)	Deep, fertile soils (Mollisols, alluvial deposits)
Sediment Dynamics	Major sediment source due to high erosion rates	Sediment sink with significant deposition
Vegetation Cover	Dense coniferous forests and sparse vegetation on slopes	Agricultural lands, riparian vegetation, and crops
Land Use	Limited agriculture, primarily forestry and recreation	Extensive agriculture: vineyards, orchards, and crops
River Characteristics	High-energy, steep-gradient streams	Low-energy, meandering river with wide floodplains
Erosion Risk	High, due to steep slopes and thin soils	Lower, due to gentler slopes and stable soils

Human activities, such as logging and road construction in the upper watershed, can increase erosion and sediment delivery to streams, while intensive agriculture in the lower watershed relies on rich alluvial soils and influences groundwater recharge and surface water dynamics. Overall, the information presented in this Appendix illustrates the interconnectedness of geology, geomorphology, climate, hydrology, and land use shapes the physical landscape, water resources, and ecological health of the Upper Walla Walla watershed, supporting the sustained production of First Foods for the CTUIR community.

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Appendix B

Upper Walla Walla Assessment

GEOMORPHOLOGY

Technical Report

May, 2024

Technical Report

Rio Applied Science and Engineering

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Geomorphology Technical Report

Date: May 2024

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1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations. The focal fish species of the assessment and action plan consist of the following:

1. Middle Columbia River summer steelhead (ESA-listed Threatened)
2. Columbia River bull trout (ESA-listed Threatened)
3. Spring Chinook salmon
4. Pacific lamprey

The final restoration action plan will establish a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions.

This geomorphology appendix contains a reach-based assessment of the river channel and floodplain of the Walla Walla River from the confluence with Dry Creek near Lowden, Washington, to the headwaters of the North and South Forks of the Walla Walla River in northeastern Oregon. The primary study area includes approximately 114 kilometers of stream and the associated floodplain of those stream segments.

2.0 METHODS

The objectives of the geomorphic assessment were to: 1) characterize the watershed conditions based on key geomorphic characteristics at the scale of 12-digit Hydrologic Unit Code (HUC) subwatersheds, 2) characterize the channel morphology of the Walla Walla (WW) River, North Fork Walla Walla (NFWW) River, and South Fork Walla Walla (SFWW) River to identify geomorphic reaches within the valley segments that share similar physical processes and conditions, and 3) characterize existing reach-scale geomorphic conditions and processes. Data used for the assessment included existing spatial data in Geographic Information System (GIS) format from multiple sources, field data provided by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and the Walla Walla Basin Watershed Council (WWBWC), and hydraulic model results developed for this assessment (Appendix D).

2.1 REACH ASSESSMENT

Elevation data throughout the watersheds were acquired from the 10-meter digital elevation model (DEM) in the National Elevation Dataset available from the U. S. Geological Survey (USGS, 2020). High resolution elevation data in the valley bottoms was acquired from Light Detection and Ranging (LiDaR) datasets provided by CTUIR. One of the LiDaR flights occurred during November 1-5, 2019, resulting in 1-meter resolution raster datasets, including topobathymetric elevation (Quantum Spatial, 2020). In February 2020, regional flooding occurred throughout the Walla Walla watershed, resulting in significant erosion and deposition along the channels and floodplains of the WW River, NFWW River, and SFWW River. In response to these geomorphic changes, a post-flood LiDaR flight was completed during November 13-17, 2021, resulting in 1-meter resolution raster datasets, including topobathymetric elevation (NV5 Geospatial, 2022). Changes in erosion and deposition between 2019 and 2021 were evaluated by creating a DEM of elevation differences between the 2019 and 2021 LiDaR datasets.

The geological controls in the watersheds were identified by GIS mapping and description of lithology and surficial geology. Geological data were compiled from 1:100,000 scale digital datasets from the Washington Department of Natural Resources (WDNR, 2016) and multi-scale digital datasets developed by the Oregon Department of Geology and Mineral Industries (Oregon DOGAMI, 2020).

The WW River, NFWW River, and SFWW River were each delineated into distinct reaches based on their geomorphic characteristics. Reaches were delineated based on geomorphic process domains to guide the analysis, interpretation, and identification of restoration strategies within similar physical-ecological systems at the reach scale (Montgomery, 1999; Fryirs and Brierley, 2013). Reaches were delineated based on valley slope, valley confinement (Fryirs et al., 2016), geology of the valley floor and adjacent hillslopes, and anthropogenic considerations such as bridges and channel grade control structures. Hydrography data from the NHDPlus version 2 database, as modified by the Columbia Basin Historical Ecology Project (Bond et al., 2019) was used as the basis for a linear referencing system (stationing) of river kilometers

(RKM), which formed the foundation for subsequent data management, analysis, and summary by reach throughout the WW River, NFWW River, and SFWW River.

The valley slope throughout the project area was estimated from several sources, depending on the availability of LiDaR data. Elevations from the 2021 LiDaR surface were extracted at 100-meter intervals along the valley centerline in the WW River and portions of the NFWW River and SFWW River. In reaches of the NFWW River and SFWW River upstream of the LiDaR extent, elevations of the valley bottom were acquired from the NHDPlus version 2 dataset (Bond et al., 2019). The resulting elevation profiles throughout the study area were interpreted for distinct changes in slope, which was facilitated by linear regression of elevation and valley distance at the reach scale.

The valley bottom throughout the project area was also estimated from several sources, depending on the availability of LiDaR data. In the Oregon portion of the WW River, the Special Flood Hazard Area (SFHA; 1% annual chance flood extent) mapped by FEMA (FEMA, 2016) was compared to a Relative Elevation Model (REM) available from the 2021 LiDaR dataset. REM values less than or equal to 3.5 m (i.e., less than or equal to 3.5 m above the water surface elevation used to generate the REM; NV5 Geospatial, 2022) approximately corresponded to the SFHA extent. This comparison provided the first approximation of the natural valley bottom in the Oregon portion of the WW River. This approach was applied to the Washington portion of the WW River, as well as to the NFWW River and SFWW River within the LiDaR spatial extent. This first approximation of the valley bottom throughout the study area was subsequently manually edited based on interpretations of elevation data and valley morphology (CDNR, 2020) outside the lateral extent of the REM data and through comparison with a mapped channel migration zone in the Washington portion of the study area (USACE, 2023).

The resulting natural valley bottom delineated for the LiDaR extent of the project area was used as the basis for mapping the artificially confined valley bottom, which reflected the presence of levees within the Milton-Freewater, Oregon, portion of the project area. Additional constraints (e.g., non-engineered levees, road prisms, streambank protection) on lateral and downstream channel migration were mapped from high-resolution imagery available from the 2019 and 2021 LiDaR datasets. In reaches of the NFWW River and SFWW River upstream of the LiDaR extent, the estimated current and historic floodplain widths were acquired from the NHDPlus version 2 dataset (Bond et al., 2019). Throughout the entire project area, the valley confinement on the active channel was characterized as either confined (natural and artificial), partly-confined (natural and artificial), or unconfined, based on the length of active channel abutting a valley bottom margin (Fryirs et al., 2016).

The Walla Walla Basin Watershed Council (WWBWC) completed stream surveys of geomorphic and physical habitat conditions in portions of the WW River, NFWW River, and SFWW River during the 2019 and 2020 field seasons (Figure 2-1). The stream surveys were conducted using the ODFW (2017) protocol and the resulting data were provided to CTUIR for data management and distribution (Ethan Green, CTUIR, personal communication). CTUIR provided the stream survey data to the Rio ASE team in GIS and tabular file formats for mapping, analysis, and summary. Geomorphic and physical habitat data for which there are benchmark values of desired conditions (Foster, et al., 2001; ODFW, 2017) were summarized at the reach scale. The summarized data include width to depth ratios, residual pool depths, pool frequency, channel unit frequency, large wood material abundance, and grain size characteristics.

Hydraulic and sediment transport characteristics were evaluated through the analysis and summary of 2-dimensional hydraulic modeling results (Appendix D). Model results were available for the LiDaR spatial extent for both the pre-flood (2019) and post-flood (2021) topobathymetric conditions. Floodplain connectivity was evaluated by calculating the valley bottom area inundated for a range of annual peak discharges (1.5-yr, 2-yr, 5-yr, and 100-yr) and for the 50% annual probability 14-day duration discharge during the seasonal period of February 15 to April 30. Stream power and shear stress were analyzed by extracting model results for the assumed effective discharge (2-yr peak discharge) at sampling cross-sections spaced 10 m apart in the upstream-downstream direction and then summarizing the data at the reach scale. The sediment transport characteristics were indicated by estimates of the excess shear stress ratio (also known as the entrainment potential), calculated as the ratio of the applied shear stress for the 2-yr peak discharge to the critical shear stress necessary to mobilize a representative grain size on the riverbed. Available grain size data from the WWBWC stream surveys were used for calculations of the critical shear stress for representative grain sizes throughout the project area. Because of the poorly sorted, non-uniform, grain-size deposits in the project reaches, it is desirable to apply a modified critical shear stress equation that accounts for selective entrainment due to facies heterogeneity (Dey and Ali 2019). Therefore, we used the following equation of Komar (1987) for calculating the critical shear stress:

$$\tau_{ci} = \theta(\gamma_s - \gamma_w) D_i^{0.3} D_{50}^{0.7}$$

where τ_{ci} is the critical shear stress at which the grain size of interest begins to move (lb/ft^3); θ is the dimensionless Shields parameter of 0.045 for poorly sorted, non-uniform deposits; γ_s is the specific weight of the sediment (165 lb/ft^3); γ_w is the specific weight of water (62.4 lb/ft^3); D_i is the diameter (ft) of the grain size of interest, typically the D_{84} where the interest is bed mobility, which was the case for this project; D_{50} is the diameter (ft) of the median grain size.

The Rio ASE project team supplemented the desktop analyses described above with field observations from October 2020. CTUIR staff led a stakeholder field tour of select sites along the WW River and SFWW River on October 19, 2020, providing the Rio ASE project team an opportunity to observe river and floodplain conditions shortly after the February 2020 flood event. On October 20-22, 2020, two Rio ASE geomorphologists completed a field reconnaissance of the WW River, NFWW River, and SFWW River to provide on-the-ground evaluation and verification of watershed, valley, and reach conditions. The watersheds were travelled by established roads that were accessible with an all-wheel vehicle, with a focus on publicly-accessible valley bottoms and stream reaches.

Functional assessments of the geomorphic reaches were used to determine aquatic habitat conditions and restoration opportunities within the upper Walla Walla River watershed. The approach is based on evaluating functions in the five River Vision Touchstone categories (Jones et al., 2008): Hydrology, Geomorphology, Connectivity, Riparian Vegetation, and Aquatic Biota. These functional categories represent the primary watershed- and reach-scale processes responsible for determining the health of stream ecosystems. Each category is comprised of one or more functional parameters that are used to quantify or describe the status of each category. The parameters are evaluated through the use of functional metrics that are calculated from all the relevant available data, measured in accessible reaches, or modeled at the watershed and reach scales. The metrics are quantifiable attributes that are associated with one or more parameters and can be used to directly or indirectly evaluate the status and trend of stream function. This appendix contains data pertaining to the Geomorphology and Connectivity functional metrics, while the functional assessment methodology and results are described in Appendix F.

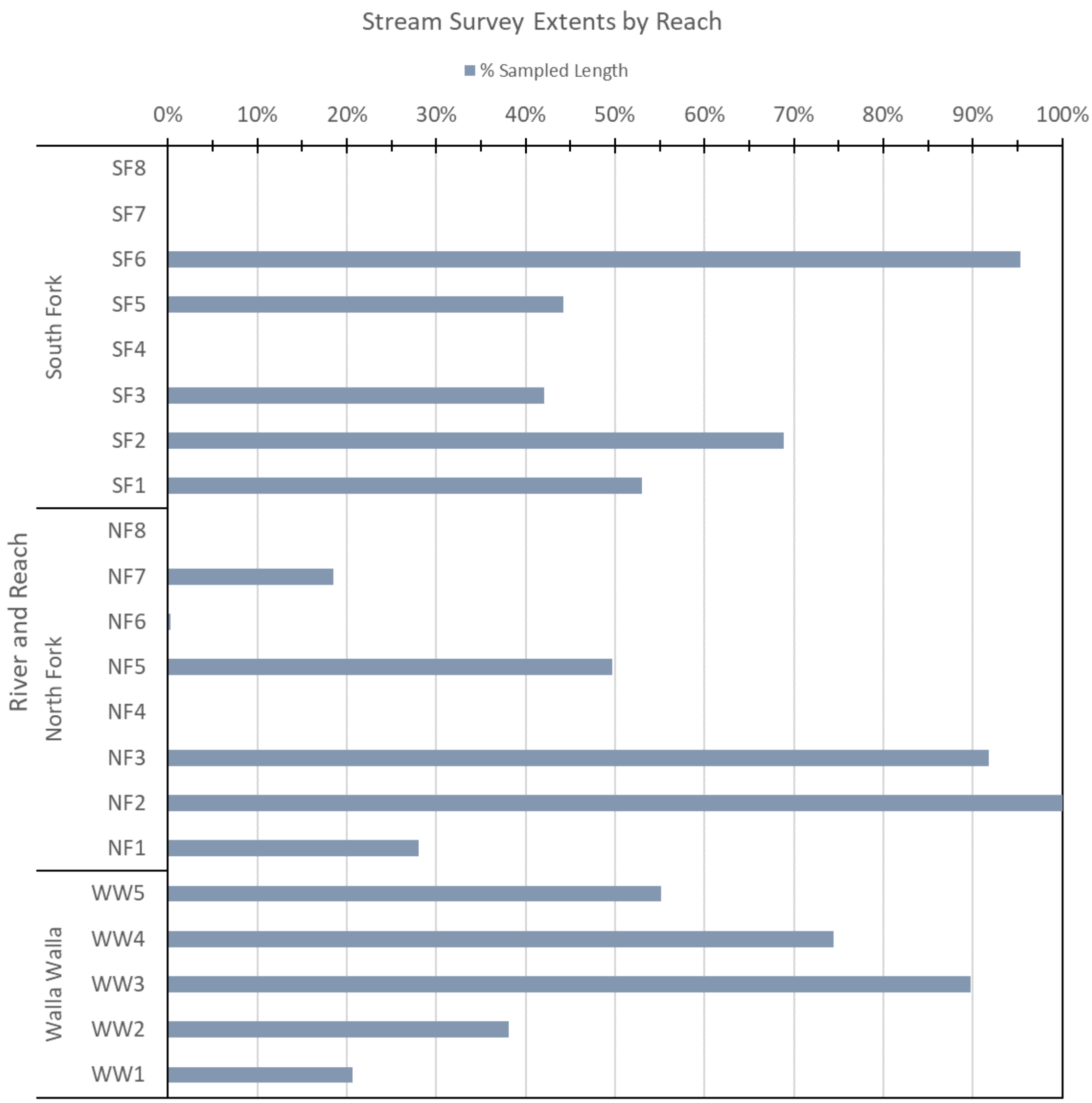

Figure 2-1. Stream survey extents as percent of the geomorphic reach length.

3.0 ENVIRONMENTAL SETTING

The following is a brief overview of the environmental setting. Additional information is provided in Appendix A (Landscape Pattern), Appendix C (Hydrology), Appendix D (Hydraulic Modeling), and Appendix E (Riparian Vegetation).

3.1 PHYSICAL GEOGRAPHY

The Walla Walla River is a tributary to the Columbia River in south-central Washington. The watershed within the study area upstream of Dry Creek extends over 1,134 km^2 and is bordered by the Columbia Plateau to the north, west, and south, and the Blue Mountains to the east. Elevations in the watershed range from approximately 1,908 m in the Blue Mountains to 144 m at the Lowden-Gardena Road bridge, with a mean watershed elevation of 802 m.

The upper Walla Walla River watershed is comprised of two Level III Ecoregions (ODFW, 2016), the Columbia Plateau Ecoregion in the lower elevations and the Blue Mountains Ecoregion in the upper elevations. The Columbia Plateau Ecoregion has an arid climate with cool winters and hot summers. This Ecoregion is underlain by basalt lava flows over 1 km deep and mantled by wind blown silt and sand. The Blue Mountains Ecoregion is comprised of a diverse mixture of mountain ranges, valleys, and plateaus over a large range in elevation. Within the study area this Ecoregion includes broad alluvial river valleys of the NFWW River and the SFWW River, deep rock-walled canyons, and plant communities of sagebrush steppe, mountain meadows, and pine-fir forests. Owing to the large elevation range, the Blue Mountains Ecoregion climate is highly variable with generally short, dry summers and long, cold winters (ODFW, 2016).

3.2 GEOLOGY

The headwaters of the Walla Walla River are situated on the west flank of the Blue Mountains, a region of broad uplift in northeastern Oregon and southeastern Washington. The Columbia River Basalt Group (CRBG) is composed of numerous flood basalt flows more than 1,500 m thick in aggregate within the watershed, which underlies the upper basin of the Walla Walla River (Walker and MacLeod 1991). The source locations of several of the major flood basalt sequences that cover the Columbia plateau are found in the Blue Mountains. Older sequences of the flood basalt flows are present in the Walla Walla River watershed from the lower watershed to the river headwaters. These flows are primarily the Grande Ronde member of the CRBG, which comprise about 85 percent of the eruptive volume of the CRBG. Flows from the younger Wanapum member are found in remnants on major ridge tops and on the margins of the Blue Mountain uplift. These are the basalt outcrops in the valley margins adjacent to the Walla Walla River within the watershed and study area. Loess (wind deposited clay and silt-sized particles) blanket much of the Walla Walla basin and the low hills and ridgetops that form the basin margins. The loess is the parent material for the soils that are present on the ridgetops. The valley bottoms of the WW River, NFWW River, and SFWW River contain deposits of Quaternary alluvium mantled by loess.

3.3 CLIMATE AND HYDROLOGY

The Walla Walla River watershed is affected by a combination of maritime and continental climates. The general arid climate of the region is a result of the Cascade Range of mountains reducing the precipitation effects of easterly moving maritime air masses. Cold continental air masses from the north and east, combined with moist maritime influences, results in precipitation that primarily occurs during the winter months as rain at lower elevations and snow at upper elevations. Average annual precipitation in the watershed ranges from 0.4 m in the valley floor to 1.6 m in the upper elevations of the Blue Mountains. Significant winter rain, rain-on-snow events, and early spring thaw are all contributors to low elevation flooding within the watershed (NPCC 2005).

The Walla Walla River in the vicinity of Milton-Freewater was historically a distributary system, wherein a primary channel bifurcated into several channels, then the several distributary channels eventually converged into a single channel farther downstream. In the mid-1800's, at least six major distributary channels of the Little Walla Walla River and Walla Walla River spread across the roughly five to six km wide alluvial fan near the present-day location of Milton-Freewater. As a result, for 24 km from the initial bifurcation upstream of Milton-Freewater to where the West Little Walla Walla River converges with the Walla Walla River, in the mid-1800's the Walla Walla River would have contained only a portion of the discharge from the river system emerging from the Blue Mountains. Today the diversion at the Little Walla Walla River is managed for irrigation water delivery, with most of the winter and spring flood flows being contained within the Walla Walla River (WWBWC, 2019). The alluvial fan was a significant element of the historical hydrological system, in part because it served the same functions as a floodplain, including providing extensive recharge of the shallow aquifer under the alluvial fan, especially during peak flows. The extensive spring system resulting from annual recharge of the shallow aquifer prompted early observers to describe the Walla Walla valley as having thousands of springs (WWBWC, 2019).

3.4 DEVELOPMENT AND LAND USE

Native tribes of the Cayuse, Umatilla, and Walla Walla people used the upper Walla Walla basin prior to the time of European contact (Quaempts et al., 2018). Settlement of European fur traders and missionaries soon resulted in agricultural development. The establishment of the town of Milton in 1872 and Freewater in 1889 (City of Milton-Freewater, 2011) brought commercial and industrial support to nearby the agricultural interests, which included development of orchards upstream in the Walla Walla River floodplain, local produce farms, and dryland grain crops. This development also heralded intensive animal grazing in the Walla Walla River basin during the 1860s and 1880s, including in the upland forest lands. Agricultural and grazing demands appear to have resulted in localized clearing of historic riparian vegetation along the Walla Walla River. This was followed by historic and modern development of irrigation diversions, bridges, and flood control levees.

Because of frequent flooding on the alluvial (distributary) fan, early settlers built individual levees to attempt to protect their property. However, frequent flooding continued and prompted the late-1930's construction of the Little Walla Walla River diversion head gate to control the inflow of water to the Little Walla Walla River and prevent flooding (WWBWC, 2019). Following construction of this diversion, the energy of peak flow events in the Walla Walla River system coming out of the mountains was no longer distributed across multiple distributary channels. The river responded to this change in energy distribution by increasing the width of its channel through Milton-Freewater. From 1949 to 1952, the U.S. Army Corps of Engineers constructed a 9 km long levee system through Milton-Freewater to prevent flooding, concentrating the available stream power within the levee corridor (Teasdale, 2010). Winter floods of 1964-65 caused extensive damage to the levee system, resulting in reconstruction of the levees during 1966-68 (Teasdale, 2010). The consequences of levee construction on the Walla Walla River geomorphology are reflected in current conditions, whereby the river has incised vertically up to 6 m and over distances of more than 20 km, prompting the construction of multiple grade-control structures along the river, including the largest one at Nursery Road bridge within the levee system in Milton-Freewater.

Currently development within the study area includes modern agricultural fields and orchards in the Walla Walla River floodplain, widely spaced rural residences, roadway infrastructure, and other infrastructure associated with cities of College Place, Walla Walla, and Milton-Freewater. The upper reaches of the NFWW River and SFWW River are public land managed by the U. S. Forest Service. The primary uses of public land include recreation, hunting, fishing, off-road travel, firewood gathering, and timber production.

4.0 REACH CHARACTERISTICS

The WW River, NFWW River, and SFWW River were each delineated into distinct geomorphic reaches. The reach delineation was based largely on valley confinement, channel slope, topography, and geology. A total of five reaches were delineated in the WW River, eight in the NFWW River, and eight in the SFWW River (Figure 4-1, Table 4-1).

The characteristics of the WW River are described below in section 4.1 and summarized in Figure 4-2 through Figure 4-38. The NFWW River characteristics are described below in section 4.2 and summarized in Figure 4-39 through Figure 4-67. The SFWW River characteristics are described below in section 4.3 and summarized in Figure 4-68 through Figure 4-106.

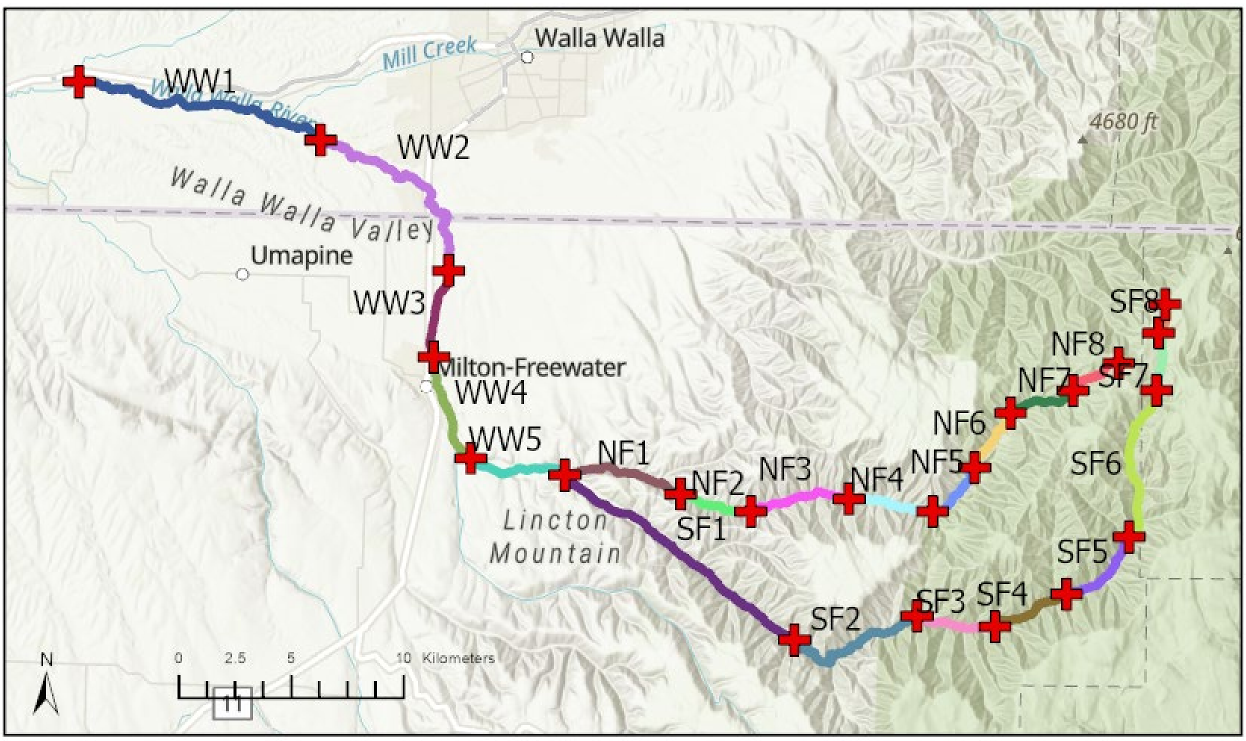

Figure 4-1. Geomorphic reach delineation in the WW River, NFWW River, and SFWW River.

Table 4-1. Geomorphic reach characteristics.

							Geology		Valley Width (m)			Valley Width (artificially confined) (m)		
River	**Reach ID**	**From RKM**	**To RKM**	**Sinuosity**	**Valley Slope**	**Valley Setting**	**Valley Bottom**	**Valley Margins**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
Walla Walla River	WW1	44.1	57.2	1.32	0.4%	unconfined	alluvium	alluvium and mixed-grain flood sediments	521	720	944	481	717	944
Walla Walla River	WW2	57.2	68.7	1.42	0.6%	partly confined (10%-50%)	alluvium	alluvium and mixed-grain flood sediments	234	479	939	143	467	939
Walla Walla River	WW3	68.7	72.8	1.21	1.1%	confined (artificial)	alluvium	alluvium and mixed-grain flood sediments	975	2154	2787	57	75	82
Walla Walla River	WW4	72.8	77.9	1.23	1.1%	confined (artificial and natural)	alluvium	basalt and mixed-grain flood and fan sediments	249	806	2062	49	65	172
Walla Walla River	WW5	77.9	82.6	1.31	1.1%	partly confined (50%-85%, artificial and natural)	alluvium	basalt	308	481	604	308	465	604
North Fork Walla Walla River	NF1	0.0	5.7	1.20	1.9%	partly confined (50%-85%, artificial and natural)	alluvium	basalt	138	238	529	138	238	529
North Fork Walla Walla River	NF2	5.7	9.2	1.27	2.2%	partly confined (50%-85%, natural)	alluvium	basalt	89	155	201	89	155	201
North Fork Walla Walla River	NF3	9.2	14.1	1.24	2.4%	confined (natural)	alluvium and basalt	basalt	33	90	135	33	90	135
North Fork Walla Walla River	NF4	14.1	18.3	1.22	3.0%	confined (natural)	basalt	basalt	27	57	125	27	57	125
North Fork Walla Walla River	NF5	18.3	21.4	1.05	3.3%	confined (natural)	basalt	basalt	31	64	95	22	64	95
North Fork Walla Walla River	NF6	21.4	24.6	1.06	4.1%	confined (natural)	basalt	basalt	53	96	158	53	96	158
North Fork Walla Walla River	NF7	24.6	27.9	1.05	6.5%	confined (natural)	basalt	basalt	52	89	146	52	89	146
North Fork Walla Walla River	NF8	27.9	30.5	1.02	13.3%	confined (natural)	basalt	basalt	42	64	94	36	63	94

Table 4-1. Geomorphic reach characteristics.

							Geology		Valley Width (m)			Valley Width (artificially confined) (m)		
River	Reach ID	From RKM	To RKM	Sinuosity	Valley Slope	Valley Setting	Valley Bottom	Valley Margins	Min	Avg	Max	Min	Avg	Max
South Fork Walla Walla River	SF1	0.0	13.3	1.23	1.6%	partly confined (50%-85%, artificial and natural)	alluvium	basalt	80	259	529	28	255	529
South Fork Walla Walla River	SF2	13.3	20.8	1.29	1.8%	partly confined (50%-85%, natural)	alluvium and basalt	basalt	50	99	223	50	99	223
South Fork Walla Walla River	SF3	20.8	24.6	1.34	2.2%	partly confined (50%-85%, natural)	alluvium	basalt	108	166	218	108	166	218
South Fork Walla Walla River	SF4	24.6	28.5	1.29	2.2%	partly confined (50%-85%, natural)	alluvium	basalt	40	107	182	40	107	182
South Fork Walla Walla River	SF5	28.5	32.8	1.13	2.5%	confined (natural)	basalt	basalt	14	30	53	14	30	53
South Fork Walla Walla River	SF6	32.8	40.5	1.05	4.9%	confined (natural)	basalt	basalt	42	67	126	42	67	126
South Fork Walla Walla River	SF7	40.5	43.2	1.03	4.7%	confined (natural)	basalt	basalt	63	100	179	63	100	179
South Fork Walla Walla River	SF8	43.2	44.6	1.02	8.2%	confined (natural)	basalt	basalt	53	69	84	53	67	84

4.1 WALLA WALLA RIVER

Reach WW1 in the WW River extends 13.1 river kilometers (RKM) from Lowden-Gardena Road upstream to Last Chance Road (Figure 4-19 and Figure 4-20). The WW River in reach WW1 has a moderate sinuosity of 1.32 and flows through an unconfined valley in a rural residential setting (Table 4-1). Reach WW1 has a valley slope of 0.4%, with the valley bottom comprised of Quaternary alluvium and the valley margins comprised of alluvium and erosion resistant Pleistocene outburst flood deposits containing mixed-grain sediments. Near Last Chance Road there is a mapped structural geologic syncline fold, likely providing a structural control on the valley slope in this area. The primary tributaries to reach WW1 include West Little Walla Walla River at RKM 54.2 and Mill Creek at RKM 54.4.

WW River reach WW2 extends 11.5 RKM from Last Chance Road upstream to near Birch Creek Road where the river becomes artificially confined by levees (Figure 4-20 and Figure 4-21). The WW River in reach WW2 has a sinuosity of 1.42 and flows through a partly-confined valley in a rural residential setting (Table 4-1). Reach WW2 has a valley slope of 0.6%, with the valley bottom comprised of alluvium and the valley margins comprised of alluvium and erosion resistant mixed-grain flood sediments. The valley margins of reach WW2 provide topographic control on the river channel, with the reach having more contact with the erosion resistant flood sediments than in the downstream (WW1) and upstream (WW3) reaches. The primary tributaries to reach WW2 include Stone Creek near RKM 59.9, East Little Walla Walla River near RKM 61.2, Yellowhawk Creek near RKM 62.6, and Birch Creek near RKM 65.8.

Reach WW3 is entirely artificially confined within the levee system through Milton-Freewater. The reach extends for 4.1 RKM from near Birch Creek Road upstream to Eastside Road at the channel spanning grade control structure (Figure 4-21). The WW River in reach WW3 has a sinuosity of 1.21 along a valley slope of 1.1% (Table 4-1). The valley bottom is comprised of alluvium while the valley margins are comprised of alluvium and erosion resistant mixed-grain flood sediments. There are no tributaries to reach WW3.

WW River reach WW4 is entirely confined throughout its 5.1 RKM extent, both from levee constraints and the valley margin comprised of erosion resistant mixed-grain flood sediments. Reach WW4 extends from Eastside Road through Milton-Freewater to the upper end of the levee system just upstream of Couse Creek Road (Figure 4-21 and Figure 4-22). The WW River in reach WW4 has a sinuosity of 1.23 along a valley slope of 1.1% (Table 4-1). The valley bottom is comprised of alluvium while the valley margins are comprised of erosion resistant mixed-grain flood sediments and basalt bedrock. Reach WW4 is located along a distributary fan of the WW River, with the Little Walla Walla River diversion structure near RKM 74.8 controlling flow into the highly modified distributary channels along the alluvial fan throughout the Milton-Freewater area. The primary tributary to reach WW4 is Couse Creek near RKM 76.9.

Reach WW5 in the WW River extends 4.7 RKM from near Couse Creek Road upstream to the confluence of NFWW River and SFWW River (Figure 4-22). The WW River in reach WW5 has a moderate sinuosity of 1.31 and flows through a partly confined valley in a rural residential setting (Table 4-1). Reach WW5 has a valley slope of 1.1%, with the valley bottom comprised of alluvium and the valley margins comprised of basalt bedrock.

River and floodplain conditions in the WW River have been highly altered as a result of rural residential development along the valley bottom. While all of the WW River reaches have large natural valley widths, floodplains have been markedly disconnected from the river by confinement of continuous levees and discontinuous constraints on lateral and longitudinal channel migration. The median natural valley width ranges from 480 m in reach WW5 to 2,154 m in reach WW3 (Figure 4-2). Artificial channel confinement from continuous levees is minimal in reaches WW1, WW2, and WW5; however that confinement is significant in reaches WW3 and WW4 (Figure 4-2) where the artificially confined valley width is 3.5% and 8.1%, respectively, of the natural valley width, owing to the continuous levee system on both sides of the river channel throughout the Milton-Freewater area (Figure 4-19 through Figure 4-22). Discontinuous constraints on channel migration (e.g., roads, bridges, bank protection, grade control structures) further limits river-floodplain connectivity in all WW River reaches. The ratio of constraint length to reach length ranges from 0.86 in reach WW1 to 1.98 in reach WW3 (Table 4-2; Figure 4-3; Figure 4-23 through Figure 4-26).

Table 4-2: Artificial floodplain disconnection by channel constraints in the WW River.

Reach ID	Reach Length (km)	Constraint Length (km)	Constraint Length Ratio of Reach Length
WW1	13.1	11.21	0.86
WW2	11.5	13.02	1.13
WW3	4.1	8.12	1.98
WW4	5.1	7.54	1.48
WW5	4.7	4.37	0.93

River manipulation throughout all WW River reaches has included a straightening of the channel and reducing the river sinuosity (Figure 4-23 through Figure 4-26). These alterations have converted what was once likely a predominantly pool-riffle channel morphology into a higher energy plane-bed structure with long subreaches of continuous riffle and much fewer subreaches of pool-riffle channel morphology. Multi-thread channels that appear on historical topographic maps, in LiDaR data, and are visible in moist soil patterns from aerial photography, have been removed, filled, drained, and/or artificially disconnected from the active channel (Figure 4-23 through Figure 4-30). These changes in channel morphology have affected the sediment transport regime whereby gravel deposition and bar formation are very limited and much less than is expected in these valley settings. The conversion of the river to a straighter, higher energy channel with greater sediment transport capacity suggests that some vertical degradation of the riverbed has occurred, an observation supported by the presence of the concrete grade control structure at Eastside Road in Milton-Freewater and multiple constructed boulder grade-control structures throughout the WW River.

Throughout all WW River reaches hydraulic connectivity of the river channel has been limited both laterally and longitudinally. The amount of natural valley bottom inundated by the 14-day discharge ranges from 1% in reach WW3 to 7% in reaches WW2 and WW5 (Figure 4-4). For the estimated effective discharge (2-yr peak flow) the inundated area ranges from 2% to 12% of the natural valley bottom in reaches WW3 and WW2, respectively. In reaches WW1, WW2, and WW5, there is a marked increase in inundation from the 2-yr to the 5-yr peak flow (Figure 4-4) suggesting that artificial channel constraints on floodplain connectivity limits much of the lower magnitude peak floods (e.g., less than 5-yr peak) to the active channel in these reaches (Figure 4-23 through Figure 4-26). Within the leveed reaches of WW3 and WW4 less than 6% of the natural valley bottom is inundated under all modeled discharges, including the 1% annual chance peak flood (100-yr event) (Figure 4-4; Figure 4-23 through Figure 4-26). These results suggest that during the more frequent peak discharges (i.e., less than the 5-yr peak), much of the available energy from the stream flow is concentrated in the active channel rather than being distributed onto the adjacent floodplain, further exacerbating the vertical channel incision and floodplain disconnection.

Under the assumed effective, channel-forming discharge (i.e., 2-yr peak), the hydraulic characteristics of stream power, shear stress, and sediment entrainment potential vary widely among the WW River reaches. The median of maximum unit stream power from sampled cross-sections ranged from approximately 122 W m^{-2} in reach WW1 to 337 W m^{-2} in reach WW4 (Figure 4-5), while the median of mean unit stream power from sampled cross-sections ranged from approximately 70 W m^{-2} in reach WW1 to 205 W m^{-2} in reach WW4 (Figure 4-6). Similarly, the median of maximum shear stress ranged from approximately 51 Pa in reach WW1 to 118 Pa in reach WW4 (Figure 4-7), while the median of mean shear stress ranged from approximately 35 Pa in reach WW1 to 85 Pa in reach WW4 (Figure 4-8). In all reaches the maximum shear stress well exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-7); similarly, at more than half of the sampled cross-sections in all reaches the mean shear stress exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-8). The entrainment potential for the coarser material (D84) within the grain-size mixtures was notable in all reaches, with the partial entrainment threshold of 1.0 being exceeded by more than half of all sampled cross-sections in all reaches with the exception of reach WW1 (Figure 4-9). At many of the sampled cross-sections in reaches WW3 and WW4 the entrainment threshold exceeded 2.0, which is indicative of full bed mobility and significant transport of bed material. In all reaches, there was a negligible change in the reach-wide magnitude of modeled hydraulic characteristics based on the pre-flood (2019) and post-flood (2021) topobathymetric surfaces used for the hydraulic modeling. However, there were notable spatial changes in bank erosion, channel migration, and subsequent changes in hydraulic characteristics and channel erosion and deposition (Figure 4-31 through Figure 4-38). For example, notable changes in channel location and alignment were observed near RKM 46-47 in reach WW1 (Figure 4-31, downstream from McDonald Road), RKM 66-68 in reach WW2 (Figure 4-33, upstream from Peppers Road Bridge), and RKM 78-81 in reaches WW4 and WW5 (Figure 4-34). These subreach locations also exhibited some of the more prominent geomorphic responses to the 2020 flood as indicated by the magnitude of scour and deposition (Figure 4-35 through Figure 4-38).

The reach-wide hydraulic and geomorphic characteristics of all WW River reaches are reflected in the observations from stream surveys at the sub-reach and site scales. Average riffle width to depth ratios ranged from 24 in reach WW5 to 45 in reach WW3 (Figure 4-10), with the average width to depth ratio in all reaches far exceeding the benchmark desirable value of less than 10. In all reaches except WW5, the average width to depth ratio exceeded the undesirable benchmark value of greater than 30 (Figure 4-10). Average residual pool depth ranged from 0.7 m in reach WW5 to 1.1 m in reach WW1, with the average value in all reaches falling well below the desirable benchmark value of greater than 1.5 m (Figure 4-11). The frequency of pools was less than desirable in reaches WW3, WW4, and WW5, ranging from 2 pools/KM in reach WW4 to 4 pools/KM in reach WW5 (Figure 4-12). Pool frequency was higher in reaches WW1 (13 pools/KM) and WW2 (15 pools/KM), exceeding the desirable pool frequency range of 5 to 8 pools/KM (Figure 4-12). While the pool frequency in reaches WW3, WW4, and WW5 was less than desirable, the total channel unit frequency in these reaches was in the desirable range (Figure 4-13), reflecting the prevalence of run, glide, and riffle geomorphic units in these reaches.

Observations from stream surveys suggest that riverbed grain size characteristics in riffles are largely within the range of desirable conditions. The average percentage of riffle areas comprised of gravel ranged from 44% in reach WW5 to 58% in reach WW1, with the average value in all reaches well exceeding the desirable value of greater than 35% (Figure 4-14). Indeed, in all reaches except one (WW5) the minimum observed percentage riffle area with gravel exceeded the desirable value. The riffle area comprised of finer sediment material was also within the desirable range in all reaches except WW5. The average percentage of riffle areas comprised of organics-silt-sand ranged from 4% in reach WW1 to 15% in reach WW5 (Figure 4-15), with the average value in none of the reaches exceeding the undesirable benchmark threshold of 25%.

Observations from stream surveys indicate that the abundance of LWM in all WW River reaches is much less than the desirable conditions. The LWM piece frequency ranged from 3 pieces per 100 m in reach WW3 to 14 pieces per 100 m in reach WW2, with the piece frequency in all reaches being well below the desirable benchmark value of greater than 20 pieces per 100 m (Figure 4-16). The LWM that is present in all reaches is predominantly smaller size class material, as indicated by the low abundance of key LWM pieces (>60 cm diameter and >10 m long). The LWM key piece frequency ranged from 0 pieces per 100 m in reaches WW3 and WW4 to 0.2 pieces per 100 m in reach WW2, with the key piece frequency in all reaches being well below the desirable benchmark value of greater than 3 key pieces per 100 m (Figure 4-17). The prevalence of smaller size class LWM in all reaches is also evident in estimates of LWM volume frequency. The LWM volume frequency ranged from 1 m^3 per 100 m in reach WW3 to 6 m^3 per 100 m in reaches WW2 and WW5, with the LWM volume frequency in all reaches being well below the desirable benchmark value of greater than 30 m^3 per 100 m (Figure 4-18).

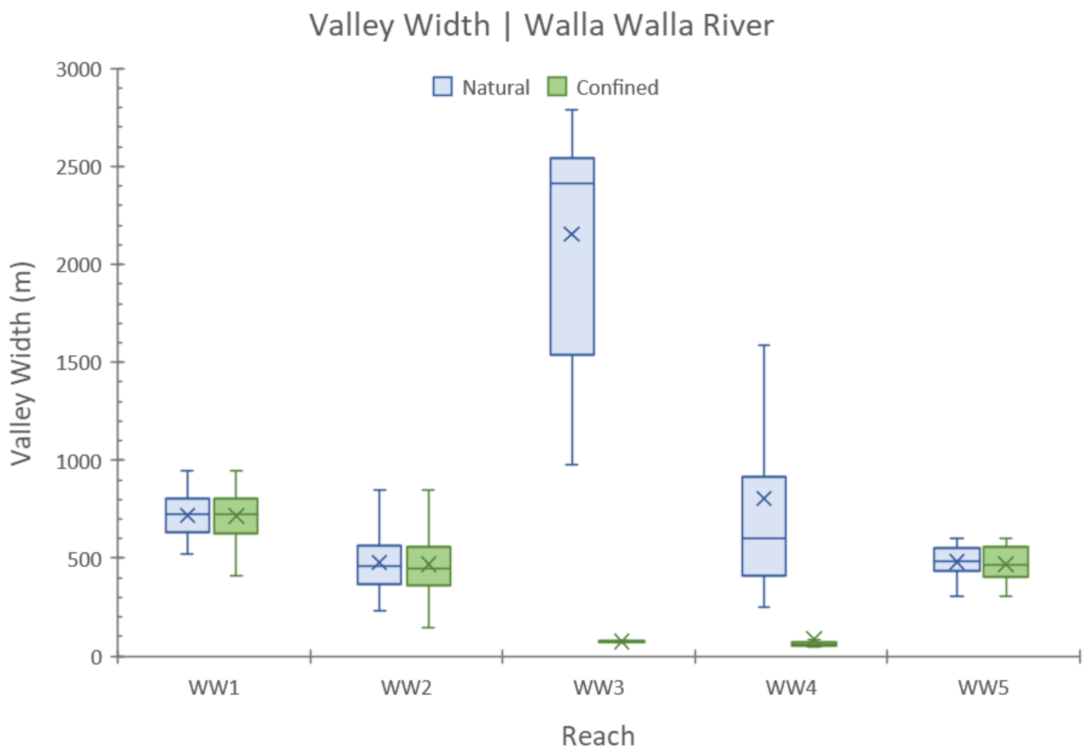

Figure 4-2. Valley width (natural and artificially confined) of the WW River by geomorphic reach.

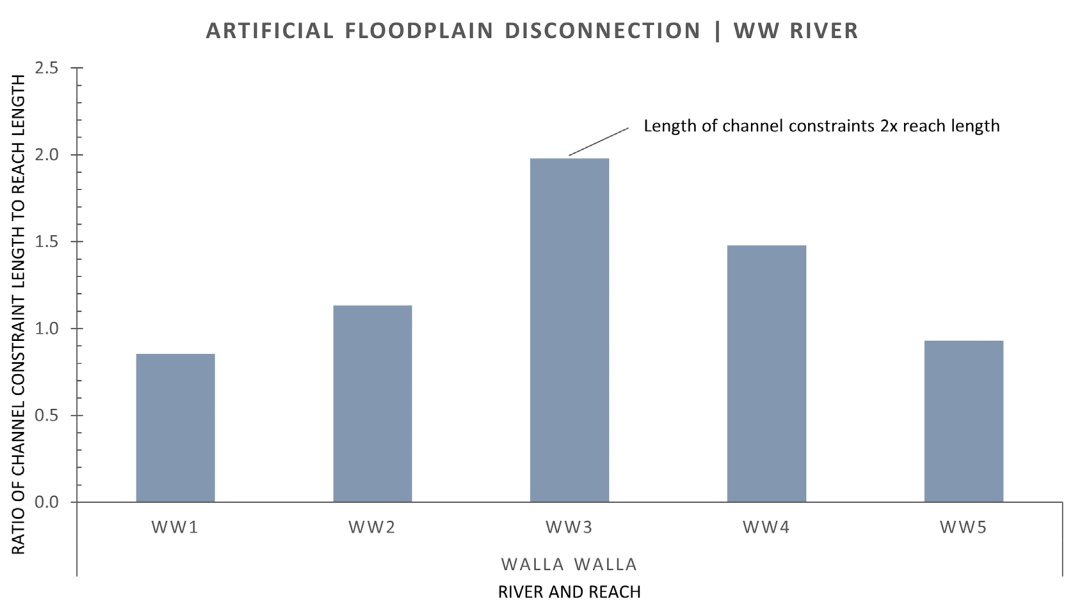

Figure 4-3. Length of channel constraints in the WW River by geomorphic reach.

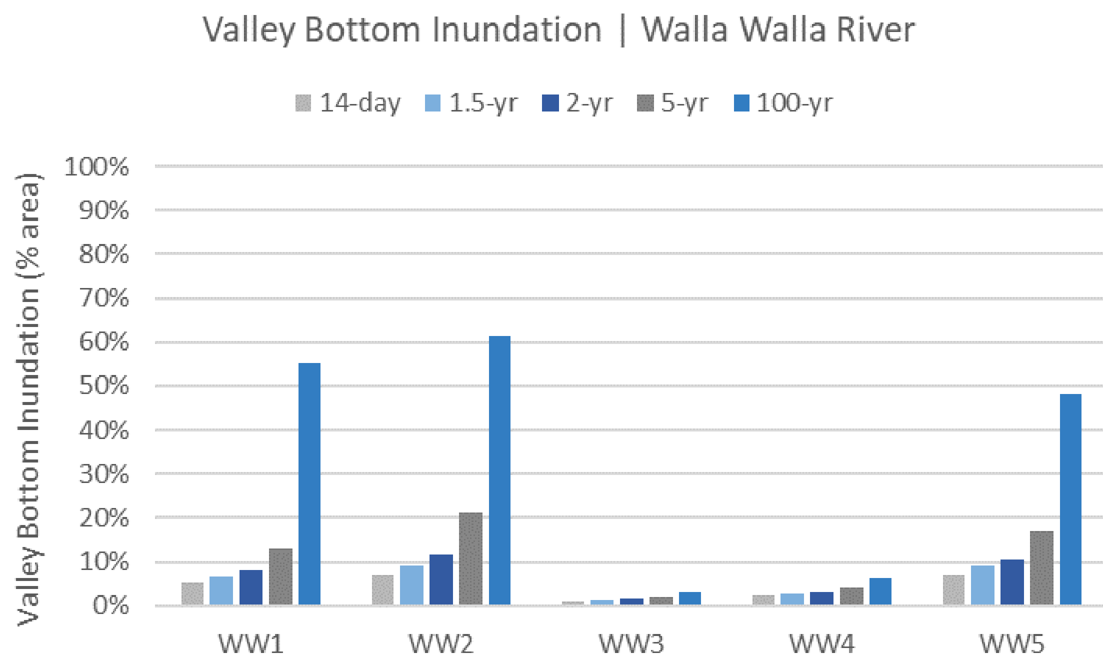

Figure 4-4. Valley bottom inundation for a range of discharges in the WW River by geomorphic reach.

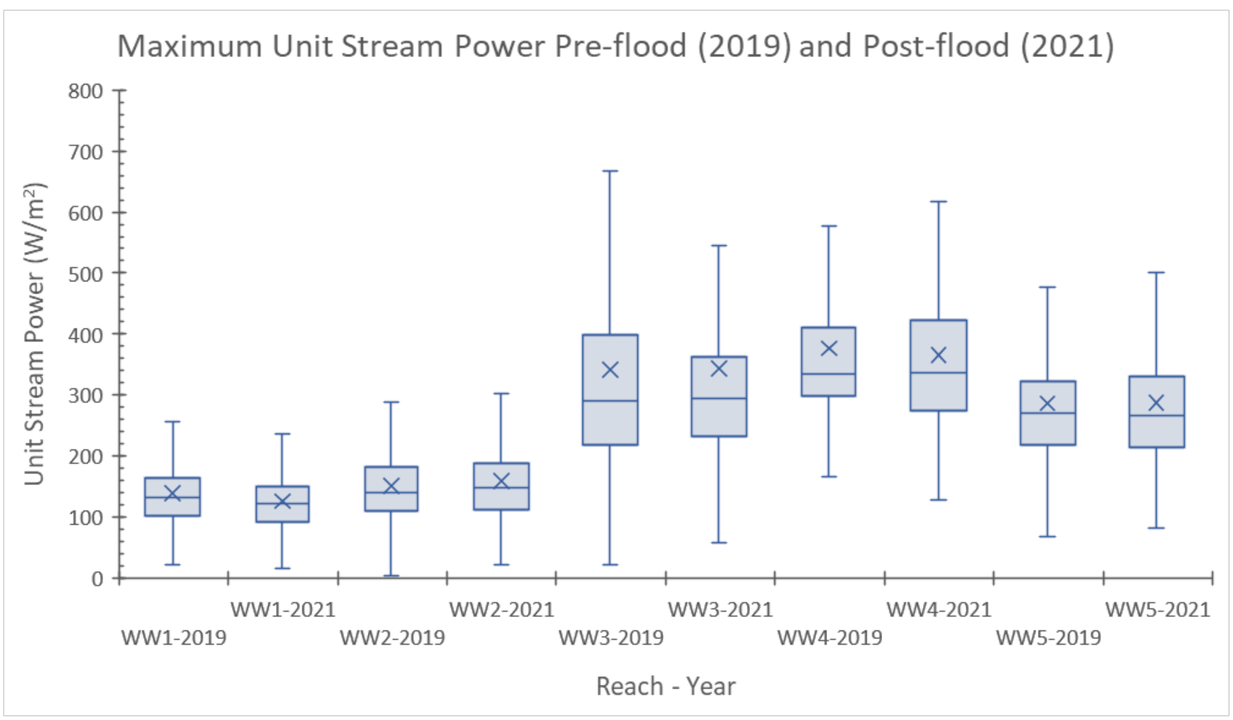

Figure 4-5. Maximum unit stream power for the 50% annual chance flood (2-yr peak) in the WW River.

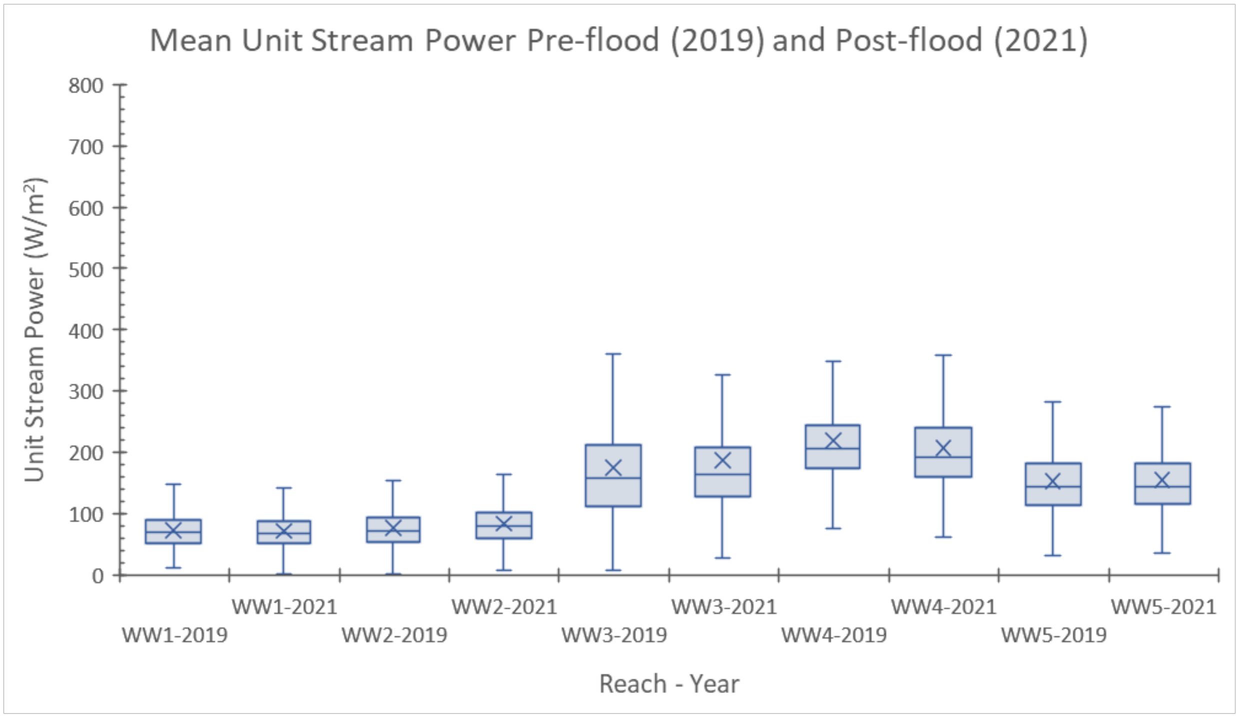

Figure 4-6. Mean unit stream power for the 50% annual chance flood (2-yr peak) in the WW River.

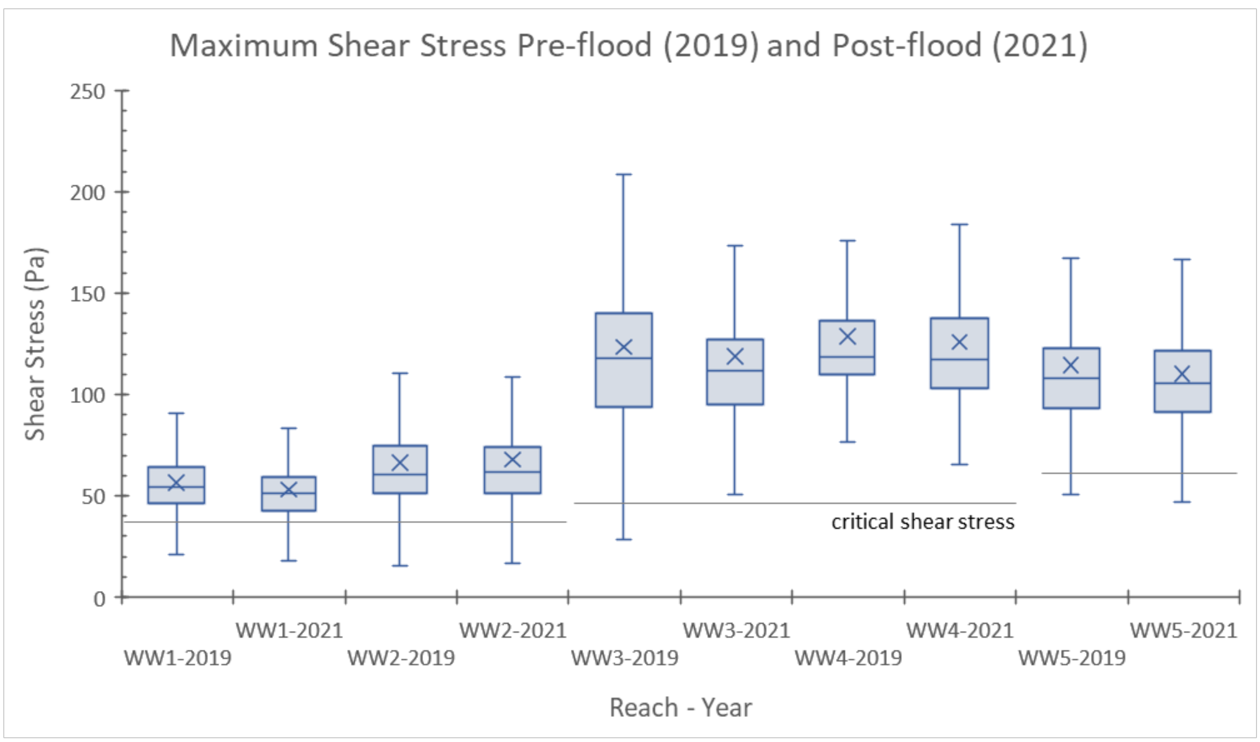

Figure 4-7. Maximum shear stress for the 50% annual chance flood (2-yr peak) in the WW River.

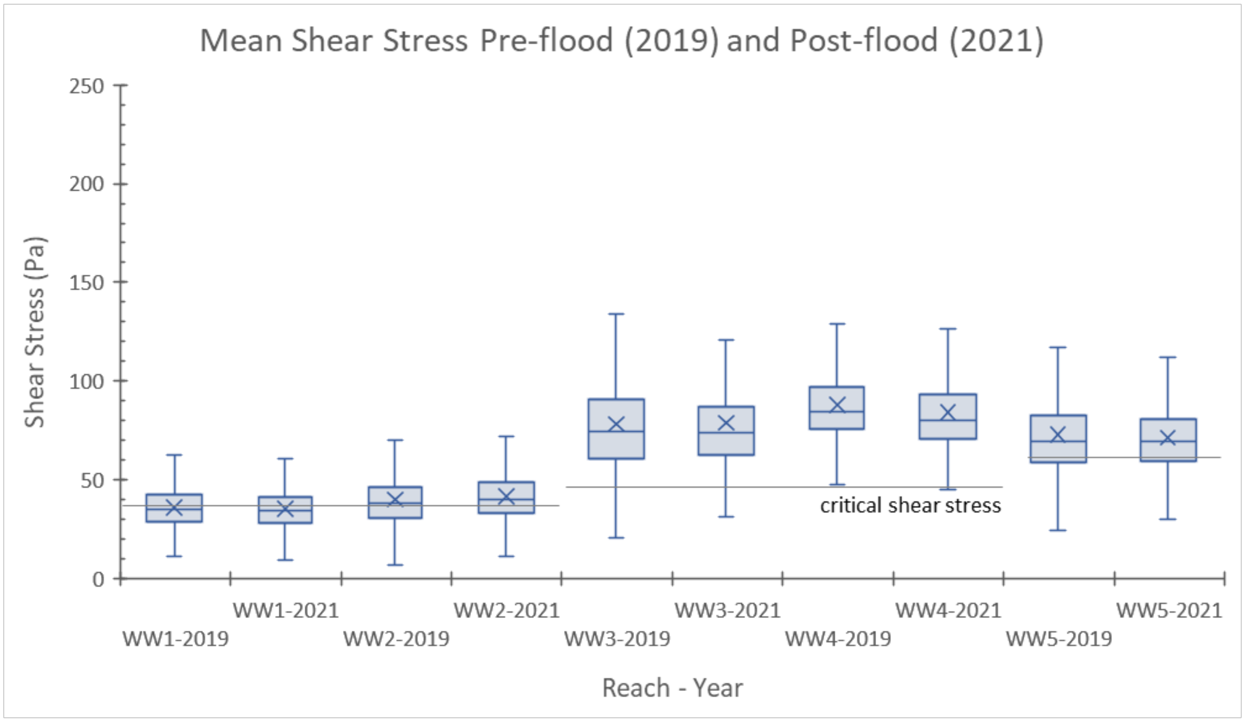

Figure 4-8. Mean shear stress for the 50% annual chance flood (2-yr peak) in the WW River.

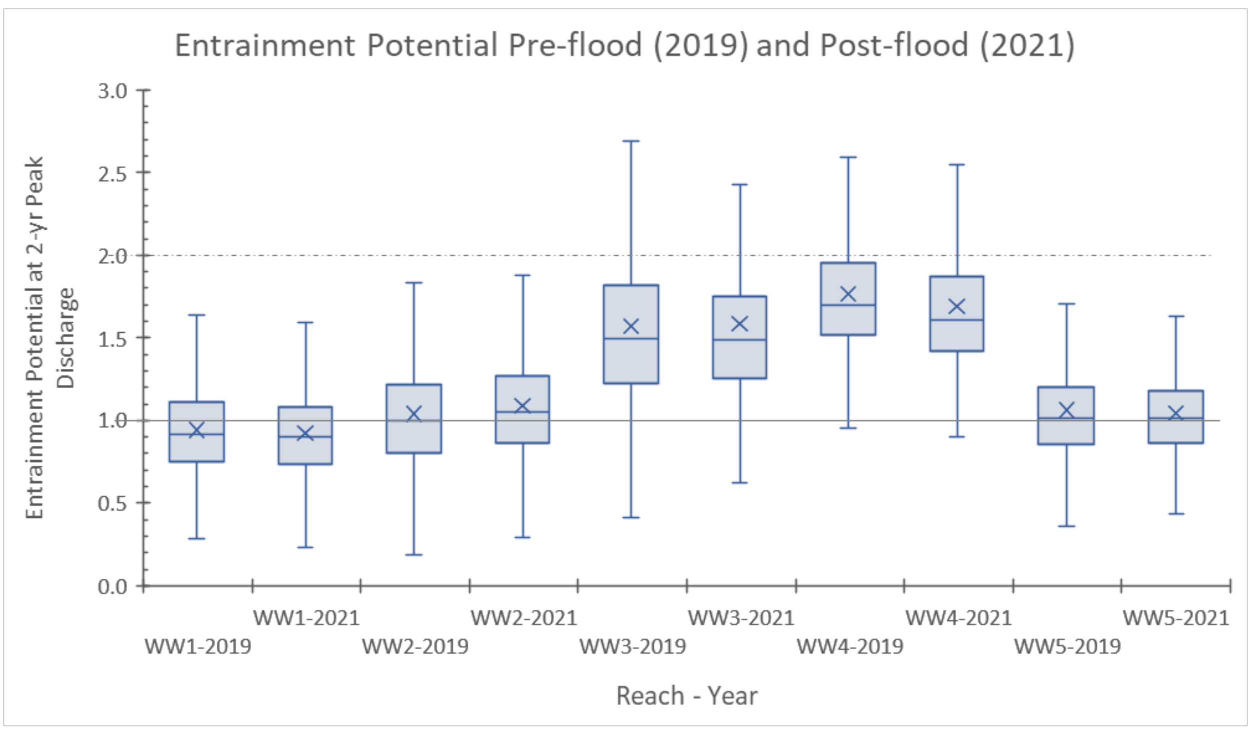

Figure 4-9. Entrainment potential for the 50% annual chance flood (2-yr peak) in the WW River.

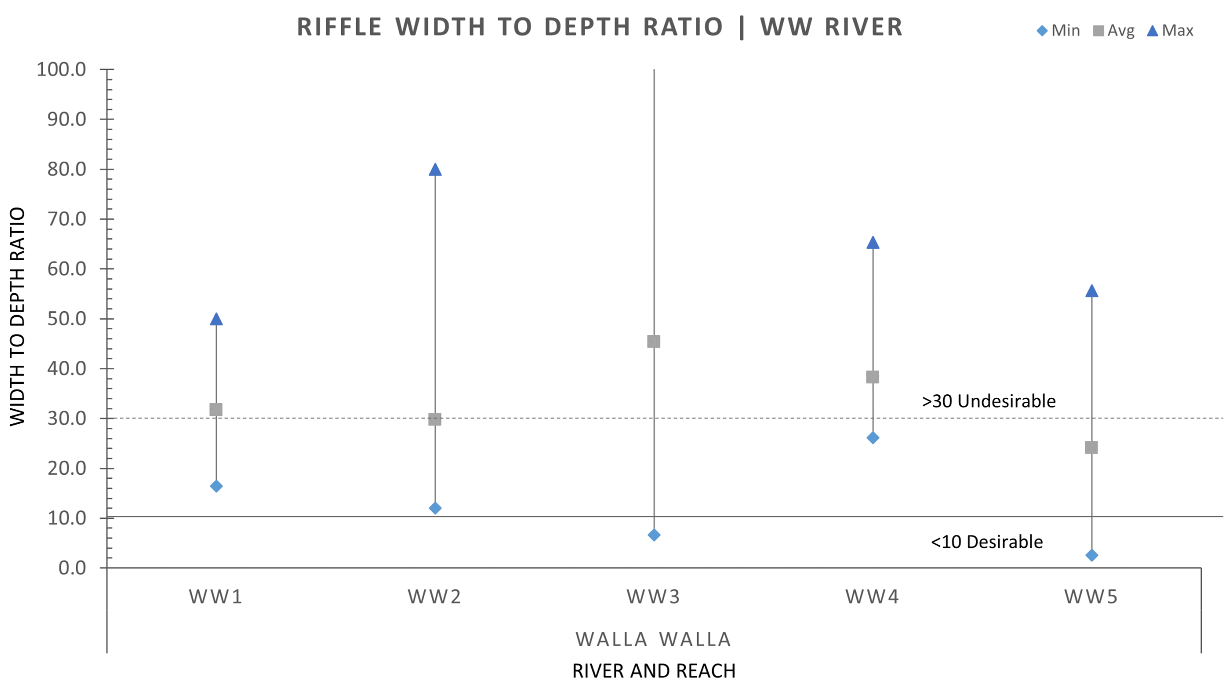

Figure 4-10. Riffle width to depth ratio in the WW River by geomorphic reach.

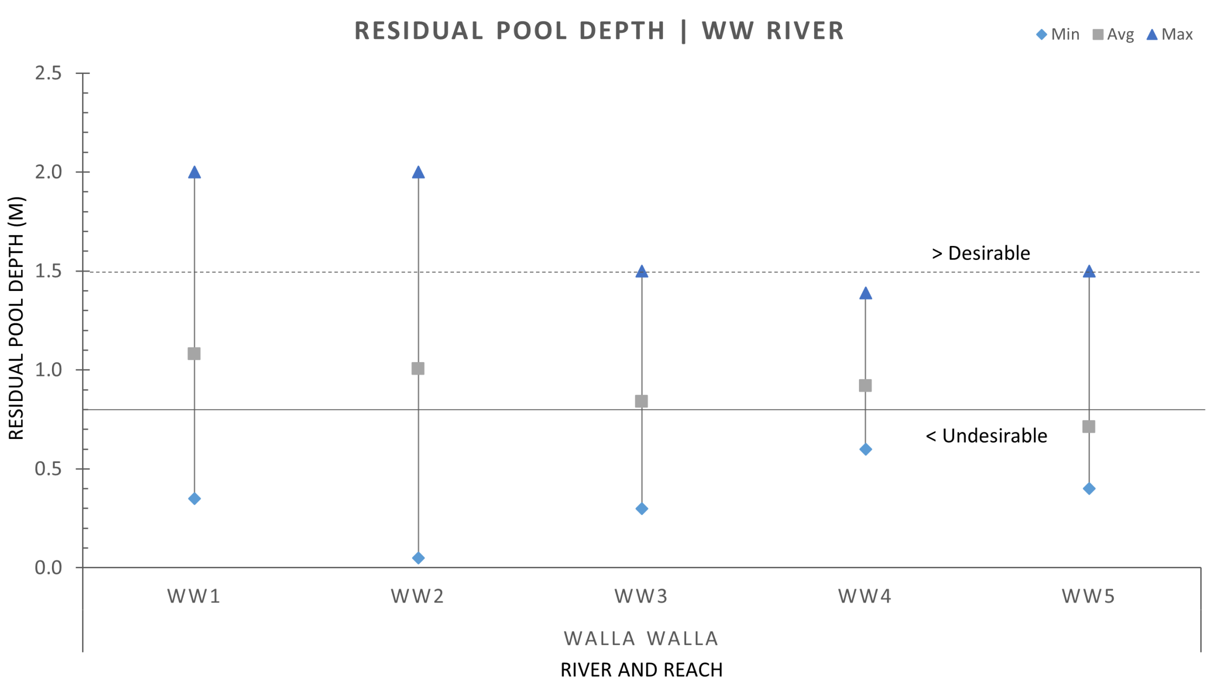

Figure 4-11. Residual pool depth in the WW River by geomorphic reach.

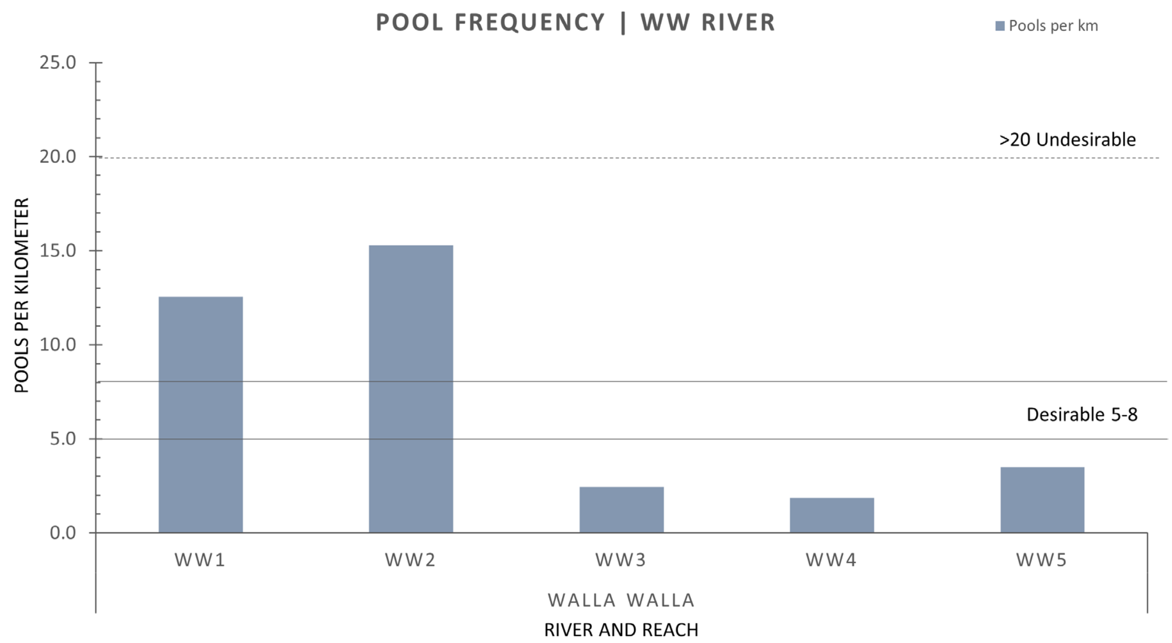

Figure 4-12. Pool frequency in the WW River by geomorphic reach.

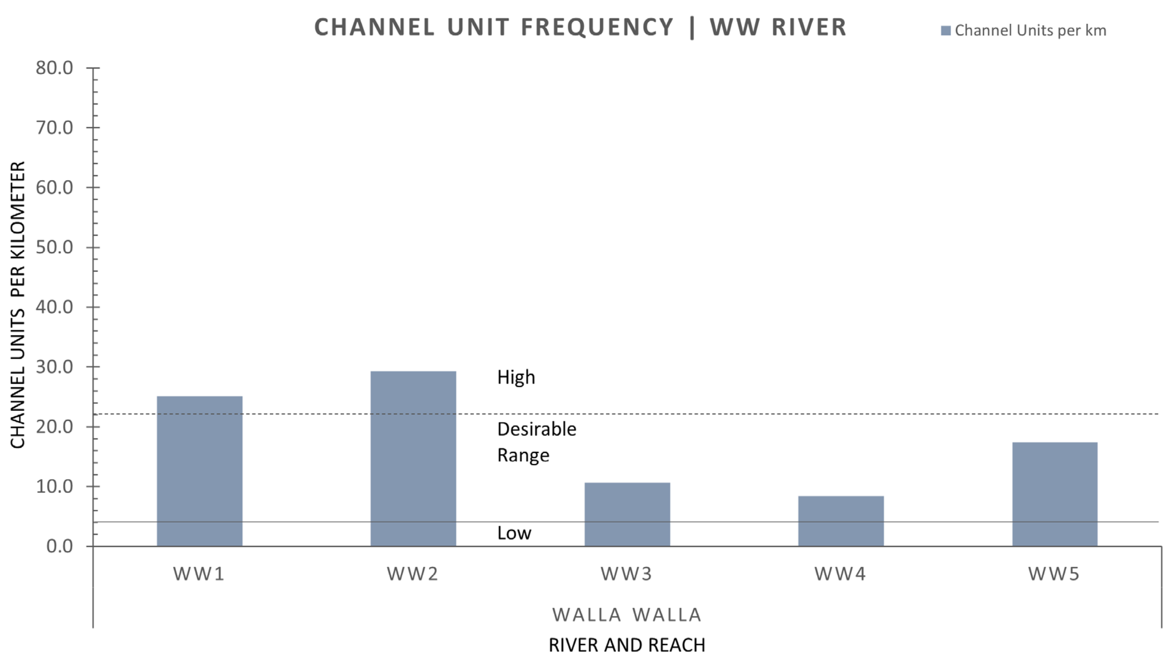

Figure 4-13. Channel unit frequency in the WW River by geomorphic reach.

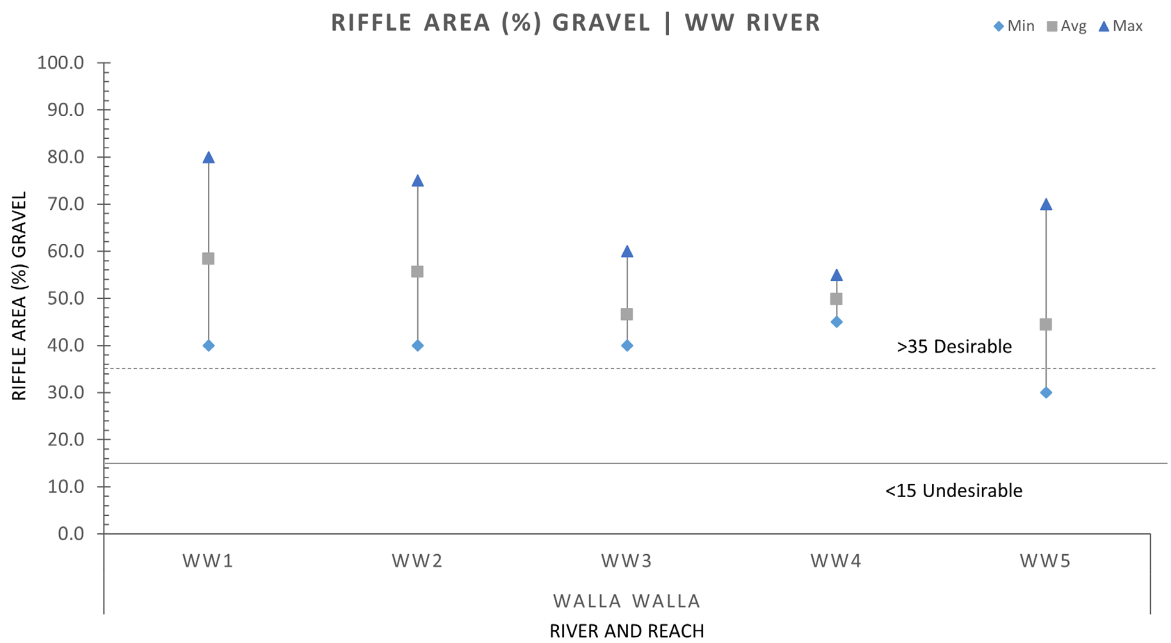

Figure 4-14. Percent of riffle area with gravel in the WW River by geomorphic reach.

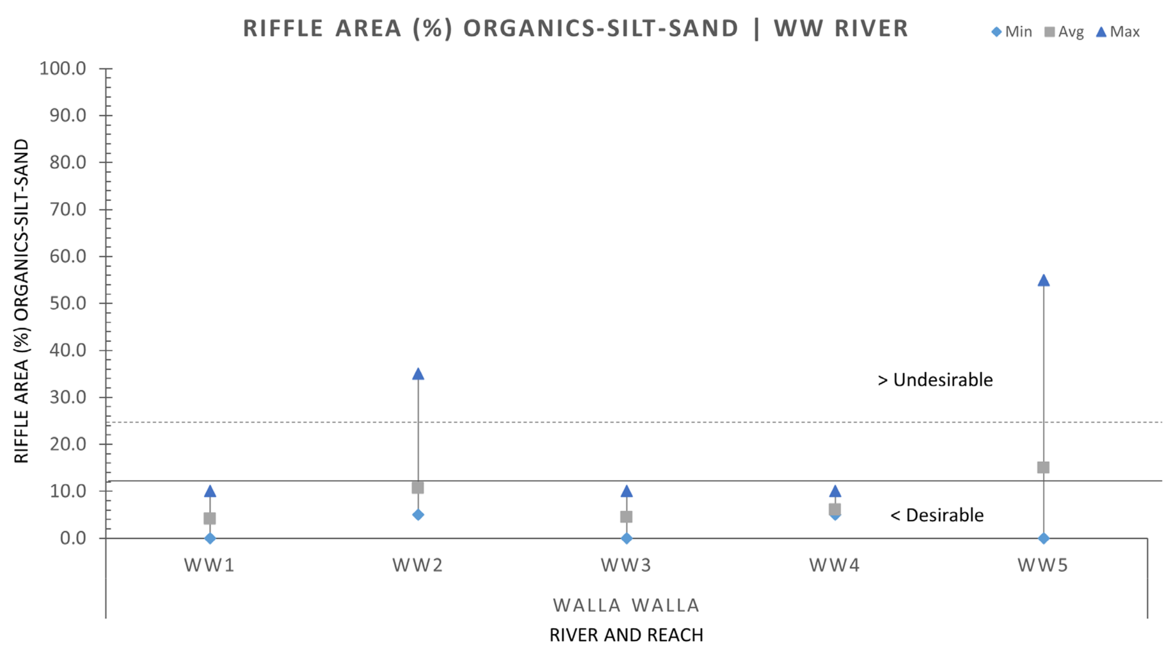

Figure 4-15. Percent of riffle area with organics-silt-sand in the WW River by geomorphic reach.

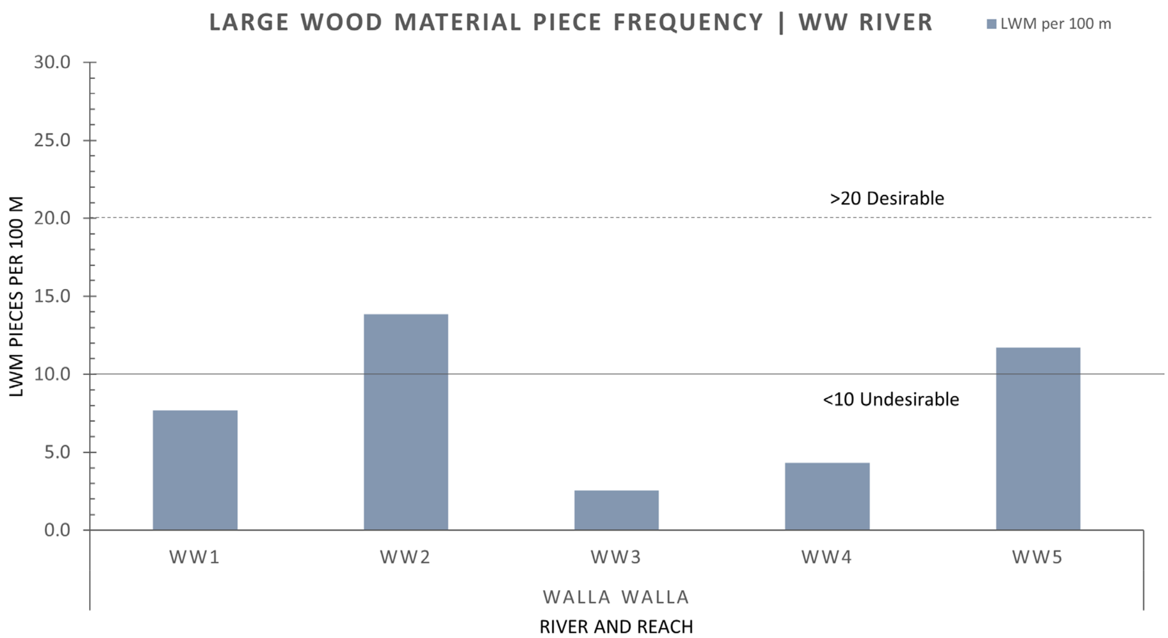

Figure 4-16. Large wood material piece frequency in the WW River by geomorphic reach.

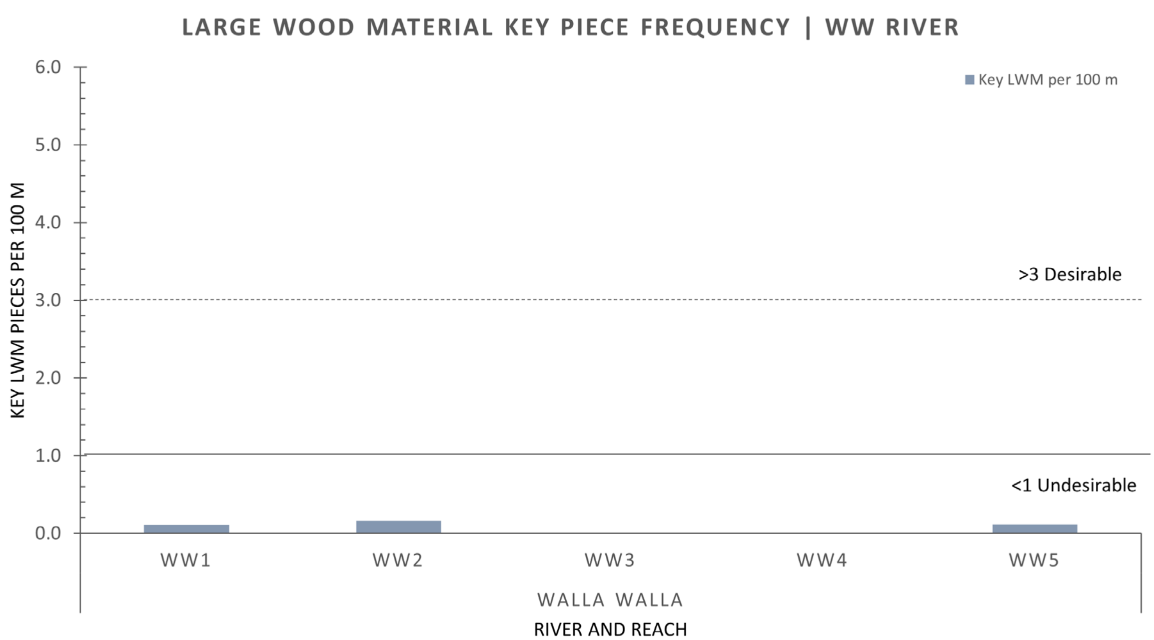

Figure 4-17. Large wood material key piece frequency in the WW River by geomorphic reach

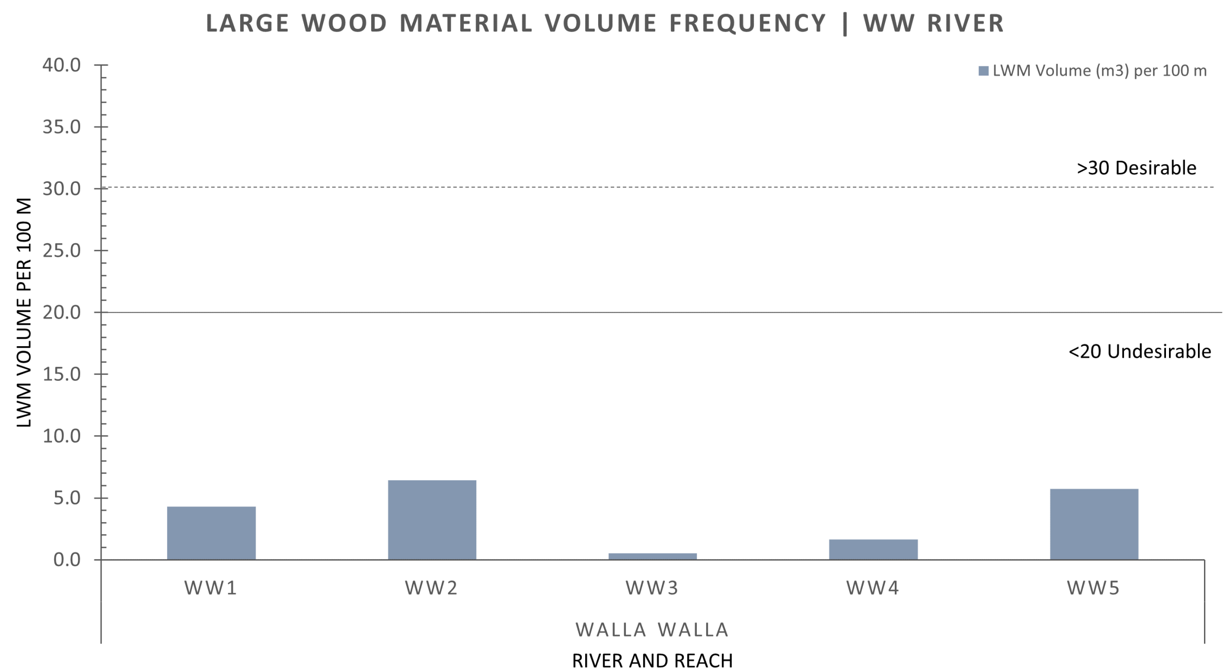

Figure 4-18. Large wood material volume frequency in the WW River by geomorphic reach.

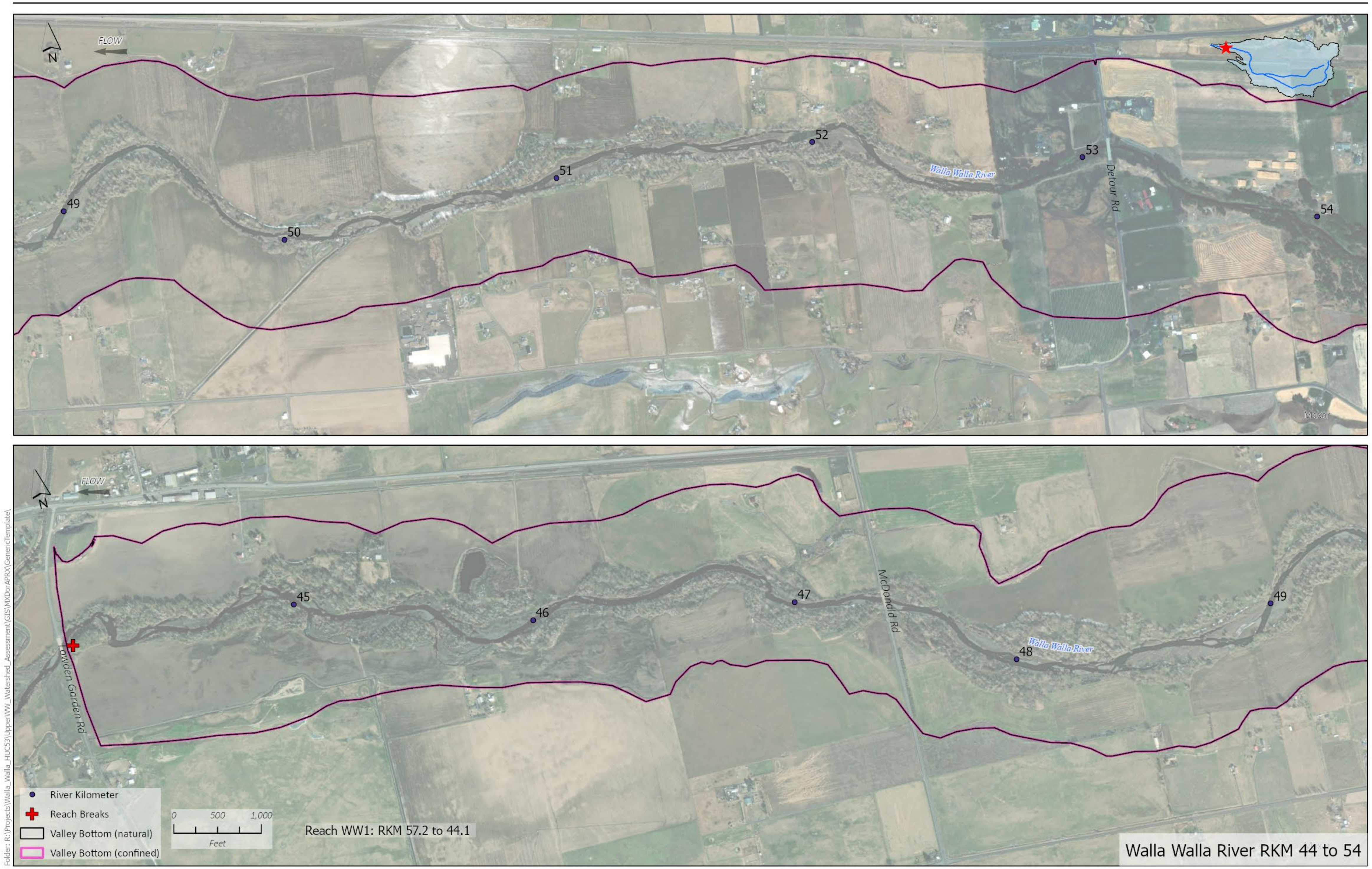

Figure 4-19. Valley bottom extent along WW River reach WW1.

Figure 4-20. Valley bottom extent along WW River reaches WW1 and WW2.

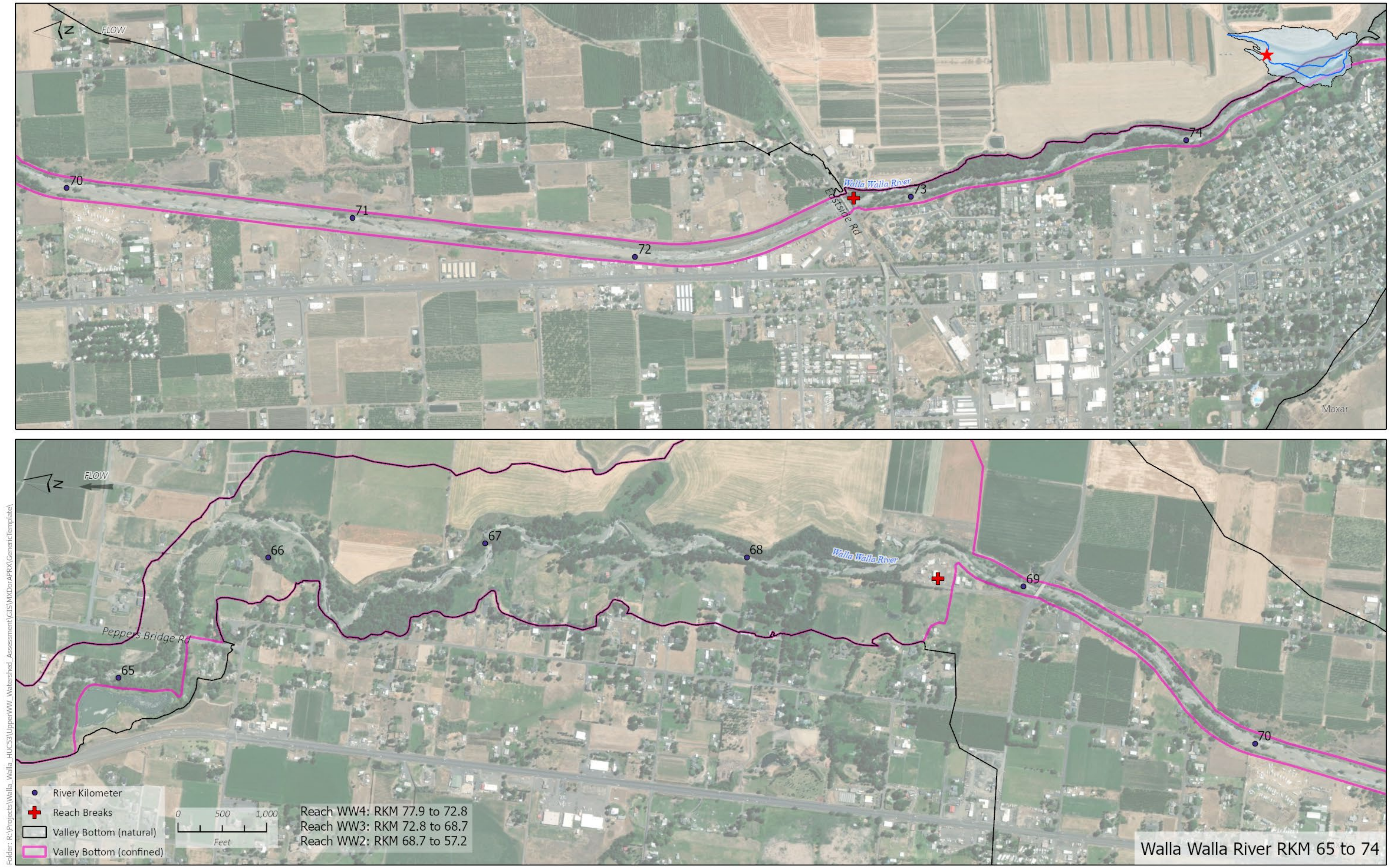

Figure 4-21. Valley bottom extent along WW River reaches WW2, WW3, and WW4.

Figure 4-22. Valley bottom extent along WW River reaches WW4 and WW5.

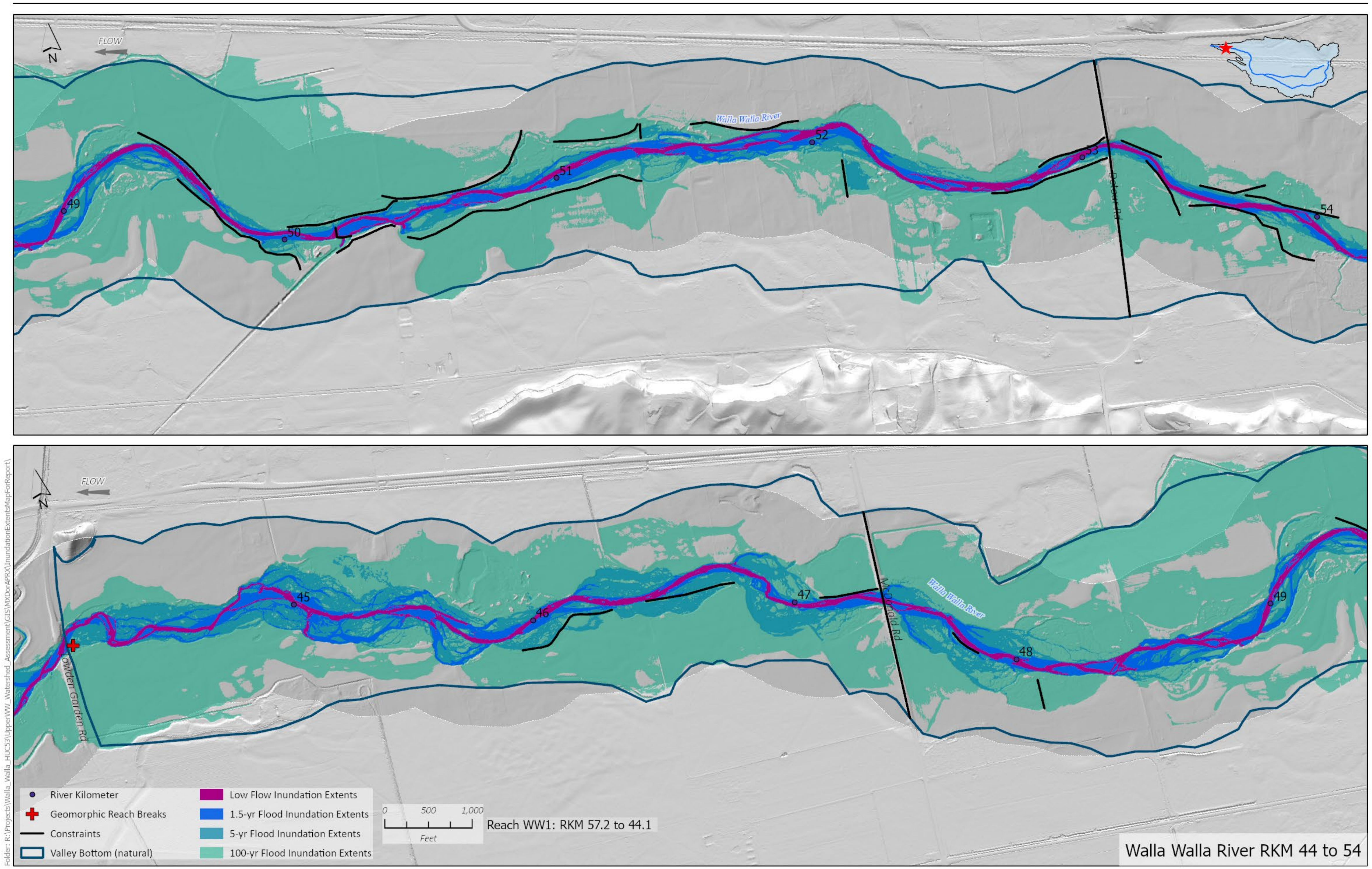

Figure 4-23. Inundation extents and channel constraints along WW River reach WW1.

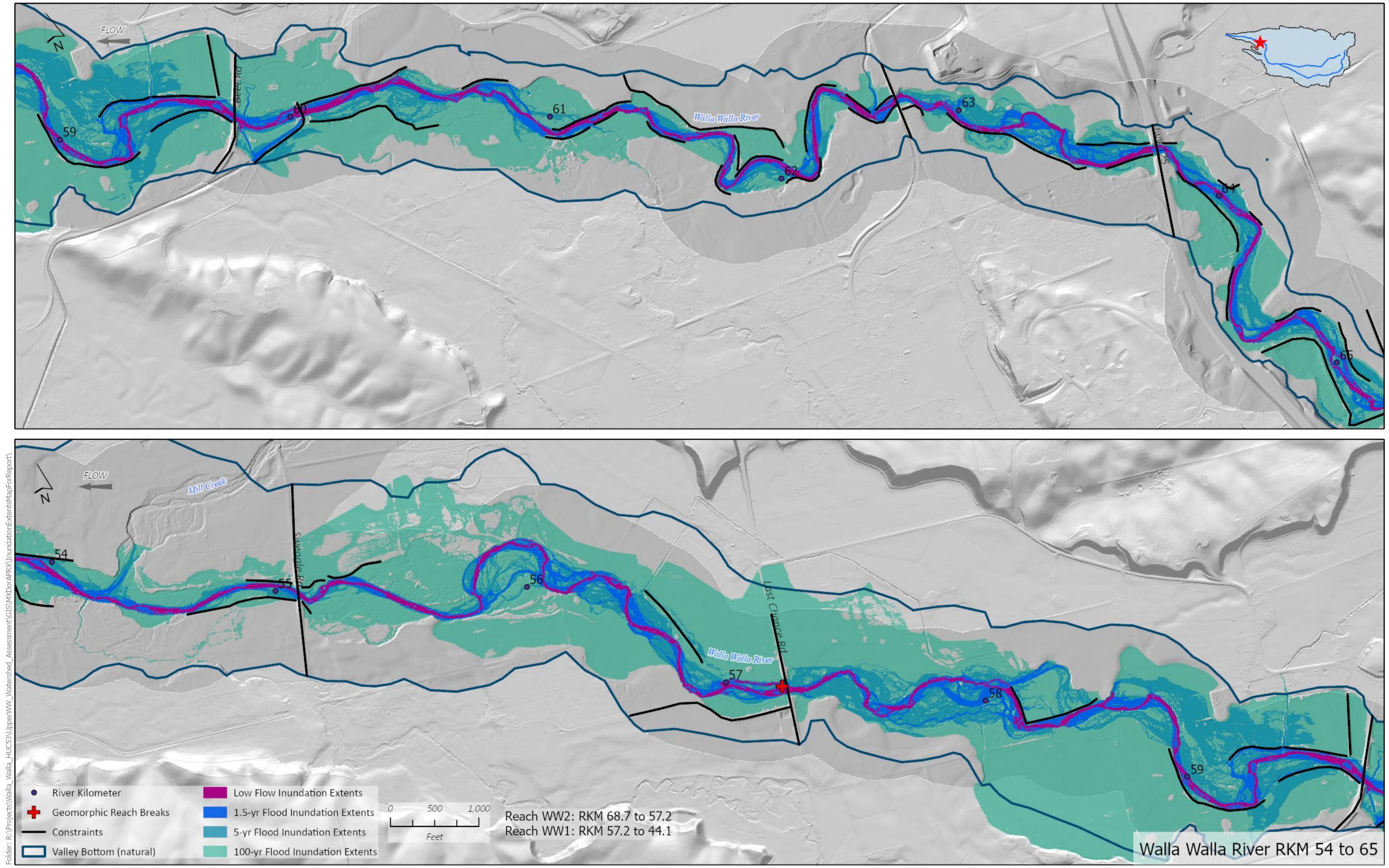

Figure 4-24. Inundation extents and channel constraints along WW River reaches WW1 and WW2.

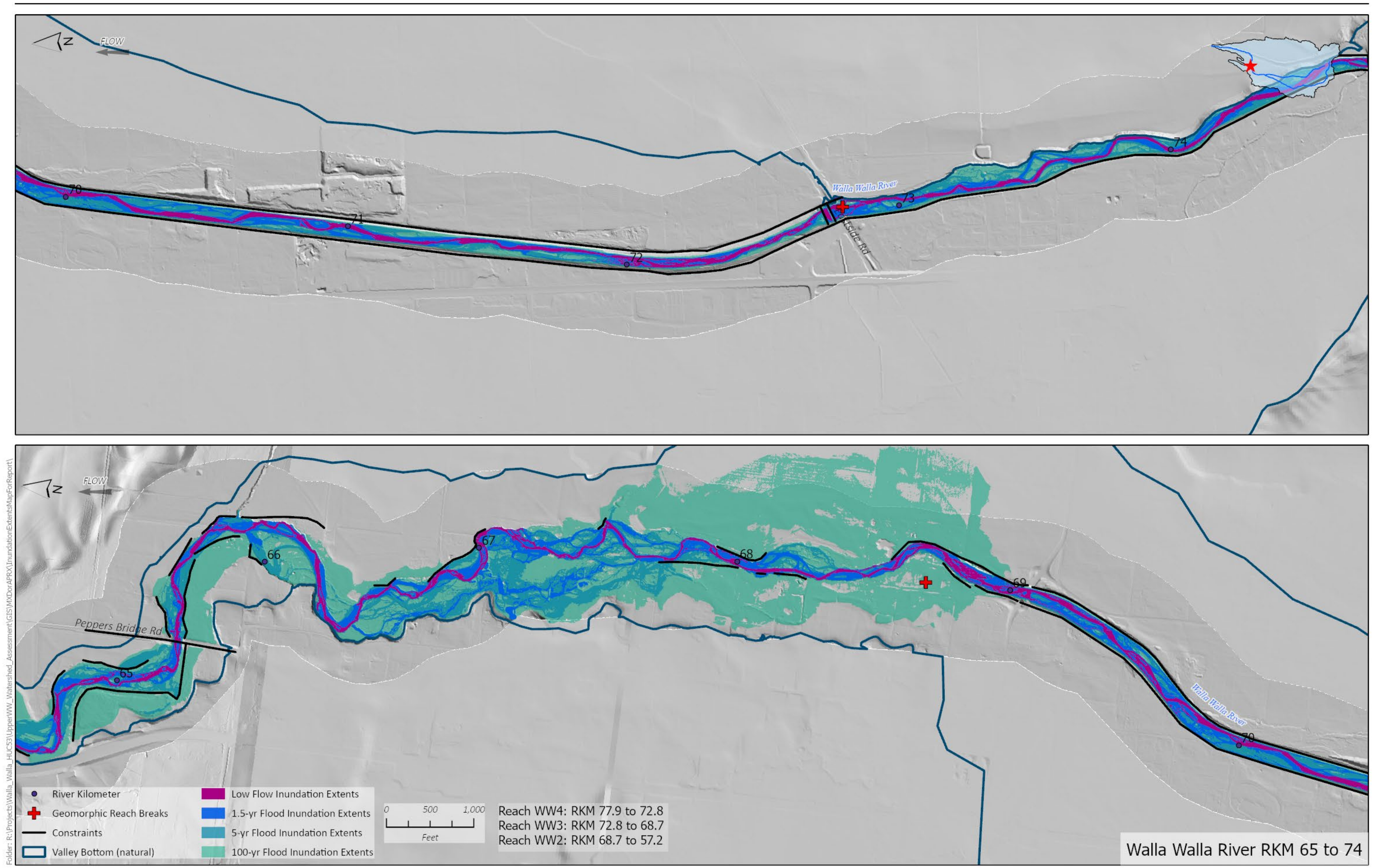

Figure 4-25. Inundation extents and channel constraints along WW River reaches WW2, WW3, and WW4.

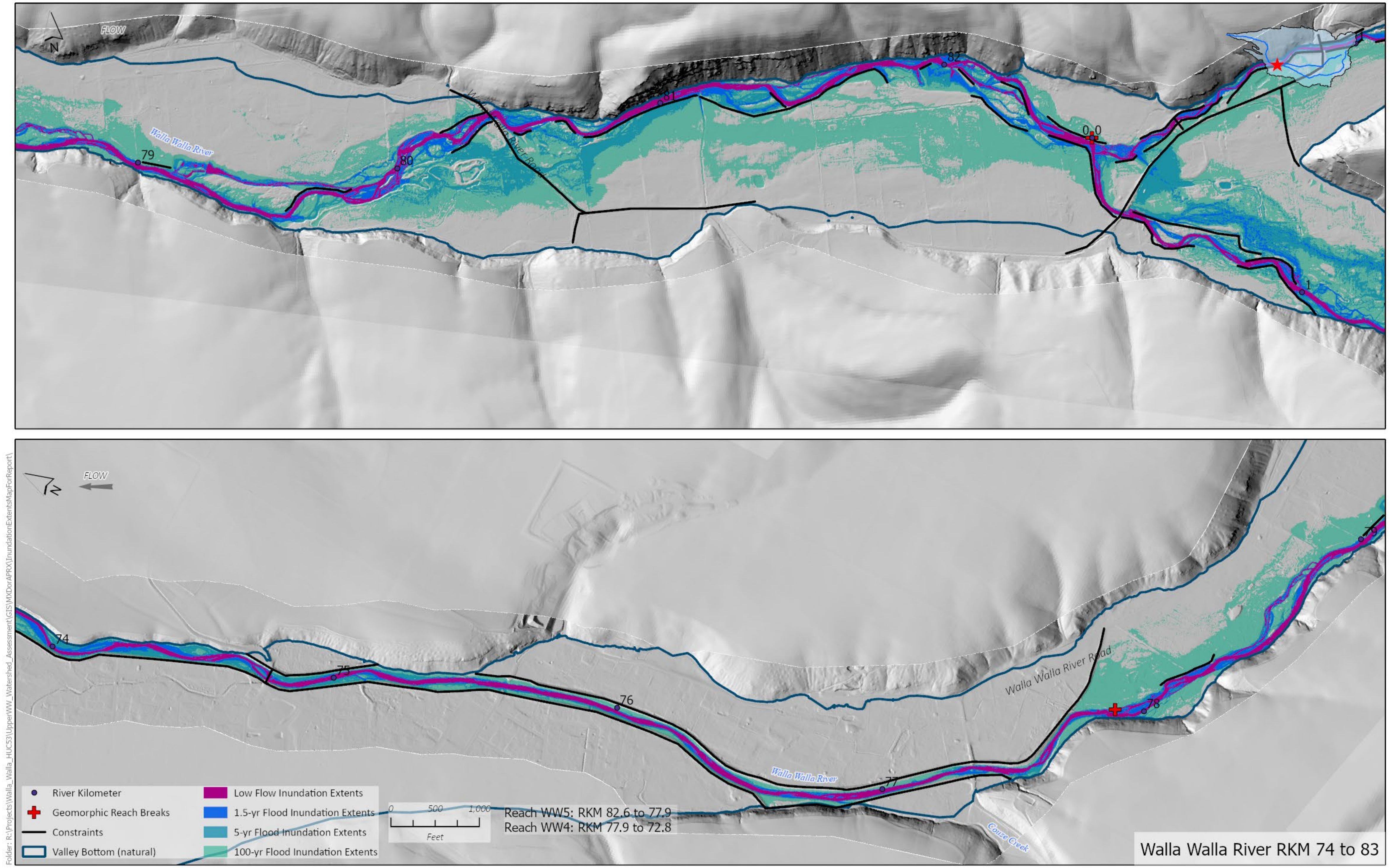

Figure 4-26. Inundation extents and channel constraints along WW River reaches WW4 and WW5.

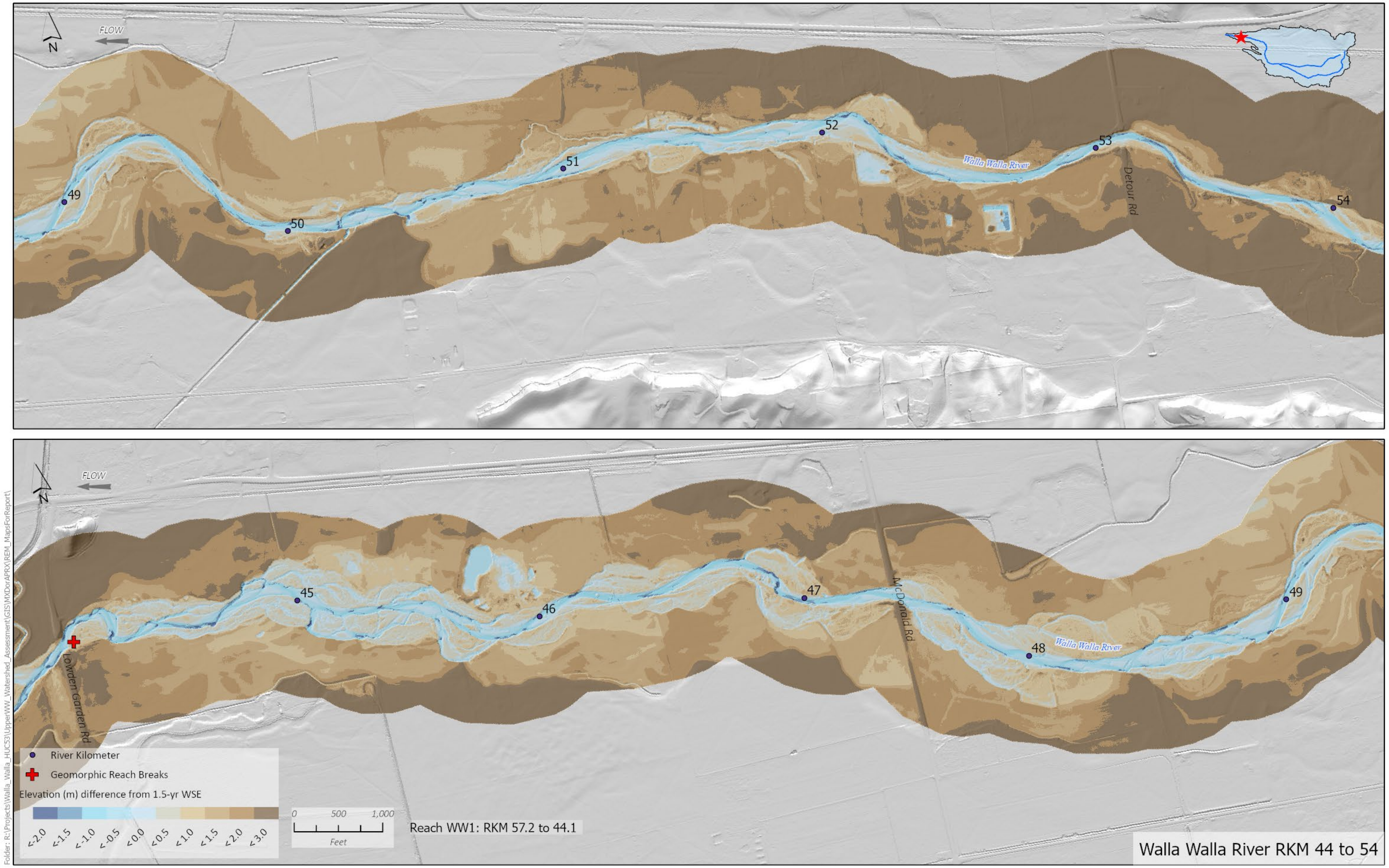

Figure 4-27. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in WW River reach WW1.

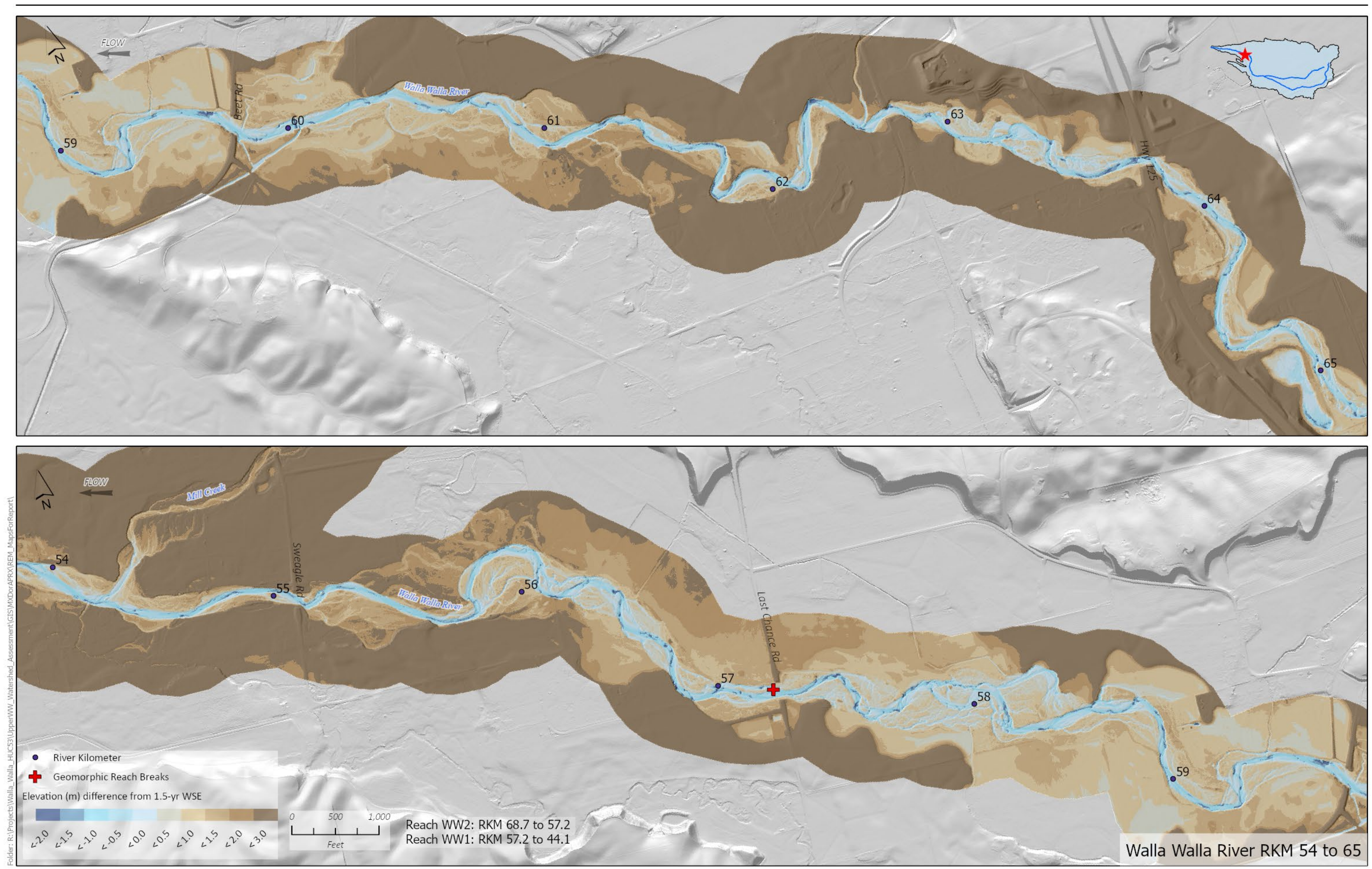

Figure 4-28. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in WW River reaches WW1 and WW2.

Figure 4-29. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in WW River reaches WW2, WW3, and WW4.

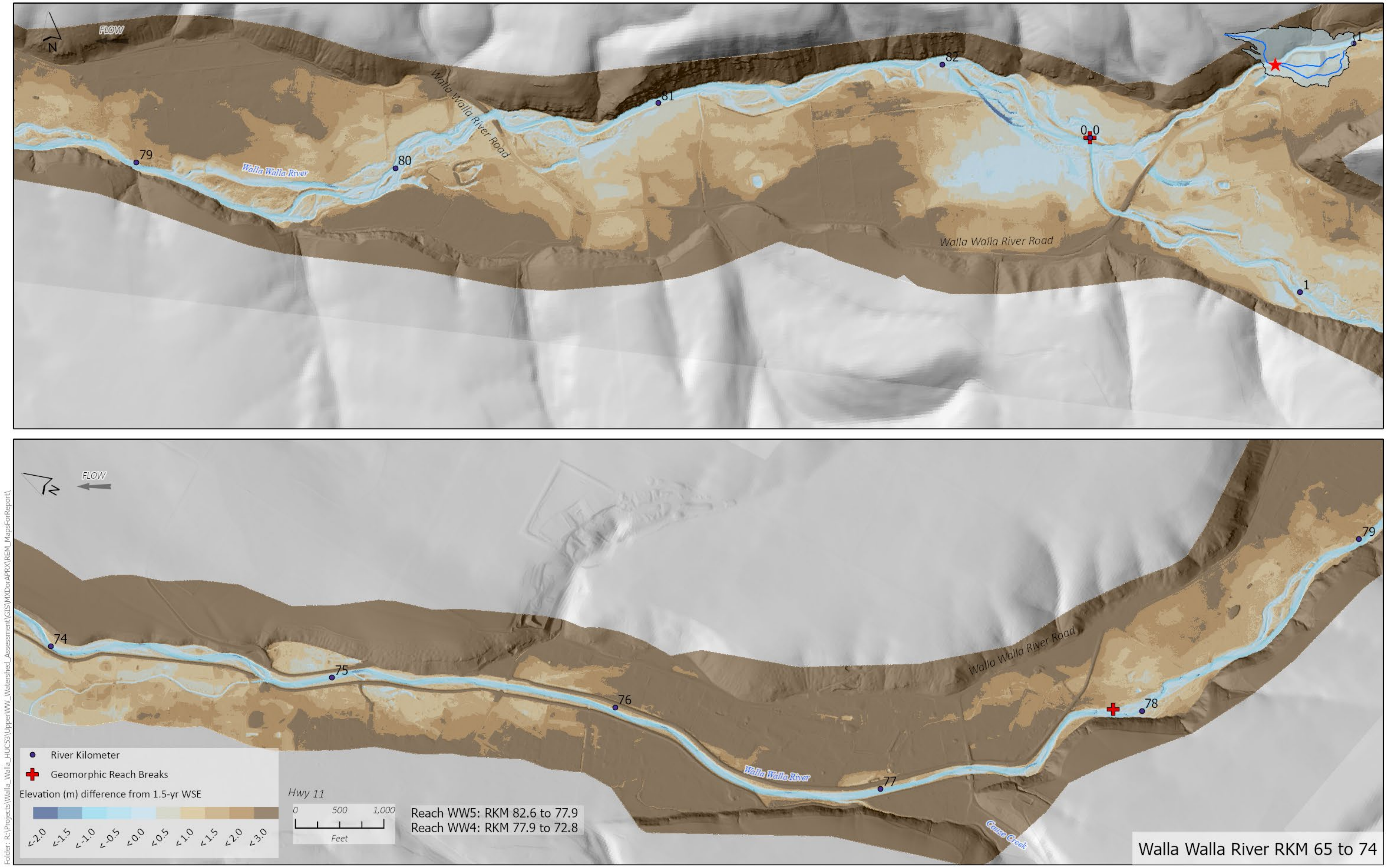

Figure 4-30. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in WW River reaches WW4 and WW5.

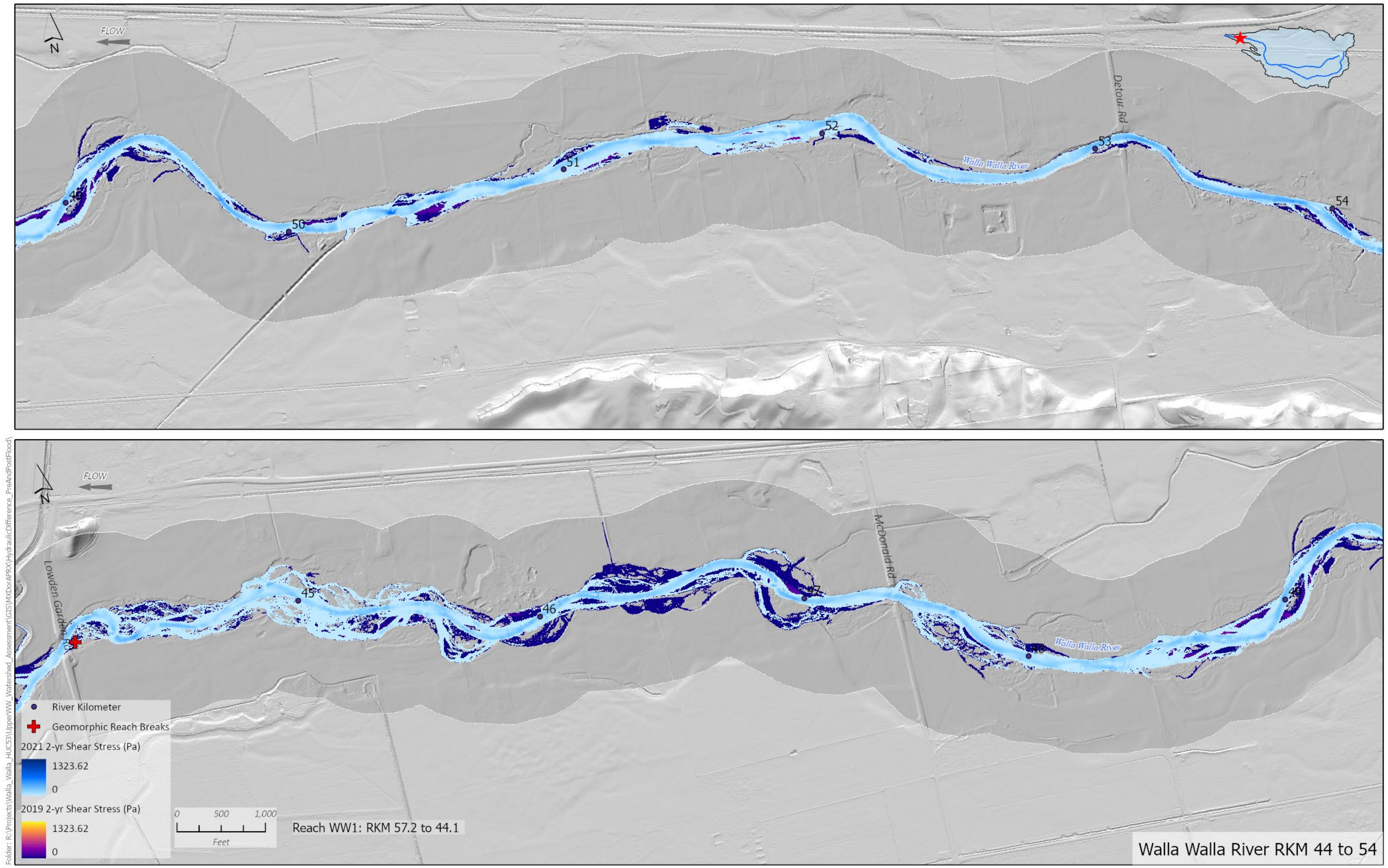

Figure 4-31. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the WW River in reach WW1.

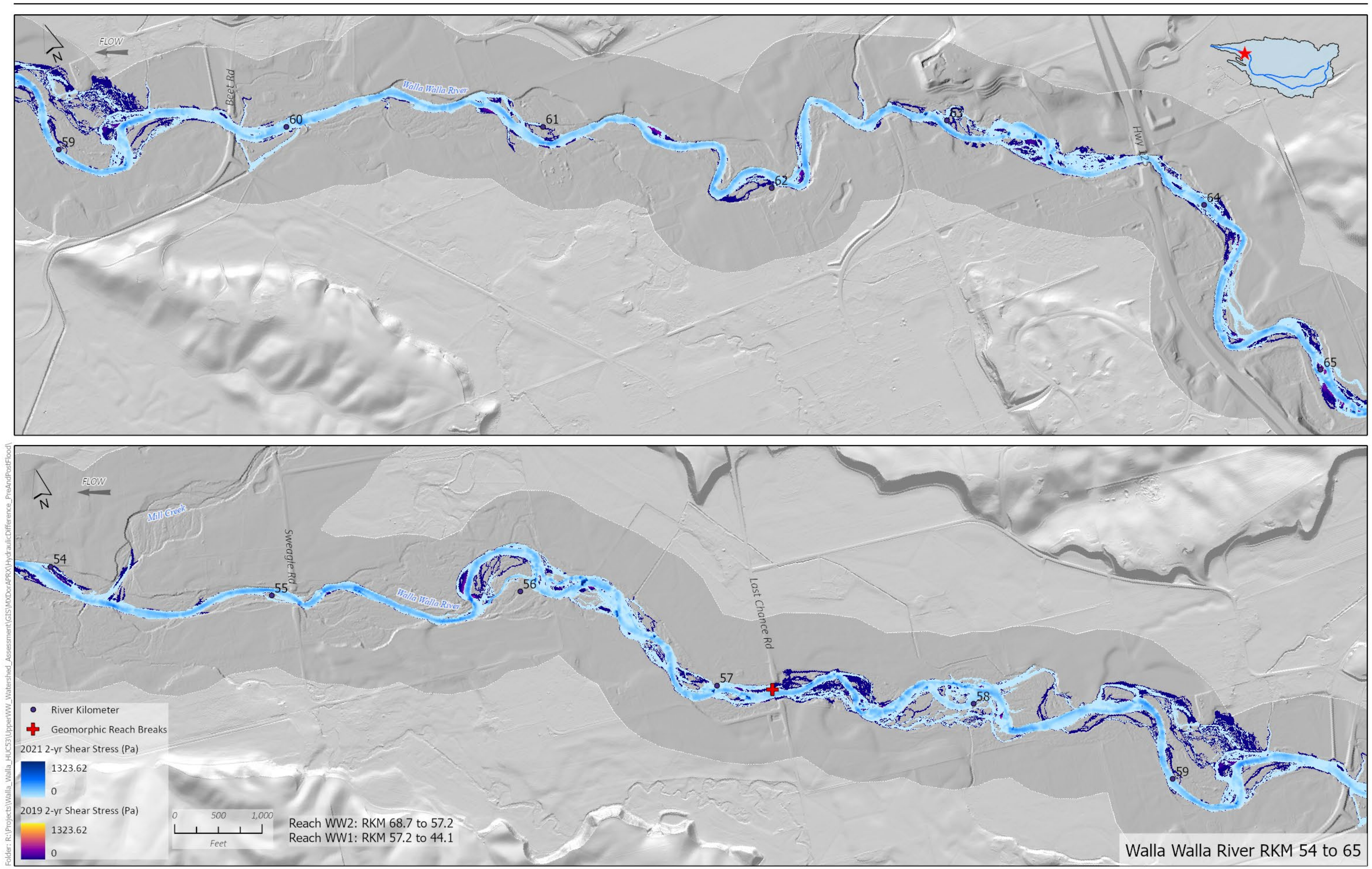

Figure 4-32. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the WW River in reaches WW1 and WW2.

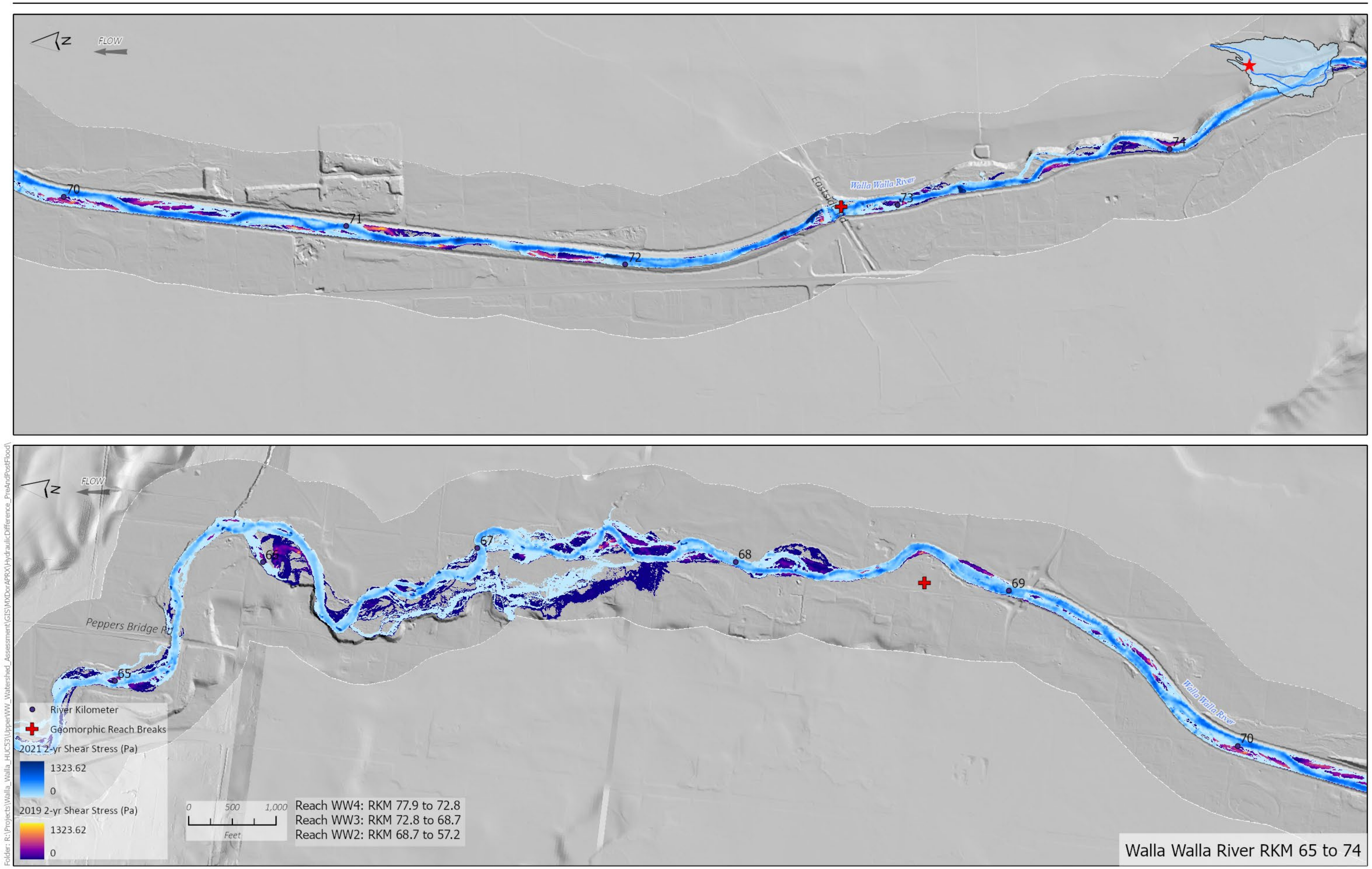

Figure 4-33. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the WW River in reaches WW2, WW3, and WW4.

Figure 4-34. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the WW River in reaches WW4 and WW5.

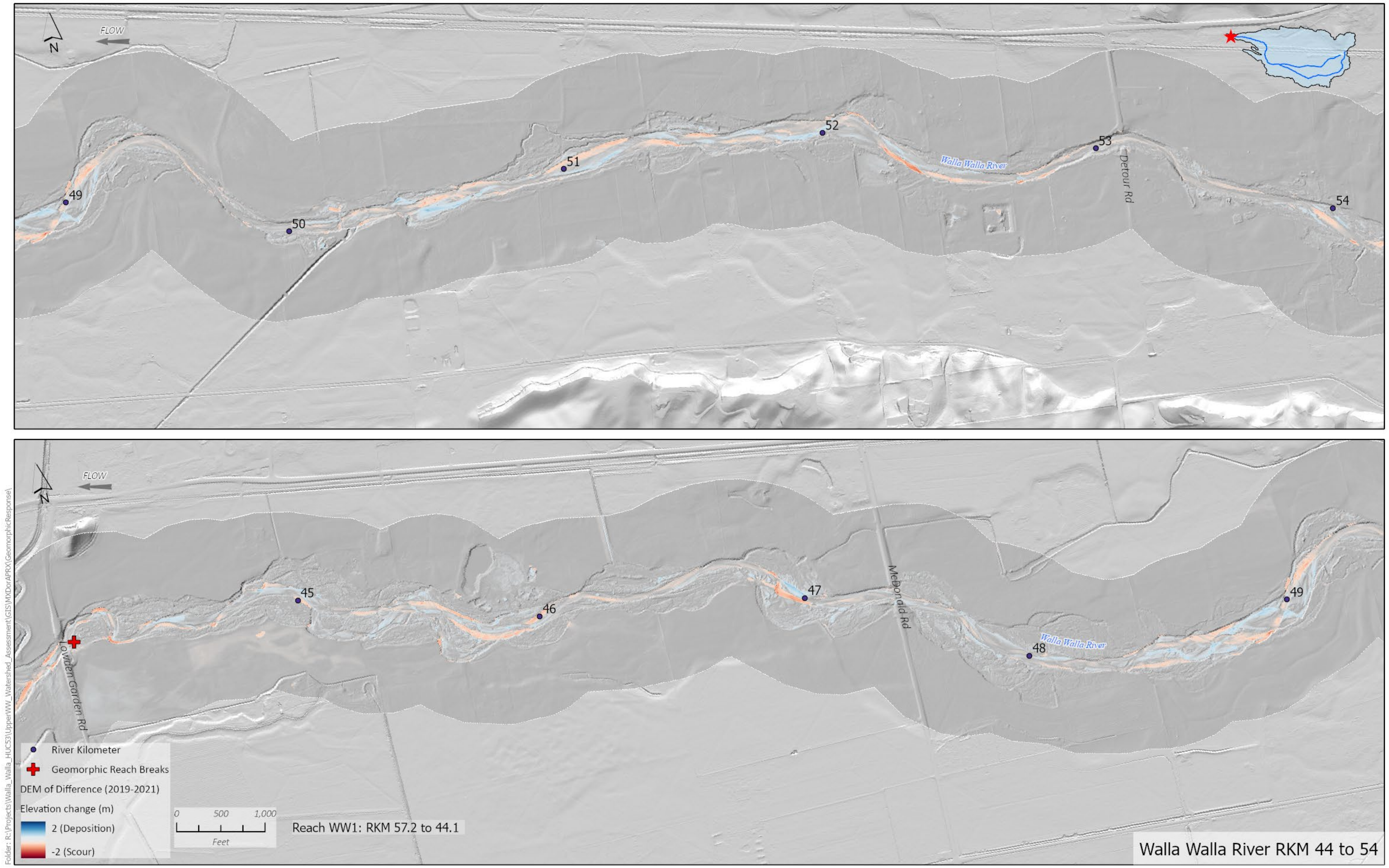

Figure 4-35. Areas of deposition and scour from the 2020 flood in WW River reach WW1.

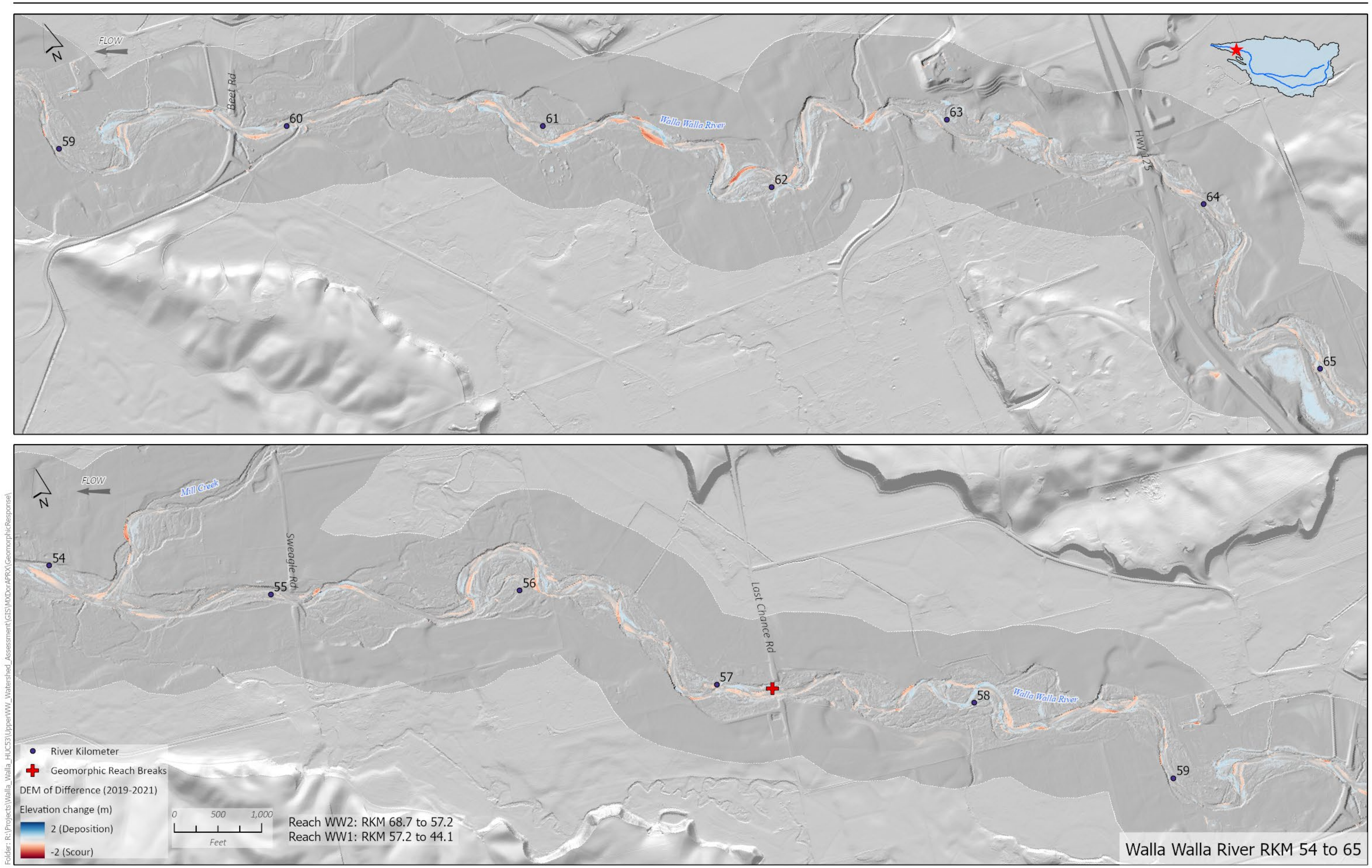

Figure 4-36. Areas of deposition and scour from the 2020 flood in WW River reaches WW1 and WW2.

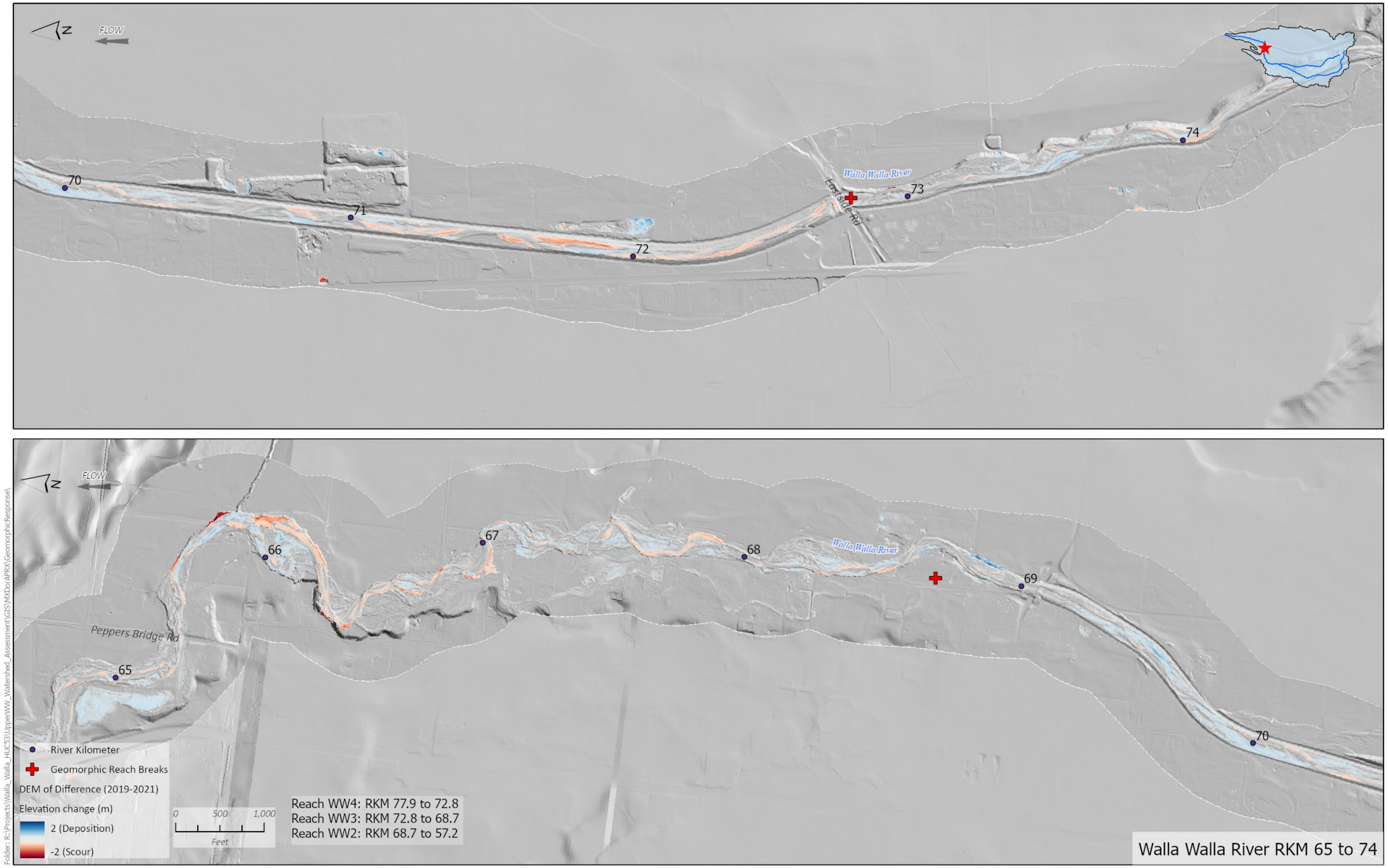

Figure 4-37. Areas of deposition and scour from the 2020 flood in WW River reaches WW2, WW3, and WW4.

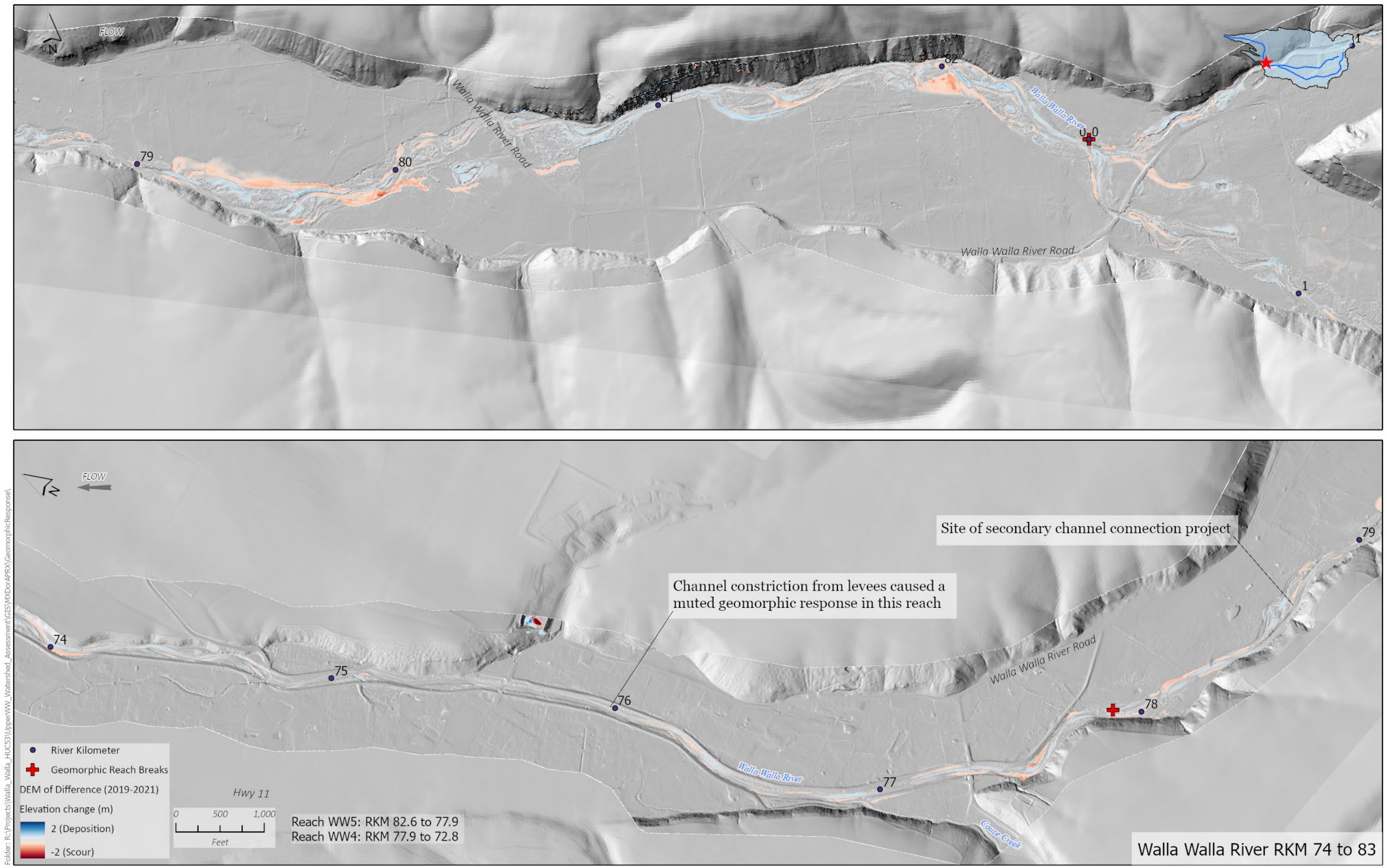

Figure 4-38. Areas of deposition and scour from the 2020 flood in WW River reaches WW4 and WW5.

4.2 NORTH FORK WALLA WALLA RIVER

Reach NF1 in the NFWW River extends 5.7 RKM upstream from its mouth at the WW River and confluence with the SFWW River (Figure 4-56). The NFWW River in reach NF1 has a low sinuosity of 1.20 and flows through partly confined valley in a rural residential setting (Table 4-1). Reach NF1 has a valley slope of 1.9%, with the valley bottom comprised of Quaternary alluvium and the valley margins comprised of basalt bedrock. Cup Gulch is a named ephemeral and intermittent tributary entering reach NF1 near RKM 4.5, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach.

NFWW River reach NF2 is 3.5 RKM in length, extending upstream to RKM 9.2 where the valley width becomes consistently more narrow than downstream (Figure 4-56). The NFWW River in reach NF2 has a low sinuosity of 1.27 and flows through partly confined valley in a rural residential setting (Table 4-1). Reach NF2 has a valley slope of 2.2%, with the valley bottom comprised of alluvium and the valley margins comprised of basalt bedrock. There are numerous unnamed ephemeral and intermittent tributaries throughout the reach.

Reach NF3 is 4.9 RKM in length, extending upstream to RKM 14.1 where there is a change in valley slope and lithology of the valley bottom (Figure 4-57). The NFWW River in reach NF3 has a low sinuosity of 1.24 and flows through a naturally confined valley that is largely undeveloped with the exception of NFWW River Road located along the valley margin (Table 4-1). Reach NF3 has a valley slope of 2.4%, with the valley bottom comprised of alluvium and basalt bedrock, while the valley margins are comprised of basalt bedrock. The perennial tributary in Little Meadow Canyon flows into the NFWW River near RKM 13.8, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach.

Reach NF4 is 4.2 RKM in length, extending upstream to RKM 18.3 where there is a change in valley slope and lithology of the valley bottom (Figure 4-57). The NFWW River in reach NF4 has a low sinuosity of 1.22 and flows through a naturally confined valley that is largely undeveloped with the exception of NFWW River Road located along the valley margin (Table 4-1). The Umatilla National Forest boundary is near RKM 17.8, with upstream reaches being contained within the national forest boundary. Reach NF4 has a valley slope of 3.0%, with the valley bottom and valley margins comprised of basalt bedrock. The perennial tributary in Big Meadow Canyon flows into the NFWW River near RKM 16.1, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach.

NFWW River reaches NF5 through NF8 flow through a naturally confined valley with the valley bottom and margins comprised of basalt bedrock (Figure 4-57 through Figure 4-59; Table 4-1). All of the reaches have low channel sinuosity, ranging from 1.02 to 1.06, with valley slopes increasing from 3.3% in reach NF5 to 13.3% in reach NF8. The reaches are undeveloped and located within the Umatilla National Forest. There are numerous unnamed perennial, ephemeral, and intermittent tributaries throughout the reaches.

River and floodplain conditions in NFWW River reaches NF1, NF2, and NF3 have been altered as a result of rural residential and agricultural development along the valley bottom. While these reaches are naturally partly confined or confined by the valley walls, the floodplains that are available have been markedly disconnected from the river by discontinuous constraints on lateral and longitudinal channel migration, especially in reach NF1. Artificial channel confinement from continuous levees is minimal in all NFWW River reaches (Figure 4-39). However, discontinuous constraints on channel migration (e.g., roads, bridges, bank protection, grade control structures) limits river-floodplain connectivity in NFWW River, especially in reach NF1. In this reach, the NFWW River has been largely confined to one side of the valley bottom by the placement of non-engineered levees and bank protection. The ratio of constraint length to reach length ranges from 0.04 in reach NF2 to 1.03 in reach NF1 (Table 4-3; Figure 4-40; Figure 4-60 and Figure 4-61).

Table 4-3: Artificial floodplain disconnection by channel constraints in the NFWW River.

Reach ID	Reach Length (km)	Constraint Length (km)	Constraint Length Ratio of Reach Length
NF1	5.7	5.89	1.03
NF2	3.5	0.14	0.04
NF3	4.9	1.01	0.21
NF4	4.2	0.00	0.00
NF5	3.1	0.00	0.00
NF6	3.2	0.00	0.00
NF7	3.3	0.00	0.00
NF8	2.7	0.00	0.00

River manipulation throughout NFWW River reach NF1 has included a straightening of the channel and reducing the river sinuosity (Figure 4-60 and Figure 4-61). These alterations have converted what was once likely a predominantly pool-riffle channel morphology into a higher energy plane-bed structure with long subreaches of continuous riffle and much fewer subreaches of pool-riffle channel morphology. Multi-thread channels that appear on historical topographic maps, in LiDaR data, and are visible in moist soil patterns from aerial photography, have been removed, filled, drained, and/or artificially disconnected from the active channel, especially in reach NF1 (Figure 4-60 through Figure 4-63). These changes in channel morphology have affected the sediment transport regime whereby gravel deposition and bar formation are very limited and much less than is expected in these valley settings. The conversion of the river to a straighter, higher energy channel with greater sediment transport capacity suggests that some vertical degradation of the riverbed has occurred.

Throughout NFWW River reaches NF1, NF2, and NF3 hydraulic connectivity of the river channel has been limited both laterally and longitudinally. The amount of natural valley bottom inundated by the 14-day discharge ranges from 6% in reach NF1 to 15% in reach NF4 (Figure 4-41). For the estimated effective discharge (2-yr peak flow) the inundated area ranges from 8% to 20% of the natural valley bottom in reaches NF1 and NF4, respectively. In reaches NF1, NF2, and NF3, there is a marked increase in inundation from the 2-yr to the 5-yr peak flow (Figure

4-41) suggesting that artificial channel constraints on floodplain connectivity limits much of the lower magnitude peak floods (e.g., less than 5-yr peak) to the active channel in these reaches, especially reach NF1 (Figure 4-60 and Figure 4-61). Within reach NF1 less than 33% of the natural valley bottom is inundated under all modeled discharges, including the 1% annual chance peak flood (100-yr event) (Figure 4-41 and Figure 4-60). These results suggest that during the more frequent peak discharges (i.e., less than the 5-yr peak), much of the available energy from the stream flow is concentrated in the active channel in reach NF1 rather than being distributed onto the adjacent floodplain, further exacerbating the vertical channel incision and floodplain disconnection.

Under the assumed effective, channel-forming discharge (i.e., 2-yr peak), the hydraulic characteristics of stream power, shear stress, and sediment entrainment potential vary among the NFWW River reaches. The median of maximum unit stream power from sampled cross-sections ranged from approximately 263 W m^{-2} in reach NF2 to 302 W m^{-2} in reach NF1 (Figure 4-42), while the median of mean unit stream power from sampled cross-sections ranged from approximately 114 W m^{-2} in reach NF2 to 162 W m^{-2} in reach NF1 (Figure 4-43). Similarly, the median of maximum shear stress ranged from approximately 126 Pa in reach NF2 to 147 Pa in reach NF4 (Figure 4-44), while the median of mean shear stress ranged from approximately 70 Pa in reach NF2 to 94 Pa in reach NF4 (Figure 4-45). In all the modeled reaches the maximum shear stress well exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-44); similarly, at more than 75% of the sampled cross-sections in all reaches the mean shear stress exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-45). The entrainment potential for the coarser material (D84) within the grain-size mixtures was notable in all reaches, with the partial entrainment threshold of 1.0 being exceeded by more than 75% of all sampled cross-sections in all reaches (Figure 4-46). At many of the sampled cross-sections in reach NF1 the entrainment threshold exceeded 2.0, which is indicative of full bed mobility and significant transport of bed material. In all reaches, there was a negligible change in the reach-wide magnitude of modeled hydraulic characteristics based on the pre-flood (2019) and post-flood (2021) topobathymetric surfaces used for the hydraulic modeling. However, there were notable spatial changes in bank erosion, channel migration, and subsequent changes in hydraulic characteristics and channel erosion and deposition (Figure 4-64 and Figure 4-65). For example, notable changes in channel location and alignment were observed near RKM 2.5 – 3.0 in reach NF1 (Figure 4-64), RKM 5.7 – 8.5 in reach NF2 (Figure 4-64), and RKM 9.2 – 17.0 in reaches NF3 and NF4 (Figure 4-65). These subreach locations also exhibited some of the more prominent geomorphic responses to the 2020 flood as indicated by the magnitude of scour and deposition (Figure 4-66 and Figure 4-67).

The reach-wide hydraulic and geomorphic characteristics of all NFWW River reaches are reflected in the observations from stream surveys at the sub-reach and site scales. Average riffle width to depth ratios ranged from 17 in reach NF5 to 31 in reach NF3 (Figure 4-47), with the average width to depth ratio in all reaches well exceeding the benchmark desirable value of less than 10. In reach NF3, the average width to depth ratio exceeded the undesirable benchmark value of greater than 30 (Figure 4-47), while in reach NF1 the average width to depth ratio of 27 nearly exceeded that threshold. Notably, NF1 and NF3 are those reaches with the greatest length of artificial channel constraints (Figure 4-40). Average residual pool depth ranged from 0.52 m in reach NF1 to 1.3 m in reach NF4, with the average value in all reaches except NF1 and NF5 falling above the desirable benchmark (Figure 4-48). Note that the benchmark values differ based on channel width and slope. The frequency of pools was less than desirable in reaches NF1, NF3, and NF4, ranging from 1.5 pools/KM in reach NF4 to 4.7 pools/KM in reach NF3 (Figure 4-49). Pool frequency was higher in reaches NF5 (5.2 pools/KM), NF2 (12 pools/KM), and NF7 (15 pools/KM), exceeding the desirable pool frequency range of 5 to 8 pools/KM (Figure 4-49). While the pool frequency in reaches NF1 and NF3 was less than desirable, the total channel unit frequency in these reaches was in the desirable range (Figure 4-50), reflecting the prevalence of run, glide, and riffle geomorphic units in these reaches. Reach NF4 exhibited values of pool frequency (Figure 4-49) and channel unit frequency (Figure 4-50) that were less than the desirable threshold, indicating a lack of channel complexity throughout this reach.

Observations from stream surveys suggest that riverbed grain size characteristics in riffles are largely within the range of desirable conditions in reaches NF1, NF2, and NF3. The average percentage of riffle areas comprised of gravel ranged from 41% in reach NF2 to 48% in reach NF3, with the average value in these reaches well exceeding the desirable value of greater than 35% (Figure 4-51). None of the NFWW River reaches sampled had a percentage of riffle area comprised of gravel that was less than the undesirable threshold of 15%. The riffle area comprised of finer sediment material was within the desirable range in all reaches. The average percentage of riffle areas comprised of organics-silt-sand ranged from 2% in reach NF4 to 7% in reach NF7 (Figure 4-52), with the average value in none of the reaches exceeding the undesirable benchmark threshold of 15%.

Observations from stream surveys indicate that the abundance of LWM in all NFWW River reaches is much less than the desirable conditions. The LWM piece frequency ranged from 1 piece per 100 m in reach NF4 to 15 pieces per 100 m in reach NF7, with the piece frequency in all reaches being well below the desirable benchmark value of greater than 20 pieces per 100 m (Figure 4-53). The LWM that is present in all reaches is predominantly smaller size class material, as indicated by the low abundance of key LWM pieces (>60 cm diameter and >10 m long). The LWM key piece frequency ranged from 0 pieces per 100 m in reaches NF1 to 1.7 pieces per 100 m in reach NF7, with the key piece frequency in all reaches being well below the desirable benchmark value of greater than 3 key pieces per 100 m (Figure 4-54). The prevalence of smaller size class LWM in all reaches is also evident in estimates of LWM volume frequency. The LWM volume frequency ranged from 1 m^3 per 100 m in reach NF4 to 26 m^3 per 100 m in reaches NF7, with the LWM volume frequency in all reaches being well below the desirable benchmark value of greater than 30 m^3 per 100 m (Figure 4-55).

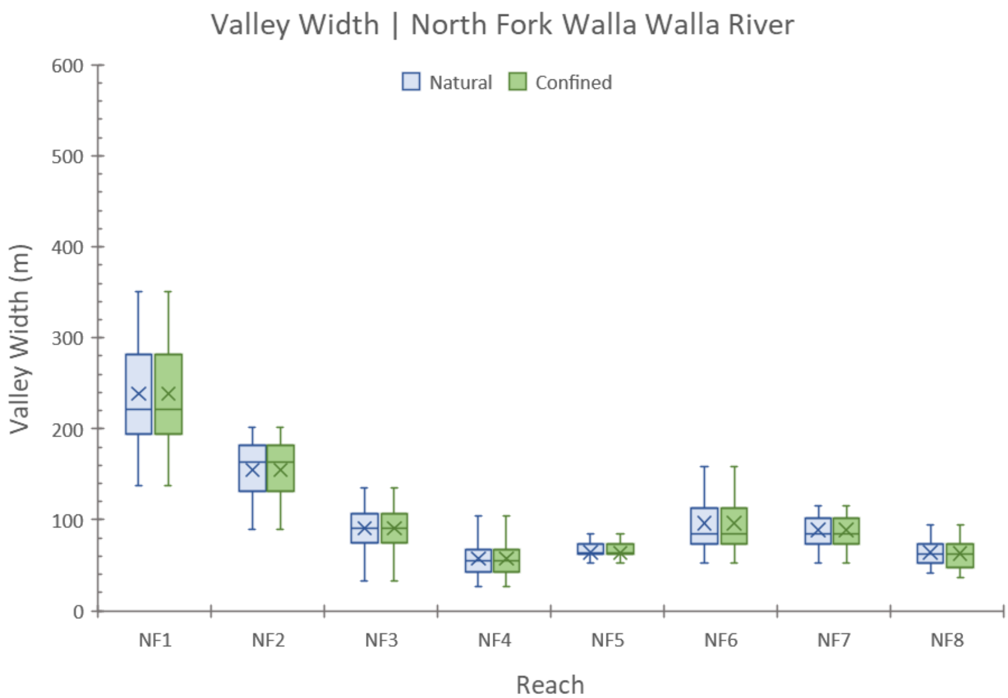

Figure 4-39. Valley width (natural and artificially confined) of the NFWW River by geomorphic reach.

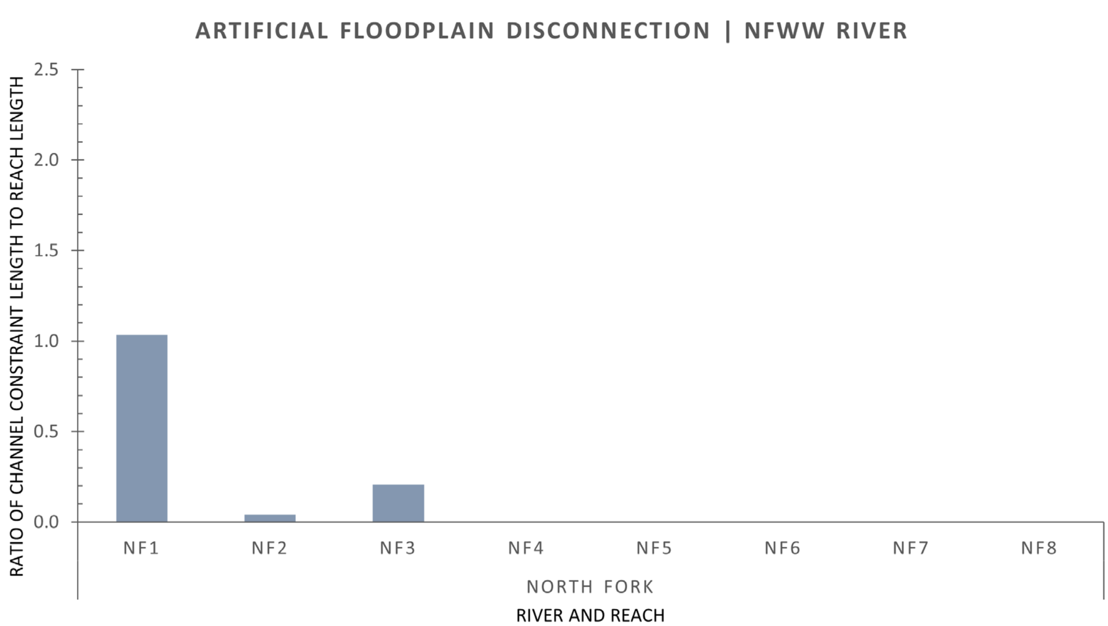

Figure 4-40. Length of channel constraints in the NFWW River by geomorphic reach.

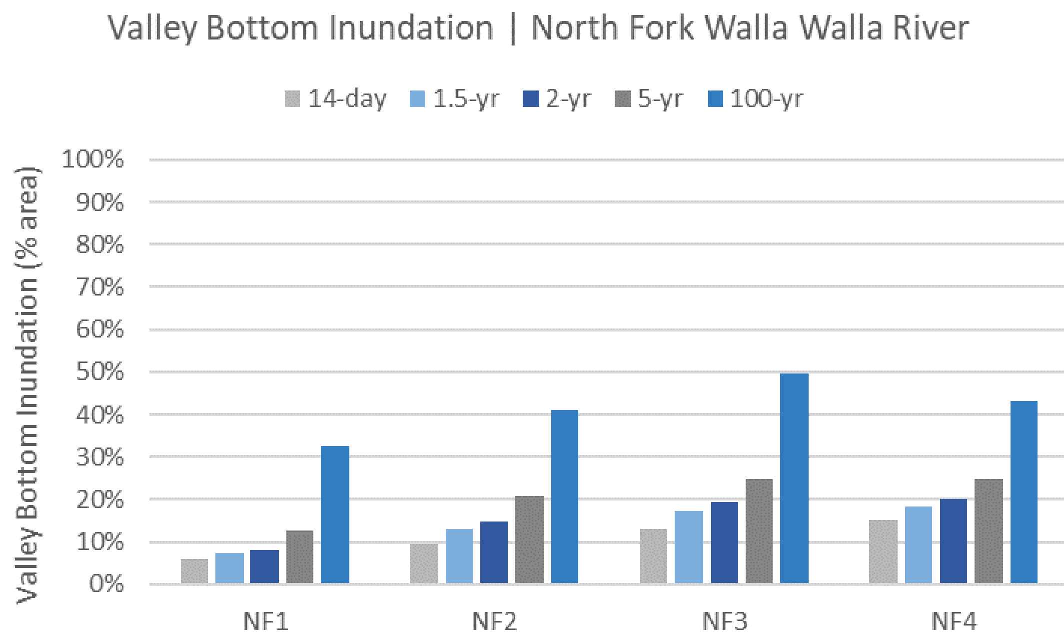

Figure 4-41. Valley bottom inundation for a range of discharges in the NFWW River by geomorphic reach.

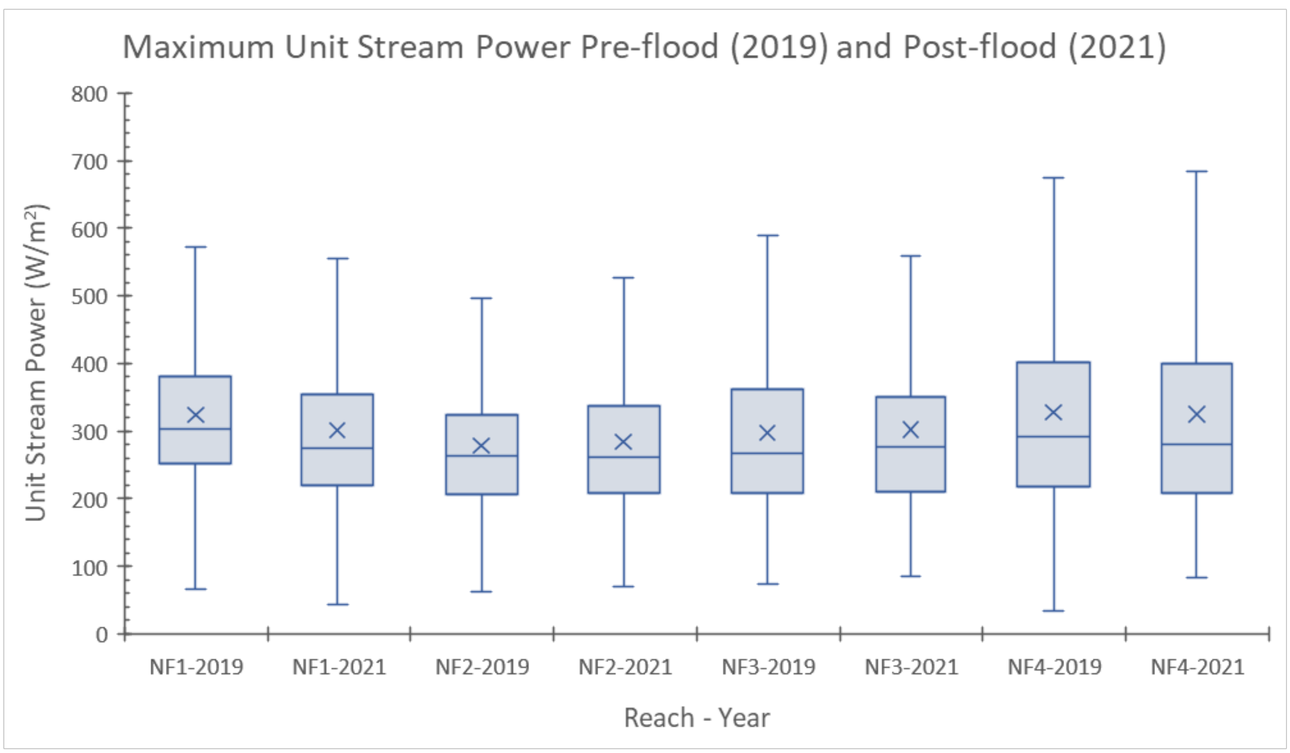

Figure 4-42. Maximum unit stream power for the 50% annual chance flood (2-yr peak) in the NFWW River.

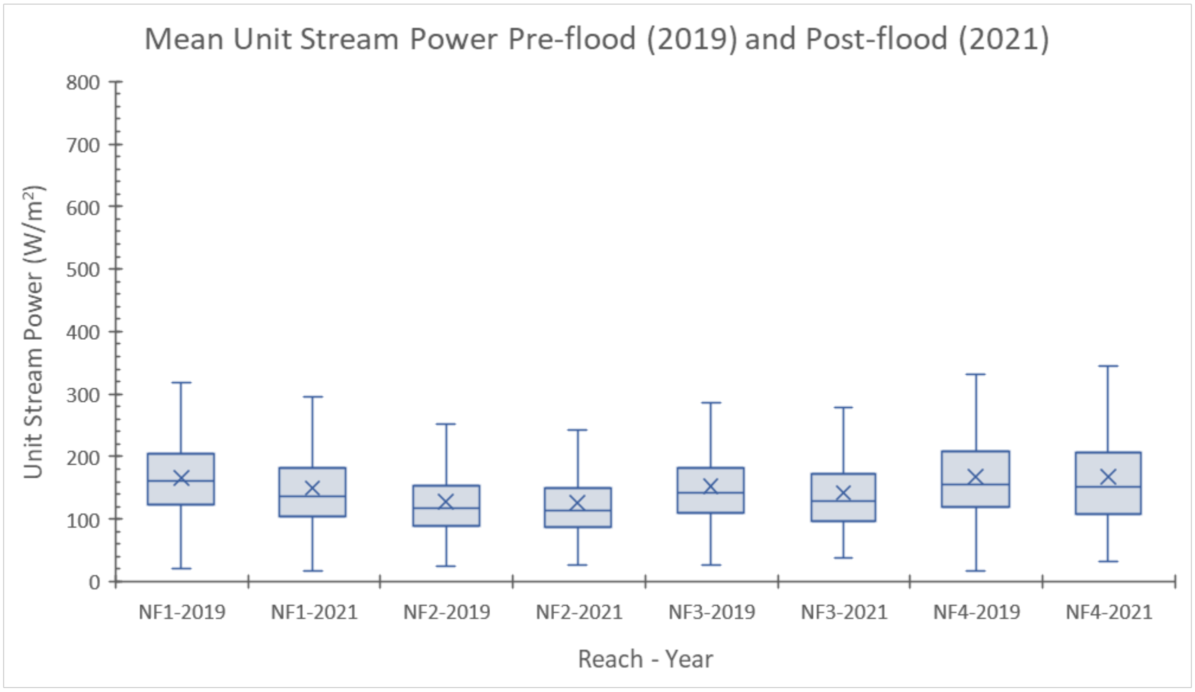

Figure 4-43. Mean unit stream power for the 50% annual chance flood (2-yr peak) in the NFWW River.

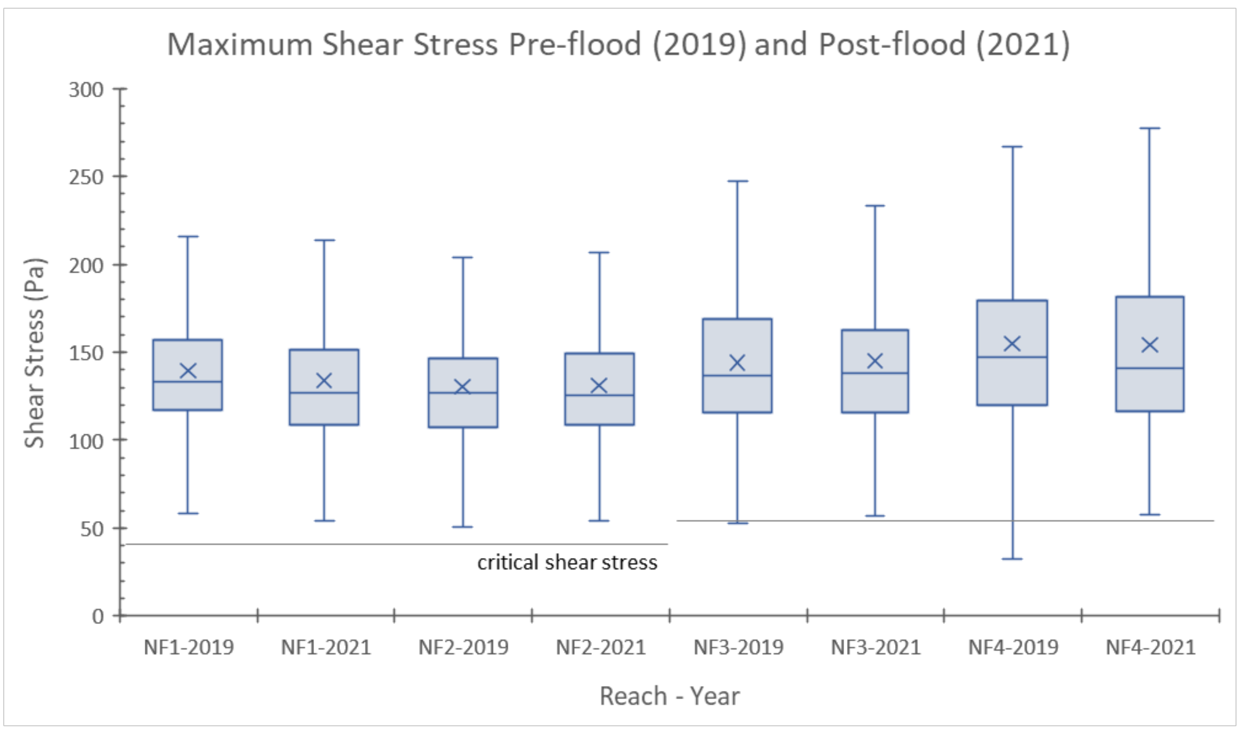

Figure 4-44. Maximum shear stress for the 50% annual chance flood (2-yr peak) in the NFWW River.

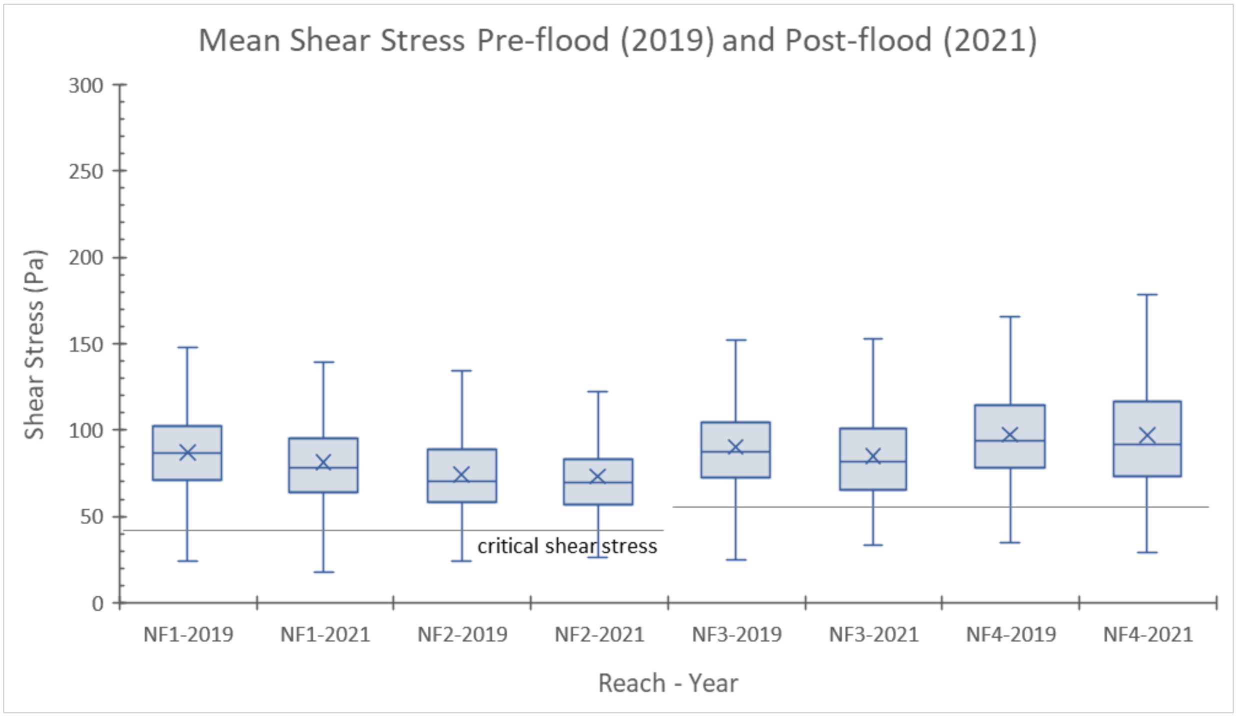

Figure 4-45. Mean shear stress for the 50% annual chance flood (2-yr peak) in the NFWW River.

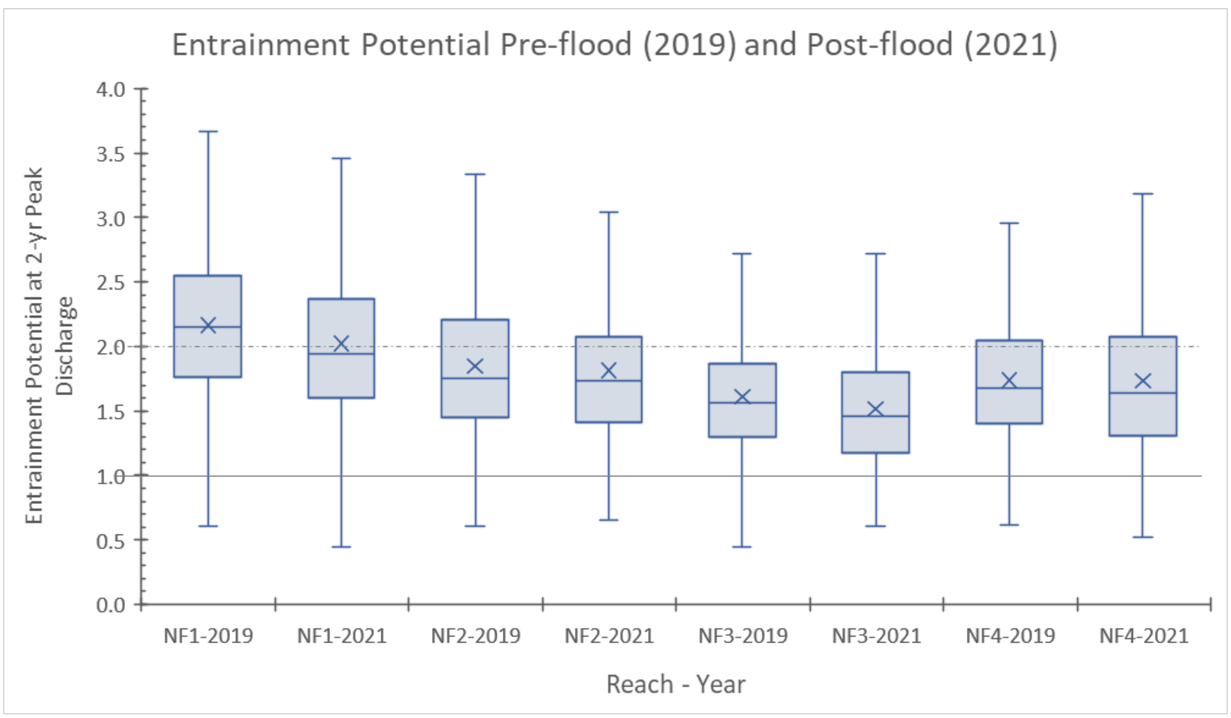

Figure 4-46. Entrainment potential for the 50% annual chance flood (2-yr peak) in the NFWW River.

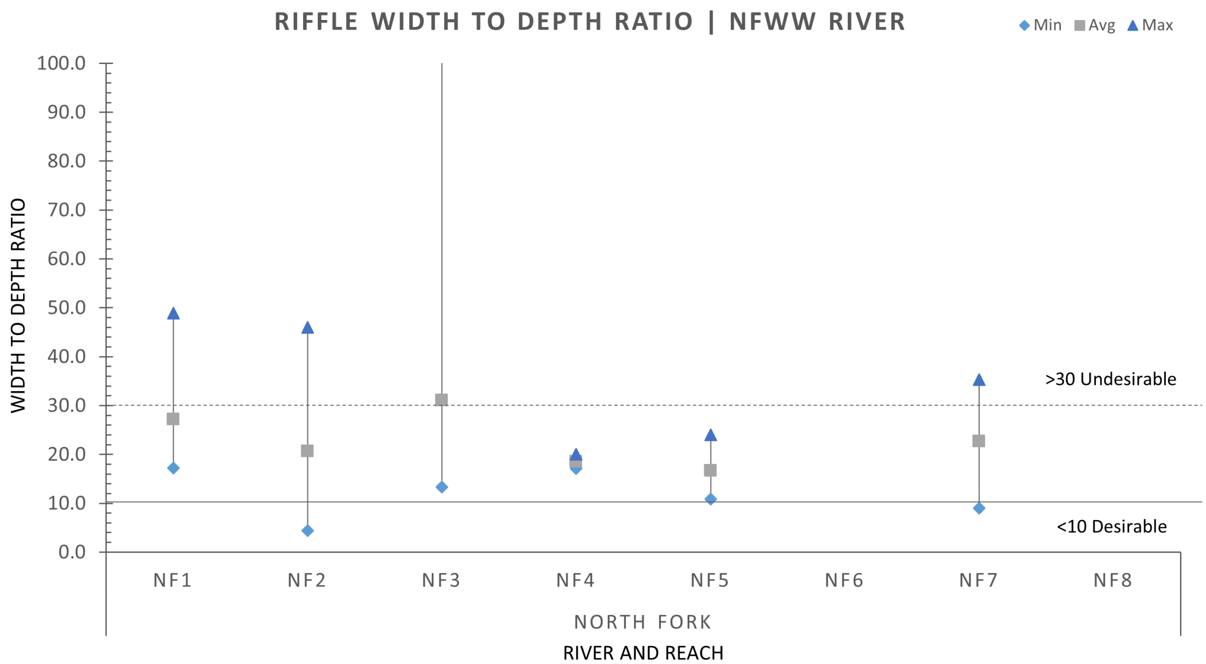

Figure 4-47. Riffle width to depth ratio in the NFWW River by geomorphic reach.

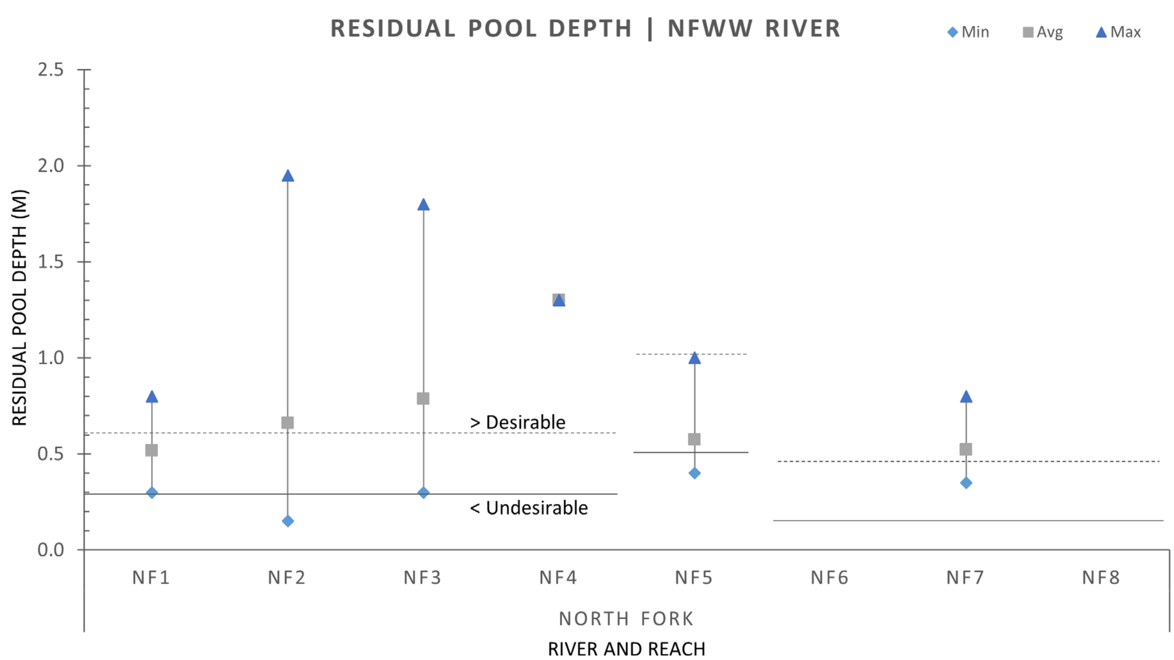

Figure 4-48. Residual pool depth in the NFWW River by geomorphic reach.

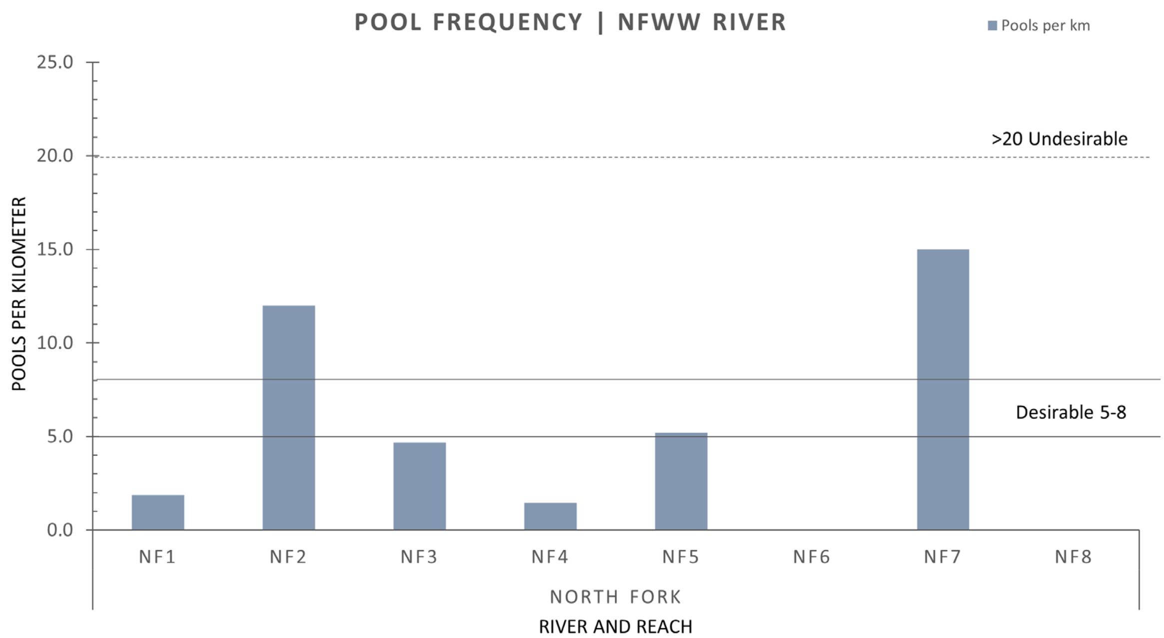

Figure 4-49. Pool frequency in the NFWW River by geomorphic reach.

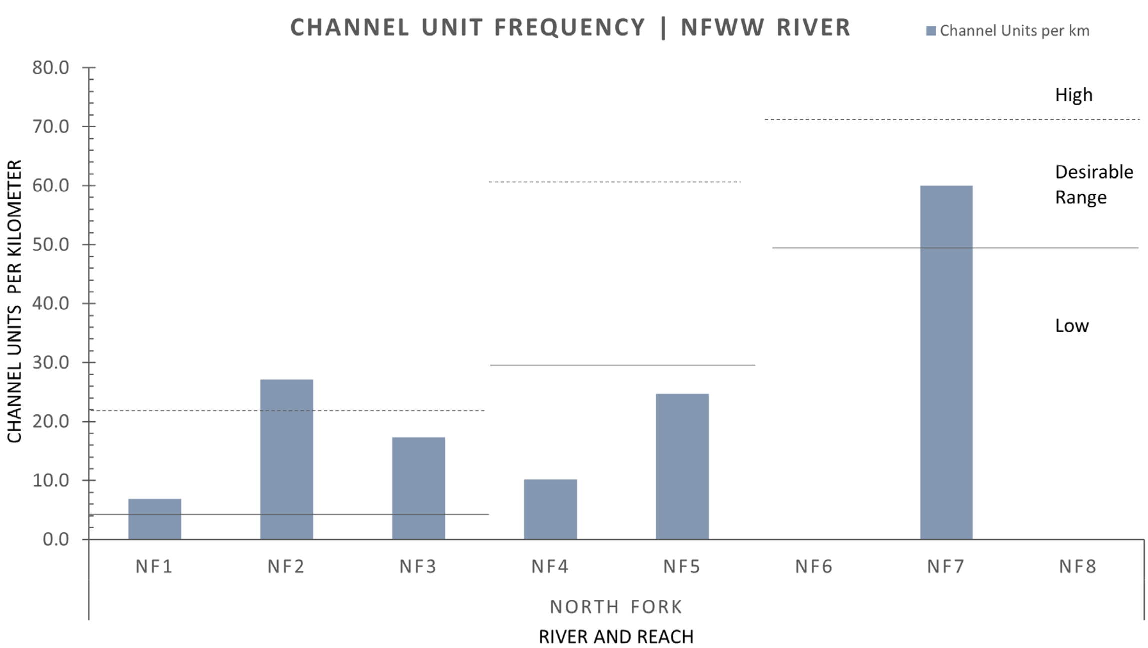

Figure 4-50. Channel unit frequency in the NFWW River by geomorphic reach.

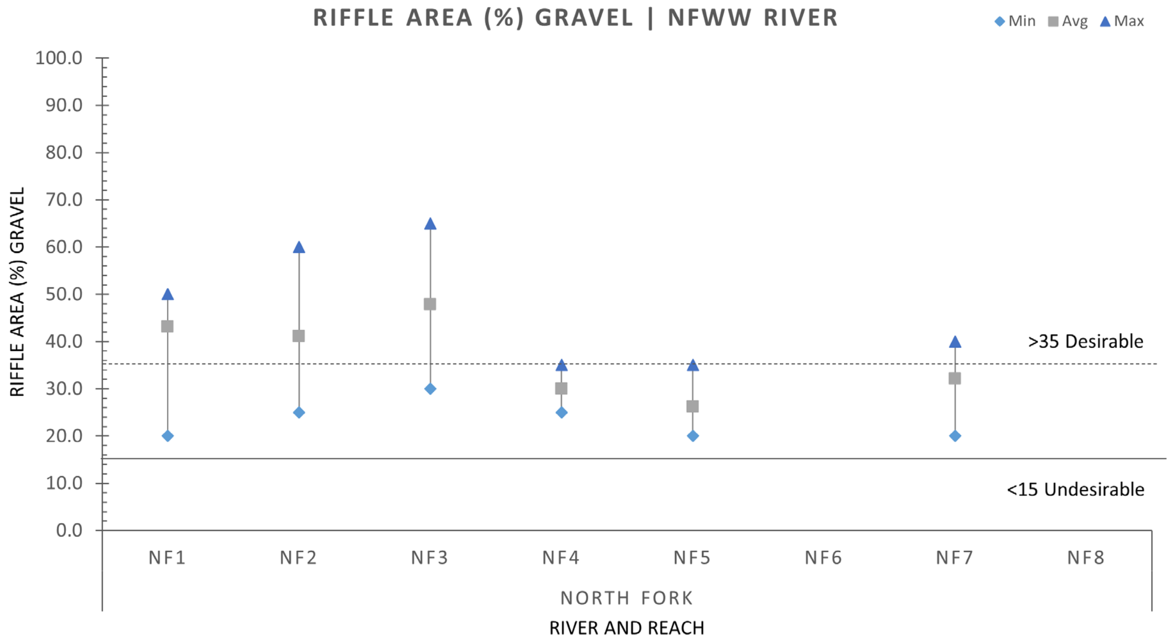

Figure 4-51. Percent of riffle area with gravel in the NFWW River by geomorphic reach.

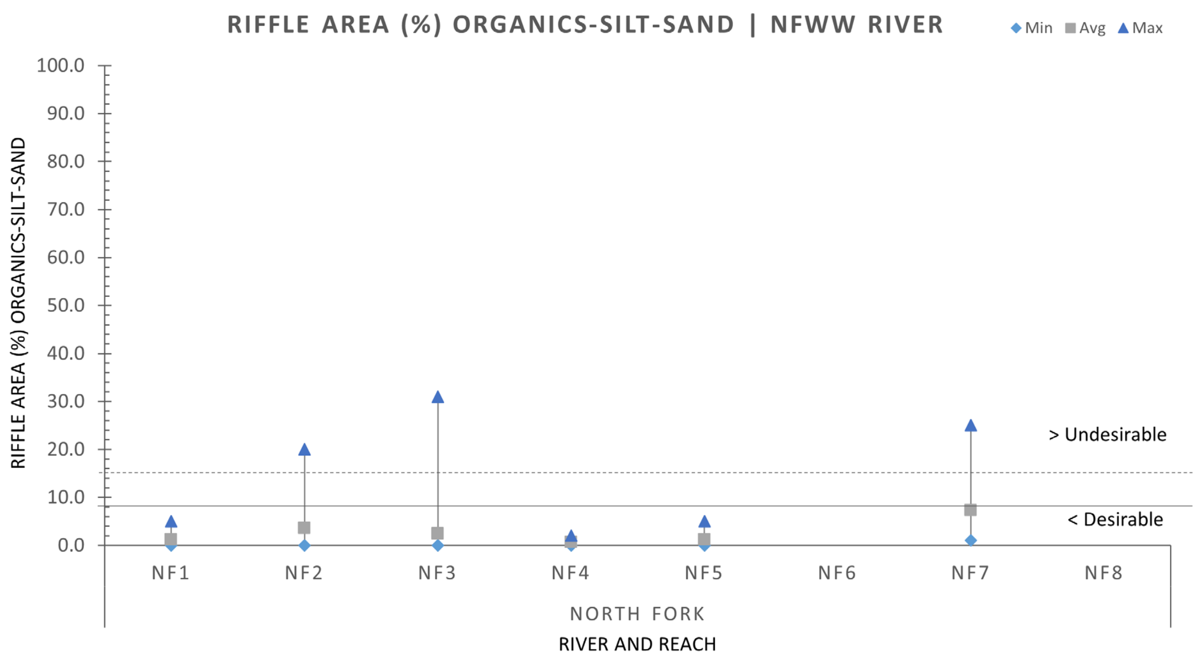

Figure 4-52. Percent of riffle area with organics-silt-sand in the NFWW River by geomorphic reach.

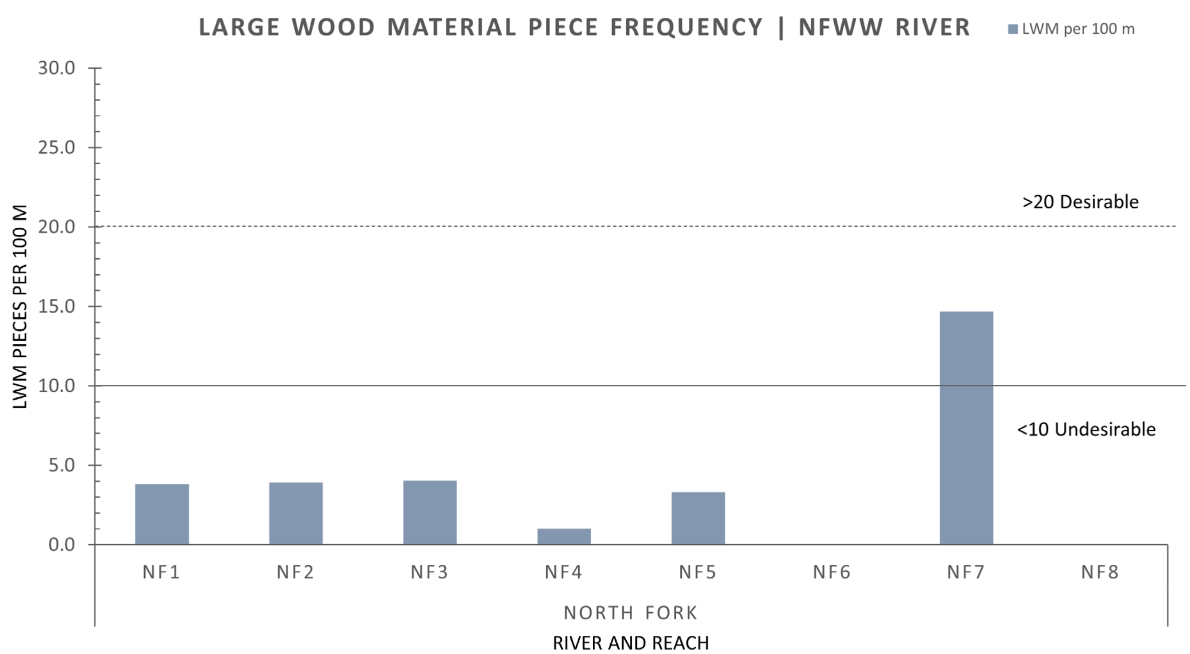

Figure 4-53. Large wood material piece frequency in the NFWW River by geomorphic reach.

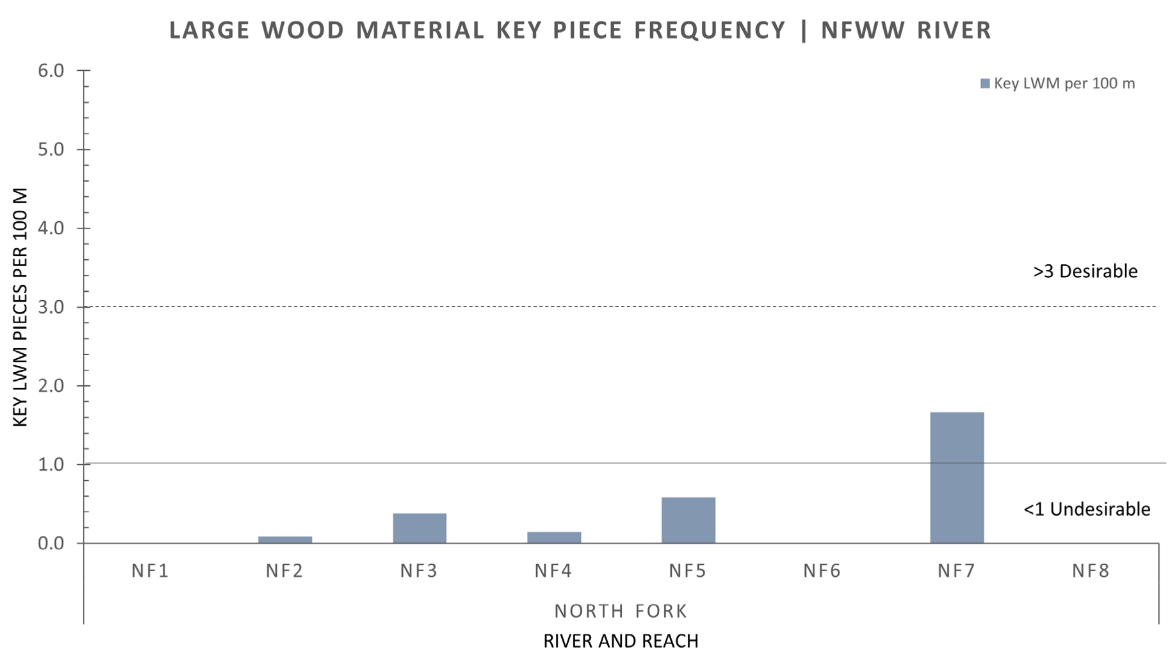

Figure 4-54. Large wood material key piece frequency in the NFWW River by geomorphic reach

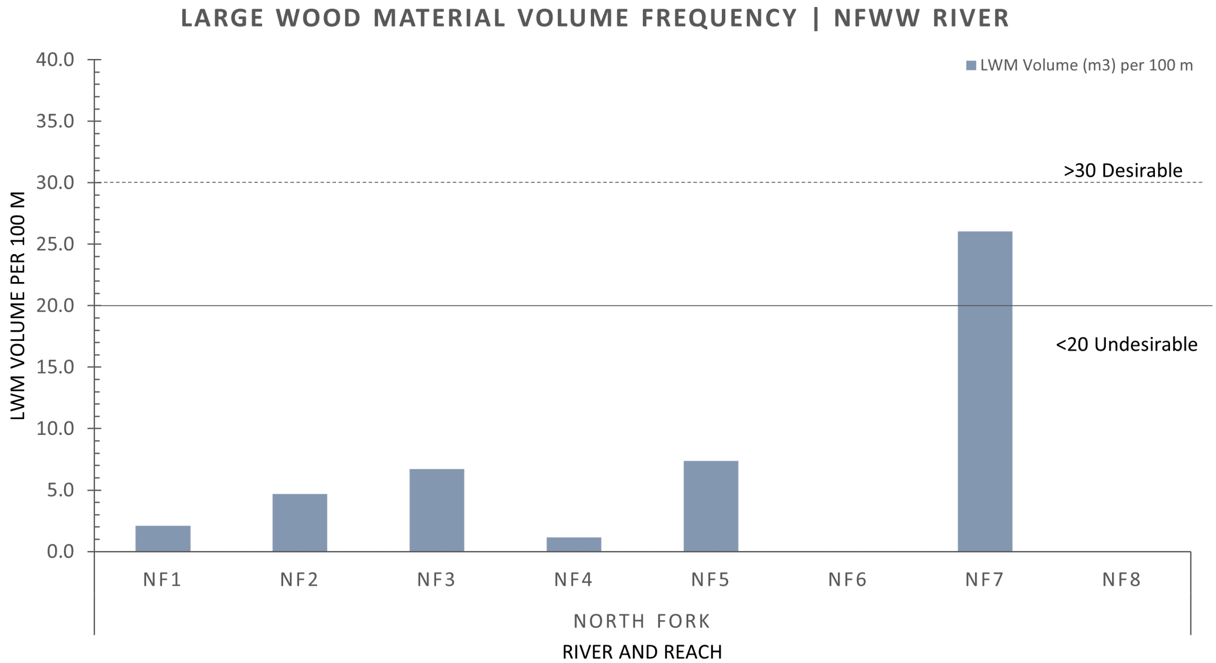

Figure 4-55. Large wood material volume frequency in the NFWW River by geomorphic reach.

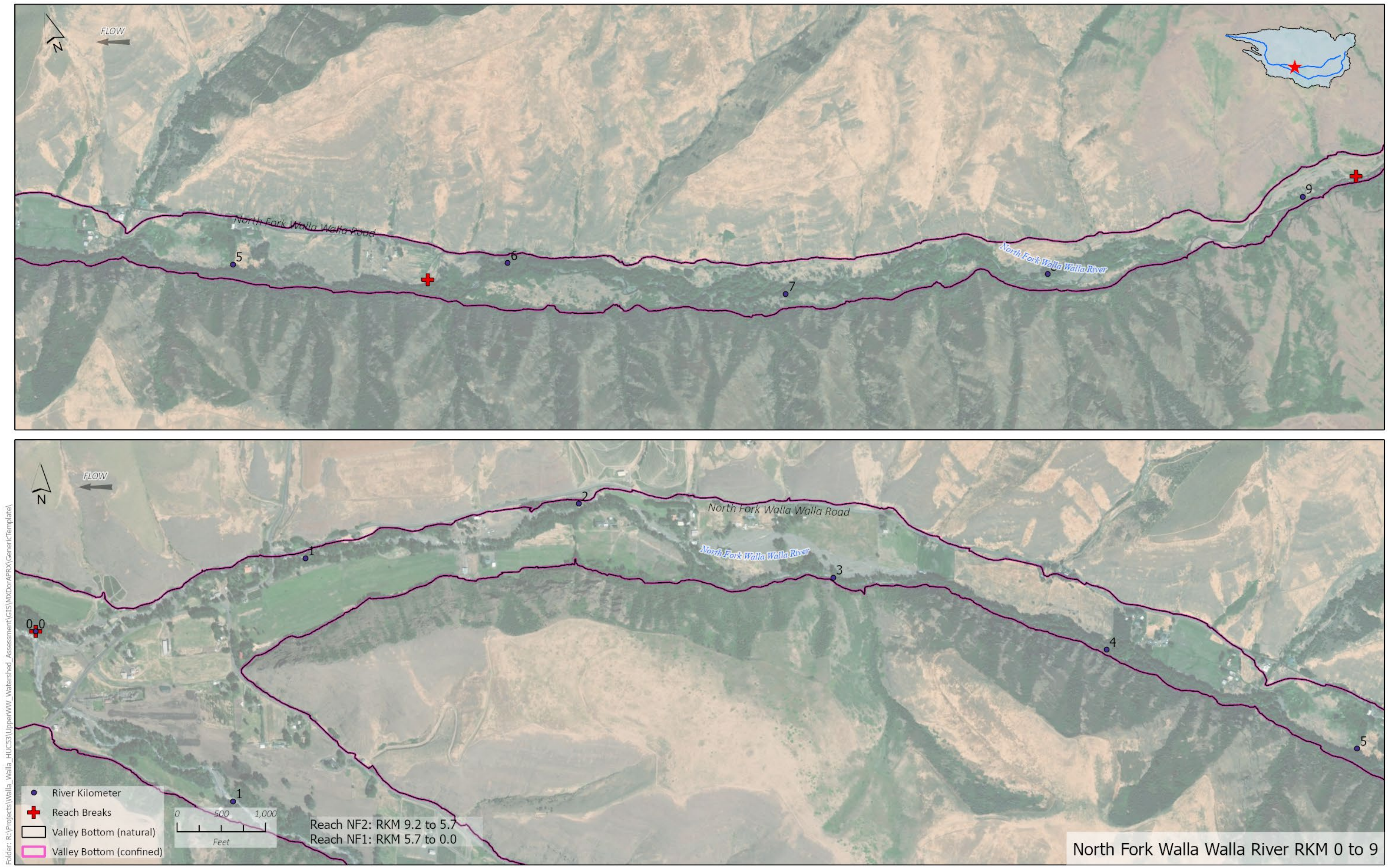

Figure 4-56. Valley bottom extent along NFWW River reaches NF1 and NF2.

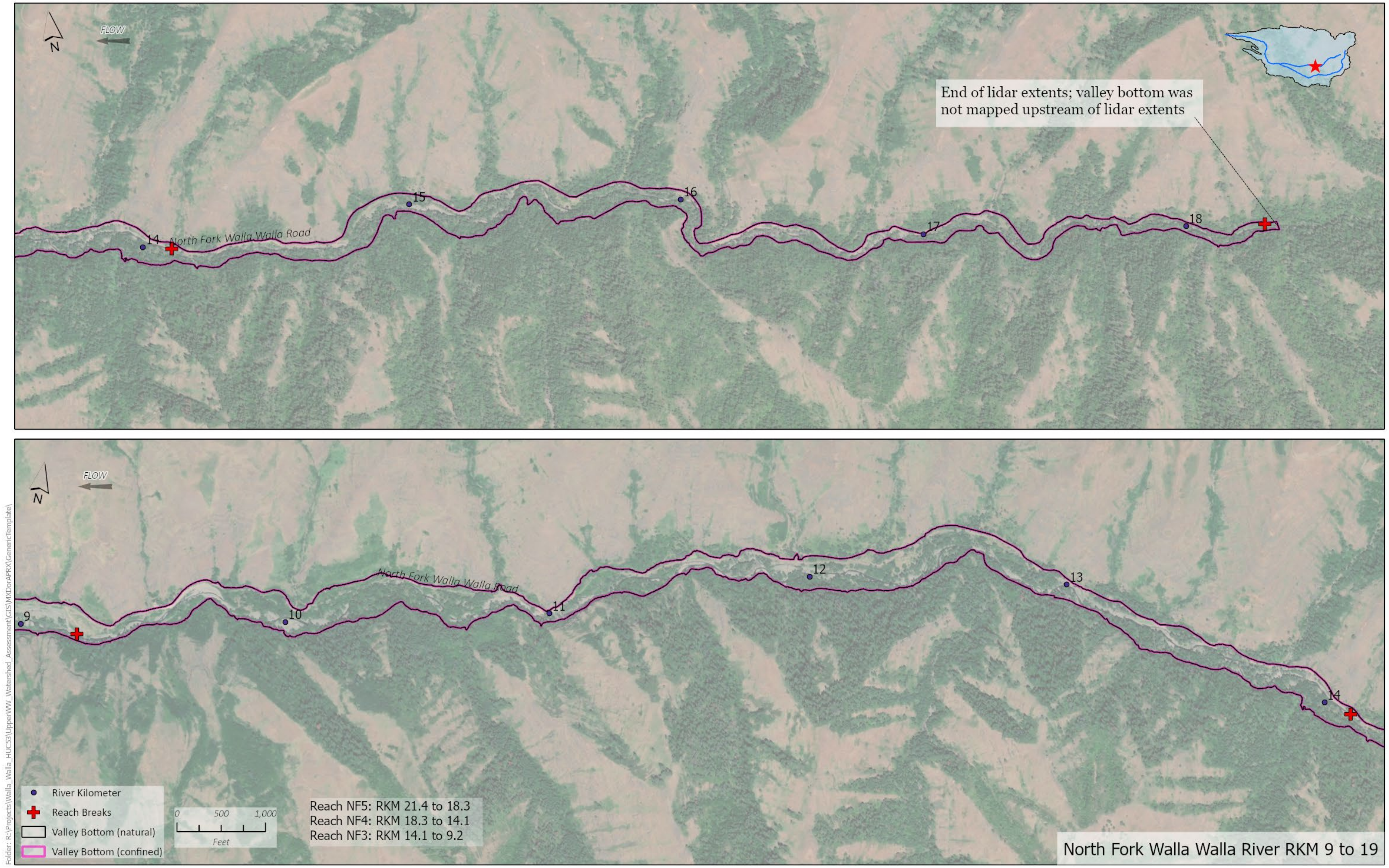

Figure 4-57. Valley bottom extent along NFWW River reaches NF3, NF4, and NF5.

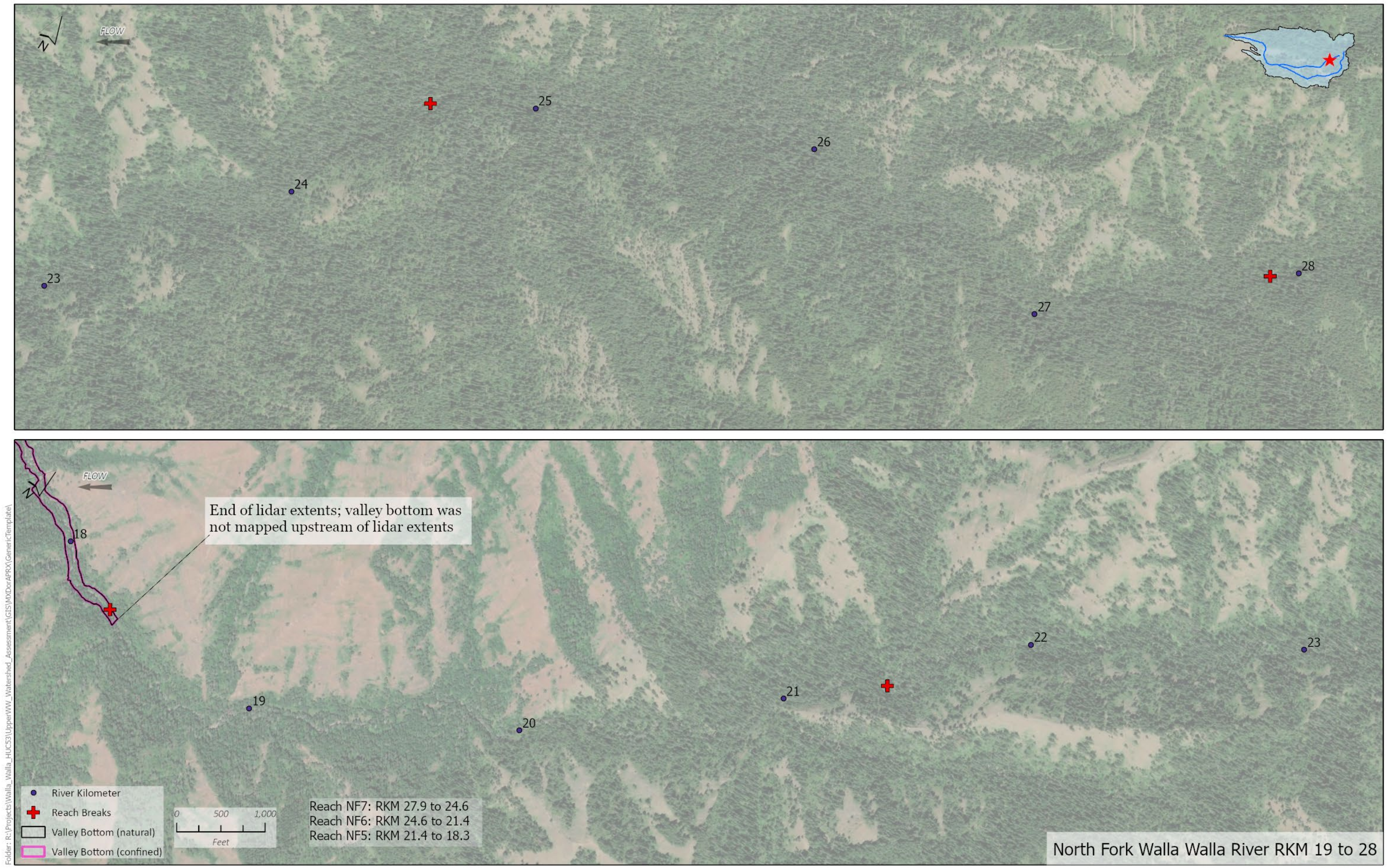

Figure 4-58. Valley bottom extent along NFWW River reaches NF5, NF6, and NF7.

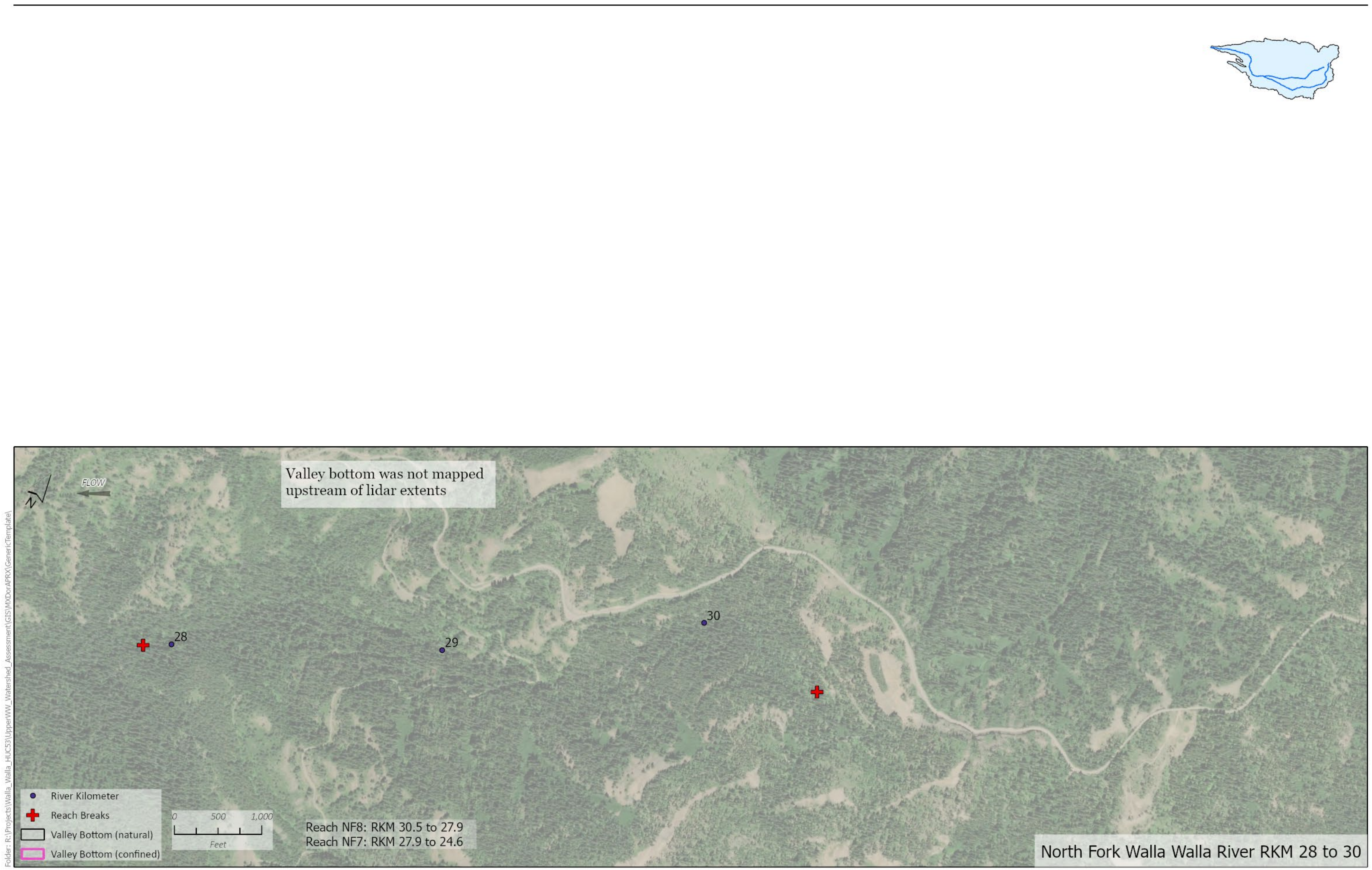

Figure 4-59. Valley bottom extent along NFWW River reaches NF7 and NF8.

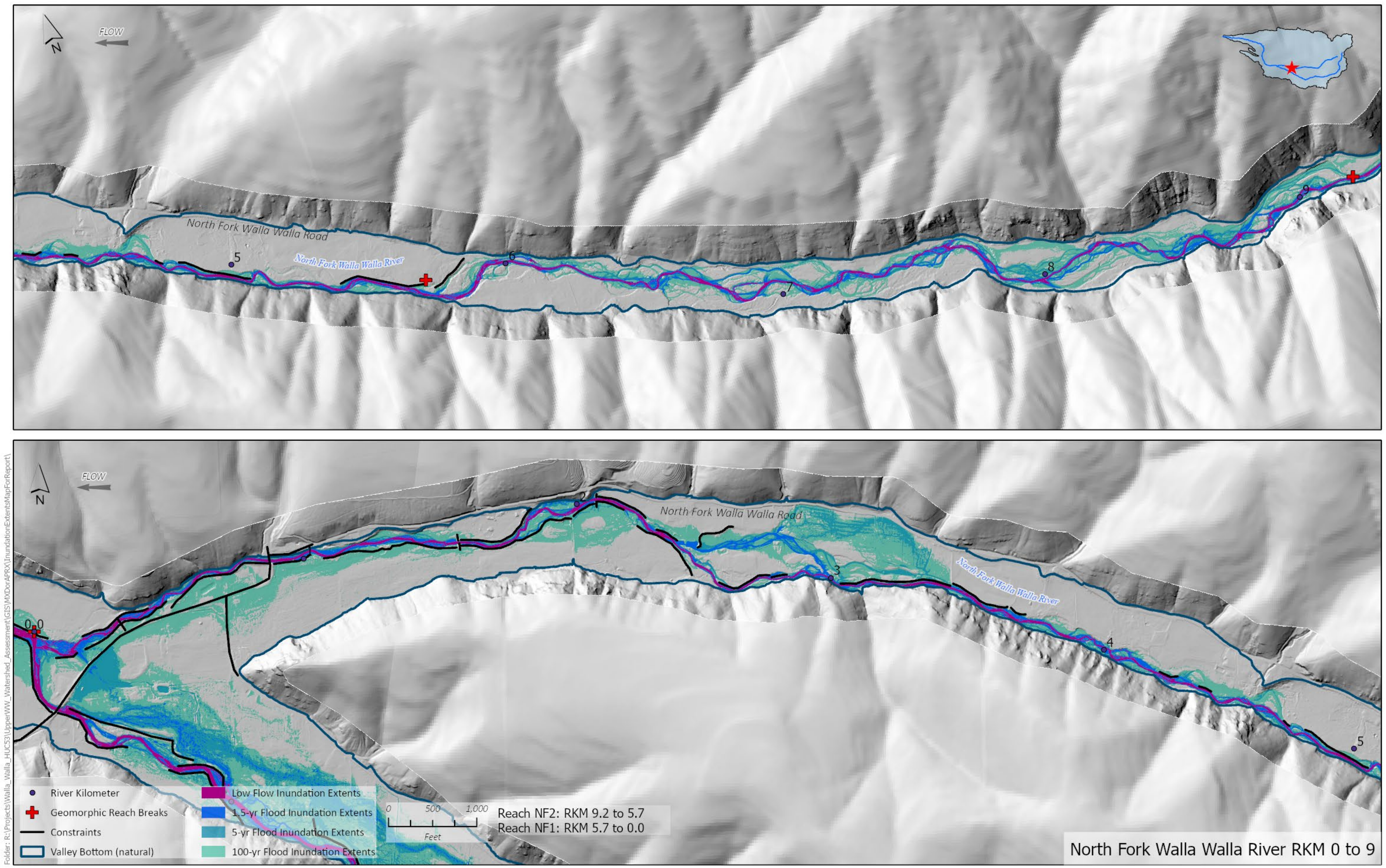

Figure 4-60. Inundation extents and channel constraints along NFWW River reach NF1 and NF2.

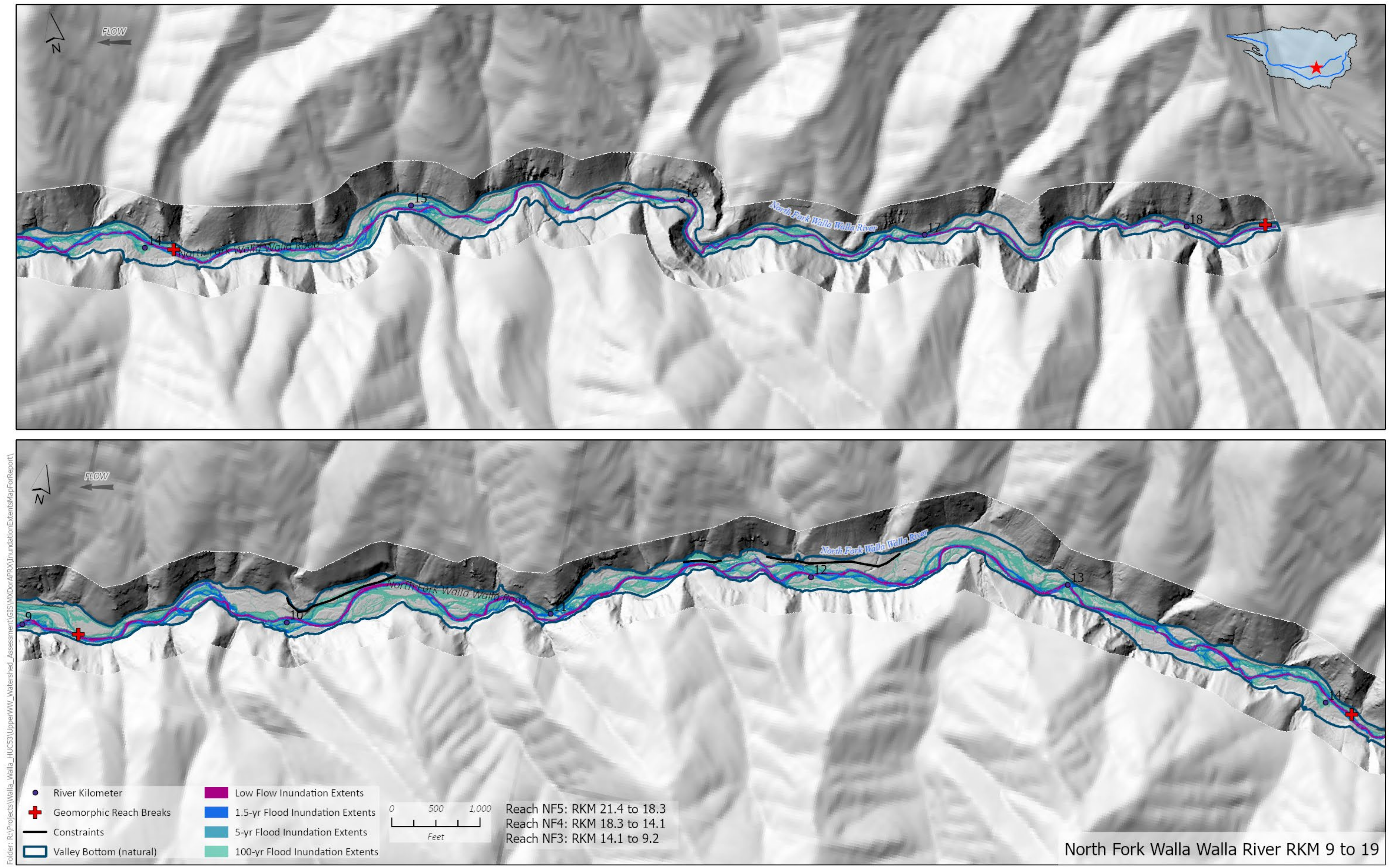

Figure 4-61. Inundation extents and channel constraints along NFWW River reaches NF3, NF4, and NF5.

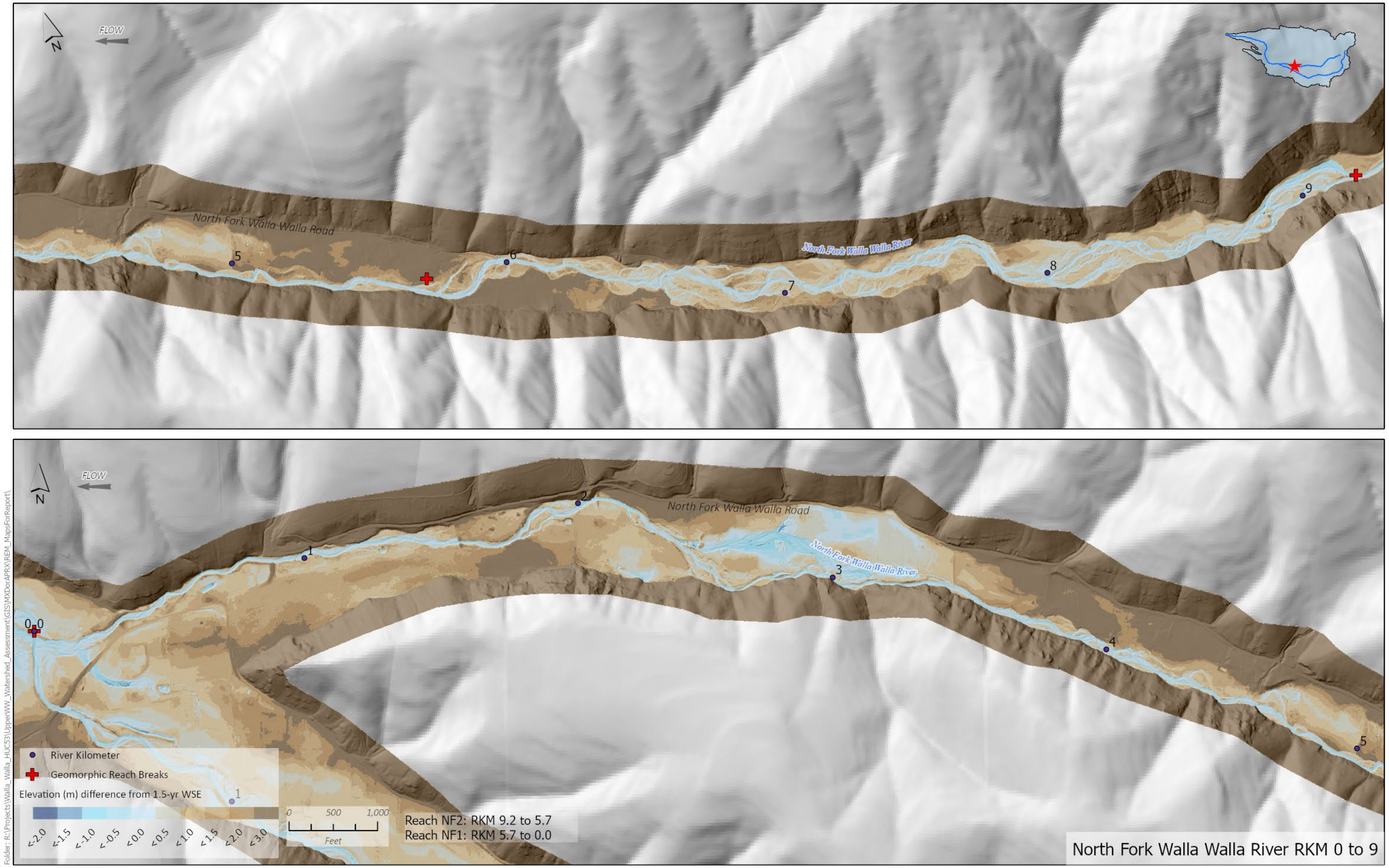

Figure 4-62. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in NFWW River reach NF1 and NF2.

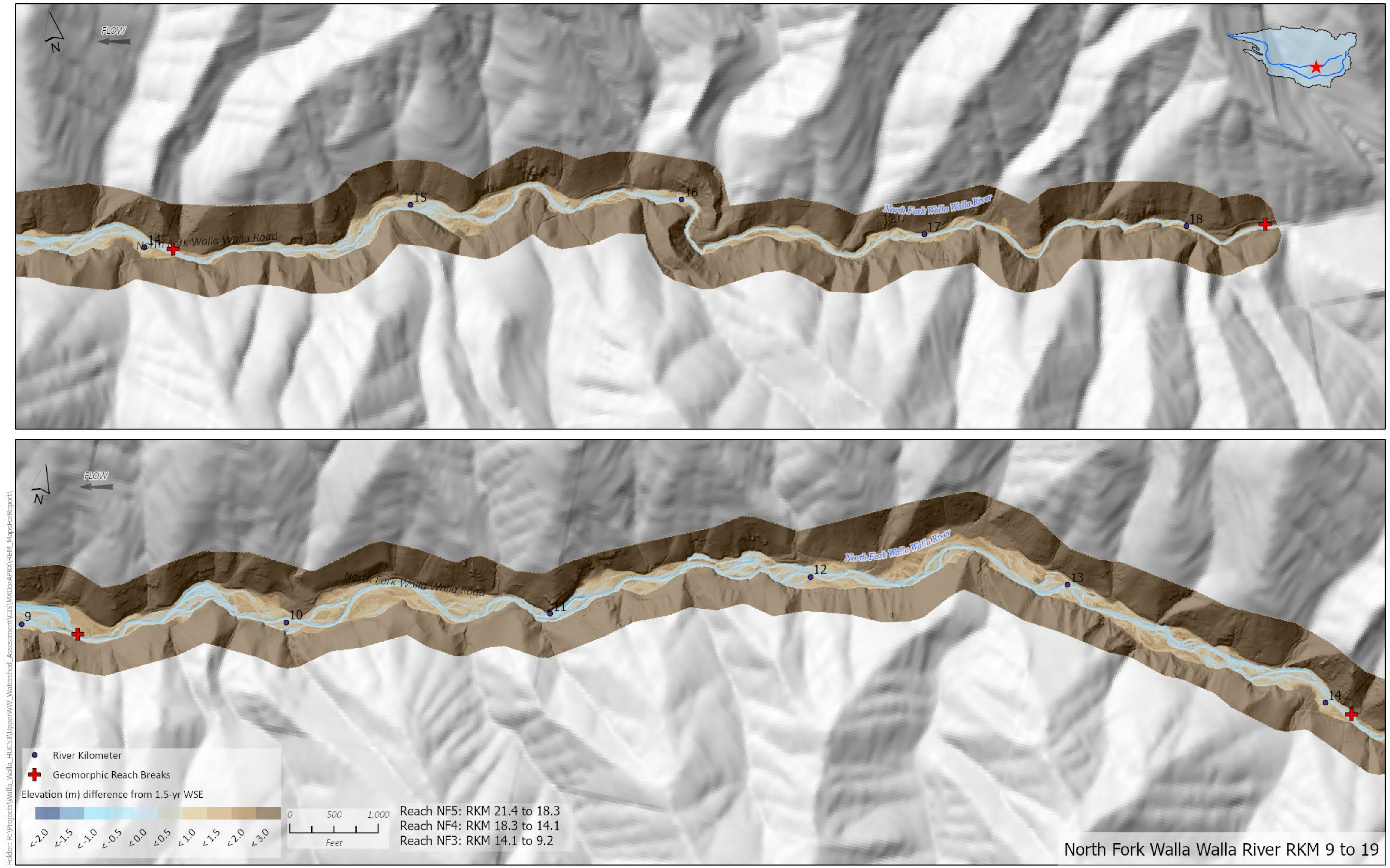

Figure 4-63. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in NFWW River reaches NF3, NF4, and NF5.

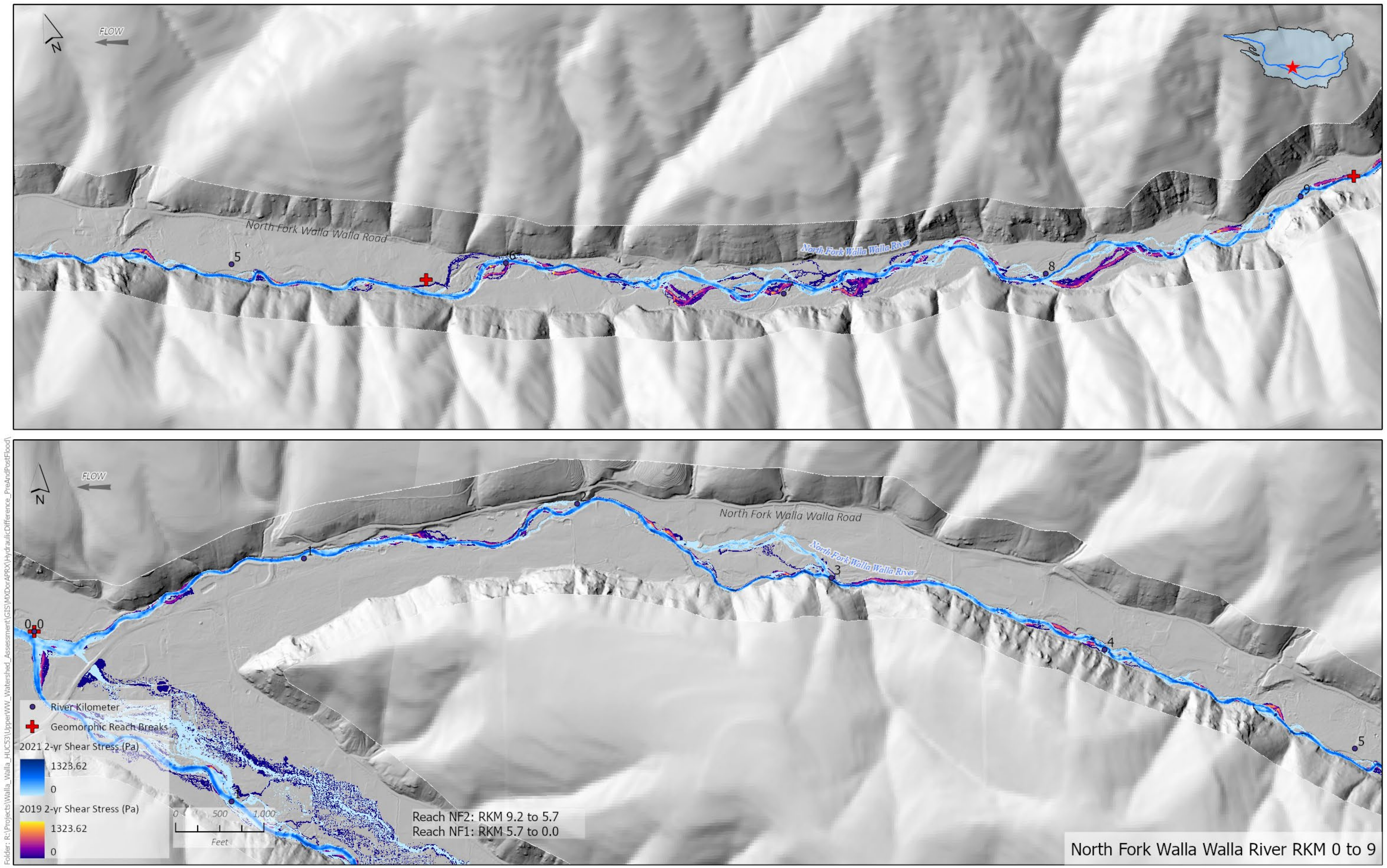

Figure 4-64. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the NFWW River in reaches NF1 and NF2.

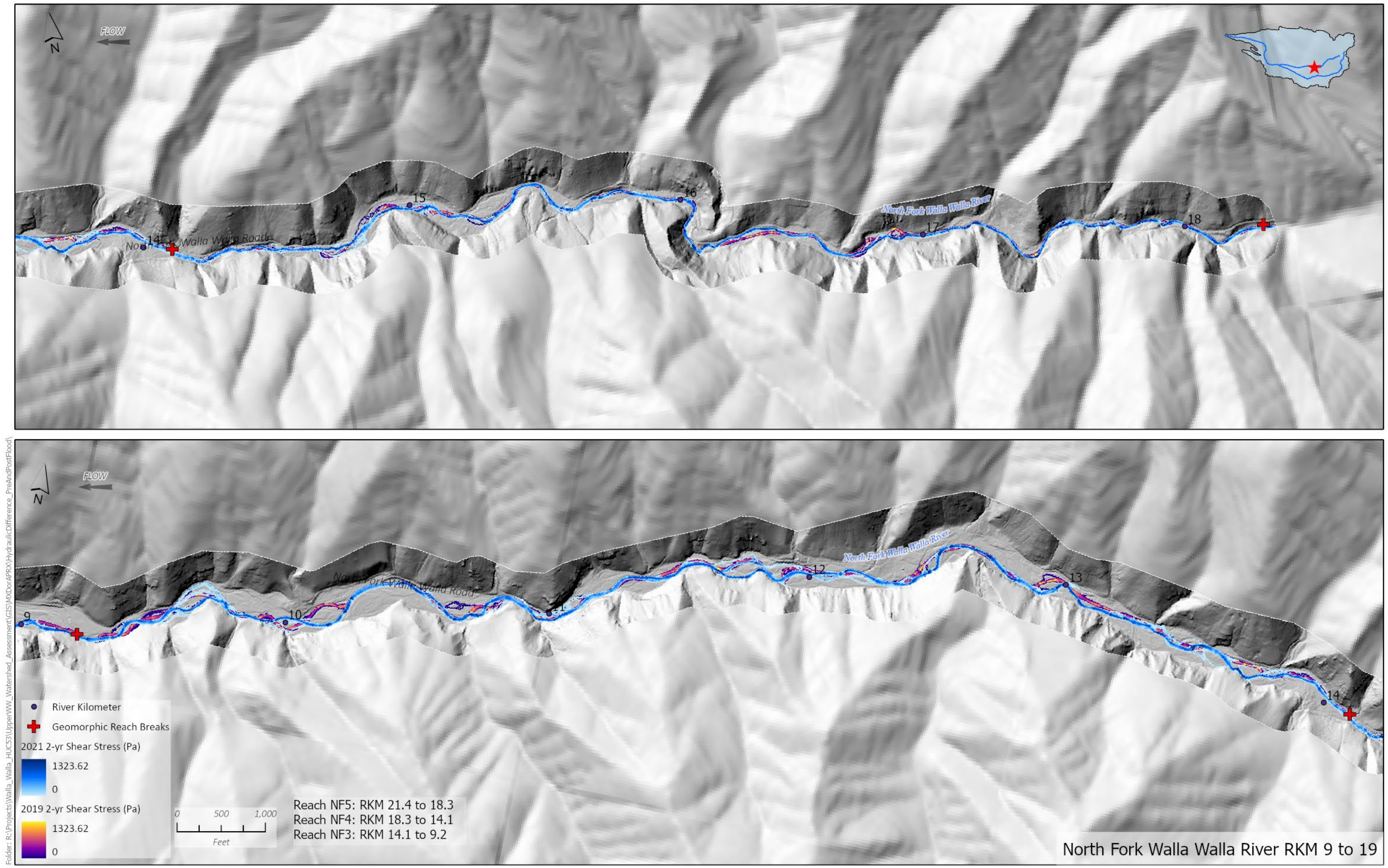

Figure 4-65. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the NFWW River in reaches NF3, NF4, and NF5.

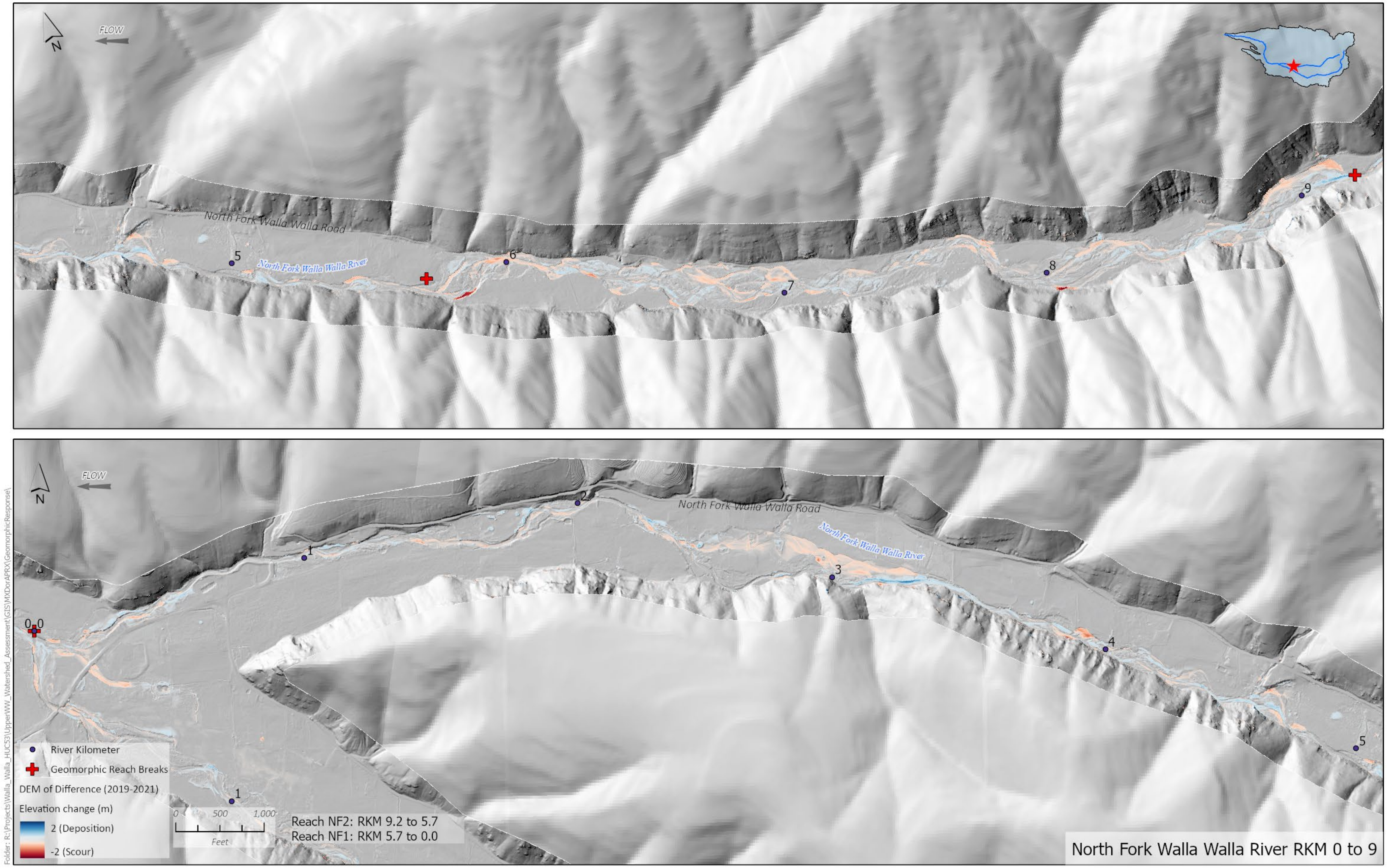

Figure 4-66. Areas of deposition and scour from the 2020 flood in NFWW River reaches NF1 and NF2.

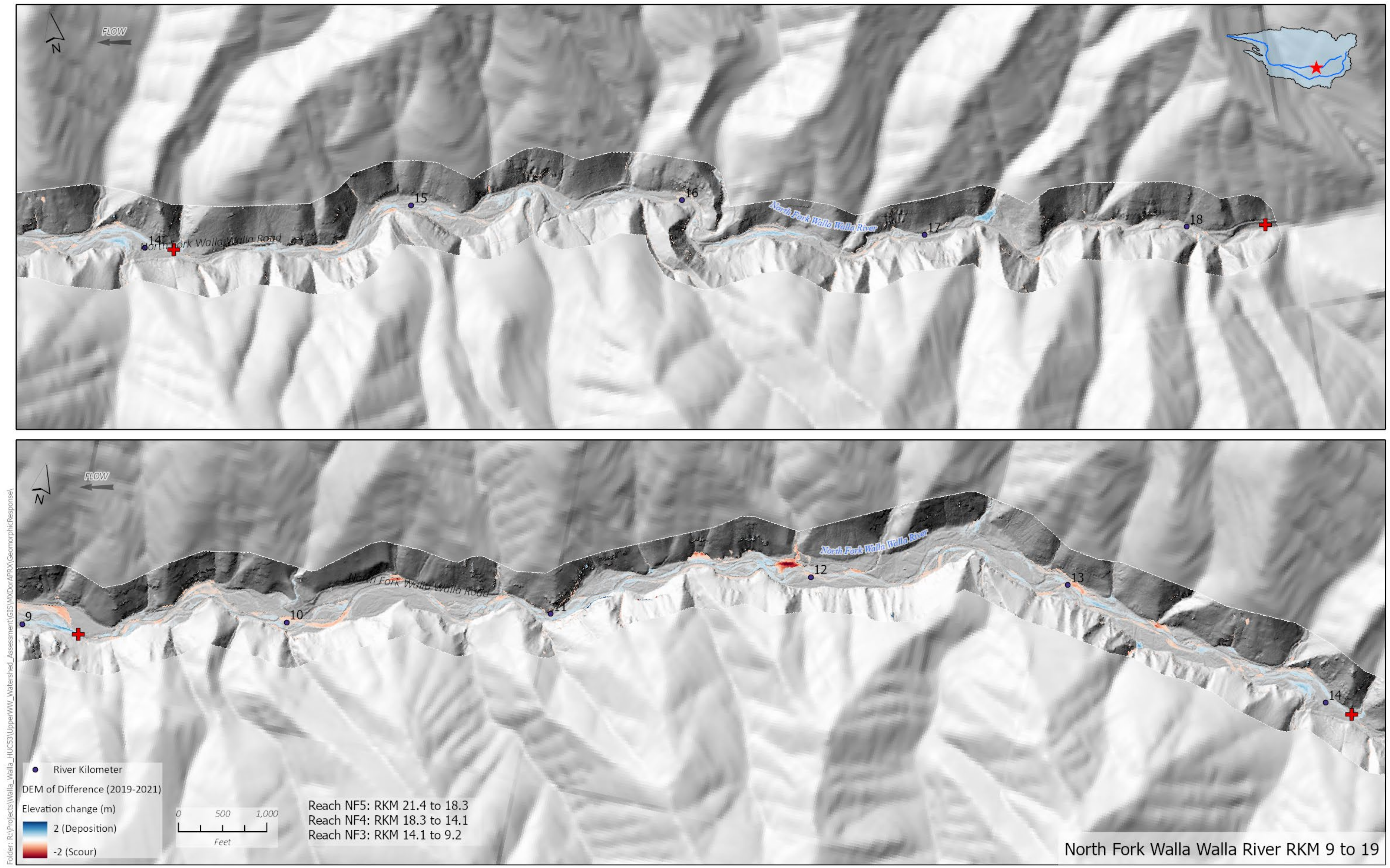

Figure 4-67. Areas of deposition and scour from the 2020 flood in NFWW River reaches NF3, NF4, and NF5.

4.3 SOUTH FORK WALLA WALLA RIVER

Reach SF1 in the SFWW River extends 13.3 RKM upstream from its mouth at the WW River and confluence with the NFWW River (Figure 4-85 and Figure 4-86). The SFWW River in reach SF1 has a low sinuosity of 1.23 and flows through partly confined valley in a rural residential and agricultural setting (Table 4-1). Reach SF1 has a valley slope of 1.6%, with the valley bottom comprised of Quaternary alluvium and the valley margins comprised of basalt bedrock. There are numerous unnamed ephemeral and intermittent tributaries throughout the reach.

SFWW River reach SF2 is 7.5 RKM in length, extending upstream to RKM 20.8 where the valley width becomes consistently more narrow than downstream (Figure 4-85 and Figure 4-86). The SFWW River in reach SF2 has a low sinuosity of 1.29 and flows through a partly confined valley in an undeveloped setting with the exception of SFWW River Road located along the valley margin (Table 4-1). Reach SF2 has a valley slope of 1.8%, with the valley bottom comprised of mix of alluvium and basalt bedrock and the valley margins comprised of basalt bedrock. Perennial tributary streams within reach SF2 include Elbow Creek near RKM 15.5, Tamarack Creek near RKM 16.2, and Bear Creek near RKM 20.7. There are numerous unnamed ephemeral and intermittent tributaries throughout the reach.

Reach SF3 is 3.8 RKM in length, extending upstream to RKM 24.6 where there is a change in valley slope and confinement of the valley bottom (Figure 4-87). The SFWW River in reach SF3 has a moderate sinuosity of 1.34 and flows through a partly confined valley that is largely undeveloped within the Umatilla National Forest (Table 4-1). Reach SF3 has a valley slope of 2.2%, with the valley bottom comprised of alluvium while the valley margins are comprised of basalt bedrock. Perennial tributaries from Tye Canyon (RKM 20.9), Rodgers Gulch (RKM 21.4), Kees Canyon (RKM 22.4), Burnt Cabin Gulch (RKM 23.1), and Swede Canyon (RKM 23.7) flow into the SFWW River, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach. Many of the tributaries originate from numerous springs throughout the SFWW River.

Reach SF4 is 3.9 RKM in length, extending upstream to RKM 28.5 where there is a change in valley confinement (Figure 4-88). The SFWW River in reach SF4 has a moderate sinuosity of 1.29 and flows through a partly confined valley that is largely undeveloped within the Umatilla National Forest (Table 4-1). Reach SF4 has a valley slope of 2.2%, with the valley bottom comprised of alluvium while the valley margins are comprised of basalt bedrock. Perennial tributaries of Table Creek (RKM 24.9), Deadman Gulch (RKM 25.1), and Skiphorton Creek (RKM 27.9) flow into the SFWW River, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach. Many of the tributaries originate from numerous springs throughout the SFWW River.

Reach SF5 is 4.3 RKM in length, extending upstream to RKM 32.8 where there is a change in valley slope and confinement of the valley bottom (Figure 4-88). The SFWW River in reach SF5 has a low sinuosity of 1.13 and flows through a naturally confined valley that is largely undeveloped within the Umatilla National Forest (Table 4-1). Reach SF5 has a valley slope of 2.5%, with the valley bottom and valley margins comprised of basalt bedrock. Perennial tributaries of Skookum Creek (RKM 30.2), Sheep Creek (RKM 32.6), and Reser Creek (RKM 32.7) flow into the SFWW River, with numerous other unnamed ephemeral and intermittent tributaries throughout the reach. Many of the tributaries originate from numerous springs throughout the SFWW River.

SFWW River reaches SF6 through SF8 flow through a naturally confined valley with the valley bottom and margins comprised of basalt bedrock (Figure 4-89 and Figure 4-90; Table 4-1). All of the reaches have low channel sinuosity, ranging from 1.02 to 1.05, with valley slopes increasing from 4.9% in reach SF6 to 8.2% in reach SF8. The reaches are undeveloped and located within the Umatilla National Forest. There are numerous unnamed perennial, ephemeral, and intermittent tributaries throughout the reaches, with many originating from numerous springs throughout the SFWW River.

River and floodplain conditions in SFWW River reach SF1 have been altered as a result of rural residential and agricultural development along the valley bottom. While this reach is naturally partly confined by the valley walls, the floodplains that are available have been markedly disconnected from the river by discontinuous constraints on lateral and longitudinal channel migration. Artificial channel confinement from continuous levees is minimal in all NFWW River reaches (Figure 4-68). However, discontinuous constraints on channel migration (e.g., roads, bridges, bank protection, grade control structures) limits river-floodplain connectivity in SFWW River reach NF1. In this reach, the SFWW River has been largely confined to one side of the valley bottom by the placement of non-engineered levees and bank protection. In all other SFWW River reaches, discontinuous constraints on channel migration are minimal or nonexistent. The ratio of constraint length to reach length ranges from 0.03 in reach SF2 to 0.96 in reach SF1 (Table 4-4; Figure 4-69; Figure 4-85 and Figure 4-86). The natural valley width among all SFWW River reaches alternates from relatively wide to relatively narrow, indicating the topographic controls on valley width, available floodplain area, and space available for geomorphic processes such as channel migration, sediment erosion and deposition, and secondary channel development (Figure 4-68; Figure 4-85 through Figure 4-90).

Table 4-4: Artificial floodplain disconnection by channel constraints in the SFWW River.

Reach ID	Reach Length (km)	Constraint Length (km)	Constraint Length Ratio of Reach Length
SF1	13.3	12.75	0.96
SF2	7.5	0.21	0.03
SF3	3.8	0.00	0.00
SF4	3.9	0.00	0.00
SF5	4.3	0.00	0.00
SF6	7.7	0.00	0.00
SF7	2.7	0.00	0.00
SF8	1.4	0.00	0.00

River manipulation throughout SFWW River reach SF1 has included a straightening of the channel and reducing the river sinuosity (Figure 4-91 and Figure 4-92). These alterations have converted what was once likely a predominantly pool-riffle channel morphology into a higher energy plane-bed structure with long subreaches of continuous riffle and much fewer subreaches of pool-riffle channel morphology. Multi-thread channels that appear on historical topographic maps, in LiDaR data, and are visible in moist soil patterns from aerial photography, have been removed, filled, drained, and/or artificially disconnected from the active channel in reach SF1 (Figure 4-91 and Figure 4-92). These changes in channel morphology have affected the sediment transport regime whereby gravel deposition and bar formation are very limited and much less than is expected in these valley settings. The conversion of the river to a straighter, higher energy channel with greater sediment transport capacity suggests that some vertical degradation of the riverbed has occurred.

Throughout SFWW River reach SF1 and the downstream subreaches in SF2, hydraulic connectivity of the river channel has been limited both laterally and longitudinally. The amount of natural valley bottom inundated by the 14-day discharge ranges from 8% in reach SF1 to 37% in reach SF5 (Figure 4-70). For the estimated effective discharge (2-yr peak flow) the inundated area ranges from 12% to 44% of the natural valley bottom in reaches SF1 and SF5, respectively. In reach SF1 there is a marked increase in inundation from the 2-yr to the 5-yr peak flow (Figure 4-70) suggesting that artificial channel constraints on floodplain connectivity limits much of the lower magnitude peak floods (e.g., less than 5-yr peak) to the active channel in this reach (Figure 4-91 and Figure 4-92). Within reach SF1 less than 38% of the natural valley bottom is inundated under all modeled discharges, including the 1% annual chance peak flood (100-yr event) (Figure 4-70; Figure 4-91 and Figure 4-92). These results suggest that during the more frequent peak discharges (i.e., less than the 5-yr peak), much of the available energy from the stream flow is concentrated in the active channel in reach SF1 rather than being distributed onto the adjacent floodplain, further exacerbating the vertical channel incision and floodplain disconnection.

Under the assumed effective, channel-forming discharge (i.e., 2-yr peak), the hydraulic characteristics of stream power, shear stress, and sediment entrainment potential vary among the SFWW River reaches. The median of maximum unit stream power from sampled cross-sections ranged from approximately 244 W m^{-2} in reach SF3 to 314 W m^{-2} in reach SF1 (Figure 4-71), while the median of mean unit stream power from sampled cross-sections ranged from approximately 113 W m^{-2} in reach SF3 to 166 W m^{-2} in reach SF1 (Figure 4-72). Similarly, the median of maximum shear stress ranged from approximately 123 Pa in reach SF3 to 143 Pa in reach SF5 (Figure 4-73), while the median of mean shear stress ranged from approximately 70 Pa in reach SF3 to 99 Pa in reach SF5 (Figure 4-74). In all the modeled reaches the maximum shear stress well exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-73); similarly, at more than half of the sampled cross-sections in all reaches the mean shear stress exceeded the critical shear stress of the bed material grain-size mixtures (Figure 4-74). The entrainment potential for the coarser material (D84) within the grain-size mixtures was notable in all reaches, with the partial entrainment threshold of 1.0 being exceeded by more than half of all sampled cross-sections in all reaches (Figure 4-75). In all reaches, there was a negligible change in the reach-wide magnitude of modeled hydraulic characteristics based on the pre-flood (2019) and post-flood (2021) topobathymetric surfaces used for the hydraulic modeling. However, there were notable spatial changes in bank erosion, channel migration, and subsequent changes in hydraulic characteristics and channel erosion and deposition (Figure 4-99 through Figure 4-102). For example, notable changes in channel location and alignment were observed near RKM 0.25 – 3.5, RKM 4.25 – 6.5, and RKM 7.0 – 10.0 in reach SF1 (Figure 4-99 and Figure 4-100), and throughout reaches SF2, SF3, and SF4 (Figure 4-100 through Figure 4-102. These subreach locations also exhibited some of the more prominent geomorphic responses to the 2020 flood as indicated by the magnitude of scour and deposition (Figure 4-103 through Figure 4-106).

The reach-wide hydraulic and geomorphic characteristics of all SFWW River reaches are reflected in the observations from stream surveys at the sub-reach and site scales. Average riffle width to depth ratios ranged from 19 in reach SF5 to 27 in reach SF2 (Figure 4-76), with the average width to depth ratio in all reaches well exceeding the benchmark desirable value of less than 10. In reaches SF1, SF2, and SF3, the average width to depth ratio nearly exceeded the undesirable benchmark value of greater than 30 (Figure 4-76). Notably, SF1 and SF2 are those reaches with the greatest length of artificial channel constraints (Table 4-4, Figure 4-69). Average residual pool depth ranged from 0.44 m in reach NF6 to 1.1 m in reach SF3, with the average value in three reaches falling below (SF2 and SF6) or near (SF1) the undesirable benchmark (Figure 4-77). Note that the benchmark values differ based on channel width and slope. The frequency of pools was less than desirable in reaches SF2, SF3, and SF5, ranging from 2.6 pools/KM in reach SF5 to 4.4 pools/KM in reach SF3 (Figure 4-78). Pool frequency in reach SF1 was 5.2 pools/KM, just exceeding the desirable threshold (Figure 4-78). While the pool frequency in reaches SF1, SF2, and SF3 was near or less than desirable, the total channel unit frequency in these reaches was in the desirable range (Figure 4-79), reflecting the prevalence of run, glide, and riffle geomorphic units in these reaches. Reach SF5 exhibited values of pool frequency (Figure 4-78) and channel unit frequency (Figure 4-79) that were less than the desirable threshold, indicating a lack of channel complexity throughout this reach.

Observations from stream surveys suggest that riverbed grain size characteristics in riffles are largely within the range of desirable conditions in reaches SF1, SF2, and SF5. The average percentage of riffle areas comprised of gravel ranged from 35% in reaches SF2 and SF5 to 39% in reach SF1, with the average value in these reaches at or slightly greater than the desirable value of greater than 35% (Figure 4-80). None of the SFWW River reaches sampled had a percentage of riffle area comprised of gravel that was less than the undesirable threshold of 15%. The riffle area comprised of finer sediment material was within or near the desirable range in reaches SF1, SF2, SF5, and SF6. The average percentage of riffle areas comprised of organics-silt-sand ranged from 6% in reach SF1 to 9% in reach SF2 (Figure 4-81), with the average value only in reach SF3 exceeding the undesirable benchmark threshold of 15%.

Observations from stream surveys indicate that the abundance of LWM in all SFWW River reaches is much less than the desirable conditions. The LWM piece frequency ranged from 3 piece per 100 m in reach SF2 to 14 pieces per 100 m in reach SF5, with the piece frequency in all reaches being well below the desirable benchmark value of greater than 20 pieces per 100 m

(Figure 4-82). The LWM that is present in all reaches is predominantly smaller size class material, as indicated by the low abundance of key LWM pieces (>60 cm diameter and >10 m long). The LWM key piece frequency ranged from 0.1 pieces per 100 m in reaches SF1 to 1.0 pieces per 100 m in reach SF6, with the key piece frequency in all reaches being well below the desirable benchmark value of greater than 3 key pieces per 100 m (Figure 4-83). The prevalence of smaller size class LWM in all reaches is also evident in estimates of LWM volume frequency. The LWM volume frequency ranged from 4 m^3 per 100 m in reach SF1 to 19 m^3 per 100 m in reaches SF6, with the LWM volume frequency in all reaches being well below the desirable benchmark value of greater than 30 m^3 per 100 m (Figure 4-84).

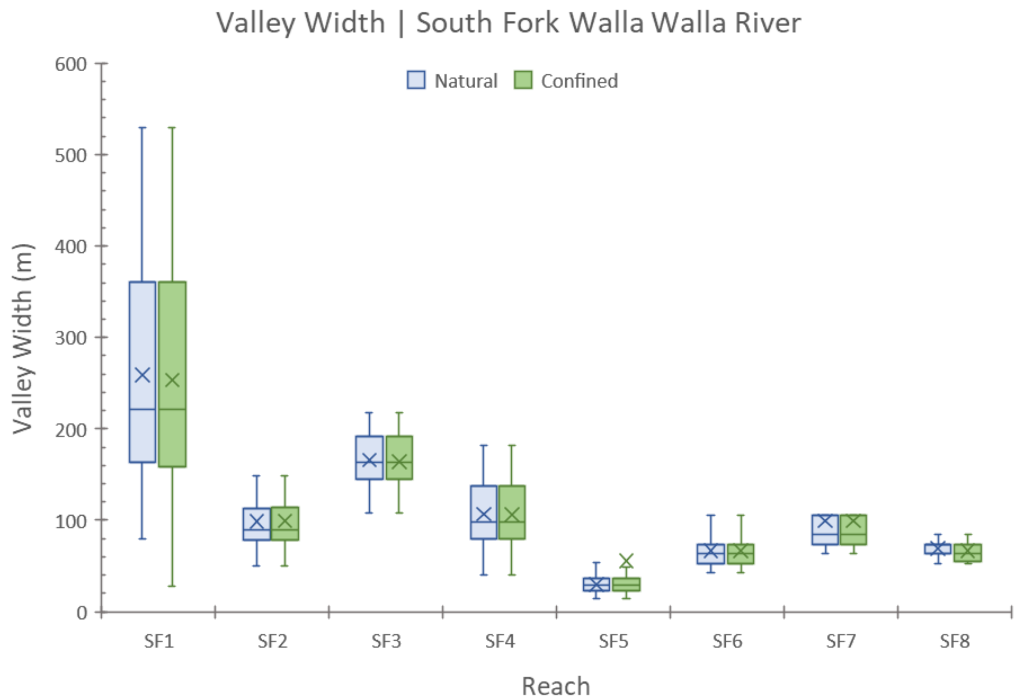

Figure 4-68. Valley width (natural and artificially confined) of the SFWW River by geomorphic reach.

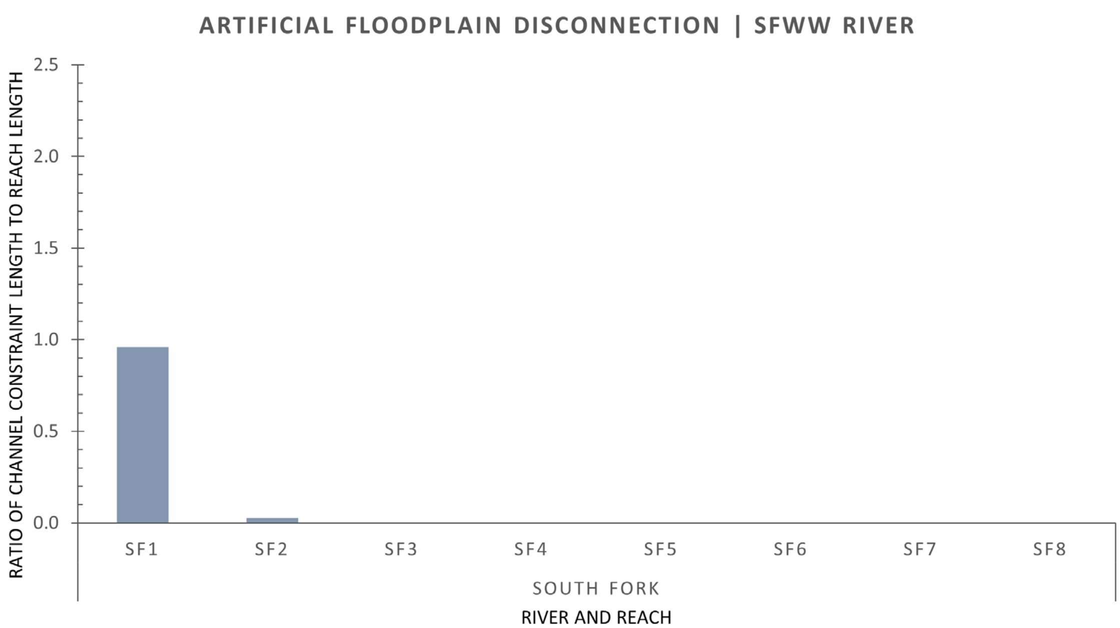

Figure 4-69. Length of channel constraints in the SFWW River by geomorphic reach.

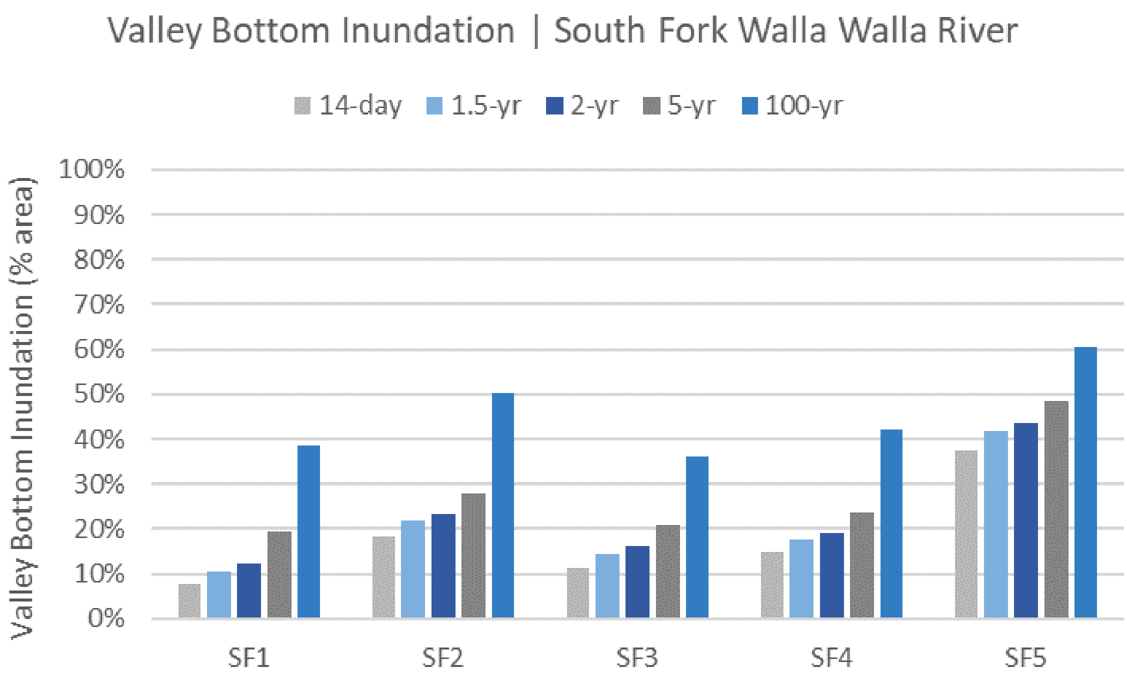

Figure 4-70. Valley bottom inundation for a range of discharges in the SFWW River by geomorphic reach.

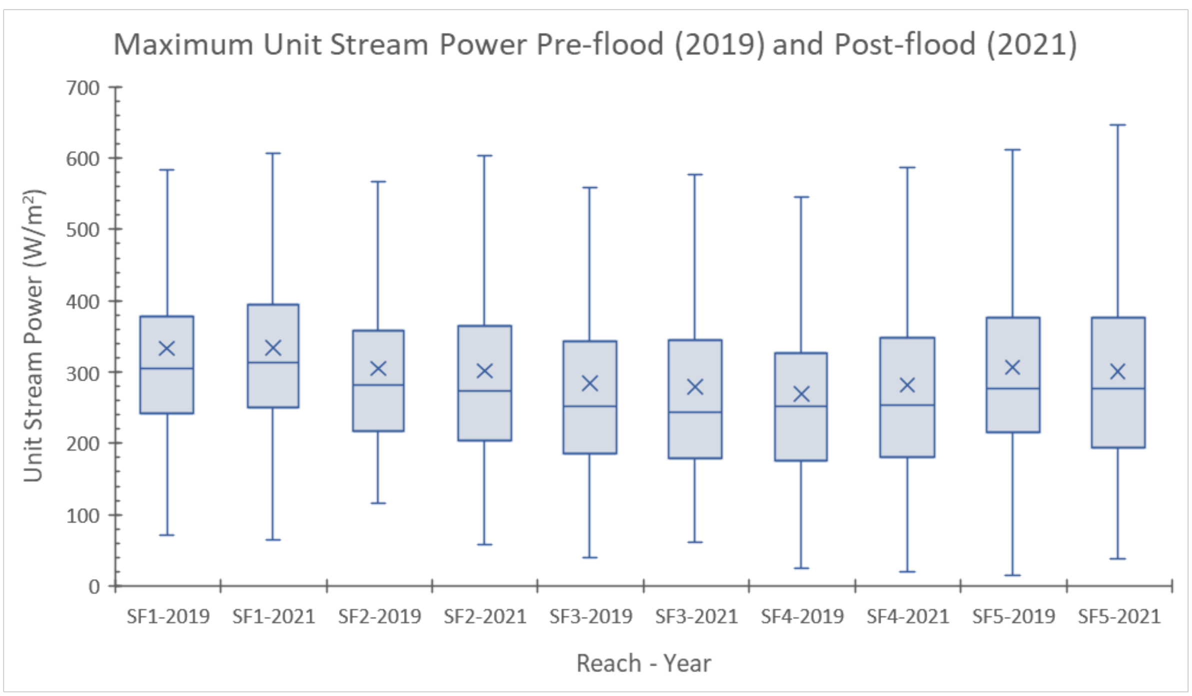

Figure 4-71. Maximum unit stream power for the 50% annual chance flood (2-yr peak) in the SFWW River.

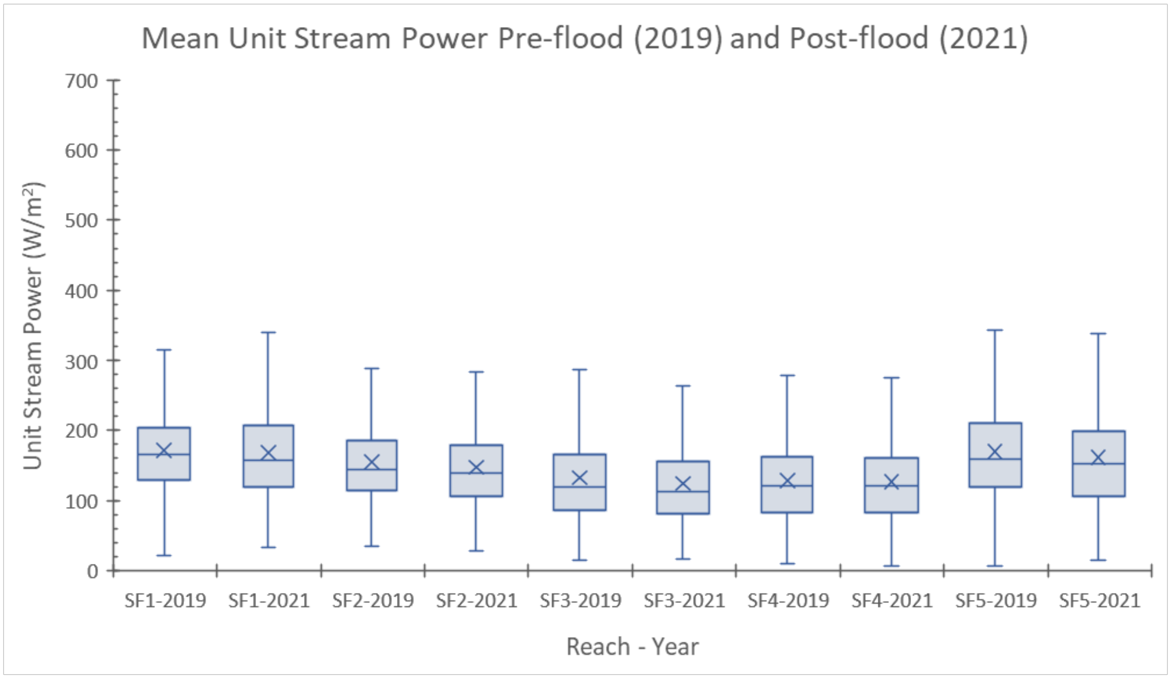

Figure 4-72. Mean unit stream power for the 50% annual chance flood (2-yr peak) in the SFWW River.

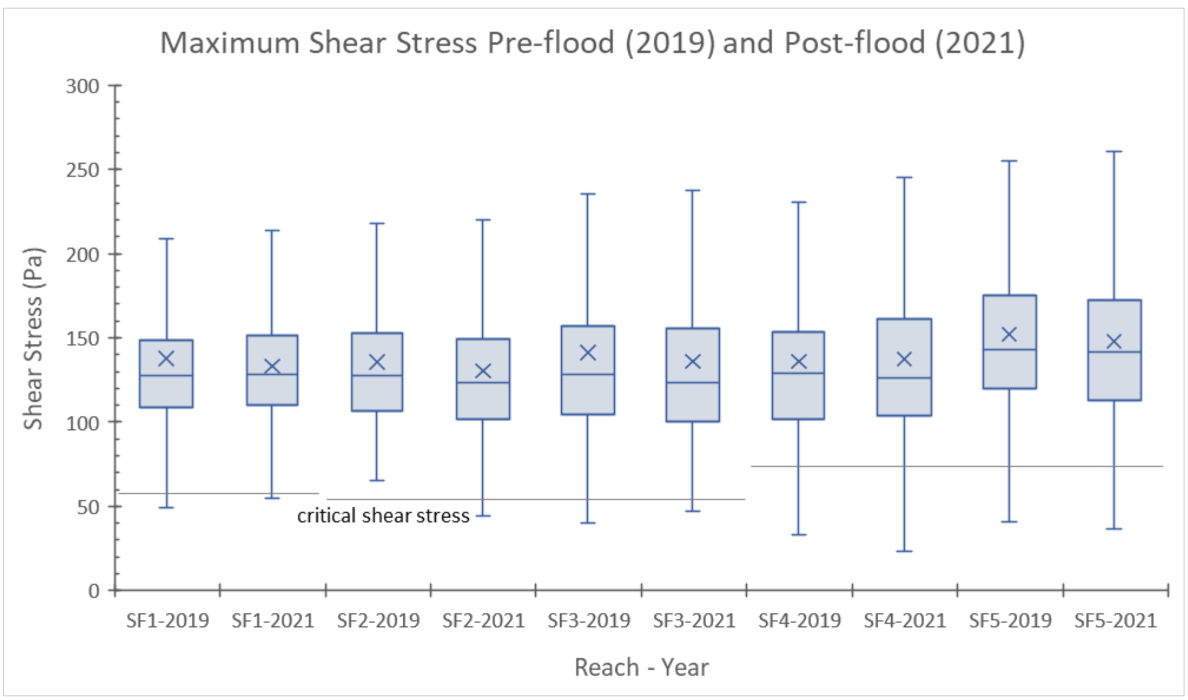

Figure 4-73. Maximum shear stress for the 50% annual chance flood (2-yr peak) in the SFWW River.

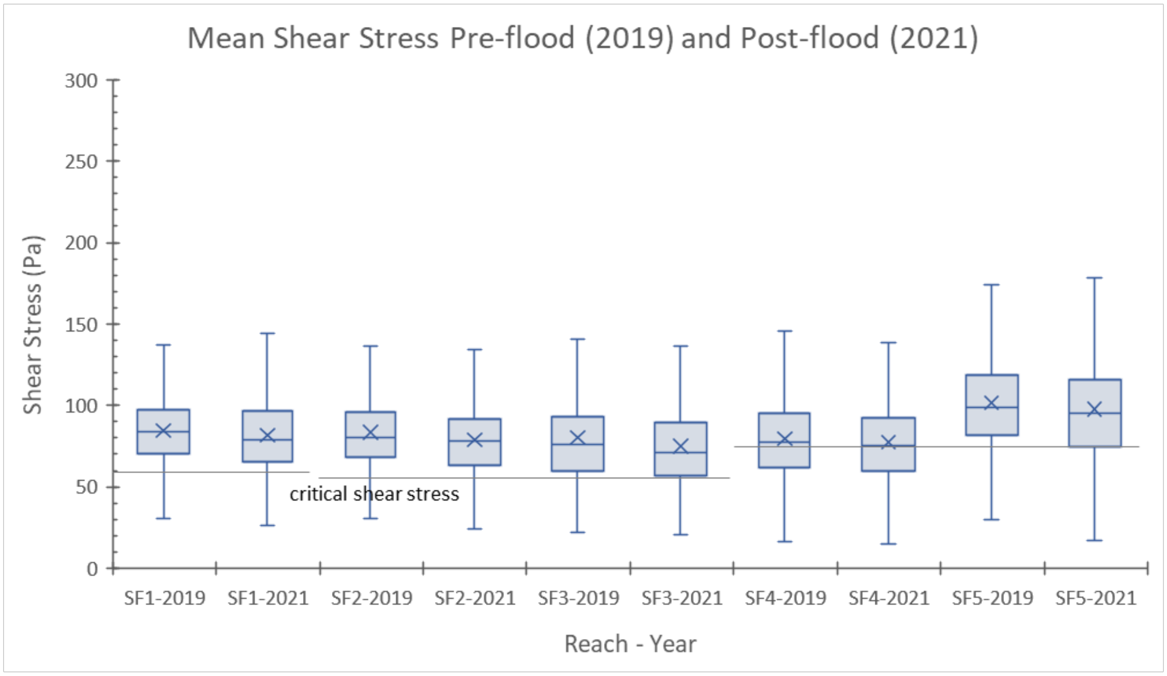

Figure 4-74. Mean shear stress for the 50% annual chance flood (2-yr peak) in the SFWW River.

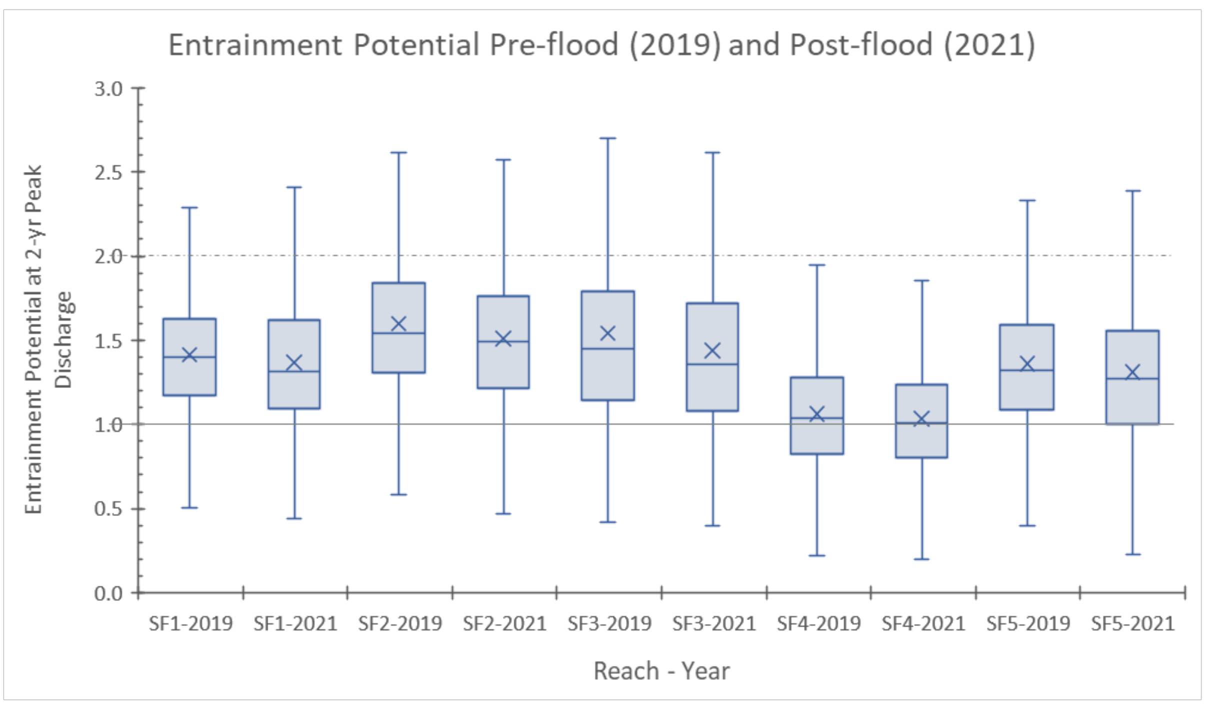

Figure 4-75. Entrainment potential for the 50% annual chance flood (2-yr peak) in the SFWW River.

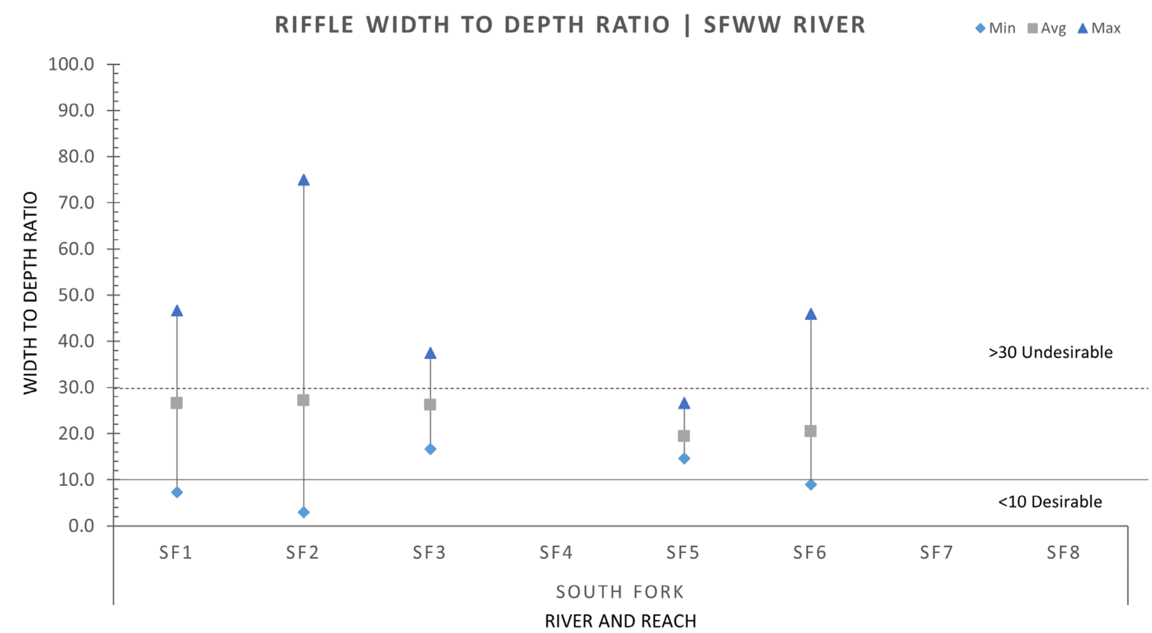

Figure 4-76. Riffle width to depth ratio in the SFWW River by geomorphic reach.

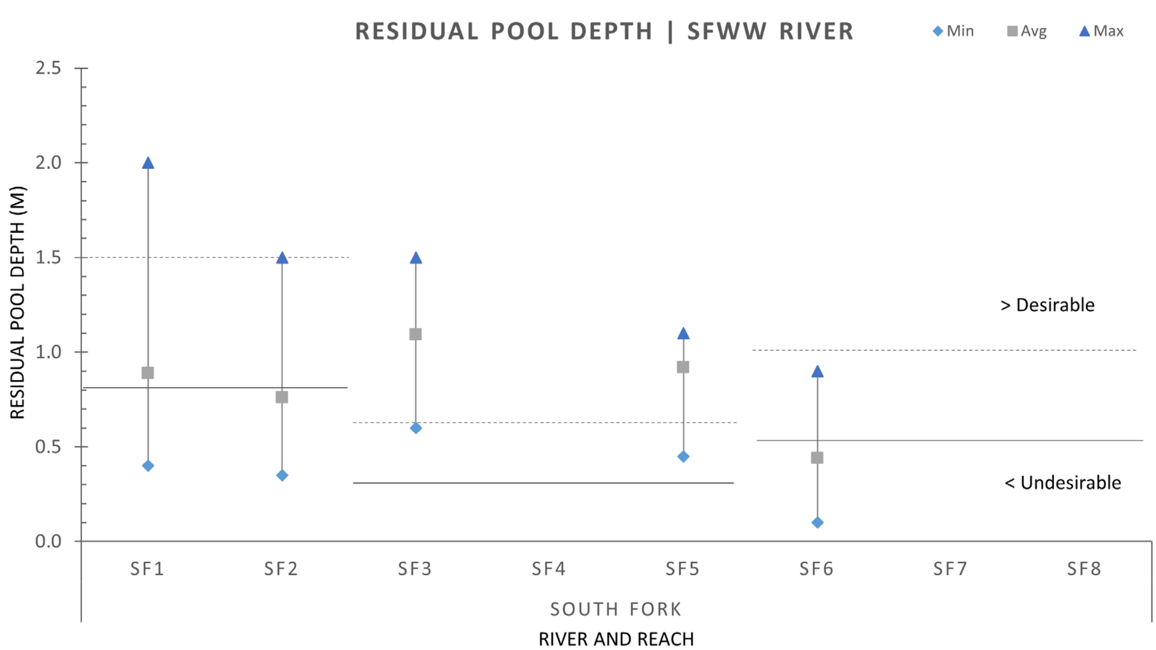

Figure 4-77. Residual pool depth in the SFWW River by geomorphic reach.

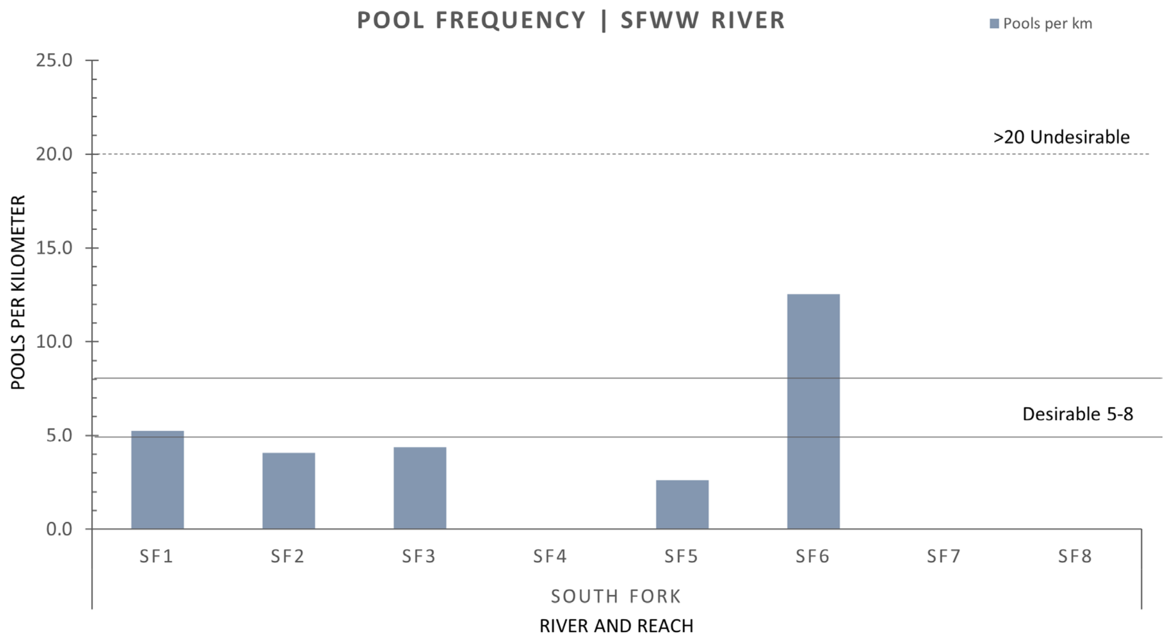

Figure 4-78. Pool frequency in the SFWW River by geomorphic reach.

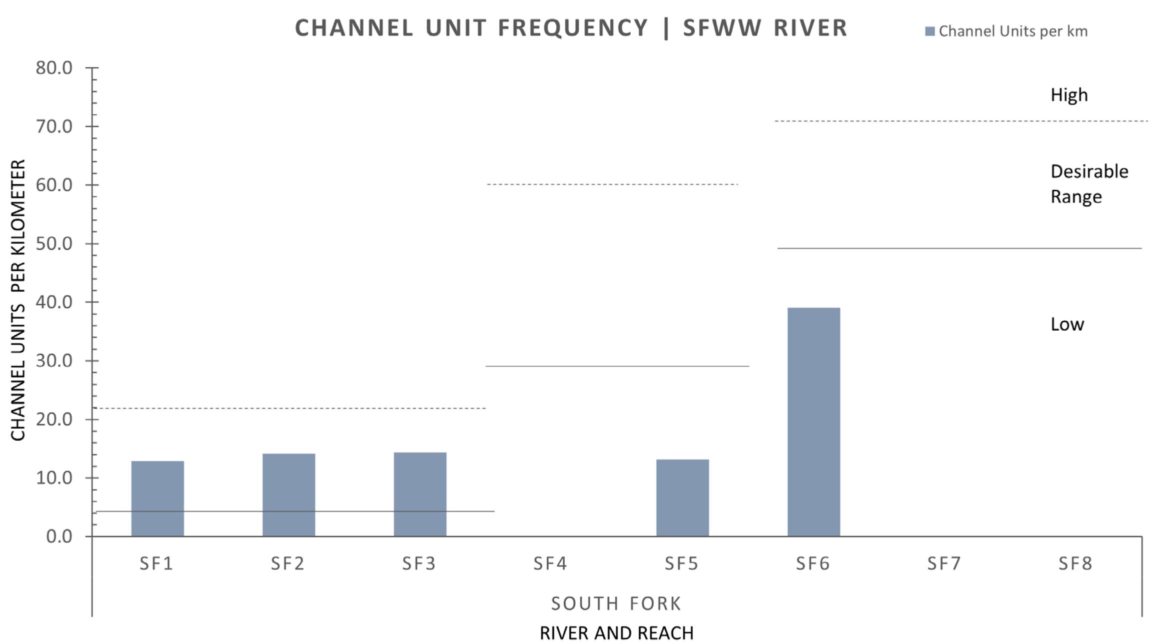

Figure 4-79. Channel unit frequency in the SFWW River by geomorphic reach.

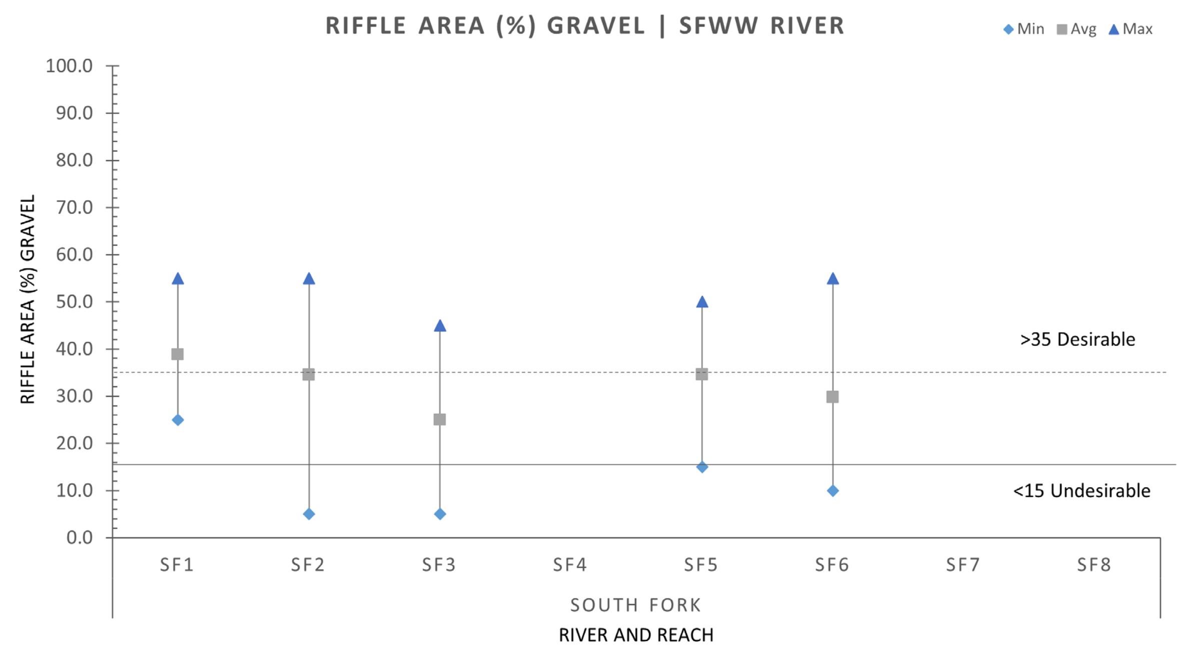

Figure 4-80. Percent of riffle area with gravel in the SFWW River by geomorphic reach.

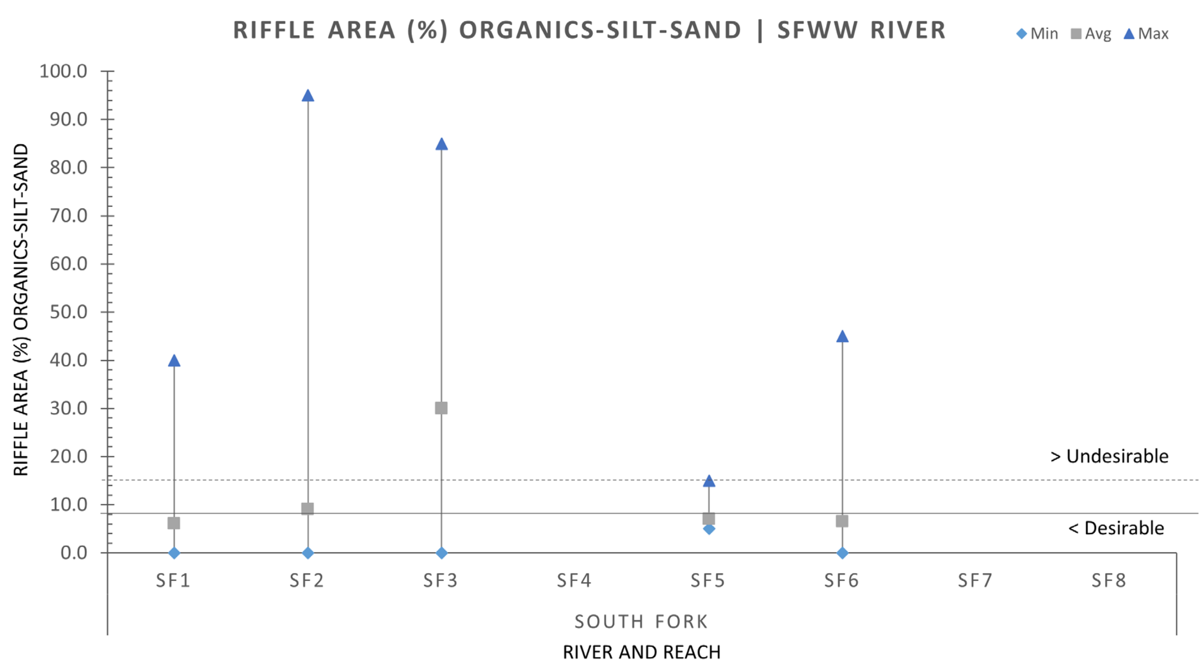

Figure 4-81. Percent of riffle area with organics-silt-sand in the SFWW River by geomorphic reach.

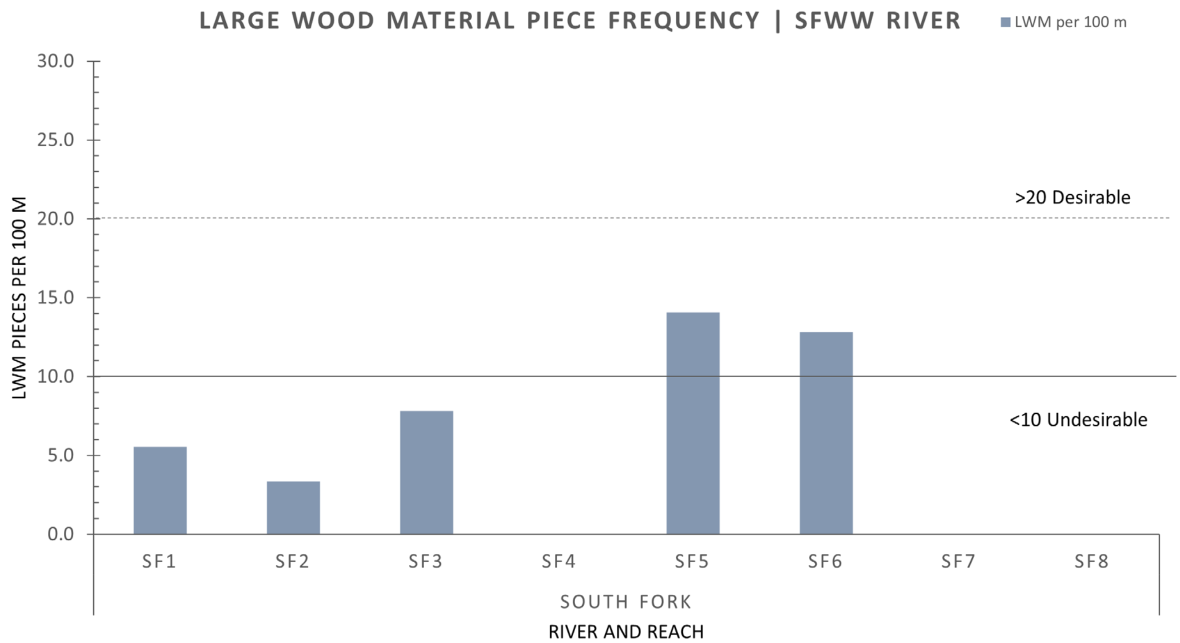

Figure 4-82. Large wood material piece frequency in the SFWW River by geomorphic reach.

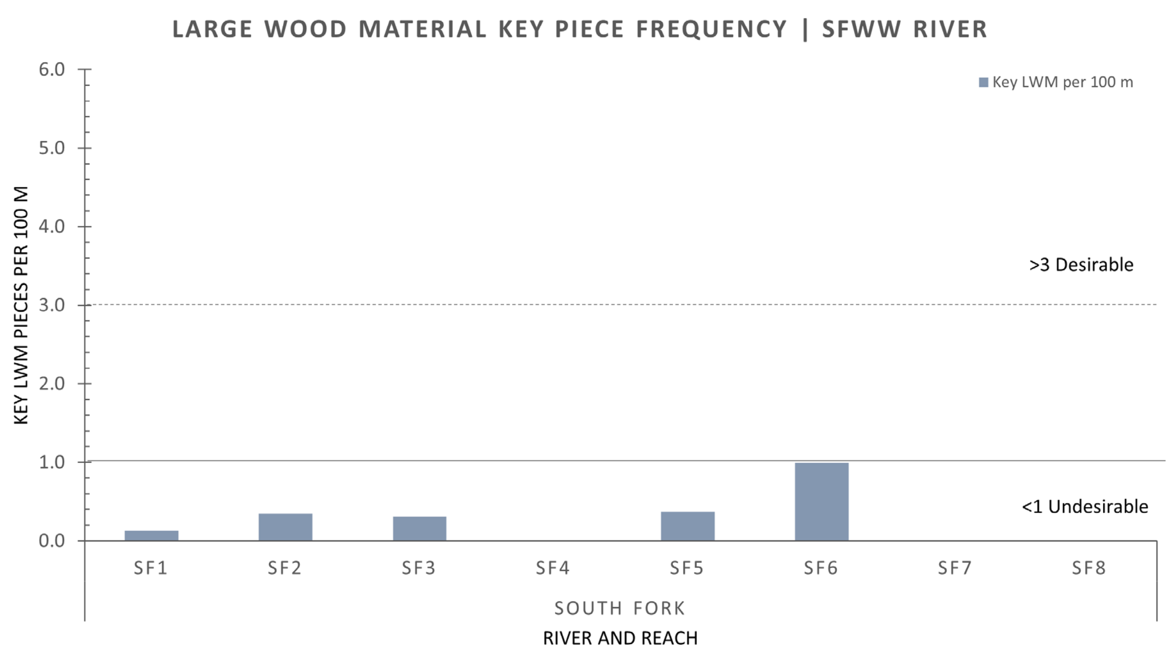

Figure 4-83. Large wood material key piece frequency in the SFWW River by geomorphic reach

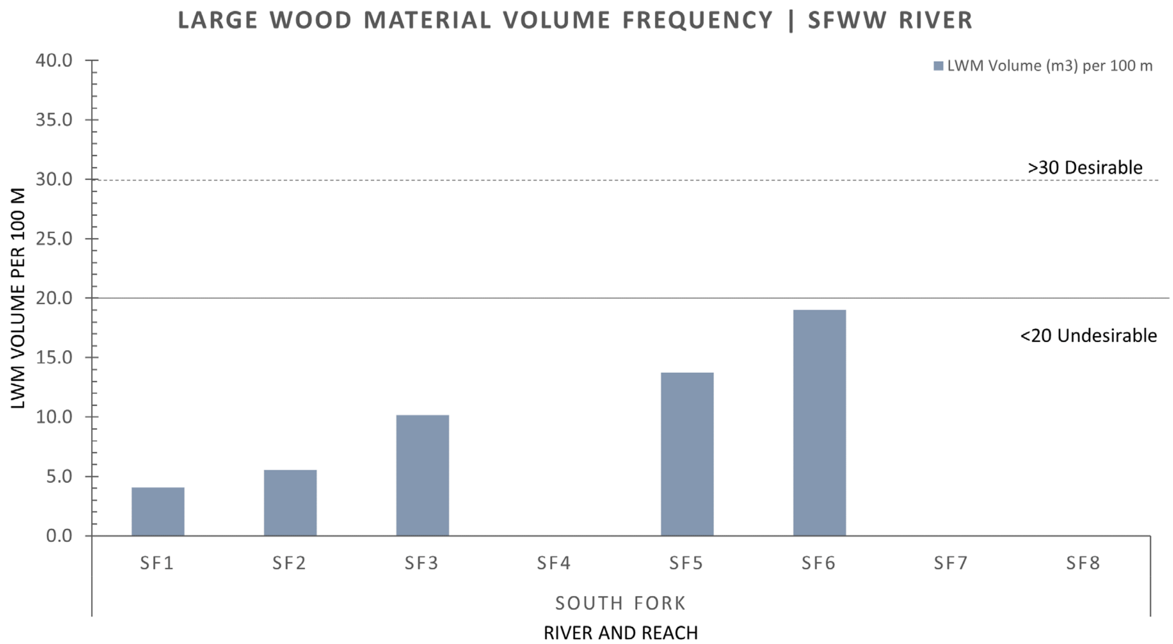

Figure 4-84. Large wood material volume frequency in the SFWW River by geomorphic reach.

Figure 4-85. Valley bottom extent along SFWW River reach SF1.

Figure 4-86. Valley bottom extent along SFWW River reaches SF1 and SF2.

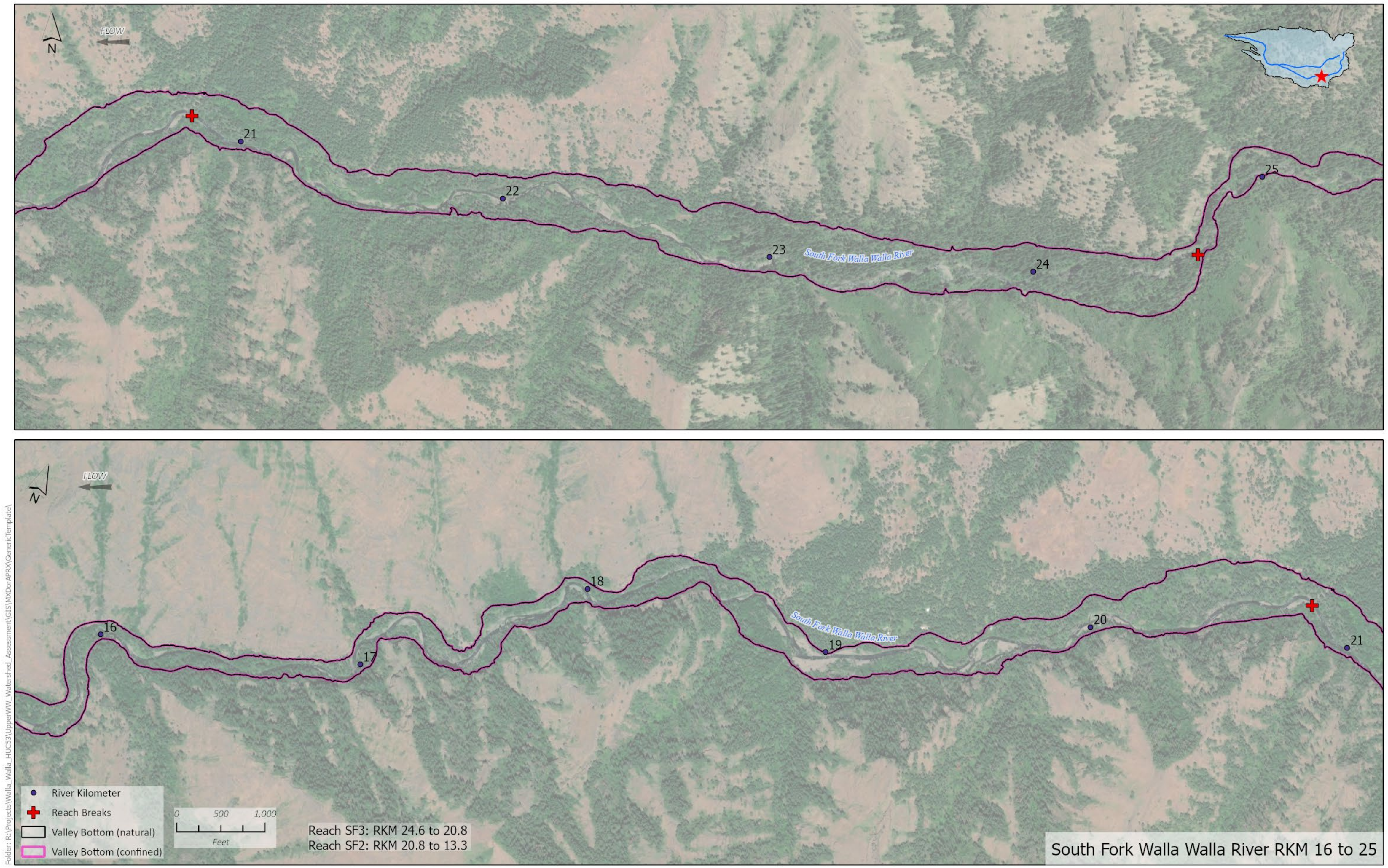

Figure 4-87. Valley bottom extent along SFWW River reaches SF2 and SF3.

Figure 4-88. Valley bottom extent along SFWW River reaches SF4 and SF5.

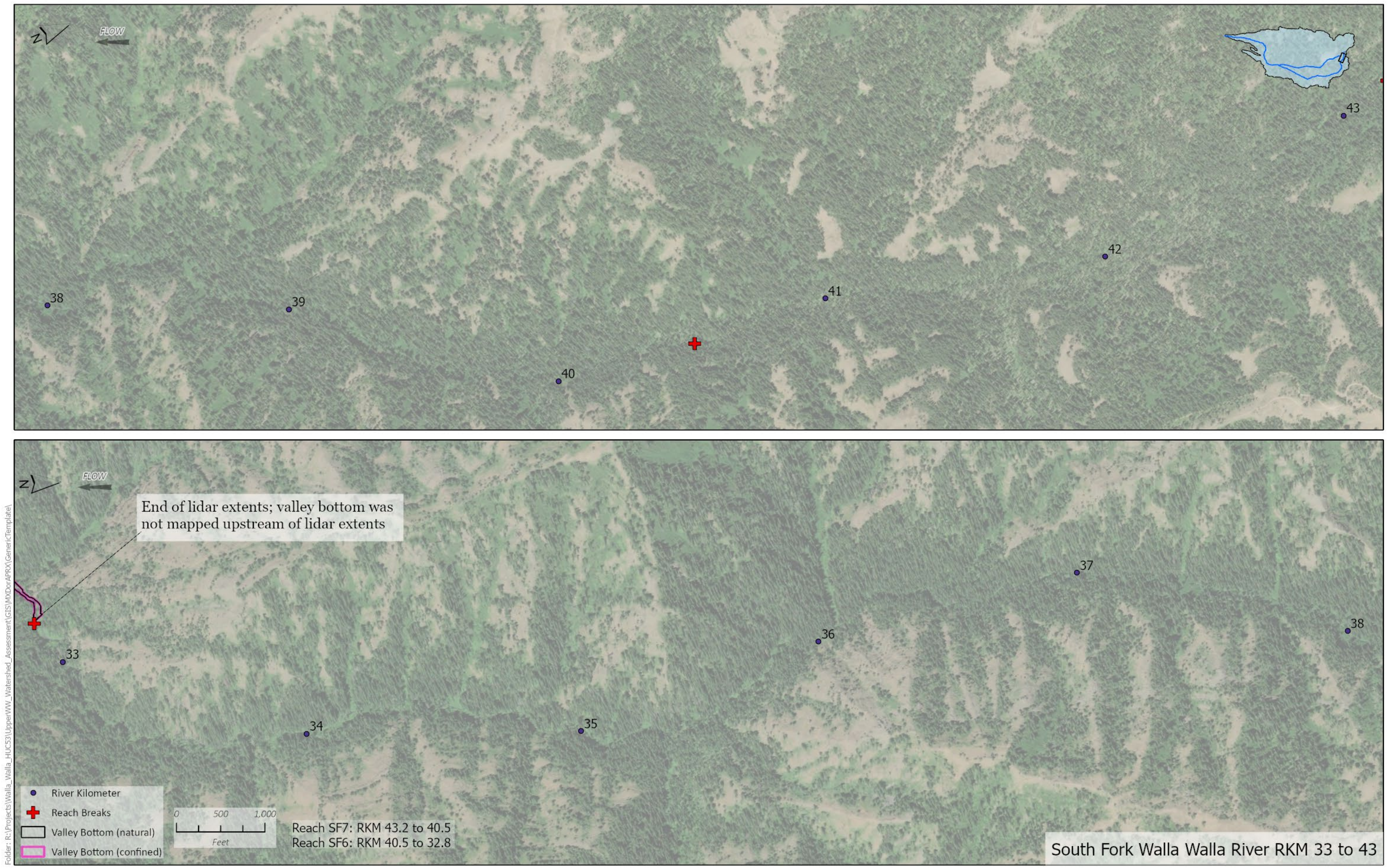

Figure 4-89. Valley bottom extent along SFWW River reaches SF6 and SF7.

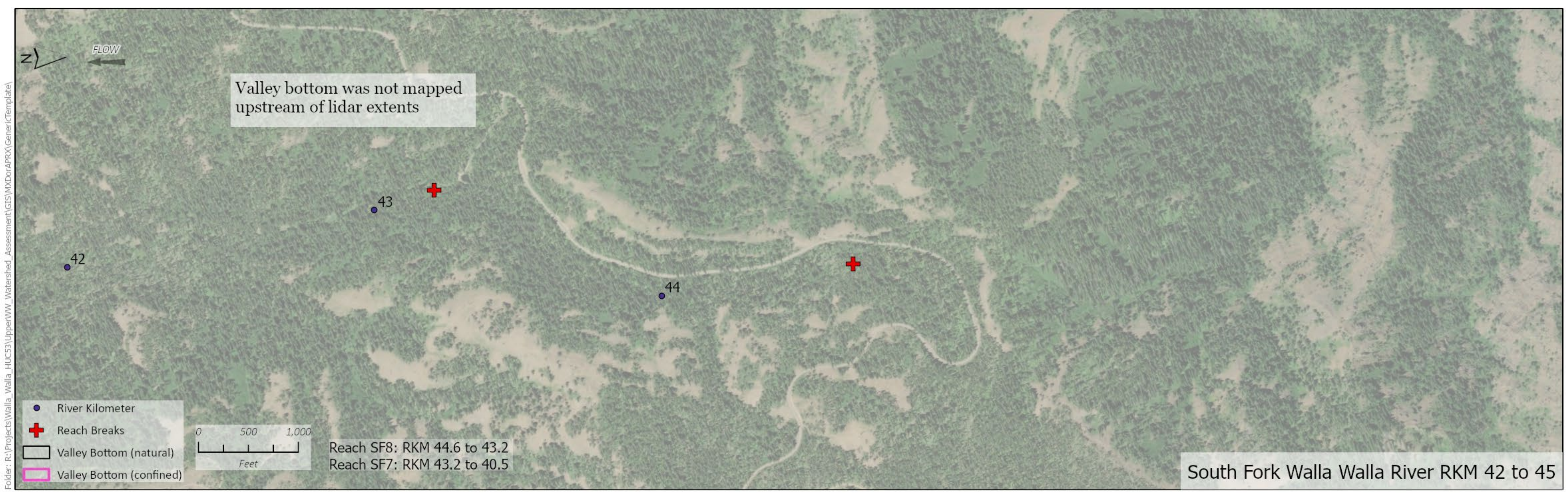

Figure 4-90. Valley bottom extent along SFWW River reaches SF7 and SF8.

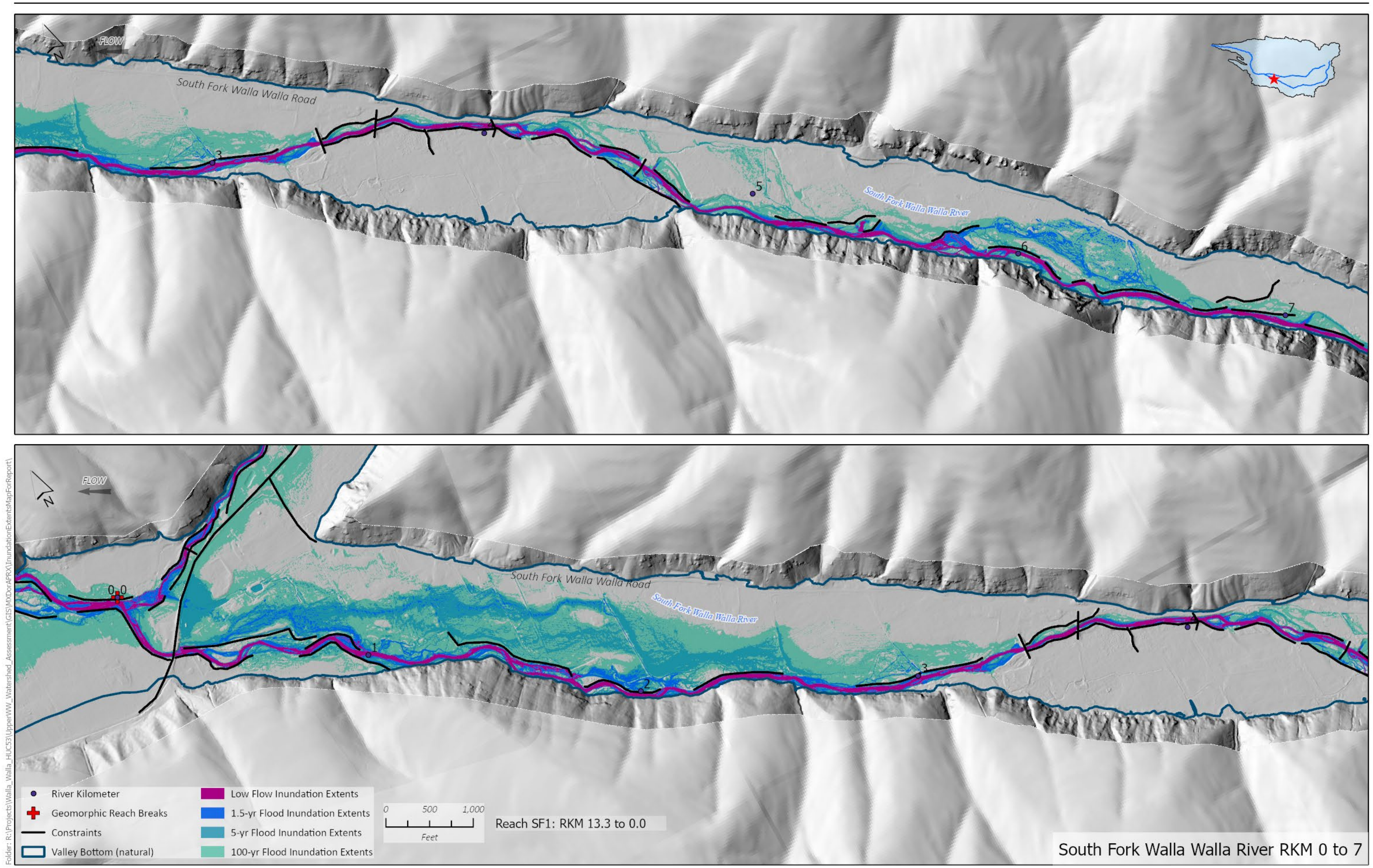

Figure 4-91. Inundation extents and channel constraints along SFWW River reach SF1.

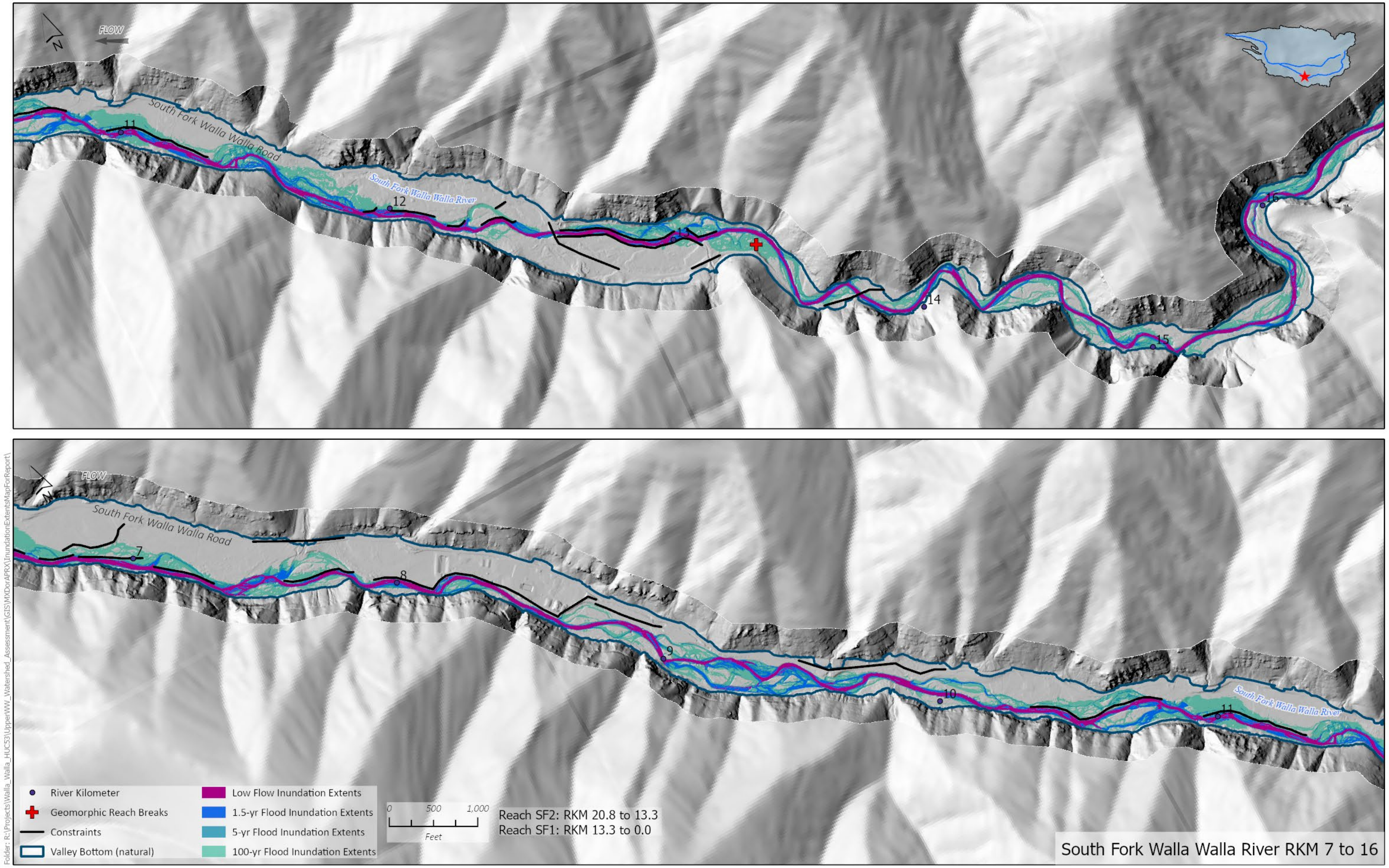

Figure 4-92. Inundation extents and channel constraints along SFWW River reaches SF1 and SF2.

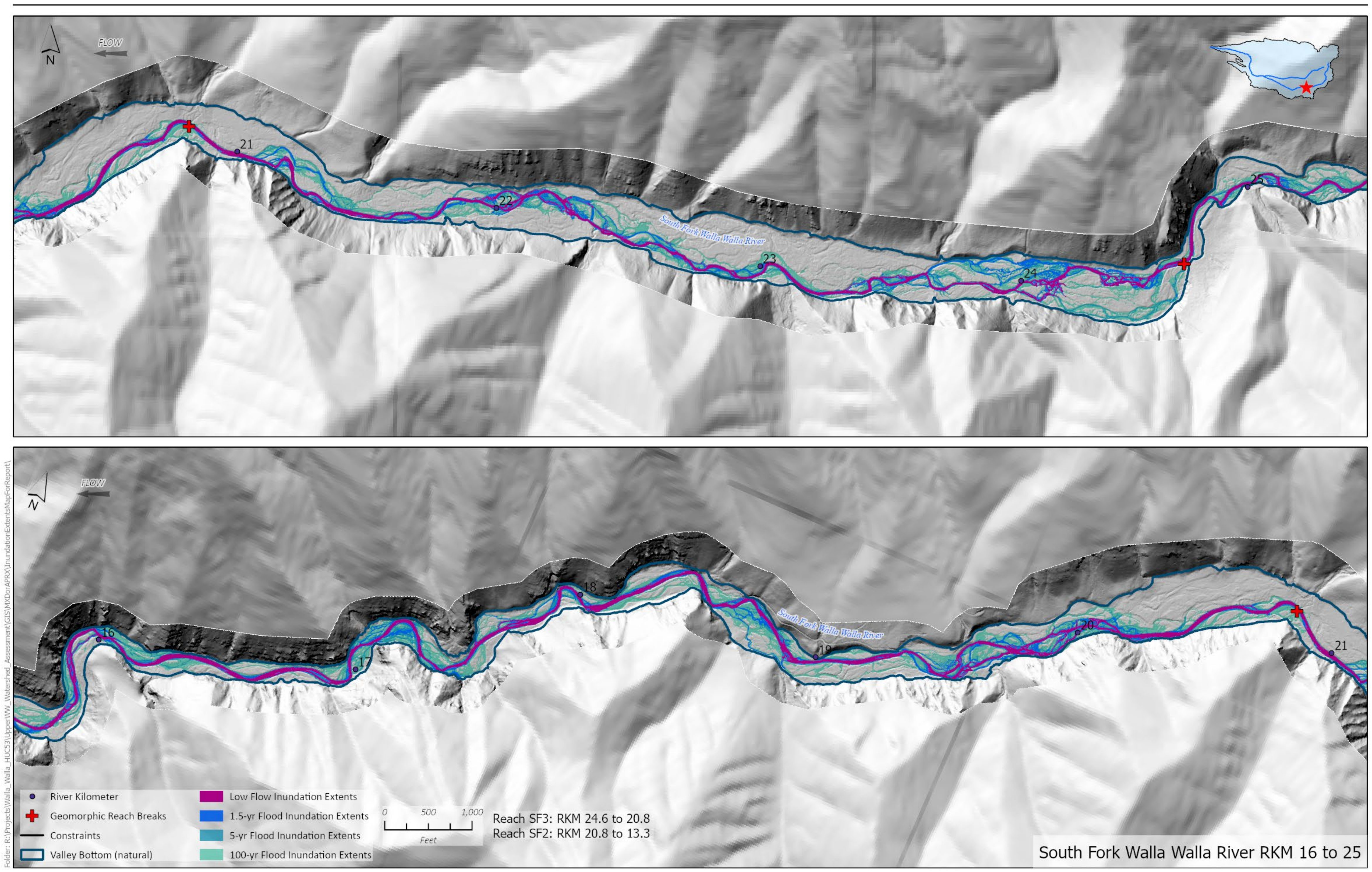

Figure 4-93. Inundation extents and channel constraints along SFWW River reaches SF2 and SF3.

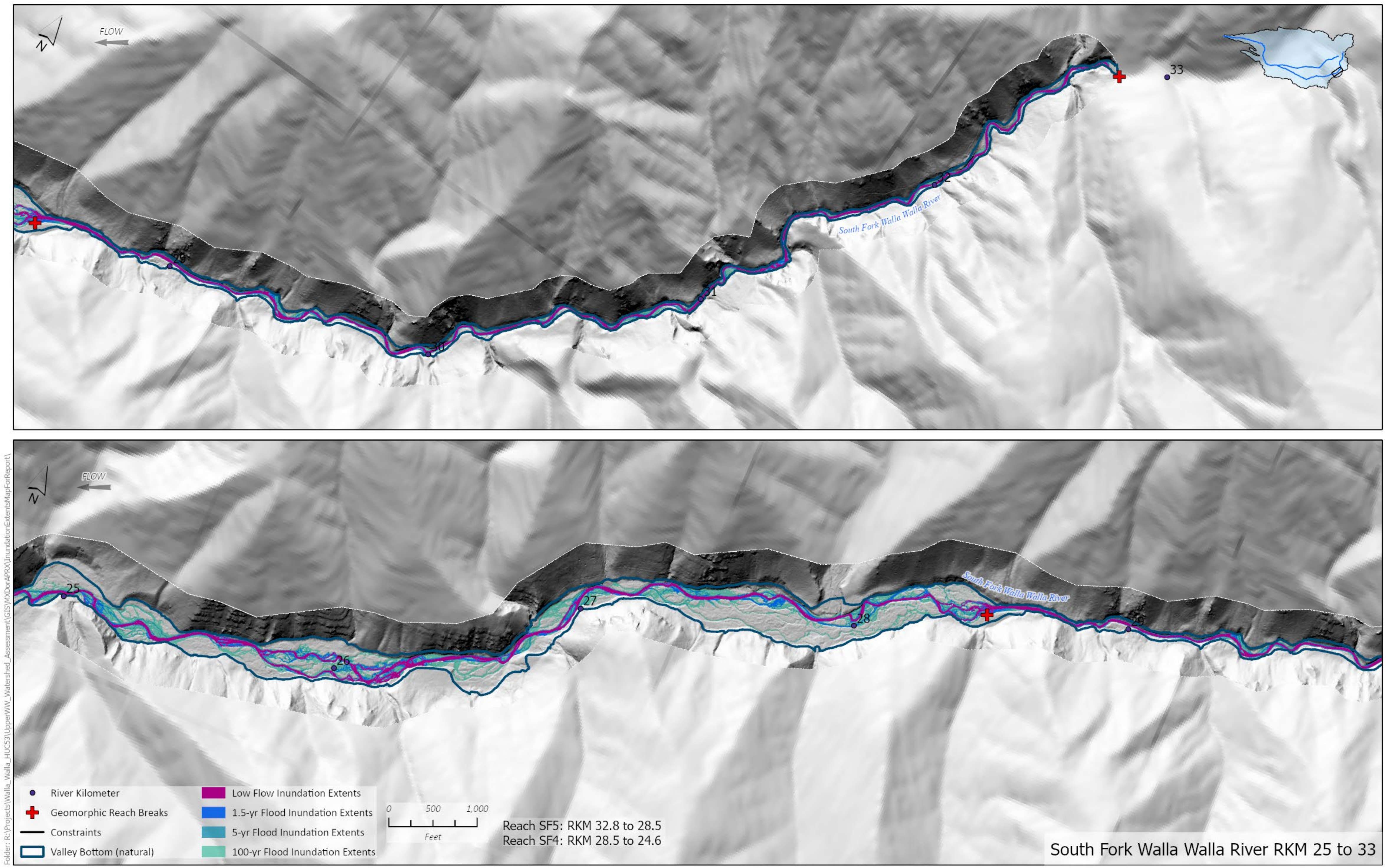

Figure 4-94. Inundation extents and channel constraints along SFWW River reaches SF4 and SF5.

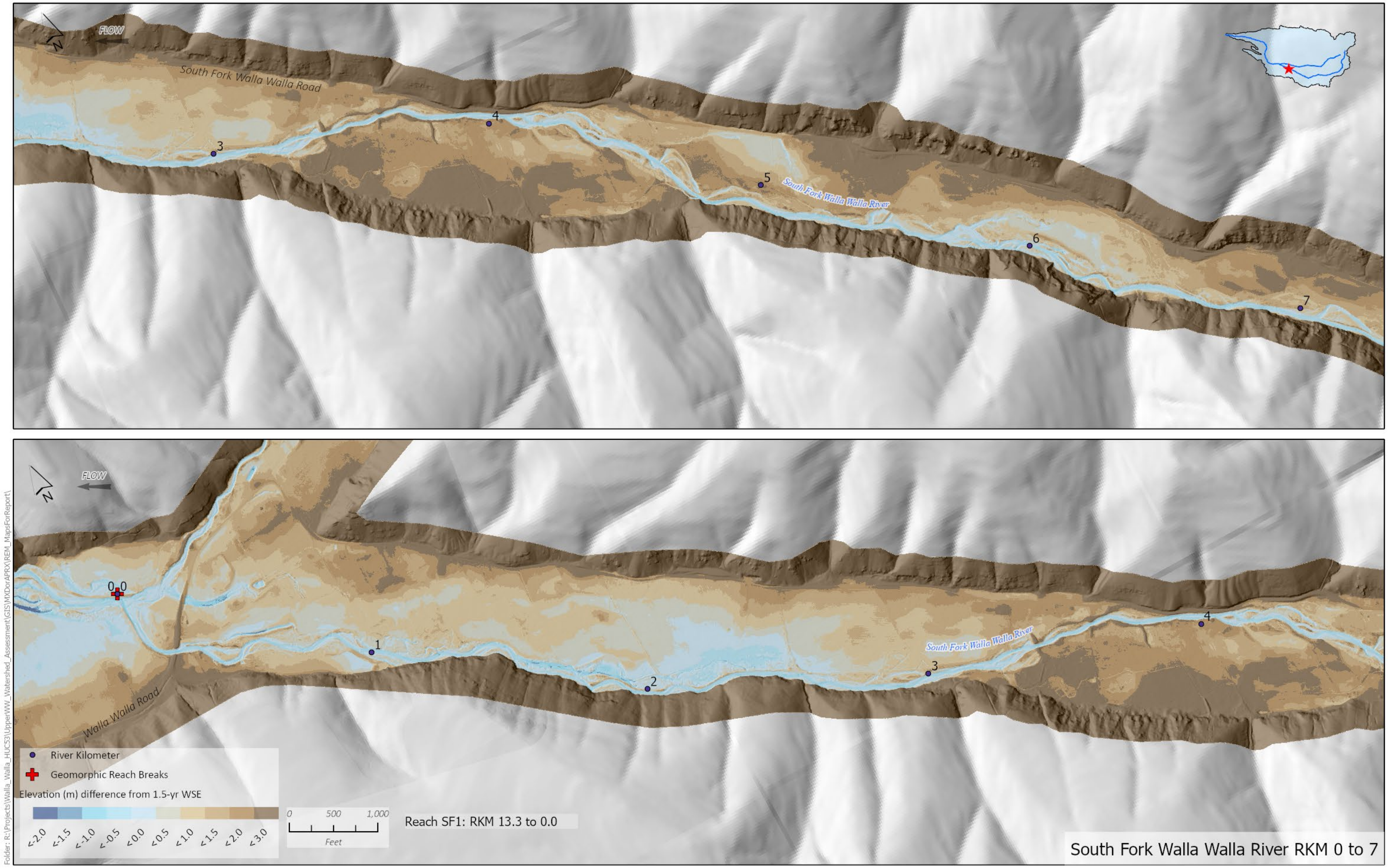

Figure 4-95. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in SFWW River reach SF1.

Figure 4-96. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in SFWW River reaches SF1 and SF2.

Figure 4-97. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in SFWW River reaches SF2 and SF3.

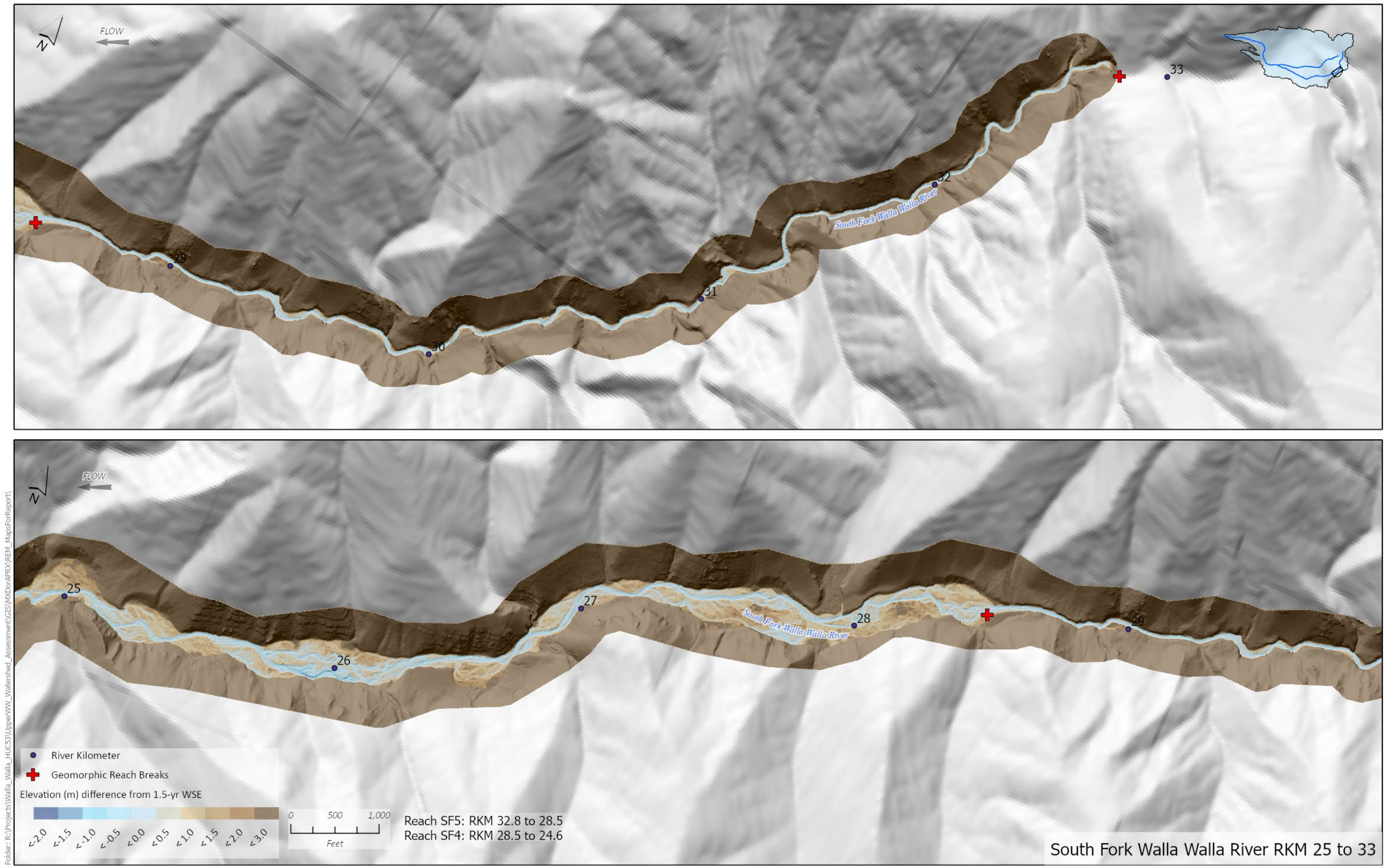

Figure 4-98. Floodplain and river channel elevations relative to the 1.5-yr peak discharge water surface elevation (WSE) in SFWW River reaches SF4 and SF5.

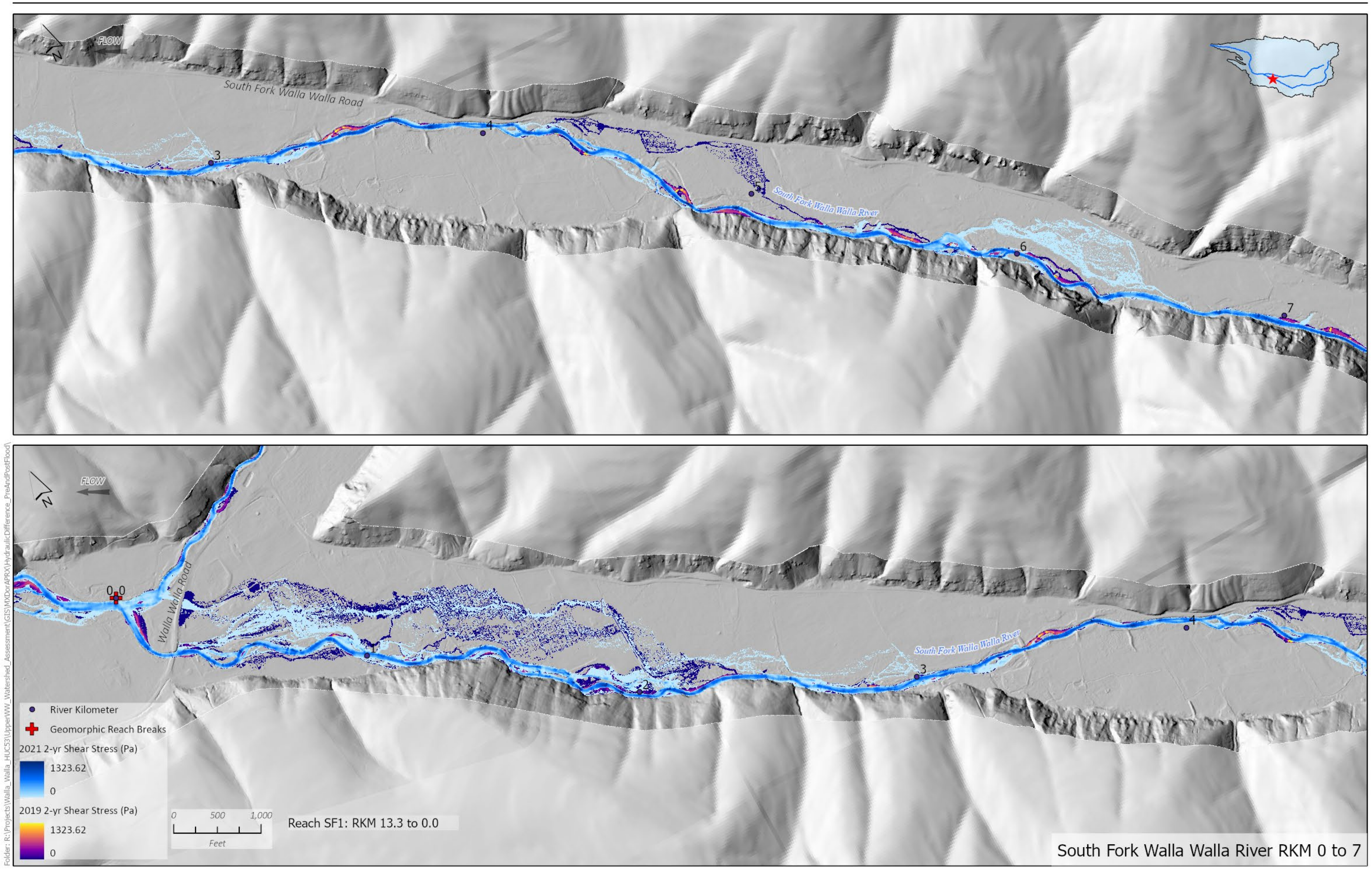

Figure 4-99. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the SFWW River in reach SF1.

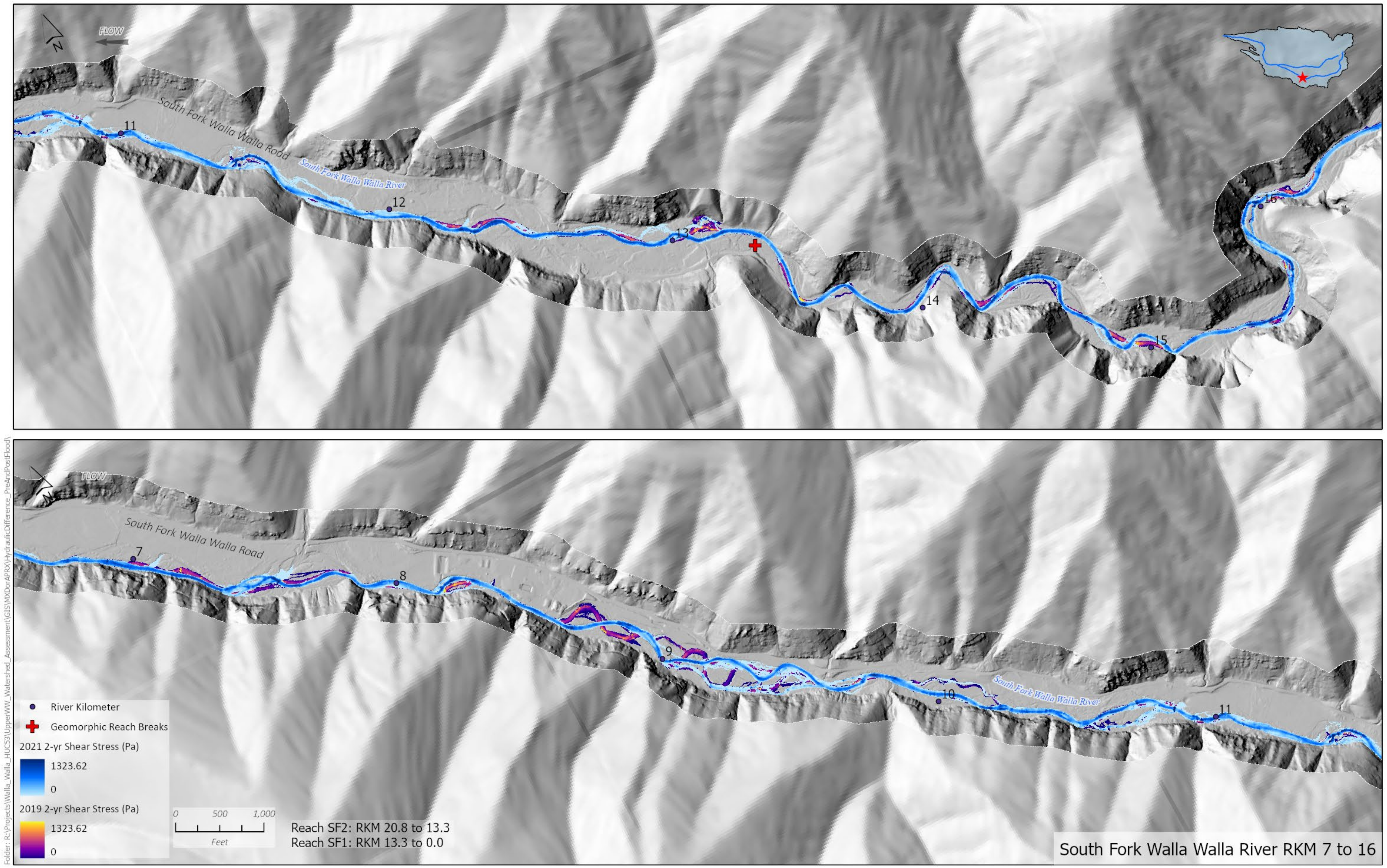

Figure 4-100. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the SFWW River in reaches SF1 and SF2.

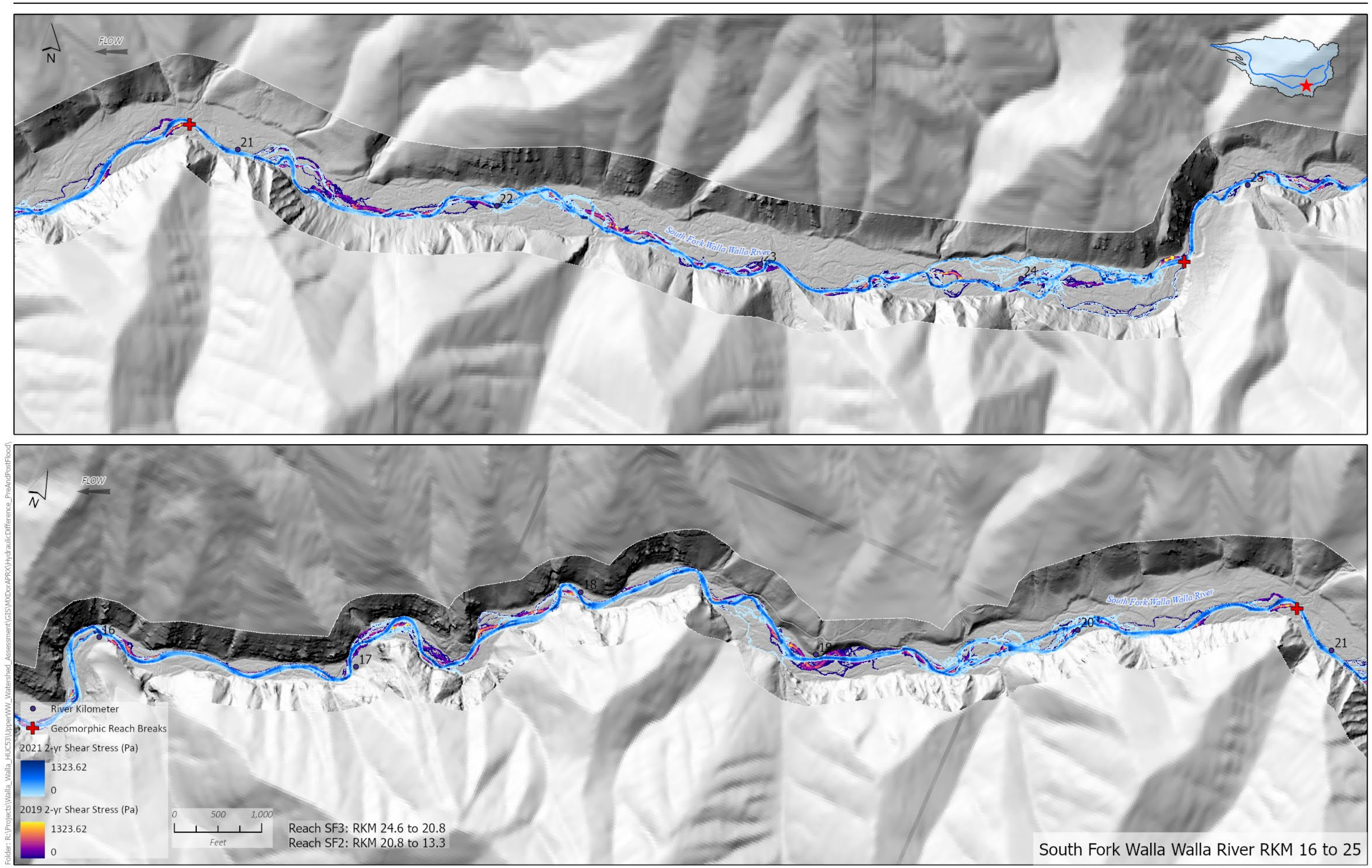

Figure 4-101. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the SFWW River in reaches SF2 and SF3.

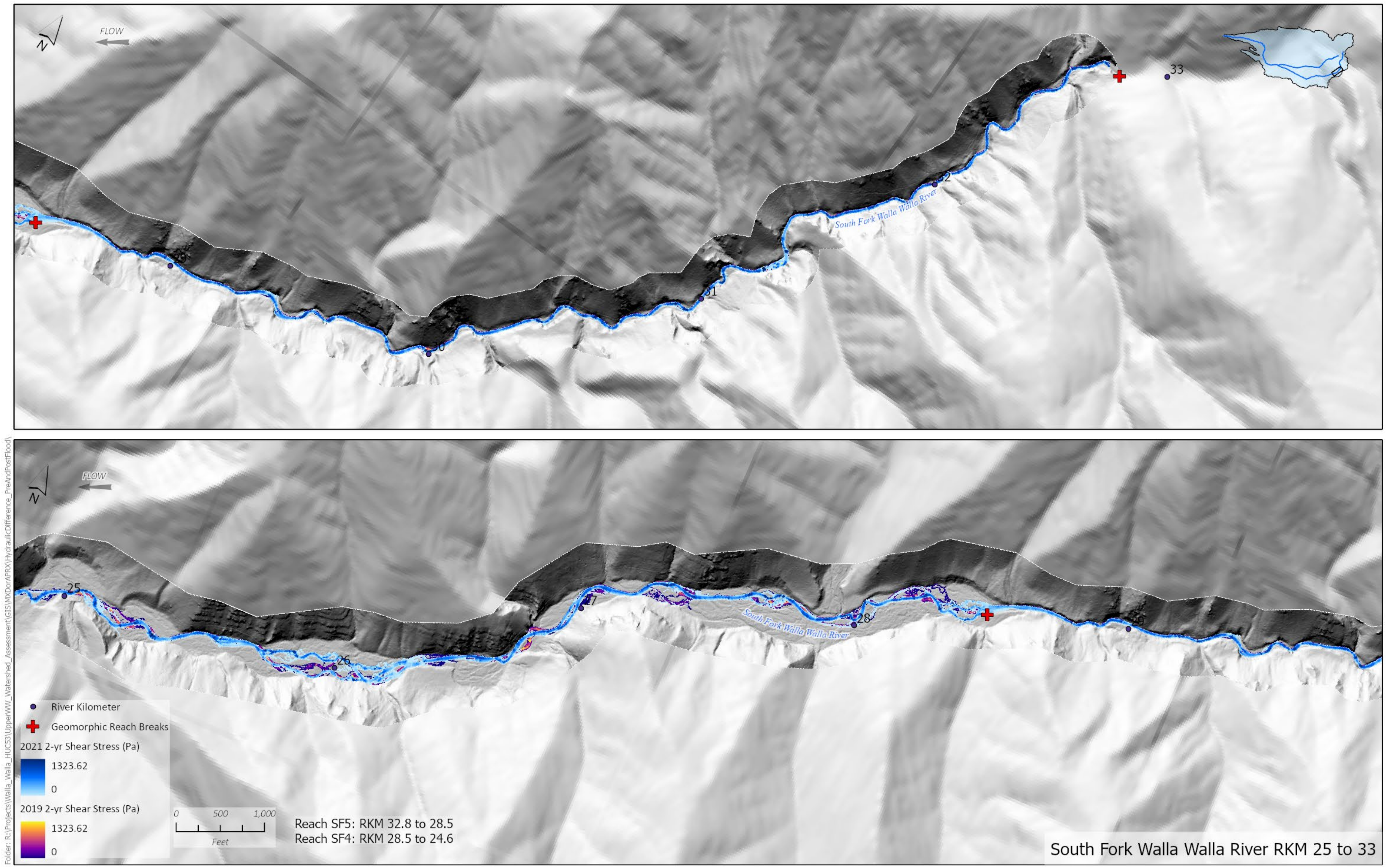

Figure 4-102. Shear stress of the 2-yr peak discharge for the 2019 and 2021 topobathymetric elevations of the SFWW River in reaches SF4 and SF5.

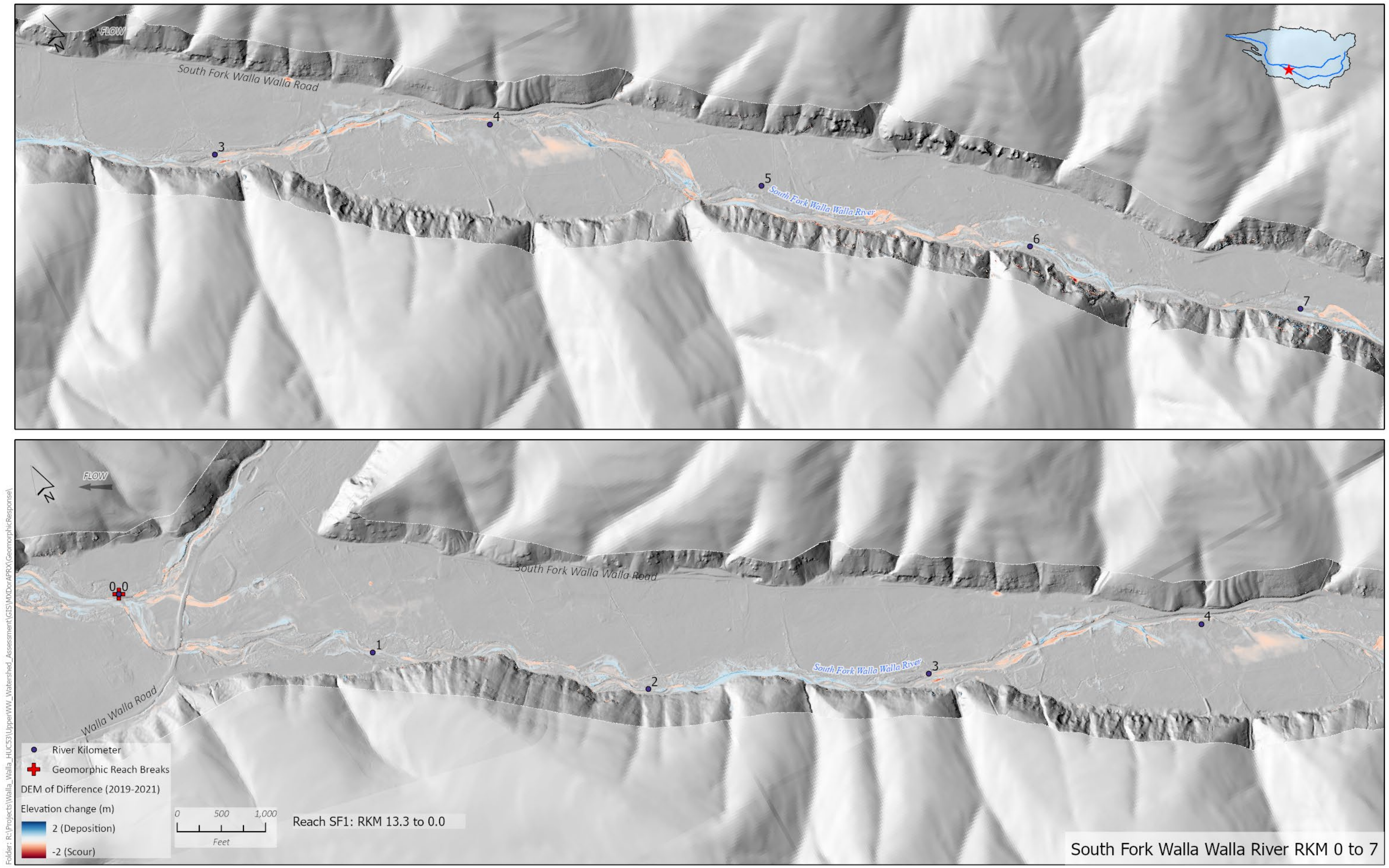

Figure 4-103. Areas of deposition and scour from the 2020 flood in SFWW River reach SF1.

Figure 4-104. Areas of deposition and scour from the 2020 flood in SFWW River reaches SF1 and SF2.

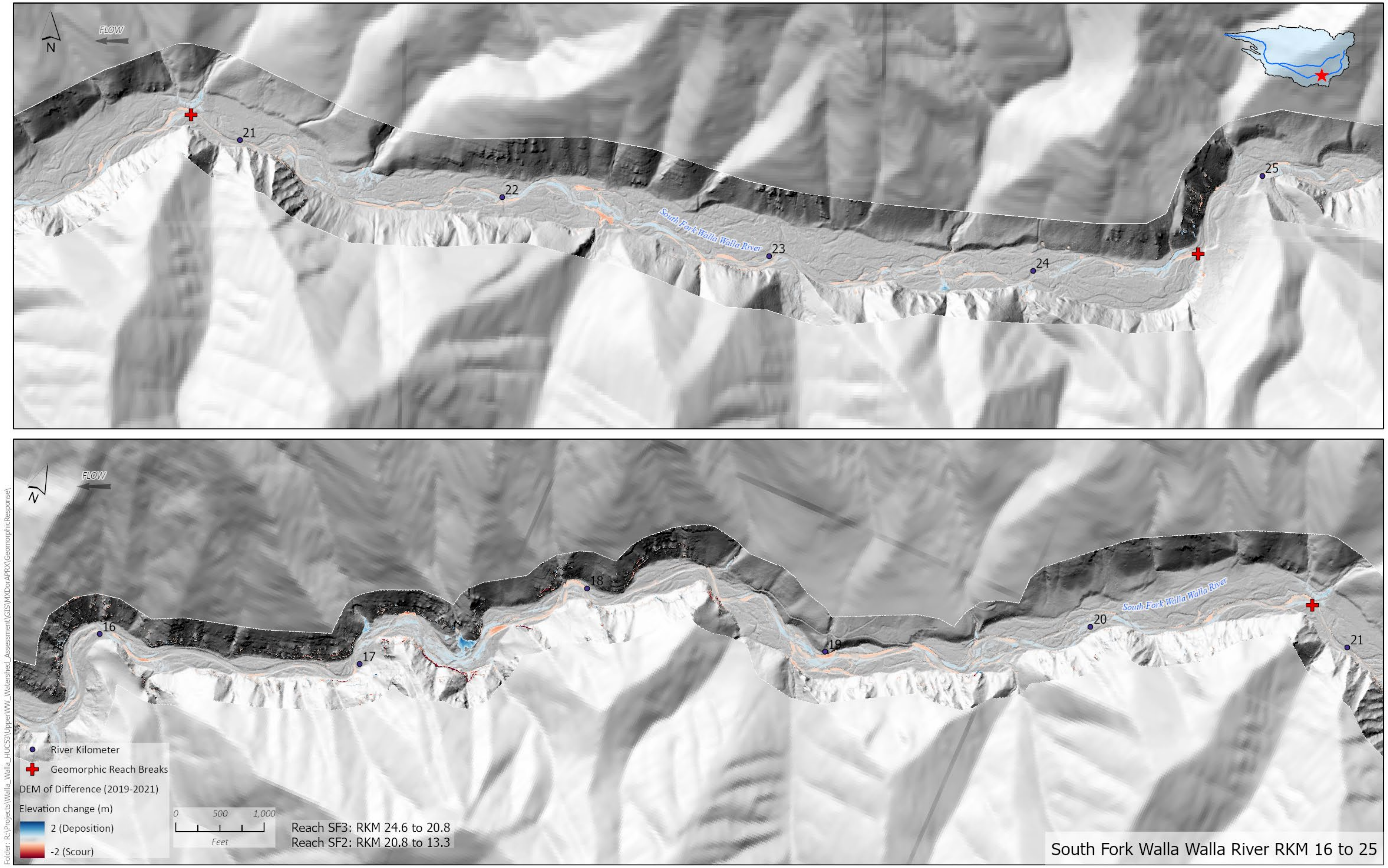

Figure 4-105. Areas of deposition and scour from the 2020 flood in SFWW River reaches SF2 and SF3.

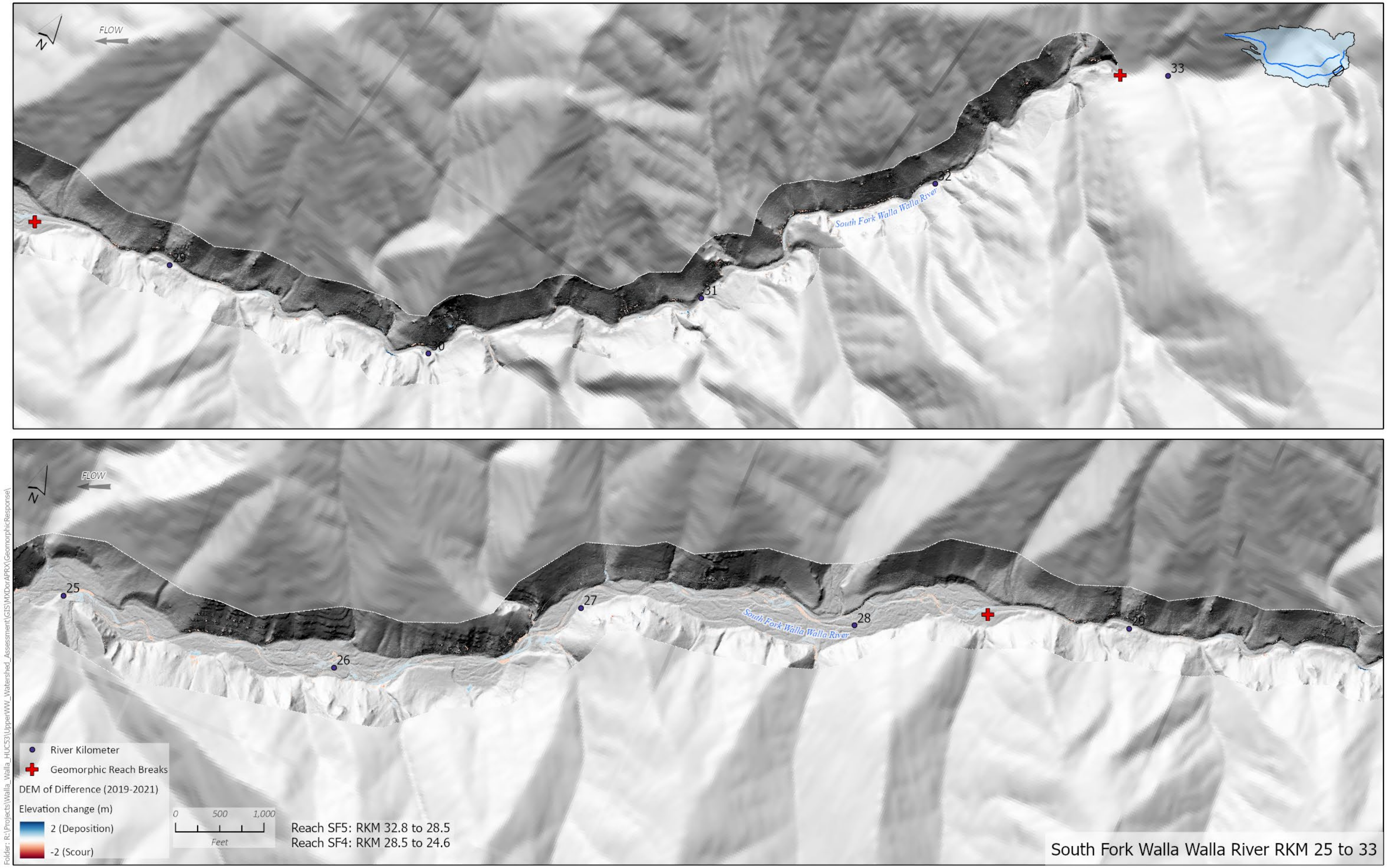

Figure 4-106. Areas of deposition and scour from the 2020 flood in SFWW River reaches SF4 and SF5.

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Appendix C

Upper Walla Walla Assessment

HYDROLOGY

Technical Report

May, 2024

Technical Report

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Hydrology Technical Report

Date: May 2024

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1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations. The focal fish species of the assessment and action plan consist of the following:

1. Middle Columbia River summer steelhead (ESA-listed Threatened)
2. Columbia River bull trout (ESA-listed Threatened)
3. Spring Chinook salmon
4. Pacific lamprey

The final restoration action plan will establish a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions.

This Appendix focuses on describing the hydrology of the mainstem Walla Walla River (WWR), North Fork WWR, and South Fork WWR, with a specific focus on inputs for hydraulic modeling. The purpose and methodology of the hydraulic modeling is described in detail in Appendix D. Within this Appendix is a summary of the general climatic and hydrologic context (both groundwater and surface water) of the Upper Walla Walla, with a detailed description of the methodology used to provide hydrologic inputs to the hydraulic model.

Streamflow discharge values throughout the model domain were estimated at both peak flows and biologically relevant low flows for use in hydraulic modeling. Estimates were made at or near geomorphic reach breaks, at tributary confluences and distributary bifurcations, and at several gage locations. The location of each streamflow estimate corresponds to a boundary condition in the hydraulic model. Peak flow streamflow values were estimated at the 1.5-, 2-, 5-, and 100-year recurrence intervals. Ecologically relevant low flows were calculated at the summer 95% exceedance low flow, the 14-day duration flow during spring runoff, and the 50% exceedance winter flow. Both peak and low flows were estimated using a gage extension with a long-running gage followed by interpolation or extrapolation based on drainage area and location in the watershed.

2.0 CLIMATE

The Walla Walla River watershed is affected by a combination of maritime and continental climates. The general semiarid climate of the region is a result of the Cascade Range of mountains reducing the precipitation effects of easterly moving maritime air masses. Cold continental air masses from the north and east, combined with moist maritime influences, results in precipitation that primarily occurs during the winter months as rain at lower elevations and snow at upper elevations. Average annual precipitation in the watershed ranges from 40 cm (15.75 in) in the valley floor to 160 cm in the upper elevations of the Blue Mountains. Significant winter rain, rain-on-snow events, and early spring thaw are all contributors to low elevation flooding within the watershed (NPCC, 2005).

Climatic differences within the watershed are predominantly due to differences in elevations, with mostly low-elevation lands in the west, and with the higher elevation Blue Mountains to the east. The climate pattern in the lower elevation portion of the Upper Walla Walla is depicted by the National Climate Data Center records at the Whitman Mission (USC00459200), near RKM 55 (WRCC, 2024). The gage is located at an elevation of 192.6 m (632 ft) and has a period of record from 1962 to 2024. Mean monthly air temperatures range from 1.1°C (33.9°F) in January to 21.8°C (71.2°F) in July with maximum monthly air temperatures ranging from 5.2°C (41.3°F) to 31.9°C (89.4°F), respectively. Mean annual precipitation is approximately 36.1 cm (14.21 in), with a mean winter accumulation of 12.1 cm (4.76 in) and mean summer accumulation of 5.0 cm (1.97 in). Due to orographic lift, the Blue Mountains receive substantially more precipitation than the downstream valley bottom (USFS, 2017). The differences in precipitation based on elevation can be seen in Figure 2-1. The higher elevation Blue Mountains receive most precipitation as snow, with snowmelt providing most of the streamflow in the Walla Walla River during the dry, summer months (USFS, 2017).

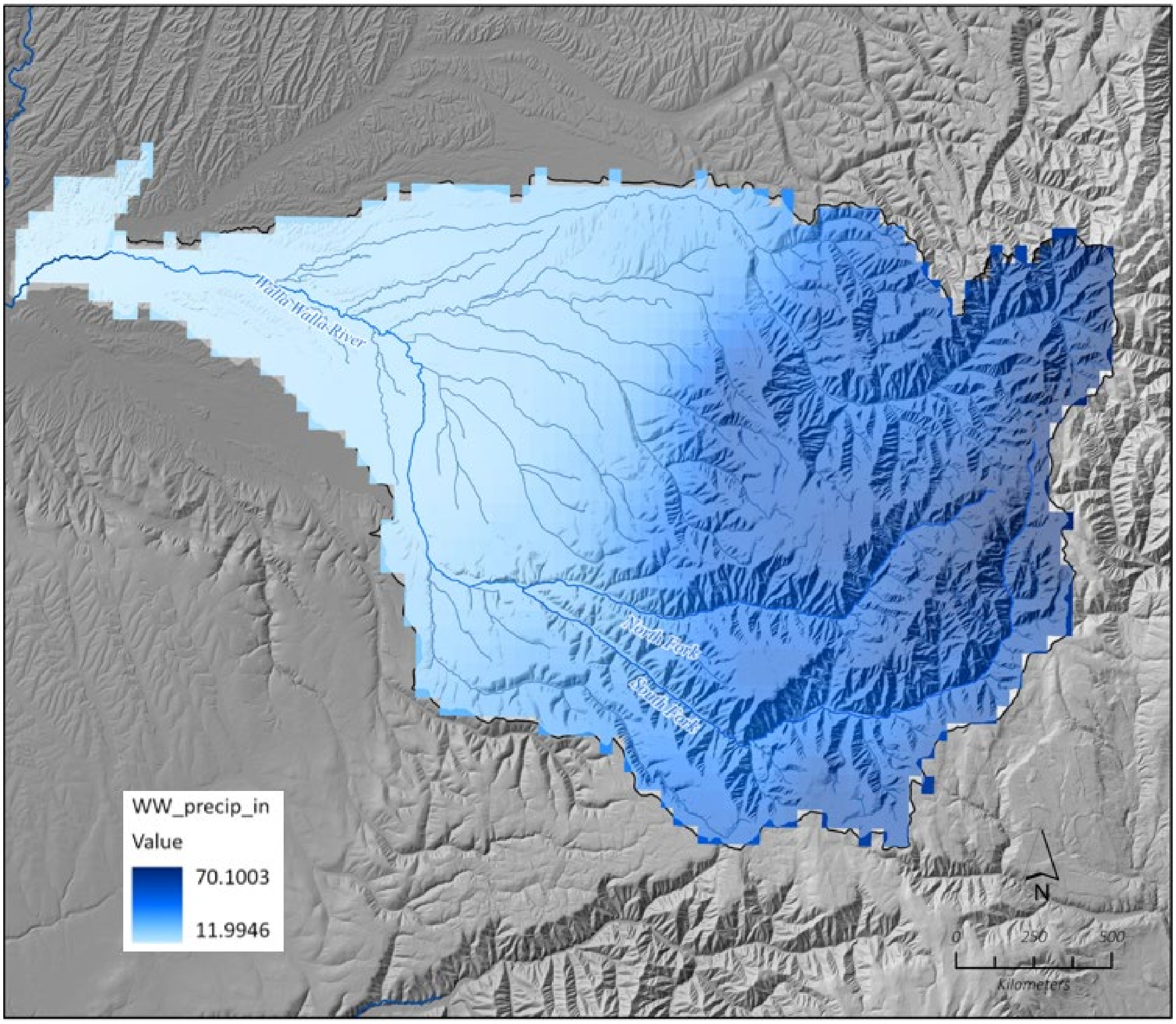

Figure 2-1: Annual precipitation range in the Upper Walla Walla Basin.

2.1 CLIMATE CHANGE

Climate change is expected to impact peak flow and low flow timing and magnitude in the Walla Walla watershed. The Blue Mountains have been identified as an area where the snowpack is sensitive to climate change, where large areas could lose all or significant portions of the April 1 snow water equivalent (SWE) under a 3°C temperature increase. Warming temperatures in the winter will lead to decreased snowpack accumulation and earlier melt out, shifting the timing of peak flows to earlier in the year. Over time this will cause the Walla Walla watershed to transition from a snowmelt-dominated basin into a mixed rain-and-snow basin (USFS, 2017). A typical hydrograph for a mixed rain-and-snow basin in the Columbia Basin has a peak in the fall due to rain, followed by a snowmelt-driven peak in the spring. Climate change-induced transition into a mixed rain-and-snow basin will increase the number of rain-on-snow events, which increases the potential for extreme peak flows (Cho, 2021). The impact on more frequent peak flows, such as the 1.5-year flood, is less clear. Climate change will impact low flow timing and magnitude in several ways. Earlier melt out of the snowpack will cause headwater streams to experience low flow for a longer duration of the year, and decreased snowpack accumulation will reduce the magnitude of low water flows.

Climate change is also expected to have more direct and indirect impacts on water quality and quantity. Water temperatures are expected to increase, both due to higher air temperatures and due to smaller volumes of water during the summer (USFS, 2017). The flashier peak flows will likely alter the geomorphic regime of the watershed, potentially resulting in channel scouring and increased sedimentation, which can alter water quality (USFS, 2017). Climate change is also expected to increase the frequency and severity of wildfire, which will reduce shading and increase sediment delivery to the system. Climate change will also alter riparian and upland ecosystem composition, but the full impacts and connections are complex and not yet fully understood.

3.0 GROUNDWATER HYDROLOGY

Within the Walla Walla watershed, there are two hydrogeologic rock units that contain most of the groundwater storage: Columbia River Basalts and Pleistocene/recent alluvium (Newcomb, 1965). The Columbia River Basalts have a thickness of 600-900 meters. Groundwater storage and transport within the basalt is governed by structural features and spatial heterogeneity in permeability. Much of the groundwater within the basalt layer is confined and can produce artesian wells in many locations (Newcomb, 1965). More recent unconsolidated sediments are overlaid on top of the basalts, with different characteristics based on location and mechanism of deposition. Some clay layers act as confining layers on the basalt. Many of the tributaries to the Walla Walla, such as the South Fork, North Fork, and Mill Creek, produced recent alluvium which provides significant unconfined groundwater storage. This groundwater storage is recharged by meteoric water, streamflow, and infiltration from upslope irrigation (Newcomb, 1965).

There are many springs located near where alluvial fans from large tributaries meet the Walla Walla River, such as in Milton-Freewater from the South Fork and the North Fork, and in Walla Walla from Mill Creek. During a November 2022 survey of known springs by the Walla Walla Basin Watershed Council (WWBWC, 2023), the upper South Fork (upstream from RKM 13) received 0.34 cms (12 cfs) of water from springs and the upper North Fork (upstream from RKM 6) received 0.006 cms (0.2 cfs; some springs were too diffuse to measure). A similar study has been funded and is planned for the Mill Creek watershed in the future. Seepage runs were conducted in July and September 2014 on the South Fork from RKM 13 (near the BLM trailhead) down to downstream of the project extents. Total measured gains from groundwater during summer and fall seepage measurements within the Upper Walla Walla were 1.70 cms (59.97 cfs) and 1.67 cms (59.12 cfs) respectively. The net channel gain/loss to and from groundwater for the seepage run within the project area was -0.11 cms (-3.93 cfs; indicates a net losing reach) in the summer and 0.11 cms (3.82 cfs; indicates a net gaining reach) in the fall. These seepage runs represent measurements at only two points in time and should not be assumed to be representative of conditions during all years and all seasons. For example, the 2014 seepage run report noted that multiple projects in the leveed section of the WWR near Milton-Freewater in 2014 disturbed the channel bed, and so the measured channel/groundwater interactions within that region likely differed from prior years (Baker, 2014). Subsequent seepage assessments were recommended to better understand these interactions. The total of the average groundwater gains measured in the seepage run and the measured springs in the headwaters is 2.03 cms (71.8 cfs), which compares favorably with a historical survey of known springs that estimated the total spring flow to be 1.95 cms (69 cfs).

Much of the baseflow in the South Fork and North Fork (and subsequently the mainstem Walla Walla) come from groundwater, which means that changes to groundwater levels will have implications for low water levels in the Walla Walla (WDOE, 2021). In long-term records, water levels have been documented to be declining throughout much of the basin. Rates of decline over the last 70 years range from 0.9 cm to 12.2 cm per year (WDOE, 2021). With less cool, clean groundwater available to streams, this decline in groundwater levels is likely to have profound implications for stream health in the future. This decline in water levels is driven by a variety of resource management practices, which lower water levels by reducing recharge and increasing withdrawals. Recharge has also been reduced by stream channelization, surface water diversions, and increased efficiency in agricultural water conveyance and irrigation (WDOE, 2021). Integrated management of surface water and groundwater is a significant challenge in the Walla Walla Basin, and strategies to address these challenges have been under development for decades (WDOE, 2021). More information on surface water and groundwater resources is available in the Walla Walla Water 2050 Strategic Plan (WDOE, 2021) and related documents.

4.0 SURFACE WATER HYDROLOGY

The Walla Walla River is a snowmelt-driven basin with extensive irrigation withdrawals and some historical distributaries. In the fall, rivers are typically low, except for some rainfall-driven freshets in the fall/winter when temperatures are higher than average. In a typical year, snowfall accumulates in the Blue Mountains throughout the winter until the spring. During the spring/early-summer, there is typically a snowmelt driven peak. Rain-on-snow events are common, and often produce the highest peak flows. These rain-on-snow events are commonly associated with moisture-laden storms coming from the Pacific Ocean. Because the primary tributaries drain different elevations with correspondingly different snowmelt peak timing, peak discharges at the downstream end of the basin tends to be longer in duration than any individual tributary (Figure 4-1). Irrigation withdrawals begin in the spring and continue through the summer, substantially lowering the in-stream flows, with relatively more withdrawals occurring moving downstream through the project area (e.g., Walla Walla River). Flows increase in the fall as the irrigation withdrawals are turned off.

The Walla Walla River starts at the confluence of the South Fork and North Fork Walla Walla. Both forks drain the Blue Mountains, with the South Fork draining roughly two times the area as the North Fork. Downstream from that confluence, Couse Creek enters the mainstem from river left. Milton-Freewater is immediately downstream from Couse Creek. Starting in this area and moving downstream, the number and volume of irrigation diversions rapidly increases. Historically, there were several distributaries of the Walla Walla such as the Little Walla Walla starting near Milton-Freewater until near the state line (WDOE, 2021). In the past, these distributaries varied in their seasonal activation and provided shallow groundwater recharge. Some distributaries return to the Walla Walla near Yellowhawk Creek and Mill Creek, while others return downstream near Lowden and Touchet. Near College Place and Walla Walla, Yellowhawk Creek and Mill Creek enter from river right. Yellowhawk Creek is a distributary of Mill Creek. Due to flood control concerns on Mill Creek, the Mill Creek dam was built in 1942, forming Bennington Lake (USACE, 2021). Bennington Lake is still managed primarily as a flood-control resource. However, as flood risks decrease during a typical season, the reservoir is filled to allow for recreational use.

In total, water use (both surface and groundwater) in the entire Walla Walla basin is estimated to be approximately 186,000 acre-feet (0.229 km^3) per year, with Washington taking 109,800 acre-feet (0.135 km^3) and Oregon taking 76,000 acre-feet (0.094 km^3; WDOE, 2021). In Oregon and Washington, the agricultural sector accounts for 85% and 93% respectively, of the annual water used in the basin. Of the agricultural usage, 70% of the agricultural water usage in Oregon and 60% of the usage in Washington comes from surface water diversions, with the rest coming from groundwater wells (WDOE, 2021).

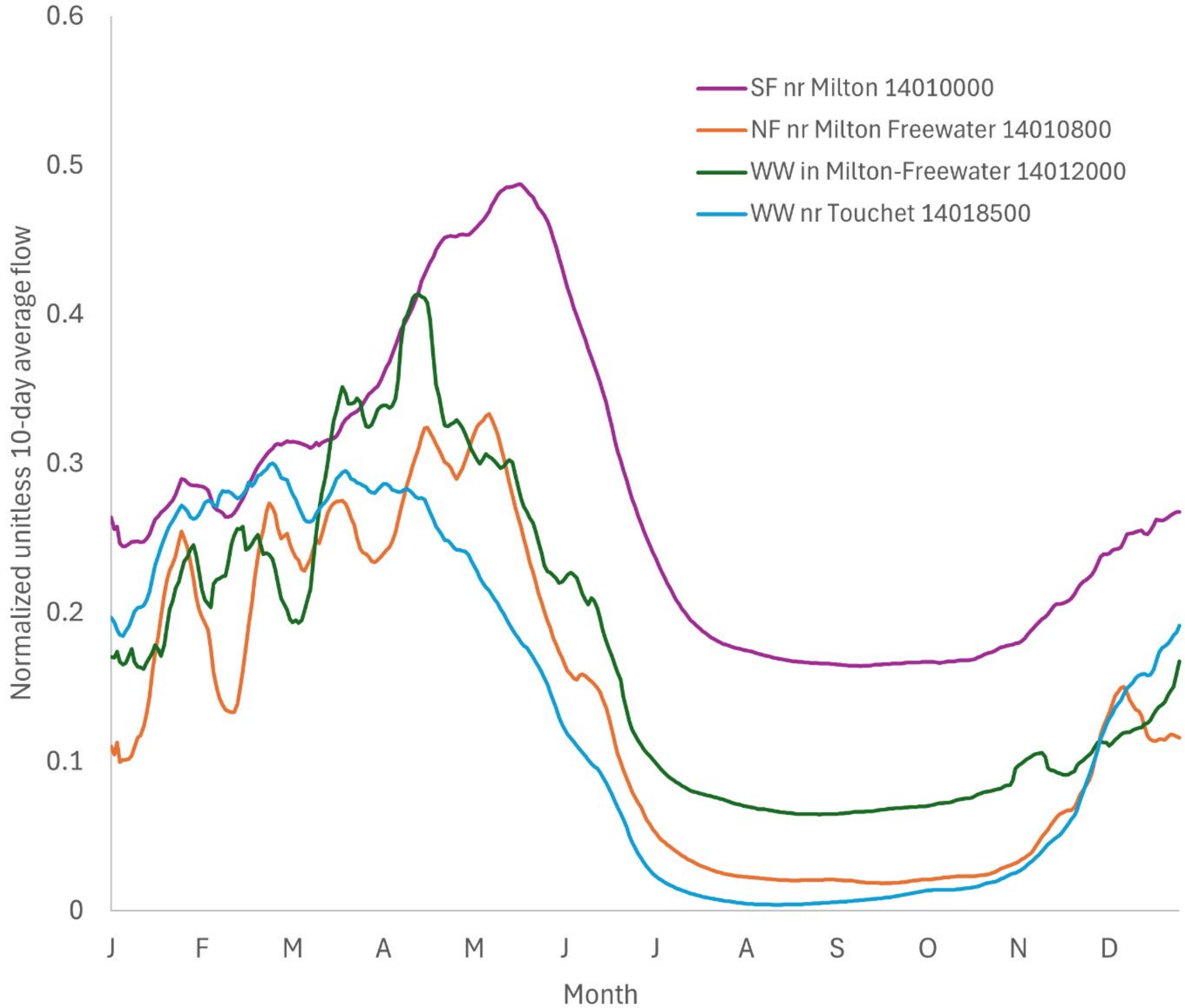

Figure 4-1. Relative timing and magnitude of streamflow at gage locations.

Note: Values were calculated as a 10-day average of the daily average flows normalized by the 1.5-yr peak discharge.

4.1 STREAMFLOW ESTIMATES

Streamflow discharge estimates throughout the Upper Walla Walla were calculated at both peak flows and biologically relevant low flows for use in hydraulic modeling. Estimates were made at or near geomorphic reach breaks, at tributary and distributary convergence and divergence points, and at several gage locations. Peak flows were estimated using a combination of gage extension using a long-running gage on the Walla Walla River near Touchet (USGS #14018500) and subsequent interpolation (or extrapolation when needed) based on drainage area. Low flow values were calculated using a similar workflow to provide representative values for summer, winter, and spring flows.

4.1.1 Available Data

The Upper Walla Walla has been extensively gaged by a combination of the USGS, WWBWC, and WDOE. All known gages within this area are summarized in Table 4-1. These gages vary in geographical location (Figure 4-2), the time period when it was monitored, and perennial vs seasonal monitoring. Some gages which were initially seasonally monitored later transitioned into being perennially monitored gages.

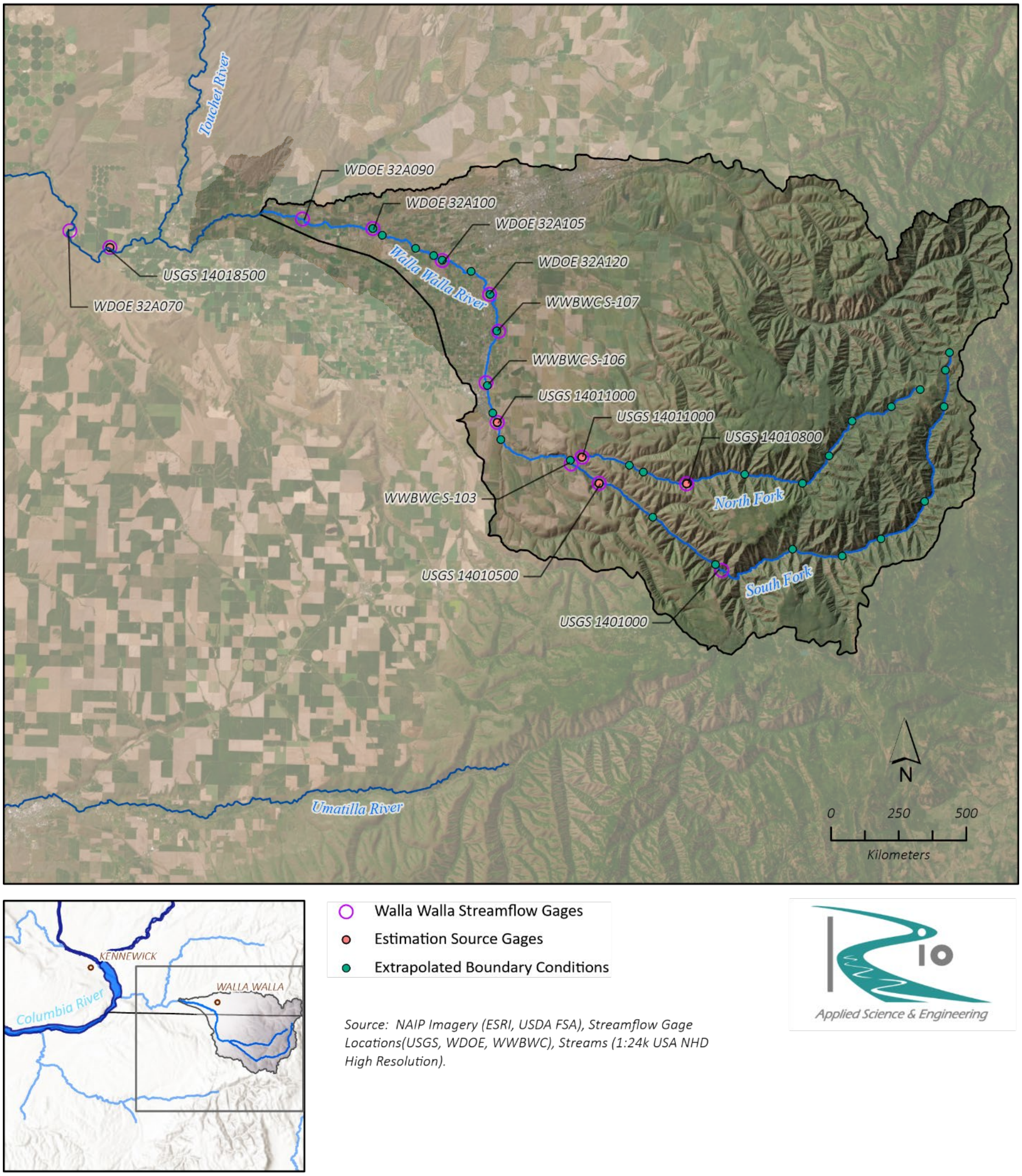

Figure 4-2: Locations of streamflow gages used to develop peak flow metrics and hydraulic modeling inputs.

Table 4-1: Summary of available gages.

Gage ID	Description	Operator
14010000[1,3]	SOUTH FORK WALLA WALLA RIVER NEAR MILTON,OREG.	USGS
14010500[1]	SOUTH FORK WALLA WALLA RIVER NEAR MILTON, OR	USGS
14010800[1,3]	NORTH FRK WALLA WALLA RIVER NR MILTON FREEWATER,OR	USGS
14011000[1]	NO FK WALLA WALLA RIVER NR MILTON, OREG.	USGS
14018500[1,3]	WALLA WALLA RIVER NEAR TOUCHET, WA	USGS
14012000[1,3]	WALLA WALLA RIVER AT MILTON-FREEWATER, OR	USGS (was WWBWC before 2021)
S-103	South Fork Walla Walla River at Walla Walla River Road Bridge	WWBWC
S-104	North Fork Walla Walla River at Walla Walla River Road Bridge	WWBWC
S-105[1]	WALLA WALLA RIVER AT MILTON-FREEWATER, OR (USGS 14012000)	Formerly WWBWC, now operated by USGS
S-106	Walla Walla River Below Nursery Bridge	WWBWC
S-107	Walla Walla River Below Tum-A-Lum Bridge	WWBWC
32A070	WALLA WALLA RIVER NEAR TOUCHET	WDOE
32A100[2]	Walla Walla R. @ E. Detour Rd.	WDOE
32A105[2]	Walla Walla R. @ Beet Rd.	WDOE
32A120[2]	Walla Walla R. @ Pepper Bridge	WDOE
32A090[2]	Walla Walla R. nr Lowden	WDOE
14013000	MILL CREEK NEAR WALLA WALLA, WA	USGS
14013500	BLUE CREEK NEAR WALLA WALLA, WA	USGS
14013600	MILL CREEK BELOW BLUE CREEK NEAR WALLA WALLA, WA	USGS
14013700	MILL CREEK AT FIVE MILE RD BR NR WALLA WALLA, WA	USGS
14015000	MILL CREEK AT WALLA WALLA, WA	USGS
14014000	YELLOWHAWK CREEK AT WALLA WALLA, WA	USGS
14014500	GARRISON CREEK AT WALLA WALLA, WA	USGS

[1] Gage used in this analysis to calculate peak flows

[2] Gage used to assess accuracy of peak flow calculation.

[2] Gage used in this analysis to calculate low flows

For summer low flows on the mainstem Walla Walla, irrigation diversions play a key role. These records are hosted for Oregon and Washington by the Oregon Water Resource Department (OWRD) and the WDOE, respectively. These records were not used in this analysis because factors such as timing of water use and water right use based on river level and regulation status determine the amount of water withdrawn for irrigation. The amount of water withdrawn from a point of diversion at a given time depends on the timing of the water right, timing of agricultural need, and the regulation status of the river based on streamflow and prior appropriations. Because many these factors change from year-to-year, streamflow records rather than irrigation diversion records were used to calculate low flow values for hydraulic modeling.

4.1.2 Methods

4.1.2.1 Peak Flood Methods

When appropriate, gage data was extended by comparison with a downstream, long-running gage (gage 14018500, WW nr Touchet). Recurrence intervals (RI) were calculated using PeakFQ (Flynn et al., 2006) for all gages with sufficient record. Along with being calculated for the entire period of record, recurrence intervals were calculated for the overlapping time period between 14018500 and the gage of interest. The ratio of Equation 1 was assumed to be the same ratio for the short-term gage of interest. An extended recurrence interval was then calculated for the short-term gage of interest using Equation 2.

Equation 1

$$\text{Recurrence Interval Ratio} = RI_{14018500,\ short} / RI_{14018500,\ long}$$

Equation 2

$$RI_{gage\ of\ interest,\ extended} = RI_{gage\ of\ interest,\ measured} * RI_{14018500,\ long} / RI_{14018500,\ short}$$

The discharge for a specific recurrence interval at a selected boundary condition locations were then calculated using a combination of extrapolation and interpolation based on drainage area. Typical locations for boundary condition changes in the hydraulic model were the start of geomorphic reaches, inflows of major tributaries, sites of bridges/gages, and large distributaries such as the Little Walla Walla River. See Table 4-1 for a list of gages that were used.

Peak flows were extrapolated from the nearest downstream gage or linearly interpolated between available gages using drainage area. For extrapolating upstream flow (done on the North Fork Walla Walla and South Fork Walla Walla), exponents for drainage area adjustments were taken from Table 22 in “Estimation of Peak Discharges for Rural, Unregulated Streams in Eastern Oregon” (Cooper, 2006). Exponents were provided in that document for each peak recurrence interval. Exponents increased from 0.7407 for the 500-yr peak discharge to 0.7947 for the 2-yr peak discharge. For interpolation, a linear relationship between drainage area and discharge was assumed. Note that the StreamStats software currently considers all drainage area upstream from the Little Walla Walla to be a part of the Little Walla Walla downstream, rather than a part of the Walla Walla. If this analysis is being repeated, drainage areas downstream from Milton-Freewater should be reviewed for accuracy.

4.1.2.2 Low Flow Methods

Three low flow model runs were conducted: summer, winter, and spring. These used different calculation techniques to better quantify the range of flows possible during those time periods. The summer low flow is associated with the 95% exceedance flow during the period July 1 – September 30, the winter low flow is associated with the 50% exceedance flow for the seasonal period December 1 – January 31, and the spring low flow is associated with the 14-day duration flow for the seasonal period February 15 – April 30.

Exceedance values for the summer and winter low flows were calculated using the four gages identified in Table 4-1, and then extended using the same ratio technique and drainage area interpolation/extrapolation described in the section above. The four gages used (14010000, 14010500, 14010800, and 14018500) were selected because of their long period of record with consistent daily measurements with sufficient overlap with the Walla Walla nr Touchet gage (14018500). Equations of the same form as Equation 1 and Equation 2 were used to extend these gages, followed by an interpolation/extrapolation of those values to different points within the model domain based on a drainage area equation. For extrapolating upstream flow, there were no exponents provided for low flow values; therefore, the 1.5-year peak discharge exponent was used (Cooper, 2006). For interpolation, a linear relationship between drainage area and discharge was assumed.

The summer low flow discharge estimates were compared to ecological flow targets in order to evaluate the baseflow hydrological function by geomorphic reach. Empirical low flow estimates were calculated for the flow change locations of the hydraulic model using extrapolation methods described earlier and then applied to each geomorphic reach. Previously identified monthly ecological flow targets (Stillwater Sciences, 2013) for the July-September time period were averaged and applied to the corresponding geomorphic reach. An Ecological Flow Attainment metric was calculated for each reach as the ratio of empirical low flow estimate to the flow target. For reaches upstream of surface water points of diversion it was assumed that empirical flows meet the ecological flow targets.

Estimates of the 14-day duration flow were developed for hydraulic modeling of floodplain inundation benefits to rearing salmonids. A probability-duration analysis with average daily discharge data was used to estimate the 50% annual probability 14-day duration discharge during the seasonal period of February 15 to April 30. The analysis was completed with the software HEC-EFM using daily average gage data for the full periods of record from the Walla Walla River at Touchet (14018500), Walla Walla River at Milton-Freewater (14012000), North Fork Walla Walla River (14010800), and South Fork Walla Walla River (14010000). The analysis workflow in HEC-EFM included: 1) calculating the 14-day minimum for each day of the seasonal period, 2) calculating the maximum for each season (year) in the time series, and 3) calculating the 50% exceedance frequency flow for the time series. The resulting 14-day duration flows were then extrapolated to the flow change locations of the hydraulic model using extrapolation methods described earlier.

4.1.3 Results

The resulting hydrology used for hydraulic modeling is provided in Table 4-2. The subsequent use of the streamflow estimates in hydraulic modeling is described in Appendix D.

Surface water diversions have a pronounced effect on baseflows during the July-September time period. In those reaches affected by surface water withdrawal, ecological flow attainment ranges from 14% in reach WW2 to 62% in reach NF2 (Figure 4-3).

Table 4-2: Hydrologic Inputs

River	Flow Change Location/Model Boundary Condition	Area (m^2)	River Kilometer (km)	Encompassing Geomorphic Reach	Discharge (cms)								
					Summer Low Flow	Winter 50% Ex.	Spring 14-day	1.5-year	2-year	5-year	100-year	Bankfull Manning's n	Low Flow Manning's n
North Fork Walla Walla River	Start of NF4 (no major confluences)	17.4	NF18.3	NF4	0.079	0.55	1.64	5.08	6.82	12.60	40.98	0.057	0.217
	Downstream of Little Meadow Creek	28.7	NF13.7	NF3	0.118	0.82	2.45	7.57	10.16	18.60	59.66	0.057	0.217
	Start of NF2 (no major confluences)	34.6	NF9.2	NF2	0.140	0.96	2.85	8.79	11.79	21.54	68.86	0.052	0.196
	Start of NF1 (no major confluences)	37.4	NF5.7	NF1	0.192	1.04	3.12	9.40	12.67	23.38	75.94	0.053	0.172
	Downstream of Cup Gulch	41.0	NF4.5	NF1	0.258	1.16	3.46	10.18	13.81	25.74	85.04	0.050	0.134
	NF at confluence with SF	44.6	NF0	NF1	0.325	1.27	3.80	10.97	14.94	28.11	94.14	N/A	N/A
South Fork Walla Walla River	Downstream of Sheep and Reser Creek (approximate start of SF5)	18.4	SF32.5	SF5	1.007	0.02	0.04	6.70	8.19	13.02	35.98	0.059	0.091
	Downstream of confluence with Skiphorton Creek (~0.5 km from start of SF4)	28.0	SF27.9	SF4	1.408	0.08	0.15	9.37	11.43	18.05	49.31	0.054	0.084
	Start of SF3	32.7	SF24.6	SF3	1.594	0.35	0.63	10.60	12.93	20.37	55.40	0.053	0.082
	Downstream of confluence with Bear Creek (start of SF2)	49.0	SF20.8	SF2	2.201	1.59	2.88	14.64	17.84	27.90	75.05	0.049	0.076
	Start of SF1	62.3	SF13.3	SF1	2.666	2.22	4.02	17.74	21.59	33.63	89.88	0.047	0.073
	Downstream of Flume Canyon	74.5	SF7.5	SF1	2.663	2.52	4.56	20.05	25.27	42.22	125.64	0.046	0.074
	SF at confluence with NF	81.9	SF0	SF1	2.646	3.48	6.30	21.43	27.52	47.55	148.17	N/A	N/A
Walla Walla River	Confluence of NF and SF; start of WW5	127.0	82.6	WW5	2.541	4.22	7.63	29.87	41.22	80.07	285.45	0.042	0.078
	Downstream of confluence with Couse Creek (1 km downstream from start of WW4)	159.0	76.8	WW4	2.466	4.33	8.53	35.86	50.93	103.14	382.86	0.040	0.079
	At Little Walla Walla divergence	162	74.7	WW4	0.701	4.37	9.06	36.17	51.40	104.12	386.58	0.041	0.138
	Start of WW3 (no major confluence)	162	72.8	WW3	0.640	4.65	12.31	36.19	51.42	104.16	386.67	0.042	0.149
	Start of WW2 (no major confluence)	164	68.7	WW2	0.255	4.85	14.61	36.27	51.52	104.34	387.14	0.037	0.176
	Pepper Bridge: site of WDOE gage and downstream of Birch Creek	201	65.3	WW2	0.263	4.88	14.71	38.53	54.45	109.22	399.68	0.034	0.163
	Downstream of confluence with Yellowhawk Creek	277	62.5	WW2	0.389	4.88	14.71	43.20	60.48	119.29	425.55	0.033	0.150
	Beet Road (downstream of East Prong Little Walla Walla and Stone Creek additions)	287	59.8	WW2	0.405	4.89	14.73	43.80	61.25	120.58	428.87	0.032	0.145
	Downstream of Garrison Creek	292	58.8	WW2	0.417	5.20	15.22	44.07	61.60	121.16	430.36	0.035	0.157
	Last Chance Bridge (Start of WW1)	293	57.2	WW1	0.420	5.84	16.25	44.13	61.67	121.29	430.69	0.033	0.148
	Downstream of Mill Creek and West Prong Little Walla Walla River	427	54.1	WW1	0.779	5.93	16.38	52.34	72.28	139.00	476.18	0.036	0.140
	Detour Bridge	428	53.1	WW1	0.782	5.96	16.44	52.36	72.30	139.04	476.30	0.032	0.124

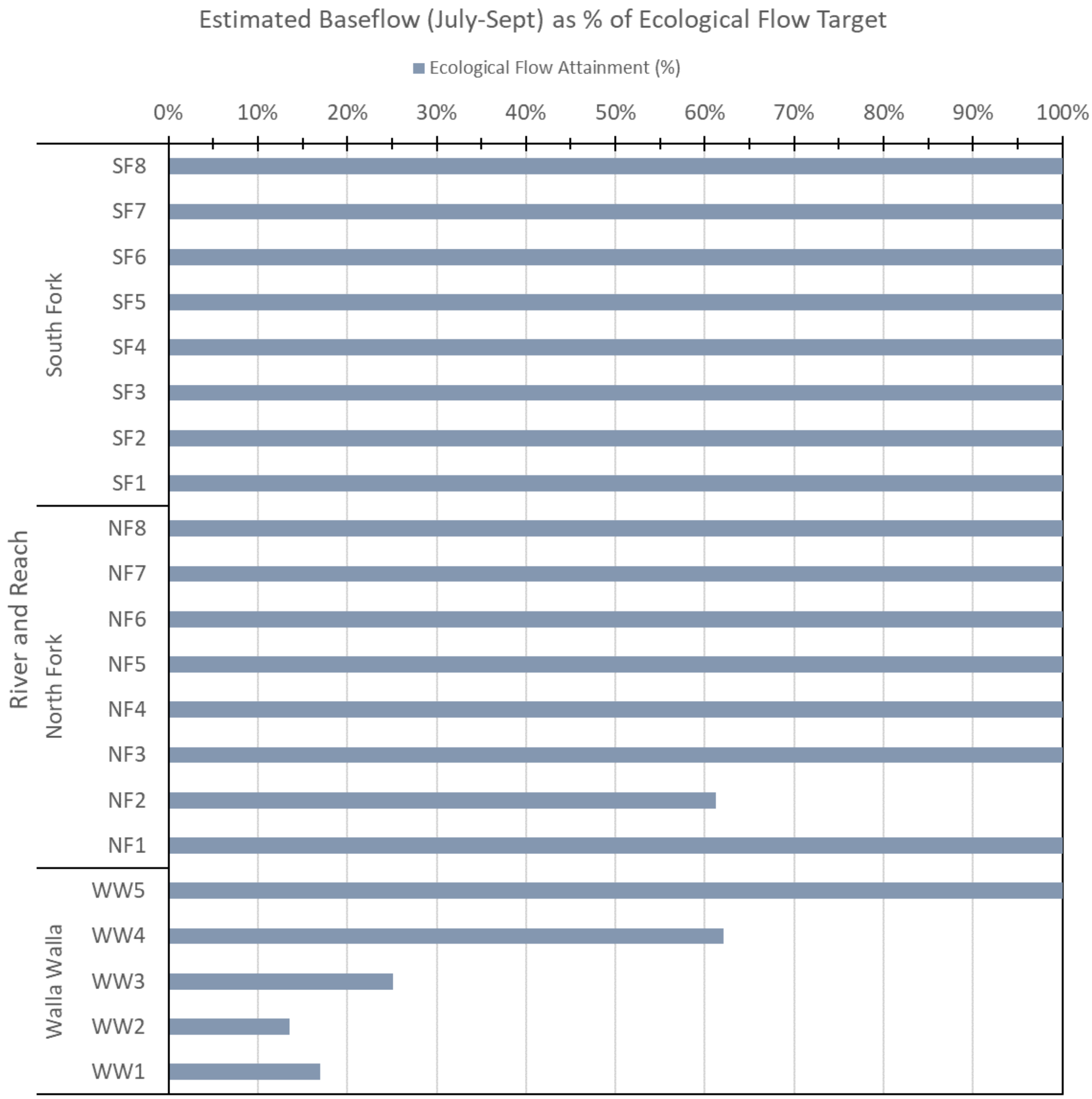

Figure 4-3. Ecological flow attainment (%) by geomorphic reach.

5.0 WATER QUALITY

Water quality assessment, monitoring, and management in the Walla Walla Basin has been coordinated between the Oregon Department of Environmental Quality (ODEQ) and the WDOE, due to the basin spanning both states. The Walla Walla River, South Fork Walla Walla River, North Fork Walla Walla River, and some tributaries have been 303(d) listed for temperature in both Oregon and Washington (Table 5-1; ODEQ, 2005; Baldwin and Stohr, 2007). The main causes of stream heating have been identified as flow reduction, vegetation loss, and channel widening (ODEQ, 2005). Identified pollutants of concern include chlorinated pesticides and PCBs, fecal coliforms, dissolved oxygen, and pH (Dugger, 2021). Iron has been identified as a concern, but listing has been deferred to future assessment (ODEQ, 2005).

Within groundwater, contaminants such as nitrate, pesticides, and lead have been detected in wells in the Walla Walla watershed. For the most part, these contaminants were below established acceptable levels for drinking water. Contaminants such as aluminum, lead, atrazine, and bacteria have increased in concentration from 1999-2016 (Haxton-Evans and Brown, 2020).

Table 5-1: TMDL listings on the Walla Walla River, South Fork Walla Walla River, and North Fork Walla Walla River.

Stream	Reasons for listing (citation)
Mainstem Walla Walla River	Temperature (ODEQ, 2005; Baldwin and Stohr, 2007), bacteria (WDOE, 2021), dissolved oxygen (WDOE, 2021), pH (WDOE, 2021)
South Fork Walla Walla River	Temperature (ODEQ, 2005)
North Fork Walla Walla River	Temperature (ODEQ, 2005)

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Appendix D

Upper Walla Walla Assessment

HYDRAULIC MODELING

Technical Report

May, 2024

Technical Report

Rio Applied Science and Engineering

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Hydraulic Modeling Technical Report

Date: May 2024

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1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations. The focal fish species of the assessment and action plan consist of the following:

1. Middle Columbia River summer steelhead (ESA-listed Threatened)
2. Columbia River bull trout (ESA-listed Threatened)
3. Spring Chinook salmon
4. Pacific lamprey

The final restoration action plan will establish a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions.

This Appendix focuses on describing the development of two-dimensional (2D) hydraulic models of portions of the mainstem Walla Walla River (WWR), North Fork WWR, and South Fork WWR for pre-flood (2019) and post-flood (2020) conditions. The purpose of the hydraulic models are as follows:

- Estimate the hydraulic conditions (inundation extent, depth, velocity, shear stress, and water surface elevation) to evaluate in-stream habitat conditions, floodplain connectivity at the reach-scale, and changes and trends between pre- and post-flood conditions at the reach-scale.
- Utilize the depth and velocity model outputs at low flow conditions as the basis for habitat suitability analyses preformed by Mount Hood Environmental, of which methods and results are summarized in separate reports of the Upper Walla Walla Assessment.

The 2D hydraulic models were developed using the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center’s River Analysis System (HEC-RAS), version 6.3.1 (USACE, 2022a).

2.0 HYDRAULIC MODEL INPUT DATA

The following data and information were used to develop the pre- and post-flood 2D hydraulic models. ArcGIS Pro geographic information system (GIS) software developed by Esri was used to manage and visualize the data.

2.1 TOPOGRAPHY

Topographic information used to develop the pre- and post-flood hydraulic models are discussed below.

2.1.1 Pre-flood Topography

The pre-flood conditions terrain model was developed by merging the following data sources in order of priority as listed:

- 2019 topobathymetric light detection and ranging data (2019 LiDAR) (CTUIR, 2020) provided by CTUIR which was collected by Quantum Spatial in fall 2019. Data was provided as a 1-meter ESRI gridded raster file in UTM Zone 11 North projection (project coordinate system). The horizontal and vertical datums are North American Datum of 1983 (NAD 83) and North American Vertical Datum of 1988 (NAVD 88), respectively, in units of meters (project datums and units). The spatial extent of the 2019 LIDAR is from river kilometer (RKM) 44.1 on the mainstem WWR (at the Lowden Bridge near Lowden, WA) extending upstream to RKM 18.3 on the North Fork WWR and RKM 32.8 on the South Fork WWR for a combined total river length of approximately 90 kilometers.
- 2018 LiDAR (USGS, 2018) obtained from Washington Department of Natural Resources Washington LIDAR Portal website was used in portions of the WWR floodplain (in Washington) not covered by the 2019 LiDAR. This data was collected by Quantum Spatial in the Spring of 2018 for the United States Geological Survey (USGS). Data was obtained as 3-foot ESRI gridded raster files in Washington State Plane South projection and reprojected to the project coordinate system. The horizontal and vertical datums are NAD83 (2011) and NAVD 88, respectively, in units of US survey feet which was converted to meters. The spatial extent of the 2018 LIDAR ends at the Oregon border.
- 2016 LiDAR (DOGAMI, 2016) obtained from the Oregon Department of Geology and Mineral Industries (DOGAMI) website was used in portions of the WWR floodplain (in Oregon) not covered by the 2019 LiDAR. This data was collected by Quantum Spatial in the May 2018 for DOGAMI. Data was obtained as 3-foot ESRI gridded raster files in Oregon Statewide Lambert projection and reprojected to the project coordinate system. The horizontal and vertical datums are NAD83 (2011) and NAVD 88, respectively, in units of international feet which was converted to meters. The spatial extent of the 2018 LIDAR ends at the Washington border.

2.1.2 Post-flood Topography

The post-flood conditions terrain model was developed by merging the following data sources in order of priority as listed:

- 2021 topobathymetric LIDAR (USACE, 2022b) provided by CTUIR which was collected by NV5 Geospatial in fall 2021 for DJ&A. Data was provided as a 1-meter ESRI gridded raster file in UTM Zone 11 North projection. The horizontal and vertical datums are North American Datum of 1983 (NAD 83) and North American Vertical Datum of 1988 (NAVD 88), respectively, in units of meters. The spatial extent of the 2021 LIDAR matches the 2019 LIDAR, as described in Section 2.1.1.
- 2018 LiDAR was used in the same manner as described in Section 2.1.1.
- 2016 LiDAR was used in the same manner as described in Section 2.1.1.

2.2 AERIAL IMAGERY

Aerial imagery used to aid in development of the pre-flood hydraulic model are as follows:

- 2019 National Agriculture Imagery Program (NAIP) digital ortho mosaic. Administered by the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA, 2019). The spatial extent of the imagery is for Walla Walla County in Washington.
- 2017 National Agriculture Imagery Program (NAIP) digital ortho mosaic. Administered by the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA, 2017). The spatial extent of the imagery is for Umatilla County in Oregon.

Aerial imagery used to aid in development of the post-flood hydraulic model are as follows:

- 2021 High-resolution imagery obtained from CTUIR in *.sid file format. The spatial extent of the imagery is for the full project area. No other metadata was provided but it is assumed that the imagery was collected as part of the 2021 LiDAR (USACE, 2022b).

2.3 FLOOD INSURANCE RATE MAPS

Flood insurance rate maps (FIRM) were obtained from the Federal Emergency Management Agency (FEMA) Map Service Center website for the mainstem WWR in Washington (FEMA, 1983). The digital FIRMs were georeferenced in ArcGIS Pro. For mainstem WWR in Oregon, FEMA's National Flood Hazard Layer was obtained in digital format (FEMA, 2010). These data sources were used to aid in creating the model domain.

3.0 HYDRAULIC MODEL DEVELOPMENT

The 2D hydraulic models were developed using the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center's River Analysis System (HEC-RAS), version 6.3.1 (USACE, 2022a). Development of any HEC-RAS 2D hydraulic model requires delineation of the model domain, a terrain surface, designation of hydraulic roughness (Manning's n values), creation of the model mesh, and designation of boundary conditions specifying the inflow(s) hydrology and conditions for outflow(s). Each of these major components of the hydraulic model are discussed in greater detail in subsequent sections.

3.1 MODEL DOMAIN

Three separate HEC-RAS 2D hydraulic models were created (mainstem WWR, North Fork WWR, and South Fork WWR) each containing pre- and post-flood conditions. Table 1 summarizes the spatial extent, length, description, and encompassing geomorphic reaches within each model. Descriptions of the geomorphic reaches are provided in Appendix B. The combined total river length of all three models is approximately 90 kilometers.

Table 1: Hydraulic Model Spatial Extent

Model	Downstream Extent (RKM)	Upstream Extent (RKM)	Total Length (RKM)	Description	Encompassing Geomorphic Reaches
Mainstem WWR	44.1	82.6	38.5	From Lowden Bridge to North Forth and South Fork WWR confluence	WW1 – WW5
NFWWR	0	18.3	18.3	Confluence to upstream of Big Meadow Canyon	NF1 – NF4
SFWWR	0	32.8	32.8	Confluence to Reser Creek and Sheep Creek	SF1 – SF5

Note: RKM = river kilometer, WWR = Walla Walla River

The model domain for the mainstem WWR model was digitized using FEMA's FIRM and National Flood Hazard Layer data as reference which show the estimated extents of the regulatory floodway, 100-year, and 500-year inundation extents. In most portions of the model, the domain extends beyond the estimated 500-year floodplain extents. In the leveed portion of the WWR at Milton-Freewater, Oregon, the model domain extends beyond the 100-year floodplain extents. For the North Fork and South Fork WWR models, the model domain encompasses the entire valley bottom visible in the LiDAR. For each model, the same model domain was used for pre- and post-flood conditions.

3.2 TERRAIN

The pre- and post-flood conditions terrain models were developed by merging the various datasets in the order of priority listed in Section 2.1. The resulting composite pre- and post-flood terrain surfaces for the mainstem WWR model have a cell size of 0.9144 meters (or 3 feet which is the cell size of the 2016 and 2018 LIDAR; the smaller cell size between the 2016 and 2018 LiDAR datasets used to supplement the 2019 and 2021 LiDAR datasets). Pre- and post-flood terrain surfaces for the North Fork and South Fork WWR models have a cell size of 1 meter.

3.3 HYDROLOGY

To develop peak flows for input to the hydraulic model, flow frequency analyses were performed using data from four USGS gaging stations (#14010800 North Fork WWR near Milton-Freewater, Oregon, #140100000 South Fork WWR near Milton-Freewater, Oregon, #14012000 WWR near Milton-Freewater, Oregon, and #14018500 WWR near Touchet, Washington) as described in Appendix C. As part of the hydrologic analyses, basin area regressions were developed to estimate discharge values at selected flow change locations within each of the models. Flow change locations correspond to features such as USGS gaging station, confluences with major tributaries, large irrigation diversions, and geomorphic reach breaks. A summary of peak flows at flow change locations within the hydraulic models is shown in Table 2 and includes a low flow, estimated to be representative of base flow conditions in the summertime, as discussed in Appendix C. Based on discussions with CTUIR, it was determined that the summer low flow, 14-day duration flow during spring runoff (Feb 15 – Mar 30), 50% exceedance winter flow (Dec 1 – Jan 31), and the 1.5-year, 2-year, 5-year, and 100-year peak flows would provide sufficient hydraulic information to support geomorphic, ecologic, and fish biology analyses each of which are discussed in separate appendices and technical reports.

Table 2: Hydraulic Model Spatial Extent

River	Flow Change Location/Model Boundary Condition	Area (m^2)	River Kilometer (km)	Encompassing Geomorphic Reach	Discharge (cms)							Bankfull Manning's n	Low Flow Manning's n
					Summer Low Flow	Winter 50% Ex.	Spring 14-day	1.5-year	2-year	5-year	100-year		
North Fork Walla Walla River	Start of NF4 (no major confluences)	17.4	NF18.3	NF4	0.079	0.55	1.64	5.08	6.82	12.60	40.98	0.057	0.217
	Downstream of Little Meadow Creek	28.7	NF13.7	NF3	0.118	0.82	2.45	7.57	10.16	18.60	59.66	0.057	0.217
	Start of NF2 (no major confluences)	34.6	NF9.2	NF2	0.140	0.96	2.85	8.79	11.79	21.54	68.86	0.052	0.196
	Start of NF1 (no major confluences)	37.4	NF5.7	NF1	0.192	1.04	3.12	9.40	12.67	23.38	75.94	0.053	0.172
	Downstream of Cup Gulch	41.0	NF4.5	NF1	0.258	1.16	3.46	10.18	13.81	25.74	85.04	0.050	0.134
	NF at confluence with SF	44.6	NF0	NF1	0.325	1.27	3.80	10.97	14.94	28.11	94.14	N/A	N/A
South Fork Walla Walla River	Downstream of Sheep and Reser Creek (approximate start of SF5)	18.4	SF32.5	SF5	1.007	0.02	0.04	6.70	8.19	13.02	35.98	0.059	0.091
	Downstream of confluence with Skiphorton Creek (~0.5 km from start of SF4)	28.0	SF27.9	SF4	1.408	0.08	0.15	9.37	11.43	18.05	49.31	0.054	0.084
	Start of SF3	32.7	SF24.6	SF3	1.594	0.35	0.63	10.60	12.93	20.37	55.40	0.053	0.082
	Downstream of confluence with Bear Creek (start of SF2)	49.0	SF20.8	SF2	2.201	1.59	2.88	14.64	17.84	27.90	75.05	0.049	0.076
	Start of SF1	62.3	SF13.3	SF1	2.666	2.22	4.02	17.74	21.59	33.63	89.88	0.047	0.073
	Downstream of Flume Canyon	74.5	SF7.5	SF1	2.663	2.52	4.56	20.05	25.27	42.22	125.64	0.046	0.074
	SF at confluence with NF	81.9	SF0	SF1	2.646	3.48	6.30	21.43	27.52	47.55	148.17	N/A	N/A
Walla Walla River	Confluence of NF and SF; start of WW5	127.0	82.6	WW5	2.541	4.22	7.63	29.87	41.22	80.07	285.45	0.042	0.078
	Downstream of confluence with Couse Creek (1 km downstream from start of WW4)	159.0	76.8	WW4	2.466	4.33	8.53	35.86	50.93	103.14	382.86	0.040	0.079
	At Little Walla Walla divergence	162	74.7	WW4	0.701	4.37	9.06	36.17	51.40	104.12	386.58	0.041	0.138
	Start of WW3 (no major confluence)	162	72.8	WW3	0.640	4.65	12.31	36.19	51.42	104.16	386.67	0.042	0.149
	Start of WW2 (no major confluence)	164	68.7	WW2	0.255	4.85	14.61	36.27	51.52	104.34	387.14	0.037	0.176
	Pepper Bridge: site of WDOE gage and downstream of Birch Creek	201	65.3	WW2	0.263	4.88	14.71	38.53	54.45	109.22	399.68	0.034	0.163
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	Downstream of Garrison Creek	292	58.8	WW2	0.417	5.20	15.22	44.07	61.60	121.16	430.36	0.035	0.157
	Last Chance Bridge (Start of WW1)	293	57.2	WW1	0.420	5.84	16.25	44.13	61.67	121.29	430.69	0.033	0.148
	Downstream of Mill Creek and West Prong Little Walla Walla River	427	54.1	WW1	0.779	5.93	16.38	52.34	72.28	139.00	476.18	0.036	0.140
	Detour Bridge	428	53.1	WW1	0.782	5.96	16.44	52.36	72.30	139.04	476.30	0.032	0.124

3.4 HYDRAULIC ROUGHNESS

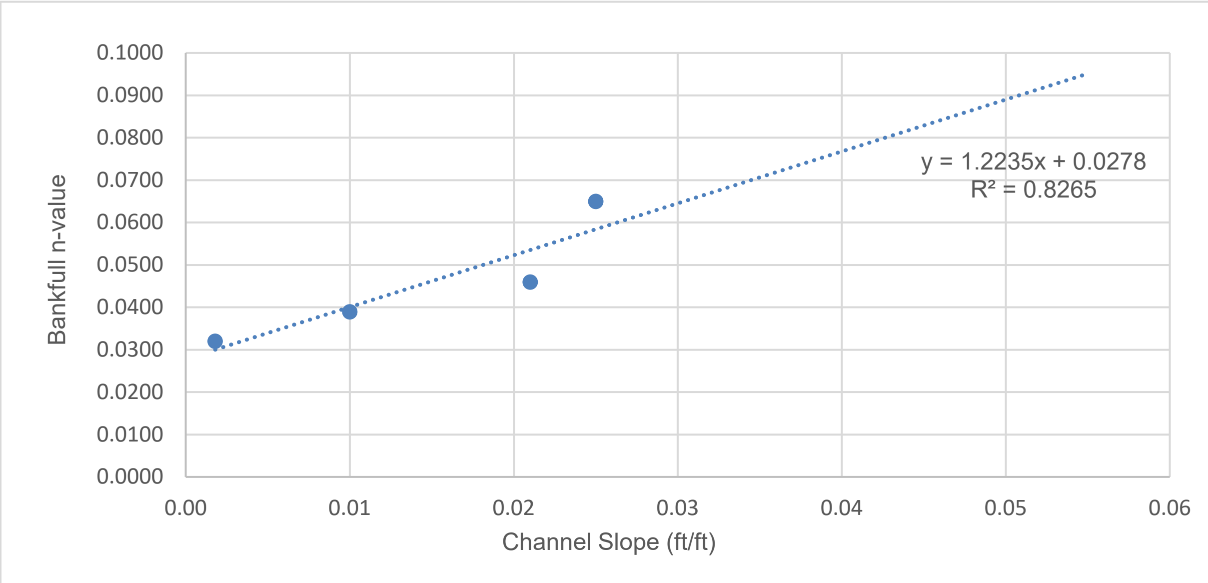
The aerial imagery discussed in Section 2.2 was used as reference to generate hydraulic roughness mapping for the entire model domain of each model for pre- and post-flood conditions. Polygons were digitized based on vegetation type and other identifiable features listed in Table 3. Hydraulic roughness values (Manning's n) were assigned to each vegetation/feature type based on a combination of values used in previous modeling efforts and based on engineering judgement. The Manning's n values in Table 3 are consistent with published values in Chow (1959). The level of detail of the roughness mapping is considered coarse but is appropriate for the modeling objectives.

Table 3: Hydraulic Model Manning's n Values

Feature	Manning's n
Canal	0.025
Forested	0.08
Gravel Road	0.025
Light Vegetation	0.04
Log Jam	0.15
Moderate Vegetation	0.05
Open Water	0.02
Pasture	0.035
Paved Road	0.016
Side Channel	Manning's n value of adjacent main channel + 0.005
Vegetated Bar	0.07

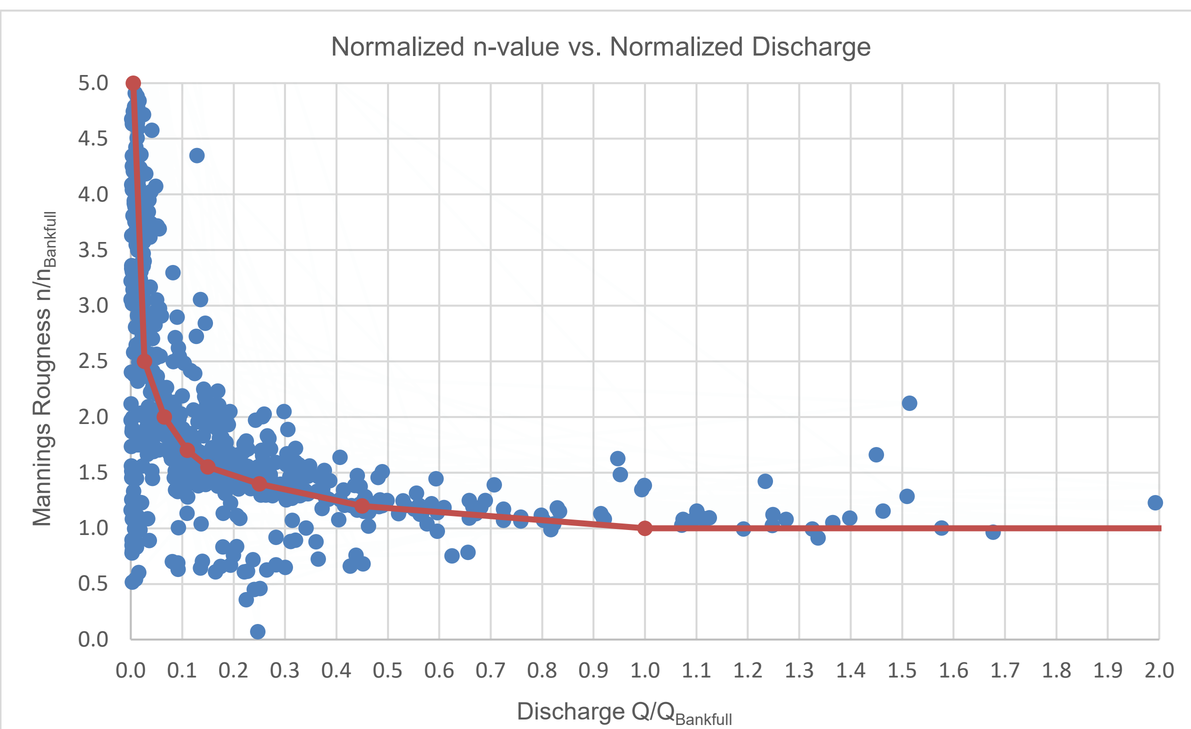
The Manning's n values used for active channels are shown in Table 2. The bankfull Manning's n values are unique to each geomorphic reach based on average reach slope. Manning's n values were calculated using the regression equation shown in Figure 1 which was developed by first creating a stage-discharge relationship at the USGS streamflow gages discussed in Section 3.3 and then correlating roughness relative to channel slope at each USGS gage site.

Figure 1: Channel Slope vs. Manning's n Regression for Bankfull Flows and Higher



The Low Flow Manning's n values in Table 2 were determined by adjusting the bankfull Manning's n values by a dimensionless ratio of (discharge) / (bankfull discharge) correlated to (Manning's n) / (bankfull discharge Manning's n) as shown in Figure 2. This relationship was developed using measured discharge data from each the USGS streamflow gages discussed in Section 3.3.

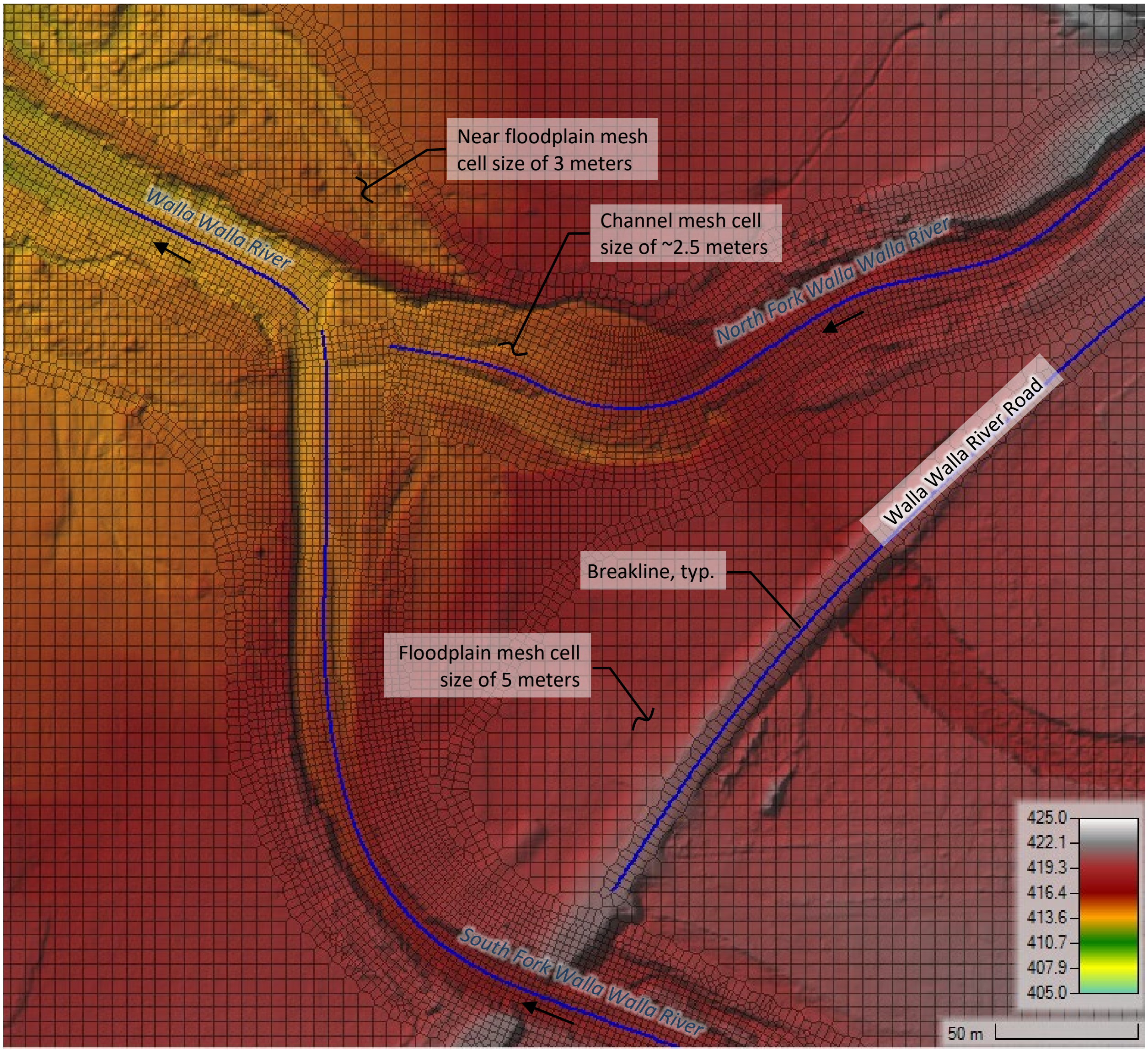
Figure 2: Q/Qbankfull vs. Manning's n/Manning's nbankfull Based on USGS Stream Gaging Stations



3.5 COMPUTATIONAL MESH

The USACE's HEC-RAS 2D program (USACE, 2022a) uses a finite-volume solution scheme, which allows for use of a structured or unstructured computational mesh. This means that the computational mesh can be a mixture of 3- to 8-sided cells. The pre- and post-flood hydraulic models uses a structured and unstructured mesh that contains variable mesh cell sizes ranging from 5-meter spacing to approximately 2.5-meter spacing. Figure 3 shows the model mesh for post-flood conditions at the North Fork and South Fork WWR confluence. Generally, the model mesh within overbank floodplain areas with low topographic complexity use a nominal grid mesh (square cells) with a resolution of 5 meters by 5 meters. Near floodplain areas with higher topographic complexity use a finer mesh with 3-meter square cells. And channels and side channels use a finer mesh with 2.5-meter square cells at the river centerline. Channel mesh cells are controlled by repeating cells away from a river centerline breakline (also visible in Figure 3) and therefore the size of mesh cells located further away from the centerline vary where curves exist in the breakline. To improve model accuracy and efficiency, breaklines were included to enforce cell size and to align the edges of mesh cells at locations of topographic change. These locations include top of banks in some cases, centerline or thalweg of channels or side channels, top of roads (as shown in Figure 3), crests of hydraulic structures or diversion structures, and any other areas requiring a more detailed mesh or where more complex hydraulic conditions are expected to occur.

Figure 3: Post-flood Conditions Model Mesh at the North Fork and South Fork Walla Walla River Confluence



3.6 HYDRAULIC STRUCTURES

No hydraulic structures are defined in the North Fork and South Fork WWR hydraulic models. The model terrains use the LiDAR as is (bridge decks are removed the LiDAR datasets). For the Walla Walla River model, three storage area connections are defined as weir structures to better represent existing irrigation diversion dam structures. Details of these structures are summarized in Table 4. The overflow computational method utilizes the weir equation for all three structures. No weir structure was included in the model for the Little Walla Walla Diversion Dam at RKM 74.7 (and model assumes the bladder structure is fully open or deflated).

Table 4: Hydraulic Structures Defined in the Walla Walla River Hydraulic Model

Feature Description	Storage Area Connection Name	River Kilometer
Garden City/Lowden II Diversion Dam	Beet Road Weir	50.2
Burlingame Diversion Dam	Detour Bridge Weir	60.0
Nursery Bridge Drop Structure	Eastside Weir	72.8

3.7 BOUNDARY CONDITIONS

Boundary conditions designated within the model specify the flow rate(s) for flow entering the model (inflow) and conditions or flow rates leaving the model (outflow). All inflow boundary conditions and the corresponding cumulative flow at each location for each the three hydraulic models (for pre- and post-flood conditions) are listed in Table 2.

The downstream outflow boundary is set to normal depth and therefore uses the Manning's equation to compute normal depth at each computational mesh cell along the boundary, assuming an energy slope of 0.002 m/m which is equal to the slope within 100 meters upstream of the model boundary.

3.8 COMPUTATIONAL METHOD AND OPTIONS

For each model flow simulation, both the diffusion wave (DW) and shallow water equation (SWE) computational engines were used. The SWE set uses full Saint-Venant momentum equations. For all model runs, separate DW and SWE plans are created and are named with a "DW" for diffusion wave or "FM" for full momentum in the plan file. Each DW model run saves a restart file at the end of the model simulation, which is then used as the initial condition for the SWE model simulation. All model runs are performed using unsteady state boundary conditions and use a fixed time step; computational interval (time step) for DW model runs were set to run at 1 second and time steps for SWE model runs ranged from 0.1 to 0.5 seconds. Low flow and 1.5-year flow DW simulations utilized initial ramp up time to fully water the channel for each model. Initial ramp up time was 30 hours for the North Fork and South Fork WWR models and 60 hours for the Walla Walla River model. All other computation options and tolerances utilize HEC-RAS default settings.

4.0 HYDRAULIC MODEL RESULTS

Results from hydraulic modeling are provided in HEC-RAS model files and ESRI geodatabase raster files. Analysis of model results are provided in Appendix B (Geomorphology) and the hydraulic habitat suitability assessment report.

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Appendix E

Upper Walla Walla Assessment

RIPARIAN VEGETATION

Technical Report

June, 2024

Technical Report

Ecosystem Sciences

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Project No.: 0000000

Technical Report

Subject: Riparian Vegetation Technical Report

Date: June, 2024

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1.0 INTRODUCTION

Riparian vegetation is a River Vision Touchstone, as it plays a critical role in ecosystem function and the production of First Foods. This report summarizes the approach, methods, and results for the analysis of riparian vegetation of the Walla Walla River. Restoration priorities should include riparian vegetation restoration and enhancement at locations where the existing condition is below its potential. Potential riparian vegetation conditions have been estimated by NOAA, the Temperature TMDL for the Walla Walla Basin, and Landfire data sets.

This document presents composite metrics that quantitatively assess the riparian vegetation condition based on existing and available data.

1.1 UPPER WALLA WALLA WATERSHED RIPARIAN VEGETATION

The Upper Walla Walla watershed consists of several subbasins—South Fork of the Walla Walla River, North Fork of the Walla Walla River, and the Walla Walla River (from the confluence of the North and South Forks to just upstream of where Dry Creek flows into the Walla Walla River). In proportion to floodplain width, the extent of riparian vegetation within the upper reaches of the Upper Walla Walla watershed is generally greater than the extent of riparian vegetation found within the mid-to-lower reaches within the upper watershed. This is mostly due to differences in land use, as cultivation, domestic livestock grazing, and flood control activities have reduced the historical extent of riparian vegetation within the mid-to-lower elevation reaches to a larger degree. As drainage area increases from headwaters to the lowest point in the project area (i.e., just upstream of the Walla Walla River's confluence with Dry Creek), floodplain width increases as larger quantities of alluvium and sediment are transported and deposited downstream. The riparian vegetation within the upper Walla Walla watershed consists of a mixed conifer/deciduous overstory with an understory of native and non-native shrub and herbaceous plant species (i.e., willow and/or Himalayan Blackberry). In the upper elevations of the watershed, steep slopes naturally confine the width of the riparian corridor.

1.1.1 South Fork Walla Walla River

The South Fork of the Walla Walla River includes riparian vegetation zones that range from high-to-mid elevations within the watershed. At the higher elevations of the South Fork Walla Walla River (upstream of the South Fork Walla Walla Trailhead), there have been minimal impacts from human disturbances. From the South Fork Walla Walla Trailhead to the confluence with the Walla Walla River, human disturbances (i.e., agricultural cultivation, domestic livestock grazing, and flood control activities) are more prevalent. These disturbances have reduced the historical extent of riparian vegetation within the South Fork Walla Walla River floodplain. The riparian vegetation along the upper reaches of the South Fork Walla Walla River consists of a mixed conifer/deciduous overstory with an understory of shrubs (i.e., willow). The mid-elevation reaches on the South Fork Walla Walla River consist of riparian vegetation dominated by deciduous trees (e.g., cottonwood, alder, and willow). In the upper elevations of the watershed, steep slopes naturally confine the width of the riparian corridor.

1.1.2 North Fork Walla Walla River

Similar to the South Fork Walla Walla River, the North Fork includes riparian vegetation zones that range from high-to-mid elevations within the watershed. At river mile (RM) 3.6 from its confluence with the South Fork Walla Walla River, the North Fork Walla Walla River Rd., which flanks the North Fork Walla Walla River, becomes private. Although the North Fork Walla Walla River Rd. continues for several miles upstream and domestic livestock grazing occurs above this point, there are a limited number of residences and agricultural cultivation is very limited. Due to these differences, the condition of riparian vegetation within the upper reaches of the North Fork Walla Walla River is generally better than the condition of riparian vegetation found within the mid-to-lower reaches within the North Fork Walla Walla River floodplain. The riparian vegetation along the North Fork Walla Walla River consists of a mixed conifer/deciduous overstory with an understory of shrubs (i.e., willow). In the upper elevations of the watershed, steep slopes naturally confine the width of the riparian corridor.

1.1.3 Walla Walla River

The Walla Walla River portion of the project area includes the riparian corridor from the confluence of the North and South Fork Walla Walla River downstream to just upstream of where Dry Creek flows into the river. This section of the Walla Walla River ranges from mid-to-low elevations within the watershed. The riparian vegetation within this portion of the subbasin has largely been confined by agricultural cultivation and roadways. Large surface water diversions that support agriculture within the valley limit the flows that would otherwise support additional riparian vegetation. The riparian vegetation within this portion of the Walla Walla watershed contains a deciduous overstory with an understory of shrubs (i.e., willow).

1.2 REACH DESCRIPTIONS

The project area contains a total of 14 distinct reaches—four within the North Fork Walla Walla River, five within the South Fork Walla Walla River, and five within the Walla Walla River. The riparian conditions of the far upper reaches of the North Fork Walla Walla River and the South Fork Walla Walla River (i.e., North Fork 5 - North Fork 8, and South Fork 6 – South Fork 8) were not analyzed due to Lidar data not being available for those areas.

The reaches are generally separated base on either natural (e.g., steep hillslopes) or artificial (e.g., bridges) features that confine the valley width or riparian corridor. The dominant plant communities along the Upper Walla Walla watershed riparian corridor differ based on elevation and historical land uses. The riparian areas along the headwaters of the South and North Fork Walla Walla Rivers are less impacted by grazing and other human activities. The lower reaches of the South and North Fork Walla Walla Rivers and the Walla Walla River have been impacted by grazing and human development to a larger extent. The dominant riparian plant communities range from coniferous dominated at the tree stratum higher up in the watershed to deciduous dominated at the tree stratum within the middle and lower reaches.

1.2.1 South Fork Walla Walla River

The South Fork Walla Walla River contains 5 distinct reaches, identified respectively as South Fork 1 (SF1), South Fork 2 (SF2), South Fork 3 (SF3), South Fork (SF4), and South Fork (SF5). The portion of the South Fork Walla Walla River analyzed within this technical report encompasses 20.4 river miles starting from its confluence with the North Fork Walla Walla River.

- **South Fork 1**- This reach encompasses the 8.3 river miles of the South Fork Walla Walla River directly upstream from its confluence with the North Fork Walla Walla River. The South Fork Walla Walla River Road and several residences occur within this reach as the floodplain is wide enough to support agriculture and grazing activities. The riparian areas within this reach are dominated by deciduous species at lower elevations and mixed deciduous-conifer species at its higher elevations.
- **South Fork 2**- This reach encompasses 4.6 river miles of the South Fork Walla Walla River from RM 8.3 to RM 12.9 upstream from its confluence with the North Fork Walla Walla River. The South Fork Walla Walla River Road ends within this reach and there are no residences farther upstream. The floodplain within this reach is more confined and sinuous than SF1, and the top of the reach is marked by Bear Creek coming in from river right. The riparian areas within this reach are dominated by mixed deciduous-conifer species.
- **South Fork 3**- This reach encompasses 2.4 river miles of the South Fork Walla Walla River from RM 12.9 to RM 15.3 upstream from its confluence with the North Fork Walla Walla River. The floodplain within this reach is less confined than SF2 and the beginning and ending of the reach is marked by constrictions in the valley. The riparian areas within this reach are dominated by conifer species.
- **South Fork 4**- This reach encompasses 2.4 river miles of the South Fork Walla Walla River from RM 15.3 to RM 17.7 upstream from its confluence with the North Fork Walla Walla River. The floodplain within this reach is slightly less confined than SF3 with several high flow side channels that are laterally connected to the main river channel. The riparian areas within this reach are dominated by conifer species.
- **South Fork 5**- This reach encompasses 2.7 river miles of the South Fork Walla Walla River from RM 17.7 to RM 20.4 upstream from its confluence with the North Fork Walla Walla River. The floodplain within this reach is much more confined than SF4 with one dominant flow channel. The riparian areas within this reach are dominated by conifer species.

1.2.2 North Fork Walla Walla River

The North Fork of the Walla Walla River contains 4 distinct reaches, identified respectively as North Fork 1 (NF1), North Fork 2 (NF2), North Fork 3 (NF3), and North Fork (NF4). The portion of the North Fork Walla Walla River analyzed within this technical report encompasses 11.4 river miles starting from its confluence with the South Fork Walla Walla River.

- **North Fork 1-** This reach encompasses the 5.7 river miles of the North Fork Walla Walla River directly upstream from its confluence with the South Fork Walla Walla River. The North Fork Walla Walla River Road and several residences occur within this reach as the floodplain is wide enough to support agriculture and grazing activities. The riparian areas within this reach are dominated by a deciduous species.
- **North Fork 2**- This reach encompasses 2.2 river miles of the North Fork Walla Walla River from RM 3.5 to RM 5.7 upstream from its confluence with the South Fork Walla Walla River. Although the North Fork Walla Walla River Road continues within this reach as there are no residences. The floodplain within this reach is moderately confined with some high flow channels that are laterally connected to the main river channel. The riparian areas within this reach are dominated by mixed deciduous-conifer species.
- **North Fork 3**- This reach encompasses 3.1 river miles of the North Fork Walla Walla River from RM 5.7 to RM 8.8 upstream from its confluence with the South Fork Walla Walla River. The North Fork Walla Walla River Road continues along this reach, which is marked at its downstream end by a USGS gage and at its upstream end by the Little Meadow Canyon, which contains a primary tributary to the North Fork Walla Walla River. The floodplain within this reach is moderately confined with several high flow side channels that are laterally connected to the main river channel. The riparian areas within this reach are dominated by conifer species.
- **North Fork 4**- This reach encompasses 2.6 river miles of the North Fork Walla Walla River from RM 8.8 to RM 11.4 upstream from its confluence with the South Fork Walla Walla River. The floodplain within this reach is more confined than the downstream reaches along the North Fork Wall Walla River. The riparian areas within this reach are dominated by conifer species.

1.2.3 Walla Walla River

The Walla Walla River contains 5 distinct reaches, identified respectively as Walla Walla 1 (WW1), Walla Walla 2 (WW2), Walla Walla 3 (WW3), Walla Walla (WW4), and Walla Walla (WW5). The portion of the Walla Walla River analyzed within this technical report encompasses 23.9 river miles starting from RM 27.4 upstream from its confluence with the Columbia River to RM 51.3 where the South Fork Walla Walla River and North Fork Walla Walla River come together to form the Walla Walla River.

- **Walla Walla 1**- This reach encompasses 8.1 river miles of the Walla Walla River from RM 27.4 to RM 35.5 upstream from its confluence with the Columbia River. The floodplain width within this reach varies and is confined at three bridge crossings. Being located lower within the Upper Walla Walla watershed, this reach runs through flat land that supports agricultural and grazing activities. There is one large agricultural surface water diversion within this reach (Mud District Number 2 Canal). The downstream end of the reach is marked by Lowden Gardena Rd., while the upstream end is marked by Last Chance Rd. The riparian areas within this reach are dominated by a deciduous species.

- **Walla Walla 2**- This reach encompasses 7.2 river miles of the Walla Walla River from RM 35.5 to RM 42.7 upstream from its confluence with the Columbia River. The floodplain width within this reach varies and is confined at four bridge crossings. Being located lower within the watershed, this reach runs through flat land that supports agricultural and grazing activities. There is one large agricultural surface water diversion within this reach (Burlingame Ditch). The downstream end of the reach is marked by Last Chance Rd., while the upstream end is located just upstream of Birch Creek Rd. The riparian areas within this reach are dominated by a deciduous species.
- **Walla Walla 3**- This reach encompasses 2.5 river miles of the Walla Walla River from RM 42.7 to RM 45.2 upstream from its confluence with the Columbia River. The floodplain width within this reach is more modified/confined than WW1 or WW2 and is confined at two bridge crossings. The upstream portion of this reach is channelized and contains industrial development directly adjacent to the river as it flows through the City of Milton-Freewater. The downstream end of the reach is marked by Birch Creek Rd., while the upstream end is located just upstream of Eastside Rd. The riparian areas within this reach are dominated by a deciduous species.
- **Walla Walla 4**- This reach encompasses 3.2 river miles of the Walla Walla River from RM 45.2 to RM 48.4 upstream from its confluence with the Columbia River. The floodplain width within this reach varies as it flows through the City of Milton-Freewater; the upstream portion of the reach is more channelized than the downstream portion of the reach due to development within city limits. This reach is confined at three bridge crossings. The downstream end of the reach is marked by Eastside Rd., while the upstream end is located just upstream of Couse Creek Rd. The riparian areas within this reach are dominated by a deciduous species.
- **Walla Walla 5**- This reach encompasses 2.9 river miles of the Walla Walla River from RM 48.4 to RM 51.3 upstream from its confluence with the Columbia River. This reach is confined at one bridge crossing. The downstream end of the reach is located just upstream of Couse Creek Rd., while the upstream end is marked by the confluence of the North and South Fork of the Walla Walla River. The riparian areas within this reach are dominated by a deciduous species.

1.3 RIPARIAN CONDITION

The riparian conditions within the project area are influenced by the types and extent of historical and current land uses. Examples of land uses that have affected the riparian condition within the project area include—crop production and agricultural diversions; cattle grazing; and roads, levees, bridges, and building development. The high flow event in 2020 scoured out many riparian areas within the project area, especially within the upper reaches of the project area (i.e., South and North Forks of the Walla Walla River).

As part of its Columbia Basin Historical Ecology Project, the National Oceanic and Atmospheric Administration (NOAA) conducted a Riparian Condition Assessment (RCA). The RCA tools use several GIS layers (e.g., Riparian Vegetation Departure, land use intensity, and floodplain fragmentation) to describe the extent, condition and recovery potential of riparian ecosystems within the Columbia River Basin's subwatersheds. The resulting hydrography is composed of stream segments that estimate riparian condition on a continuous scale from 0 (poor) to 1 (intact) (Riverscapes Consortium 2024). The riparian condition values of the stream segments that fall within each of the three reaches within the project area were averaged using a distance weighting and summarized below.

1.3.1 South Fork Walla Walla River

The riparian conditions within the South Fork Walla Walla River are influenced by crop production, cattle grazing, roads, levees and building development within its lower reaches. In the upper reaches, the riparian conditions are more affected by the 2020 high flow event, which scoured out depressional wetland areas adjacent to the main channel and modified much of the riparian vegetation along the river. Surface water diversions that supply agricultural areas adjacent to the river also play a role as they decrease the water that is available for riparian vegetation.

The distance weighted average RCA-derived value for the five reaches evaluated within the South Fork Walla Walla River is 0.55. The RCA-derived values for the four individual reaches that were evaluated within the South Fork Walla Walla River are presented in Table 1.

1.3.2 North Fork Walla Walla River

Similar to the South Fork Walla Walla River, the riparian conditions within the North Fork Walla Walla River are influenced by crop production, cattle grazing, roads, levees and building development within its lower reaches. In the upper reaches, the riparian conditions are more affected by the 2020 high flow event, which scoured out depressional wetland areas adjacent to the main channel and modified much of the riparian vegetation along the river. Surface water diversions that supply agricultural areas adjacent to the river also play a role as they decrease the water that is available for riparian vegetation.

The distance weighted average RCA-derived value for the four reaches evaluated within the North Fork Walla Walla River is 0.44. The RCA-derived values for the four individual reaches that were evaluated within the South Fork Walla Walla River are presented in Table 1.

1.3.3 Walla Walla River

The riparian conditions within the Walla Walla River are influenced to a larger degree by crop production, cattle grazing, and roads, levees, bridges, and building development as it is lower in the watershed and more urbanized in some areas within the floodplain. Large surface water diversions to supply agricultural areas adjacent to the river also play a role as they decrease the water that is available for riparian vegetation.

The distance weighted average RCA-derived value for the five reaches evaluated within the Walla Walla River is 0.24. The RCA-derived values for the four individual reaches that were evaluated within the South Fork Walla Walla River are presented in Table 1.

Table 1. RCA-derived values for the individual reaches evaluated within the project area.

Reach Name	Reach Length (km)	Reach RCA-Derived Value
South Fork Walla Walla River		
SF1	13.25	0.54
SF2	7.58	0.54
SF3	3.78	0.77
SF4	4.19	0.71
SF5	4.40	0.28
Total	33.19	0.55
North Fork Walla Walla River		
NF1	5.77	0.49
NF2	3.78	0.58
NF3	4.78	0.38
NF4	4.18	0.31
Total	18.51	0.44
Walla Walla River		
WW1	13.16	0.24
WW2	11.39	0.23
WW3	4.22	0.12
WW4	5.22	0.16
WW5	4.78	0.46
Total	38.77	0.24

1.4 LARGE WOOD RECRUITMENT

Large wood recruitment is associated with healthy aquatic stream conditions and is influenced by several factors, including magnitude of streamflow, geomorphic configuration of channel and floodplain, and average wood size and shape. Above bankfull discharge is associated with high rates of large wood transportation, especially in multi-tread stream reaches. Large wood recruitment is particularly important to the Upper Walla Walla watershed due to past and current land uses, which have disconnected the river from portions of its potential riparian area. Riparian forest succession within the remaining riparian areas along the Upper Walla Walla watershed depend on large wood loading.

1.4.1 South Fork Walla Walla River

The South Fork Walla Walla River experienced a high magnitude streamflow event in 2020. Although this event scoured out areas of riparian vegetation that existed at the time, it effectively transported large wood through the system and likely added channel complexity in some reaches where the floodplain allowed for lateral migration. It also likely provided propagation opportunities for large wood establishment along the higher elevations within the floodplain. However, if future streamflows/groundwater levels do not support seed and sapling growth, the flood-related riparian forest succession will be minimal.

1.4.2 North Fork Walla Walla River

The North Fork Walla Walla River experienced a similar high magnitude streamflow event in 2020. Although this event scoured out areas of riparian vegetation that existed at the time, it provided similar benefits in large wood accumulation as flood waters receded. These instances of large wood wracking will evolve into healthy aquatic habitat features as they impound sediment. The 2020 flood also likely provided propagation opportunities for additional riparian forest establishment along the higher elevations within the floodplain. However, if future streamflow/groundwater levels do not support seed and sapling growth, succession will be minimal.

1.4.3 Walla Walla River

Large wood recruitment along the Walla Walla River is limited by the capacity of upstream reaches to deliver larger natural woody material and by the extent of riparian area that is available to inundation at higher flows. Roads or other buildings and infrastructure that are located along the river have been protected by levees. Reaches of the river that have been confined to a single channel serve to transport large wood but contain less potential to recruit large wood and develop healthy riparian systems. Reaches that have been dewatered due to surface water diversions may lack the flows that are necessary to initiate large wood recruitment in some of the high flow side channels within the Walla Walla River.

1.5 INVASIVE SPECIES

There are numerous invasive plant species that have colonized the Upper Walla Walla watershed. The degree to which these species have established themselves varies based on location within the watershed. Invasive plant species recruitment at sites across the Upper Walla watershed is influenced by the current and historical local land use practices of the region. Common invasive species known to in riparian areas throughout the Upper Walla Watershed include black locust (*Robiniia pseudoacacia*), Canada thistle (*Cirsium arvense*), cheatgrass (*Bromus tectorum*), false indigo bush (*Amorpha fruticosa*), Himalalyan blackberry (*Rubus armeniacus*), purple loosestrife (*Lythurm salicaria*), reed canarygrass (*Phalaris arunidacea*), Russian olive (*Elaegnus angustifolia*), and yellow star thistle (*Centaurea solstitialis*).

2.0 RIPARIAN SHADE ANALYSIS

This Riparian Shade Analysis is part of the Upper Walla Walla Basin Assessment (the Assessment). The Assessment is a scientifically defensible and strategic habitat restoration plan. The habitat restoration plan is based on several analyses of the geomorphic, hydrologic, and biological conditions in the upper Walla Walla River in Washington and Oregon. The Riparian Shade Analysis is one of The Assessment's biological conditions analyses. The project focuses on the alluvial channel and floodplain of the Walla Walla River from its confluence with Dry Creek near Lowden, Washington, to the headwaters of the North and South Forks of the Walla Walla River. The project, or study area, includes approximately 70 miles of stream and its associated floodplains. The Riparian Shade Analysis presented herein is a scientifically robust, accepted, and effective method to identify locations within the project area that are not meeting system potential for shade. System Potential is defined by the State of Oregon's Temperature Total Maximum Daily Load (TMDL) for the Walla Walla Basin (ODEQ 2005).

Oregon relies on the Heat Source model (Version 8.0.8) to simulate stream thermodynamics and hydrology (Boyd and Kasper 2007). Heat Source is Oregon's preferred model to determine thermal load to stream and river channels. Heat Source consists of a Microsoft Excel spreadsheet that contains model input and output (Boyd and Kasper 2007). Shade-A-Lator is a solar routing model that is part of Heat Source and calculates potential and received solar radiation at a stream's surface and also provides shade output data (aka effective shade metric). Most of the output presented below is derived via the Shade-A-Lator model.

2.1 PURPOSE AND NEED

The Walla Walla River and several of its tributaries (aka North and South Forks) do not currently meet water quality standards for temperature (ODEQ 2005). A major driver of non-attainment of Temperature standards is lack of shade along the Walla Walla and its tributaries. Riparian vegetation is the primary shade agent in the Walla Walla Basin. To analyze the efficacy of riparian vegetation to shade stream channels in the project area a Shade-A-Lator model (executable within the Heat Source model) was built for each reach within the project area. The purpose of the Riparian Shade Analyses is threefold; 1. quantify the **thermal load** (Average Kilocalories[kcal]/day in summer) at 100m intervals within the project area and summarize per reach (WW1, WW2, SF1, NF1 etc.), 2. Determine the **effective shade** (received solar radiation/ potential solar radiation) at 100m intervals and summarize per reach, and 3. Determine locations (100m points) within the project area that are meeting **System Potential** and areas that are not, as defined by the Walla Walla Temperature TMDL (ODEQ 2005).

Thermal Load is defined as the average kilo-calorie per day (kcal/day) the stream surface receives from May 15th to October 15th. A thermal load value is provided every 100m throughout the project area and summarized at the reach level (WW1, SF1, NF1 etc.). Radiant heat energy per time (aka thermal load) is not readily translatable to on-the-ground management. Therefore surrogates, such as effective shade, are established to translate the TMDL to everyday terms (ODEQ 2005). Effective shade will be used below to examine system potential.

Effective shade is defined as the percent reduction of potential solar radiation load delivered to the water surface, over the course of a mid-summer day (received solar radiation/potential solar radiation) (ODEQ 2005). The effective shade surrogates address both the size of shade-producing features and stream width, thus entirely addressing solar radiation received by streams (ODEQ 2005)**.** The Walla Walla Basin Temperature TMDL identifies "Effective Shade" as a load allocation surrogate measure. The effective shade surrogate measure are compared to channel width to determine whether the area (100m point location) is meeting System Potential. If the site (100m point) is meeting System Potential, then attainment is met; the effective shade surrogates below fulfill the Walla Walla Subbasin load allocation.

System Potential is defined by Oregon DEQ and establishes numeric goals for on-the-ground conditions that would lead to more natural temperatures. The TMDL identifies vegetation types (height/density) and stable channel widths that provide for lessened, more natural, heating (solar radiation) (ODEQ 2012). System potential is organized by dominant vegetation types (e.g., primarily deciduous, deciduous-coniferous mix and primarily coniferous). System potential curves (channel width v. effective shade) are organized by vegetation types and channel orientation (east-west, north-south, and northeast or northwest.

2.2 METHODS

The methods employed for the Riparian Shade Analysis are dictated by the State of Oregon and their Heat Source Model (Boyd and Kasper 2007). Heat Source is a computer model used by Oregon DEQ to simulate stream thermodynamics and hydrology (ODEQ 2022). The model was developed in 1996 at Oregon State University in the Departments of Bioresource Engineering and Civil Engineering. DEQ currently maintains the Heat Source methodology and computer programming (ODEQ 2022). Heat Source is a macro-enabled excel file, with several modules, of which Shade-a-lator is most germane to this project. The data that populates the Heat Source model is derived in ArcGIS using an extension named TTools.

The methodology described below includes deriving the requisite data (Ttools) to run Heat Source (aka Shade-a-Lator), populating the model, and running Shade-a-lator, and then comparing the results to the System Potential Curves found in the Walla Walla Basin Temperature TMDL (ODEQ 2005a). Other entities such as the Freshwater Trust and Idaho Power Company rely on the Heat Source model, and methodology described herein, to evaluate riparian shade for many of their projects (Willamette Partnership 2014, and IPC 2018).

2.2.1 TTools

TTools (v7.56) is an ArcGIS extension used to sample geospatial data and assemble high-resolution inputs for the Heat Source model or other water quality analysis (ODEQ 2022). TTools is run in ArcGIS 10.0 and includes a five-step process that creates the data needed to run Heat Source and Shade-a-lator. The data used for each step of the TTools analyses is found in Table 2. Figure X provides an example of the data used in the TTools analyses. The five step analyses include:

1. *Segment Stream Centerline and Calculate Aspect:* Segment's each reach's stream centerline into 100m segments, places a point every 100m, and calculates the aspect for each point. The result of this step is the stream centerline points per reach and their associated aspect (Table 2, Stream Centerlines, Stream Centerline Points).
2. *Measure Channel Width*: Measures the channel width at each centerline point based on the right bank and left bank lines (Table 2). The bank lines are the water break lines from the 2022 Lidar.
3. *Measure Elevation/Gradient*: This step measures the elevation of each centerline point and the stream gradient associated with that point. The elevational data employed in this step is the bare earth 2022 lidar raster (Table 2).
4. *Measure Topographic Angles*: This TTools analyses determines the topographic shade at each point. Data employed in this step included a 10m DEM from the National Elevation Dataset (NED). This raster layer was needed as topographic shade is based on landforms that are outside the floodplain, and thus a larger extent than the 2022 lidar was needed for this step.
5. *Sample Land Cover*: Sampling land cover entails determining the height and density of the local riparian vegetation. For this analysis 2022 lidar data was employed. A "canopy height" layer was created by subtracting the 2022 Bare Earth DEM from the 2022 Hight Hit DEM. This subtraction resulted in a raster layer that quantifies the height of local (aka riparian) vegetation (Table 2). This step will sample the canopy height from the vegetation raster layer.

Table 2. Data Employed in TTools Analyses.

Data Layer	Type	Description	Citation
Stream Centerlines	Vector - Derived	Centerline between bank lines	Derived in ArcGIS Pro
Stream Centerline Points	Vector - Derived	Every 100m per reach	Derived in TTools
Left and Right Bank Lines	Vector	Lidar break lines	2022 Lidar
Stream Elevation	Raster	Lidar Bare Earth	2022 Lidar
Vegetation Height	Raster – Derived	Lidar High Hit – Lidar Bare Earth	2022 Lidar
Topographic Elevation	Raster	NED (10m)	NED

The result of the TTools analyses is a *.csv file that is used to populate the Heat Source macro enabled Microsoft Excel file. The TTools derived *.csv file populates the following four worksheets of the Heat Source model: 1. Heat Source inputs, 2. TTools Data, 3. Morphology Data and 4. Continuous Data.

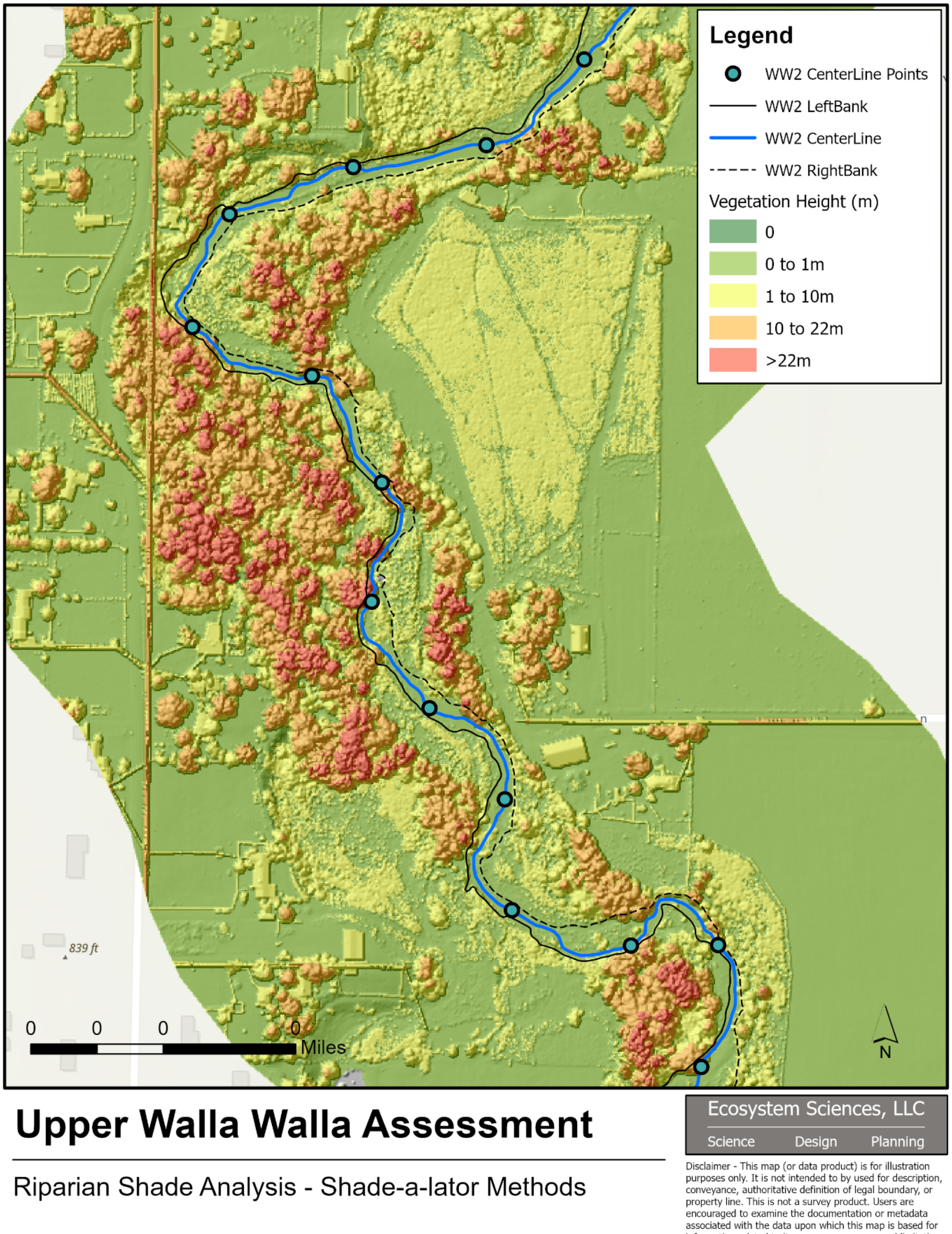

Figure 1. Reach Walla Walla 2 example data used to perform TTools analyses.

2.2.2 Heat Source/Shade-a-Lator

The Heat Source model was run for the summer period May 15th through October 15th. This timeframe was selected to include the warmest days of the year, and thus represent the highest solar radiation potential for the Walla Walla Basin. Typically, the highest stream temperatures in the Walla Walla Basin occur in late July and early to mid August (ODEQ 2005a). There are several time steps, variables and coefficients that need to be entered into Heatsource for it to run properly. These variables and coefficients were derived using the following literature: Boyd and Kasper 2007, Willamette Partnership 2014, and IPC 2018. Once all data is entered into the appropriate worksheets and the timesteps, variables and coefficients were entered properly, the Shade-a-Lator module was run. One Shade-a-Lator model was run per reach (Walla Walla River reaches 1 – 5, North Fork reached 1 – 4, and South Fork Reaches 1 – 5).

2.2.3 System Potential – TMDL Analysis

The term *system potential* refers to the best estimate of vegetation, channel shape and other riparian conditions that would occur with past and present human disturbance minimized. ***System potential channel and vegetation conditions are the basis for the load allocations of this TMDL (ODEQ 2005a)***. Figure 3 describes the Riparian Zone types, their associated species, and general locations ODEQ used to determine the Walla Walla Basins "system

River Mile	Riparian Zone Name	Height Dominant Plants
23.0 to 52.2 (South Fork - 2.8 miles upstream of North Fork Confluence)	Deciduous Zone	Mixed Willow, Mixed Alder, interspersed Black Cottonwood
52.2 to 59.0 (Lower South Fork to BLM Trailhead)	Deciduous-Conifer Zone	**Deciduous -** Quaking Aspen, Black Cottonwood, Mixed Willow, Mixed Alder, Red Osier Dogwood. **Conifer -** Grand Fir, Douglas Fir, Ponderosa Pine
59.0 to 67.0 (BLM Trailhead to Model Upper Boundary at Skiphorton Ck)	Conifer Zone	**Deciduous -** Quaking Aspen, Mixed Willow, Mixed Alder, Red Osier Dogwood, Paper Birch, etc. **Conifer -** Mixed Firs, Ponderosa Pine, Engelmann Spruce

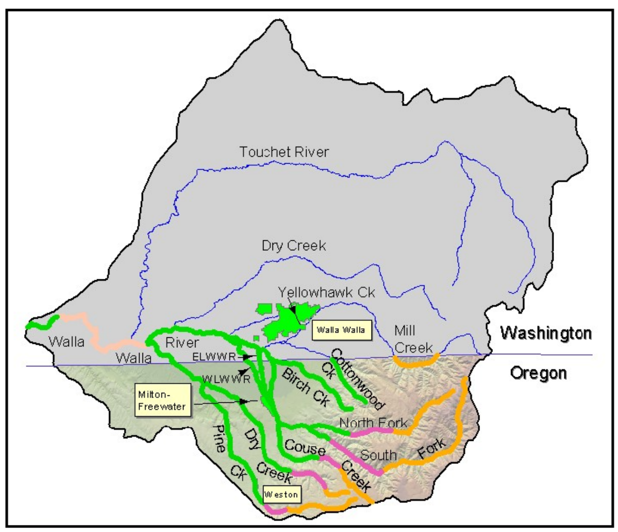

Figure 2. Estimated potential vegetation species and Walla Walla basin locations (Table 1.6 and Figure 1.8 from ODEQ 2005a).

potential." The System Potential curves (Figure 4), are used to analyze whether points analyzed via the Heat Source/Shade-a-Lator model are meeting system potential (above the lines) or not meeting system potential (below the lines). The curves of shade v. channel width can be expressed as current or site potential. The idea is that the curves express all possibilities, ultimately based on natural potential (as best ODEQ can determine, full grown willows, cottonwood and alders), and that as channel width and shade improve, the system moves up the curve toward natural potential (a desired condition in the Walla Walla Basin). ODEQ is trying to establish a trajectory for riparian vegetation (aka shade), through restoration and the removal of stressors, which would move the basin towards a more natural condition. The numeric goals, found in the System Potential Curves (Figure 4), are guides that ultimately will move local riparian vegetation towards a more natural condition and reduce stream temperature.

The system potential curves are organized by riparian zone name (Deciduous, Deciduous-Coniferous [mixed] and Coniferous) (Figure 5). Each riparian zone's name curve is subset by aspect; east-west orientation, north-south orientation and northeast or northwest orientation) (Figure 4). Thus, each TMDL Riparian Zone has three associated curves, and centerline points from the Shade-a-Lator analyses are compared against each curve. Points whose Effective Shade is above the curve for its channel width are considered to be meeting System Potential or rather meeting the TMDL load allocation. Points that are located below the applicable curve indicate that they are not meeting system potential and are therefore not meeting the TMDL load allocation (ODEQ 2005).

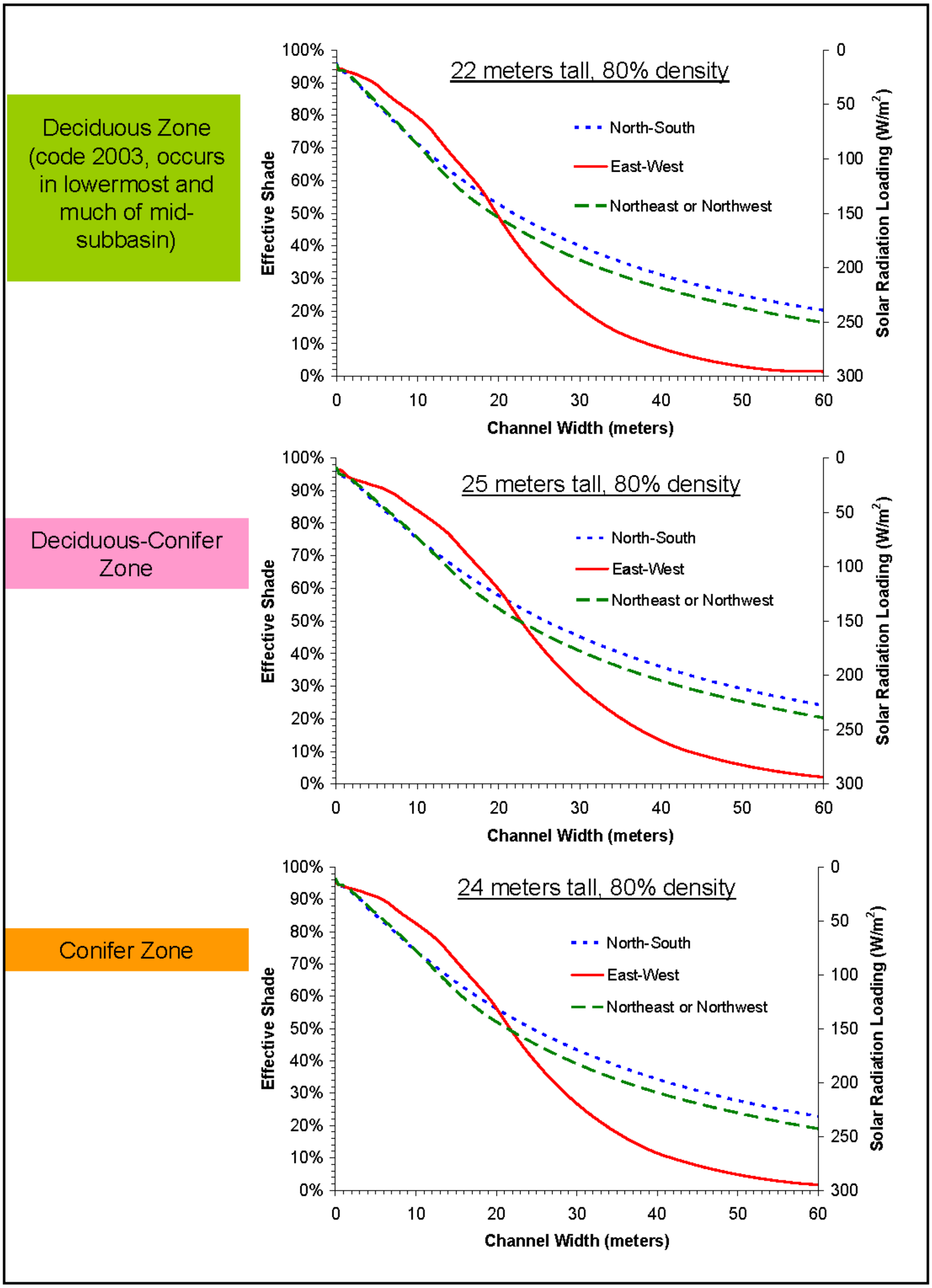

Figure 3. System Potential Curves for the Walla Walla Basin (ODEQ 2005a).

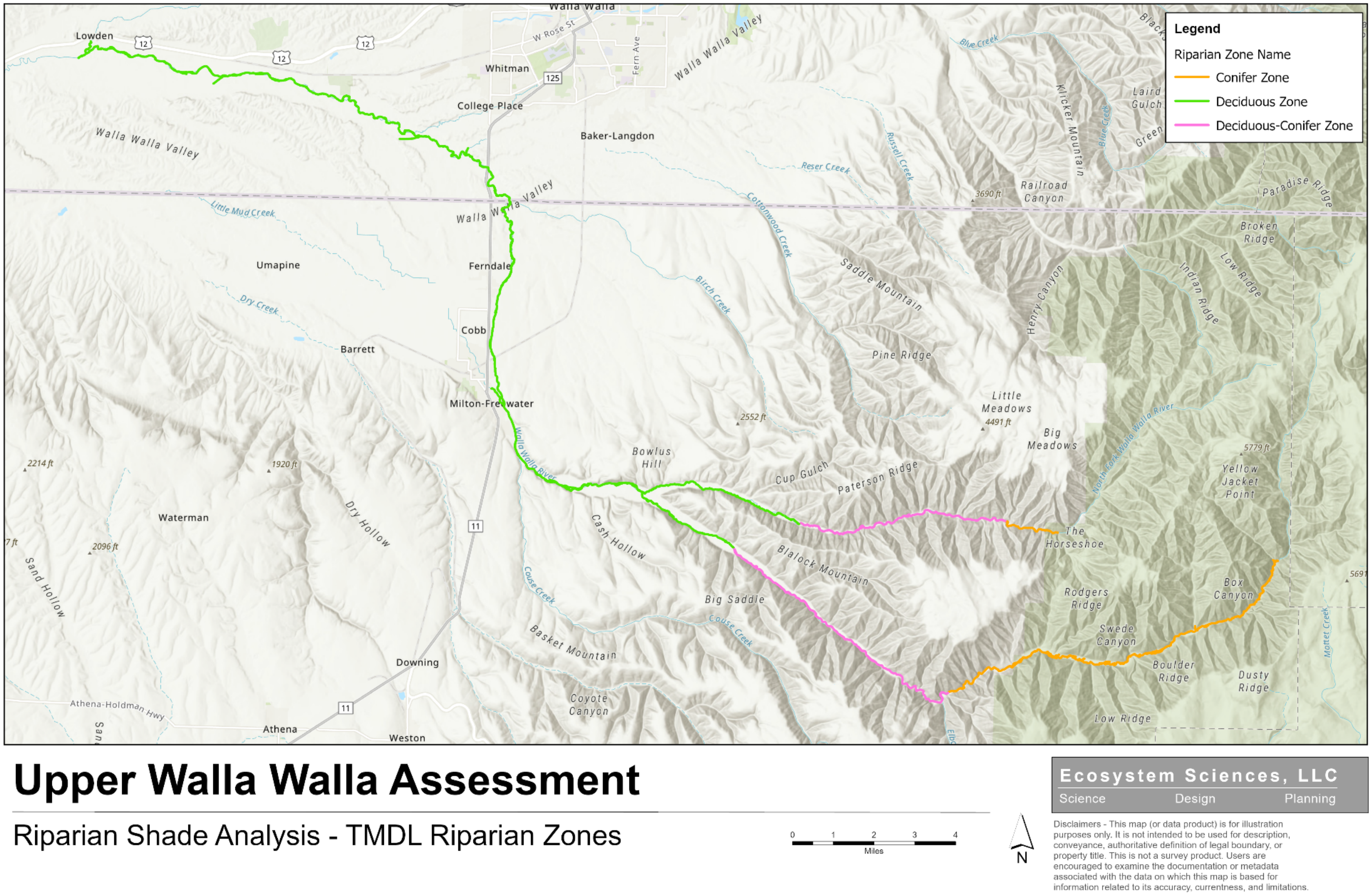

Figure 4. TMDL riparian zones within the project area.

2.3 RESULTS

The following section details the results of the Riparian Shade Analysis; Heat Souce/Shade-a-lator model and subsequent System Potential analysis. Table 3 depicts the results of the analysis at the reach level; Thermal Load, Thermal load per meter, Mean Effective Shade Percent, and Reach Length. Table 3 also includes a summarization of the System Potential at the reach level; Reach TMDL Riparian Zone Name, Total # of Centerline Points, and number and percentage of Centerline Points that achieve System Potential.

Table 3. Riparian shade analysis results for each reach within the project area.

Name	ID	Thermal Load (Kcal/day) Sum	Thermal Load (Kcal/m)	Mean Eff. Shade %	Mean Chan. Width	Riparian Zone Name*	Total Points	Sys Poten. Points	Sys. Poten. %	Reach Length (m)
North Fork	NF1	40,377,945	6,699	48%	8.1	DZ	61	4	7%	6,028
	NF2	33,156,379	8,616	33%	8.0	DZ and DCZ	39	1	3%	3,848
	NF3	26,045,859	5,004	52%	6.5	DCZ	53	0	0%	5,205
	NF4	14,468,730	3,172	62%	5.1	DCZ and CZ	46	2	4%	4,561
South Fork	SF1	178,730,848	12,842	46%	14.9	DZ and DCZ	139	24	17%	13,918
	SF2	117,534,916	14,344	45%	16.1	DCZ and CZ	82	9	11%	8,194
	SF3	52,325,857	12,318	41%	13.6	CZ	43	2	5%	4,248
	SF4	42,426,038	9,856	47%	11.3	CZ	44	4	9%	4,305
	SF5	23,085,414	4,881	62%	7.6	CZ	48	2	4%	4,729
Walla Walla	WW1	296,547,679	21,875	16%	17.2	DZ	135	6	4%	13,557
	WW2	192,280,975	14,927	28%	13.7	DZ	128	6	5%	12,881
	WW3	90,845,680	21,345	12%	16.0	DZ	43	0	0%	4,256
	WW4	80,372,423	15,249	31%	14.2	DZ	54	2	4%	5,271
	WW5	138,672,208	27,082	22%	22.6	DZ	52	4	8%	5,120

*DZ – Deciduous Zone, DCZ = Deciduous-Coniferous Zone and, CZ -= Coniferous Zone

2.3.1 Thermal Load

Thermal Load at the reach level equals the sum of a reach's (e.g., Walla Walla 1 [WW1]) centerline points' Thermal Load (average kcal/day). Thus, Thermal Load at the reach level is influenced by reach length. Figure six below demonstrates the relationship between reach length and thermal load, as the three longest reaches (WW1, WW2, SF1) receive the greatest average daily thermal load (sum of the average kcal/day from May 15th through October 15th).

A better metric for reach comparison of thermal load is thermal load per meter; thermal load divided by reach length (Figure 7). This metric removes the influence of reach length. Shorter reaches such as WW3 and WW5 have a substantial per meter level Thermal Load (Figure 7). Conversely, SF1, the longest reach in the project area, has a much lower per meter thermal load than it's neighboring SF2, which is much shorter. Figure 8 depicts the project area centerline points symbolized for thermal load. Red values indicate high thermal load, while green indicates low thermal load (Figure 8).

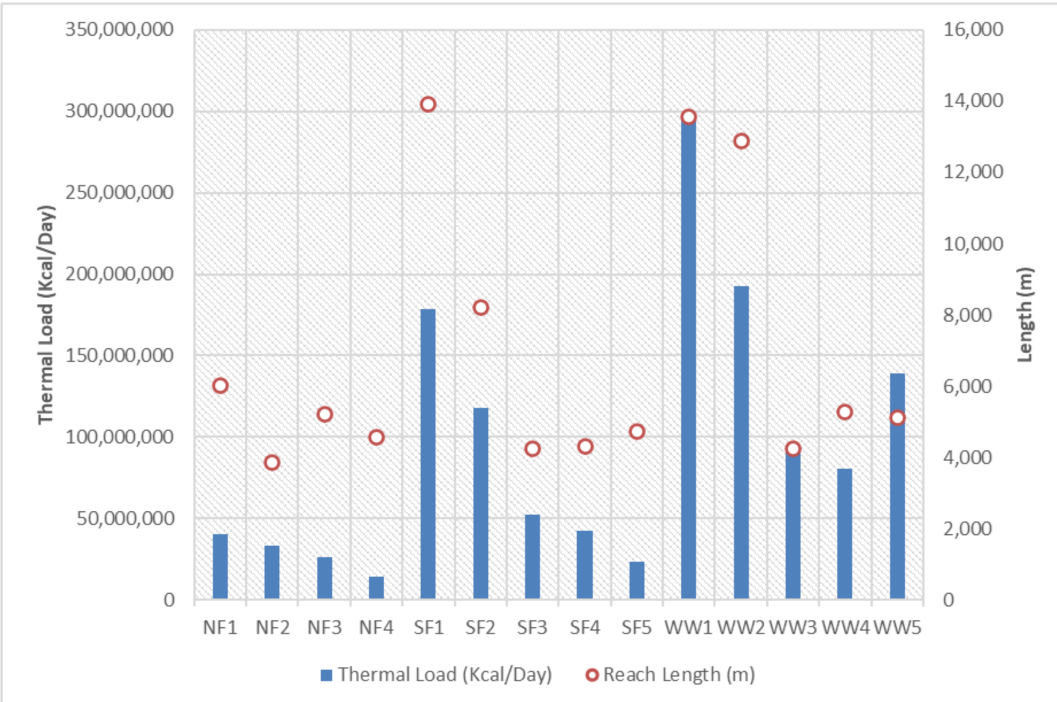

Figure 5. Thermal load (Kcal/day) and reach length for each reach within the project area.

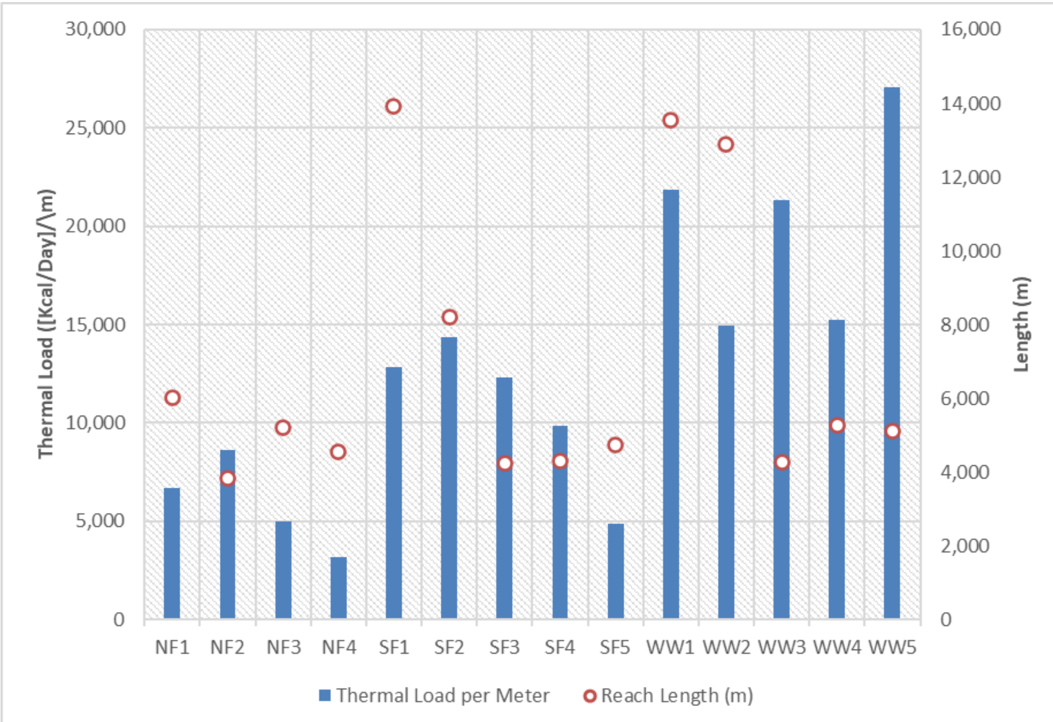

Figure 6. Thermal load per meter ([Kcal/day]/m) and reach length for each reach within the project area.

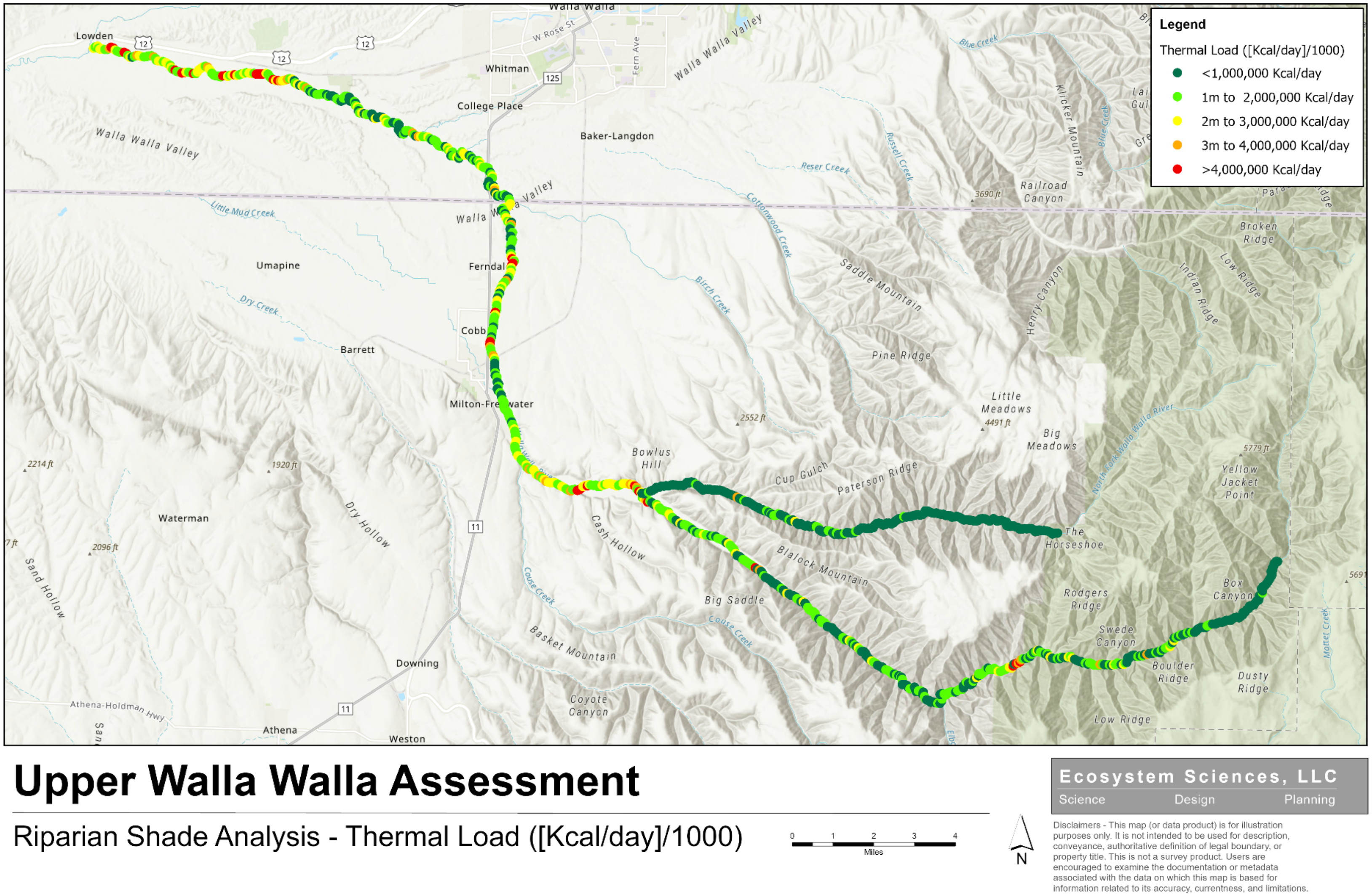

Figure 7. Centerline points symbolized for thermal load (average kcal/day over the analysis timeline) within the project area.

2.3.2 Effective Shade

Effective shade, the percent reduction of potential solar radiation load delivered to the stream surface (received solar radiation/potential solar radiation) (ODEQ 2005), at the reach level is variable within the project area. In general, the Walla Walla River reaches (WW1, WW2, WW3, and WW4) have the lowest effective shade percent (Figure 9). Unfortunately, for the Walla Walla reaches they have larger mean channel width (Figure 9). Low Effective Shade percent coupled with wide channels indicates high thermal load. Figure 10 below demonstrates the low (<25%) percent effective shade throughout the mainstem Walla Walla River within the project area. The South Fork Walla Walla River reaches (SF1 – SF5) achieve greater effective shade percent than mainstem reaches with similar channel widths (Figure 9). The North Fork Walla Walla River reaches generally have smaller channel widths and higher percent effective shade than the South Fork and mainstem Walla Walla reaches (Figure 9). The effective shade characteristics of the project area mentioned are depicted in Figure 10. The North and South Forks generally have higher percent effective shade than the mainstem Walla Walla River (Figure 10).

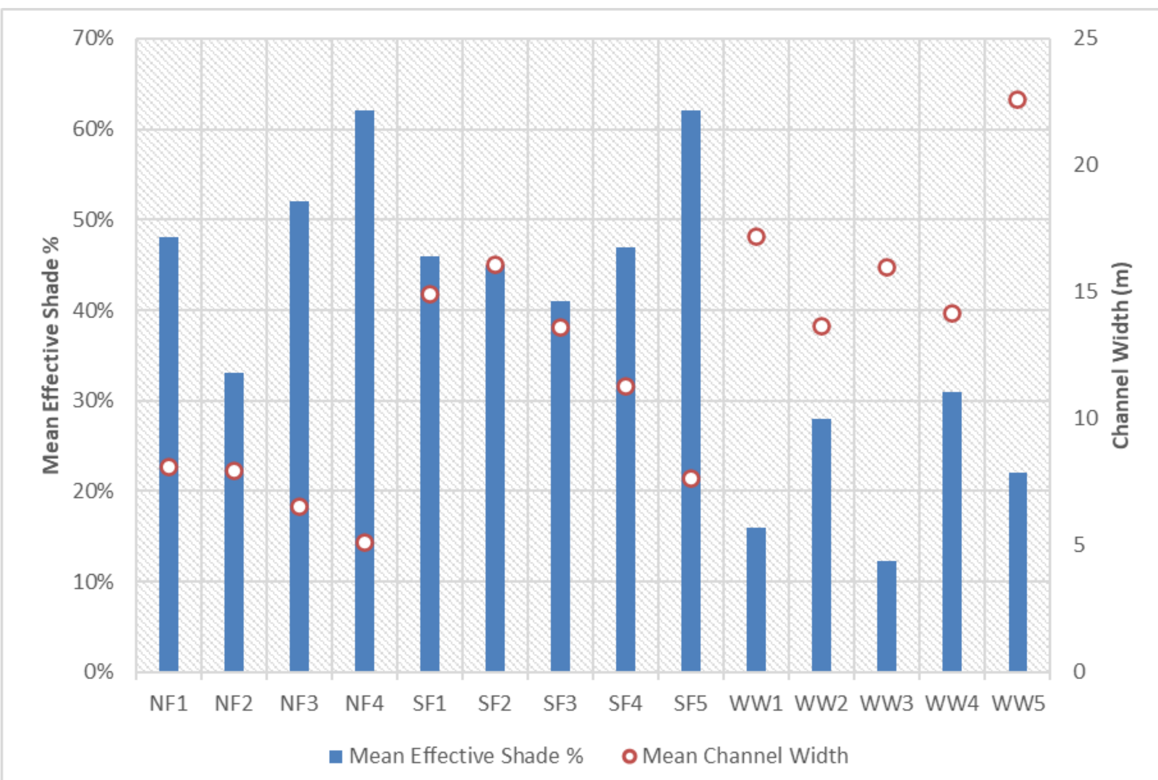

Figure 8. Effective shade (%) compared to Channel Width (m) for each reach within the project area.

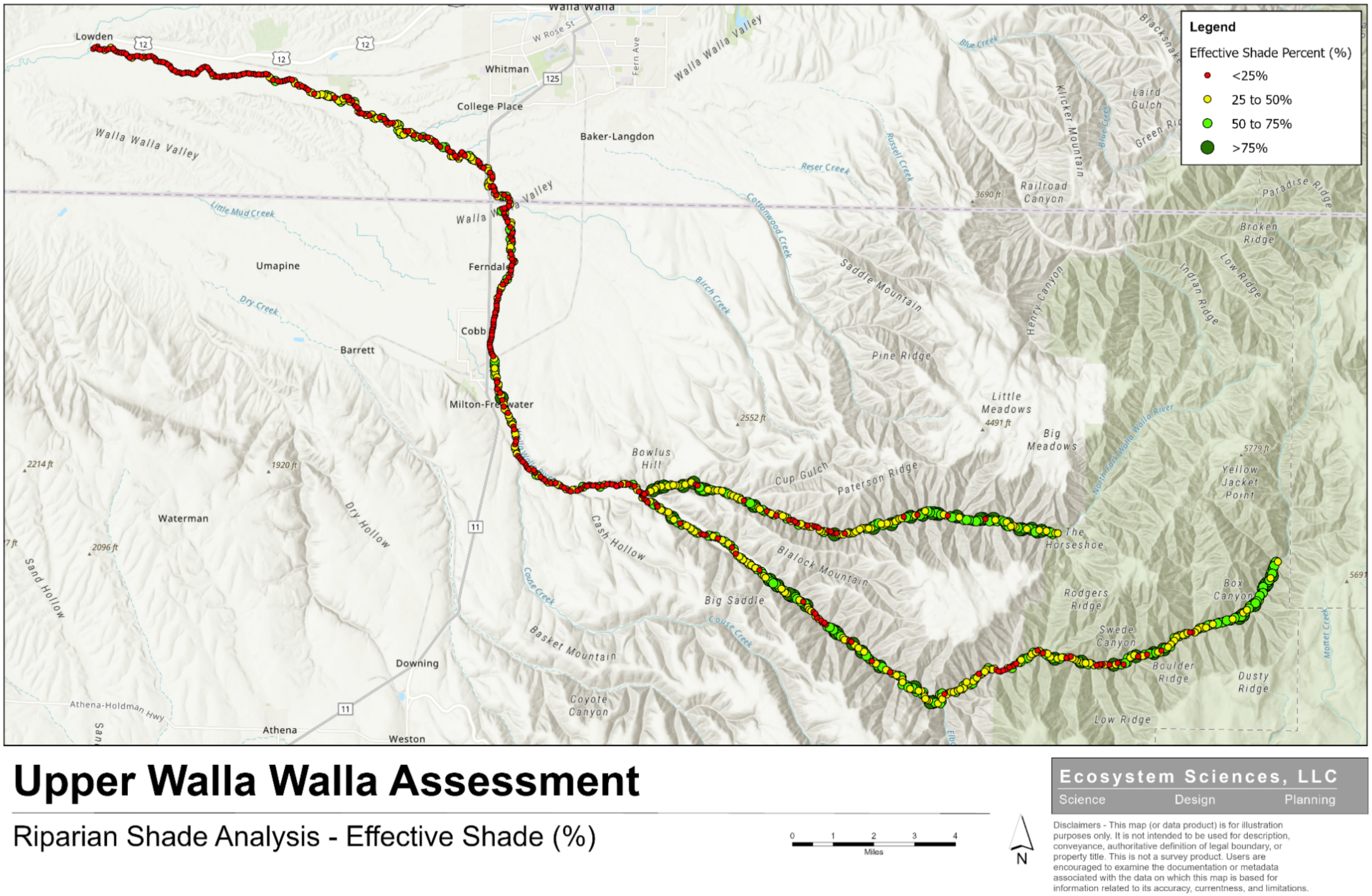

Figure 9. Effective shade per centerline point within the project area.

2.3.3 System Potential

System Potential is examined at the center point (100m points per reach) level and summarized to the reach level. Each center point's percent effective shade (e.g., Shade-a-lator derived) and channel width (TTools derived) is plotted and compared to the Walla Walla Basin TMDL's System Potential Curves (Figure 4, ODEQ 2005a). The results are summarized per TMDL riparian zone name (e.g., Deciduous Zone [DZ], Deciduous-Coniferous Zone [DCZ], and Coniferous Zone [CZ]). Figure 11 depicts the results of the System Potential Analysis for center points in the Deciduous Zone (DZ). A total of 30 points are at or above the system potential curves within the deciduous zone (Figure 11). In the Deciduous-Coniferous Zone (DCZ), a total of 22 center points were at or above system potential (Figure 12). In the Coniferous Zone (CZ) a total of 14 were at or above system potential (Figure 13). Overall, sixty-six of the 967 points analyzed in the project area Riparian Shade Analysis were at or above System Potential as defined by the Walla Walla Basin Temperature TMDL (ODEQ 2005a).

At the reach level, SF1, the longest reach in the project area, has the most centerline points (24, 17%) that are at or above system potential (Table 3). SF2 is the only other reach in the project area that contains more than 6 points that meet system potential (Table 3). Figure 14 below depicts the results of the System Potential Analysis at the project area scale.

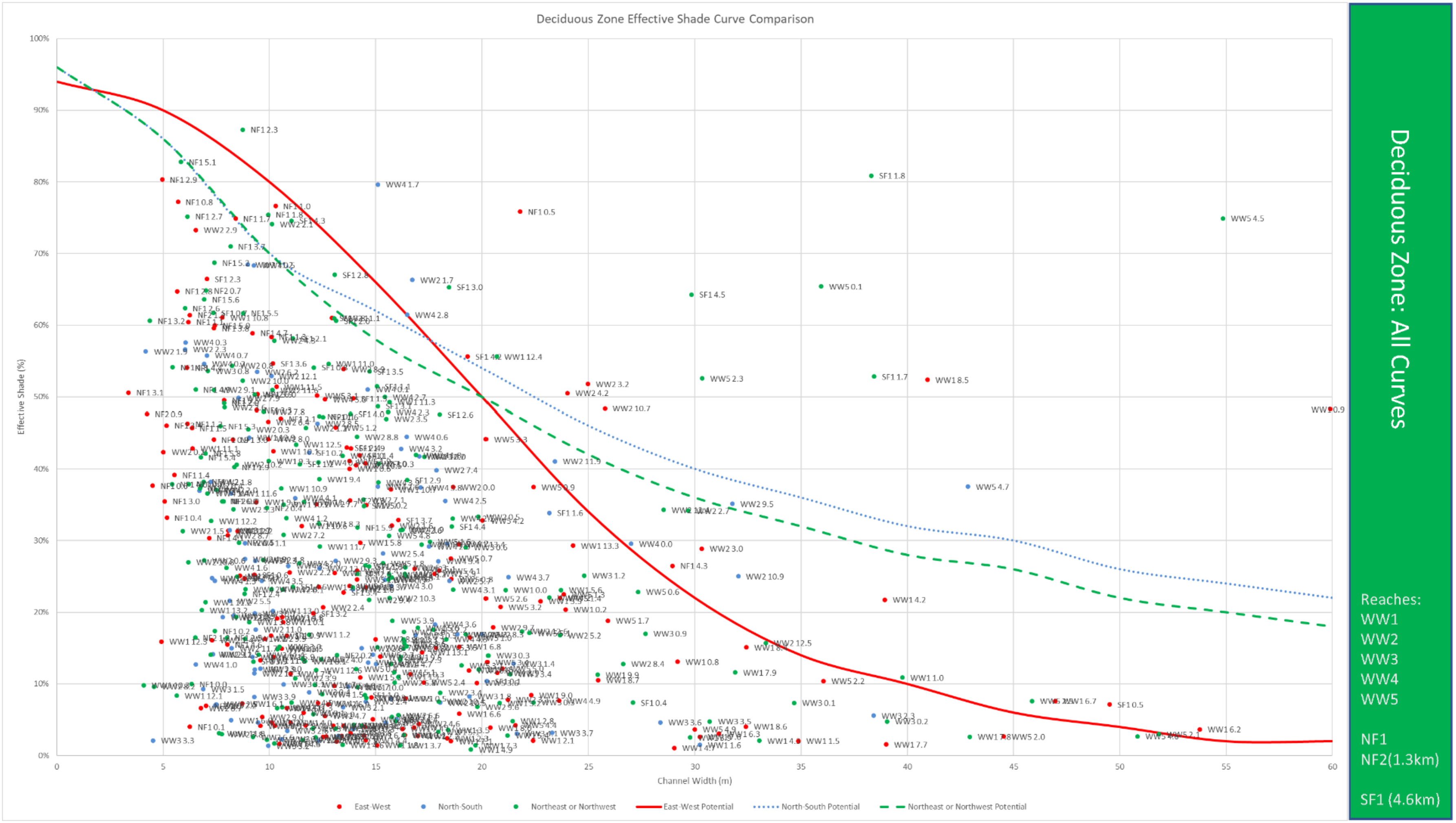

Figure 10. Deciduous zone (DZ) centerline points effective shade and channel width compared to system potential curves.

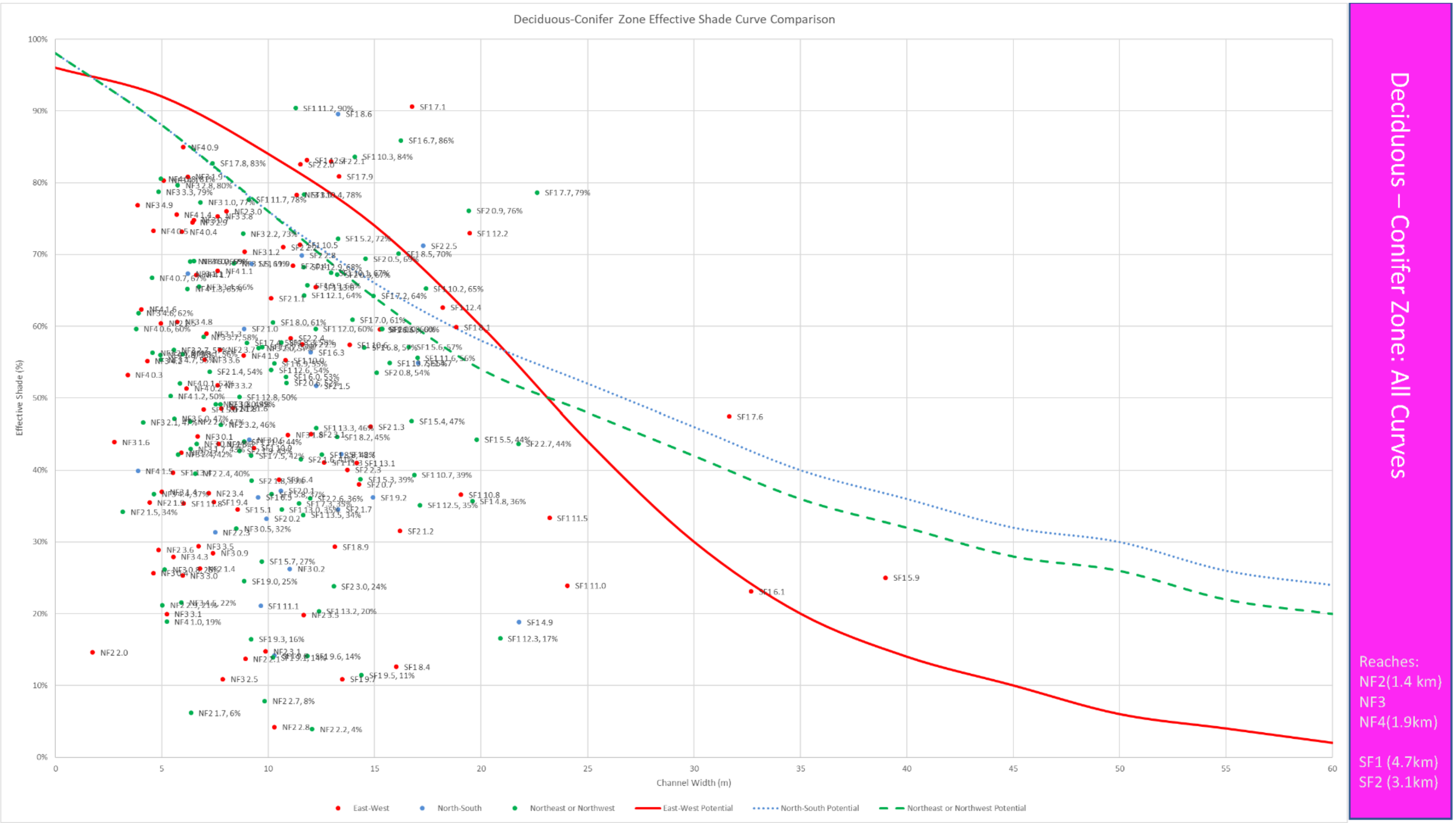

Figure 11. Deciduous-coniferous zone (DCZ) centerline points effective shade and channel width compared to system potential.curves.

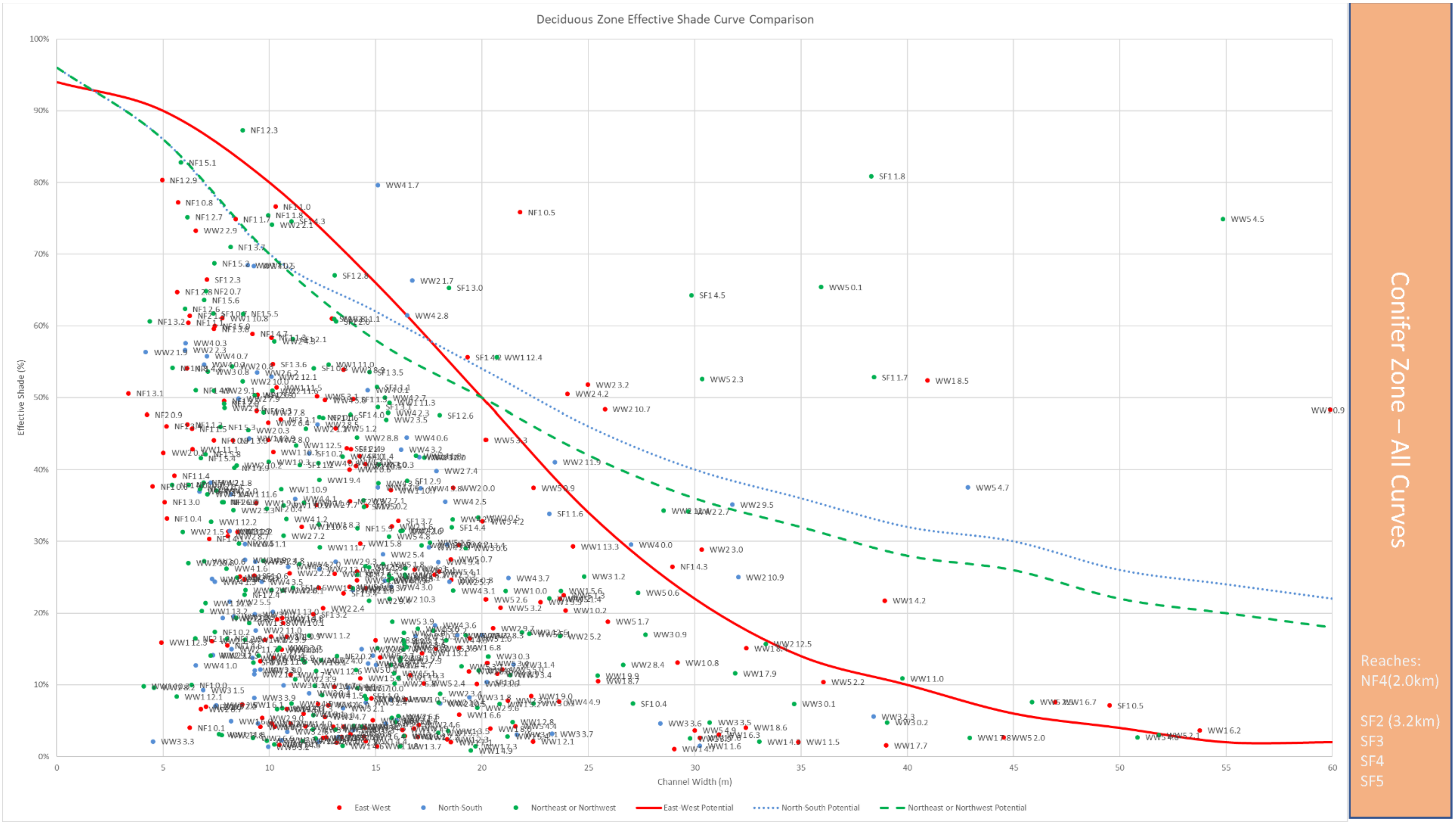

Figure 12. Coniferous zone centerline points effective shade and channel width compared to system potential curves.

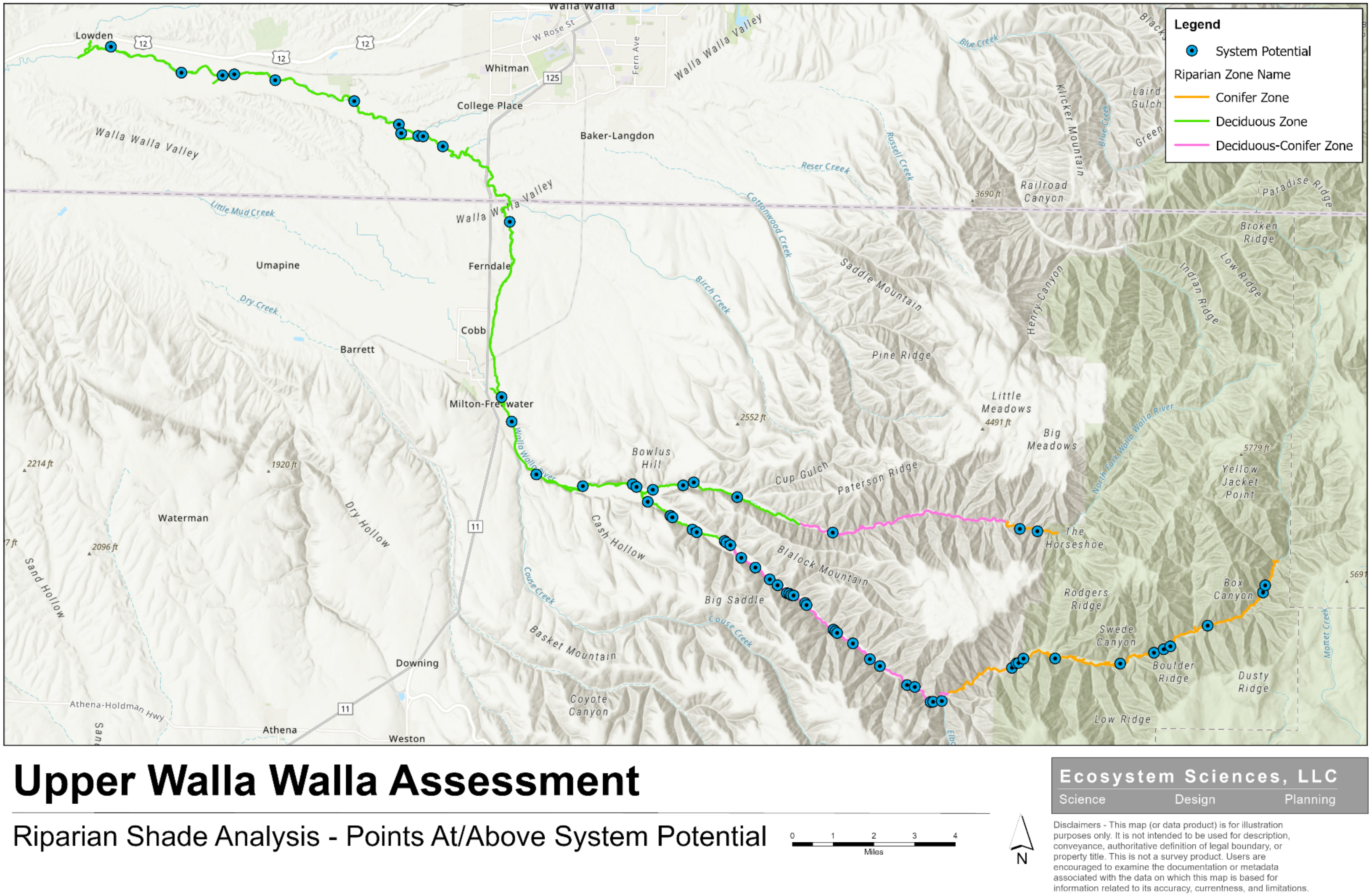

Figure 13. Centerline points that meet system potential within the project area.

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Appendix F

Upper Walla Walla Assessment

FUNCTIONAL ASSESSMENT

Technical Report

May, 2024

Technical Report

Rio Applied Science and Engineering

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Functional Assessment Technical Report

Date: May 2024

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1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations. The focal fish species of the assessment and action plan consist of the following:

1. Middle Columbia River summer steelhead (ESA-listed Threatened)
2. Columbia River bull trout (ESA-listed Threatened)
3. Spring Chinook salmon
4. Pacific lamprey

The final restoration action plan will establish a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions.

This technical appendix describes the approach and results of functional assessments of the geomorphic reaches (Appendix B) that were used to determine aquatic habitat conditions and restoration opportunities within the upper Walla Walla River watershed.

2.0 FUNCTIONAL ASSESSMENT APPROACH

The approach is based on evaluating functions in the five CTUIR River Vision Touchstone categories (Jones et al., 2008): Hydrology, Geomorphology, Connectivity, Riparian Vegetation, and Aquatic Biota. These functional categories represent the primary watershed- and reach-scale processes responsible for determining the health of stream ecosystems. Each category is comprised of one or more functional parameters that are used to quantify or describe the status of each category. The parameters are evaluated through the use of functional metrics (Table 2-1 and Table 2-2) that are calculated from all the relevant available data, measured in accessible reaches, or modeled at the watershed and reach scales. The metrics are quantifiable attributes that are associated with one or more parameters and can be used to directly or indirectly evaluate the status and trend of stream function.

2.1 FUNCTIONAL METRICS

Table 2-1. Reach-based functional assessment categories and metrics for the CTUIR River Vision Touchstones.

Touchstone Functional Category	Functional Parameter	Functional Metric
Hydrology	Base flow	Ecological Flow Attainment (%)
	Water Quality	Mean August Stream Temperature
Geomorphology	Channel Structure	Residual Pool Depth
		Riffle Width:Depth Ratio
	Channel Complexity	Pool Frequency
		Channel Unit Frequency
	LWD Transport and Storage	LWM Piece Frequency
		LWM Key Piece Frequency
		LWM Volume Frequency
	Bed Material Characterization	Riffle Area Organics and Sand (%)
		Riffle Area Gravel (%)
Connectivity	Floodplain Connectivity	Inundated Area Ratios (% of Valley Bottom)
		Artificial Floodplain Disconnection (% of Reach Length)
	Longitudinal Connectivity	Instream Barrier Burden
Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment

Table 2-1. Reach-based functional assessment categories and metrics for the CTUIR River Vision Touchstones.

Touchstone Functional Category	Functional Parameter	Functional Metric
	Shade	System Effective Shade Potential Attainment
Aquatic Biota	Habitat Availability	Multispecies Habitat Suitability Index

Table 2-2. Reach-based functional metric definitions.

Functional Metric	Functional Metric Description
Ecological Flow Attainment (%)	% of reach length meeting ecological flow target (WDOE, 2021; Stillwater Sciences, 2013); based on Rio ASE hydrology analysis (Appendix C)
Mean August Stream Temperature	% of reach length (mean of species/life stage) below the optimum temperature threshold; based on MHE analysis of NORWEST recent historic temperature scenario (Stream Temperature Appendix)
Residual Pool Depth	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Riffle Width:Depth Ratio	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Pool Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Channel Unit Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
LWM Piece Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
LWM Key Piece Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
LWM Volume Frequency	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Riffle Area Organics and Sand (%)	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Riffle Area Gravel (%)	Reach-averaged values; based on WWBWC stream survey data; benchmarks from ODFW (2017), Foster et al. (2001); Appendix B
Inundated Area Ratios (% of Valley Bottom)	Ratio of 1% annual chance flood area to the valley bottom area; based on Rio ASE modeling and analysis; Appendix B

Table 2-2. Reach-based functional metric definitions.

Functional Metric	Functional Metric Description
Artificial Floodplain Disconnection (% of Reach Length)	Ratio of the length of artificial confinement features to the reach length; based on Rio ASE analysis; Appendix B
Instream Barrier Burden	Cumulative fish passage barrier burden; based on CTUIR analysis; Fish Distribution Appendix
Vegetative Height Potential Attainment	% of the analysis area within a reach meeting the vegetative height potential (ODEQ, 2005); based on Ecosystem Sciences analysis; Appendix E
System Effective Shade Potential Attainment	% of the analysis area within a reach meeting the effective shade potential (ODEQ, 2005); based on Ecosystem Sciences analysis; Appendix E
Multispecies Habitat Suitability Index	Mean hydraulic habitat suitability index value for species/life stage in the reach; based on modeling and analysis by Rio ASE and MHE; Hydraulic Habitat Suitability Appendix

2.2 FUNCTIONAL SCORING

Functional assessments of the geomorphic reaches were used to determine aquatic habitat conditions and restoration opportunities within the upper Walla Walla River watershed. Information from the Watershed and Reach Assessments was used to score the Functional Metrics on a scale from 0.0 (absent/non-functional) to 1.0 (abundant/fully functional). The data were evaluated relative to performance standards based on regional benchmarks (ODFW, 2017; Figure 2-1), properly functioning conditions defined for salmon recovery planning in the Columbia River Basin (Hillman and Giorgi, 2002), or literature values. For many environmental attributes in general, performance standards are nonexistent, ambiguous, and not applicable to the spatial scale of interest; therefore, literature values and professional judgment are commonly used to score the relative functionality of stream conditions (Table 2-3; Hillman and Giorgi, 2002; Fischenich, 2006; Sear et al., 2009; Somerville, 2010; Harman et al., 2012; Cluer and Thorne, 2014; Palmer et al., 2014). Functional Parameter values are calculated as the average Functional Metric scores, Functional Category values are calculated as the average Functional Parameter scores, and overall reach functionality is estimated as the average of Functional Category scores. This approach helps identify the fundamental drivers of overall reach functionality and fosters comparability of functionality among reaches (Langhans et al., 2013).

Within each geomorphic reach of the project area, the Functional Metrics are scored on a scale from 0.0 (absent/non-functional) to 1.0 (abundant/fully functional) based on benchmark values (Table 2-3).

- Metrics with continuous values (e.g., % of a reach meeting ecological flow targets) use the calculated value as the metric score. For example, a reach with 80% of its length meeting the ecological flow target is scored as 0.80.

- Metrics based on discrete data (e.g., stream survey data using the ODFW (2017) protocol) are scored based on benchmarks for these data (Foster et al. 2001) that are adapted to the scale 0.0 to 1.0. The scale is divided into quartiles (0.0-0.25, 0.26-0.50, 0.51-0.75, 0.76-1.0) and the midpoint value of each quartile is used as the score for that metric value falling within that range. For example, a reach with an average Width:Depth ratio <=10 is scored as 0.88 (the mid-point of the upper quartile).

Table 3. ODFW Aquatic Inventory and Analysis Project: Habitat Benchmarks.

POOLS	UNDESIRABLE	DESIRABLE
POOL AREA (% Total Stream Area)	<10	>35
POOL FREQUENCY (Channel Widths Between Pools)	>20	5-8
RESIDUAL POOL DEPTH (m)		
SMALL STREAMS (<7m width)	<0.2	>0.5
MEDIUM STREAMS (≥ 7m and < 15m width)		
LOW GRADIENT (slope <3%)	<0.3	>0.6
HIGH GRADIENT (slope >3%)	<0.5	>1.0
LARGE STREAMS (≥15m width)	<0.8	>1.5
COMPLEX POOLS (Pools w/ LWD pieces ≥3) / km	<1.0	>2.5
RIFFLES		
WIDTH / DEPTH RATIO (Active Channel Based)		
EAST SIDE	>30	<10
WEST SIDE	>30	<15
GRAVEL (% AREA)	<15	≥35
SILT-SAND-ORGANICS (% AREA)		
VOLCANIC PARENT MATERIAL	>15	<8
SEDIMENTARY PARENT MATERIAL	>20	<10
CHANNEL GRADIENT <1.5%	>25	<12
SHADE (Reach Average, Percent)		
STREAM WIDTH <12 meters		
WEST SIDE	<60	>70
NORTHEAST	<50	>60
CENTRAL - SOUTHEAST	<40	>50
STREAM WIDTH >12 meters		
WEST SIDE	<50	>60
NORTHEAST	<40	>50
CENTRAL - SOUTHEAST	<30	>40
LARGE WOODY DEBRIS* (15cm x 3m minimum piece size)		
PIECES / 100 m STREAM LENGTH	<10	>20
VOLUME / 100 m STREAM LENGTH	<20	>30
"KEY" PIECES (>60cm dia. & ≥10m long)/100m	<1	>3
RIPARIAN CONIFERS (30m FROM BOTH SIDES CHANNEL)		
NUMBER >20in dbh/ 1000ft STREAM LENGTH	<150	>300
NUMBER >35in dbh/ 1000ft STREAM LENGTH	<75	>200

* Values for Streams in Forested Basins

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Figure 2-1. Benchmarks for stream survey data (ODFW, 2017).

2.3 MISSING DATA HANDLING

All of the available and relevant data were used to quantify the metrics. However, some of the reaches had no available data because, 1) stream surveys by WWBWC were not completed in all reaches, and 2) the Lidar data acquisition did not include the upper reaches of the North Fork Walla Walla River (NFWW River) and South Fork Walla Walla River (SFWW River). The data gaps are identified in Table 2-4.

In order to include the reaches with missing data into the functional assessment and reach prioritization, functional metric scores were assigned to the missing data reaches as follows:

- NF5: uses scores from NF4 for metrics based on Lidar data
- NF6: uses average scores from NF5 and NF7 for metrics based on stream survey data; uses scores from NF4 for metrics based on Lidar data
- NF7: uses scores from NF4 for metrics based on Lidar data
- NF8: uses scores from NF7 for metrics based on stream survey data; uses scores from NF4 for metrics based on Lidar data
- SF4: uses average scores from SF3 and SF5 for metrics based on stream survey data
- SF6: uses scores from SF5 for metrics based on Lidar data
- SF7: uses scores from SF6 for metrics based on stream survey data; uses scores from SF5 for metrics based on Lidar data
- SF8: uses scores from SF6 for metrics based on stream survey data; uses scores from SF5 for metrics based on Lidar data

Table 2-3. Functional metric performance benchmarks for scoring.

	Mid-point values of the scoring categories--assigned value for each category			
	0.125	**0.38**	**0.63**	**0.88**
	Metrics are scored on a continuous scale from 0.0 to 1.0, using the performance standards as a guide.			
Functional Metric	**absent/dysfunctional 0.0 - 0.25**	**0.26 - 0.50**	**0.51 - 0.75**	**abundant/fully functional 0.76 - 1.0**
Ecological Flow Attainment (% of reach length)	use calculated %	use calculated %	use calculated %	use calculated %
Mean August Stream Temperature (% of reach BELOW threshold)	use calculated %	use calculated %	use calculated %	use calculated %
Residual pool depth	< 50% desirable value	50 - 75% desirable value	76 - 100% desirable value	>= desirable value
Width to depth ratio	>= undesirable value (30)	20 to 30	10 to 20	<= desirable value (10)
Pool frequency (channel widths between pools)	>20 or <5	14 to 20	8 to 14	5 to 8
channel unit frequency (number of geomorphic units per km)	0 - 25% of fully functional	26 - 50% of fully functional	51 - 75% of fully functional	100%-76% of target: Channel width : units/km <3 m: 48-220 3-5 m: 70-120 5-6 m: 60-80 6-8 m: 48-70 8-15 m: 28-60 15-23 m: 6-16 23-30 m: 4-28 >30 m: 4-22
LWM piece frequency (per 100 m)	<10	10 to 15	15 to 20	>=20
Key LWM piece frequency (per 100 m)	<1	1 to 2	2 to 3	>3

Table 2-3. Functional metric performance benchmarks for scoring.

	Mid-point values of the scoring categories--assigned value for each category			
	0.125	**0.38**	**0.63**	**0.88**
	Metrics are scored on a continuous scale from 0.0 to 1.0, using the performance standards as a guide.			
	absent/dysfunctional			**abundant/fully functional**
Functional Metric	**0.0 - 0.25**	**0.26 - 0.50**	**0.51 - 0.75**	**0.76 - 1.0**
LWM volume frequency (m3 per 100 m)	<20	20 to 25	25 to 30	>=30
Riffle area (%) organics and sand	>= undesirable value (15 or 25)	18 to 15, or 11 to 15	12 to 18, or 8 to 11	<= desirable value (12 or 8)
Riffle area (%) gravel	<= undesirable value (15)	15 to 25	25 to 35	>= desirable value (35)
Valley Inundated Area % (100-y:Valley Bottom)	WW unconfined: < 18	18 to 49	49 to 79	> 79
	WW partly confined: < 37	37 to 64	64 to 91	> 91
	NF/SF partly confined: < 9	9 to 39	39 to 68	> 68
	NF/SF confined: < 36	36 to 56	56 to 75	> 75
Artificial Floodplain Disconnection (Length ratio of reach)	> .50	.20 to .50	.20 to .10	< .10
Instream Barriers Burden			<= 0.99	> 0.99
Vegetative Height Potential Attainment	use calculated %	use calculated %	use calculated %	use calculated %
System Effective Shade Potential Attainment	use calculated %	use calculated %	use calculated %	use calculated %
Multispecies Habitat Suitability Index	use calculated value	use calculated value	use calculated value	use calculated value

Table 2-4. Functional metric missing data by geomorphic reach.

	NFWW River Reaches				SFWW River Reaches				
Functional Metric	**NF5**	**NF6**	**NF7**	**NF8**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**
Ecological Flow Attainment									
Mean August Stream Temperature (% of reach below threshold)									
Residual Pool Depth		No survey		No survey	No survey			No survey	No survey
Riffle Width:Depth Ratio		No survey		No survey	No survey			No survey	No survey
Pool Frequency		No survey		No survey	No survey			No survey	No survey
Channel Unit Frequency		No survey		No survey	No survey			No survey	No survey
LWM Piece Frequency		No survey		No survey	No survey			No survey	No survey
LWM Key Piece Frequency		No survey		No survey	No survey			No survey	No survey
LWM Volume Frequency		No survey		No survey	No survey			No survey	No survey
Riffle Area Organics and Sand (%)		No survey		No survey	No survey			No survey	No survey
Riffle Area Gravel (%)		No survey		No survey	No survey			No survey	No survey
Valley Inundated Area % (100-y:Valley Bottom)	No Lidar	No Lidar	No Lidar	No Lidar			No Lidar	No Lidar	No Lidar
Artificial Floodplain Disconnection (% of Reach Length)									
Instream Barriers Burden									
Vegetative Height Potential Attainment	No Lidar	No Lidar	No Lidar	No Lidar			No Lidar	No Lidar	No Lidar
System Effective Shade Potential Attainment	No Lidar	No Lidar	No Lidar	No Lidar			No Lidar	No Lidar	No Lidar
Multispecies Habitat Suitability Index	No Lidar	No Lidar	No Lidar	No Lidar			No Lidar	No Lidar	No Lidar

3.0 FUNCTIONAL ASSESSMENT RESULTS

The summary of functional assessment results are provide in the following tables and figures:

- Functional metrics: Table 3-1
- Functional parameters: Table 3-2, Figure 3-1
- Functional categories: Table 3-3, Figure 3-2 and Figure 3-3

Table 3-1. Functional metric scores.

			Walla Walla					North Fork								South Fork							
Touchstone Functional Category	**Functional Parameter**	**Functional Metric**	**WW1**	**WW2**	**WW3**	**WW4**	**WW5**	**NF1**	**NF2**	**NF3**	**NF4**	**NF5**	**NF6**	**NF7**	**NF8**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**
Hydrology	Baseflow	Ecological Flow Attainment	0.17	0.14	0.25	0.62	1.00	1.00	0.61	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Mean August Stream Temperature (% of reach below threshold)	0.00	0.07	0.44	0.70	0.75	0.23	0.42	0.88	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Geomorphology	Channel Structure	Residual Pool Depth	0.38	0.38	0.38	0.38	0.125	0.63	0.88	0.88	0.88	0.38	0.63	0.88	0.88	0.38	0.38	0.88	0.88	0.88	0.125	0.125	0.125
		Riffle Width:Depth Ratio	0.125	0.125	0.125	0.125	0.38	0.38	0.38	0.125	0.63	0.63	0.51	0.38	0.38	0.38	0.38	0.38	0.51	0.63	0.63	0.63	0.63
	Channel Complexity	Pool Frequency	0.63	0.38	0.125	0.125	0.125	0.125	0.63	0.125	0.125	0.88	0.63	0.38	0.38	0.88	0.125	0.125	0.13	0.125	0.63	0.63	0.63
		Channel Unit Frequency	0.88	0.88	0.38	0.38	0.63	0.38	0.88	0.88	0.125	0.38	0.63	0.88	0.88	0.63	0.63	0.63	0.38	0.125	0.63	0.63	0.63
	LWM Transport and Storage	LWM Piece Frequency	0.125	0.38	0.125	0.125	0.38	0.125	0.125	0.125	0.125	0.125	0.25	0.38	0.38	0.125	0.125	0.125	0.25	0.38	0.38	0.38	0.38
		LWM Key Piece Frequency	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.25	0.38	0.38	0.125	0.125	0.125	0.13	0.125	0.38	0.38	0.38
		LWM Volume Frequency	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.38	0.63	0.63	0.125	0.125	0.125	0.13	0.125	0.125	0.125	0.125
	Bed Material Characterization	Riffle Area Organics and Sand (%)	0.88	0.88	0.88	0.88	0.63	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.63	0.125	0.50	0.88	0.88	0.88	0.88
		Riffle Area Gravel (%)	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.63	0.63	0.63	0.63	0.63	0.88	0.88	0.63	0.76	0.88	0.63	0.63	0.63
Connectivity	Floodplain Connectivity	Valley Inundated Area % (100-y:Valley Bottom)	0.63	0.38	0.125	0.125	0.38	0.38	0.63	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.63	0.38	0.63	0.63	0.63	0.63	0.63
		Artificial Floodplain Disconnection (% of Reach Length)	0.125	0.125	0.125	0.125	0.125	0.125	0.88	0.38	1.00	1.00	1.00	1.00	1.00	0.125	0.88	1.00	1.00	1.00	1.00	1.00	1.00
	Longitudinal Connectivity	Instream Barriers Burden	0.88	0.88	0.88	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment	0.06	0.1	0.01	0.04	0.09	0.06	0.03	0.2	0.24	0.24	0.24	0.24	0.24	0.14	0.22	0.31	0.26	0.28	0.28	0.28	0.28
	Shade	System Effective Shade Potential Attainment	0.04	0.05	0.00	0.04	0.08	0.07	0.03	0.00	0.04	0.04	0.04	0.04	0.04	0.17	0.11	0.05	0.09	0.04	0.04	0.04	0.04
Aquatic Biota	Habitat Suitability	Multispecies Habitat Suitability Index	0.50	0.47	0.44	0.43	0.41	0.42	0.38	0.39	0.37	0.37	0.37	0.37	0.37	0.33	0.38	0.41	0.42	0.44	0.44	0.44	0.44

Table 3-2. Functional parameter scores.

			Walla Walla					North Fork								South Fork							
Touchstone Functional Category	**Functional Parameter**	Functional Metric	**WW1**	**WW2**	**WW3**	**WW4**	**WW5**	**NF1**	**NF2**	**NF3**	**NF4**	**NF5**	**NF6**	**NF7**	**NF8**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**
Hydrology	Baseflow	Ecological Flow Attainment Mean August Stream Temperature (% of reach below threshold)	0.08	0.10	0.34	0.66	0.88	0.61	0.52	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Geomorphology	Channel Structure	Residual Pool Depth Riffle Width:Depth Ratio	0.25	0.25	0.25	0.25	0.25	0.51	0.63	0.50	0.76	0.51	0.57	0.63	0.63	0.38	0.38	0.63	0.69	0.76	0.38	0.38	0.38
	Channel Complexity	Pool Frequency Channel Unit Frequency	0.76	0.63	0.25	0.25	0.38	0.25	0.76	0.50	0.13	0.63	0.63	0.63	0.63	0.76	0.38	0.38	0.25	0.13	0.63	0.63	0.63
	LWM Transport and Storage	LWM Piece Frequency LWM Key Piece Frequency LWM Volume Frequency	0.13	0.21	0.13	0.13	0.21	0.13	0.13	0.13	0.13	0.13	0.29	0.46	0.46	0.13	0.13	0.13	0.17	0.21	0.30	0.30	0.30
	Bed Material Characterization	Riffle Area Organics and Sand (%) Riffle Area Gravel (%)	0.88	0.88	0.88	0.88	0.76	0.88	0.88	0.88	0.76	0.76	0.76	0.76	0.76	0.88	0.76	0.38	0.63	0.88	0.76	0.76	0.76
Connectivity	Floodplain Connectivity	Valley Inundated Area % (100-y:Valley Bottom) Artificial Floodplain Disconnection (% of Reach Length)	0.38	0.25	0.13	0.13	0.25	0.25	0.76	0.38	0.69	0.69	0.69	0.69	0.69	0.25	0.76	0.69	0.82	0.82	0.82	0.82	0.82
	Longitudinal Connectivity	Instream Barriers Burden	0.88	0.88	0.88	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment	0.06	0.10	0.01	0.04	0.09	0.06	0.03	0.20	0.24	0.24	0.24	0.24	0.24	0.14	0.22	0.31	0.26	0.28	0.28	0.28	0.28
	Shade	System Effective Shade Potential Attainment	0.04	0.05	0.00	0.04	0.08	0.07	0.03	0.00	0.04	0.04	0.04	0.04	0.04	0.17	0.11	0.05	0.09	0.04	0.04	0.04	0.04
Aquatic Biota	Habitat Suitability	Multispecies Habitat Suitability Index	0.50	0.47	0.44	0.43	0.41	0.42	0.38	0.39	0.37	0.37	0.37	0.37	0.37	0.33	0.38	0.41	0.42	0.44	0.44	0.44	0.44

Table 3-3. Functional category scores.

			Walla Walla					North Fork								South Fork							
Touchstone Functional Category	Functional Parameter	Functional Metric	**WW1**	**WW2**	**WW3**	**WW4**	**WW5**	**NF1**	**NF2**	**NF3**	**NF4**	**NF5**	**NF6**	**NF7**	**NF8**	**SF1**	**SF2**	**SF3**	**SF4**	**SF5**	**SF6**	**SF7**	**SF8**
Hydrology	Baseflow	Ecological Flow Attainment																					
		Mean August Stream Temperature (% of reach below threshold)	0.08	0.10	0.34	0.66	0.88	0.61	0.52	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Geomorphology	Channel Structure	Residual Pool Depth																					
		Riffle Width:Depth Ratio																					
	Channel Complexity	Pool Frequency																					
		Channel Unit Frequency																					
	LWM Transport and Storage	LWM Piece Frequency																					
		LWM Key Piece Frequency																					
		LWM Volume Frequency																					
	Bed Material Characterization	Riffle Area Organics and Sand (%)																					
		Riffle Area Gravel (%)	0.50	0.49	0.38	0.38	0.40	0.44	0.60	0.50	0.44	0.50	0.56	0.62	0.62	0.54	0.41	0.38	0.44	0.49	0.51	0.51	0.51
Connectivity	Floodplain Connectivity	Valley Inundated Area % (100-y:Valley Bottom)																					
		Artificial Floodplain Disconnection (% of Reach Length)																					
	Longitudinal Connectivity	Instream Barriers Burden	0.63	0.57	0.50	0.38	0.44	0.44	0.69	0.51	0.66	0.66	0.66	0.66	0.66	0.44	0.69	0.66	0.72	0.72	0.72	0.72	0.72
Riparian Vegetation	Plant Community Type	Vegetative Height Potential Attainment																					
	Shade	System Effective Shade Potential Attainment	0.05	0.075	0.005	0.04	0.085	0.065	0.03	0.1	0.14	0.14	0.14	0.14	0.14	0.155	0.165	0.18	0.175	0.16	0.16	0.16	0.16
Aquatic Biota	Habitat Suitability	Multispecies Habitat Suitability Index	0.50	0.47	0.44	0.43	0.41	0.42	0.38	0.39	0.37	0.37	0.37	0.37	0.37	0.33	0.38	0.41	0.42	0.44	0.44	0.44	0.44
Reach Composite Functionality Scores			0.35	0.34	0.33	0.38	0.44	0.40	0.44	0.49	0.52	0.53	0.55	0.56	0.56	0.49	0.53	0.53	0.55	0.56	0.57	0.57	0.57

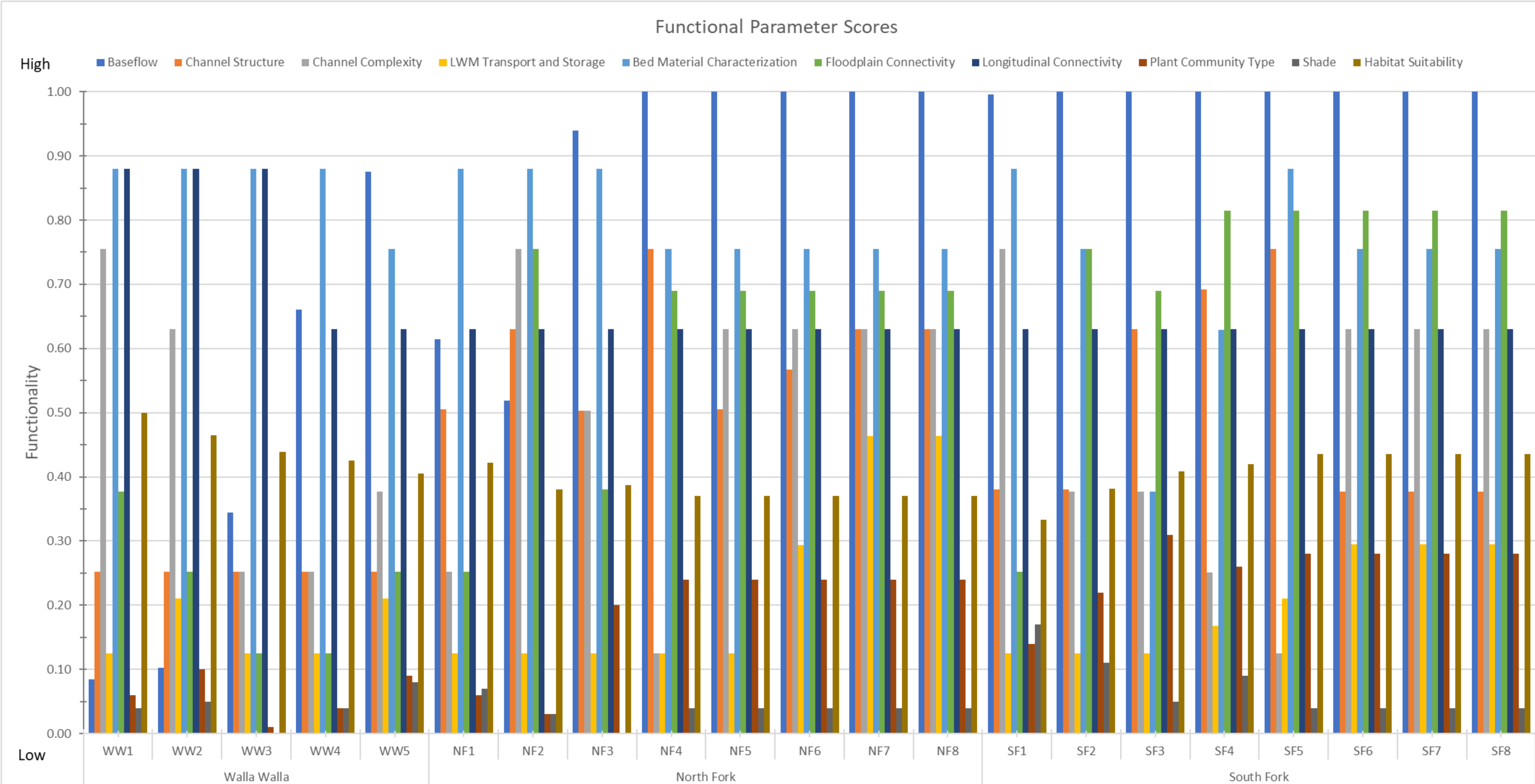

Figure 3-1. Functional parameter scores by reach.

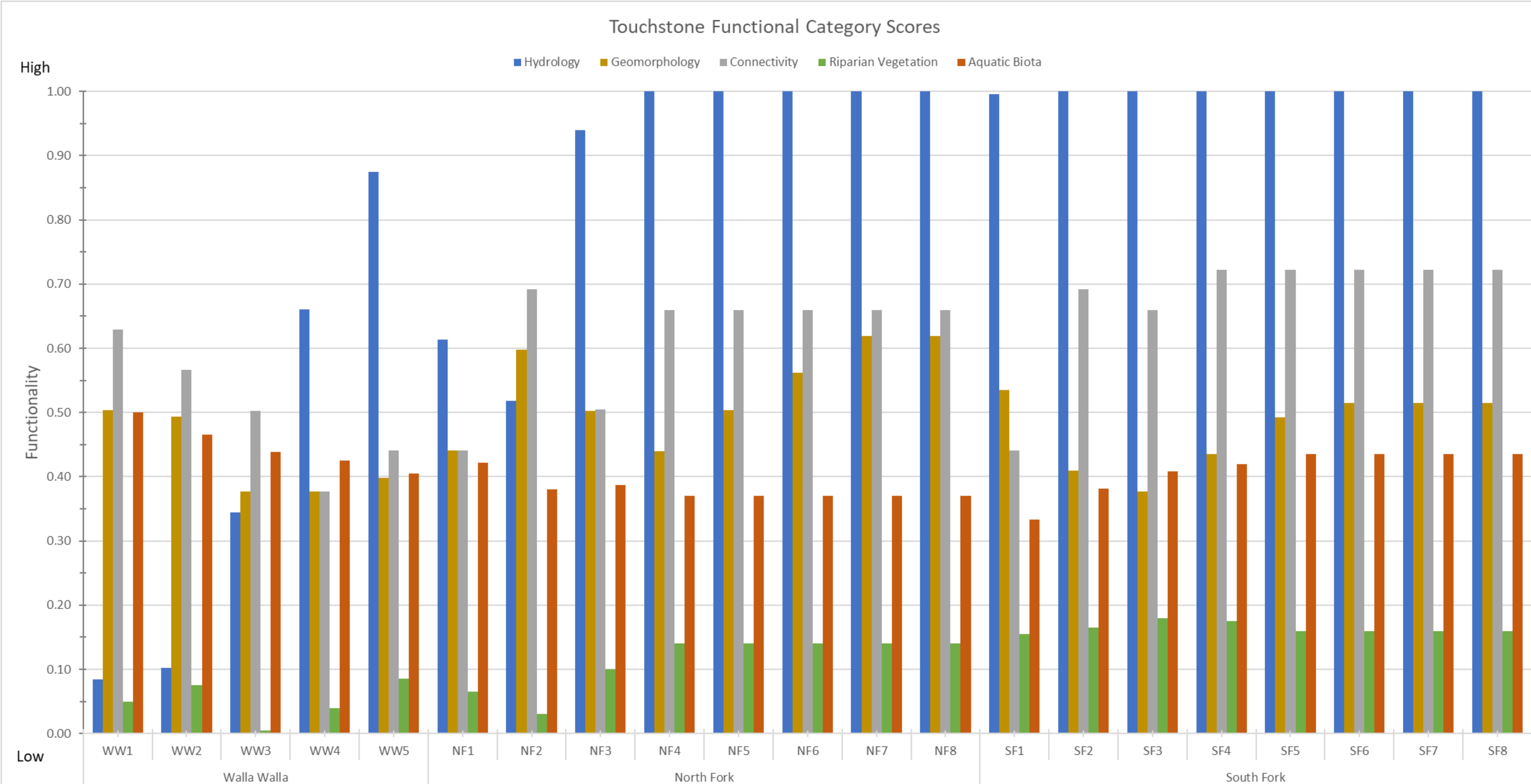

Figure 3-2. Functional category scores by reach.

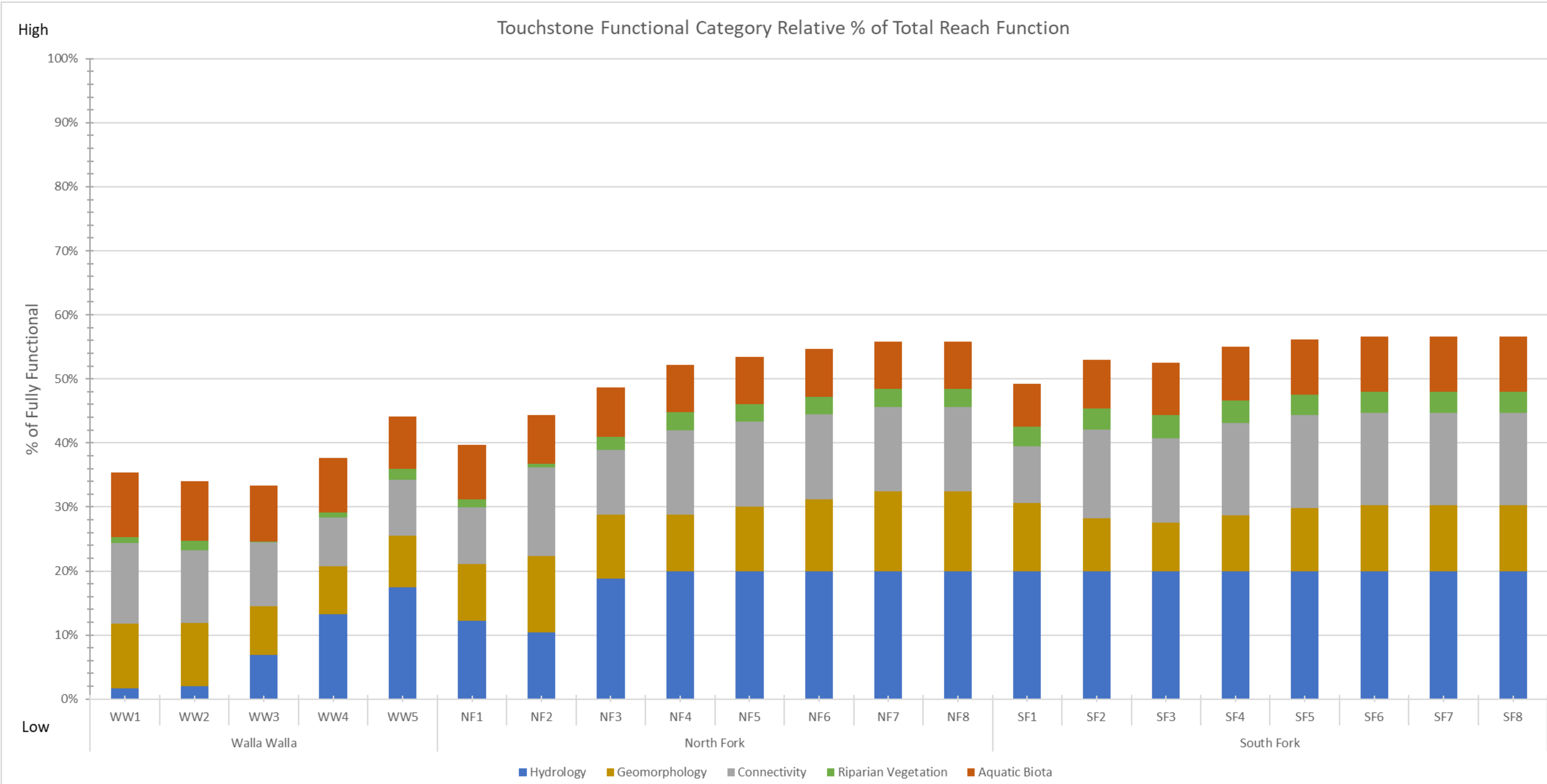

Figure 3-3. Composite reach functionality scores.

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Appendix G

Upper Walla Walla Assessment

FISH STATUS, DISTRIBUTION, AND LIMITING FACTORS

Technical Report

May 23, 2024

Technical Report

Ecosystem Sciences

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MOUNT HOOD ENVIRONMENTAL

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March 29, 2024

Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Project No.: 001-053-004-01

Technical Report

Subject: Historic and Contemporary Fish Distribution, Status, and Limiting Factors - Upper Walla Walla Watershed

Final Date: May 23, 2024

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1.0 BACKGROUND

This qualitative biological assessment focuses on the historic and contemporary distribution and status of spring-run Chinook salmon (*Oncorhynchus tshawytscha*; hereafter Chinook salmon), Middle Columbia River summer steelhead (*O. mykiss*; hereafter steelhead; ESA-listed threatened), Columbia River bull trout (*Salvelinus confluentus*; ESA-listed threatened), and Pacific lamprey (*Entosphenus tridentata*) in the Upper Walla Walla watershed. Following is a description of previously identified limiting factors within the Upper Walla Walla watershed, which in many cases, are interrelated and shared among focal species.

2.0 SPRING-RUN CHINOOK SALMON

2.1 DISTRIBUTION

There are historical accounts of spring-run Chinook salmon occurring in the Upper Walla Walla River watershed in Mill Creek, the Walla Walla River, the North Fork Walla Walla River, the South Fork Walla Walla River, and many Upper Walla Walla River watershed tributaries (Swindell, 1942; Volkman, 2005). The contemporary Upper Walla Walla River watershed Chinook salmon distribution spans the mainstem Walla Walla River, the South Fork Walla Walla River, and Mill Creek (Mahoney et al., 2009; Mendel et al., 2014, 2007).

Chinook salmon are documented to have historically spawned in approximately the upper 40 km of the mainstem Walla Walla River (Fulton, 1968). Documentation of spawning runs, habitat attributes, and the contemporary spawning distribution indicate Mill Creek, the North Fork Walla Walla River, South Fork Walla Walla River, and various Walla Walla River tributaries were also likely important Chinook salmon spawning grounds historically (Fulton, 1968; Mahoney et al., 2009; Mendel et al., 2014, 2007; Swindell, 1942; Volkman, 2005; Yun et al., 2016). The contemporary spawning distribution includes Mill Creek above Mill Creek Diversion Dam (also referred to as Bennington Dam), the mainstem Walla Walla River above Nursery Bridge Dam, and the South Fork Walla Walla River (Mendel et al., 2014, 2007). There is no evidence that Chinook salmon currently spawn in the North Fork Walla Walla River (Mahoney et al., 2009; Mendel et al., 2014).

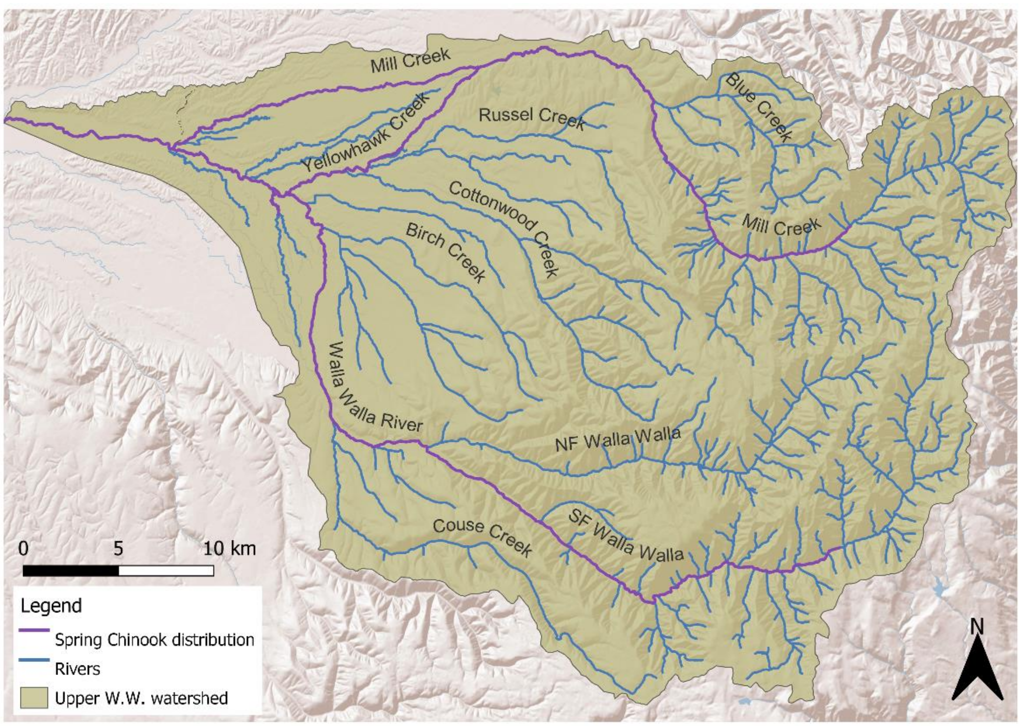

Figure 1: Current estimated distribution of spring-run Chinook salmon in the Upper Walla Walla watershed.

2.2 POPULATION STATUS

The contemporary Upper Walla Walla River watershed Chinook salmon population size is smaller than historical estimates and natural-origin adult abundance is lower than the conservation goal of 1,100 adults (Mahoney et al., 2009). The abundance of natural-origin Chinook salmon shows a slightly increasing trend, but the abundance of hatchery-origin upstream migrating adults shows a decreasing trend (Mahoney et al., 2009; Mendel et al., 2014, 2007; Yun et al., 2016).

There are accounts of large Chinook salmon runs in the Walla Walla River watershed (Swindell, 1942; Volkman, 2005). The last sizeable run in the Walla Walla River watershed took place in 1925 and by the late 1950s Chinook salmon were extirpated, largely due to the construction of Nine Mile dam in the lower Walla Walla River (ACOE, 1997; Mahoney et al., 2009; Mendel et al., 2000; Nielson, 1950; Van Cleve and Ting, 1960). Movement of Chinook salmon into Mill Creek was blocked between 1942 and 1985 after the construction of the Mill Creek Diversion Dam (rkm 18.5) and Mill Creek Division Dam (rkm 16.9) until fish ladders were installed at both dams in 1985 (Mahoney et al., 2009; Martin et al., 1992). Reintroductions of adults and smolts to the South Fork Walla Walla River and Mill Creek started in 2000 and 2005, respectively (Mahoney et al., 2009; Mendel et al., 2007).

Counts of upstream migrating adult Chinook salmon at Nursery Bridge Dam are used as the primary index of run sizes and population abundance in the Walla Walla River watershed. Additional counts have been made at Mill Creek Diversion Dam, Yellowhawk Creek Weir, and Mill Creek Division Dam (Mahoney et al., 2009). Smolt abundance was monitored in the Upper Walla Walla River watershed using two traps, one in the Upper Walla Walla River and one in Mill Creek (Mendel et al., 2014). Upstream migrating adult Chinook salmon were first documented at Nursery Bridge Dam in 2000 and in upper Mill Creek at the Mill Creek Diversion Dam in 2004 (Mahoney et al., 2009; Mendel et al., 2007). In 2004, the first adults returned as progeny from initial reintroductions (Mahoney et al., 2009). From 2000 to 2004, a total of 84 upstream migrating adult Chinook salmon returned to the Upper Walla Walla River watershed and were likely strays from the Umatilla River (Mahoney et al., 2009). Counts of upstream migrating natural-origin Chinook salmon at Nursery Bridge Dam (2000 - 2013) ranged from 2 (2003) to 293 (2011), exhibited a positive trend, and a 10-year geometric mean of 142 (Mahoney et al., 2009; Mendel et al., 2014, 2007). Counts of hatchery-origin Chinook salmon at Nursery Bridge Dam (2007 - 2013) ranged from 29 (2013) to 932 (2010), had a negative trend, and a 7-year geometric mean of 204 (Mendel et al., 2014). Total counts of upstream migrating adults (natural-origin plus hatchery-origin fish) declined from 2010 to 2013, primarily driven by a reduction in hatchery-origin counts (Mendel et al., 2014). The abundance of naturally produced smolts in the Walla Walla River basin has been stable (2005 - 2013) and the smolt-to-adult survival rate of natural-origin Chinook salmon exhibited a positive trend (2002 - 2010) (Mendel et al., 2014). Counts of upstream migrating adult Chinook salmon returning to Mill Creek (counted at Mill Creek Diversion Dam, Yellowhawk Creek Weir, and Mill Creek Division Dam from 2004 to 2008) ranged from a low of 0 (2007) to a high of 68 (2004) with a 5-year geometric mean of 21.8 (± 33.0) (Mahoney et al., 2009).

Redd counts in sections of the upper mainstem of the Walla Walla River, South Fork Walla Walla River, and Mill Creek began in 2000 and sampling expanded in 2005 to include the entire spring-run Chinook salmon production area in the Upper Walla Walla River watershed (Mahoney et al., 2009; Mendel et al., 2014). During 2000 - 2008, the number of redds at sampling locations generally increased in the South Fork Walla Walla River and upper mainstem Walla Walla River and the number of redds in Mill Creek remained relatively constant (Mahoney et al., 2009).

3.0 MIDDLE COLUMBIA RIVER SUMMER STEELHEAD

3.1 DISTRIBUTION

Historically, steelhead occupied much of the Upper Walla Walla River watershed (Mendel et al., 2014; Mendel et al., 2001; Washington Department of Fisheries et al., 1993). The steelhead spawning distribution has been dramatically reduced in the Lower Walla Walla River watershed, but much of the historical spawning grounds in the Upper Walla Walla River watershed are still used, although habitat degradation has likely eliminated spawning habitat in some areas (Kuttel, 2001; Mahoney et al., 2009; NOAA, 2021). Anadromous life history was not expressed by O. mykiss in Mill Creek between 1942 and 1990, the period when Mill Creek Division Dam and Mill Creek Diversion Dam prevented movement of fish further upstream (Martin et al., 1992). Fish ladders were installed at both dams in 1985 and steelhead were first documented returning to Mill Creek above the Mill Creek Diversion Dam in 1990 (Mahoney et al., 2009; Martin et al., 1992). Spawning occurs in the mainstem Walla Walla River from Nursery Bridge Dam downstream to at least Mill Creek and possibly below, in many Walla Walla River tributaries (e.g., Couse Creek, Yellowhawk Creek, and Cottonwood Creek), the South Fork Walla Walla River, the North Fork Walla Walla River, and Mill Creek above Mill Creek Diversion Dam and at its confluence with the Walla Walla River (Carmichael and Taylor, 2010; Mahoney et al., 2009; Mendel et al., 2014; Yun et al., 2016). Mendel et al. (2014) report that steelhead spawn in several Mill Creek tributaries, but do not specify which tributaries spawning occurs in or provide empirical evidence to support this claim. Likely, steelhead spawning historically occurred throughout most of Mill Creek, but does not currently occur throughout most of the section downstream of Mill Creek Diversion Dam, likely due to habitat degradation from the Mill Creek Flood Control Project, agriculture, livestock grazing, and urbanization (Mahoney et al., 2009; NOAA, 2021; Underwood et al., 1995).

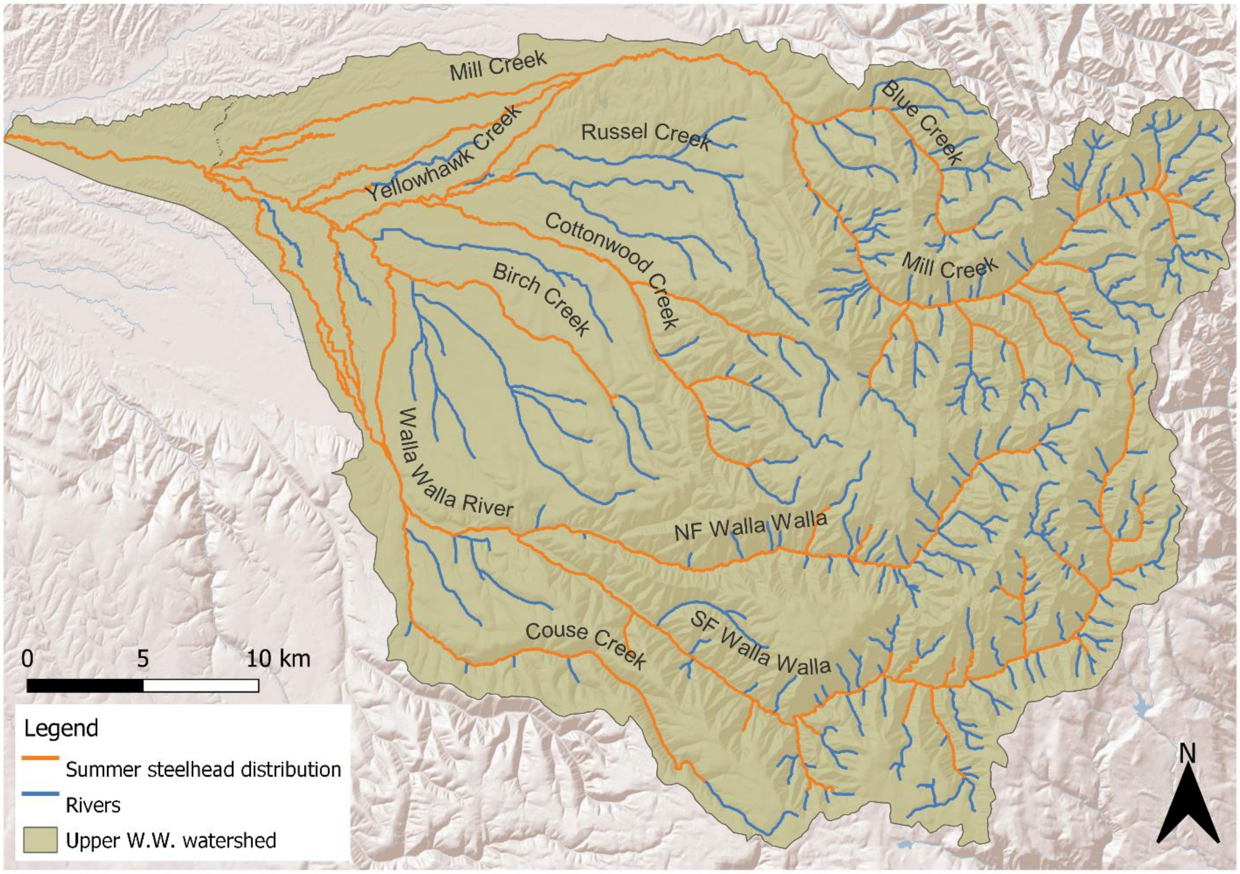

Figure 2: Current estimated distribution of Middle Columbia River summer-run steelhead in the Upper Walla Walla watershed.

3.2 POPULATION STATUS

The contemporary steelhead population in the Upper Walla Walla River watershed is smaller than historical estimates, time-series data suggest abundance is decreasing, and both productivity (recruits per spawner) and adult abundance in the Walla Walla River watershed are below ESA minimum recovery goals (Mendel et al., 2014; Mendel et al., 2001; NOAA, 2021, 2009; Washington Department of Fisheries et al., 1993; Yun et al., 2016) (ODFW salmon and steelhead recovery tracker).

Counts of upstream migrating adults at Nursery Bridge Dam are used as the primary index of steelhead run sizes and population abundance in the Walla Walla River watershed. Fish counts at Nursery Bridge Dam do not include returns to important spawning areas in the Upper Walla Walla River watershed such as Mill Creek, Yellowhawk Creek, and Cottonwood Creek or returns to the Lower Walla Walla River watershed. During the period of 1993 - 2013, the Walla Walla River watershed steelhead population was inferred to be stable based on counts of upstream migrating adults at Nursery Bridge Dam (Carmichael and Taylor, 2010; Mahoney et al., 2009; Mendel et al., 2014). During 2011-2019, upstream migrating adult counts at Nursery Bridge Dam exhibited a negative trend and the 10-year geometric mean of upstream migrating adults decreased, indicative of declining steelhead abundance in the Upper Walla Walla River watershed (Mendel et al., 2014; NOAA, 2021) (ODFW salmon and steelhead recovery tracker). Five-year mean counts of hatchery-origin upstream migrating adults were less than 4% from 1993 - 2014, but the most recent 5-year mean count of hatchery origin upstream migrating adults (2015 - 2019) was 13% (Carmichael and Taylor, 2010; Mendel et al., 2014) (ODFW salmon and steelhead recovery tracker). Mahoney et al. (2009) conducted partial counts of returning steelhead (not all fish could be counted due to logistical constraints) on upper Yellowhawk Creek (at Yellowhawk weir) and Mill Creek (at Mill Creek Division Dam and Mill Creek Diversion Dam) during 1990 - 2005. Counts ranged from 1 fish in 1998 to 57 fish in 2001 (Mahoney et al., 2009). The 16-year mean return was 21.6 adults, with a 13.9% mean return of hatchery-origin upstream migrating adults. Downstream migrating smolts trapped in the Upper Walla Walla River showed a positive trend during 2009 - 2013 and adult-to-adult returns (based on counts at Nursery Bridge Dam) were stable during 1993 - 2006 (Mendel et al., 2014).

The ESA minimum recovery abundance goal for the Walla Walla River watershed is 1,000 adults and the minimum productivity goal is 1.35 (Washington Department of Fisheries et al., 1993). The adult population size has been consistently estimated to be below the ESA recovery goal and the most recent 10-year (2010 - 2019) geometric mean of natural-origin steelhead spawners available is 713 NOAA (2021) (ODFW salmon and steelhead recovery tracker). Productivity has fluctuated above and below the ESA recovery goal and the most recent 20-year (1993 - 2012) geometric mean productivity estimate available for the Walla Walla River watershed steelhead population is 0.9873, below the minimum productivity goal (Mahoney et al., 2009; Mendel et al., 2014; NOAA, 2021) (ODFW salmon and steelhead recovery tracker).

4.0 COLUMBIA RIVER BULL TROUT

4.1 DISTRIBUTION

Historically, bull trout likely occurred throughout most of the Upper Walla Walla River watershed but are now largely absent from much of the mainstem Walla Walla River and highly anthropogenically modified reaches within the Upper Walla Walla River watershed, such as Mill Creek below the Mill Creek Diversion Dam and the mainstem Walla Walla River downstream of rkm 75 (Barrows et al., 2014; Buchanan et al., 1997; Howell et al., 2016; Mendel et al., 2007). Fluvial and resident bull trout persist in the upper portion of the mainstem Walla Walla River, in the North Fork and South Fork Walla Walla River, and Mill Creek (Al-Chokhachy et al., 2005; Anglin et al., 2009; Buchanan et al., 1997; Howell et al., 2016; Mahoney et al., 2009; Martin et al., 1992; Mendel et al., 2007; Underwood et al., 1995; Yun et al., 2016).

Fluvial bull trout exhibit substantial movement and seasonal differences in distribution and habitat use in the Walla Walla River watershed. Fluvial bull trout over-winter in the upper mainstem Walla Walla River and the lower reaches of the North Fork and South Fork Walla Walla River and Walla Walla River tributaries such as Mill Creek from December through June, summer rearing and the upstream spawning migration occurs from June through September, and the fall return to rearing areas occurs in October and November (Anglin et al., 2009; Howell et al., 2016). During periods of low flow, bull trout are mostly limited to the upper portions of the Upper Walla Walla River watershed subbasins due to high water temperatures in the lower reaches (Al-Chokhachy and Budy, 2007; Mendel et al., 2007). Bull trout move between the Walla Walla River basin and the Columbia River system and different subbasins with the Walla Walla River watershed, such as the South Fork Walla Walla River and Mill Creek (Anglin et al., 2009; Howell et al., 2016; Newlon, 2018).

The historical bull trout spawning distribution in the Upper Walla Walla River watershed is not documented prior to 1990 (Buchanan et al., 1997; Martin et al., 1992). However, habitat degradation and declines in the spawning distributions of steelhead and Chinook salmon in the Upper Walla Walla River watershed suggests the bull trout spawning distribution has likely shrunk (Buchanan et al., 1997; Jacobs et al., 2009; Mahoney et al., 2009; Schaller et al., 2014). Contemporary bull trout spawning occurs in Mill Creek and the South Fork Walla Walla River (Barrows et al., 2014; Budy et al., 2006; Yun et al., 2016). Redd counts have been consistently higher in the South Fork Walla Walla River than in Mill Creek from 1990 to 2007 (Barrows et al., 2014; Conner et al., 2014). In Mill Creek, much of the spawning is concentrated between Deadman Creek and North Fork Mill Creek, with spawning also occurring in several Mill Creek tributaries, including Bull Creek, Deadman Creek, Paradise Creek, Broken Creek, and Low Creek (Buchanan et al., 1997; Howell et al., 2016; Jacobs et al., 2009; Martin et al., 1992; Mendel et al., 2007; Underwood et al., 1995). Spawning in the South Fork Walla Walla River watershed primarily occurs between Table Creek and Reser Creek and in the lower portions of Reser Creek and Skiphorton Creek (Al-Chokhachy et al., 2005; Buchanan et al., 1997; Budy et al., 2017). Spawning may occur in the North Fork Walla Walla River, but requires verification

(Barrows et al., 2014). Figure 4.1 shows the current estimated distribution of bull trout in the Upper Walla Walla watershed according to StreamNet (https://www.streamnet.org).

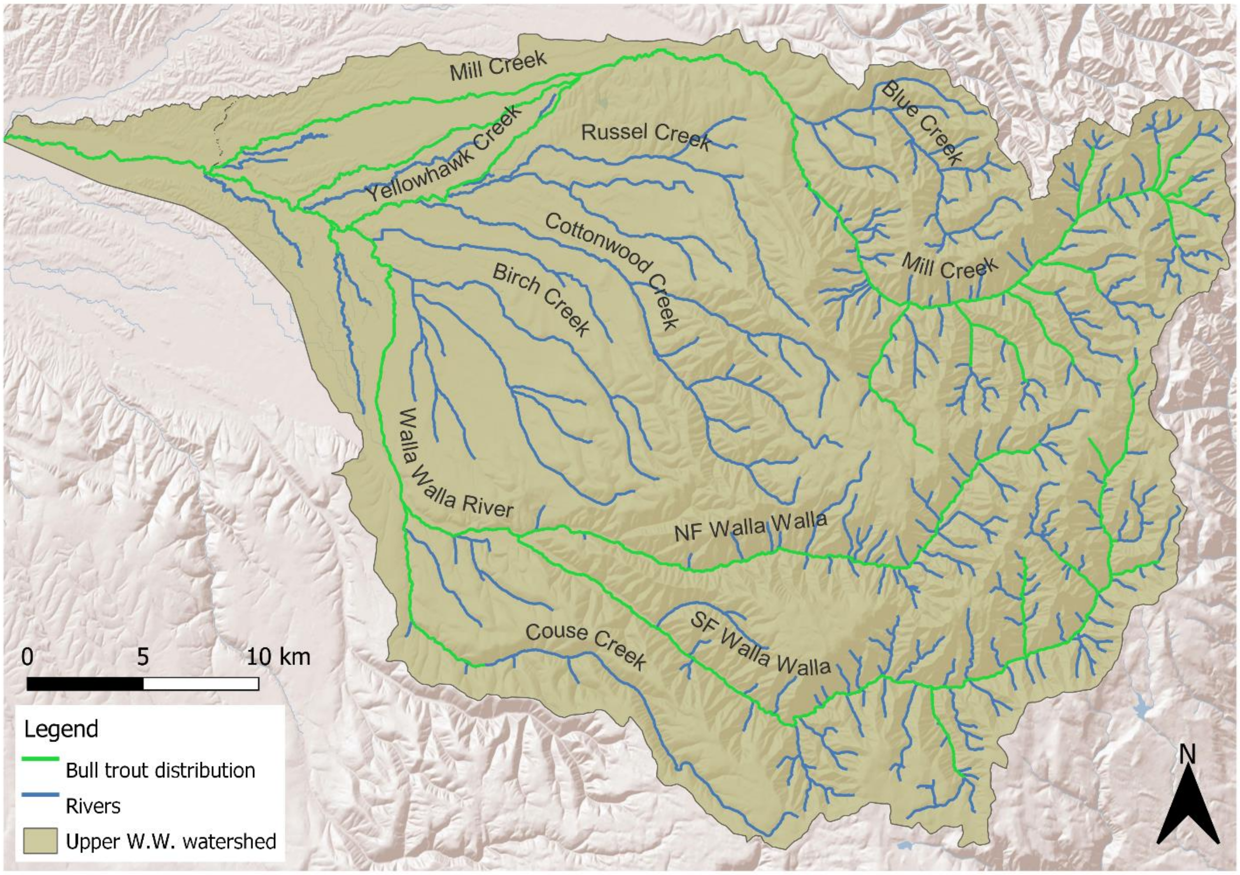

Figure 3: Current distribution of bull trout in the Upper Walla Walla watershed.

4.2 POPULATION STATUS

Historical bull trout abundance in the Upper Walla Walla River watershed is poorly documented, but habitat degradation and putative decreases in the bull trout distribution in the Upper Walla Walla River watershed suggest a corresponding reduction in population size. Contemporary mark-recapture and redd count data indicate that the bull trout population in the Walla Walla River watershed is stable.

Bull trout redd counts in Mill Creek increased during 1990 - 1994, declined slightly during 1994 - 2007, and were most abundant in 2000 and 2001 (Mahoney et al., 2009; Martin et al., 1992; Mendel et al., 2007; Underwood et al., 1995). In the South Fork Walla Walla River redd counts increased from 1994 until 2001, declined again until 2007, increased from 2007 - 2009, then declined until 2011 (Al-Chokhachy et al., 2005; Barrows et al., 2014; Budy et al., 2017; Mahoney et al., 2009). Upstream migrating adult counts at Nursery Bridge Dam showed a slightly positive trend from 2000 to 2008 and a strongly positive trend from 2008 to 2013, with counts ranging between a low of 20 in 2000 and a high of 416 in 2011 (Mendel et al., 2014).

Upstream migrating adult counts during 2004 - 2008 for upper Mill Creek (counts from Yellowhawk Weir, Mill Creek Division Dam, and Mill Creek Diversion Dam) ranged between a low of three and a high of 20 adults (not sufficient data for trend analysis) (Mahoney et al., 2009). A mark-recapture study on Mill Creek bull trout during 1998 - 2009 found that adult abundance was stable during 1998 - 2005, then declined 63% during 2006 - 2010, driven primarily by a reduction in adult returns (Howell et al., 2016). A mark-recapture study in the South Fork Walla Walla River during 2002 - 2011 inferred a population growth rate of 1.01 (95% confidence interval = 0.84-1.20), indicating a stable population (Barrows et al., 2014; Budy et al., 2017). However, the adult population was dominated by small adults, and the contribution of large adults to total biomass declined during the study period (Budy et al., 2017).

5.0 PACIFIC LAMPREY

5.1 DISTRIBUTION

Pacific lamprey once occurred throughout much of the Upper Walla Walla River watershed (Jackson et al., 1997; Swindell, 1942). Pacific lamprey now appear to be extirpated from their entire historical range within the Upper Walla Walla River watershed (Close, 2000; Harris and Jolley, 2017; Jackson et al., 1997; Kostow, 2002; Moser and Close, 2003).

5.2 POPULATION STATUS

There are no quantitative data available on the historical abundance of Pacific lamprey in the Upper Walla Walla River watershed. However, interviews with tribal members and fisheries biologists and the historical importance of several locations within the Walla Walla River watershed for Pacific lamprey harvest by the CTUIR, including the North and South Forks of the Walla Walla River and nearby Skiphorton Creek on the mainstem Walla Walla River, indicate Pacific lamprey were once abundant in the Upper Walla Walla River watershed (Jackson et al., 1997; Swindell, 1942). Pacific lamprey have not been identified in any surveys conducted within the past 25 years, suggesting they are now extirpated from the Upper Walla Walla River watershed (Close, 2000; Close and Bronson, 2001; Harris and Jolley, 2017; Kostow, 2002; Moser and Close, 2003). Pacific lamprey were most recently documented in the Upper Walla Walla River watershed in 1997 near the confluence of the Walla Walla River and the Little Walla Walla River (Jackson et al., 1997). Jackson et al. (1997) recovered fifty-five lamprey from sediment removed from the Little Walla Walla River diversion structure, of which four were Pacific lamprey and 51 were western brook lamprey (*Lampetra richardsoni*). To address mainstem Columbia River passage impediments on Pacific lamprey, CTUIR began an adult lamprey translocation program in 2000, primarily in the Umatilla River subbasin (CRITFC et al. 2018). In 2012, CTUIR began Pacific lamprey artificial propagation research (CRITFC et al. 2018). Pacific lamprey population augmentation efforts are proposed for the Walla Walla River watershed through larval out-planting (CRITFC et al. 2018).

6.0 LIMITING FACTORS

A number of interrelated factors limiting population productivity have previously been identified in the Upper Walla Walla watershed. Limiting factors were not separated for each species, as most are shared among species.

6.1 RIPARIAN HABITAT

River channelization, straightening, channel incision, construction of impoundments, flood control structures, and irrigation diversions, timber harvest, urbanization, and agriculture has eliminated riparian habitat in many parts of the Upper Walla Walla River watershed (Barrows et al., 2014; Beechie et al., 2008; Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001; Martin et al., 1992). Riparian habitat is in especially poor condition along portions of Garrison Creek, the Walla Walla River, lower reaches of Mill Creek, the North Fork Walla Walla River, and Yellowhawk Creek (Beechie et al., 2008; Buchanan et al., 1997; Kuttel, 2001; Mendel et al., 2007). High quality riparian habitat is more prevalent along the South Fork Walla Walla River and tributaries (e.g., Reser Creek and Skiphorton Creek) and upper Mill Creek and tributaries (e.g., North Fork Mill Creek, Paradise Creek, Broken Creek, Low Creek, and Tiger Creek) (Buchanan et al., 1997; Kuttel, 2001).

Riparian zones influence a number of more proximal limiting factors for focal species in the Upper Walla Walla River watershed, including water temperature, woody debris, sedimentation, chemical pollution, North American beavers (Castor canadensis), and food webs, and are considered crucial for maintaining aquatic ecosystem integrity (Allan et al., 2003; Kiffney et al., 2003; Martin et al., 1999; Naiman et al., 1988; Richardson et al., 2010; Rutherford et al., 2004; Sweeney et al., 2004). High quality riparian habitat is considered a key limiting factor for all life stages of all focal species (Barrows et al., 2014; Carmichael and Taylor, 2010). There have been efforts to restore riparian habitat in the Upper Walla Walla River watershed, but additional work is needed (Carmichael and Taylor, 2010; Mahoney et al., 2009).

6.2 TEMPERATURE

Rising air temperatures, removal of riparian vegetation, sedimentation, and water extractions resulting in low flows have increased stream temperatures in the Upper Walla Walla watershed (Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Mendel et al., 2001). High water temperatures can be acutely lethal to fishes, impose a variety of sublethal fitness costs, and create barriers to movement (Bjornn and Reiser, 1991; Mahoney et al., 2009; McCullough, 1999; Meeuwig et al., 2005; Mendel et al., 2014, 2007; Richter and Kolmes, 2005; Whitesel and Uh, 2022). Water temperatures high enough to harm focal species have been recorded in many locations in the Upper Walla Walla River watershed, including in Blue Creek, Bryant Creek, Caldwell Creek, Cold Creek, Cottonwood Creek, Doan Creek, East Little Walla Walla River, Garrison Creek, Mill Creek, Russell Creek, Stone Creek, the Walla Walla River, West Little Walla Walla River, and Yellowhawk Creek (Baldwin et al., 2008; Johnson et al., 2004; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Mendel et al., 2001).

High water temperatures in the Upper Walla Walla River watershed have previously been identified as the most important limiting factor for Chinook salmon, steelhead, and bull trout (Mahoney et al., 2009; Mendel et al., 2014, 2007; Schaller et al., 2014). Warm temperatures have also been identified as a potential limiting factor for Pacific lamprey in the Upper Walla Walla watershed, but relationships between water temperature and Pacific lamprey physiology, ecology, and distributions are poorly understood (Close, 2000; Close et al., 1995; Jackson et al., 1997; Mallatt, 1983; Meeuwig et al., 2005; Whitesel and Uh, 2022). Bull trout is the focal species most sensitive to warm temperatures, with maximum temperature thresholds to avoid detrimental effects to juvenile rearing, adult migration, and spawning of 12-14ºC, 10-14ºC, and 7-9ºC, respectively (Mendel et al., 2007; Selong et al., 2001). Chinook salmon and steelhead are more tolerant of warm temperatures, with maximum temperature thresholds to avoid detrimental effects to juvenile rearing, adult migration, and spawning of 15-18ºC, 17-20ºC, and 12.5-14ºC, respectively (Bjornn and Reiser, 1991; McCullough, 1999; Mendel et al., 2007; Richter and Kolmes, 2005). The temperature tolerance of Pacific lamprey, particularly adults, is poorly understood. However, Meeuwig et al. (2005) documented elevated mortality of ammocetes at temperatures of 22ºC relative to cooler temperatures and Whitesel and Uh (2022) documented elevated ammocete mortality at temperatures of 30ºC relative to cooler temperatures. Moser et al. (2019) report that in aquaculture settings, Pacific lamprey adults are generally held at temperatures between 3-15.5ºC, but that adult lamprey can be help at temperatures up to 27ºC for long periods without increased mortality.

Suboptimal temperatures for focal species primarily occur in the Upper Walla Walla watershed from May through October. Consequently, high water temperatures have the potential to negatively impact the juvenile and adult life stages of all focal salmonid species, including adult steelhead during upstream migrations in September - October and May - June, adult bull trout during downstream migrations in September - October and May - July, and Chinook salmon during upstream migrations in May - July (Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Mendel et al., 2001). There is empirical evidence that in some years Chinook salmon run timing has been truncated in late May and upstream steelhead migrations may be inhibited during the summer by warm water temperatures in the Walla Walla River watershed (Mahoney et al., 2009; Mendel et al., 2014; Yun et al., 2016). There is also evidence that warm temperatures exclude Chinook salmon, steelhead, and bull trout from portions of the Walla Walla River and the lower reach of several Upper Walla Walla tributaries during the summer (Al-Chokhachy and Budy, 2007; Mendel et al., 2007; Yun et al., 2016).

6.3 SEDIMENTATION

Contemporary sedimentation rates are above historical levels in many areas in the Upper Walla Walla watershed due to increased erosion from agricultural activities, urbanization, and removal of riparian habitat (Beechie et al., 2008; Kuttel, 2001; Underwood et al., 1995). High sedimentation rates have embedded cobble and gravel substrates in several areas in the Upper Walla Walla watershed, particularly in Garrison Creek, Yellowhawk Creek, the Walla Walla River, Mill Creek, and Skiphorton Creek (Barrows et al., 2014; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2007). Deposition of fine sediments can kill salmonid embryos and all focal species require unembedded cobble and gravel substrate for redd construction and spawning and fine sediments can reduce embryonic survival (Barrows et al., 2014; Bowerman et al., 2014; Clemens et al., 2010; Gallion et al., 2014; Gunckel et al., 2009; Mayfield et al., 2014; McMillan et al., 2015; Moir and Pasternack, 2010). Sedimentation is an important factor limiting the spawning distributions of focal salmonid species (Barrows et al., 2014; Bowerman, 1993; Gallion et al., 2014; Mahoney et al., 2009). Due to the similar substrate requirements of focal salmonid species and Pacific lamprey, sedimentation also likely limits the quantity of suitable spawning habitat for Pacific lamprey in the Upper Walla Walla watershed (Clemens et al., 2010).

6.4 RIVER MORPHOLOGY

Substantial channelization, straitening, and channel incision and the construction of impoundments, flood control structures, and irrigation diversions has occurred throughout the Upper Walla Walla River watershed (Barrows et al., 2014; Beechie et al., 2008; Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001). This has reduced channel complexity, shortened several river reaches, diminished connectivity of main channels to floodplains, which in turn has eliminated in-channel, off-channel, and riparian fish habitat and negatively impacted the quality of remaining habitat in many ways, several of which we discuss further in separate subsections (e.g., sedimentation, temperature, food web structure, pool and riffle habitat, large woody material, and riparian habitat) (Barrows et al., 2014; Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001). Substantial alterations to river morphology, including elimination of off-channel habitat, reduced floodplain connectivity, has occurred in reaches of the Garrison Creek, the North Fork Walla Walla River, Walla Walla River, lower Mill Creek, and Yellowhawk Creek (Buchanan et al., 1997; Kuttel, 2001). High quality off-channel habitat and floodplain connectivity remains in the upper reaches of Mill Creek and in Mill Creek tributaries (e.g., North Fork Mill Creek, Paradise Creek, Broken Creek, Low Creek, Tiger Creek) and the South Fork Walla Walla River and many of its tributaries (e.g., Reser Creek, and Skiphorton Creek). Altered river morphology has been identified as an important limiting factor for all life history stages of every focal species, impacting species via a myriad of proximal factors, most notably water quality and rearing and spawning habitat availability (Buchanan et al., 1997; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Schaller et al., 2014).

6.5 TIMING AND MAGNITUDE OF FLOWS

Water withdrawals, regulation of water flows, and modification of river morphology has had major impacts on water flow in the Upper Walla Walla River watershed. Altered water flows have been identified as a limiting factor for all focal species (Close et al., 1995; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Schaller et al., 2014). Altered water flows have impacted many biotic and abiotic processes in the Upper Walla Walla River watershed. For example, low water flows have caused barriers to fish movement, contributed to high water temperatures, reduced the quantity of available fish habitat, and diminished floodplain connectivity (Anglin et al., 2009; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2007). Loss of high flows have prevented sediment from being flushed from gravel and cobble substrates that are used by focal species for spawning (Kuttel, 2001). Climate change is predicted to alter hydrographs throughout the Columbia River Basin in ways that may be harmful to all life stages of focal species (Carmichael and Taylor, 2010).

6.6 LARGE WOODY MATERIAL

Removal of large woody material from rivers, harvest of large trees from riparian areas that serve as inputs of large woody material, and diminished connectivity of main channels to flood plains has reduced the volumes of large woody material below historical levels in several areas in the Upper Walla Walla River watershed (Barrows et al., 2014; Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001). Large woody material provides habitat for a several types of salmonid prey, stabilizes river beds and banks, captures gravel substrate important for salmonid and lamprey spawning, and contributes to the formation of pools, which are important habitat for all life stages of Pacific Lamprey and salmonids and have been positively correlated with bull trout densities in Mill Creek (Bilby, 1981; Gonzalez et al., 2017; Hilderbrand et al., 1997; Keller and Swanson, 1979; Martin et al., 1992; Mossop and Bradford, 2004; Muhlfeld and Marotz, 2005; Roni and Quinn, 2001). Large woody material volumes are particularly lacking in reaches of Garrison Creek, the North Fork Walla Walla River, the Walla Walla River, Yellowhawk Creek (Buchanan et al., 1997; Kuttel, 2001). Multiple studies have identified the lack of large woody material as a limiting factor for Chinook salmon, steelhead, and bull trout in the Upper Walla Walla River (Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001; Volkman, 2005). Large woody material is not listed as a limiting factor by any Pacific Lamprey planning documents or research articles focused on upper Walla Walla River watershed. Additional research is needed to determine if large woody material is a limiting factor for Pacific lamprey. Projects have added large woody material to some areas in the Upper Walla Walla River watershed (Carmichael and Taylor, 2010).

6.7 POOL AND RIFFLE HABITAT

Changes to river morphology, sedimentation, removal of large woody material, reduction in the size of the North American beaver population, and water withdrawals have eliminated pool and riffle habitat in the Upper Walla Walla River watershed (Beechie et al., 2008; Carmichael and Taylor, 2010; Kuttel, 2001). Pools and riffles are important habitat for all life stages of Pacific lamprey and focal salmonids (Gonzalez et al., 2017; Gunckel et al., 2009; Martin et al., 1992; Mossop and Bradford, 2004; Muhlfeld and Marotz, 2005). Martin et al. (1992) found that in Mill Creek, 1+ year old juvenile bull trout, young of the year steelhead, and 1+ year old steelhead used pool habitat types more than run and riffle habitats, while young of the year bull trout used riffle habitats more than other habitats. Riffles are often used by Pacific lamprey for redd construction (Gunckel et al., 2009). Multiple studies have identified lack of pool and riffle habitats as limiting factors for Chinook salmon, steelhead, and bull trout in the Upper Walla Walla River watershed (Carmichael and Taylor, 2010; Kuttel, 2001; Mendel et al., 2001; Volkman, 2005). Additional research is needed to determine if riffle and habitat availability is a limiting factor for Pacific lamprey in the Upper Walla Walla River watershed.

6.8 NORTH AMERICAN BEAVER

The North American beaver population in the Upper Walla Walla River watershed is smaller than historically (Kuttel, 2001). North American beavers are keystone species that enhance river habitat complexity by creating low velocity off-channel habitat that is used by juvenile and adult salmonids and larval lampreys (Bouwes et al., 2016; Kemp et al., 2012; Schultz et al., 2016). The presence of beaver dams has been correlated with increased survival of juvenile salmonids, potentially because this habitat is hypothesized to help juvenile salmonids to escape predation, take refuge during high water flow events, and enhance productivity of prey species (Bouwes et al., 2016; Kemp et al., 2012). Encouraging natural growth of the North American beaver population in the Upper Walla Walla River watershed has been identified as important to the recovery of salmonid populations (Kuttel, 2001), but further research is needed to determine if it will also contribute to the recovery of Pacific lamprey.

6.9 CHEMICAL WATER POLLUTION

Chlorinated pesticides, polychlorinated biphenyls (PCBs), and low levels of lead and mercury, all chemicals that are toxic to fishes (Morcillo et al., 2017; Murty, 2018), have been documented throughout the Upper Walla Walla watershed (Davis et al., 1995; Davis and Johnson, 1994; Fischnaller et al., 2003; Hopkins et al., 1985; Johnson and Era, 2002; Meredith and Roberts, 2011). Wastewater treatment plant effluent, urban water runoff, and erosion and runoff from agricultural fields have been identified as sources of this pollution (Close et al., 1995; Johnson and Era, 2002; Kuttel, 2001; Schaller et al., 2014). Chemical pollution is hypothesized to have contributed to declines in populations of focal species (Jackson et al., 1997; Mendel et al., 2007; Schaller et al., 2014). Chlorine pollution has been identified as the cause of fish kills in lower Mill Creek (Mendel et al., 2007). Ongoing mitigation efforts are successfully reducing chlorinated pesticides and polychlorinated biphenyl pollution in the Walla Walla watershed and no additional fish kills related to acute toxicity from chemical pollutants have been reported (Baldwin et al., 2008; Carmichael and Taylor, 2010; Gray et al., 2006; Johnson et al., 2004; Lubliner, 2007; Mendel et al., 2007). Chemical water pollution is considered to be a secondary limiting factor for all focal species (Close, 2000; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014; NOAA, 2021; Schaller et al., 2014).

6.10 DISSOLVED OXYGEN

Dissolved oxygen concentrations low enough to be harmful to fishes have been recorded at some sampling sites in the Walla Walla River, Mill Creek, and the Yellowhawk Creek tributaries Garrison Creek, Cottonwood Creek, and Russel Creek (Baldwin et al., 2008; Dugger, 2021; Joy et al., 2007; Mendel et al., 2001; Swanson, 2005). Low levels of dissolved oxygen have been attributed to high primary productivity resulting from nutrient enrichment and warm water temperatures and reduced dissolved oxygen holding capacity due to warm water temperatures (Joy et al., 2007; Swanson, 2005). Actions have been taken to improve dissolved oxygen levels in the Upper Walla Walla watershed but have been met with limited success (Carmichael and Taylor, 2010; Dugger, 2021). Dissolved oxygen has not been identified as a key limiting factor for any focal species, but it has been hypothesized to act as a secondary limiting factor for Chinook salmon, steelhead, and bull trout and may be one of the multiple mechanisms through which temperature acts as a limiting factor in the watershed (Carmichael and Taylor, 2010; Mendel et al., 2001). Dissolved oxygen requirements are not well characterized for Pacific lamprey. Larval Pacific lamprey are thought to be relatively tolerant of low dissolved oxygen concentrations, but adult Pacific lamprey appear to be only slightly less sensitive to low dissolved oxygen than focal salmonid species (Lampman et al., 2021; Swanson, 2005). Additional research on the potential of dissolved oxygen to be a limiting factor is warranted.

6.11 pH

High primary productivity resulting from nutrient enrichment through urban water runoff and erosion and runoff from agricultural fields has caused high pH in several locations in the Upper Walla Walla River watershed (Dugger, 2021; Joy et al., 2007; Mendel et al., 2001). The Washington State Water Quality Standards consider a pH range of 6.5 - 8.5 to be safe for aquatic animals (Joy et al., 2007). High and low pH can have negative, sublethal effects and cause mortality in all life stages of salmonids and warm temperatures can amplify the harmful effects of high and low pH (Daye and Garside, 1977; Wagner et al., 1997). Low pH can be lethal to lamprey embryos and larvae, but the effects of high pH are not well characterized for any life stage of Pacific lamprey (Myllynen et al., 1997). pH below 6.5 has not been recorded in the Upper Walla Walla watershed, but pH greater than 8.5 has been documented in several locations, including in Cottonwood Creek, Mill Creek, and the Walla Walla River (Dugger, 2021; Joy et al., 2007; Mendel et al., 2001). Mendel et al. (2001) identified pH as a potential limiting factor of secondary importance for salmonids in the Upper Walla Walla watershed.

6.12 BARRIERS TO MOVEMENT

Anthropogenic physical (e.g., culverts, flood control and water diversion structures, and dewatered streambeds) and water quality (e.g., temperature and dissolved oxygen) barriers to fish movement have been identified throughout the Upper Walla Walla River watershed and are considered important limiting factors for all focal species (Carmichael and Taylor, 2010; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2007). Barriers to movement have been identified in Garrison Creek, the lower reaches of Mill Creek, Russel Creek, the Walla Walla River, and Yellowhawk Creek (Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2007). Cottonwood Creek, the upper reaches of Mill Creek and tributary streams (e.g., North Fork Mill Creek, Paradise Creek, Broken Creek, Low Creek, and Tiger Creek), the North Fork Walla Walla River, and the South Fork Walla Walla River have relatively few anthropogenic barriers to fish movement (Kuttel, 2001; Mendel et al., 2007). Some physical barriers have been removed, but additional work is needed to eliminate additional barriers, paying particular attention to facilitating the upstream migration of Pacific lamprey because their movement can be inhibited by conditions distinct from those that limit salmonids (Goodman and Reid, 2017). See Kuttel (2001) and Mendel et al. (2007) for detailed lists and descriptions of physical barriers to fish movement in the Upper Walla Walla River watershed.

High water temperatures have been identified as the most important barrier to the movement of focal salmonid species related to water quality, potentially impacting juveniles and adults, including during migration (Anglin et al., 2009; Barrows et al., 2014; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Mendel et al., 2001; Yun et al., 2016). High water temperatures likely impact the movement of all salmonid life stages, but appear particularly for adult migrations, including during adult steelhead upstream migrations in September - October and May - June, adult bull trout downstream migrations in September - October and May - July, and upstream Chinook salmon migrations during May - July (Anglin et al., 2009; Barrows et al., 2014; Kuttel, 2001; Mahoney et al., 2009; Mendel et al., 2014, 2007; Mendel et al., 2001; Yun et al., 2016). Additional research is needed to determine if high temperatures or other water quality variables are barriers to the movement of Pacific lamprey.

6.13 FOOD WEBS

The substantial anthropogenic modification of the Upper Walla Walla River watershed has likely impacted food webs in a variety of ways. For example, degradation of riparian habitat can reduce inputs of terrestrial insects into rivers and nutrient enrichment can lead to increased primary productivity and abundances of aquatic macroinvertebrates (DeBruyn et al., 2003; Kiffney et al., 2003; Xiang et al., 2017). Additionally, changes to the Upper Walla Walla River ecosystem have likely impacted native fishes other than focal species, which may alter prey availability.

Changes in prey availability are a primary mechanism through which anthropogenic modification of food webs might impact focal species and has been proposed as a potential explanation for the substantial spatial variation in bull trout growth rates in the Upper Walla Walla River watershed (Bowerman et al., 2014). Larval lamprey primarily feed on suspended detritus, algae, and diatoms and may benefit from nutrient enrichment and increased primary productivity (Moore and Mallatt, 1980). The availability of invertebrate prey potentially impacts all focal salmonid species because at small sizes, Chinook salmon, steelhead, and bull trout primarily consume aquatic and terrestrial invertebrates before transitioning to piscivory at larger sizes (Budy et al., 2017; Huntsman and Falke, 2019, 2019; Johnson, 1980; Litz et al., 2017; Lowery and Beauchamp, 2015; Martin et al., 1992; Monnet et al., 2020; Schoby and Keeley, 2011).

Chinook salmon and steelhead typically become piscivorous after migrating to marine environments (Atcheson et al., 2012; Huntsman and Falke, 2019; Litz et al., 2017). Putatively, adult Chinook salmon don't consume significant quantities of fish in the Upper Walla Walla River watershed because this species typically doesn't feed during upstream spawning migrations or in freshwater after spawning (Quinn, 2018). In contrast, O. mykiss are likely highly piscivorous in the Upper Walla Walla River watershed because non-migratory individuals grow to sizes at which this species can consume other fishes and steelhead can resume feeding in freshwater after spawning (Kendall et al., 2015; Savvaitova et al., 2003). Pacific lamprey parasitically feed on fishes, but don't often feed in freshwater environments (Beamish, 1980; Close et al., 1995). Consequently, steelhead and bull trout are likely the focal species that consume the greatest quantities of fish in the Upper Walla Walla River watershed, and thus are the most likely to be impacted by abundances of fish species that are important prey. Additional fishes native to the Upper Walla Walla River watershed that may be important prey for steelhead and bull trout include chiselmouth (*Acrocheilus alutaceus*), mountain whitefish (*Prosopium williamsoni*), margined sculpin (*Cottus marginatus*), Paiute sculpins (*Cottus beldingi*), torrent sculpins (*Cottus rhotheus*), western brook lampreys (*Lampetra richardsoni*), speckled dace (*Rhinichthys osculus*), longnose dace (*Rhinichthys alutaceus*), redside shiners (*Richardsonius balteatus*), bridgelip suckers (*Catostomus columbianus*), and largescale suckers (*Catostomus macrocheilus*) Close (2000).

Only a handful of studies have investigated trophic interactions in the Upper Walla Walla River watershed. Martin et al. (1992) and Underwood et al. (1995) characterized the diets of juvenile O. mykiss and bull trout in Mill Creek. They report that the most important prey for juvenile bull trout and O. mykiss were aquatic macroinvertebrates. Budy et al. (2006) investigated the diets of bull trout in the South Fork Walla Walla River and found that aquatic macroinvertebrates and fish were the most important prey items. Only one study has investigated prey availability for focal species in the Upper Walla Walla River watershed and found evidence that macroinvertebrate prey availability was not limiting for juvenile O. mykiss and bull trout in Mill Creek (Underwood et al., 1995). Additional research on the diets and abundances of focal species, other fishes, primary productivity, and non-fish prey (e.g., aquatic macroinvertebrates) is necessary to determine the extent to which prey availability or other mechanism associated with food webs are limiting to focal species in the Upper Walla Walla River watershed.

6.14 NON-NATIVE SPECIES

Non-native species have the potential to negatively impact focal species in the Upper Walla Walla River watershed, particularly through competition, predation, and hybridization. Brown trout (*Salmo trutta*), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), bluegill (*Lepomis macrochirus*), three-spine stickleback (*Gasterosteus aculeatus*) are non-native species that have been documented in the Walla Walla River watershed (Fischnaller et al., 2003; Johnson et al., 2004; Mahoney et al., 2009; Mendel et al., 2007). To date, these species are restricted to the lower Walla Walla River watershed and therefore non-native species are not currently considered a limiting factor. However, the distributions of these species should be monitored as it is possible that they could expand their distributions into the Upper Walla Walla River watershed, particularly if water temperatures continue to increase.

6.15 UNSCREENED SURFACE WATER DIVERSIONS

Many unscreened irrigation diversions have been identified in the Upper Walla Walla River watershed and some screened diversions do not meet state criteria for fish screens (Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001; Mendel et al., 2001). Fish passing through unscreened diversions can become stranded in agricultural fields (Anglin et al., 2009; Carmichael and Taylor, 2010). Unscreened irrigation diversions have likely caused substantial fish mortality in the Upper Walla Walla River watershed, and unscreened irrigation diversions are still considered a limiting factor for all focal species (Anglin et al., 2009; Carmichael and Taylor, 2010). Work has been done to add and improve screening on irrigation diversions, but additional screening may be needed and monitoring is required to ensure screens remain functional (Buchanan et al., 1997; Carmichael and Taylor, 2010; Kuttel, 2001; Mahoney et al., 2009). Priority locations for improving diversion screening include lower Mille Creek mainstem, Yellowhawk Creek, and the Bennington Diversion Dam on Mill Creek (The Watershed Company 2015).

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Appendix H

Upper Walla Walla Assessment

HABITAT CAPACITY ASSESSMENT

Technical Report

May 23, 2024

Technical Report

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MOUNT HOOD ENVIRONMENTAL

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Subject: Habitat Capacity Assessment Technical Report

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1.0 BACKGROUND

Water is one of the First Foods that traditionally sustained the people of CTUIR alongside salmon, deer, cous, and huckleberry. It nourishes people and all other First Foods, and it is inherently tied to the five River Vision touchstones: hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation (Jones et al., 2008). These touchstones form the Umatilla River Vision, a holistic approach to water quality restoration. In support of the Vision, population status and habitat use of riverine fishes defined as First Foods, including Endangered Species Act (ESA) listed middle Columbia River summer-run steelhead, spring-run Chinook salmon, bull trout, and Pacific lamprey, have been identified as critical data needs in the assessment of biotic communities (Jones et al., 2008). The decline of anadromous Pacific salmonid populations (*Oncorhynchus* spp.) across the Pacific Northwest, USA, has prompted numerous actions aimed at reversing that trend, and recovery plans have identified adult escapement targets for populations throughout the Columbia Basin. These abundance targets provide a benchmark against which habitat rehabilitation actions can be measured. Here, we apply a novel approach to estimate life stage specific habitat capacity for spring-run Chinook salmon and summer-run steelhead to quantify the magnitude and types of tributary habitat restoration needed to achieve recovery goals in the Upper Walla Walla watershed.

1.1 FOCAL SPECIES

Focal species in this assessment were spring-run Chinook salmon (*Oncorhynchus tshawytscha*; ESA-listed “threatened”) and Middle Columbia River summer steelhead (*Oncorhynchus mykiss*; ESA-listed “threatened”). While the habitat capacity models used in this assessment specifically address Chinook salmon and steelhead, any benefit in habitat for these species was also expected to benefit Columbia River bull trout (*Salvelinus confluentus*; ESA-listed “threatened”) and Pacific lamprey (*Entosphenus tridentatus*).

1.2 STUDY AREA

The study area included the spatial domains of Chinook salmon and steelhead within the Upper Walla Walla River watershed, which encompasses approximately 2,292 square kilometers (Figure 1). The spatial extents of Chinook salmon and steelhead in the Upper Walla Walla watershed were initially defined by StreamNet (https://www.streamnet.org) and validated through consultation with regional experts (E. Green, personal communication, May, 2022). A thorough description of the study area and species spatial extents can be found in *Appendix G: Fish status, distribution, and limiting factors.*

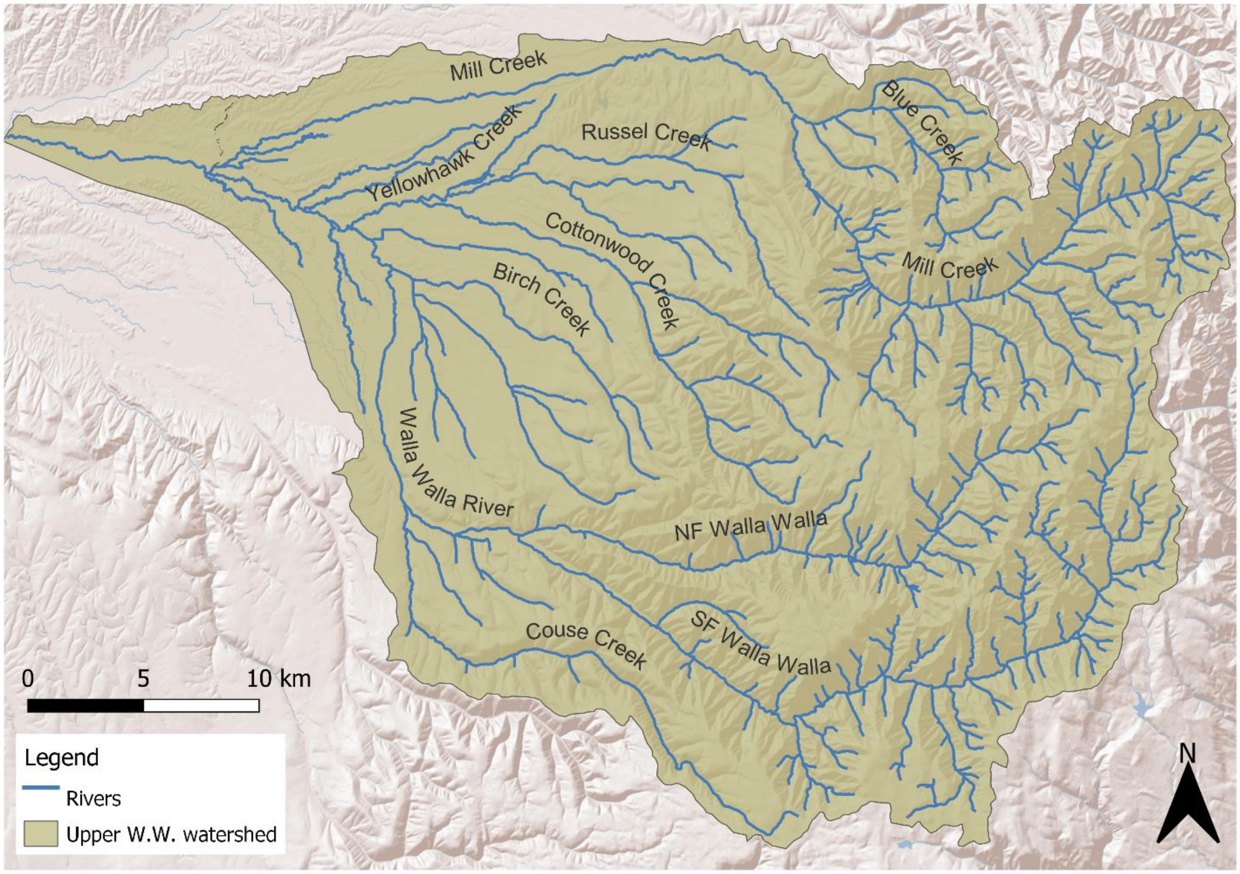

Figure 1: Study area for the Upper Walla Walla watershed. Primary rivers and tributaries used by Chinook salmon and steelhead are labeled.

2.0 HABITAT CAPACITY ASSESSMENT

2.1 OVERVIEW

Potential species and life-stage specific bottlenecks resulting from limitations in habitat quantity and/or quality were assessed for Chinook salmon and steelhead spawning (redds), juvenile summer rearing (parr), and juvenile winter rearing (presmolts) life stages. First, the required capacity to meet adult abundance escapement goals were estimated for each species and life stage using a Generalized Capacity Model approach (Appendix C in Idaho OSC Team, 2019). Next, available habitat capacity was estimated using a quantile random forest (QRF) framework (Appendix B in Idaho OSC Team, 2019; See et al., 2021). Capacity limitations were then quantified by subtracting required capacity from available capacity, providing an estimate of (potential) capacity deficit by species and life stage.

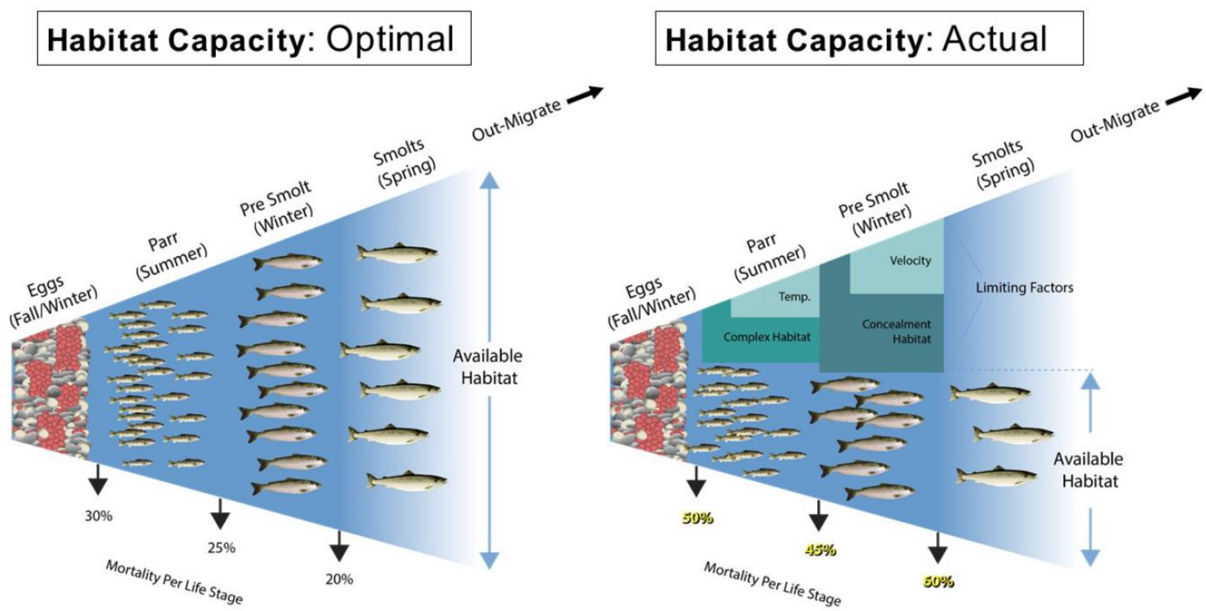

Figure 2: Schematics conceptualizing habitat capacity scenarios. The scenario on the left has no limiting factors, while the scenario on the right has significant limiting factors resulting in reduced habitat capacity and production.

2.2 REQUIRED HABITAT CAPACITY

Life-stage specific capacity requirements were estimated using a Generalized Capacity Model (GCM) approach. The GCM uses a combination of empirical and literature-based parameter estimates to determine the capacity required to achieve a given adult escapement goal. Adult escapement goals of 3,600 and 3,400 were used for Chinook salmon and steelhead, respectively. These were considered high-range goals and intended to represent *"healthy and harvestable abundance levels that would sustain very high levels of species viability, significant fishery opportunities and harvest, and a fuller range of ecological values"* (CBPTF, 2020). The required capacities to achieve these goals were estimated using the GCM with a simulation to account for expected interannual variation in life history parameters. The simulation was conducted by repeatedly drawing applicable parameters from normal distributions with means and standard deviations defined in Table 1 and constrained within the range of observed values. Standard deviations for egg-to-parr and parr-to-presmolt survival parameters were set to zero due to small sample sizes, high variability, and potential bias leading to potentially unreliable results. Then, adult escapement goals were multiplied step-wise through the applicable parameter values to obtain capacity requirements by life stage. For example, the number of redds necessary for recovery was calculated by multiplying the adult escapement goal by the female ratio and the estimated redds per female. We conducted 5,000 simulations, resulting in a range of capacity requirements that were summarized to provide the mean required capacity by life stage with associated confidence intervals. The resulting estimated habitat capacity requirements are shown in Table 2 and represent the necessary abundance at each life stage to achieve adult escapement goals.

Table 1. Life history parameters, and supporting data sources, for the Generalized Capacity Model. Standard deviations for egg-to-parr and parr-to-presmolt survival parameters were set to zero due to small sample sizes, high variability, and possible bias leading to potentially unreliable results.

Species	Parameter	Value	SD	Source	Detail
Chinook	Female Ratio	0.432	0.04	Kinzer et al. (2020)	Snake River basin monitoring data collected at Lower Granite dam
Chinook	Redds/Female	0.772	0.264	Upper Salmon, Pahsimeroi weirs and RST monitoring data, Lemhi PIT arrays & redd surveys	38 total years of monitoring data in 3 watersheds
Chinook	Fecundity	3,726	655.8	Gallinat and Kiefel (2020)	30-year dataset of natural-origin fish spawned at Tucannon hatchery
Chinook	Egg:Parr	0.1	–	Gallinat and Kiefel (2020)	20-year dataset of in-river natural-origin egg and parr production
Chinook	Parr:Presmolt	0.405	–	Lemhi River Empirical Data	Lemhi PIT arrays and screw traps
Chinook	Egg:Smolt	0.047	0.028	Gallinat and Kiefel (2020)	20-year dataset of in-river natural-origin egg and smolt production
Steelhead	Female Ratio	0.662	0.03	Kinzer et al. (2020)	Snake River basin monitoring data collected at Lower Granite dam

Species	Parameter	Value	SD	Source	Detail
Steelhead	Redds/Female	0.892	0.293	Jonasson et al. (2016)	15 years of Grande Ronde River Subbasin redd survey data
Steelhead	Fecundity	4,926	459	IDFG, S. Pomerlau & T. Garlie, personal communication, June 2019	Sawtooth and Pahsimeroi hatcheries
Steelhead	Egg:Parr	0.134	–	McHugh et al. (2017)	Life-cycle model for Middle Fork John Day steelhead
Steelhead	Parr:Presmolt	0.359	–	McHugh et al. (2017)	Life-cycle model for Middle Fork John Day steelhead
Steelhead	Egg:Smolt	0.008	0.004	White et al. (2007)	12 years of Umatilla natural-origin steelhead data

Table 2: Life-stage specific habitat capacity requirement estimates necessary to achieve given escapement recovery goals.

Species	Life stage	Abundance	Abundance SE	90% CI
Chinook	Escapement	3,600	–	(NA - NA)
Chinook	Female Escapement	1,553	145	(1,314 - 1,797)
Chinook	Redds	1,242	369	(758 - 1904)
Chinook	Eggs	4,664,724	1,579,436	(2,576,255 - 7,643,021)
Chinook	Summer Juveniles	466,472	157,944	(257,626 - 764,302)
Chinook	Winter Juveniles	188,921	63,967	(104,338 - 309,542)
Chinook	Smolts	219,242	74,234	(134,037 - 319,296)
Steelhead	Escapement	3,400	–	(NA-NA)
Steelhead	Female Escapement	2,251	105	(2,078 - 2,425)
Steelhead	Redds	2,017	638	(920 - 3,092)
Steelhead	Eggs	10,117,483	3,271,198	(4,657,945 - 15,582,813)
Steelhead	Summer Juveniles	1,355,743	438,341	(624,165 - 2,088,097)
Steelhead	Winter Juveniles	486,712	157,364	(224,075 - 749,627)
Steelhead	Smolts	83,975	27,151	(46,939 - 120,280)

2.3 AVAILABLE HABITAT CAPACITY

Available habitat capacity was defined as the maximum abundance the habitat could support for a species and life stage given current habitat quantity and quality. Within fisheries research and management, biotic and abiotic factors have been identified as limiting productivity within, and across, life stages. However, it is assumed that observed fish density is generally a poor indicator of habitat capacity due to both a paucity of individuals (i.e., low spawner abundance) and the existence of unmeasured biotic or abiotic variables that may limit capacity. Therefore, available habitat capacity was estimated using a quantile random forest (QRF) and random forest extrapolation framework developed by the Idaho OSC Team (2019).

2.3.1 Quantile Random Forest Models

The QRF framework is a novel approach to estimate Chinook salmon and steelhead habitat carrying capacity in wadable streams in the Columbia River Basin. The approach involves fitting a random forest model (Meinshausen & Ridgeway, 2006; Cade & Noon, 2003) to paired fish and habitat data across hundreds of sites from eleven watersheds throughout the Columbia River Basin and selecting the 90th quantile of predictions as a proxy for carrying capacity. Importantly, the QRF model places no constraints on possible fish-habitat relationships; instead, relationships were estimated from the empirical data regardless of being positive, negative, linear, non-linear, etc. Habitat data from the Columbia River Habitat Monitoring Program (CHaMP) were paired to juvenile fish and redd survey data to develop the fish-habitat modeled relationships. Currently, available QRF models allow for evaluation of three anadromous life stages: 1) spawning (redd), 2) juvenile summer rearing (parr), and 3) juvenile winter rearing (presmolt). Using the observed fish-habitat relationships, habitat capacity could then be predicted at locations where the necessary habitat data were available. The QRF framework is described in further detail in Appendix B of Idaho OSC Team (2019) and See et al. (2021). The list of habitat metrics by species and life stage used in the assessment, along with their relative importance within each model, are described in Table 3.

Table 3: Descriptions of habitat covariates used in each of the QRF capacity models. Numbers indicate where each metric ranked in relative importance for each model. Dashes indicate a metric was not used for a given model.

Name	Juv Sum Chnk	Juv Sum Sthd	Juv Win Chnk	Juv Win Sthd	Redds Chnk	Redds Sthd	Description
Channel Unit Frequency	5	11	3	2	1	1	Number of channel units per 100 meters.
Fast NonTurbulent Frequency	9	13	–	–	13	6	Number of Fast Water Non-Turbulent channel units per 100 meters.
Fast Turbulent Frequency	3	6	–	–	4	2	Number of Fast Water Turbulent channel units per 100 meters.
Sinuosity	13	7	6	5	10	11	Ratio of the thalweg length to the straight-line distance between the start and end points of the thalweg.
Wetted Channel Braidedness	14	14	10	11	–	–	Ratio of the total length of the wetted mainstem channel plus side channels and the length of the mainstem channel.

Name	Juv Sum Chnk	Juv Sum Sthd	Juv Win Chnk	Juv Win Sthd	Redds Chnk	Redds Sthd	Description
Fish Cover: LW	–	–	4	6	–	–	Percent of wetted area that has woody debris as fish cover.
Fish Cover: Some Cover	7	3	11	8	9	4	Percent of wetted area with some form of fish cover
Residual Depth	–	–	2	3	–	–	Residual depth of the channel unit.
Average Thalweg Depth	1	2	–	–	2	3	Average Thalweg Depth, meters
Thalweg Exit Depth	–	–	5	4	–	–	Depth of the thalweg at the downstream edge of the channel unit.
Residual Pool Depth	12	10	–	–	11	5	The average difference between the maximum depth and downstream end depth of all Slow Water/Pool channel units.
Discharge	–	–	1	1	–	–	The sum of station discharge across all stations. Station discharge is calculated as depth x velocity x station increment for all stations except first and last. Station discharge for first and last station is 0.5 x station width x depth x velocity.
Substrate Est: Boulders	8	9	–	–	6	12	Percent of boulders (256-4000 mm) within the wetted site area.
Substrate Est: Cobble and Boulder	–	–	7	10	–	–	Total cobble plus boulder percentage
Substrate Est: Cobbles	11	5	–	–	8	8	Percent of cobbles (64-256 mm) within the wetted site area.
Substrate Est: Coarse and Fine Gravel	6	8	8	9	5	13	Percent of coarse and fine gravel (2-64 mm) within the wetted site area.
Substrate Est: Sand and Fines	10	4	9	7	7	7	Percent of sand and fine sediment (0.01-2 mm) within the wetted site area.
Avg. August Temperature	2	1	–	–	3	10	Average predicted daily August temperature from NorWest, averaged across the years 2002-2011.
Large Wood Frequency: Wetted	4	12	–	–	12	9	Number of large wood pieces per 100 meters within the wetted channel.

2.3.2 Random Forest Extrapolation Models

Although there are hundreds of sites across the Columbia River basin with detailed habitat data (i.e., CHaMP sites), this only covers a small percentage of the anadromous zone, and only within CHaMP watersheds. Capacity predictions were extrapolated to areas outside of CHaMP sites and watersheds using an accompanying random forest extrapolation model fit to a stream layer dataset available from NOAA Fisheries (2022).This dataset consists of a polyline shapefile divided into 200 meter reaches with various attributes associated with each reach. We refer to these as globally available attributes (GAAs) because they are associated with every reach across all watersheds in the Columbia River Basin derived from the National Hydrography Dataset High Resolution (NHDPlus HR) dataset (USGS, 2022).

The random forest extrapolation models were fit using GAAs from the NOAA Fisheries (2022) dataset as predictor covariates (Table 4) and QRF capacity estimates as the response variable. The random forest approach again allows for non-linear associations between predictor and response variables and constricts capacity predictions within the estimated range from the initial QRF model. Using the random forest extrapolation model, density predictions were calculated for each 200-meter reach segment within the species spatial extents for Upper Walla Walla watershed, and reach capacities were calculated by multiplying the predicted fish/m by the length of the reach. Predicted habitat capacities from the extrapolation model were then summarized at the watershed and geomorphically delineated reach scales.

Table 4: Description of globally available attributes used in the random forest extrapolation models.

Metric	Description
Gradient %	Stream gradient (%).
Sinuosity	Reach sinuosity. 1 = straight, 1 < sinuous.
Alpine accumulation	Number of upstream cells in alpine terrain.
Fines accumulation	Number of upstream cells in fine grain lithologies.
Flow accumulation	Number of upstream DEM cells flowing into reach.
Gravel accumulation	Number of upstream cells in gravel producing lithologies.
Precipitation accumulation	Number of upstream cells weighted by average annual precipitation.
Floodplain width	Current unmodified floodplain width.
Avg Aug stream temperature	Historical composite scenario representing 10-year average August mean stream temperatures for 2002-2011 (Isaak et al. 2017).
Disturbance PCA 1	Disturbance Classification PCA 1 score (Whittier et al. 2011).
Natural PCA 1	Natural Classification PCA 1 score (Whittier et al. 2011).
Natural PCA 2	Natural Classification PCA 2 score (Whittier et al. 2011).

2.3.3 Capacity Estimates

Habitat capacity was estimated for 644 reaches totaling 128 km in length for Chinook salmon and 1,936 reaches totaling 381 km in length for steelhead within the Upper Walla Walla watershed (Table 5). Each reach was approximately 200 meters in length. Maps depicting capacity extrapolations are useful to visualize relatively low- versus high-capacity areas (Figure 3; Figure 4).

Table 5: Estimates of current available habitat capacity, by species and life stage, in the Upper Walla Walla watershed within the spatial domains.

Species	Life stage	Reaches	Stream length (km)	Capacity	SE	Capacity 90% CI	Avg. capacity/m
Chinook	Summer juveniles	644	128	578,205	21,586	(542,589 – 613,822)	4.515
Chinook	Winter juveniles	644	128	453,518	16,990	(425,485 – 481,551)	3.541
Chinook	Redds	644	128	298	6	(289 - 307)	0.002
Steelhead	Summer juveniles	1,936	381	1,016,587	10,649	(999,016 – 1,034,157)	2.671
Steelhead	Winter juveniles	1,936	381	1,403,405	20,447	(1,369,667- 1,437,143)	3.687
Steelhead	Redds	1,936	381	1,079	15	(1,054 – 1,104)	0.003

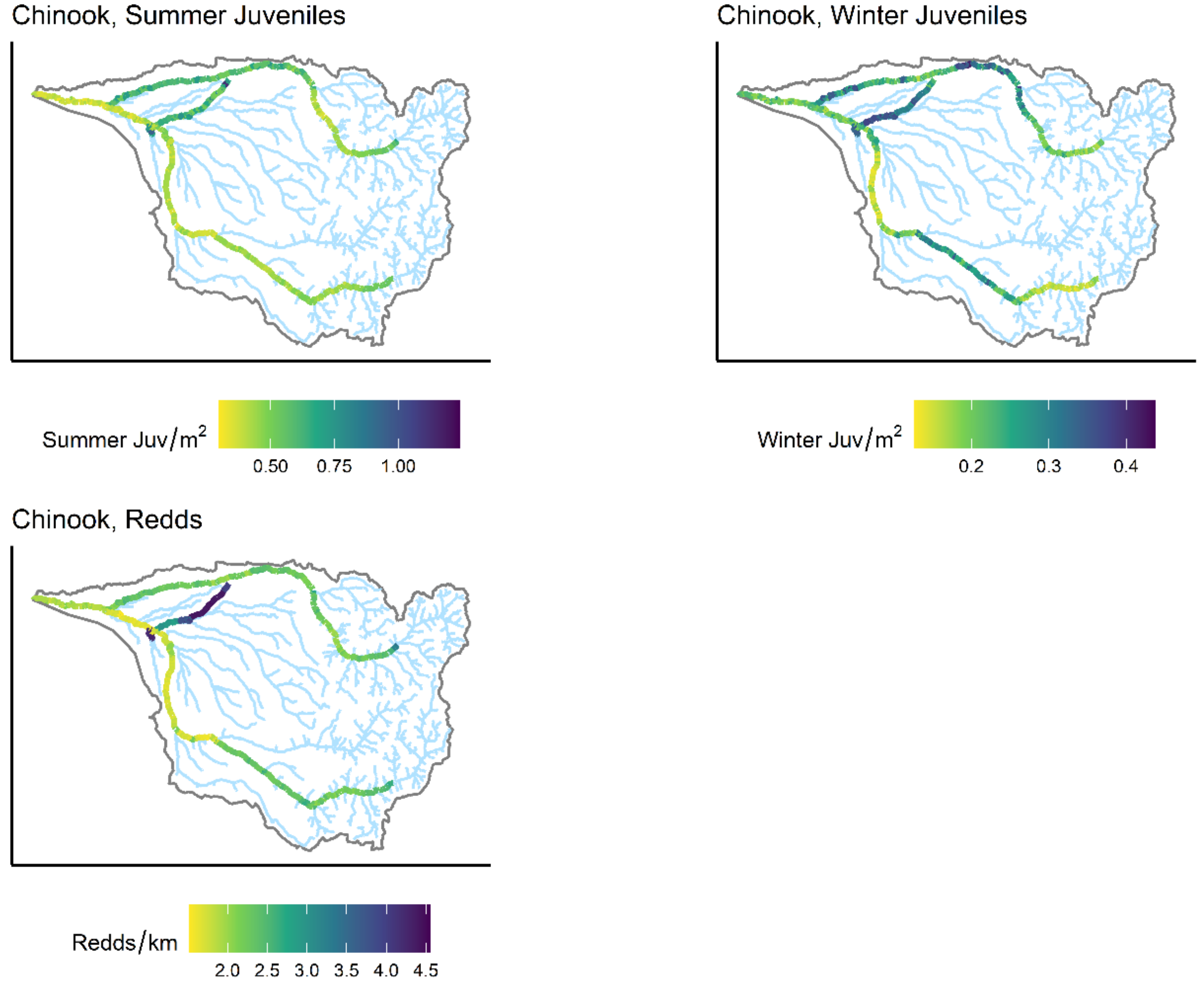

Figure 3: Estimates of habitat capacity for Chinook salmon, by life-stage, within the Upper Walla Walla watershed.

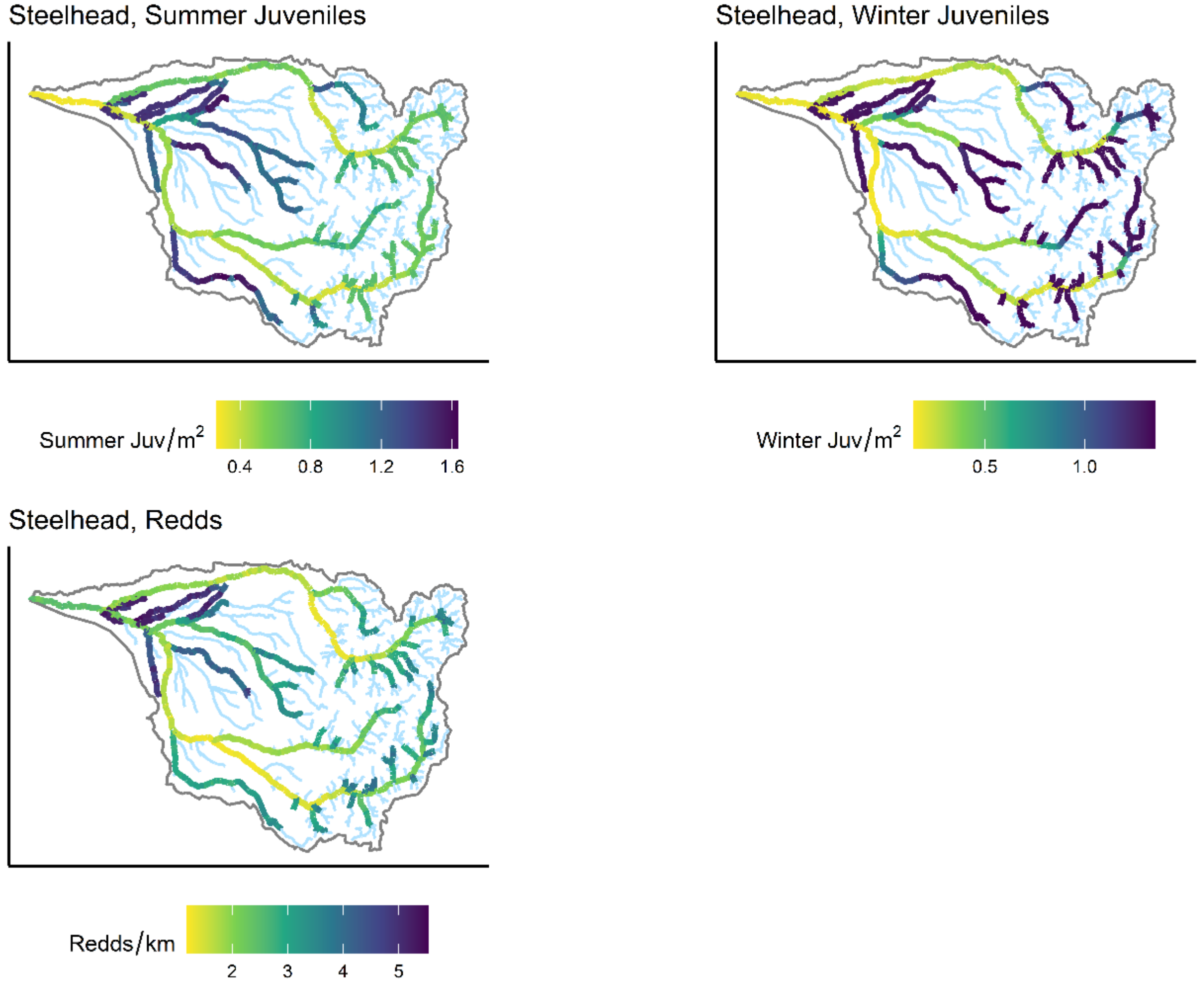

Figure 4: Estimates of habitat capacity for steelhead, by life-stage, within the Upper Walla Walla watershed.

2.4 CAPACITY LIMITATIONS

Potential habitat capacity limitations were quantified by subtracting required capacity from available capacity (Table 6). When required capacity exceeded available capacity, this represented a habitat capacity deficit for a given species and life stage within the Upper Walla Walla watershed. Contrary, a "negative deficit" was indicative of a surplus of available habitat capacity necessary to meet adult escapement goals. Relative habitat capacity deficits were also calculated as available capacity divided by required capacity. Comparisons of available and required capacity by species and life stages are also depicted in Figure 5 and Figure 6.

Table 6: Standard and relative capacity deficits for Chinook salmon and steelhead in the Upper Walla Walla watershed based on 3,600 Chinook salmon escapement and 3,400 steelhead escapement goals.

Species	Scenario	Life stage	Required capacity	Required capacity SE	Available capacity	Available capacity SE	Deficit	Relative deficit
Chinook	CBPTF 2020	Escapement	3,600	–	–	–	–	–
Chinook	CBPTF 2020	Female Escapement	1,553	145	–	–	–	–
Chinook	CBPTF 2020	Redds	1,242	369	298	6	944	3.17
Chinook	CBPTF 2020	Eggs	4,664,724	1,579,436	–	–	–	–
Chinook	CBPTF 2020	Summer Juveniles	466,472	157,944	578,205	21,586	-111,733	-0.19
Chinook	CBPTF 2020	Winter Juveniles	188,921	63,967	453,518	16,990	-264,597	-0.58
Steelhead	CBPTF 2020	Escapement	3,400	–	–	–	–	–
Steelhead	CBPTF 2020	Female Escapement	2,251	105	–	–	–	–
Steelhead	CBPTF 2020	Redds	2,017	638	1,079	15	938	0.87
Steelhead	CBPTF 2020	Eggs	10,117,483	3,271,198	–	–	–	–
Steelhead	CBPTF 2020	Summer Juveniles	1,355,743	438,341	1,016,587	10,649	339,156	0.33
Steelhead	CBPTF 2020	Winter Juveniles	486,712	157,364	1,403,405	20,447	-916,693	-0.65

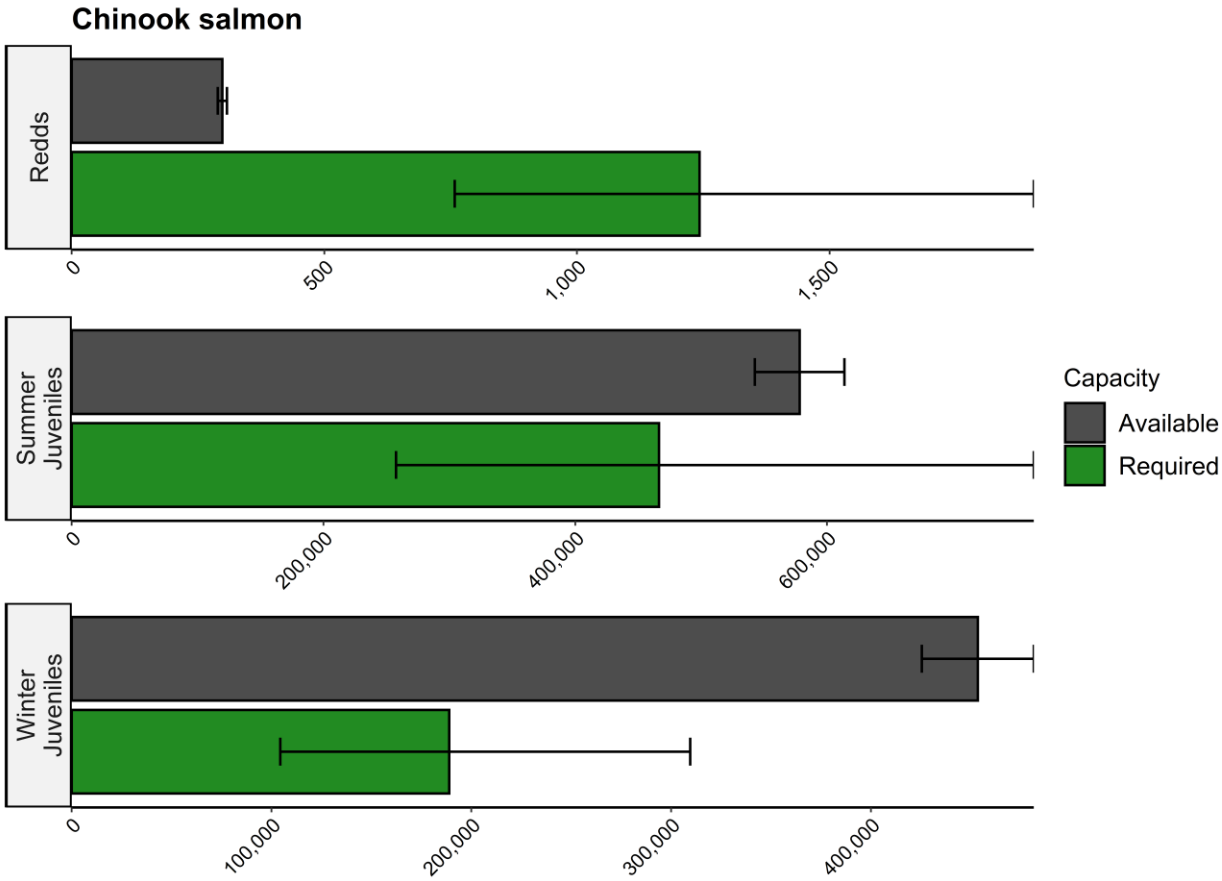

Figure 5: Estimated available habitat capacity and required habitat capacity for Chinook salmon for three life stages in the Upper Walla Walla watershed. Available capacity was calculated using a quantile random forest approach, and required capacity was calculated using a generalized capacity model with an escapement goal of 3,600 adults. Error bars represent 90% confidence intervals.

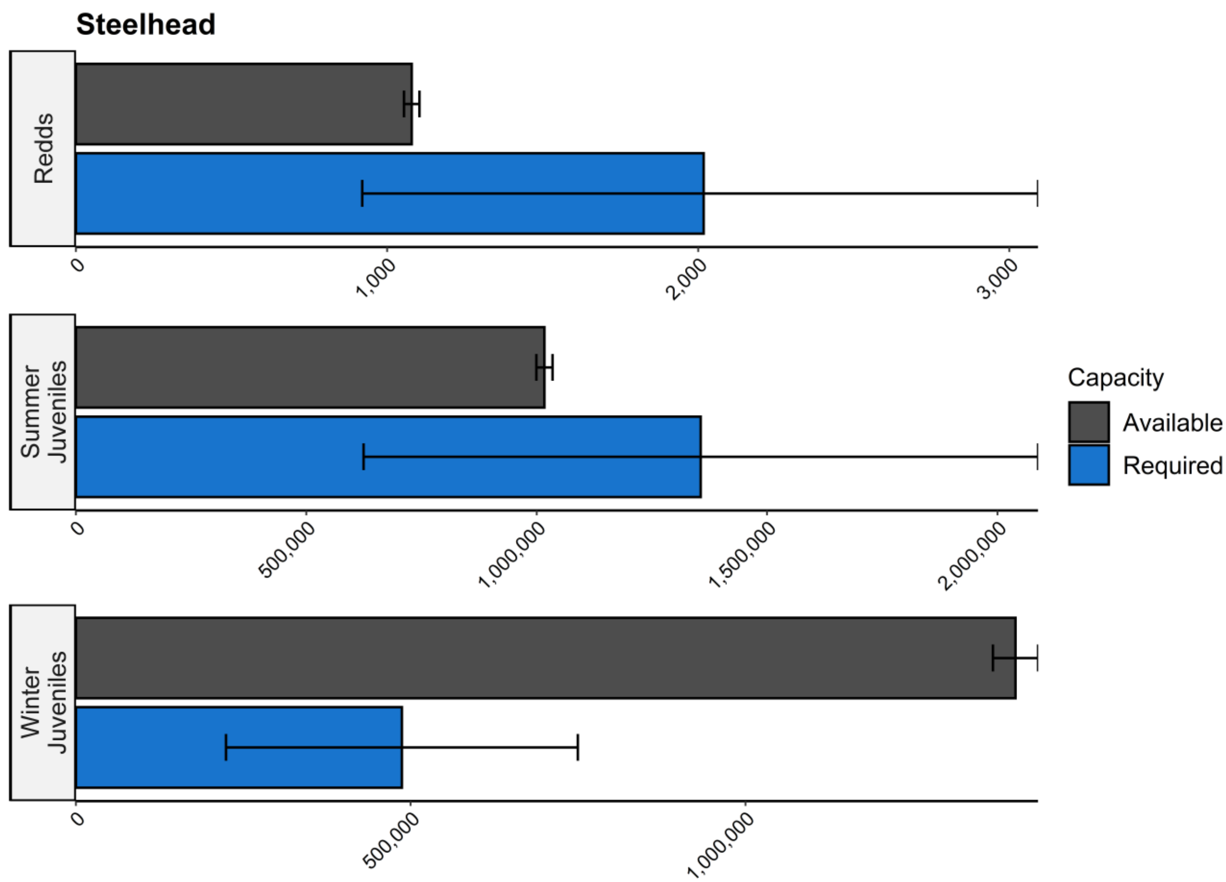

Figure 6: Estimated available capacity and required habitat capacity for steelhead for three life stages in the Upper Walla Walla watershed. Available capacity was calculated using a quantile random forest approach, and required capacity was calculated using a generalized capacity model with an escapement goal of 3,400 adults. Error bars represent 90% confidence intervals.

As an alternative and complementary approach, available capacity deficits were also evaluated in terms of spawning escapement abundance using the GCM approach (Table 7). The predicted available habitat capacity for a given life stage was converted into an estimate of the number of spawners that life stage could support using life stage transition parameters (Table 1). For example, predicted redd capacity was divided by the estimated number of redds per female and the female ratio to provide an estimate of the spawner abundance that could be "supported" by the spawning (redd) capacity.

Table 7: Estimated capacity by life stage and the predicted abundance of spawners that could be supported.

Species	Life stage	Available capacity	Predicted spawners
Chinook	Summer juveniles	578,205	4,653
Chinook	Winter juveniles	453,518	9,011
Chinook	Redds	298	894
Steelhead	Summer juveniles	1,016,587	2,608
Steelhead	Winter juveniles	1,403,405	10,029
Steelhead	Redds	1,079	1,827

3.0 DISCUSSION

3.1 LIMITED SPECIES AND LIFE STAGES

Results from the watershed-scale habitat capacity assessment estimate that juvenile Chinook salmon summer and winter rearing habitat was likely sufficient to support an escapement of 3,600 Chinook salmon adults. However, it was estimated that available spawning (redd) habitat capacity was insufficient to meet Chinook salmon escapement objectives. It was estimated that habitat in the Upper Walla Walla watershed would need to support an estimated 1,242 redds (90% CI: 758 - 1,904) to support 3,600 adults; a 317% increase from the estimated available capacity of 298 redds (90% CI: 289 - 307). The available capacity estimate suggest that the current spawning habitat could support roughly 900 adult spawners.

It was estimated that juvenile winter steelhead rearing habitat was sufficient to support the escapement goal of 3,400 adults. However, estimates of habitat capacity of steelhead spawning (redd) and juvenile summer rearing were insufficient to meet steelhead adult escapement objectives. It was estimated habitat in the watershed would need to support 2,017 redds (90% CI: 920 - 3,092) to support 3,400 adults; an 87% increase from the estimated available capacity of 1,079 redds (90% CI: 1,054 - 1,104). Similar, it was estimated that habitat would need to support 1,355,743 juveniles (90% CI: 624,165 - 2,088,097) during summer months to meet adult escapement goals; a 33% increase from the estimated available capacity of 1,016,587 juveniles (90% CI: 999,016 - 1,034,157).

3.2 TARGET CONDITIONS TO ADDRESS LIMITATIONS

Conservation and rehabilitation actions taken in the Upper Walla Walla watershed should aim to increase the quantity and/or quality of available habitat for Chinook salmon and steelhead. The focus should be on improving spawning habitat for both species, as well as juvenile summer rearing habitat, at least for steelhead. There are two primary strategies to address the habitat capacity deficits: 1) implement rehabilitation actions within lower-quality habitats to increase available capacity (i.e., increase quality by restoring ecological and river processes), or 2) increase the available stream network in tributaries and headwater habitats by addressing issues with habitat connectivity (i.e., increase habitat quantity by improving or removing barriers). More than likely, a combination of both strategies will be necessary to address potential capacity limitations.

Actions targeted at increasing spawning habitat capacity should aim to increase stream complexity (including channel unit frequency and hydraulic diversity), cover, and provide ample riffle-pool interfaces with substrates consisting of fine and coarse gravels. The combination of these characteristics provides slow-water refuge with cover for holding adults, as well as suitable conditions for egg incubation (i.e., sufficient flow and interstitial spaces for protection and oxygenation of eggs). Pool tailouts and pool-riffle interfaces additionally provide sufficient sediment sorting during redd excavation (Moir and Pasternack, 2010) and encourage hyporheic flow which aids in oxygenation of eggs (Harrison et al., 2019).

During summer, juvenile Chinook salmon and steelhead aim to maximize growth while minimizing exposure to predators. Actions targeted at improving summer rearing habitat should strive to create deeper pools and runs (i.e., increases average thalweg and pool depths), increase channel unit frequency, provide ample cover (large wood and total fish cover), and include a variety of substrate sizes geomorphically appropriate to channel unit conditions. Combined, these characteristics present juvenile fish the opportunity to occupy a variety of microhabitats that optimize bioenergetic inputs and expenses. Juvenile fish can rest and hold in slow-velocity water (i.e., pools, behind structure or boulders, within cover, etc.) adjacent to higher velocity water that present increased forage opportunities while cover and instream structure provides protection from predators. This combination of microhabitats present options where the amount of energy necessary to maintain instream position is minimized, the amount of forage available is maximized (or at least increased), and cover provides refuge from predators at minimal energetic cost. Last, incorporating side channels, off-channels, and/or island complexes can also be an effective tool to increase the frequency and scale of target characteristics, ultimately allowing for more microhabitat options for juvenile fish.

Deficiencies in fish-habitat data specific to fry and early parr life stages precluded analysis of potential limitations for these early life stages. However, it is generally recognized that fry and early parr require slow velocity habitats (e.g., off-channel areas, beaver complexes, floodplains, small side-channels) and instream cover for growth and predator avoidance. Due to changes in land use practices within the Upper Walla Walla floodplain, it is likely that floodplain connectivity (a critical component for fry and early parr rearing and growth) has been greatly altered. When possible, incorporating strategies to increase the frequency and duration of floodplain inundation and connectivity into designs would provide fry and early parr access to valuable habitats where they can hold and feed in near-lentic conditions.

Increasing Chinook salmon and steelhead abundances to meet recovery objectives will likely require a combination of actions. While primary objectives for rehabilitation actions may be focused on improving or increasing habitat for a particular species and life stage, it is important that actions address fish habitat and ecosystem processes in a holistic manner. This means considering connectivity, complexity, and overall functionality to support a variety of species and life stages. Designing and planning holistic rehabilitation projects that employ watershed- and reach-scale strategies while considering geomorphic, hydraulic, and biological habitat conditions will likely result in more robust projects that optimize population-level benefits to focal species and ecosystem functions.

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5.0 SUPPLEMENTARY TABLES AND FIGURES

Table 8: Estimated habitat capacity for Chinook salmon summer parr in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
SF1	66	13.2	69,778	3,676	5,298
SF2	37	7.4	39,996	2,892	5,405
SF3	19	3.8	20,237	2,135	5,326
SF4	15	3.0	16,922	2,947	5,641
WW1	66	13.2	59,421	10,371	4,502
WW2	57	11.4	49,542	8,680	4,346
WW3	21	4.2	15,862	2,751	3,777
WW4	24	4.8	17,980	3,023	3,746
WW5	24	4.8	16,853	2,961	3,511

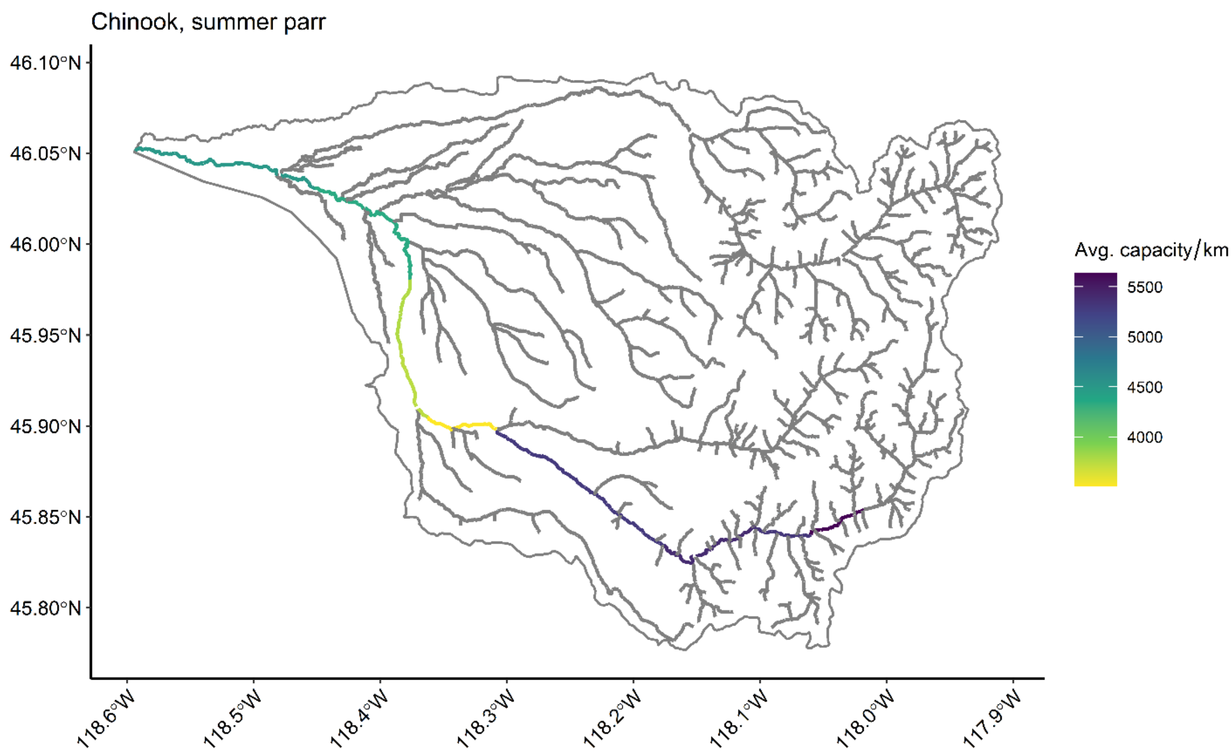

Figure 7: Chinook salmon summer parr capacity (fish/km) by geomorphic reach for the Upper Walla Walla watershed.

Table 9: Estimated habitat capacity for Chinook salmon winter presmolts in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
SF1	66	13.2	38,601	5,437	2,931
SF2	37	7.4	15,611	3,089	2,110
SF3	19	3.8	6,596	1,902	1,736
SF4	15	3.0	5,260	1,697	1,753
WW1	66	13.2	51,762	5,110	3,921
WW2	57	11.4	42,897	4,638	3,763
WW3	21	4.2	14,579	2,891	3,471
WW4	24	4.8	16,669	3,067	3,473
WW5	24	4.8	17,670	3,546	3,681

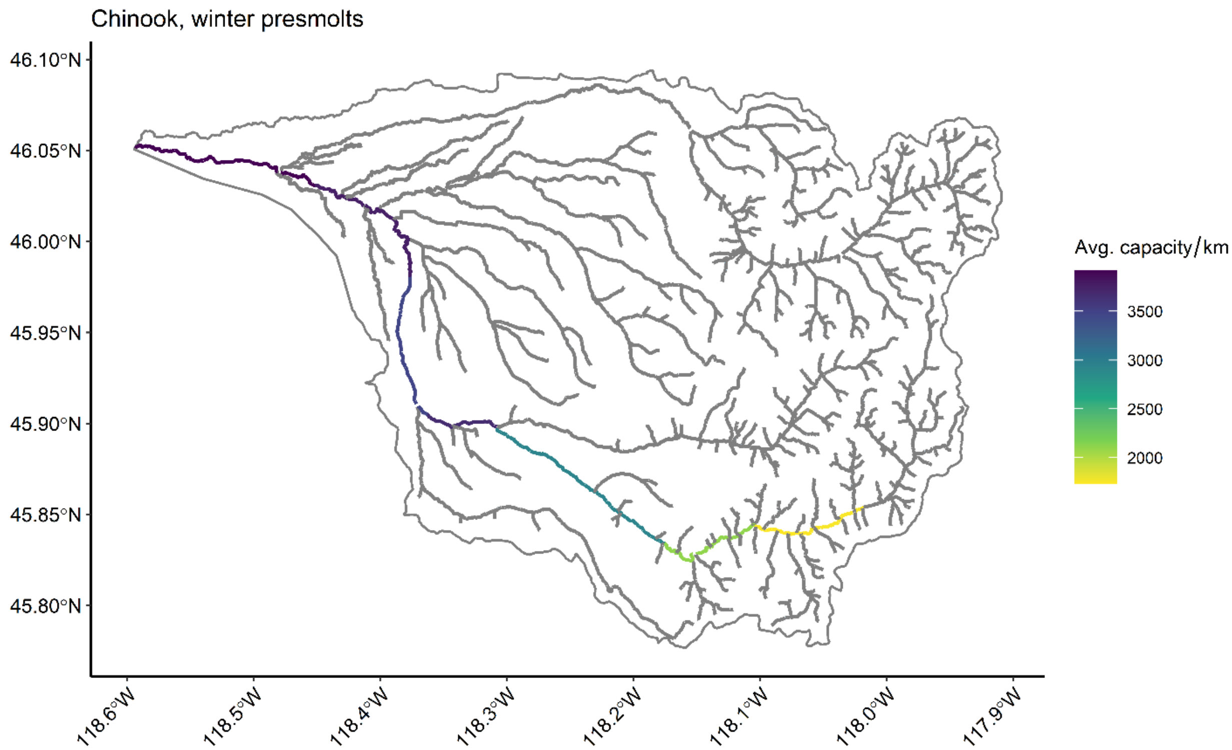

Figure 8: Chinook salmon winter presmolt capacity (fish/km) by geomorphic reach for the Upper Walla Walla watershed.

Table 10: Estimated habitat capacity for Chinook salmon spawning (redds) in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
SF1	66	13.2	30.5	1.9	2.3
SF2	37	7.4	16.9	1.2	2.3
SF3	19	3.8	8.7	0.8	2.3
SF4	15	3.0	7.5	0.9	2.5
WW1	66	13.2	24.6	1.3	1.9
WW2	57	11.4	20.0	1.4	1.8
WW3	21	4.2	7.2	0.7	1.7
WW4	24	4.8	8.6	0.8	1.8
WW5	24	4.8	8.2	0.7	1.7

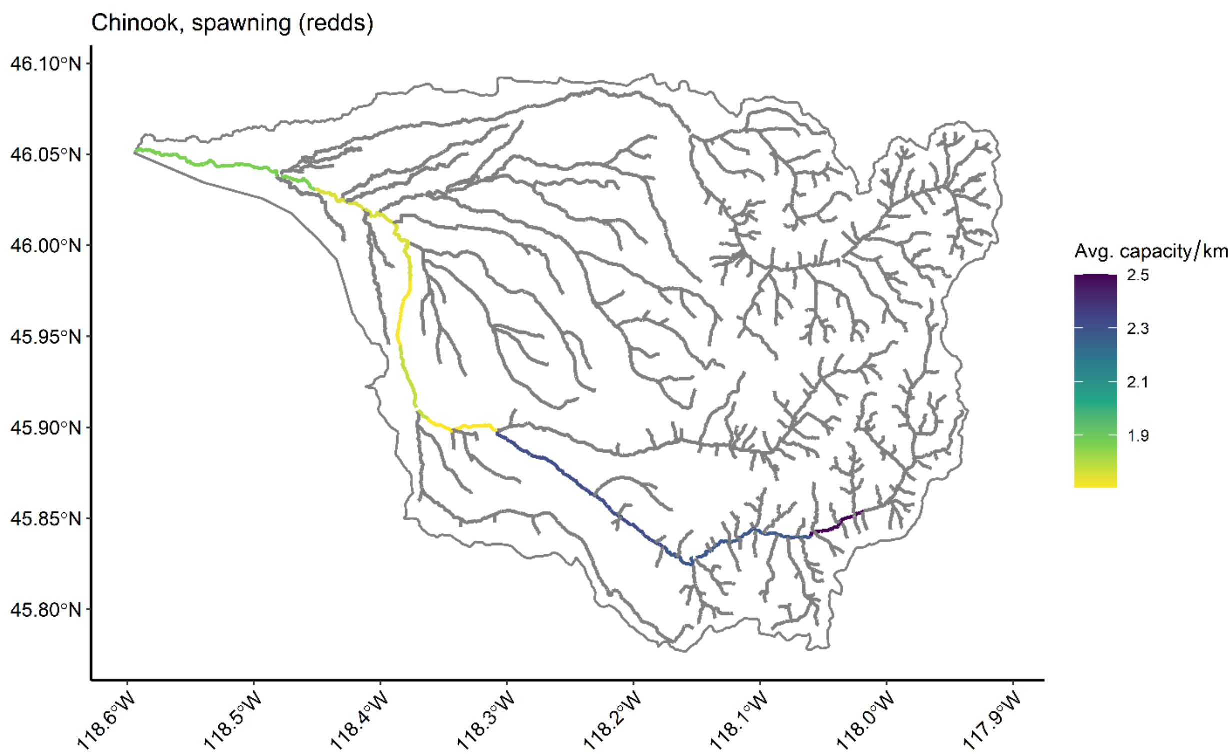

Figure 9: Chinook salmon spawning capacity (redds/km) by geomorphic reach for the Upper Walla Walla watershed.

Table 11: Estimated habitat capacity for steelhead summer parr in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
NF1	29	5.8	18,265	1,209	3,149
NF2	17	3.4	10,966	838	3,225
NF3	25	5.0	15,424	779	3,085
NF4	21	4.2	12,059	827	2,871
NF5	15	3.0	7,778	728	2,593
NF6	16	3.2	7,747	913	2,421
NF7	17	3.4	6,362	577	1,871
NF8	1	0.2	330	103	1,652
SF1	66	13.2	43,978	3,021	3,339
SF2	37	7.4	23,551	2,611	3,183
SF3	19	3.8	9,704	1,175	2,554
SF4	19	3.8	10,125	1,221	2,664
SF5	21	4.2	11,464	1,338	2,729
SF6	39	7.8	17,368	1,356	2,227
SF7	13	2.6	4,806	615	1,848
SF8	2	0.4	658	240	1,644
WW1	66	13.2	40,717	3,215	3,085
WW2	57	11.4	34,925	2,002	3,064
WW3	21	4.2	14,766	1,153	3,516
WW4	24	4.8	16,570	1,235	3,452
WW5	24	4.8	14,493	1,261	3,019

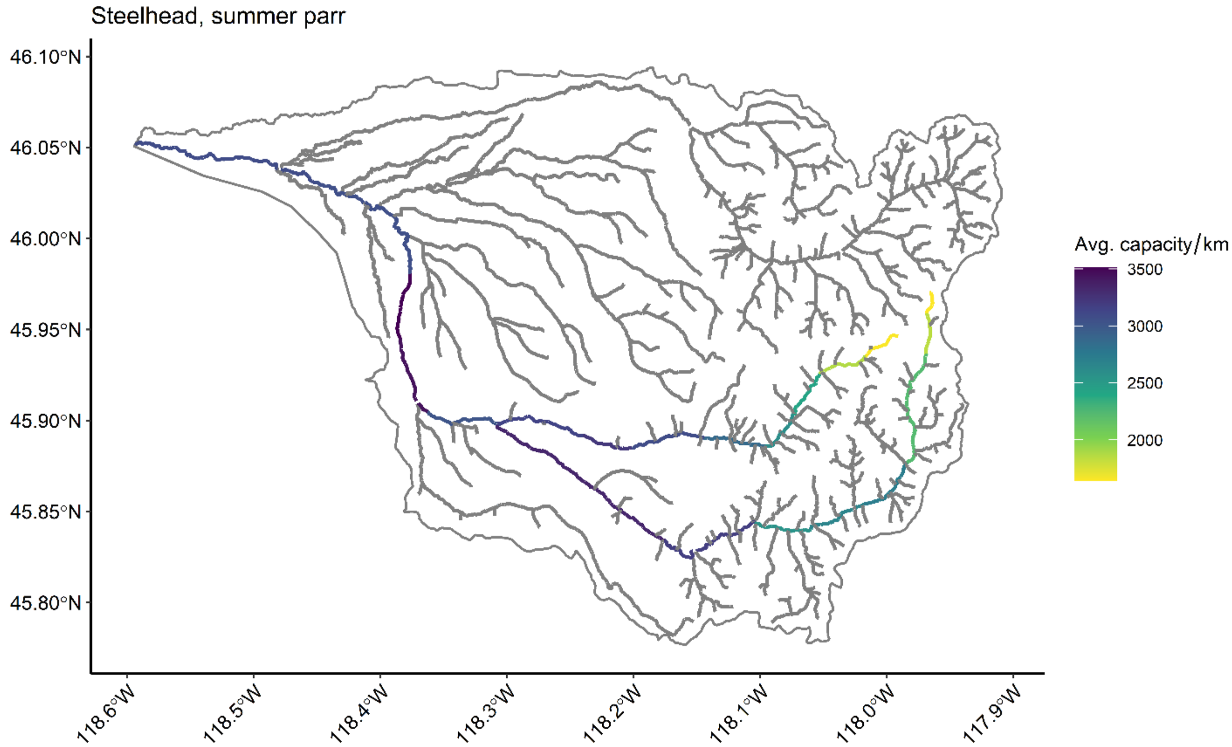

Figure 10: Steelhead summer parr capacity (fish/km) by geomorphic reach for the Upper Walla Walla watershed.

Table 12: Estimated habitat capacity for steelhead winter presmolts in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
NF1	29	5.8	22,203	2,482	3,828
NF2	17	3.4	12,944	1,748	3,807
NF3	25	5.0	19,578	2,154	3,916
NF4	21	4.2	16,648	2,064	3,964
NF5	15	3.0	12,153	1,515	4,051
NF6	16	3.2	10,824	1,726	3,382
NF7	17	3.4	10,557	1,863	3,105
NF8	1	0.2	624	458	3,121
SF1	66	13.2	52,047	3,947	3,952
SF2	37	7.4	15,877	2,534	2,146
SF3	19	3.8	6,424	1,374	1,690
SF4	19	3.8	6,940	1,411	1,826
SF5	21	4.2	9,703	1,742	2,310
SF6	39	7.8	22,252	2,588	2,853
SF7	13	2.6	7,087	1,425	2,726
SF8	2	0.4	1,178	587	2,945
WW1	66	13.2	46,935	4,958	3,556
WW2	57	11.4	36,344	3,977	3,188
WW3	21	4.2	12,883	2,386	3,067
WW4	24	4.8	14,451	2,422	3,011
WW5	24	4.8	14,735	2,285	3,070

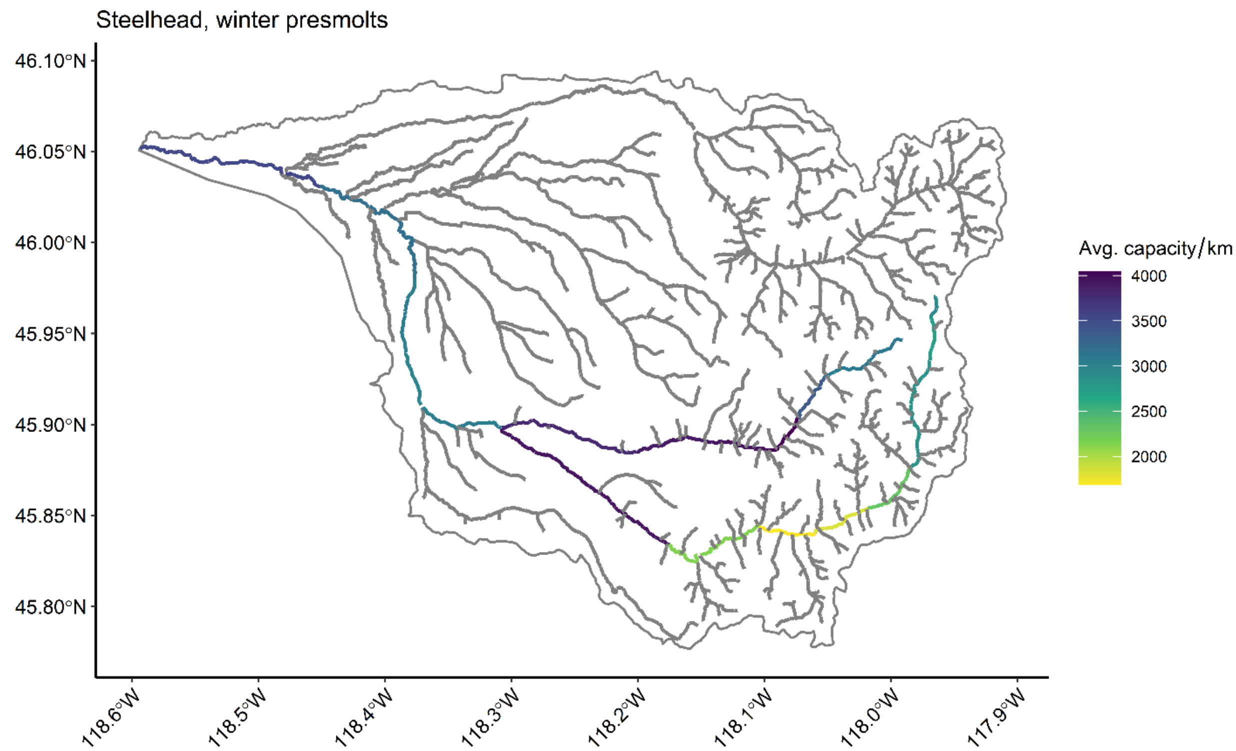

Figure 11: Steelhead winter presmolt capacity (fish/km) by geomorphic reach for the Upper Walla Walla watershed.

Table 13: Estimated habitat capacity for steelhead spawning (redds) in the Upper Walla Walla watershed by geomorphic reach.

Geo reach	# Sub reaches	Stream length (km)	Capacity	Capacity SE	Avg. capacity/km
NF1	29	5.8	10.4	1.0	1.8
NF2	17	3.4	6.2	0.7	1.8
NF3	25	5.0	9.2	0.7	1.8
NF4	21	4.2	8.2	0.6	1.9
NF5	15	3.0	6.0	0.5	2.0
NF6	16	3.2	7.4	0.8	2.3
NF7	17	3.4	9.6	1.3	2.8
NF8	1	0.2	0.6	0.3	2.9
SF1	66	13.2	17.3	0.8	1.3
SF2	37	7.4	10.9	0.9	1.5
SF3	19	3.8	6.9	0.8	1.8
SF4	19	3.8	7.9	0.8	2.1
SF5	21	4.2	9.0	0.7	2.1
SF6	39	7.8	19.8	1.8	2.5
SF7	13	2.6	9.0	1.8	3.5
SF8	2	0.4	1.4	0.7	3.6
WW1	66	13.2	31.6	1.5	2.4
WW2	57	11.4	22.5	1.2	2.0
WW3	21	4.2	7.1	0.6	1.7
WW4	24	4.8	7.9	0.6	1.6
WW5	24	4.8	6.5	0.5	1.3

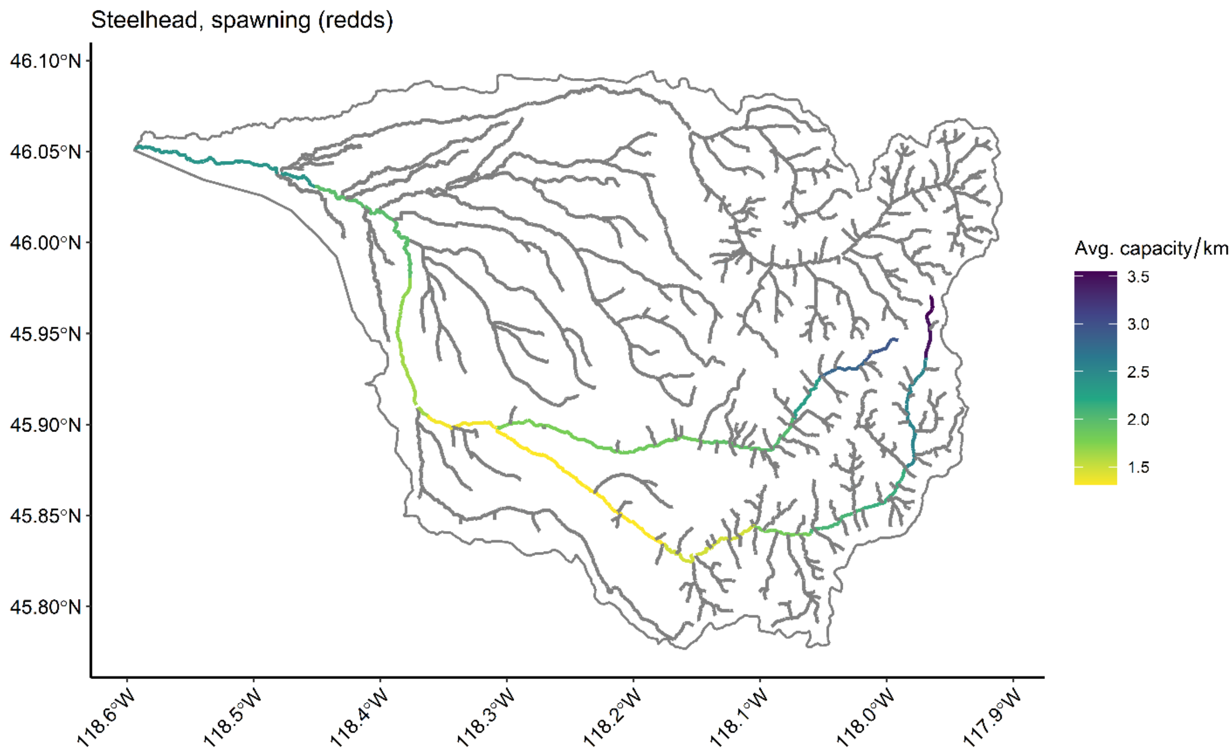

Figure 12: Steelhead spawning capacity (redds/km) by geomorphic reach for the Upper Walla Walla watershed.

Appendix I

Upper Walla Walla Assessment

HYDRAULIC SUITABILITY ASSESSMENT

Technical Report

May 23, 2024

Technical Report

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MOUNT HOOD ENVIRONMENTAL

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Project No.: 001-053-004-01

Technical Report

Subject: Hydraulic Suitability Assessment

Final Date: May 23, 2024

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1.0 BACKGROUND

Water is one of the First Foods that traditionally sustained the people of the CTUIR alongside salmon, deer, cous, and huckleberry. It nourishes people and all other First Foods, and is inherently tied to the five River Vision touchstones: hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation (Jones et al., 2008). These touchstones form the Umatilla River Vision, a holistic approach to water quality restoration. In support of the Vision, population status and habitat use of riverine fishes defined as First Foods including Endangered Species Act [ESA] listed middle Columbia River summer-run steelhead, spring-run Chinook salmon, bull trout, and Pacific lamprey have been identified as critical data needs in the assessment of biotic communities (Jones et al., 2008).

In this document, we assess the hydraulic habitat suitability (HHS) in the Upper Walla Walla study area needed to support select life stages of spring-run Chinook salmon and summer-run steelhead. By comparing depth and velocity suitability curves for Chinook salmon and steelhead to continuous modeled depths and depth-averaged velocities for the Upper Walla Walla study area, we can identify hydraulic habitat that may be limiting the recovery of Chinook salmon and steelhead. This information can help identify reaches where existing depths and velocities may be limiting species and life stages at multiple spatial scales. Evaluating the results of the analysis in context of the habitat capacity, summer stream temperature, and morphological analyses will provide for a robust assessment of existing habitat conditions in the Upper Walla Walla study area that can be used to inform and prioritize restoration efforts and strategies.

1.1 OBJECTIVE

The objective of the analysis was to assess the hydraulic suitability of stream habitat for juvenile summer rearing, juvenile winter rearing, and adult spawning for spring-run Chinook salmon (hereafter Chinook salmon), as well as Middle Columbia River summer-run steelhead (hereafter steelhead). Suitability is based on depths and depth-averaged velocities of reaches in the North Fork Walla Walla (NFWW), South Fork Walla Walla (SFWW), and upper mainstem Walla Walla (MSWW) rivers. Although Chinook salmon currently do not utilize the NFWW, the species was included to better understand if hydraulic conditions were limiting in the NFWW. Data from LiDAR surveys in 2019 and 2021 were used to develop the hydraulic models necessary for HHS analyses, and HHS analyses were conducted for both years to consider changes resulting from extensive flooding that occurred in 2020.

1.2 FOCAL SPECIES

The focal species for the HHS analyses were:

- Chinook salmon (*Oncorhynchus tshawytscha,* ESA-listed “threatened”)
- Steelhead (*O. mykiss*, ESA-listed “threatened”)

While our HHS models specifically address Chinook salmon and steelhead, any uplift in habitat for these species are also expected to benefit:

- Columbia River bull trout (*Salvelinus confluentus*; hereafter bull trout, ESA-listed "threatened")
- Pacific lamprey (*Entosphenus tridentatus*)

1.3 STUDY AREA

The study area for this assessment was limited to sections of the MSWW, NFWW, and SFWW where LiDAR data were available and hydraulic models could be developed. The downstream extent of the MSWW began at the confluence with Dry Creek near Lowden, Washington and extended upstream to the confluence of the NFWW and SFWW (approximately 38.5 rkm). The NFWW and SFWW reaches began at the confluence of the two rivers and extended upstream approximately 18.5 km and 33 km, respectively.

2.0 METHODS

Depth, velocity, and composite suitability calculations were completed for each combination of species, life stage, and year, resulting in 12 scenarios (Table 1). Calculations were done for each pixel within a raster (flow scenario) and summarized at the river kilometer (rkm) and geomorphic reach scales (Table 2 and Table 3). Below is a generalized description of the methods performed for each scenario.

1. Rasters containing modeled depth and depth-averaged velocity values derived from LiDAR data were imported into R (R Core Team, 2024) with a raster pixel resolution of 1m x 1m. Rasters were provided by Rio Applied Science and Engineering (Rio ASE).
2. Depth and velocity suitability curves specific to the species and life stages developed by Maret et al. (2006) and Anchor QEA (2023) were used to calculate the depth and velocity suitability values for each pixel within the raster.
3. Composite suitability values were calculated for each pixel as the geometric mean of the depth and velocity suitability values.
4. Depth, velocity, and composite suitability values were summarized by river kilometers and geomorphic reaches.
5. Total wetted area, weighted usable area (WUA), and normalized weighted usable area (i.e., HHS) were calculated by river kilometer and geomorphic reach. Total wetted area was calculated by counting the total number of pixels (each with an area of 1 m^2), that occur within each river kilometer and geomorphic reach. The WUA was calculated by summing the composite suitability values of all pixels within that same area. The normalized weighted usable area was calculated by dividing the WUA by the total wetted area for each river kilometer and geomorphic reach.

Table 1. Model scenarios for evaluated depth, velocity, and composite suitability including the corresponding depth and velocity rasters used for each scenario.

Scenario	Species	Life stage	Season	Year	Depth raster	Velocity raster
1	Chinook salmon	Juvenile	Summer	2019	Combined_2019lidar_LowFlow_Depth_metric.tif	Combined_2019lidar_LowFlow_Velocity_metric.tif
2	Chinook salmon	Juvenile	Summer	2021	Combined_2021lidar_LowFlow_Depth_metric.tif	Combined_2021lidar_LowFlow_Velocity_metric.tif
3	Chinook salmon	Spawning	Summer	2019	Combined_2019lidar_LowFlow_Depth_metric.tif	Combined_2019lidar_LowFlow_Velocity_metric.tif
4	Chinook salmon	Spawning	Summer	2021	Combined_2021lidar_LowFlow_Depth_metric.tif	Combined_2021lidar_LowFlow_Velocity_metric.tif
5	Chinook Salmon	Juvenile	Winter	2019	Combined_2019lidar_Winter_depth.tif	Combined_2019lidar_Winter_velocity.tif
6	Chinook Salmon	Juvenile	Winter	2021	Combined_2021lidar_Winter_depth.tif	Combined_2021lidar_Winter_velocity.tif
7	Steelhead	Juvenile	Summer	2019	Combined_2019lidar_LowFlow_Depth_metric.tif	Combined_2019lidar_LowFlow_Velocity_metric.tif
8	Steelhead	Juvenile	Summer	2021	Combined_2021lidar_LowFlow_Depth_metric.tif	Combined_2021lidar_LowFlow_Velocity_metric.tif
9	Steelhead	Juvenile	Winter	2019	Combined_2019lidar_Winter_depth.tif	Combined_2019lidar_Winter_velocity.tif
10	Steelhead	Juvenile	Winter	2021	Combined_2021lidar_Winter_depth.tif	Combined_2021lidar_Winter_velocity.tif
11	Steelhead	Spawning	Spring	2019	Combined_2019lidar_Spring_depth.tif	Combined_2019lidar_Spring_velocity.tif
12	Steelhead	Spawning	Spring	2021	Combined_2021lidar_Spring_depth.tif	Combined_2021lidar_Spring_velocity.tif

Table 2. Description of flow scenarios used in Hydraulic Habitat Suitability assessment. See *Appendix D: Hydraulic Modeling* for further details.

Season	Flow description
Summer	95% exceedance summer flow (Jul. 1 – Sept. 30)
Winter	50% exceedance winter flow (Dec. 1 - Jan. 31)
Spring	14-day duration flow during spring runoff (Feb. 15 – Mar. 30)

Table 3. The extents (upstream and downstream river kilometer) and total length for each geomorphic reach. Note, river kilometers increase moving upstream.

Geomorphic reach	River	Min rkm	Max rkm	Length (km)
GR_01_MS	Walla Walla River	44.1	57.2	13.1
GR_02_MS	Walla Walla River	57.2	68.7	11.5
GR_03_MS	Walla Walla River	68.7	72.8	4.1
GR_04_MS	Walla Walla River	72.8	77.9	5.1
GR_05_MS	Walla Walla River	77.9	82.6	4.7
GR_01_NF	North Fork Walla Walla River	0	5.7	5.7
GR_02_NF	North Fork Walla Walla River	5.7	9.2	3.5
GR_03_NF	North Fork Walla Walla River	9.2	14.1	4.9
GR_04_NF	North Fork Walla Walla River	14.1	18.3	4.2
GR_05_NF	North Fork Walla Walla River	18.3	19.2	0.9
GR_01_SF	South Fork Walla Walla River	0	13.3	13.3
GR_02_SF	South Fork Walla Walla River	13.3	20.8	7.5
GR_03_SF	South Fork Walla Walla River	20.8	24.6	3.8
GR_04_SF	South Fork Walla Walla River	24.6	28.5	3.9
GR_05_SF	South Fork Walla Walla River	28.5	32.8	4.3

2.1 SUITABILITY CURVES

Depth and velocity suitability curves for Chinook salmon spawning, steelhead spawning, juvenile Chinook summer rearing, and juvenile steelhead summer rearing were derived from Maret et al. (2006) (Figure 1 and Figure 2). Juvenile Chinook salmon winter rearing and juvenile steelhead winter rearing depth and velocity suitability curves used in this analysis were consistent with those implemented in the Analysis Summary and Results; Tucannon River 2020 LiDAR Analysis (Anchor QEA, 2023). These curves were originally derived from the summer rearing suitability curves from 2022 WDFW Instream Flow Study Guidelines (WDFW 2022) and modified to better represent hydraulic suitability preferences for juvenile winter rearing based on local expert knowledge (Anchor QEA, 2023). The 12 suitability curves were used to calculate the depth or velocity suitability for each pixel within a given scenario. The composite suitability for a pixel was then calculated as the geometric mean of the depth and velocity suitability values.

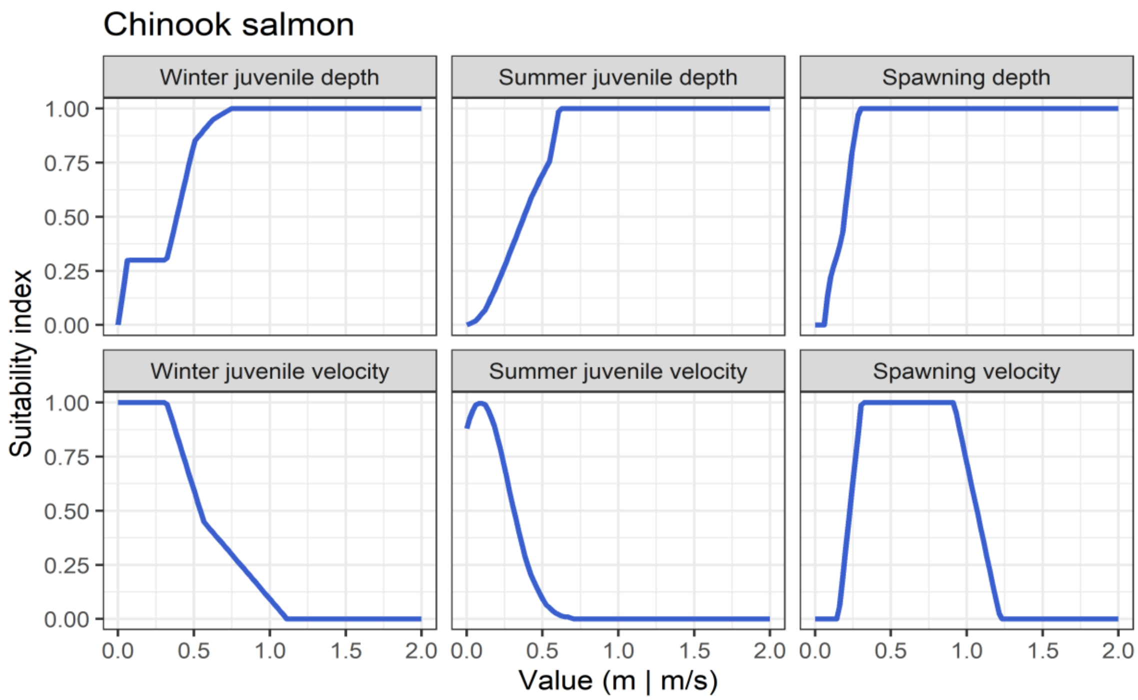

Figure 1: Suitability indices at varying depths and velocities for juvenile Chinook salmon rearing and adult spawning from Maret et al. (2006) and Anchor QEA (2023).

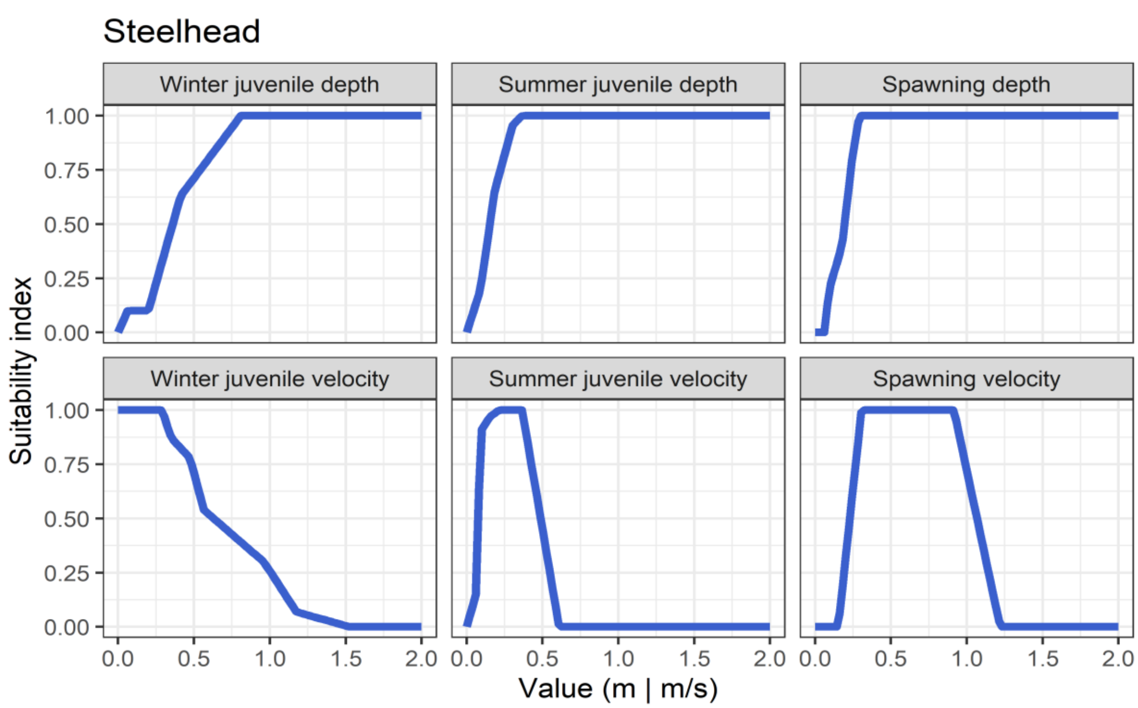

Figure 2: Suitability indices at varying depths and velocities for juvenile steelhead rearing and adult spawning from Maret et al. (2006) and Anchor QEA (2023).

3.0 RESULTS

Depth, velocity, and composite suitability results were summarized for the MSWW, NFWW, and SFWW within the study area. Results were parsed by each species and life stage for both 2019 and 2021 datasets. We focused primarily on results from 2021 to describe "current" hydraulic suitability. Additional results, including higher-resolution summaries and results for 2019, are provided in the Supplemental Tables and Figures section.

3.1 CHINOOK SALMON SPAWNING

The composite hydraulic suitability for spawning was highly variable across the three stream reaches with the SFWW, on average, being most suitable (Figures 3 and Figures 4). The MSWW exhibited the greatest intra-variability, where Reach 4 and Reach 5 were most suitable, Reach 1 and Reach 2 were least suitable, and Reach 3 was in between. The low composite suitability for MSWW Reaches 1-3 were primarily the result of unsuitable velocities. The NFWW had low composite suitability and was limited by both depth and velocity. In contrast, the SFWW exhibited suitable spawning velocities with moderate to high spawning depth suitability. Comparing the HHS by river kilometer between 2019 and 2021, the extensive flooding in 2020 had minimal influence on overall HHS conditions (Figure 5). In general, HHS in the MSWW above river kilometer 75 and all the SFWW appear relatively suitable with average HHS above 0.65. Conversely, downstream reaches of the MSWW and all the NFWW reaches were generally poor for Chinook salmon spawning.

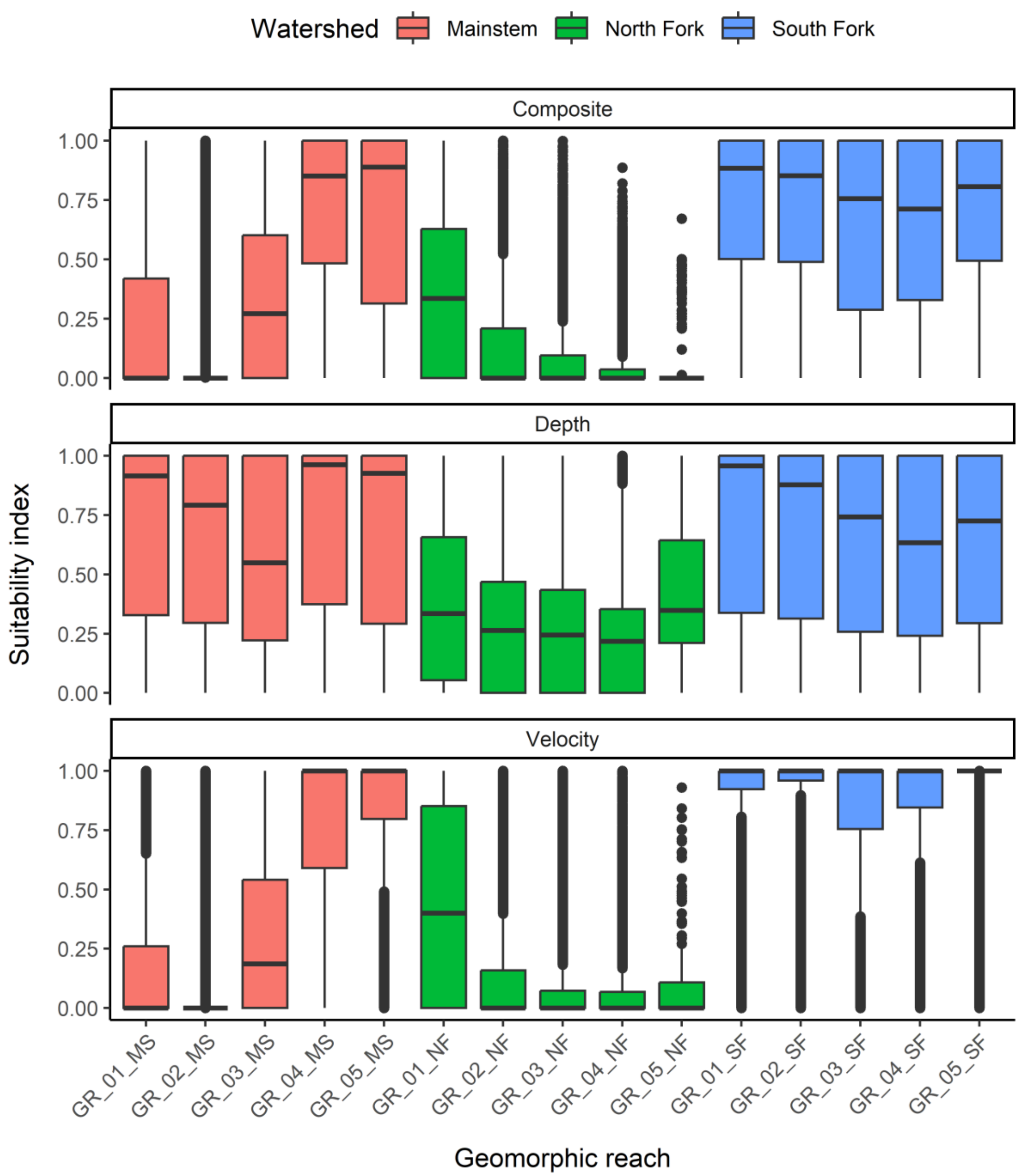

Figure 3: Box plots showing the distribution of suitability values for composite, depth and velocity for Chinook salmon spawning across geomorphic reaches in the Upper Walla Walla study area in 2021.

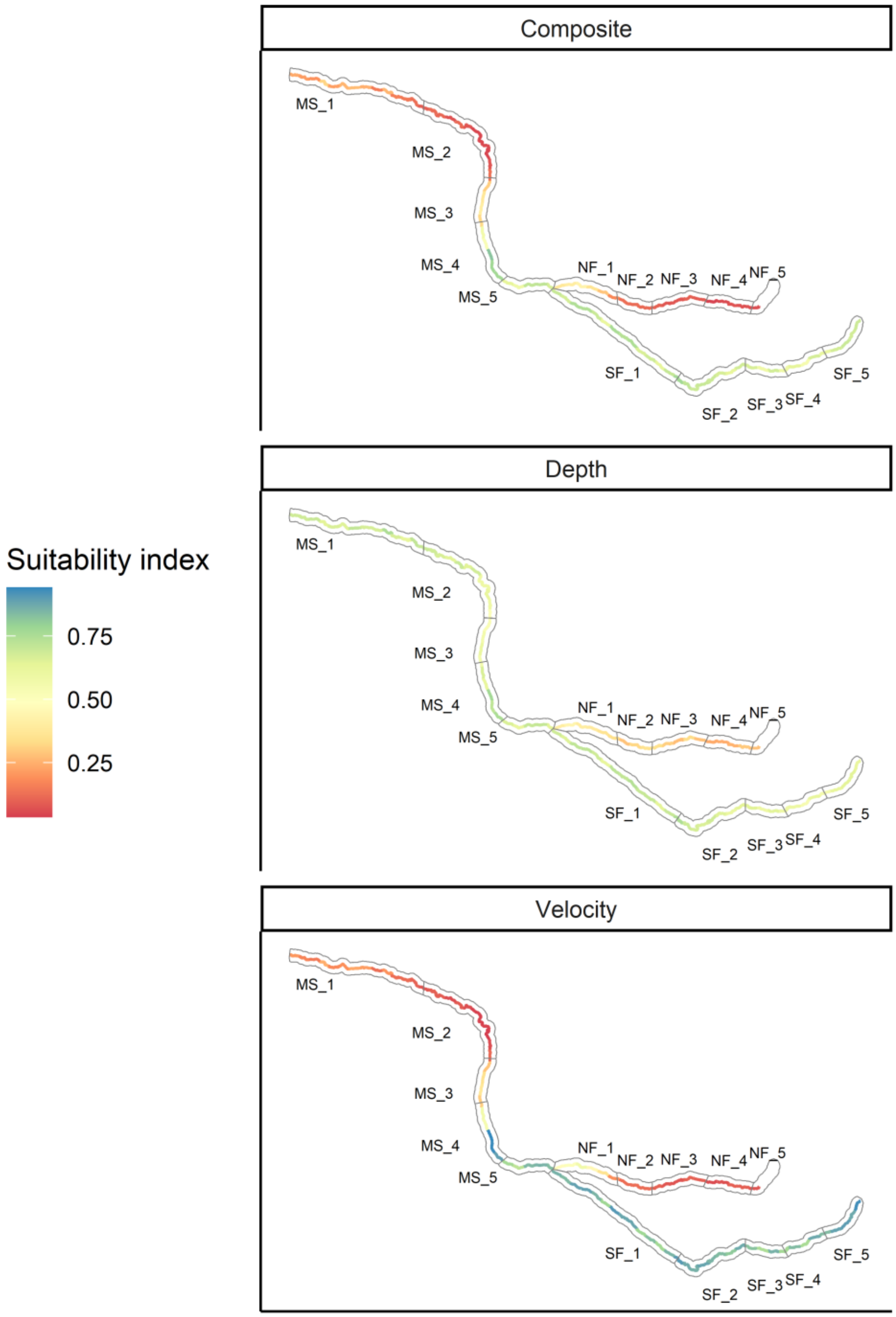

Figure 4: Map showing the hydraulic habitat suitability for Chinook salmon spawning in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

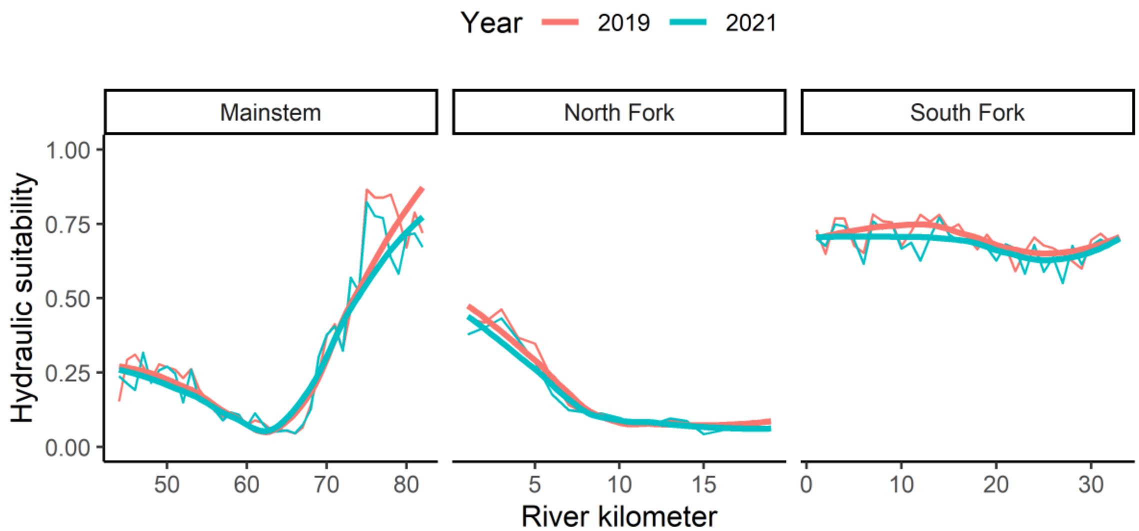

Figure 5: Hydraulic habitat suitability by river kilometer for Chinook salmon spawning for 2019 and 2021.

3.2 STEELHEAD SPAWNING

Composite hydraulic suitability within geomorphic reaches was highly variable for steelhead spawning (Figure 6 and Figure 7). Composite hydraulic suitability for the MSWW was largely driven by velocity; where depth suitability within the MSWW was generally high and velocity suitability within reaches was variable. MSWW Reach 4 had the least suitable steelhead spawning habitat out of all reaches in the Upper Walla Walla study area. In contrast, the NFWW had the highest composite suitability within the study area with reaches having a median composite suitability score of ~0.70. The SFWW displayed an increasing trend in composite suitability values from the confluence moving upstream. Similar to Chinook salmon spawning, the flooding in 2020 had minimal impacts on steelhead spawning hydraulic suitability between 2019 and 2021 (Figure 8). In general, hydraulic conditions were relatively suitable for steelhead spawning for all geomorphic reaches so long as velocity wasn't a limiting factor.

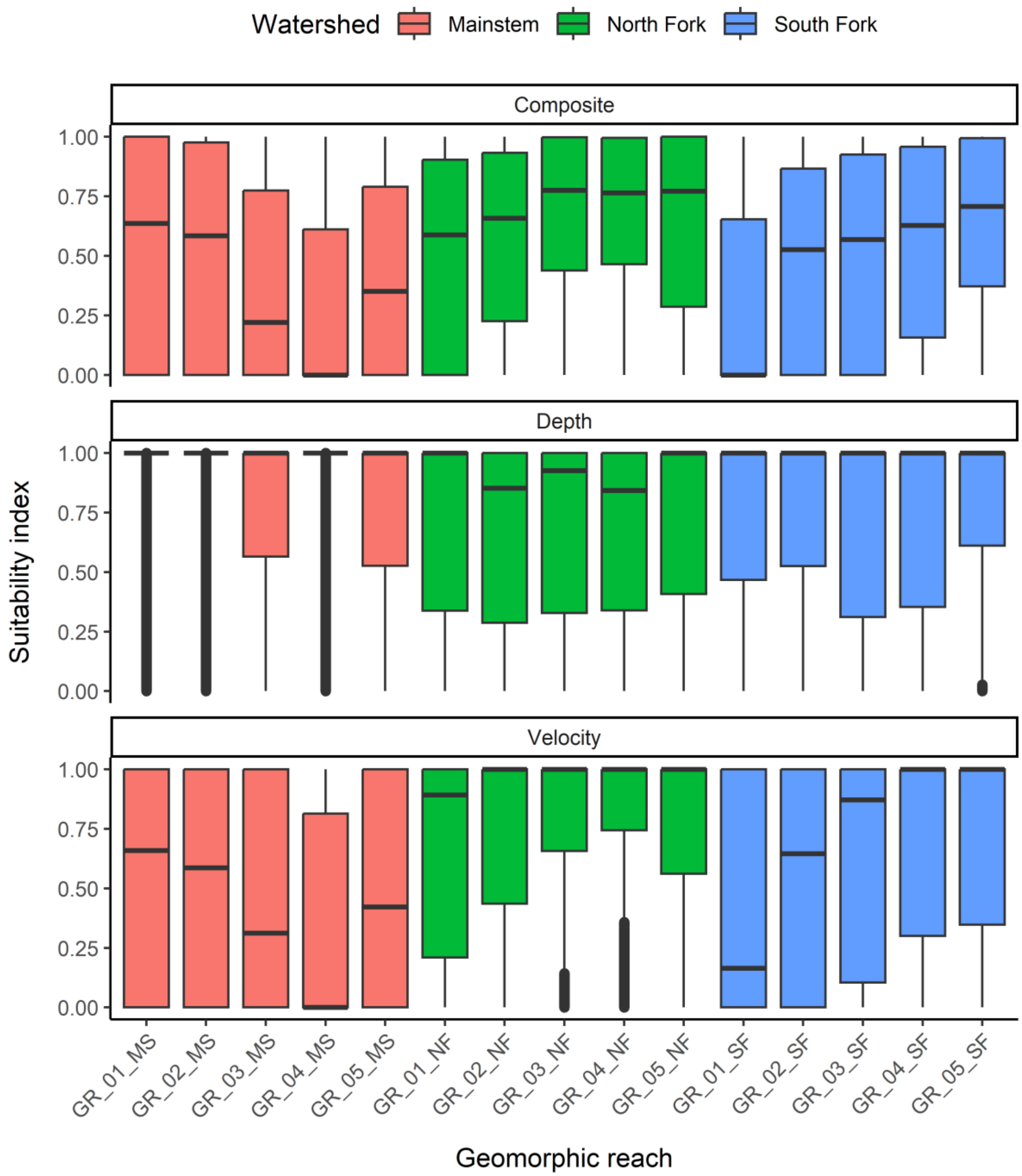

Figure 6: Box plots showing the distribution of suitability values for composite, depth and velocity for steelhead spawning across geomorphic reaches in the Upper Walla Walla study area in 2021.

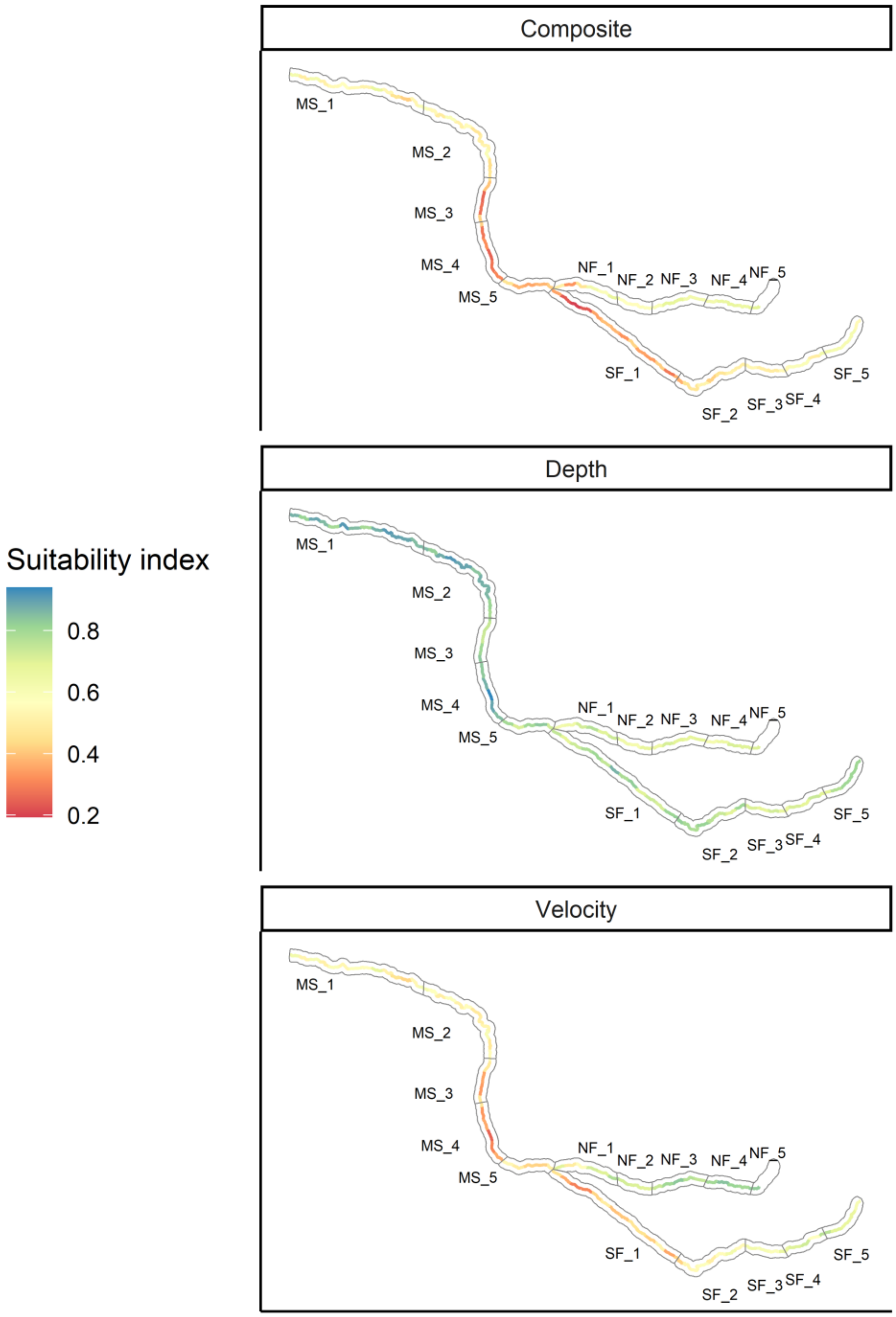

Figure 7: Map showing the hydraulic habitat suitability for steelhead spawning in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

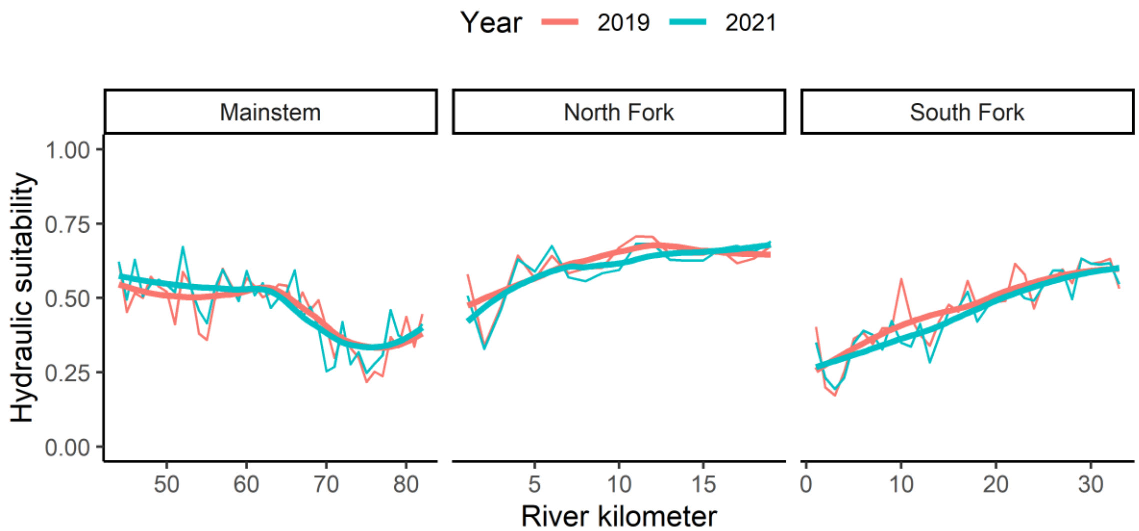

Figure 8: Hydraulic habitat suitability by river kilometer for steelhead spawning for 2019 and 2021.

3.3 CHINOOK SALMON JUVENILE SUMMER REARING

Composite suitability was lowest for Chinook salmon juvenile summer rearing relative to the other species and life stages (Figure 9 and Figure 10). Composite suitability was relatively low across all geomorphic reaches and rivers, and lowest in the SFWW. MSWW Reach 1 and MSWW Reach 2 had moderate composite suitability but were still below 0.50. Depth appeared to be a limiting factor for Chinook salmon juvenile summer rearing in all three rivers, while velocities were most suitable in the MSWW and NFWW and least suitable in the SFWW. In general, HHS for Chinook salmon juvenile summer rearing was poor in all rivers, with only lower portions of the MSWW (below rkm 62) being moderately suitable. Similar to other species and life stages, HHS for Chinook salmon juvenile rearing changed little from 2019 to 2021 (Figure 11).

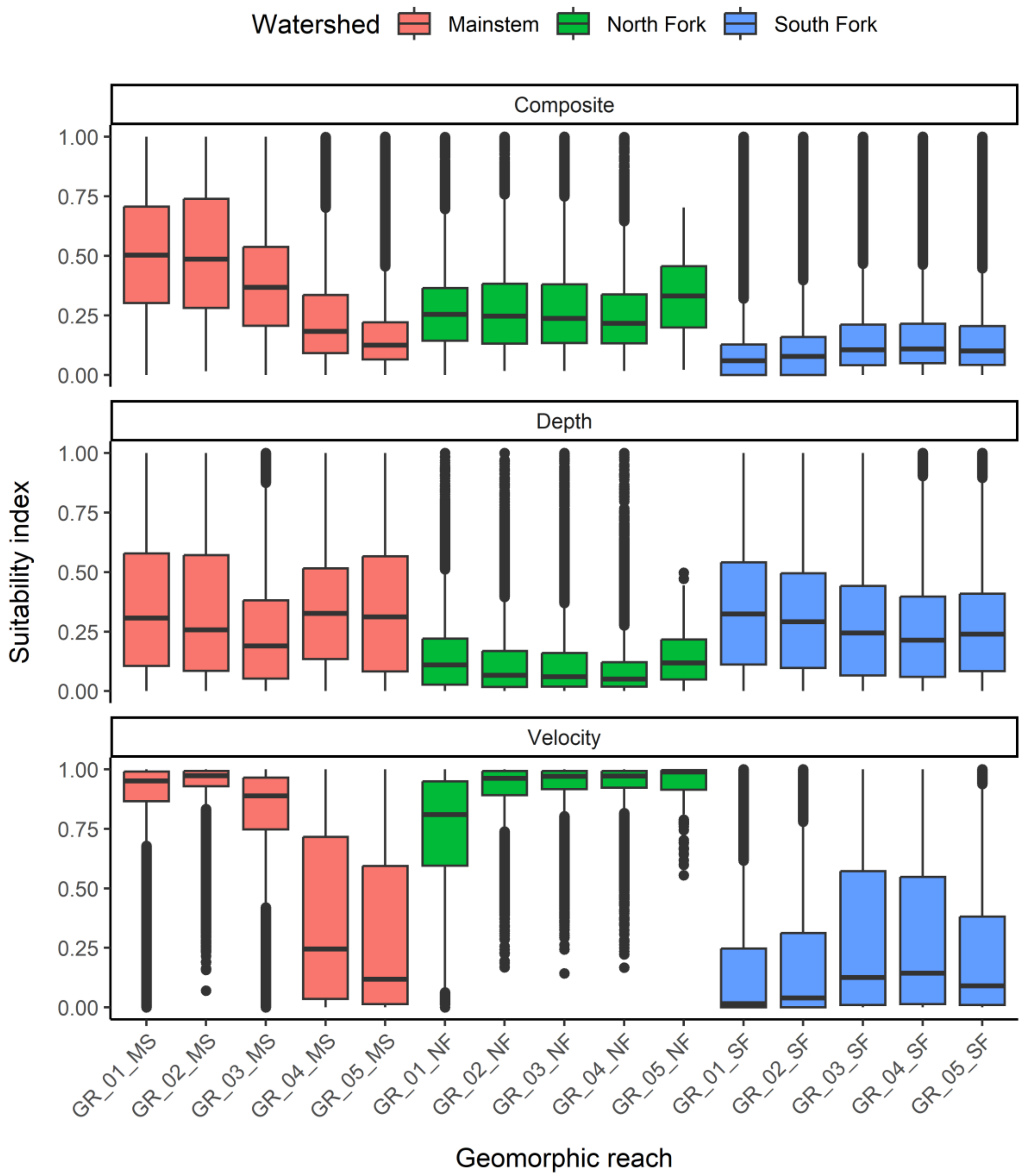

Figure 9: Box plots showing the distribution of suitability values for composite, depth and velocity for Chinook salmon juvenile summer rearing across geomorphic reaches in the Upper Walla Walla study area in 2021.

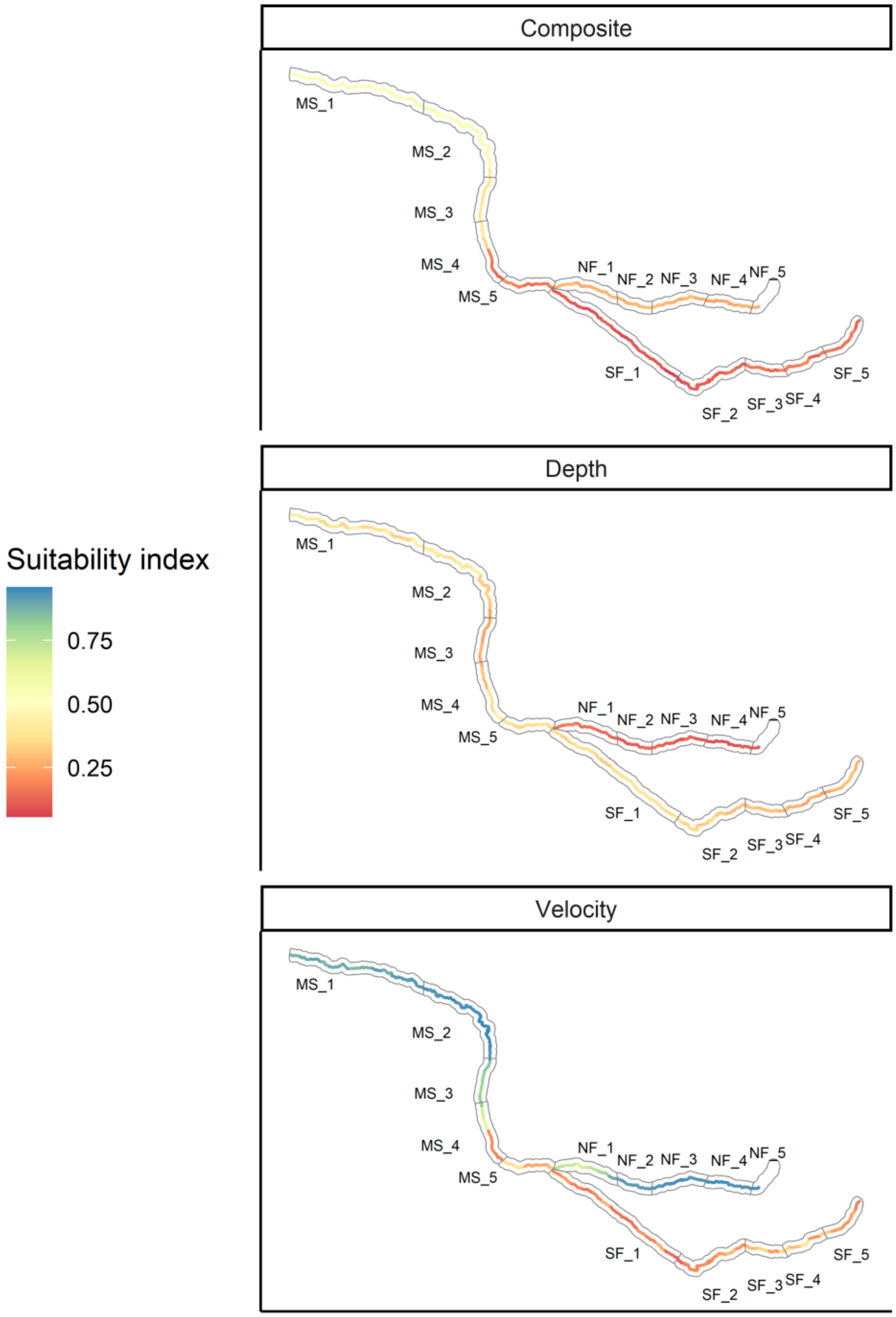

Figure 10: Map showing the hydraulic habitat suitability for Chinook salmon juvenile summer rearing in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

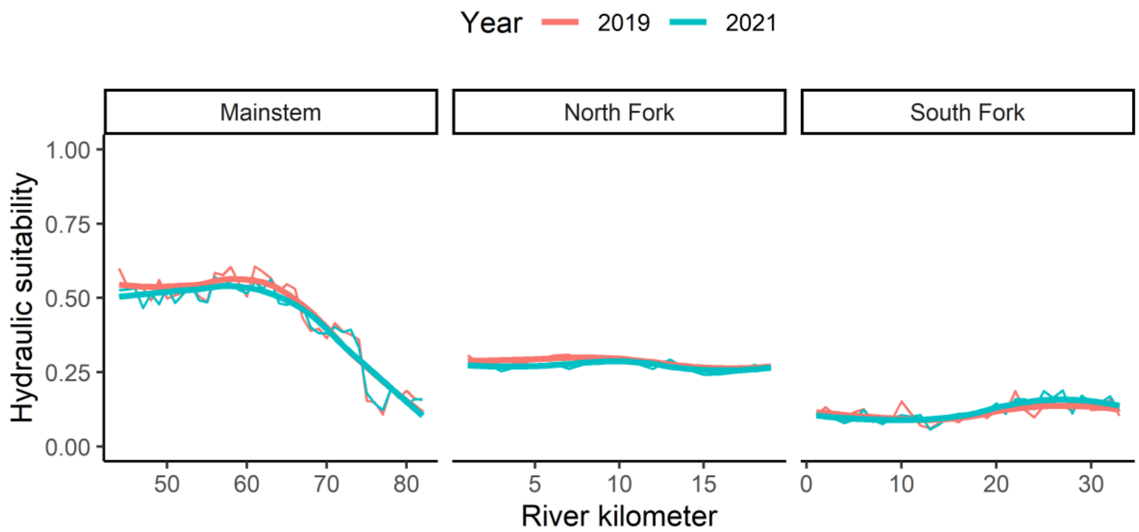

Figure 11: Hydraulic habitat suitability by river kilometer for Chinook salmon summer juvenile rearing for 2019 and 2021.

3.4 STEELHEAD JUVENILE SUMMER REARING

Composite suitability for steelhead juvenile summer rearing was moderate to high (median scores between 0.4-08) in both the MSWW and NFWW (Figure 12 and Figure 13). Hydraulic habitat conditions were less suitable in the SFWW, largely due to less suitable velocities. The distribution of velocity suitability across all three rivers were consistently higher than those of depth suitability, except for the NFWW. Again, there was little difference in the HHS from 2019 to 2021 for steelhead juvenile summer rearing (Figure 14).

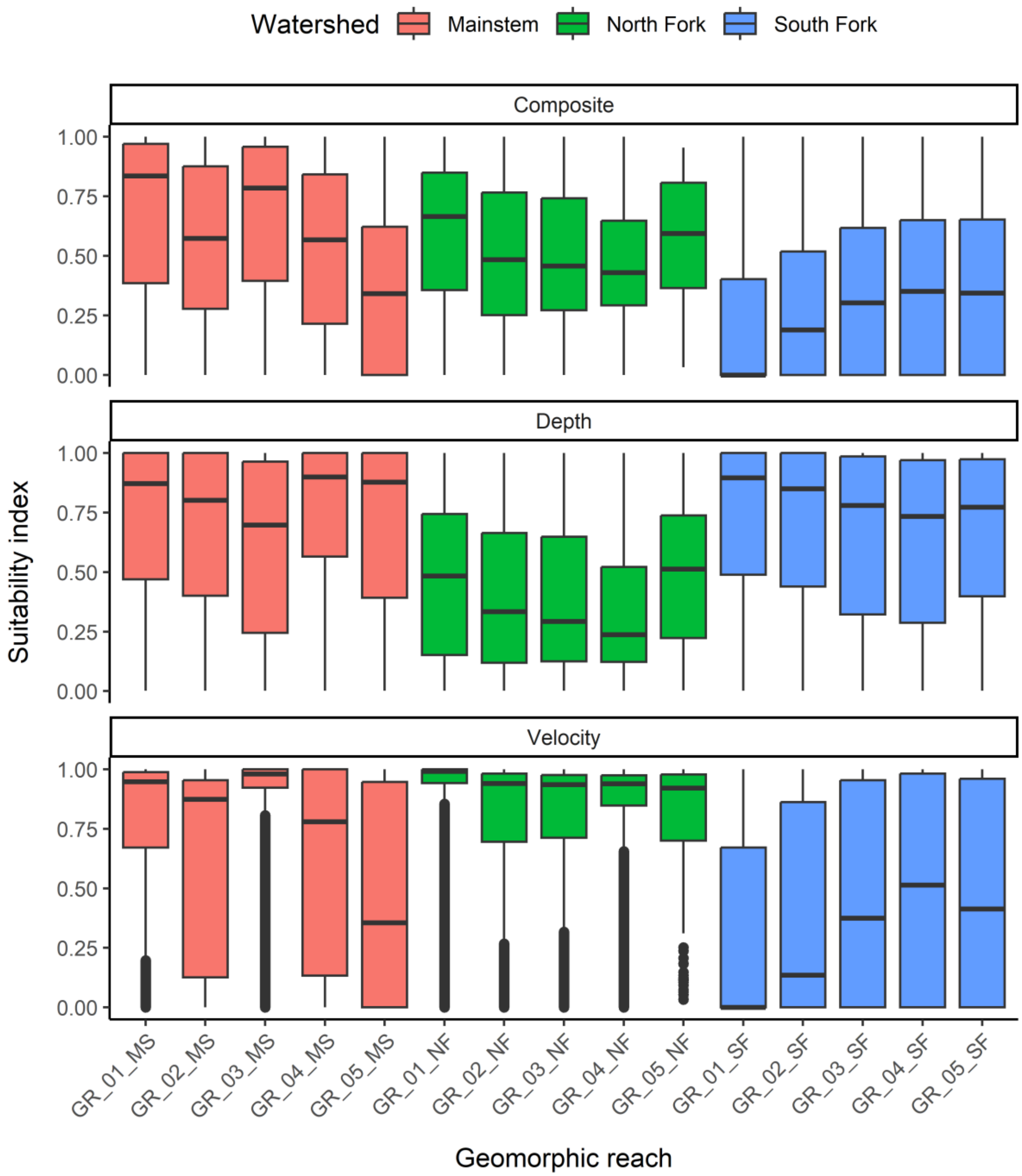

Figure 12: Box plots showing the distribution of suitability values for composite, depth and velocity for steelhead juvenile summer rearing across geomorphic reaches in the Upper Walla Walla study area in 2021.

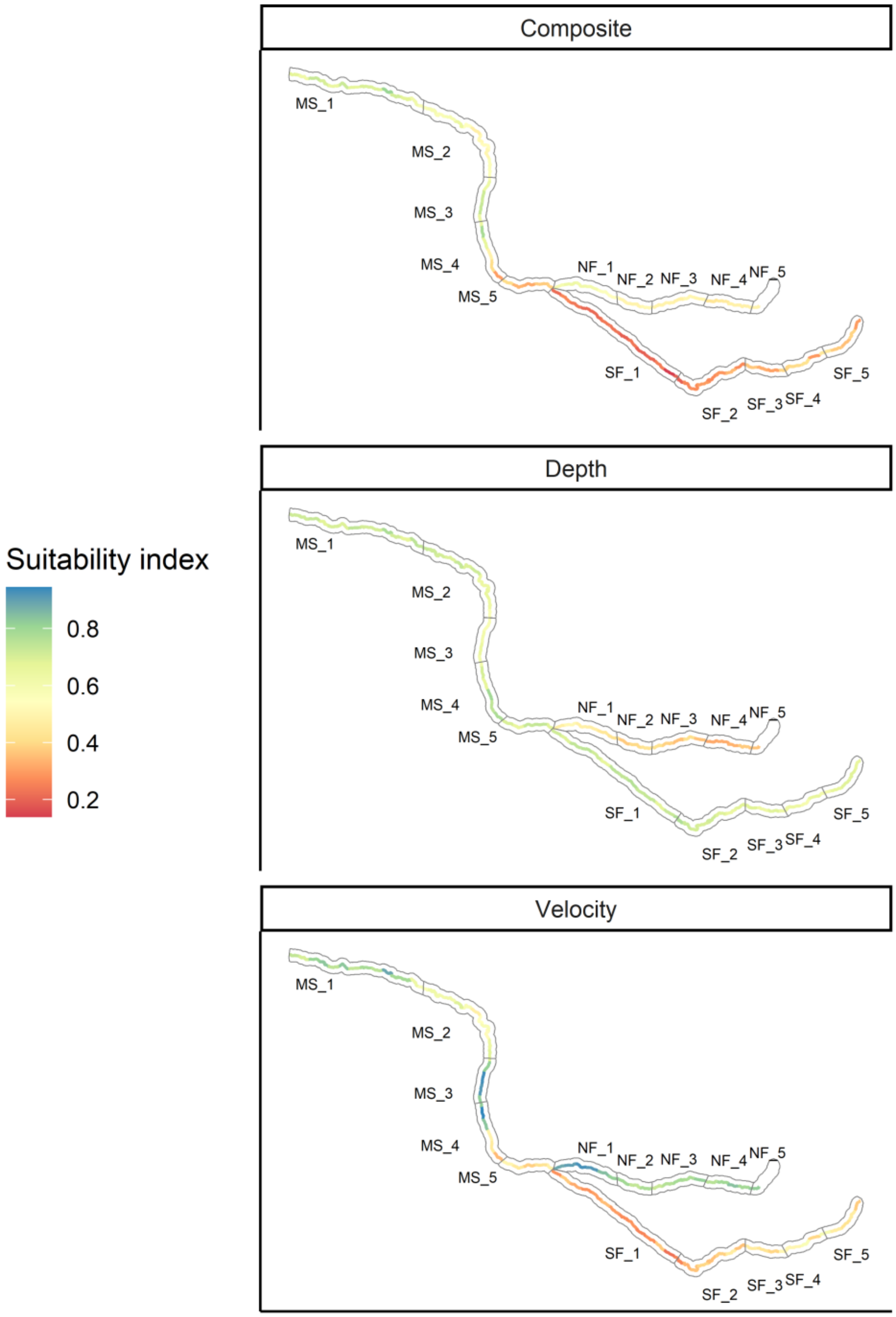

Figure 13: Map showing the hydraulic habitat suitability for steelhead juvenile summer rearing in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

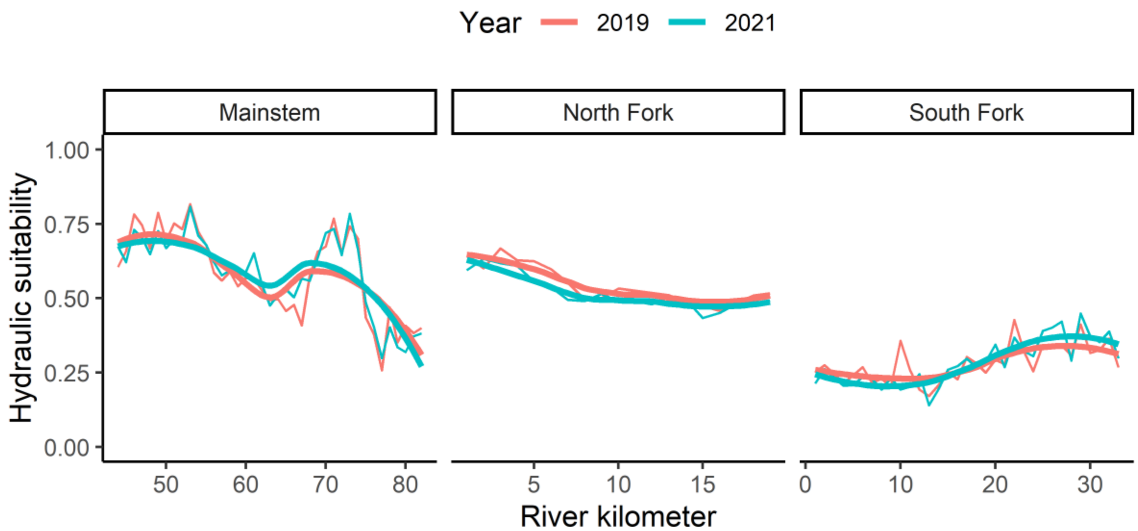

Figure 14: Hydraulic habitat suitability by river kilometer for steelhead juvenile summer rearing for 2019 and 2021.

3.5 CHINOOK SALMON JUVENILE WINTER REARING

The composite suitability for Chinook salmon juvenile winter rearing was relatively consistent across rivers with all reaches having a median composite suitability between 0.4 - 0.5 (Figure 15 and 16). The composite suitability generally declined moving upstream from MSWW Reach 1 to MSWW Reach 5, as both depth and velocity suitability declined. The NFWW reaches had the highest velocity suitability and the lowest depth suitability in the study area. The composite suitability increased from SFWW Reach 1 to SFWW Reach 3 as depth suitability remained relatively constant and velocity suitability increased by ~ 0.2. In general, both depth and velocity were moderately suitable for Chinook salmon juvenile winter rearing for all reaches except for depths in the NFWW, and to a lesser the SFWW. Changes in composite suitability for winter juvenile Chinook salmon from 2019 to 2021 were nearly indistinguishable, particularly for the MSWW (Figure 17).

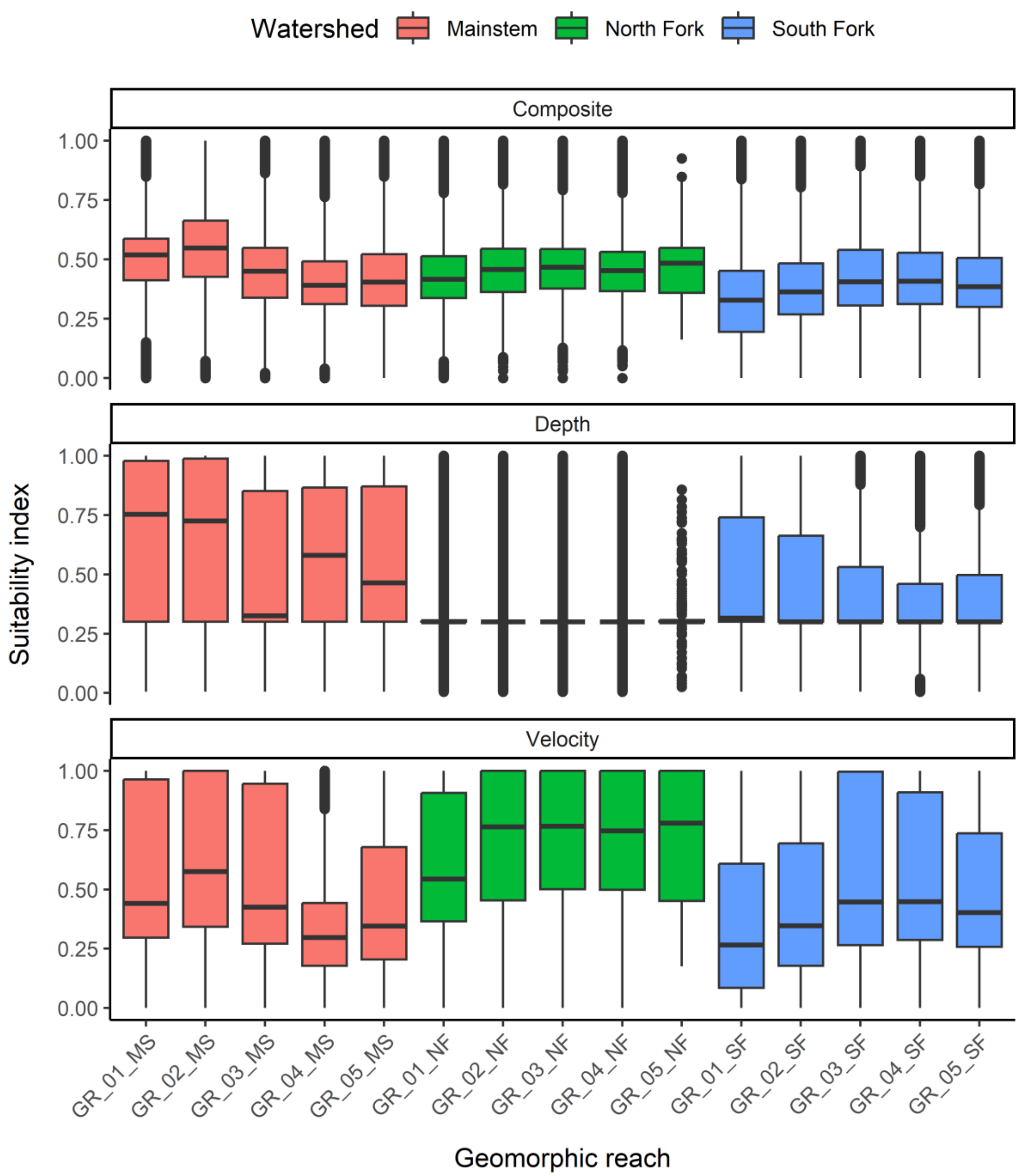

Figure 15: Box plots showing the distribution of suitability values for composite, depth and velocity for Chinook salmon juvenile winter rearing across geomorphic reaches in the Upper Walla Walla study area in 2021.

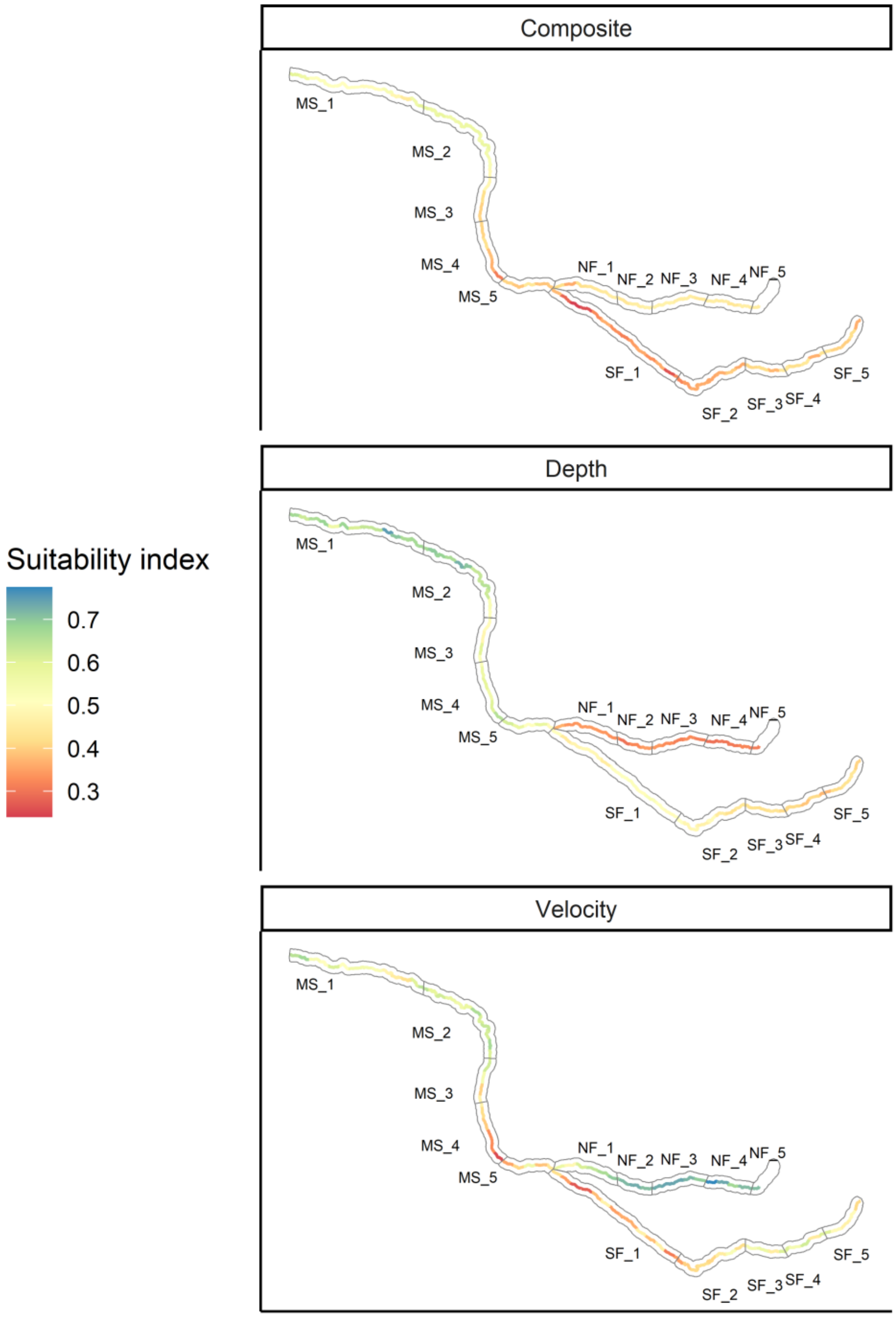

Figure 16: Map showing the hydraulic habitat suitability for Chinook salmon juvenile winter rearing in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

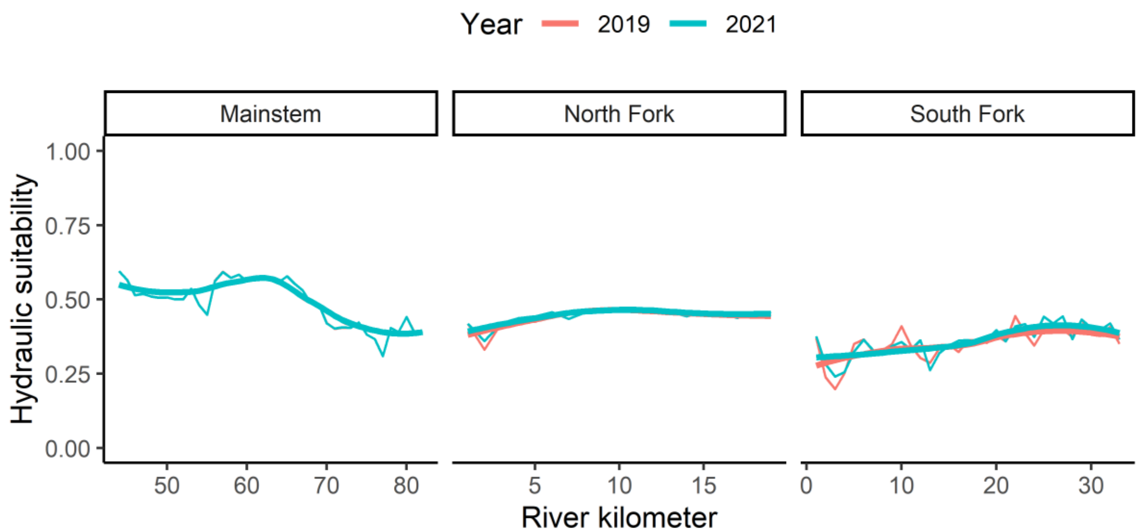

Figure 17: Hydraulic habitat suitability by river kilometer for Chinook salmon juvenile winter rearing for 2019 and 2021.

3.6 STEELHEAD JUVENILE WINTER REARING

Composite suitability for steelhead juvenile winter rearing was moderate with MSWW reaches having the highest median composite suitability (Figure 18 and Figure 19). Similar to Chinook salmon juvenile winter rearing, median composite suitability ranged from 0.3 - 0.55. In general, there was an inverse relationship between velocity and depth suitability for reaches. All NFWW reaches had relatively high velocity suitability while exhibiting the lowest depth suitability. In contrast, SFWW Reach 1, SFWW Reach 2, MSWW Reach 4, MSWW Reach 5 had relatively high depth suitability but low velocity suitability. The two exceptions were MSWW Reach 1 and MSWW Reach 2 which had relatively high depth and velocity suitability, resulting in the two highest steelhead juvenile winter rearing composite suitability scores in the study area. Similar to other species and life stages, there was little difference in hydraulic suitability between 2019 and 2021 for steelhead juvenile winter rearing (Figure 20).

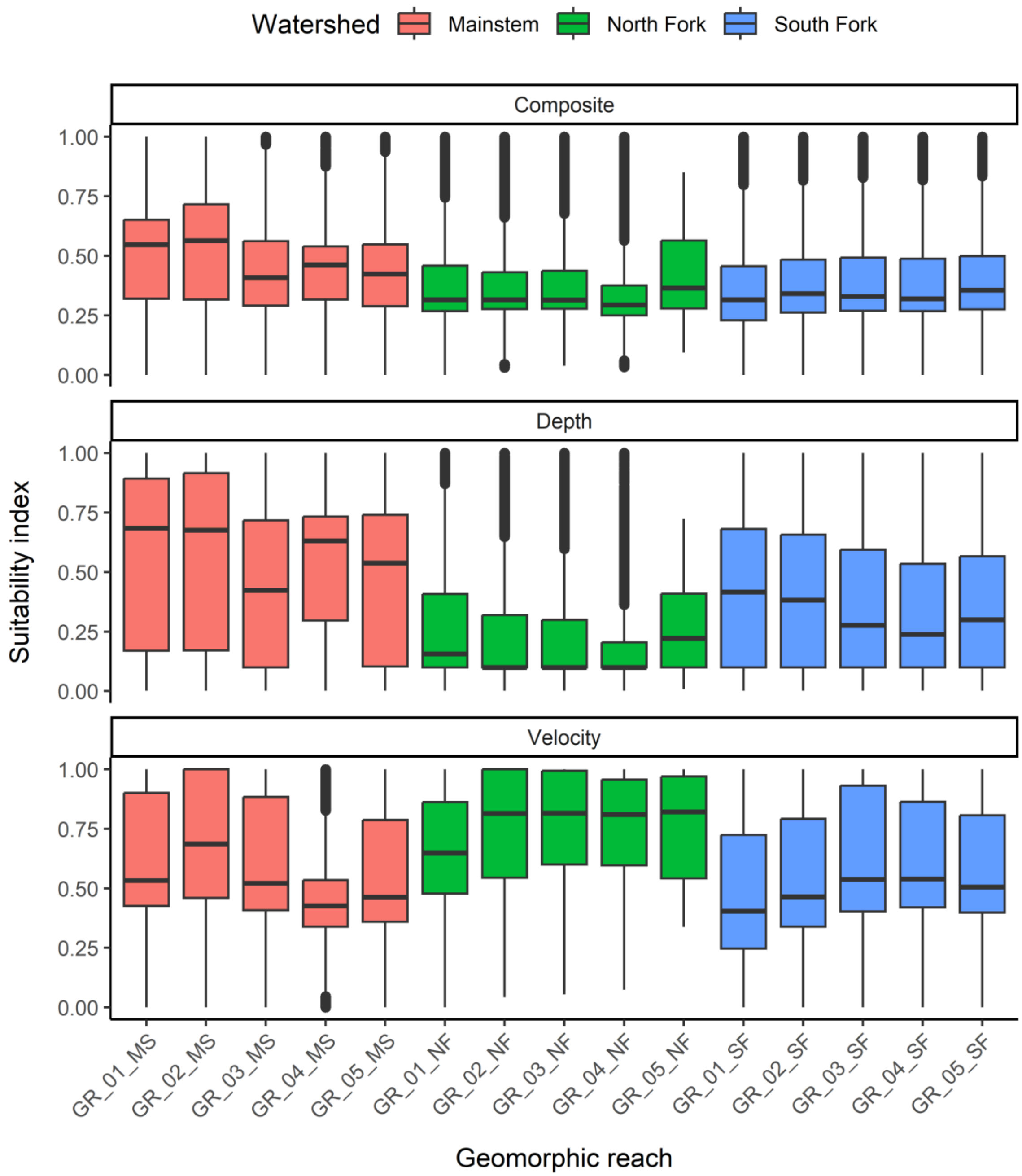

Figure 18: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile winter rearing across geomorphic reaches in the Upper Walla Walla study area in 2021.

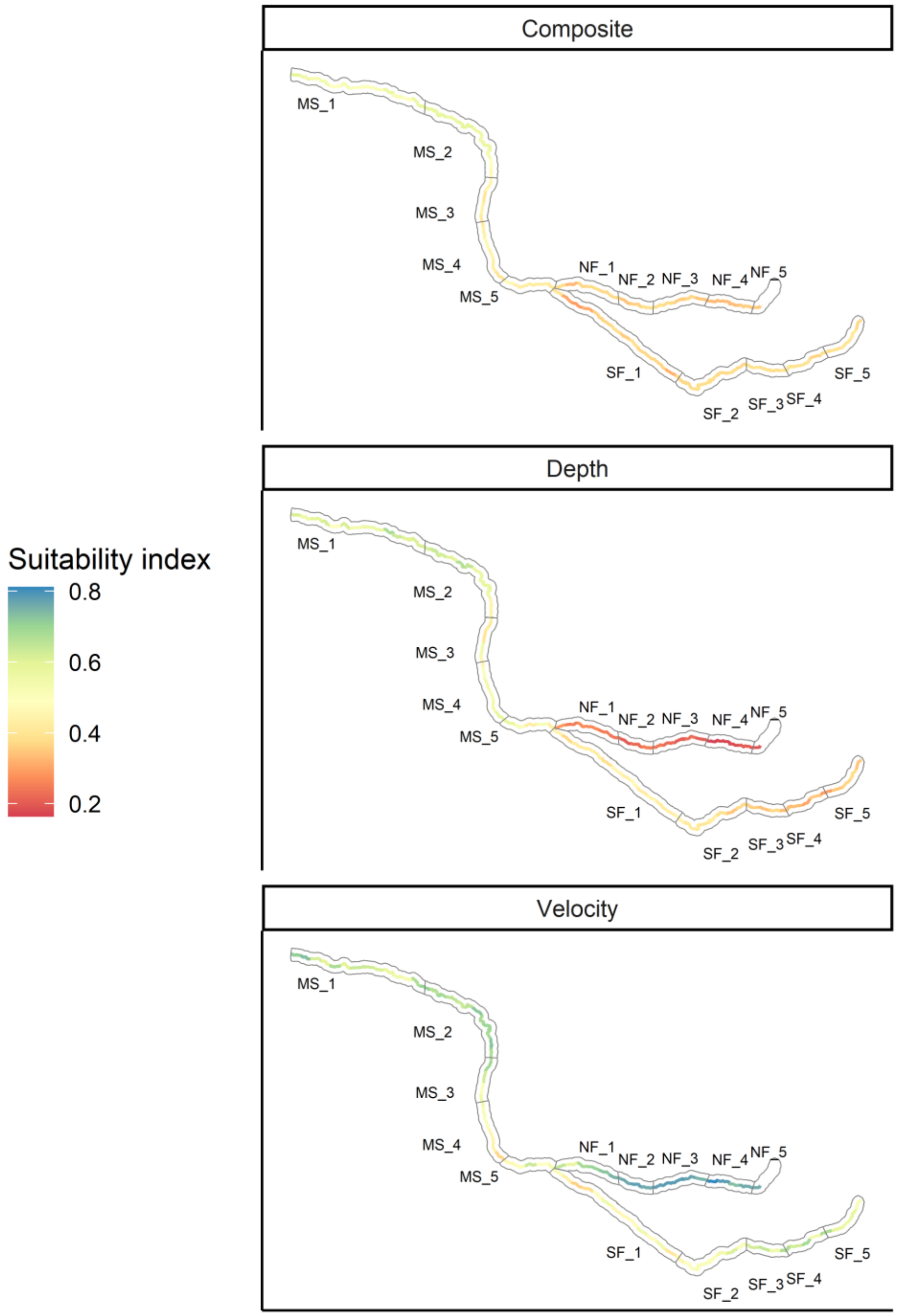

Figure 19: Map showing the hydraulic habitat suitability for steelhead juvenile winter rearing in the Upper Walla Walla study area for 2021, plotted by river kilometer with geomorphic reaches shown.

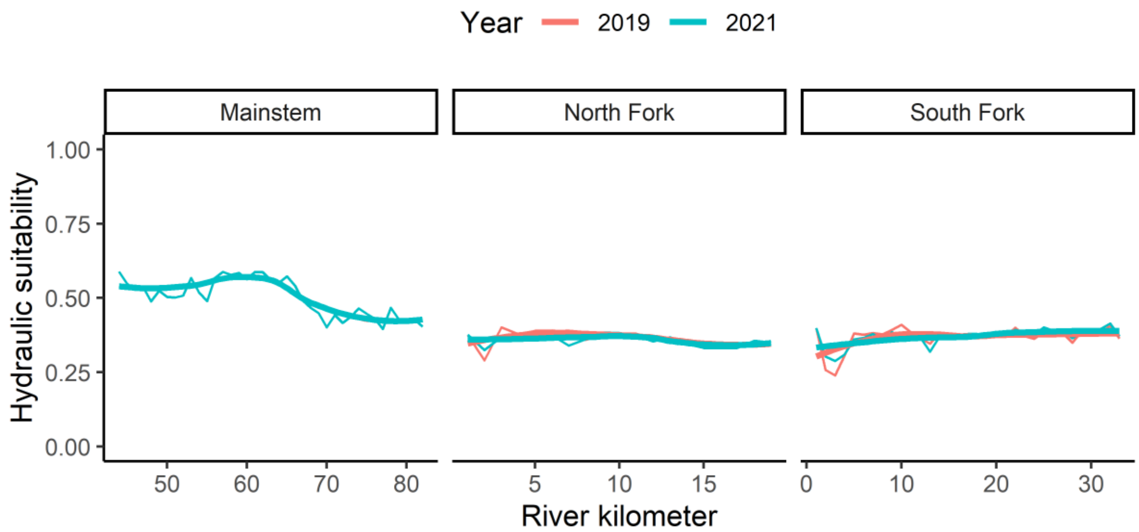

Figure 20: Hydraulic habitat suitability by river kilometer for steelhead juvenile winter rearing for 2019 and 2021.

4.0 DISCUSSION

4.1 SUMMER BASE FLOW SCENARIO

Composite hydraulic suitability in the Upper Walla Walla study area at summer base flow appears to be most suitable for steelhead juvenile rearing and least suitable for Chinook salmon juvenile rearing. Hydraulic suitability curves for steelhead juvenile rearing had a greater tolerance for shallower depths and higher velocities compared to Chinook salmon juvenile rearing hydraulic suitability curves. A lack of habitat with depths greater than 0.25 meters at low flows appears to limit Chinook salmon rearing throughout the Upper Walla Walla study area, with velocities contributing to unsuitable conditions in the SFWW. Chinook salmon spawning composite suitability was more variable, with suitable spawning conditions in the SFWW, unsuitable conditions in the NFWW, and a wide distribution across reaches in the MSWW. With low suitability for Chinook salmon spawning in the NFWW, hydraulic conditions may likely be a limiting factor for the species in this part of the watershed. Depth was limiting for both species during summer life stages in the NFWW, but interestingly, NFWW velocities appeared to be suitable for Chinook salmon and steelhead summer rearing. This information further suggests the NFWW may be flow limited during low flow conditions prohibiting use by the species.

4.2 WINTER FLOW SCENARIO

Juvenile Chinook salmon and steelhead displayed comparable composite hydraulic suitability results during the winter flow scenario in the Upper Walla Walla study area. Both species exhibited moderate composite suitability values with the MSWW having the highest overall suitability for both species. Notably, MSWW Reaches 1 and 2 had the highest composite suitability with median values just above 0.5. The increased composite suitability relative to other reaches was largely a product of the MSWW reaches having more suitable depths. In general, the limiting factor for both juvenile Chinook salmon and steelhead during the winter flow scenario was depth. This was particularly evident for the NFWW where a significant portion of the depths were less than or equal to 0.3 meters, resulting in the distribution of depth suitability scores being concentrated around 0.26 or 0.23 for Chinook salmon and steelhead, respectively. This further suggests that low flows may be prohibiting species use of NFWW habitat.

4.3 SPRING FLOW SCENARIO

Steelhead spawning was the only species and life stage that corresponded with the spring flow scenario. Unlike other species and life stages, depth suitability for spawning steelhead was notably high across the entire Upper Walla Walla study area. This was not surprising, as the spring flow scenario had a higher discharge than the summer and winter flow scenarios. The more suitable depths resulting from the higher discharge came at the expense of unsuitable velocities in some reaches. This was particularly evident in MSWW Reach 3 through SFWW Reach 1, where depth suitability was high, but velocity suitability was very low. The highest composite suitability for steelhead spawning generally occurred in the upper portions of the of the NFWW and SFWW where suitable depths and velocities coexisted during high spring flows.

4.4 OTHER FOCAL SPECIES

Hydraulic preferences for juvenile bull trout align closest with Chinook salmon juvenile suitability curves used in this analysis (Al-Chokhachy and Budy, 2007; WDFW, 2022). Composite suitability was generally lowest for Chinook salmon juvenile rearing in the Upper Walla Walla study area out of all species and life stages, indicating that similar limitations may exist for juvenile bull trout. Bull trout spawning suitability curves (WDFW, 2022) were most similar to the Chinook salmon juvenile summer rearing velocity curve and Chinook salmon spawning depth curve used in this study. Using these suitability results as a proxy for bull trout spawning suitability, the lowest reaches of the MSWW and upper reaches of the NFWW and SFWW are likely the most hydraulically suitable habitats for bull trout in the study area. Literature review of Pacific lamprey habitat preferences did not yield any hydraulic suitability information, prohibiting further discussion on the species.

4.5 MODEL LIMITATIONS

HHS analyses yield valuable insights by aligning modeled hydraulic conditions with the preferences of various species and life stages. However, it's essential to interpret these results within the broader context of fish habitat. It is widely recognized that high-quality salmonid habitats encompass a diverse range of characteristics. By incorporating information about cover, substrate, water temperature, food availability, and other factors, an HHS could be transformed in a more comprehensive Habitat Suitability Assessment. However, due to the projects' scope, which excluded further data collection, the findings in this appendix should be viewed in conjunction with other biological and geomorphic appendices in this report. This type of integrated approach would support more holistic and comprehensive restoration and rehabilitation strategies, maximizing benefits for the focal species in the Upper Walla Walla watershed.

5.0 REFERENCES

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6.0 SUPPLEMENTAL TABLES AND FIGURES

6.1 GEOMORPHIC REACH RESULTS

Table 4. Composite (HHS), depth, and velocity suitability values, area, and weighted usable area (WUA) by scenario, geomorphic reach, and year in the Upper Walla Walla study area.

Scenario	River	Reach	Year	Area m^2	WUA	HHS	Depth suitability	Velocity suitability
Chinook juvenile summer	Mainstem	GR_01_MS	2019	182920	97222	0.53	0.40	0.88
Chinook juvenile summer	Mainstem	GR_01_MS	2021	202666	104100	0.51	0.38	0.89
Chinook juvenile summer	Mainstem	GR_02_MS	2019	152205	81869	0.54	0.40	0.94
Chinook juvenile summer	Mainstem	GR_02_MS	2021	149558	77069	0.52	0.36	0.94
Chinook juvenile summer	Mainstem	GR_03_MS	2019	58668	23124	0.39	0.26	0.82
Chinook juvenile summer	Mainstem	GR_03_MS	2021	61472	23681	0.39	0.25	0.82
Chinook juvenile summer	Mainstem	GR_04_MS	2019	68956	16333	0.24	0.35	0.38
Chinook juvenile summer	Mainstem	GR_04_MS	2021	70396	16436	0.23	0.35	0.37
Chinook juvenile summer	Mainstem	GR_05_MS	2019	81378	14032	0.17	0.40	0.23
Chinook juvenile summer	Mainstem	GR_05_MS	2021	93833	15763	0.17	0.36	0.31
Chinook juvenile summer	North Fork	GR_01_NF	2019	41393	11971	0.29	0.16	0.71

Chinook juvenile summer	North Fork	GR_01_NF	2021	43771	11899	0.27	0.15	0.75
Chinook juvenile summer	North Fork	GR_02_NF	2019	25771	7668	0.30	0.14	0.92
Chinook juvenile summer	North Fork	GR_02_NF	2021	27893	7773	0.28	0.12	0.92
Chinook juvenile summer	North Fork	GR_03_NF	2019	33497	9508	0.28	0.12	0.94
Chinook juvenile summer	North Fork	GR_03_NF	2021	34623	9578	0.28	0.12	0.94
Chinook juvenile summer	North Fork	GR_04_NF	2019	22566	5890	0.26	0.10	0.94
Chinook juvenile summer	North Fork	GR_04_NF	2021	24411	6168	0.25	0.09	0.94
Chinook juvenile summer	North Fork	GR_05_NF	2019	164	58	0.35	0.16	0.94
Chinook juvenile summer	North Fork	GR_05_NF	2021	159	54	0.34	0.15	0.94
Chinook juvenile summer	South Fork	GR_01_SF	2019	187190	19253	0.10	0.36	0.18
Chinook juvenile summer	South Fork	GR_01_SF	2021	182242	17153	0.09	0.35	0.19
Chinook juvenile summer	South Fork	GR_02_SF	2019	100327	10379	0.10	0.32	0.19
Chinook juvenile summer	South Fork	GR_02_SF	2021	100783	11507	0.11	0.33	0.21
Chinook juvenile summer	South Fork	GR_03_SF	2019	46716	6441	0.14	0.27	0.27
Chinook juvenile summer	South Fork	GR_03_SF	2021	48544	7696	0.16	0.29	0.30

Chinook juvenile summer	South Fork	GR_04_SF	2019	44454	6232	0.14	0.26	0.27
Chinook juvenile summer	South Fork	GR_04_SF	2021	46654	7401	0.16	0.26	0.30
Chinook juvenile summer	South Fork	GR_05_SF	2019	34444	4506	0.13	0.27	0.19
Chinook juvenile summer	South Fork	GR_05_SF	2021	35644	5356	0.15	0.28	0.24
Chinook juvenile winter	Mainstem	GR_01_MS	2019	286049	149371	0.52	0.65	0.56
Chinook juvenile winter	Mainstem	GR_01_MS	2021	286044	149372	0.52	0.65	0.56
Chinook juvenile winter	Mainstem	GR_02_MS	2019	247880	139244	0.56	0.65	0.61
Chinook juvenile winter	Mainstem	GR_02_MS	2021	247877	139242	0.56	0.65	0.61
Chinook juvenile winter	Mainstem	GR_03_MS	2019	83618	36736	0.44	0.52	0.54
Chinook juvenile winter	Mainstem	GR_03_MS	2021	83623	36747	0.44	0.52	0.54
Chinook juvenile winter	Mainstem	GR_04_MS	2019	78959	30380	0.38	0.59	0.36
Chinook juvenile winter	Mainstem	GR_04_MS	2021	78966	30386	0.38	0.59	0.36
Chinook juvenile winter	Mainstem	GR_05_MS	2019	94949	38566	0.41	0.55	0.44
Chinook juvenile winter	Mainstem	GR_05_MS	2021	94949	38564	0.41	0.55	0.44
Chinook juvenile winter	North Fork	GR_01_NF	2019	50094	20428	0.41	0.35	0.56

Chinook juvenile winter	North Fork	GR_01_NF	2021	57978	24186	0.42	0.35	0.60
Chinook juvenile winter	North Fork	GR_02_NF	2019	35072	16120	0.46	0.34	0.72
Chinook juvenile winter	North Fork	GR_02_NF	2021	37393	16975	0.45	0.32	0.72
Chinook juvenile winter	North Fork	GR_03_NF	2019	42816	19662	0.46	0.32	0.72
Chinook juvenile winter	North Fork	GR_03_NF	2021	44064	20377	0.46	0.32	0.73
Chinook juvenile winter	North Fork	GR_04_NF	2019	29042	12985	0.45	0.30	0.72
Chinook juvenile winter	North Fork	GR_04_NF	2021	29928	13509	0.45	0.31	0.72
Chinook juvenile winter	North Fork	GR_05_NF	2019	199	99	0.50	0.36	0.75
Chinook juvenile winter	North Fork	GR_05_NF	2021	198	94	0.47	0.34	0.72
Chinook juvenile winter	South Fork	GR_01_SF	2019	202844	65122	0.32	0.49	0.36
Chinook juvenile winter	South Fork	GR_01_SF	2021	216130	68534	0.32	0.49	0.37
Chinook juvenile winter	South Fork	GR_02_SF	2019	109162	38768	0.36	0.46	0.41
Chinook juvenile winter	South Fork	GR_02_SF	2021	111886	40706	0.36	0.47	0.43
Chinook juvenile winter	South Fork	GR_03_SF	2019	52527	20815	0.40	0.41	0.52
Chinook juvenile winter	South Fork	GR_03_SF	2021	55714	22949	0.41	0.42	0.55

Chinook juvenile winter	South Fork	GR_04_SF	2019	48896	19441	0.40	0.39	0.52
Chinook juvenile winter	South Fork	GR_04_SF	2021	51865	21474	0.41	0.40	0.55
Chinook juvenile winter	South Fork	GR_05_SF	2019	36871	14172	0.38	0.40	0.45
Chinook juvenile winter	South Fork	GR_05_SF	2021	38506	15567	0.40	0.42	0.49
Chinook spawning	Mainstem	GR_01_MS	2019	182920	42691	0.23	0.71	0.19
Chinook spawning	Mainstem	GR_01_MS	2021	202666	42775	0.21	0.68	0.17
Chinook spawning	Mainstem	GR_02_MS	2019	152205	11166	0.07	0.66	0.07
Chinook spawning	Mainstem	GR_02_MS	2021	149558	11724	0.08	0.64	0.06
Chinook spawning	Mainstem	GR_03_MS	2019	58668	19184	0.33	0.56	0.32
Chinook spawning	Mainstem	GR_03_MS	2021	61472	20246	0.33	0.56	0.31
Chinook spawning	Mainstem	GR_04_MS	2019	68956	47598	0.69	0.73	0.75
Chinook spawning	Mainstem	GR_04_MS	2021	70396	48937	0.70	0.71	0.78
Chinook spawning	Mainstem	GR_05_MS	2019	81378	61559	0.76	0.73	0.88
Chinook spawning	Mainstem	GR_05_MS	2021	93833	61885	0.66	0.67	0.80
Chinook spawning	North Fork	GR_01_NF	2019	41393	16066	0.39	0.43	0.50
Chinook spawning	North Fork	GR_01_NF	2021	43771	15545	0.36	0.40	0.45
Chinook spawning	North Fork	GR_02_NF	2019	25771	3104	0.12	0.35	0.13
Chinook spawning	North Fork	GR_02_NF	2021	27893	3166	0.11	0.32	0.12
Chinook spawning	North Fork	GR_03_NF	2019	33497	2684	0.08	0.31	0.09
Chinook spawning	North Fork	GR_03_NF	2021	34623	2858	0.08	0.30	0.08
Chinook spawning	North Fork	GR_04_NF	2019	22566	1666	0.07	0.27	0.09
Chinook spawning	North Fork	GR_04_NF	2021	24411	1440	0.06	0.26	0.08
Chinook spawning	North Fork	GR_05_NF	2019	164	13	0.08	0.45	0.10

Chinook spawning	North Fork	GR_05_NF	2021	159	14	0.09	0.42	0.11
Chinook spawning	South Fork	GR_01_SF	2019	187190	135895	0.73	0.71	0.87
Chinook spawning	South Fork	GR_01_SF	2021	182242	127498	0.70	0.69	0.85
Chinook spawning	South Fork	GR_02_SF	2019	100327	70975	0.71	0.67	0.88
Chinook spawning	South Fork	GR_02_SF	2021	100783	69530	0.69	0.67	0.86
Chinook spawning	South Fork	GR_03_SF	2019	46716	30236	0.65	0.61	0.83
Chinook spawning	South Fork	GR_03_SF	2021	48544	30289	0.62	0.61	0.80
Chinook spawning	South Fork	GR_04_SF	2019	44454	28400	0.64	0.59	0.85
Chinook spawning	South Fork	GR_04_SF	2021	46654	28789	0.62	0.58	0.82
Chinook spawning	South Fork	GR_05_SF	2019	34444	24244	0.70	0.63	0.92
Chinook spawning	South Fork	GR_05_SF	2021	35644	24259	0.68	0.62	0.89
Steelhead juvenile summer	Mainstem	GR_01_MS	2019	182920	129553	0.71	0.74	0.78
Steelhead juvenile summer	Mainstem	GR_01_MS	2021	202666	138771	0.68	0.72	0.76
Steelhead juvenile summer	Mainstem	GR_02_MS	2019	152205	78693	0.52	0.70	0.54
Steelhead juvenile summer	Mainstem	GR_02_MS	2021	149558	83703	0.56	0.69	0.60
Steelhead juvenile summer	Mainstem	GR_03_MS	2019	58668	40241	0.69	0.62	0.87
Steelhead juvenile summer	Mainstem	GR_03_MS	2021	61472	40926	0.67	0.61	0.85
Steelhead juvenile summer	Mainstem	GR_04_MS	2019	68956	35273	0.51	0.76	0.58
Steelhead juvenile summer	Mainstem	GR_04_MS	2021	70396	36777	0.52	0.74	0.60
Steelhead juvenile summer	Mainstem	GR_05_MS	2019	81378	32571	0.40	0.76	0.44

Steelhead juvenile summer	Mainstem	GR_05_MS	2021	93833	33857	0.36	0.70	0.45
Steelhead juvenile summer	North Fork	GR_01_NF	2019	41393	26136	0.63	0.51	0.91
Steelhead juvenile summer	North Fork	GR_01_NF	2021	43771	26293	0.60	0.47	0.89
Steelhead juvenile summer	North Fork	GR_02_NF	2019	25771	13345	0.52	0.42	0.78
Steelhead juvenile summer	North Fork	GR_02_NF	2021	27893	13823	0.50	0.40	0.77
Steelhead juvenile summer	North Fork	GR_03_NF	2019	33497	17214	0.51	0.39	0.80
Steelhead juvenile summer	North Fork	GR_03_NF	2021	34623	16939	0.49	0.38	0.77
Steelhead juvenile summer	North Fork	GR_04_NF	2019	22566	10860	0.48	0.36	0.79
Steelhead juvenile summer	North Fork	GR_04_NF	2021	24411	11308	0.46	0.34	0.80
Steelhead juvenile summer	North Fork	GR_05_NF	2019	164	94	0.58	0.53	0.73
Steelhead juvenile summer	North Fork	GR_05_NF	2021	159	92	0.58	0.50	0.78
Steelhead juvenile summer	South Fork	GR_01_SF	2019	187190	45398	0.24	0.74	0.31
Steelhead juvenile summer	South Fork	GR_01_SF	2021	182242	39074	0.21	0.72	0.30
Steelhead juvenile summer	South Fork	GR_02_SF	2019	100327	26696	0.27	0.70	0.35
Steelhead juvenile summer	South Fork	GR_02_SF	2021	100783	28304	0.28	0.70	0.37

Steelhead juvenile summer	South Fork	GR_03_SF	2019	46716	15836	0.34	0.66	0.45
Steelhead juvenile summer	South Fork	GR_03_SF	2021	48544	16905	0.35	0.66	0.45
Steelhead juvenile summer	South Fork	GR_04_SF	2019	44454	15420	0.35	0.64	0.46
Steelhead juvenile summer	South Fork	GR_04_SF	2021	46654	17714	0.38	0.63	0.50
Steelhead juvenile summer	South Fork	GR_05_SF	2019	34444	11478	0.33	0.68	0.40
Steelhead juvenile summer	South Fork	GR_05_SF	2021	35644	13310	0.37	0.67	0.46
Steelhead juvenile winter	Mainstem	GR_01_MS	2019	286049	150900	0.53	0.58	0.64
Steelhead juvenile winter	Mainstem	GR_01_MS	2021	286044	150900	0.53	0.58	0.64
Steelhead juvenile winter	Mainstem	GR_02_MS	2019	247880	138047	0.56	0.58	0.68
Steelhead juvenile winter	Mainstem	GR_02_MS	2021	247877	138047	0.56	0.58	0.68
Steelhead juvenile winter	Mainstem	GR_03_MS	2019	83618	35990	0.43	0.44	0.62
Steelhead juvenile winter	Mainstem	GR_03_MS	2021	83623	35998	0.43	0.44	0.62
Steelhead juvenile winter	Mainstem	GR_04_MS	2019	78959	34555	0.44	0.53	0.47
Steelhead juvenile winter	Mainstem	GR_04_MS	2021	78966	34561	0.44	0.53	0.47
Steelhead juvenile winter	Mainstem	GR_05_MS	2019	94949	40809	0.43	0.49	0.54

Steelhead juvenile winter	Mainstem	GR_05_MS	2021	94949	40808	0.43	0.49	0.54
Steelhead juvenile winter	North Fork	GR_01_NF	2019	50094	18426	0.37	0.27	0.64
Steelhead juvenile winter	North Fork	GR_01_NF	2021	57978	21122	0.36	0.26	0.67
Steelhead juvenile winter	North Fork	GR_02_NF	2019	35072	13036	0.37	0.24	0.77
Steelhead juvenile winter	North Fork	GR_02_NF	2021	37393	13493	0.36	0.22	0.77
Steelhead juvenile winter	North Fork	GR_03_NF	2019	42816	15680	0.37	0.22	0.77
Steelhead juvenile winter	North Fork	GR_03_NF	2021	44064	16031	0.36	0.22	0.78
Steelhead juvenile winter	North Fork	GR_04_NF	2019	29042	9849	0.34	0.18	0.77
Steelhead juvenile winter	North Fork	GR_04_NF	2021	29928	10104	0.34	0.18	0.77
Steelhead juvenile winter	North Fork	GR_05_NF	2019	199	89	0.45	0.30	0.79
Steelhead juvenile winter	North Fork	GR_05_NF	2021	198	83	0.42	0.27	0.77
Steelhead juvenile winter	South Fork	GR_01_SF	2019	202844	72472	0.36	0.43	0.46
Steelhead juvenile winter	South Fork	GR_01_SF	2021	216130	75408	0.35	0.42	0.47
Steelhead juvenile winter	South Fork	GR_02_SF	2019	109162	40789	0.37	0.40	0.51
Steelhead juvenile winter	South Fork	GR_02_SF	2021	111886	42119	0.38	0.40	0.53

Steelhead juvenile winter	South Fork	GR_03_SF	2019	52527	19856	0.38	0.34	0.60
Steelhead juvenile winter	South Fork	GR_03_SF	2021	55714	21628	0.39	0.35	0.63
Steelhead juvenile winter	South Fork	GR_04_SF	2019	48896	18368	0.38	0.32	0.60
Steelhead juvenile winter	South Fork	GR_04_SF	2021	51865	19866	0.38	0.32	0.63
Steelhead juvenile winter	South Fork	GR_05_SF	2019	36871	14207	0.39	0.35	0.55
Steelhead juvenile winter	South Fork	GR_05_SF	2021	38506	15192	0.39	0.35	0.58
Steelhead spawning	Mainstem	GR_01_MS	2019	382917	194773	0.51	0.85	0.52
Steelhead spawning	Mainstem	GR_01_MS	2021	399401	218091	0.55	0.86	0.56
Steelhead spawning	Mainstem	GR_02_MS	2019	342257	175961	0.51	0.82	0.53
Steelhead spawning	Mainstem	GR_02_MS	2021	315134	161947	0.51	0.86	0.53
Steelhead spawning	Mainstem	GR_03_MS	2019	111130	46453	0.42	0.78	0.51
Steelhead spawning	Mainstem	GR_03_MS	2021	108062	40507	0.37	0.78	0.45
Steelhead spawning	Mainstem	GR_04_MS	2019	90526	25552	0.28	0.91	0.31
Steelhead spawning	Mainstem	GR_04_MS	2021	97401	27576	0.28	0.88	0.32
Steelhead spawning	Mainstem	GR_05_MS	2019	118276	45897	0.39	0.79	0.44
Steelhead spawning	Mainstem	GR_05_MS	2021	132016	52396	0.40	0.77	0.48
Steelhead spawning	North Fork	GR_01_NF	2019	60670	32391	0.53	0.77	0.62
Steelhead spawning	North Fork	GR_01_NF	2021	72330	37790	0.52	0.70	0.65
Steelhead spawning	North Fork	GR_02_NF	2019	43638	26108	0.60	0.66	0.76
Steelhead spawning	North Fork	GR_02_NF	2021	47753	27619	0.58	0.65	0.72
Steelhead spawning	North Fork	GR_03_NF	2019	51779	34950	0.67	0.70	0.82
Steelhead spawning	North Fork	GR_03_NF	2021	55581	35993	0.65	0.69	0.78

Steelhead spawning	North Fork	GR_04_NF	2019	34839	22327	0.64	0.66	0.82
Steelhead spawning	North Fork	GR_04_NF	2021	35766	23454	0.66	0.67	0.81
Steelhead spawning	North Fork	GR_05_NF	2019	246	163	0.66	0.76	0.78
Steelhead spawning	North Fork	GR_05_NF	2021	247	156	0.63	0.74	0.76
Steelhead spawning	South Fork	GR_01_SF	2019	232835	83559	0.36	0.80	0.42
Steelhead spawning	South Fork	GR_01_SF	2021	240407	78380	0.33	0.76	0.41
Steelhead spawning	South Fork	GR_02_SF	2019	120858	58424	0.48	0.80	0.55
Steelhead spawning	South Fork	GR_02_SF	2021	125826	59663	0.47	0.77	0.55
Steelhead spawning	South Fork	GR_03_SF	2019	60405	33481	0.55	0.73	0.66
Steelhead spawning	South Fork	GR_03_SF	2021	66193	34102	0.52	0.69	0.63
Steelhead spawning	South Fork	GR_04_SF	2019	54962	31778	0.58	0.74	0.68
Steelhead spawning	South Fork	GR_04_SF	2021	58404	33183	0.57	0.71	0.68
Steelhead spawning	South Fork	GR_05_SF	2019	39504	24442	0.62	0.82	0.67
Steelhead spawning	South Fork	GR_05_SF	2021	41597	25745	0.62	0.79	0.69

6.2 SUITABILITY DISTRIBUTIONS, 2019 VERSUS 2021

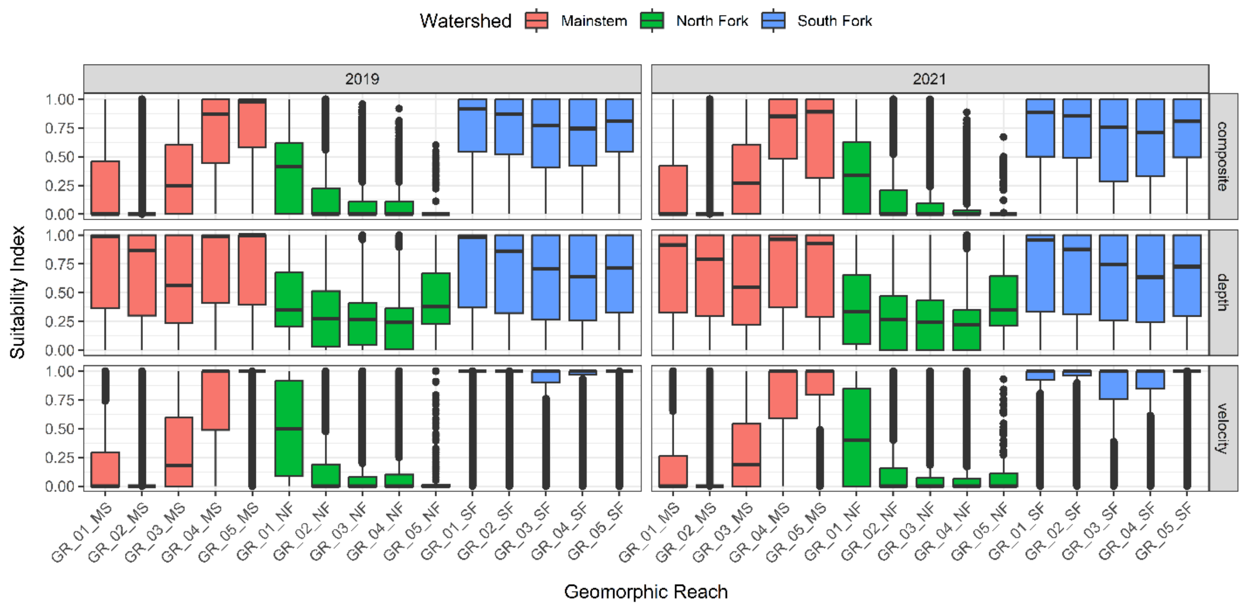

Figure 21: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon spawning across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

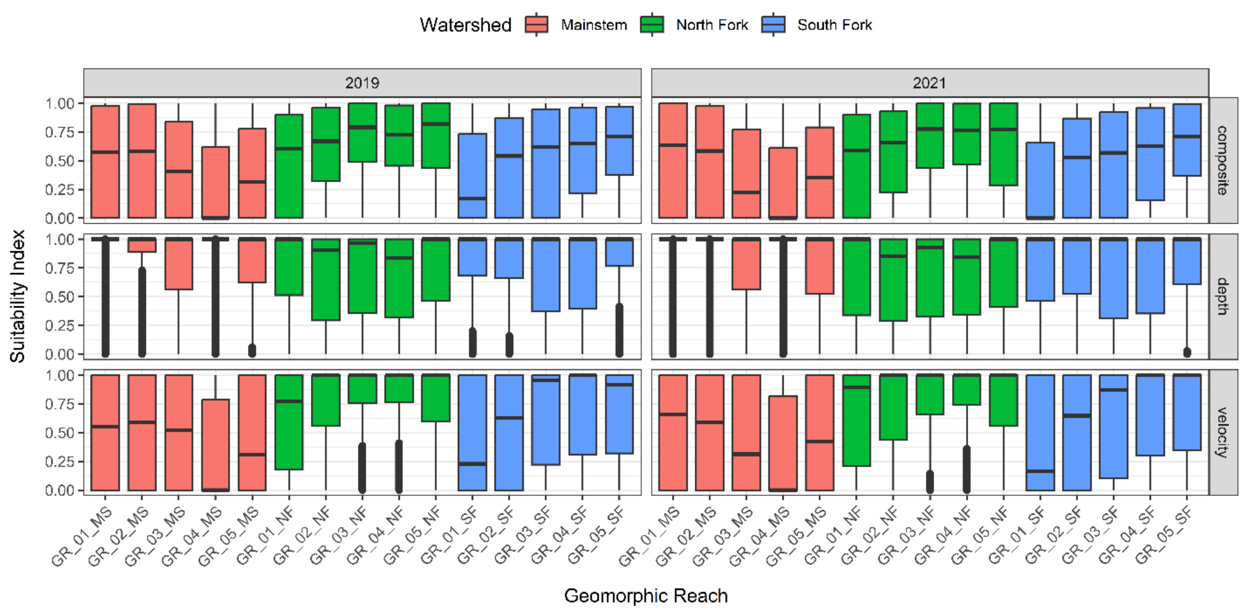

Figure 22: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead spawning across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

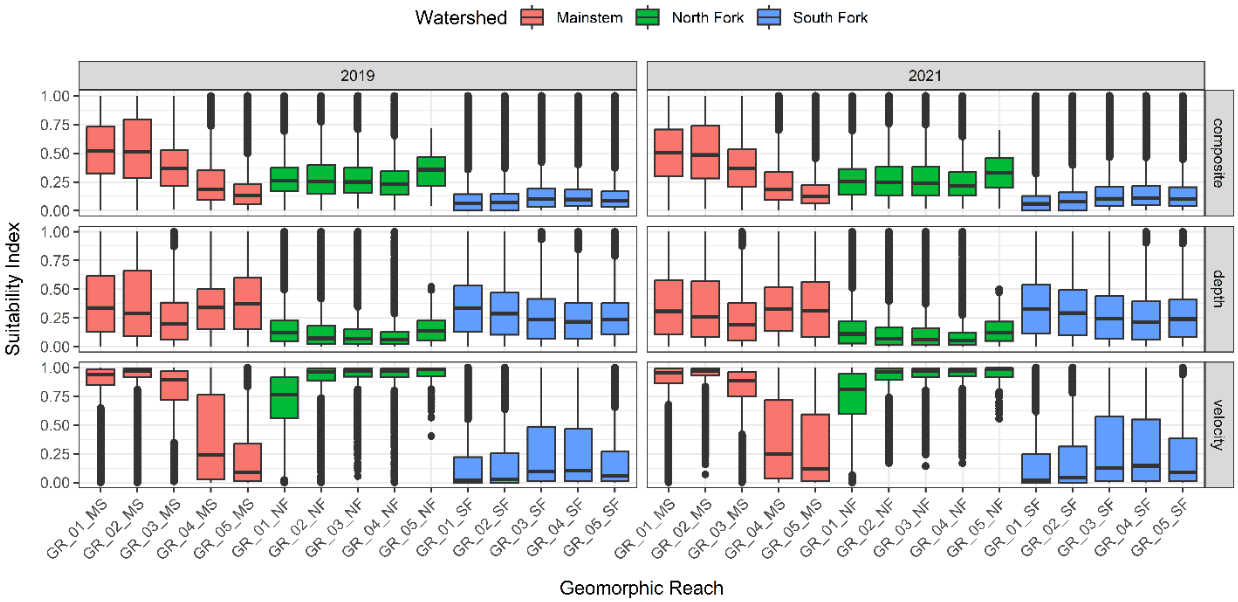

Figure 23: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile summer rearing across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

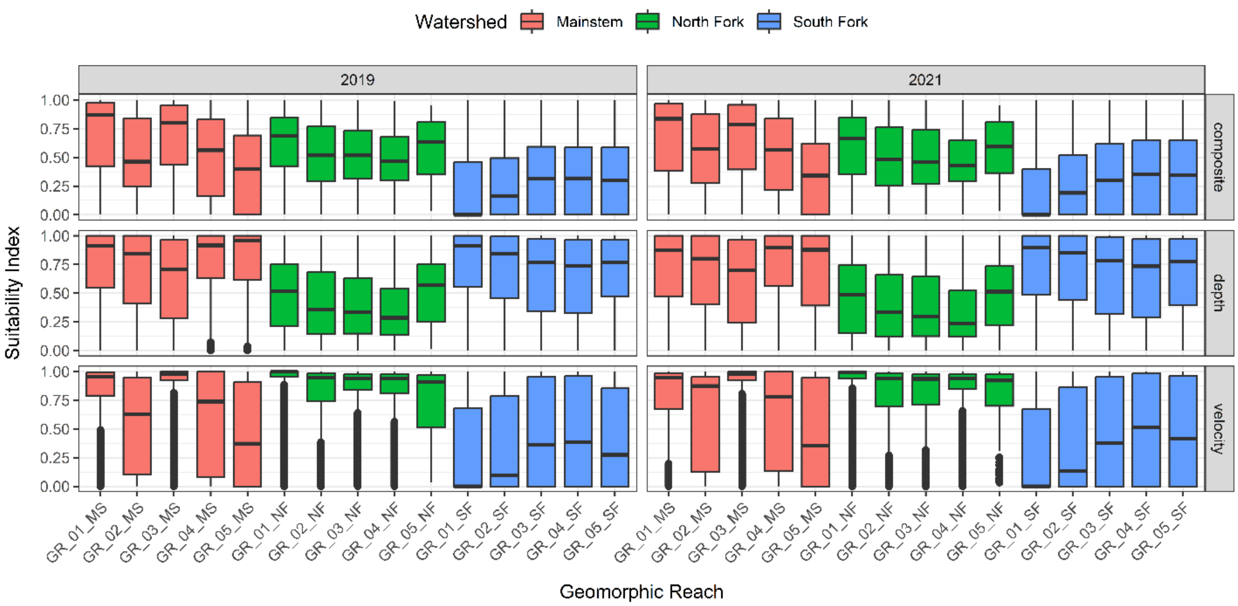

Figure 24: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile summer rearing across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

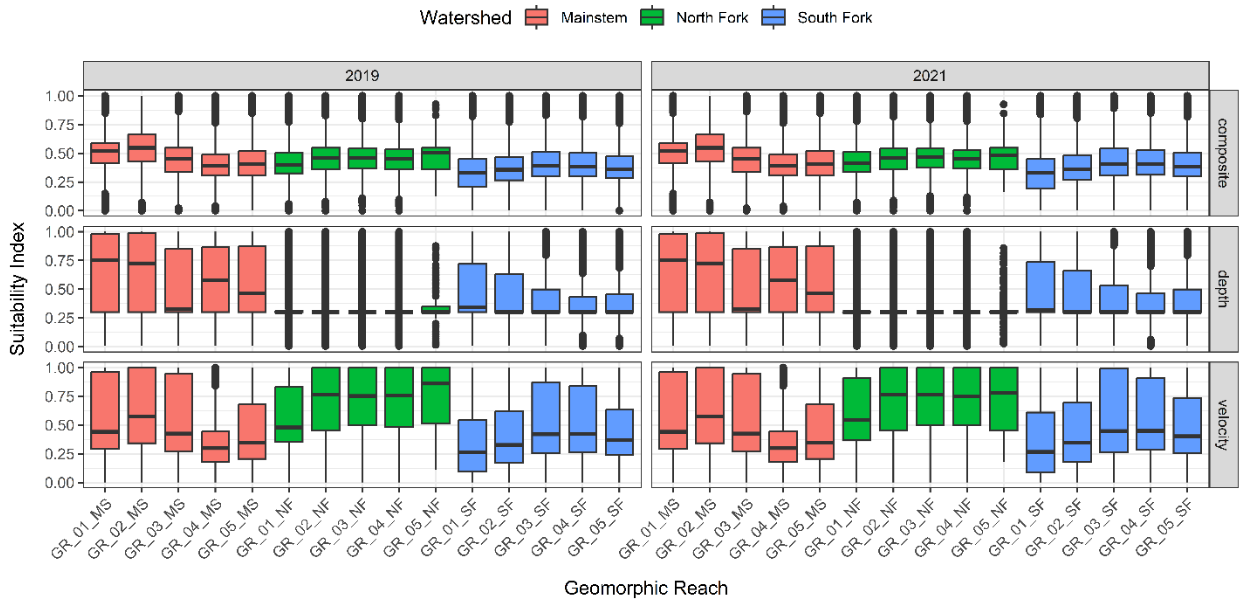

Figure 25: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook Salmon juvenile winter rearing across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

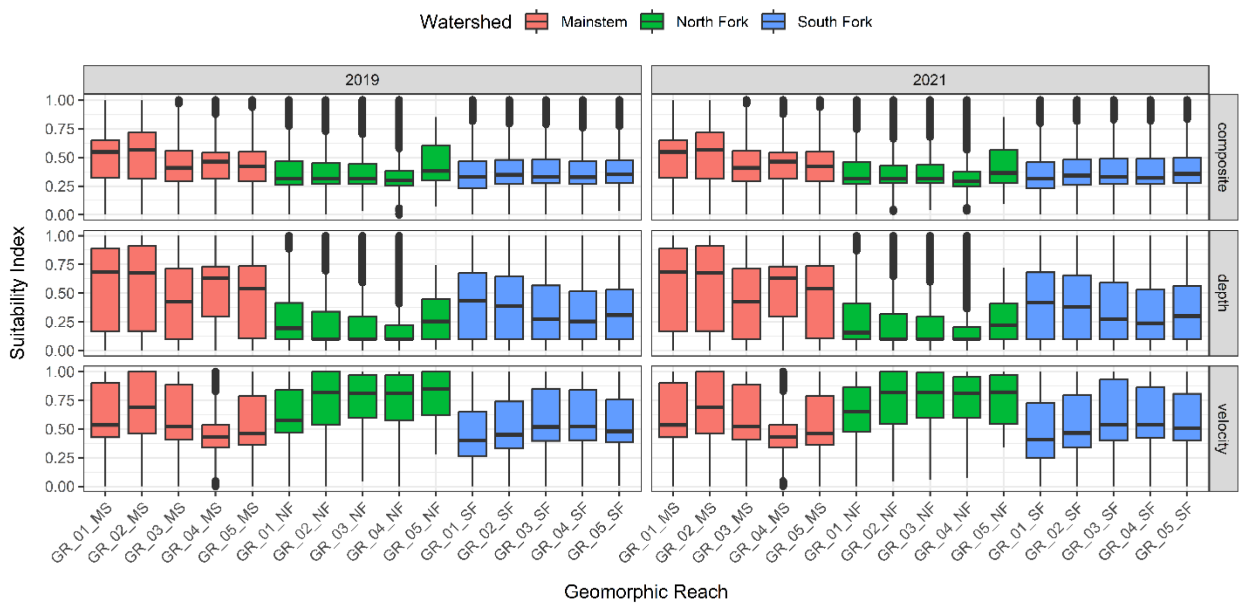

Figure 26: Box plots showing the distribution of suitability values for composite, depth, and velocity for Steelhead juvenile winter rearing across geomorphic reaches in the Upper Walla Walla study area, 2019 and 2021.

6.3 DISTRIBUTIONS BY RIVER AND RKM

6.3.1 Chinook Salmon Spawning, 2021

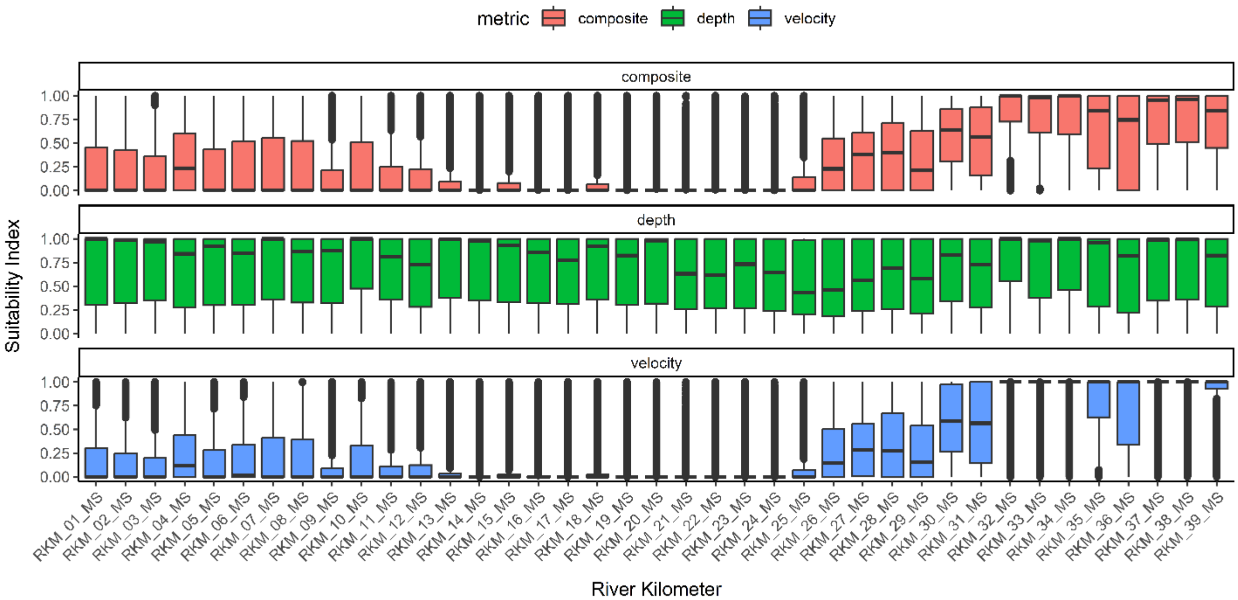

Figure 27: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon spawning across river kilometers in the mainstem Upper Walla Walla River, 2021.

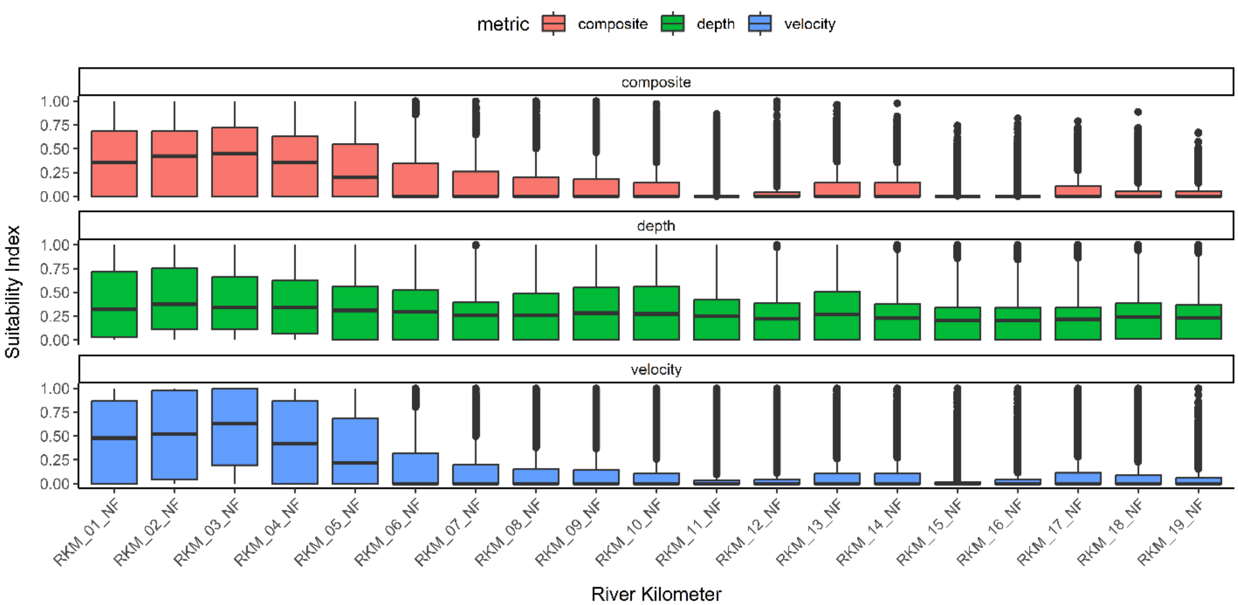

Figure 28: Box plots showing the distribution of suitability values for composite, depth and velocity for Chinook salmon spawning across river kilometers in the North Fork Walla Walla River, 2021.

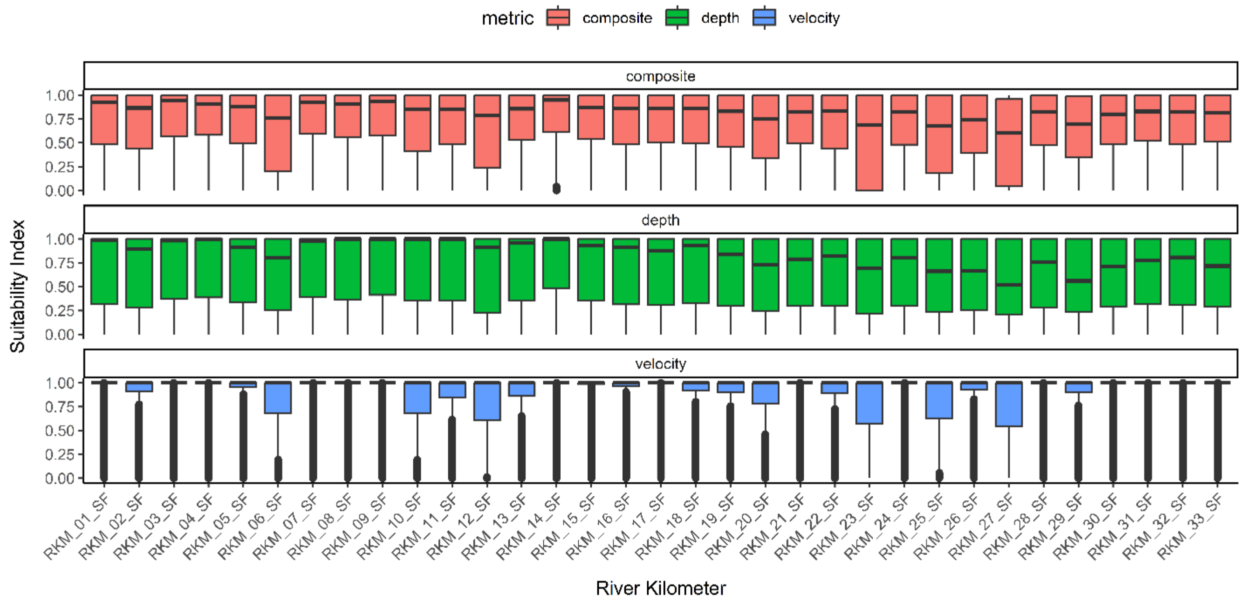

Figure 29: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon spawning across river kilometers in the South Fork Walla Walla River, 2021.

6.3.2 Steelhead Spawning, 2021

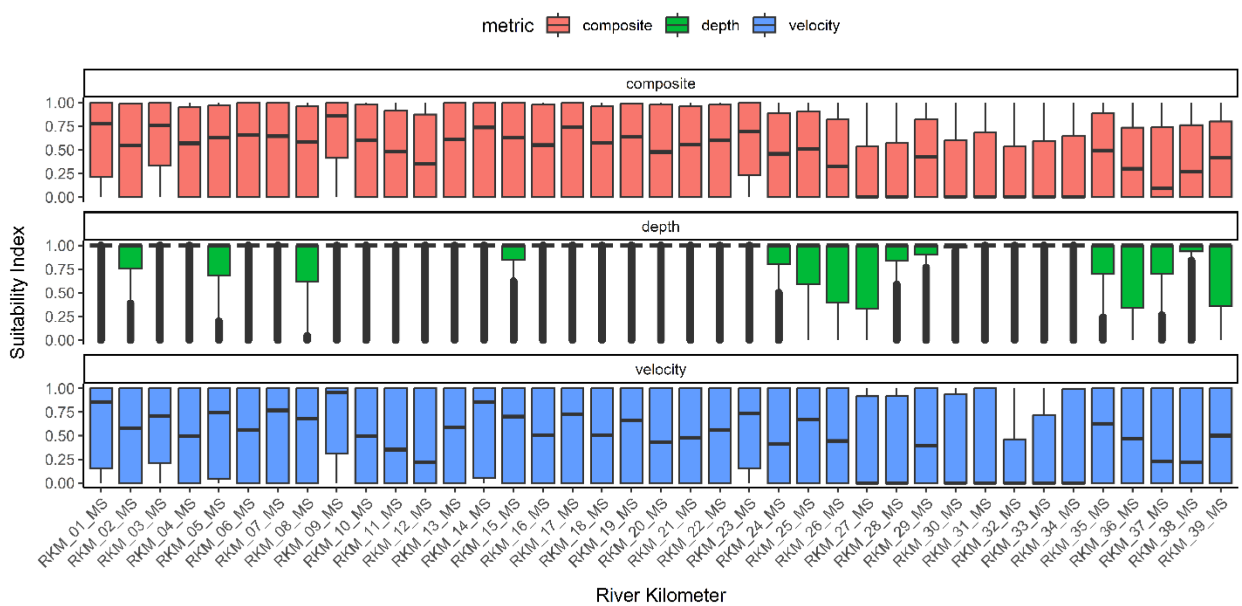

Figure 30: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead spawning across river kilometers in the mainstem Upper Walla Walla River, 2021.

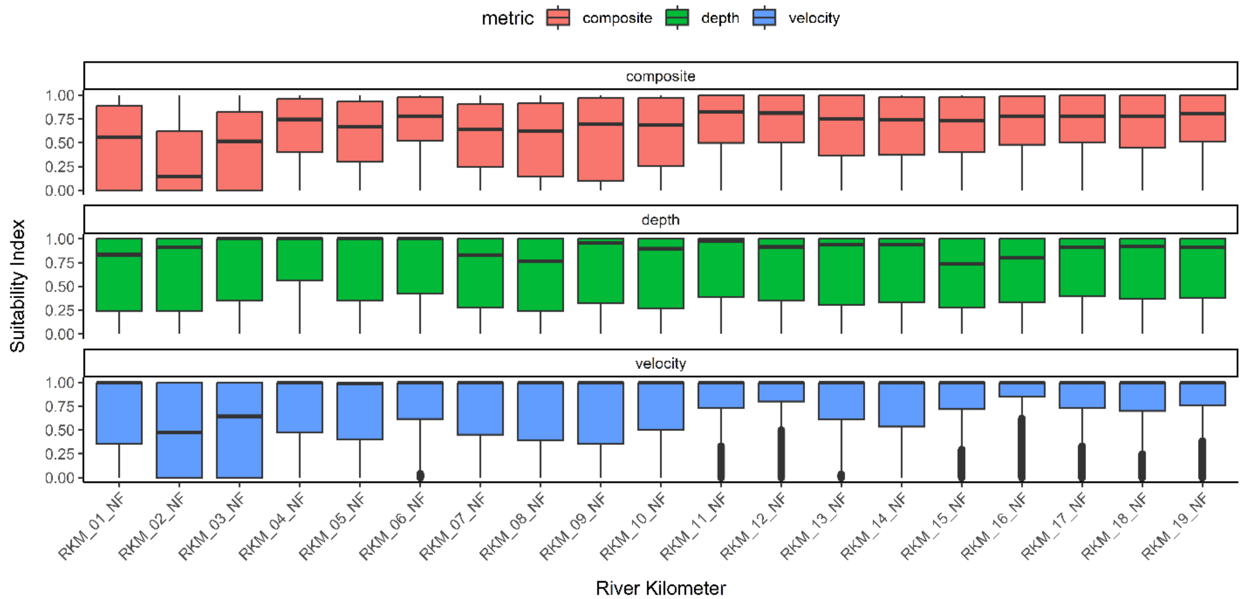

Figure 31: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead spawning across river kilometers in the North Fork Walla Walla River, 2021.

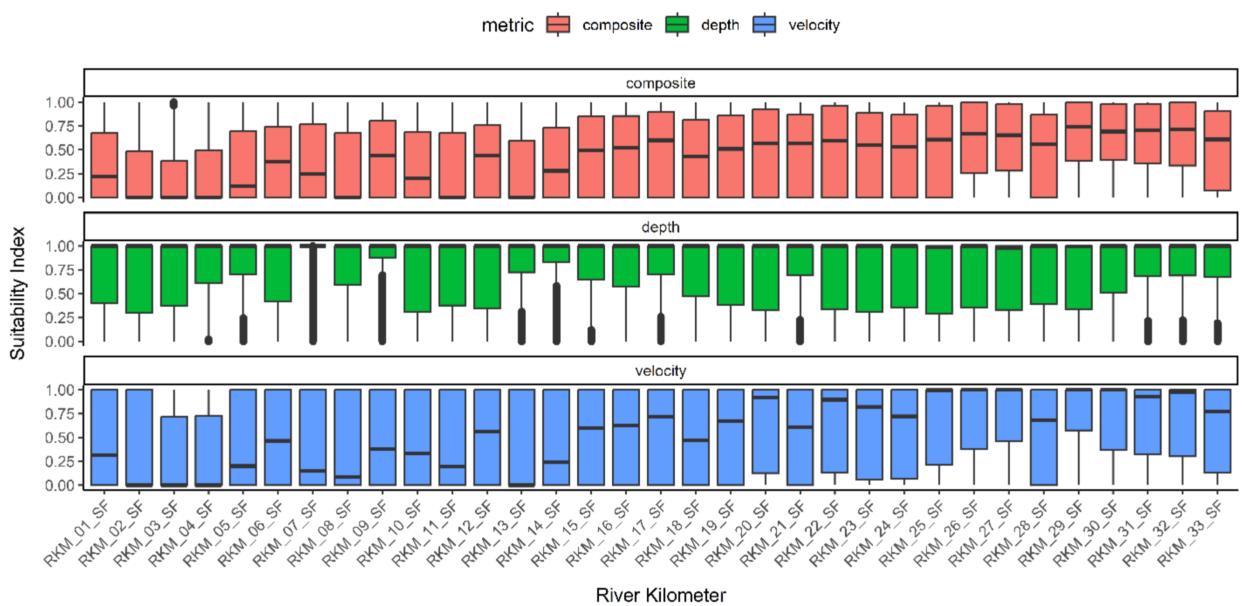

Figure 32: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead spawning across river kilometers in the South Fork Walla Walla River, 2021.

6.3.3 Chinook Salmon Juvenile Summer Rearing, 2021

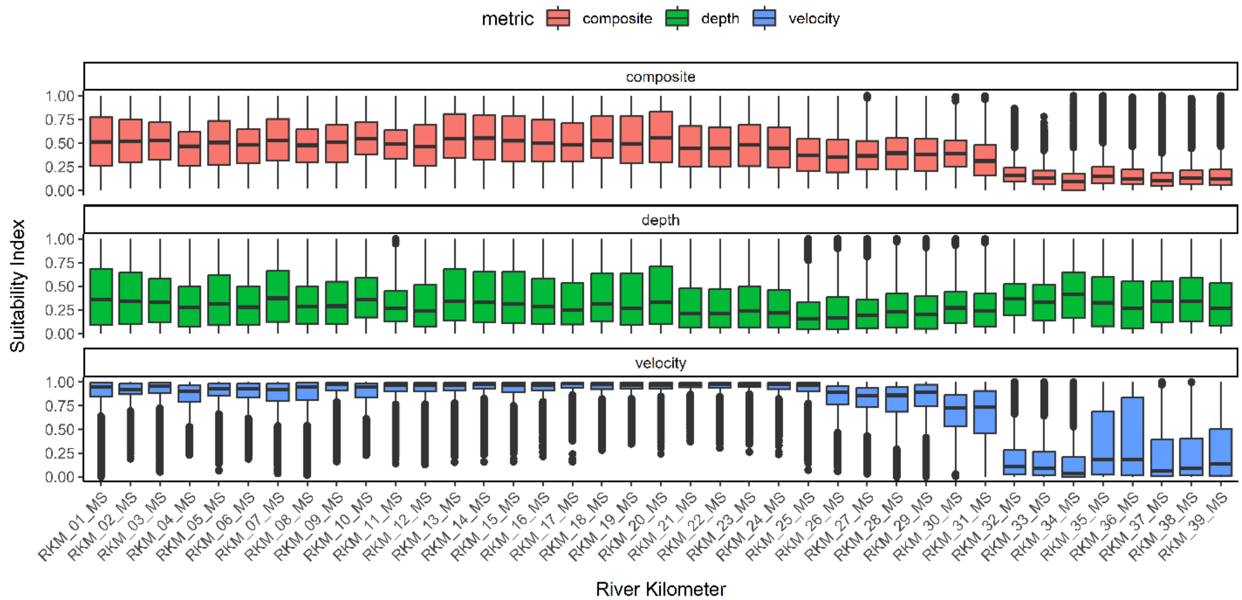

Figure 33: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile summer rearing across river kilometers in the mainstem Upper Walla Walla River, 2021.

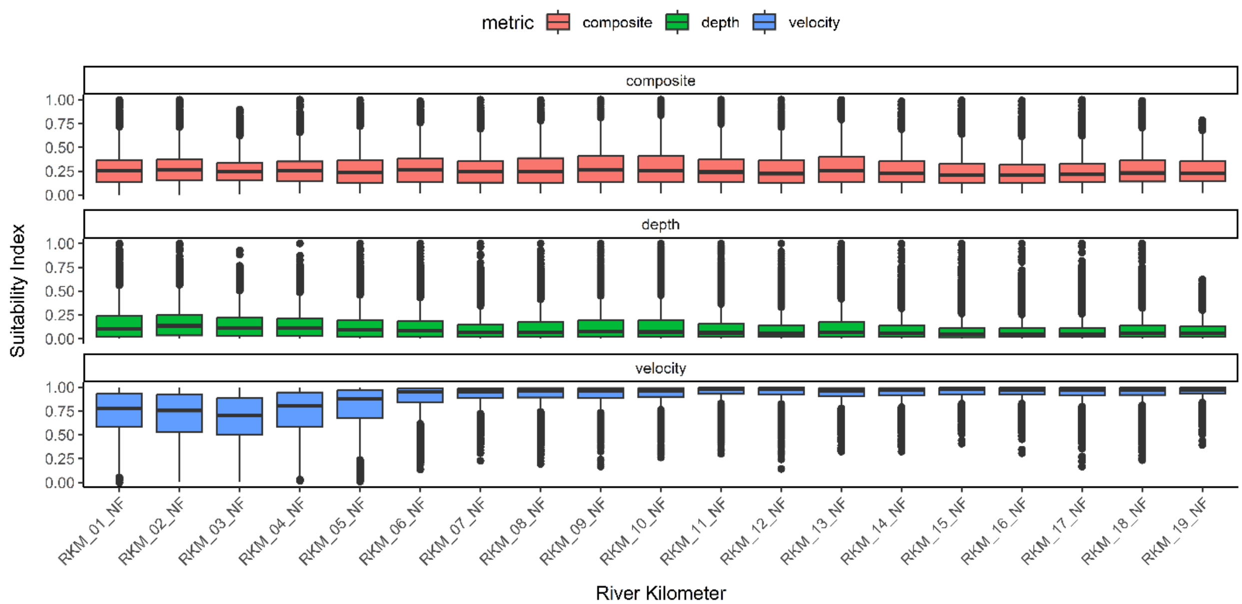

Figure 34: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile summer rearing across river kilometers in the North Fork Walla Walla River, 2021.

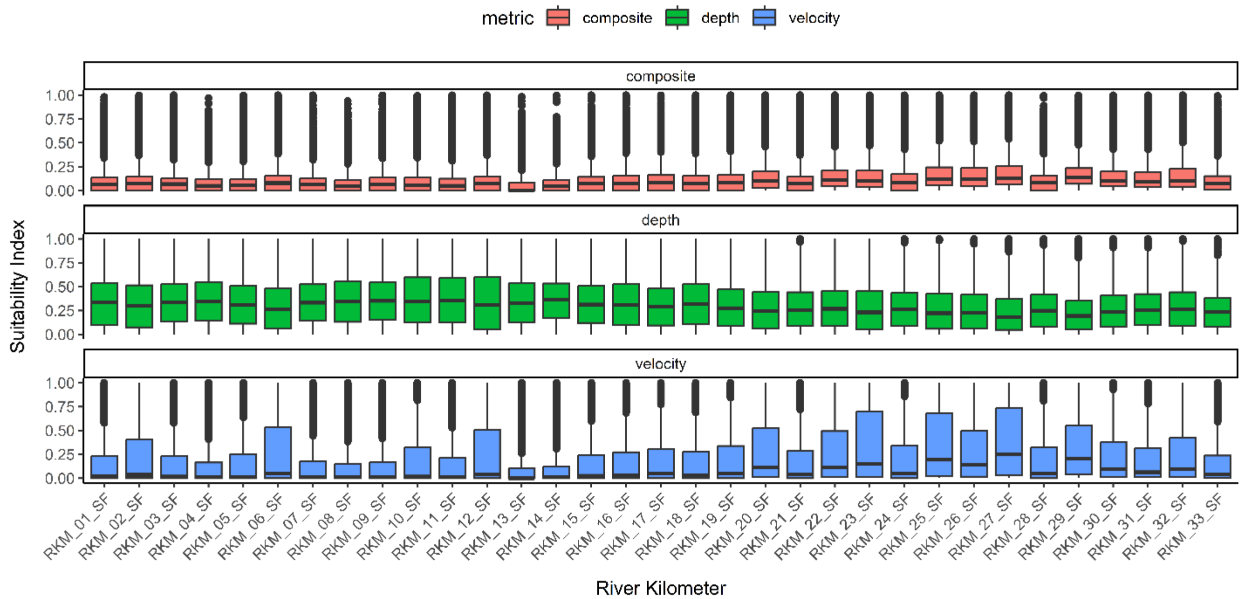

Figure 35: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile summer rearing across river kilometers in the South Fork Walla Walla River, 2021.

6.3.4 Steelhead Juvenile Summer Rearing, 2021

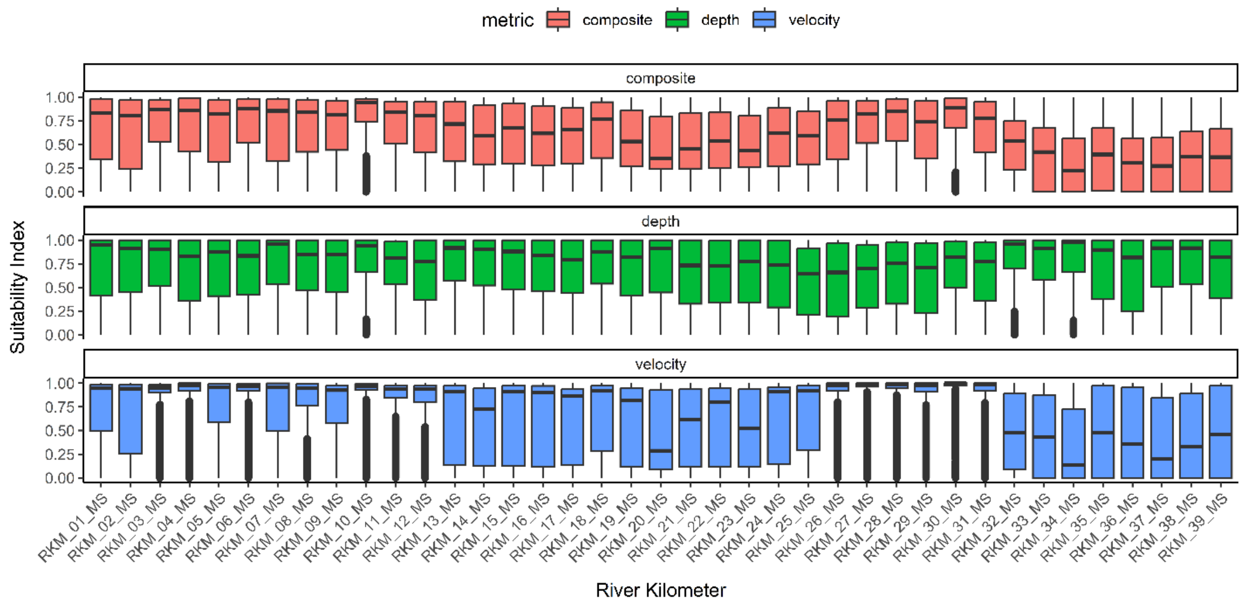

Figure 36: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile summer rearing across river kilometers in the mainstem Upper Walla Walla River, 2021.

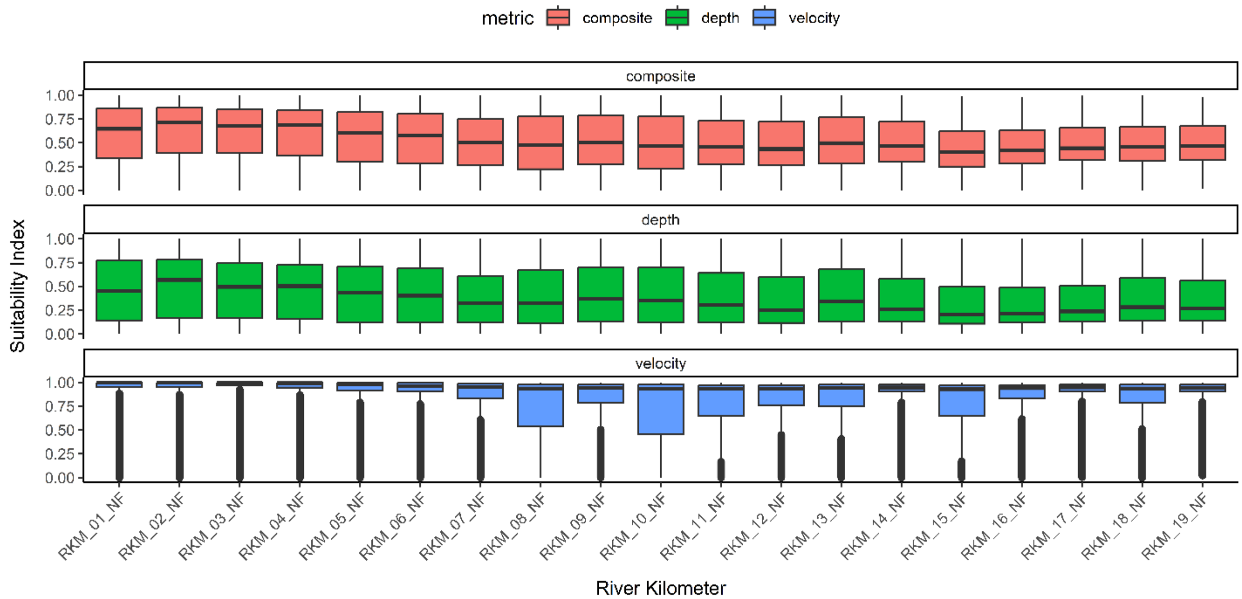

Figure 37: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile summer rearing across river kilometers in the North Fork Walla Walla River, 2021.

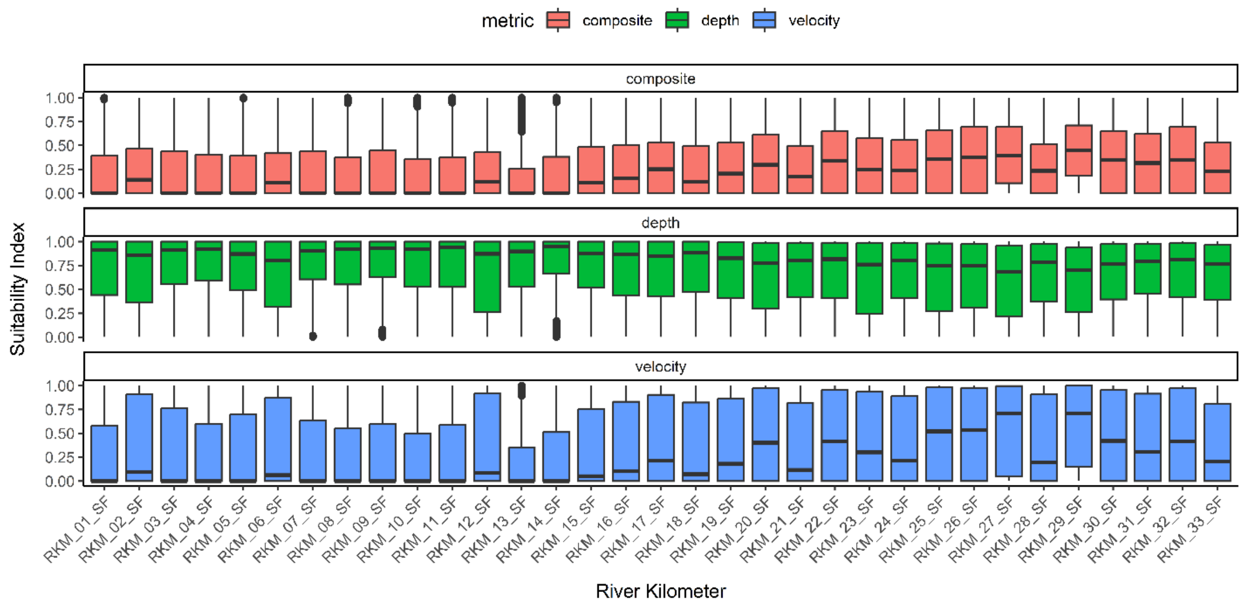

Figure 38: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile summer rearing across river kilometers in the South Fork Walla Walla River, 2021.

6.3.5 Chinook Salmon Juvenile Winter Rearing, 2021

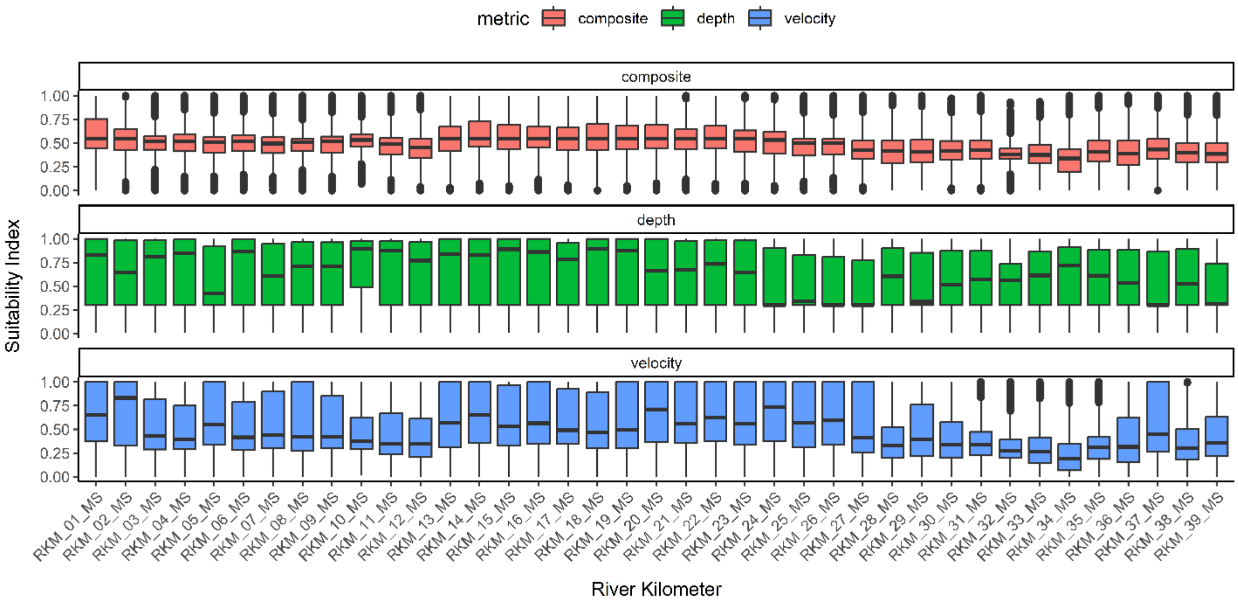

Figure 39: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile winter rearing across river kilometers in the mainstem Upper Walla Walla River, 2021.

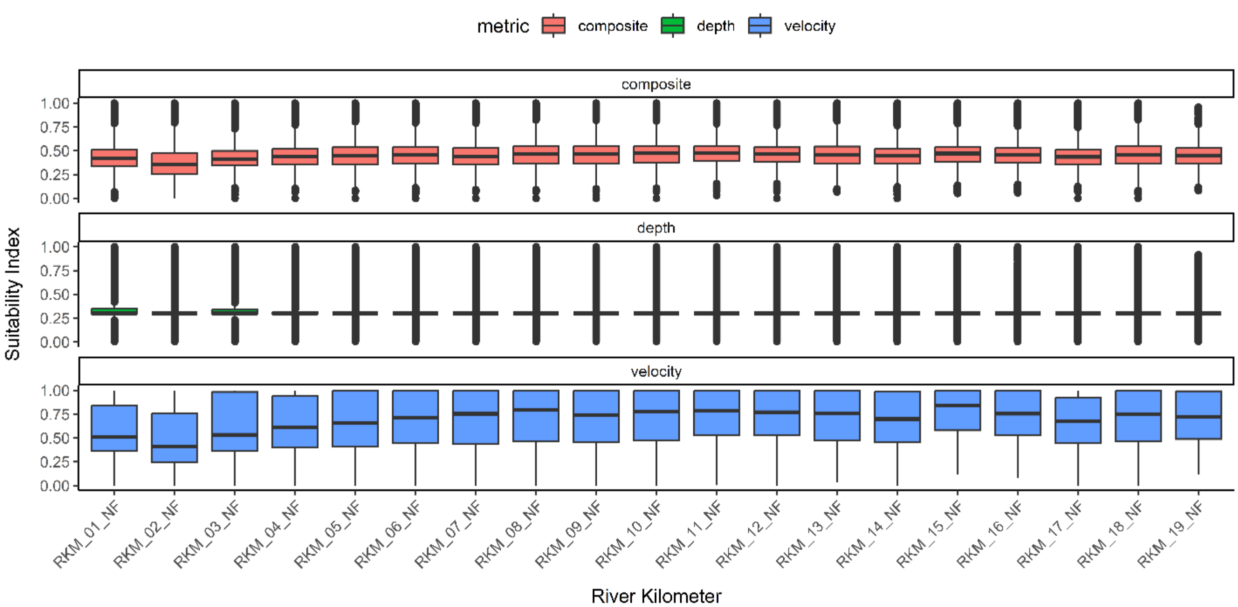

Figure 40: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile winter rearing across river kilometers in the North Fork Walla Walla River, 2021.

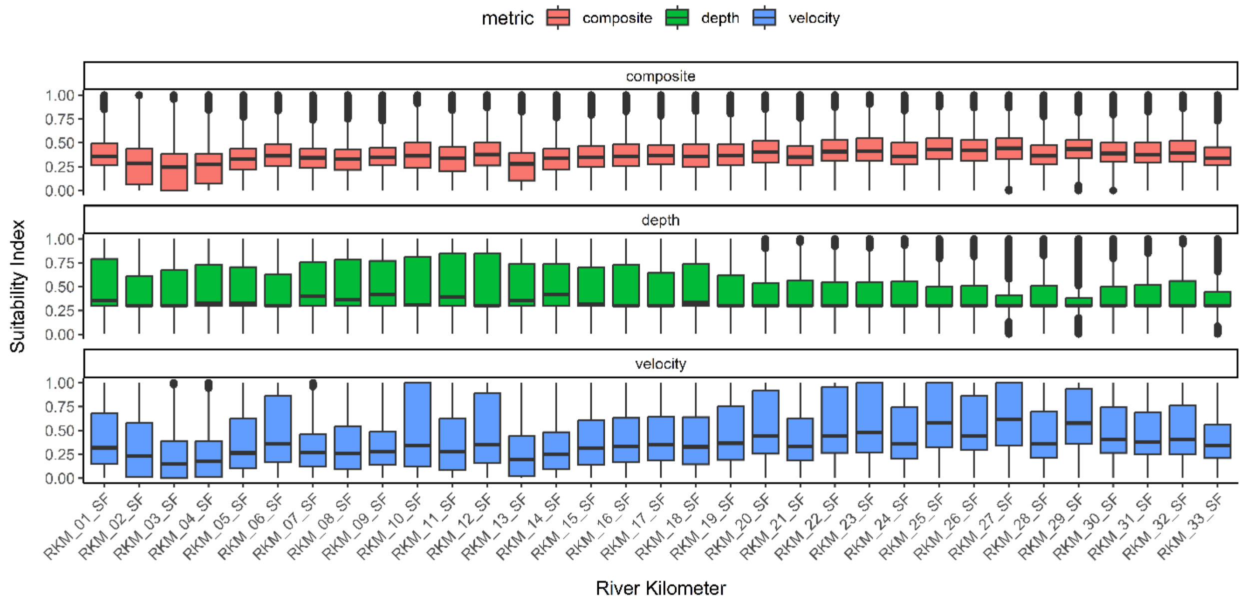

Figure 41: Box plots showing the distribution of suitability values for composite, depth, and velocity for Chinook salmon juvenile winter rearing across river kilometers in the South Fork Walla Walla River, 2021.

6.3.6 Steelhead Juvenile Winter Rearing, 2021

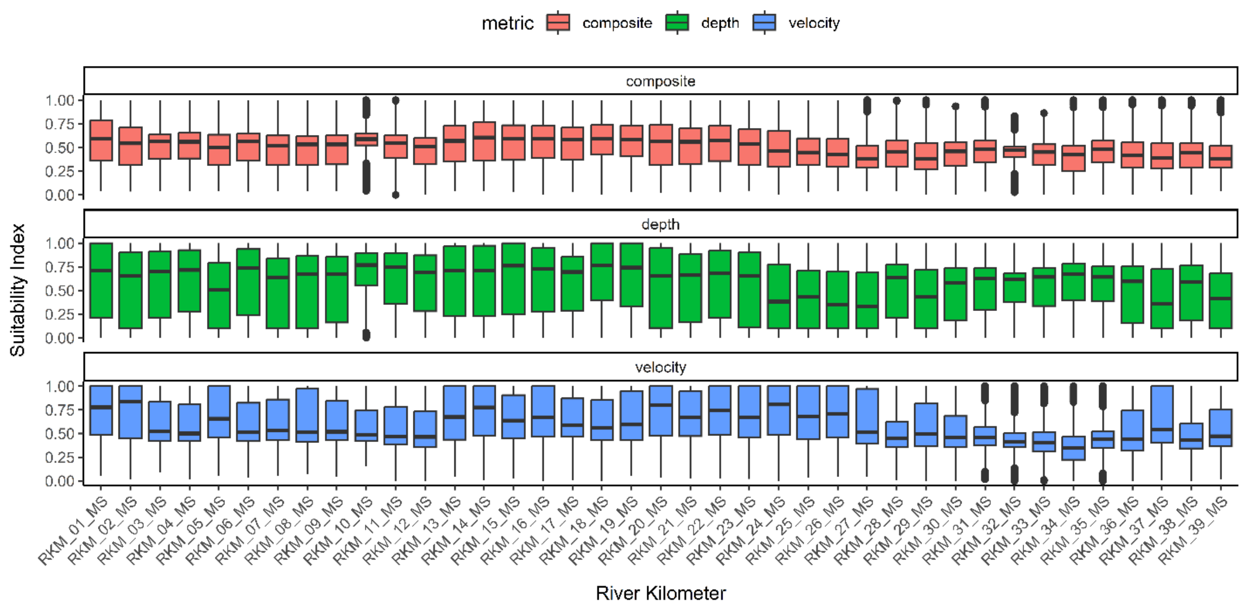

Figure 42: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile winter rearing across river kilometers in the mainstem Upper Walla Walla River, 2021.

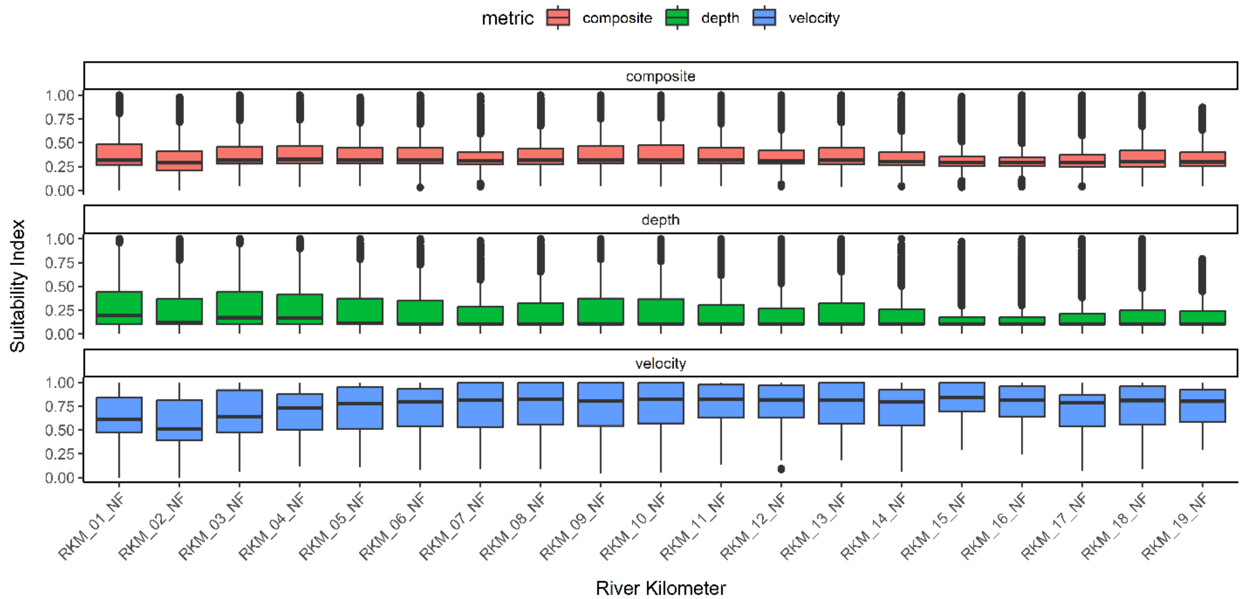

Figure 43: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile winter rearing across river kilometers in the North Fork Walla Walla River, 2021.

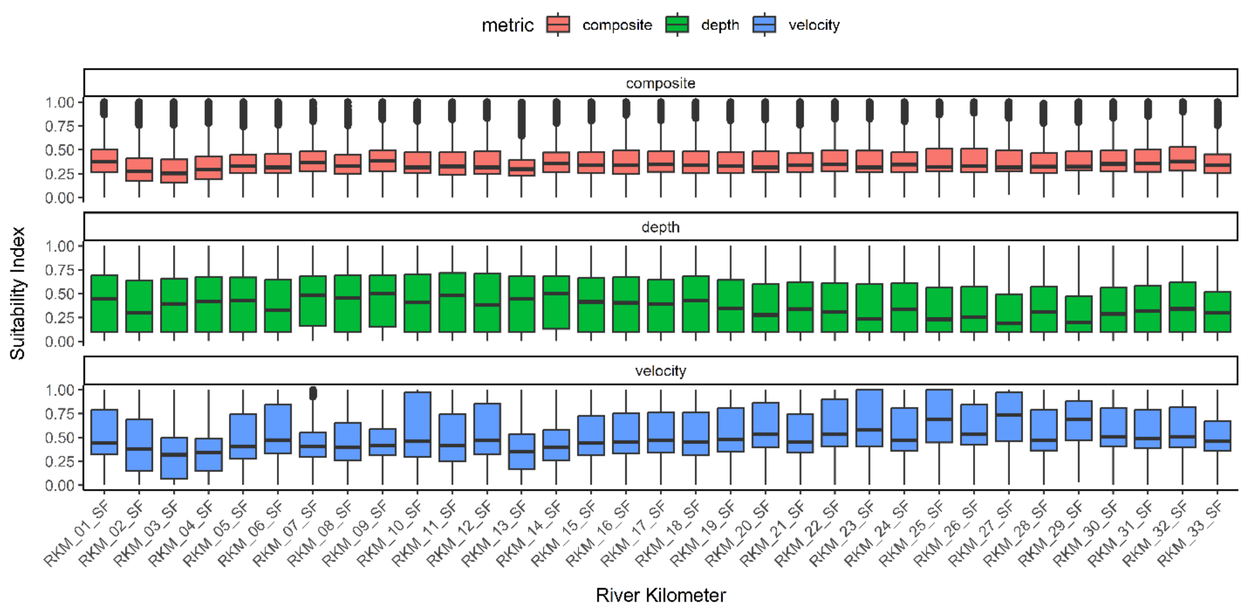

Figure 44: Box plots showing the distribution of suitability values for composite, depth, and velocity for steelhead juvenile winter rearing across river kilometers in the South Fork Walla Walla River, 2021.

Appendix J

Upper Walla Walla Assessment

SUMMER STREAM TEMPERATURE ASSESSMENT

Technical Report

May 23, 2024

Technical Report

Ecosystem Sciences

Science · Planning · Design

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MOUNT HOOD ENVIRONMENTAL

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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Project No.: 001-053-004-01

Technical Report

Subject: Summer Stream Temperature Assessment Technical Report

Final Date: May 23, 2024

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1.0 BACKGROUND

Water is one of the First Foods that traditionally sustained the people of the CTUIR alongside salmon, deer, cous, and huckleberry. It nourished people and all other First Foods, and it is inherently tied to the five River Vision touchstones: hydrology, geomorphology, habitat and network connectivity, riverine biotic community, and riparian vegetation (Jones et al., 2008). These touchstones form the Umatilla River Vision, a holistic approach to water quality restoration. Stream temperature is a critical component of the hydrology of the Upper Walla Walla watershed, directly affecting the fish community and the connectivity of their habitat. Warming climatic conditions are expected to have pronounced effects on salmonids (Kovach et al., 2016). In the Pacific Northwest, summer months are anticipated to become progressively more stressful for cold-water species as stream temperatures increase with warming air temperatures, which is likely to shift and reduce suitable habitat for many species (Isaak et al., 2015; Jones et al., 2014). Here, we evaluate recent historic and future projected summer stream temperature scenarios for the Upper Walla Walla watershed and compare them to life-stage specific temperature thresholds for focal species. The goal of this assessment was to determine whether summer stream temperature was a potential factor limiting fish population productivity and to identify if, and where, restoration actions (e.g., riparian planting, improved grazing practices) aimed at reducing stream temperatures could be considered to help mitigate future impacts of a warming climate.

1.1 OBJECTIVES

The primary objectives of the Upper Walla Walla summer stream temperature assessment include:

1. Summarize recent historic and future projected summer stream temperature scenarios for the Upper Walla Walla.
2. Compare recent historic and future projected summer stream temperature scenarios in the Upper Walla Walla to life stage specific temperature thresholds for focal species to determine whether stream temperatures may hinder their productivity.
3. Evaluate a hypothetical scenario where restoration efforts (e.g., riparian planting, improved grazing practices, etc.) decrease summer stream temperatures relative to recent historic temperatures by 1^{o}C.

2.0 METHODS

Recent historic (2002-2011) and projected (2040 & 2080) August mean stream temperature predictions (Isaak et al., 2017) were used in combination with life stage specific temperature thresholds available from the literature for focal species (Table 2) to evaluate potential habitat limitations within the Upper Walla Walla River watershed. To accomplish this, modeled recent historic and projected August mean stream temperatures were used to quantify the amount of stream habitat exceeding optimum, maximum, and acute temperature thresholds for focal species present in the Upper Walla Walla River watershed during summer months. Additionally, a scenario where hypothetical restoration actions reduced mean August stream temperatures by 1ºC relative to the recent historic temperature scenario was evaluated to illustrate the benefits restoration actions could provide for thermal suitability of habitat within the watershed.

2.1 FOCAL SPECIES

The focal species for the summer temperature assessment include:

- Spring-run Chinook salmon (*Oncorhynchus tshawytscha*; hereafter Chinook salmon)
- Middle Columbia River summer steelhead (*O. mykiss*; hereafter steelhead; ESA-listed “threatened”)
- Columbia River bull trout (*Salvelinus confluentus*; ESA-listed “threatened”)
- Pacific lamprey (*Entosphenus tridentatus*)

2.2 STUDY AREA

The summer stream temperature assessment included the Upper Walla Walla River from its confluence with Dry Creek near Lowden, Washington, to the headwaters of the North Fork and South Fork Walla Walla rivers, including tributaries (Figure 1). Temperature predictions for streams used in the assessment were pulled from the NorWeST regional database (Isaak et al., 2017). For Chinook salmon, steelhead, and bull trout, we truncated the evaluation to include the spatial distributions currently used by each species as defined by StreamNet (Table 1). Pacific lamprey were historically found throughout much of the watershed (Jackson et al., 1997; Swindell, 1942) but are now extirpated from their entire historic range (Close, 2000; Harris and Jolley, 2017; Jackson et al., 1997; Kostow, 2002; Moser and Close, 2003). We included the entirety of the modeled extent in the Upper Walla Walla watershed for Pacific lamprey.

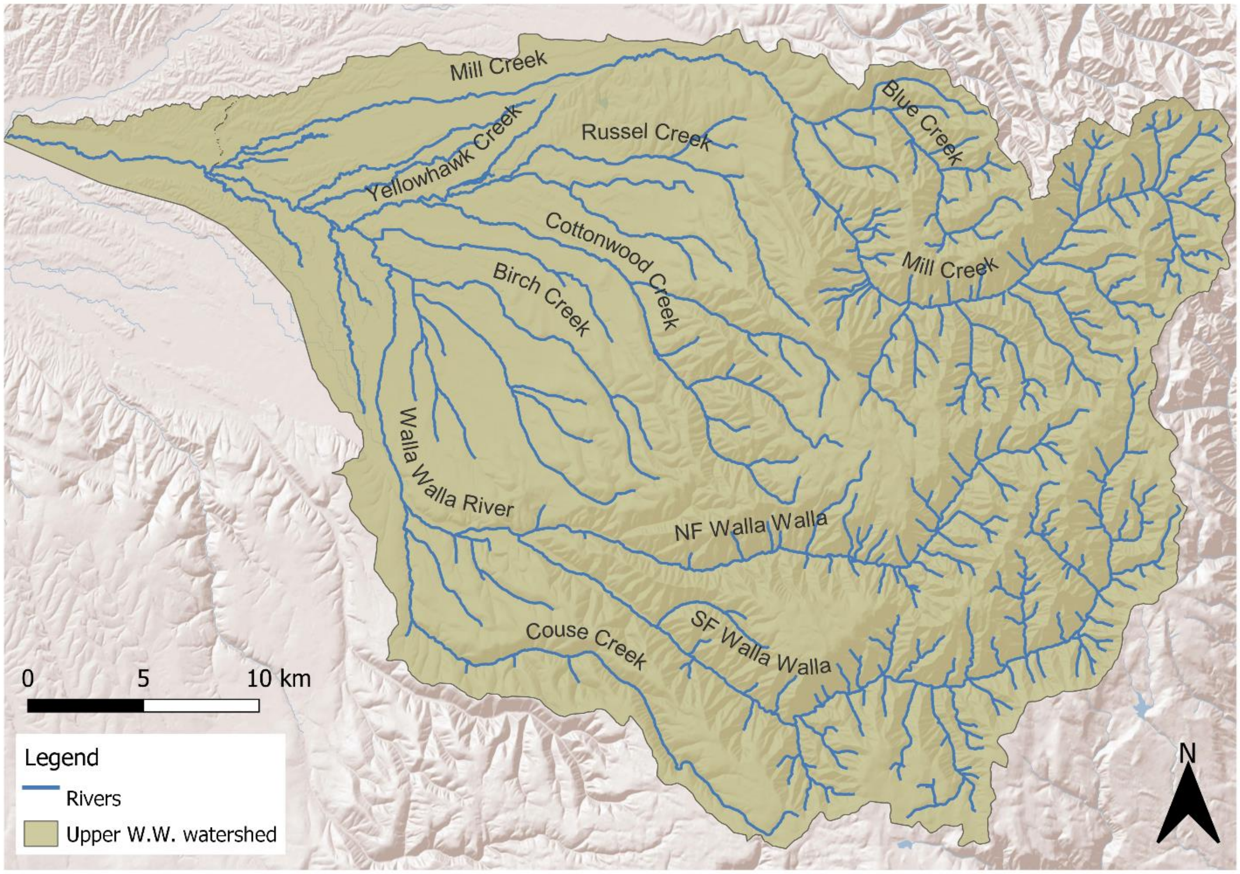

Figure 1: Stream extents for the Upper Walla Walla watershed modeled as part of the NorWeST regional database (Isaak et al. 2017). Primary rivers and tributaries used by Chinook salmon, steelhead, and bull trout are labeled in the map.

Table 1: The length (km) of rivers and tributaries within the spatial distribution of Chinook salmon, steelhead, and bull trout in the Upper Walla Walla watershed. No species distribution was available for Pacific lamprey in StreamNet; therefore, the entirety of the modeled NorWeST extent was used for Pacific lamprey.

Stream name	Chinook salmon	Steelhead	Bull trout	Pacific lamprey
Bear Creek	–	1.5	–	1.5
Birch Creek	–	13.2	–	13.2
Blue Creek	–	12.8	–	12.8
Broken Creek	–	4.5	1.7	4.5
Caldwell Creek	–	0.2	–	0.2
Cold Creek	–	5.3	–	5.3
Cottonwood Creek	–	16.8	–	16.8
Couse Creek	–	22.8	9.4	22.8
Doan Creek	–	3.4	–	3.4

Stream name	Chinook salmon	Steelhead	Bull trout	Pacific lamprey
Dorothy Ditch	6.2	6.2	6.2	6.2
East Prong Little Walla Walla River	2.0	9.2	2.2	9.2
Elbow Creek	–	3.9	–	3.9
Garrison Creek	–	13.4	13.4	13.4
Green Fork	–	1.1	1.9	1.9
Low Creek	–	4.8	4.4	4.8
Middle Fork Cottonwood Creek	–	3.2	–	3.2
Mill Creek	47.2	56.6	57.0	57.0
North Fork Cottonwood Creek	–	8.4	–	8.4
North Fork Mill Creek	–	1.5	3.3	3.3
North Fork Walla Walla River	–	28.2	27.8	28.2
Paradise Creek	–	2.6	3.4	3.4
Reser Creek	–	3.7	2.8	3.7
Russell Creek	–	6.3	–	6.3
Skiphorton Creek	–	4.8	4.6	4.8
Skookum Creek	–	1.0	–	1.0
South Fork Cottonwood Creek	–	5.6	–	5.6
South Fork Walla Walla River	21.2	37.0	37.6	37.6
Stone Creek	–	4.5	–	4.5
Table Creek	–	1.8	–	1.8
Tiger Creek	–	5.3	5.1	5.3
Walla Walla River	38.4	38.4	38.4	38.4
Walsh Creek	–	–	–	–
Webb Creek	–	1.7	–	1.7
West Crockett Branch	–	1.1	–	1.1
West Prong Little Walla Walla River	–	4.4	–	4.4
Yellowhawk Creek	13.0	13.0	11.8	13.0
Unnamed Creek(s)	–	32.4	24.5	42.0
Total	128.0	380.6	255.5	394.6

2.3 TEMPERATURE SCENARIOS

Three NorWeST summer stream temperature scenarios were considered. The Recent Historic scenario was intended to represent a contemporary scenario, whereas the 2040 Projected and 2080 Projected scenarios represent mid-century and late-century climate warming scenarios, respectively. Definitions of each scenario are as follows:

- Recent Historic: A historical composite scenario representing the 10-year average August mean stream temperatures for 2002-2011 (Isaak et al., 2017).
- 2040 Projected: A future August mean stream temperature scenario based on average projected changes in August air temperature and stream discharge for the 2040s (2030-2059). Projected changes in streams accounted for differential sensitivity among streams so that cold streams warm less than warm streams (Isaak et al., 2017).
- 2080 Projected: A future August mean stream temperature scenario based on average projected changes in August air temperature and stream discharge for the 2080s (2070-2099). Projected changes in streams accounted for differential sensitivity among streams so that cold streams warm less than warm streams (Isaak et al., 2017).

We also considered a hypothetical scenario (Recent Minus 1ºC) in which summer stream temperatures were reduced by 1ºC relative to the Recent Historic scenario. This scenario represents a situation where various restoration actions (e.g., riparian planting, improved land use practices) increase stream shading, reduce solar loading, and/or increase hyporheic exchange within the watershed resulting in cooler August stream temperatures. Each of the scenarios are summarized in Figures 2 and 3.

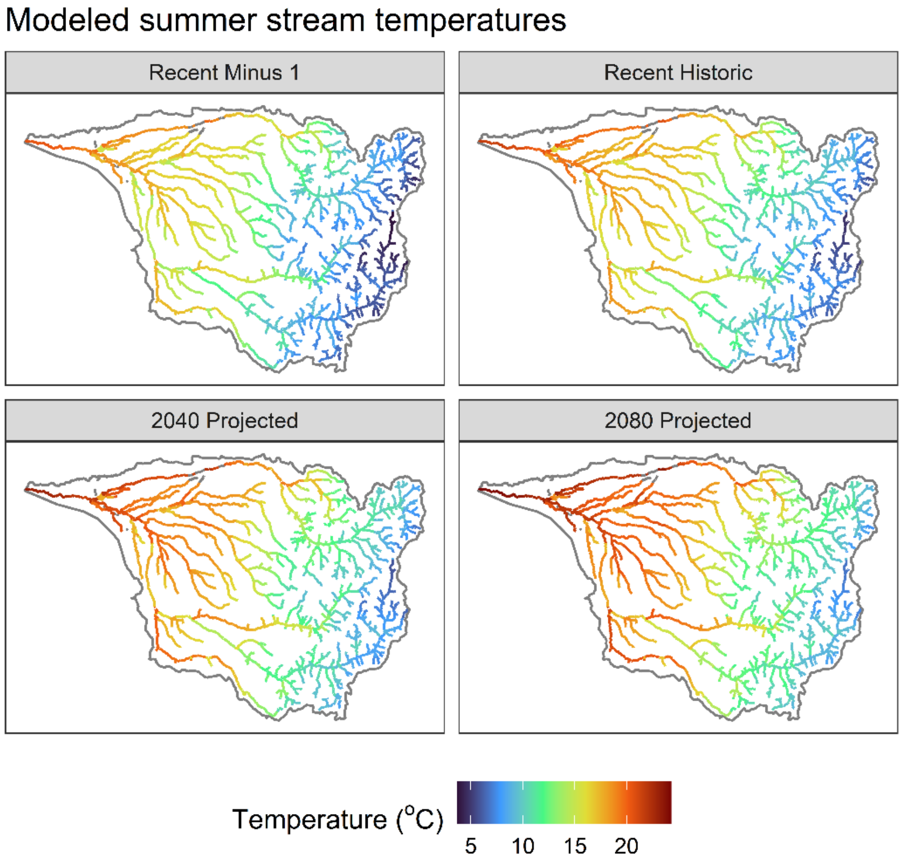

Figure 2: Modeled average August stream temperatures (°C) within the Upper Walla Walla watershed for the Recent Historic, 2040 Projected, 2080 Projected, and Recent Minus 1 (°C) temperature scenarios.

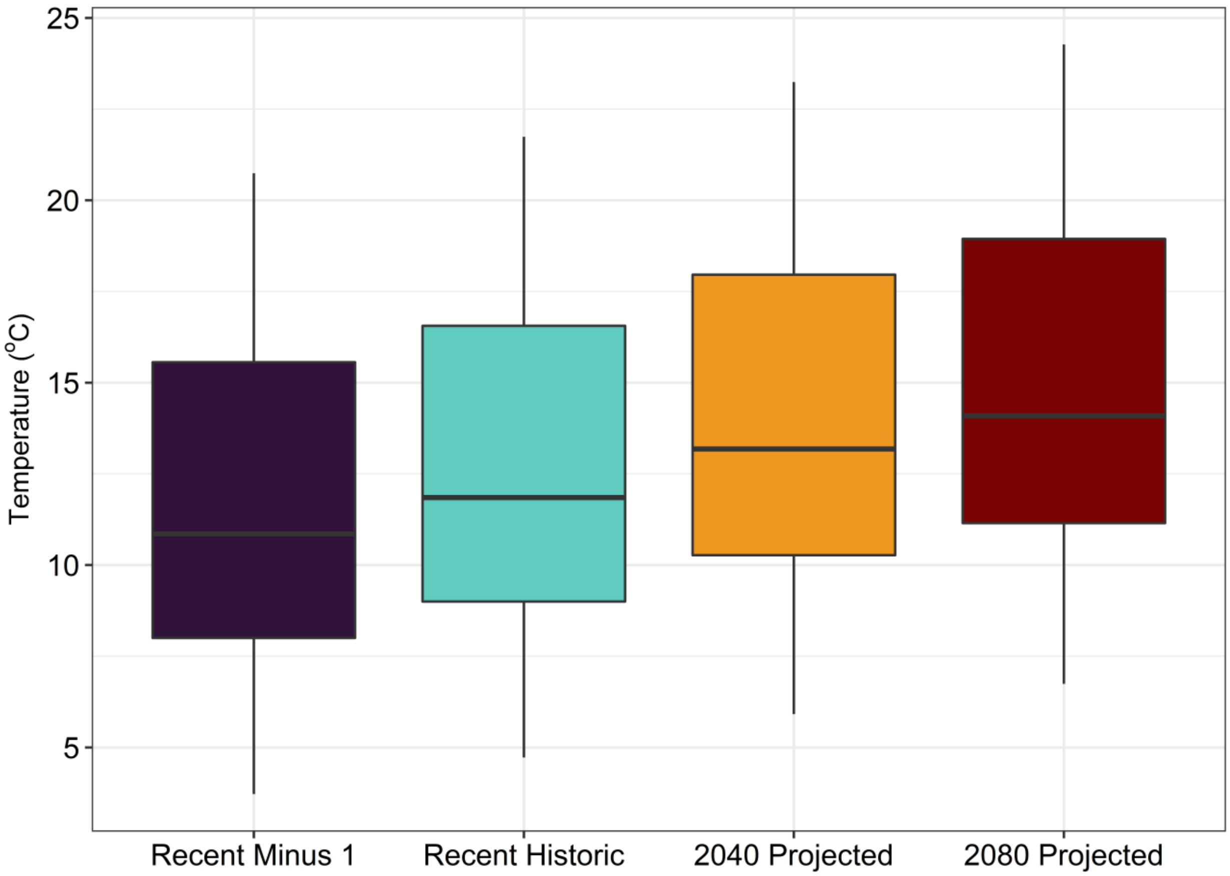

Figure 3: Distribution of average August stream temperatures (°C) in the Upper Walla Walla watershed for the Recent Historic, 2040 Projected, 2080 Projected, and Recent Minus 1 (°C) temperature scenarios.

Temperature thresholds were evaluated for Chinook salmon and steelhead life-stage(s) that occupy habitat in the Upper Walla Walla watershed in August. This included Chinook salmon spawning and summer parr life-stages and the steelhead summer parr life-stage. Temperature thresholds (expressed as the maximum weekly maximum temperature [MWMT]) identified in a literature review conducted by Carter (2005) were used for Chinook salmon and steelhead thresholds. Chinook spawning was observed over a wide range of temperatures (5.6 - 17.7°C); however, most observations cite maximum temperatures at 14.5°C. The optimal temperature range for juvenile Chinook salmon growth and rearing was 10 - 16°C. Temperatures above 19°C generally did not support Chinook salmon parr growth and Chinook salmon parr were rarely found in reaches with temperatures greater than 22°C. Juvenile steelhead summer parr have a slightly higher temperature tolerances for growth and rearing compared to Chinook salmon ranging from 10-18°C.

Bull trout tended to have more specific habitat requirements compared to other salmonids, requiring colder stream temperatures. Although bull trout have been reported in stream temperatures above 20°C, they are seldom found in waters where temperatures exceed 15 - 16°C. Temperatures above 16°C are detrimental for bull trout feeding and growth and are unlikely to be suitable for their long-term survival (Selong et al., 2001 and references therein). At temperatures greater than 18ºC, bull trout exhibit reduced consumption, growth, and survival (Selong et al., 2001).

Pacific lamprey can tolerate a temperature range of 5 - 25ºC (Clemens et al., 2017). Pacific lamprey spawning typically occurs between 10 - 18ºC with early juvenile development between 14 - 19ºC, and preferred temperatures by adults ranging from 16 - 17ºC (Clemens et al., 2016; Clemens et al., 2017). Temperatures greater than 19ºC are typically associated with stress, tissue damage, and potential mortality in Pacific lamprey (Clemens et al., 2016). Temperature thresholds along with descriptions of the thresholds are shown in Table 2 and Table 3.

Table 2: Life stage timing and minimum, optimum, maximum, and acute temperature (ºC) thresholds for summer life stages of Chinook salmon, steelhead, bull trout, and Pacific lamprey. Chinook salmon and steelhead temperatures are expressed as the 7-day Maximum Weekly Maximum Temperature (MWMT).

Species	Life stage	Source	Timing	Minimum	Optimum	Maximum	Acute
Chinook salmon	Spawning	Carter 2005	8/10 - 9/30	3.3	7.2 - 14.5	17.7	20
Chinook salmon	Summer parr	Carter 2005	6/10 - 10/15	4.5	10 - 16	19	22
Steelhead	Summer parr	Carter 2005	6/10 - 10/15	4.5	10 - 18	19	22
Bull trout	All	Selong et al. 2001	7/1 - 8/31	0	10.2 - 16	18	20
Pacific lamprey	All	Clemens et al. 2016, 2017	7/1 - 8/31	5	10 - 17	20	25

Table 3: Descriptions of maximum weekly maximum temperature and temperature thresholds used in the assessment.

Term	Description
MWMT	The maximum weekly maximum temperature (also known as the seven-day average of daily maximum temperatures (7-DADM)) is the maximum of the daily maximum temperatures over a running seven-day consecutive period. The MWMT is useful because it describes the maximum temperatures in a stream but is not overly influenced by the maximum temperature of a single day.
Minimum	A temperature below which physiological stress occurs including reduced growth and activity. Prolonged exposure below this temperature can lead to eventual mortality.
Optimum	The optimum or preferred stream temperature that fish most frequently inhabit when allowed to freely select temperatures in a thermal gradient (USEPA 1999). Also described as those temperatures at which growth rates are maximal (Armour 1991).
Maximum	A temperature above which physiological stress occurs including reduced growth and activity. Prolonged exposure above this temperature can lead to eventual mortality.
Acute	An instantaneous maximum temperature above which can be lethal in a short time.

2.4 APPROACH

Four separate analyses were conducted using the climate scenarios and temperature thresholds described above to consider the potential impacts of summer stream temperatures on each of the species and life stages of interest:

1. First, we considered whether Recent Historic, Projected 2040, and Projected 2080 summer stream temperature predictions in the Upper Walla Walla watershed fell within optimum temperature ranges (Table 2) for each species and life stage. We estimated the percentage, by length, of the stream network that fell within optimum temperature thresholds. For this evaluation, we considered the entire NorWeST modeled extent, beyond the species current distributions. Inclusion of the modeled extent can account for expanded species distributions into headwaters as partial or full migration barriers are removed.

2. Second, we evaluated stream reaches estimated to exceed optimum, maximum, and acute temperature thresholds under the Recent Historic, Projected 2040, and Projected 2080 temperature scenarios. We considered each species and life stage, independently, and focused on the current spatial domains for each species.

3. Then, we considered the theoretical cooling scenario where summer stream temperatures were decreased by 1ºC relative to the recent historic scenario (Recent Minus 1ºC). We estimated the length of stream within the Upper Walla Walla watershed that would be “gained” (i.e., fall below optimum, maximum, and acute temperature thresholds) relative to the Recent Historic scenario for each species and life stage.

4. Finally, August mean stream temperatures under the Recent Historic scenario were summarized by geomorphic reaches. The goal was to determine whether summer stream temperatures, summarized by geomorphic reach, was potentially limiting the distribution and/or productivity of each species and life stage. We estimated the percentage, by length, for each geomorphic reach that exceeded optimum, maximum, and acute thresholds by species and life stage. We used this information to determine a “thermal priority” for each reach by calculating the average percentage of each reach that was above optimum temperature thresholds among species and life stages. Reaches with 0% above optimum for all species were listed as “Low” priority, reaches between 0% and 50% were “Medium” priority, and reaches with greater than or equal to 50% above optimum thresholds were listed as “High” priority.

3.0 RESULTS

3.1 OPTIMUM TEMPERATURE RANGES

Many of the lower reaches in the Upper Walla Walla watershed were predicted to be outside of the optimum stream temperature range for each species and life stage, presumably being too warm, even under the Recent Historic scenario (Figure 4). Increasing stream temperatures were predicted to have the greatest impact on the Chinook salmon spawning life stage since they had the lowest maximum optimum temperature. Even in the case of steelhead parr rearing, with the highest optimum tolerance of 18ºC, many lower reaches were projected to be too warm during the Recent Historic scenario. Conversely, the Recent Historic scenario depicts that headwater reaches were often below optimum ranges, although cooler stream temperatures were not generally considered a limiting factor.

A large proportion of stream reaches were predicted to be “lost” or “gained” under the 2040 Projected scenario relative to Recent Historic conditions (Figure 4). Lost reaches indicate where temperatures exceed optimum ranges compared to Recent Historic conditions and gained reaches warm up to be within optimum ranges. Similarly, when the 2080 Projected is compared to the 2040 Projected scenario, optimum temperatures during August were predicted to shift upstream. The amount of the stream network within optimal temperature thresholds was predicted to increase through time for bull trout and Pacific lamprey (Table 4) resulting from gains in headwater reaches at a greater rate than losses in downstream reaches.

Table 4: The length (km) of stream that falls within optimum temperature ranges for each species and life stage and for each stream temperature scenario. The entirety of the modeled NorWeST extent in the Upper Walla Walla watershed was considered for this summary.

Life Stage	Recent Historic	2040 Projected	2080 Projected
Chinook salmon spawning	40.6	36.8	27.4
Chinook salmon parr	44.6	36.2	37.2
Steelhead parr	211.3	186.7	168.5
Bull trout	65.1	84.4	95.0
Pacific lamprey	371.7	377.5	396.4

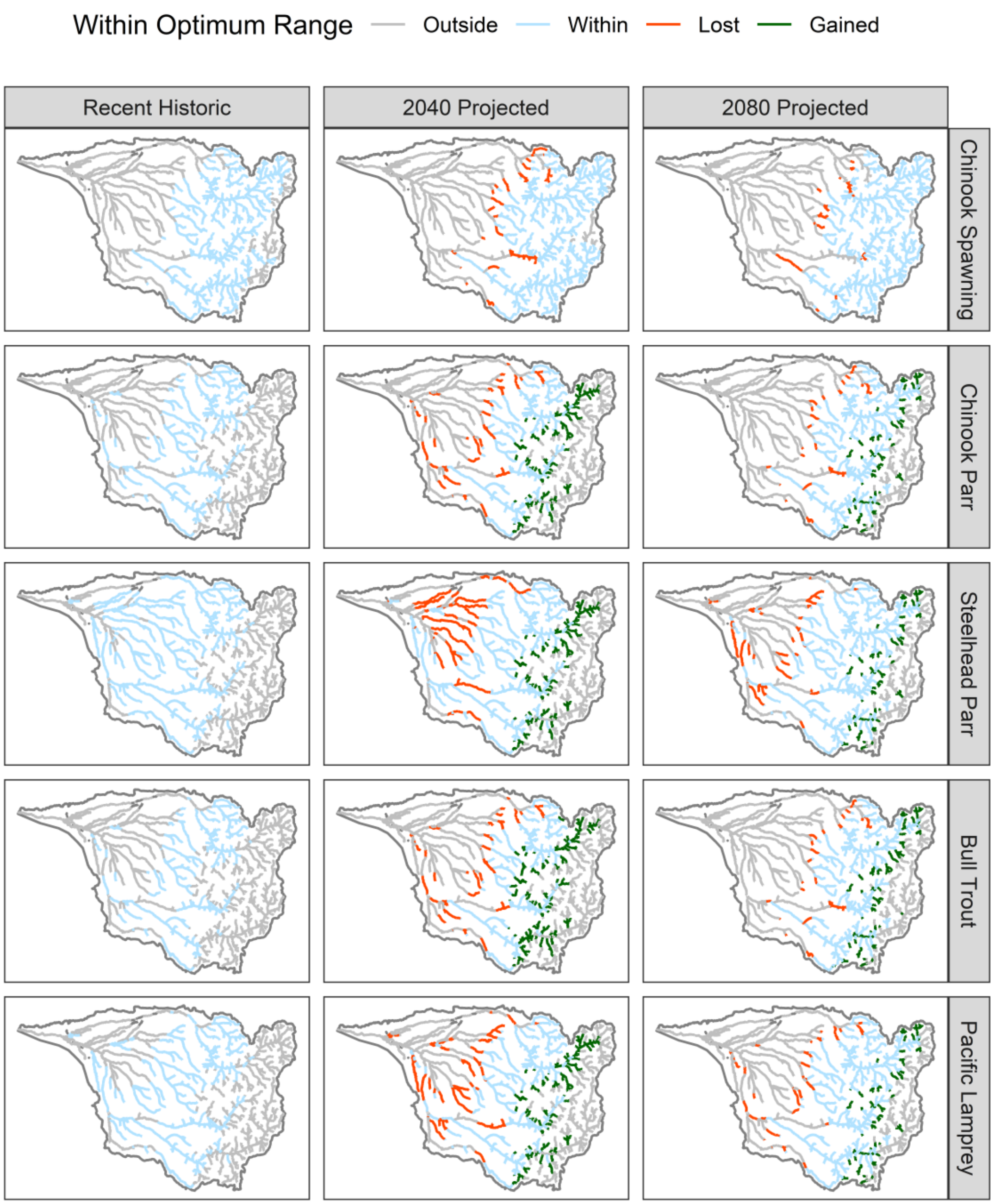

Figure 4: August mean stream temperatures for three modeled scenarios in reaches containing optimal temperatures for summer life stages of focal species within the Upper Walla Walla watershed. Lost and gained reaches indicate the change in optimal temperature relative to the prior scenario.

3.2 THRESHOLD EXCEEDANCES

3.2.1 Chinook salmon spawning

Under the Recent Historic scenario, 83.5 rkm of the Upper Walla Walla watershed was estimated to exceed optimum temperatures for Chinook salmon spawning during August (Table 5, Figure 5). This was expected to increase by an additional 3.8 rkm and 13.1 rkm in the 2040 and 2080 Projected scenarios, respectively. Similarly, maximum and acute temperature thresholds for Chinook salmon spawning under Recent Historic conditions were predicted to increase in the 2040 and 2080 projected climate warming scenarios (Table 5, Figure 5).

Table 5: The length (km) of stream above optimum, maximum, and acute temperature thresholds, and the species domain's total length, for Chinook salmon spawning for each stream temperature scenario.

Life stage	Scenario	Above optimum	Above maximum	Above acute	Species domain
Chinook salmon spawning	Recent Historic	83.5	51.5	13.4	128.1
Chinook salmon spawning	2040 Projected	87.3	65.9	43.0	128.1
Chinook salmon spawning	2080 Projected	96.6	73.9	53.7	128.1

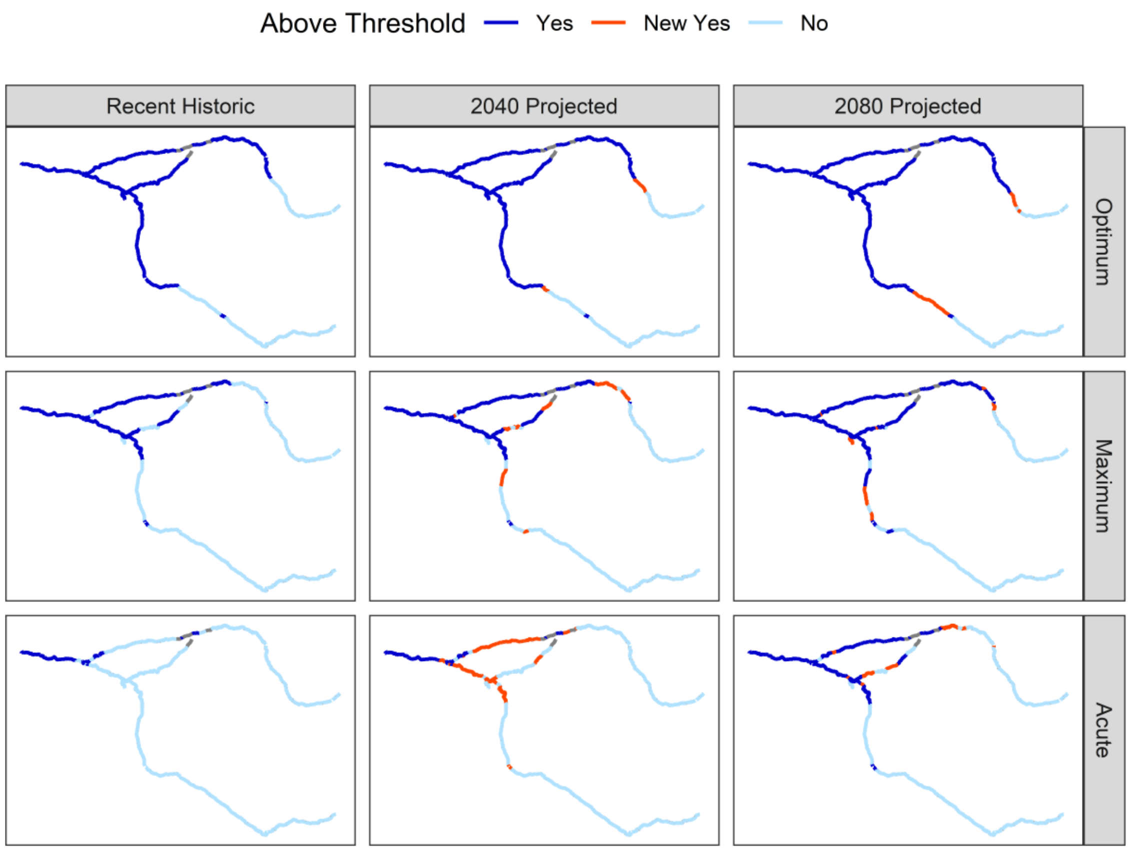

Figure 5: Modeled August mean stream temperatures that exceed optimum, maximum, and acute temperature thresholds for Chinook salmon spawning in the Upper Walla Walla watershed. Three NorWeST scenarios were shown, including a recent historic composite (Recent Historic), mid-century (2040 Projected) and late-century (2080 Projected) predictions. The Recent Historic scenario depicts where summer stream temperatures are currently estimated to exceed thresholds, whereas the 2040 Projected and 2080 Projected scenarios depict where temperature exceedances are estimated to expand (*New Yes*).

3.2.2 Chinook salmon parr

Under the Recent Historic scenario, 67.9 rkm of the Upper Walla Walla watershed was estimated to exceed optimum temperatures for Chinook salmon juvenile rearing during August (Table 6, Figure 6). It was estimated that the total length of the stream that exceeds optimum temperatures would increase for the Projected 2040 scenario and for the Projected 2080 scenario compared to the Recent Historic scenario. Likewise, 36.0 rkm was estimated to exceed maximum thresholds for Chinook salmon juvenile rearing under the Recent Historic scenario and was expected to increase in both Projected climate scenarios. Under the Recent Historic scenario, none of the Upper Walla watershed was estimated to exceed acute thresholds; however, 8.4 rkm was predicted to exceed acute thresholds in the Projected 2040 scenario and 24.6 rkm in the Projected 2080 scenario (Table 6, Figure 6).

Table 6: The length (km) of stream above optimum, maximum, and acute temperature thresholds, as well as the total length of the species domain, for Chinook salmon juvenile summer rearing for each NorWeST stream temperature scenario.

Life stage	Scenario	Above optimum	Above maximum	Above acute	Species domain
Chinook salmon parr	Recent Historic	67.9	36.0	0.0	128.1
Chinook salmon parr	2040 Projected	81.9	53.7	8.4	128.1
Chinook salmon parr	2080 Projected	84.7	60.7	24.6	128.1

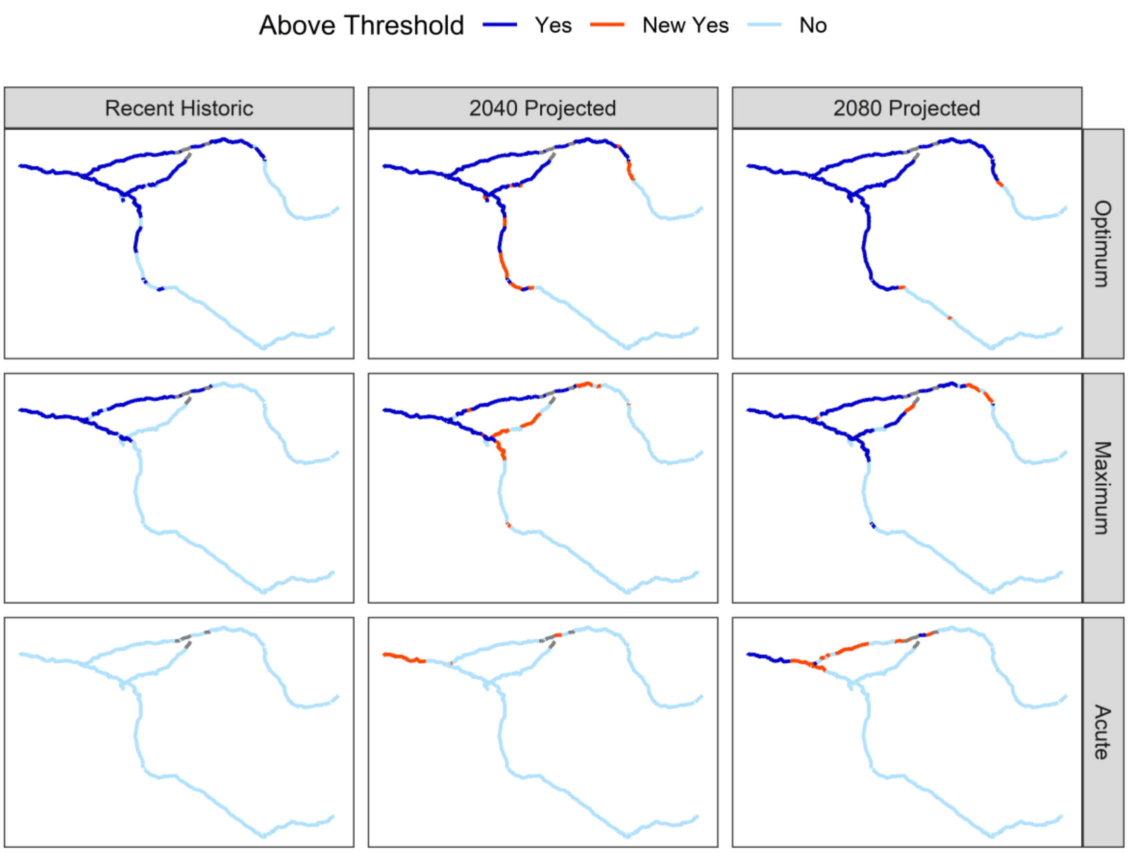

Figure 6 Modeled August mean stream temperatures that exceed optimum, maximum, and acute temperature thresholds for Chinook salmon parr summer rearing in the Upper Walla Walla watershed. Three NorWeST scenarios were shown, including a recent historic composite (Recent Historic), mid-century (2040 Projected) and late-century (2080 Projected) predictions. The Recent Historic scenario depicts where summer stream temperatures are currently estimated to exceed thresholds, whereas the 2040 Projected and 2080 Projected scenarios depict where temperature exceedances are estimated to expand (*New Yes*).

3.2.3 Steelhead parr

Under the Recent Historic scenario, 77.5 rkm of the Upper Walla Walla watershed was estimated to exceed optimum temperatures for steelhead juvenile rearing during August (Table 7, Figure 7). An additional 64.0 rkm was estimated to exceed optimum temperatures by the Projected 2040 scenario and an additional 32.1 rkm by the Projected 2080 scenario. Similar, 42.5 rkm was estimated to exceed maximum thresholds for steelhead juvenile rearing under the Recent Historic scenario and was expected to increase in both Projected scenarios. Under the Recent Historic scenario, none of the Upper Walla Walla watershed was estimated to exceed acute thresholds; however, 8.6 rkm was predicted to exceed acute thresholds in the Projected 2040 scenario and 24.6 rkm by the Projected 2080 scenario (Table 7, Figure 7).

Table 7: The length (km) of stream above optimum, maximum, and acute temperature thresholds, as well as the total length of the species domain, for steelhead juvenile summer rearing for each NorWeST stream temperature scenario.

Life stage	Scenario	Above optimum	Above maximum	Above acute	Species domain
Steelhead parr	Recent Historic	77.5	42.5	0.0	380.7
Steelhead parr	2040 Projected	141.5	97.5	8.6	380.7
Steelhead parr	2080 Projected	173.6	138.5	25.6	380.7

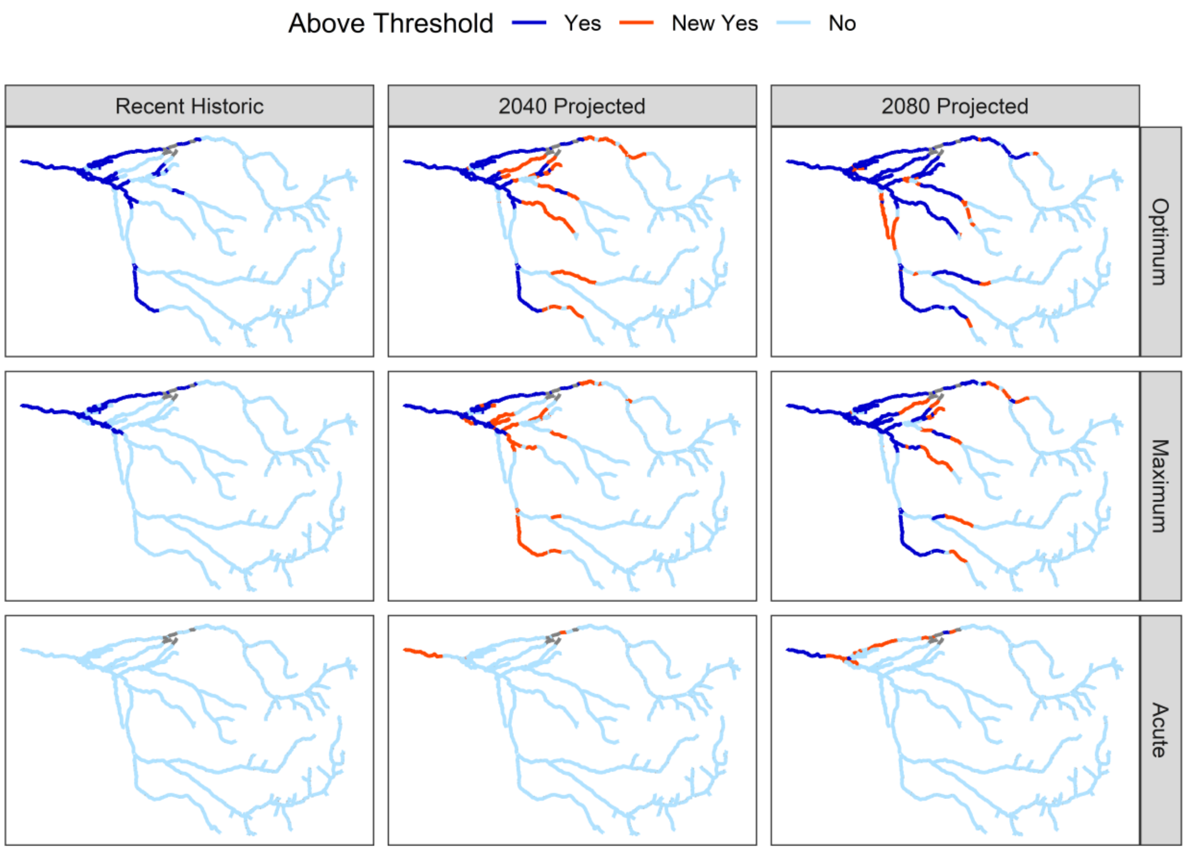

Figure 7: Modeled August mean stream temperatures that exceed optimum, maximum, and acute temperature thresholds for steelhead parr summer rearing in the Upper Walla Walla watershed. Three NorWeST scenarios were shown, including a recent historic composite (Recent Historic), mid-century (2040 Projected) and late-century (2080 Projected) predictions. The Recent Historic scenario depicts where summer stream temperatures are currently estimated to exceed thresholds, whereas the 2040 Projected and 2080 Projected scenarios depict where temperature exceedances are estimated to expand (*New Yes*).

3.2.4 Bull trout

Under the Recent Historic scenario, 98.4 rkm of the Upper Walla Walla watershed was estimated to exceed optimum temperatures for bull trout during August (Table 8, Figure 8). An additional 17.4 rkm was estimated to exceed optimum temperatures by the Projected 2040 scenario and an additional 6.4 rkm by the Projected 2080 scenario. Likewise, 59.8 rkm and 13.4 rkm were estimated to exceed maximum and acute temperature thresholds for bull trout, respectively, under the Recent Historic scenario, and both were anticipated to increase in the Projected scenarios (Table 8, Figure 8).

Table 8: The length (km) of stream above optimum, maximum, and acute temperature thresholds, as well as the total length of the species domain, for bull trout for each NorWeST stream temperature scenario.

Life stage	Scenario	Above optimum	Above maximum	Above acute	Species domain
Bull trout	Recent Historic	98.4	59.8	13.4	255.5
Bull trout	2040 Projected	115.6	89.8	45.2	255.5
Bull trout	2080 Projected	122.0	101.4	70.8	255.5

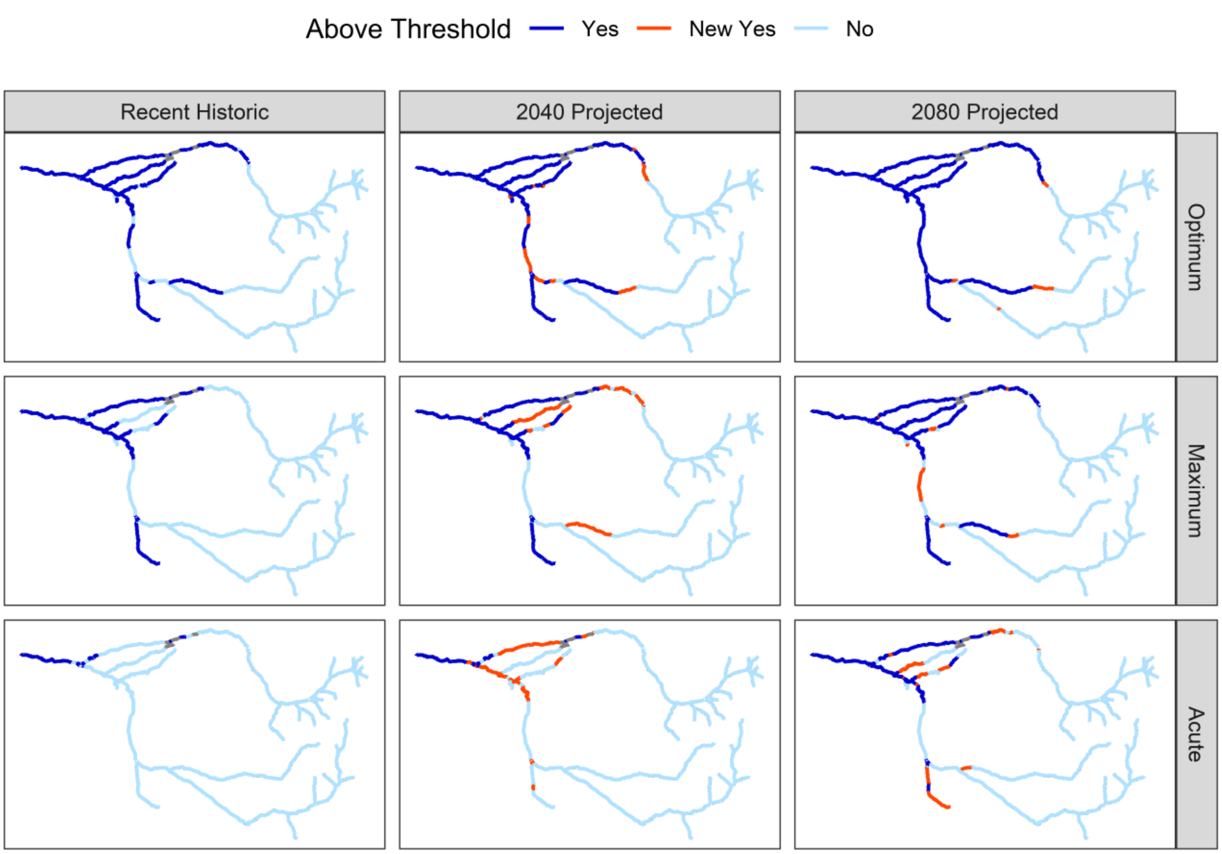

Figure 8: Modeled August mean stream temperatures that exceed optimum, maximum, and acute temperature thresholds for bull trout in the Upper Walla Walla watershed. Three NorWeST

scenarios were shown, including a recent historic composite (Recent Historic), mid-century (2040 Projected) and late-century (2080 Projected) predictions. The Recent Historic scenario depicts where summer stream temperatures are currently estimated to exceed thresholds, whereas the 2040 Projected and 2080 Projected scenarios depict where temperature exceedances are estimated to expand (*New Yes*).

Pacific lamprey

For Pacific lamprey, the entirety of the Upper Walla Walla watershed was considered for the species spatial extent since they are functionally extirpated from the watershed and their historic distribution within the watershed is not well documented. Thus, much of the area considered may not be suitable habitat for Pacific lamprey. However, results still demonstrate areas in lower reaches of the watershed that may exceed optimum, maximum, and acute temperature thresholds for Pacific lamprey (Figure 9). Under the Recent Historic scenario, 181.1 rkm of the Upper Walla Walla watershed was estimated to exceed optimum temperature thresholds for Pacific lamprey during August (Table 9, Figure 9). An additional, 100.8 rkm was estimated to exceed optimum temperatures by the 2040 Projected scenario and an additional 47.7 rkm by the 2080 Projected scenario. Likewise, 14.4 rkm was estimated to exceed maximum threshold for Pacific lamprey under the Recent Historic scenario and was expected to increase in the Projected climate scenarios. No reaches were anticipated to exceed the acute temperature threshold (25^{o}C) for Pacific lamprey under any scenario considered (Table 9, Figure 9).

Table 9: The length (km) of stream above optimum, maximum, and acute temperature thresholds, as well as the total length of the species domain, for Pacific for each NorWeST stream temperature scenario.

Life stage	Scenario	Above optimum	Above maximum	Above scute	Species domain
Pacific lamprey	Recent Historic	181.1	14.4	0.0	852.2
Pacific lamprey	2040 Projected	281.9	58.7	0.0	852.2
Pacific lamprey	2080 Projected	329.6	123.5	0.0	852.2

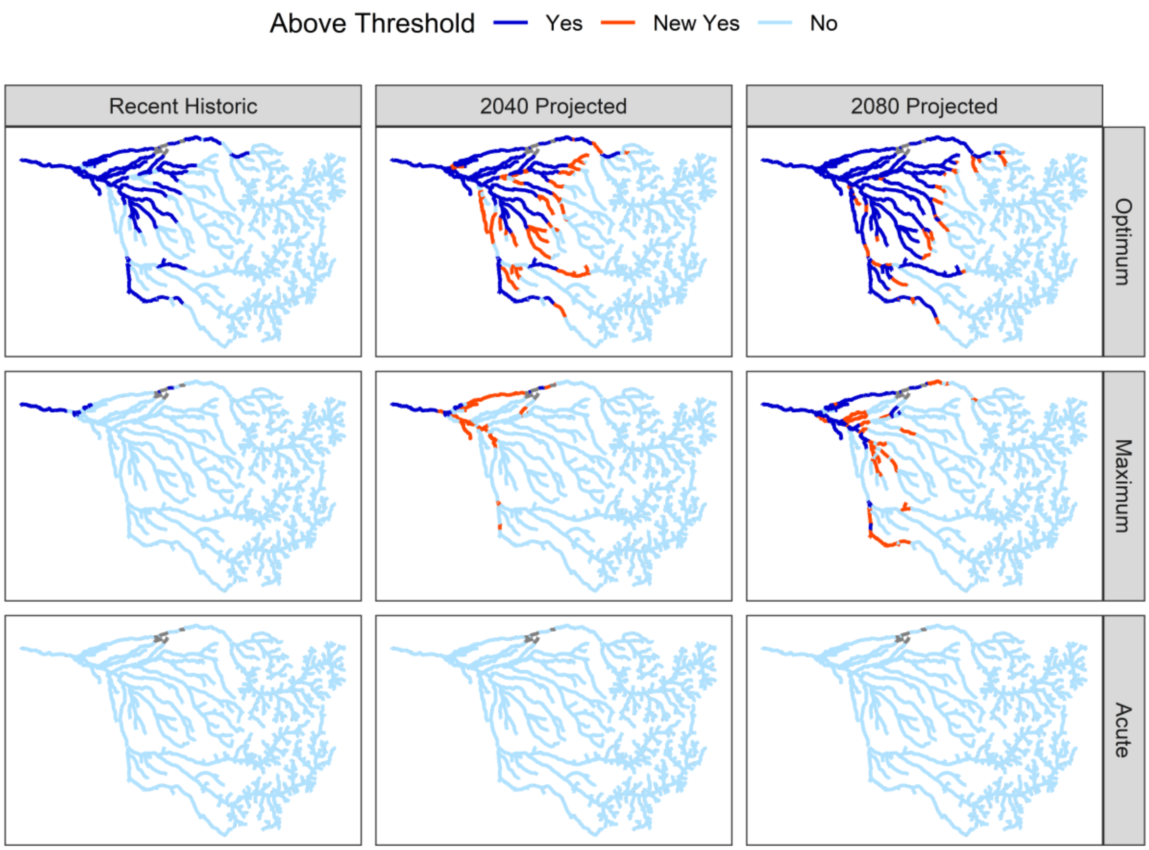

Figure 9: Modeled August mean stream temperatures that exceed optimum, maximum, and acute temperature thresholds for Pacific lamprey in the Upper Walla Walla watershed. Three NorWeST scenarios were shown, including a recent historic composite (Recent Historic), mid-century (2040 Projected) and late-century (2080 Projected) predictions. The Recent Historic scenario depicts where summer stream temperatures are currently estimated to exceed thresholds, whereas the 2040 Projected and 2080 Projected scenarios depict where temperature exceedances are estimated to expand (*New Yes*).

3.3 THEORETICAL COOLING SCENARIO

The hypothetical scenario where summer stream temperatures were decreased by 1ºC relative to the Recent Historic scenario reduced the stream length that exceeded optimum and maximum temperature thresholds for all focal species and life stages evaluated (Table 10). There were no stream reaches above acute temperature thresholds for Chinook salmon parr, steelhead parr, and Pacific lamprey under the Recent Historic scenario, and thus, no additional reaches were "gained" (Table 10). An estimated 7.4 km would be gained, or fall below acute thresholds, for Chinook salmon spawning and bull trout if stream temperatures were reduced by 1ºC. For example, if stream temperatures were reduced by 1ºC relative to Recent Historic conditions, an additional 35.0 km of stream would fall within optimum temperature ranges for steelhead summer parr rearing and an additional 28.1 km would become below maximum temperature thresholds.

Table 10: The estimated length (km) of stream in the Upper Walla Walla watershed that would be gained i.e., fall below optimum, maximum, and acute temperature thresholds under a theoretical -1°C cooling scenario relative to recent composite (2002 - 2011) conditions.

Life stage	Below optimum	Below maximum	Below acute
Chinook salmon spawning	10.8	12.3	7.4
Chinook salmon parr	9.6	22.6	–
Steelhead parr	35.0	28.1	–
Bull trout	14.0	23.2	7.4
Pacific lamprey	86.1	8.4	–

3.4 GEOMORPHIC REACHES

Three of the five geomorphic reaches in the mainstem Walla Walla River and two of the eight in the North Fork Walla Walla River were estimated to have 50% of the stream length exceed optimum temperature thresholds in the Recent Historic scenario, averaged among species and life stages (Table 11). These reaches were listed as “High” priority. Two additional geomorphic reaches within each of the mainstem and North Fork Walla Walla rivers were listed as “Medium” priority. Only one geomorphic reach in the South Fork Walla Walla River was listed as “Medium” priority, as 4.6% of the stream length exceeded optimum temperatures for Chinook salmon spawning. The remaining reaches in the South Fork Walla Walla were all listed as “Low” priority. Every geomorphic reach in the mainstem Walla Walla (WW1 - WW5) had extents that exceeded optimum temperatures for every species by life stage considered and three of five (WW1, WW2, WW4) had reaches exceeding maximum thresholds (Figure 10). Some lower reaches in the North Fork Walla Walla River (NF1 - NF3) were also of concern with extents exceeding optimum thresholds and one reach (NF1) containing reaches that exceed maximum temperatures for Chinook salmon spawning. Only one geomorphic reach in the South Fork Walla Walla (SF1) had some portion exceeding Chinook salmon optimum thresholds.

Table 11: The minimum, maximum, and mean August stream temperatures (°C) and length (km) by geomorphic reach, as well as the percentage by length of each reach that fell above the optimum temperature threshold for each species and life stage using the Recent Historic temperature scenario.

Reach	Min	Mean	Max	Length (km)	Chinook salmon spawning (%)	Chinook salmon parr (%)	Steelhead parr (%)	Bull trout (%)	Pacific lamprey (%)	Species mean (%)	Priority
WW1	19.5	20.7	21.7	13.2	100.0	100.0	100.0	100.0	100.0	100.0	High
WW2	14.9	18.7	19.5	11.4	100.0	91.2	91.2	91.2	91.2	93.0	High
WW3	14.9	16.3	16.5	4.2	100.0	90.5	0.0	90.5	0.0	56.2	High
WW4	14.9	15.9	18.6	4.8	100.0	12.5	12.5	12.5	12.5	30.0	Medium

Reach	Min	Mean	Max	Length (km)	Chinook salmon spawning (%)	Chinook salmon parr (%)	Steelhead parr (%)	Bull trout (%)	Pacific lamprey (%)	Species mean (%)	Priority
WW5	13.4	14.9	16.6	4.8	91.7	16.7	0.0	16.7	0.0	25.0	Medium
NF1	16.9	17.5	17.9	5.8	100.0	100.0	0.0	100.0	86.2	77.2	High
NF2	15.8	16.6	16.9	3.4	100.0	94.1	0.0	94.1	0.0	57.6	High
NF3	13.8	15.0	15.8	5.0	60.0	0.0	0.0	0.0	0.0	12.0	Medium
NF4	10.4	13.4	14.1	4.2	0.0	0.0	0.0	0.0	0.0	0.0	Low
NF5	9.9	12.0	12.9	3.0	0.0	0.0	0.0	0.0	0.0	0.0	Low
NF6	8.6	10.8	11.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	Low
NF7	7.4	9.5	10.8	3.4	0.0	0.0	0.0	0.0	0.0	0.0	Low
NF8	7.4	7.6	8.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF1	10.4	12.5	14.6	13.2	4.6	0.0	0.0	0.0	0.0	0.9	Medium
SF2	8.7	9.9	10.5	7.4	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF3	8.1	8.5	9.6	3.8	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF4	6.8	7.7	9.3	3.8	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF5	6.7	6.9	7.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF6	5.2	6.2	7.6	7.8	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF7	4.7	4.8	4.9	2.6	0.0	0.0	0.0	0.0	0.0	0.0	Low
SF8	4.7	5.1	7.3	1.4	0.0	0.0	0.0	0.0	0.0	0.0	Low

Figure 10: The percent of each geomorphic reach, by length, that exceeded optimum, maximum, and acute temperature thresholds for each species and life stage under the Recent Historic scenario.

4.0 DISCUSSION

In both the Projected 2040 and 2080 climate scenarios, a greater portion of the Upper Walla Walla watershed fell outside optimum temperature ranges for each species and life stage compared to the Recent Historic scenario. Moreover, a greater portion of stream length exceeded maximum and acute temperature thresholds for both Projected climate scenarios. The single exception was for the Pacific lamprey temperature threshold of 25°C, which was not exceeded under any scenario. Under the Recent Historic scenario, it was estimated that more than 21% of each species' domain within the Upper Walla Walla watershed exceeded optimum temperatures, and that value increased to 33% and 38% under Projected 2040 and 2080 climate scenarios, respectively. The amount of stream within optimal temperature thresholds for the Chinook salmon spawning life stage, was the most negatively impacted by warming scenarios. Chinook salmon spawning life stage typically occupies the Upper Walla Walla from mid-August to mid-September, when temperatures are hottest.

For Chinook salmon parr, bull trout, and Pacific lamprey, the amount of stream habitat within optimum temperature ranges increased in the Projected 2040 scenario compared to the Recent Historic scenario, and between the Projected 2040 scenario and the Projected 2080 scenario. This was the result of headwater reaches warming to optimum temperature ranges at a higher rate than downstream reaches warming to exceed the low end of optimum temperature ranges. The net gain in linear stream distance may not equate to a net gain in suitable habitat, therefore it is unclear if headwater reaches would provide usable habitat for the species and life stages of interest. Further, the loss of cold headwater flow will result in warming all reaches downstream, which is likely to have a detrimental effect on suitable habitat in lower reaches, thus negating any positive gains in the smaller tributary reaches. Consequently, the loss of thermally suitable habitats in the lower reaches of the watershed should be given priority when interpreting the potential impacts future climate conditions have on focal species distribution and productivity in the watershed.

Averaged across species and life stages, all geomorphic reaches in the mainstem Walla Walla River (WW1 - WW5) under the Recent Historic scenario were estimated to have at least 25% of their stream length exceed optimum temperature thresholds. The entirety of geomorphic reach WW1 exceeded optimum temperatures for all species and life stages under the Recent Historic scenario. All geomorphic reaches in the mainstem Walla Walla River and the lowest geomorphic reaches of the North Fork Walla Walla and South Fork Walla Walla were designated as "Medium" or "High" priority for actions to mediate or reduce summer stream temperatures. The remaining reaches were all categorized as "Low" priority for actions, though it is assumed that projects upstream, and adjacent, to the "Medium" and "High" priority reaches would likely have thermal benefits that matriculate downstream to the higher priority reaches.

While we recognize the Recent Historic - 1°C temperature scenario represents a hypothetical scenario, it illustrates how cooler stream temperatures would increase the amount of thermally suitability habitat for all focal species in the Upper Walla Walla watershed. Justice et al. (2017) similarly evaluated a 2080s climate change scenario and demonstrated that despite substantial increases in summer stream temperatures, basin-wide restoration of riparian vegetation and channel width could offset climate impacts in the Upper Grande Ronde and Catherine Creek watersheds in eastern Oregon. Future restoration and rehabilitation projects in the Upper Walla Walla watershed, particularly where stream temperatures are projected to exceed optimum, maximum, and acute temperature thresholds for focal species, should incorporate design strategies that help reduce stream temperatures. These include, but are not limited to, reducing solar loading (increased riparian vegetation, reduced channel width, and increase shading), increasing hyporheic exchange (increased floodplain connectivity), and increasing stream flow during the summer (reduced water withdrawals) to help mitigate the effects a warming climate could have on summer stream temperatures throughout the watershed.

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Appendix K

Upper Walla Walla Assessment

TREATMENT EXAMPLES

Technical Report

August, 2024

Technical Report

Rio Applied Science and Engineering

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3380 Americana Terrace, Suite 390
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Prepared for: **Confederated Tribes of the Umatilla Indian Reservation**

Project Title: **Upper Walla Walla River Watershed Assessment**

Technical Report

Subject: Stream and Floodplain Treatment Examples

Date: August 2024

TABLE OF CONTENTS

1.0 INTRODUCTION

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is developing a scientifically defensible aquatic-based and strategic habitat restoration plan founded on a watershed-scale geomorphic, hydrologic, and biological assessment of historical, current, and desired conditions in the upper Walla Walla River. The restoration plan is being developed in collaboration with state co-managers, federal and local agencies, and other stakeholders. This plan is based on using a scientifically robust, efficient, and effective approach to assess the watershed, identify target conditions for restoration, and recommend a suite of potential actions to achieve those targets. The goal of restoration is to protect, enhance, and restore functional streams, floodplains, and uplands, which support and sustain healthy aquatic habitat conditions and fish populations.

The final restoration action plan will establish a 20-year strategic approach to process-based stream/floodplain restoration and conservation based upon watershed-specific data and associated analyses with input from interested stakeholders in the watershed to assist in the recovery of the focal species. To prioritize geographic areas and potential restoration actions, the project team has assessed geomorphic and biologic relationships between land use, land cover, vegetation, aquatic biotic communities, geomorphic and hydrologic processes and conditions. Watershed- and reach-scale assessments have been conducted to identify appropriate restoration targets and treatments within the project area. Treatments include passive and active strategies. Passive restoration generally creates minimal impact. These techniques rely on removing impediments to natural channel process and/or installing features that will restore or augment natural channel processes, but generally allows the river to “do the work” as much as possible. Active restoration on the other hand generally results in greater impact and is commonly referred to as “form-based” restoration. With this technique habit is directly and immediately created via excavation, structure placement, and/or other mechanical means. Any restoration, passive or active, should be completed such that the final project will work with existing natural processes in the future. Passive restoration is commonly used to nudge the trajectory of the channel in a more positive direction and typically results in forms and features early in their evolution requiring time to mature.

Summarized on the following pages are 20 potential treatment examples along with notes on application as well as biological, geomorphic, and design considerations. These are conceptual examples for illustrating and planning purposes. The examples are not intended for construction. Due diligence in analysis and design is required from a qualified engineer to select and design treatments for any given project.

Treatment: Conservation Easements
Type: Reconnection and Restoration

Application

- *Management tool used to protect, preserve, and/or enable the enhancement of river, floodplain, and upland habitat in critical locations*
- *Can be used in conjunction with more active restoration strategies where rates of natural habitat recovery are slow or trending negatively*

Biological Considerations

- *Broad range of biological applications and benefits ranging from conservation of pristine habitat, to habitat protection enabling natural recovery, to habitat management allowing active restoration to expedite recovery*

Geomorphic Considerations

- *Management strategy is dependent on trend and rate of natural recovery*
- *May require active restoration to reverse impact trends and offset unmitigated watershed impacts*

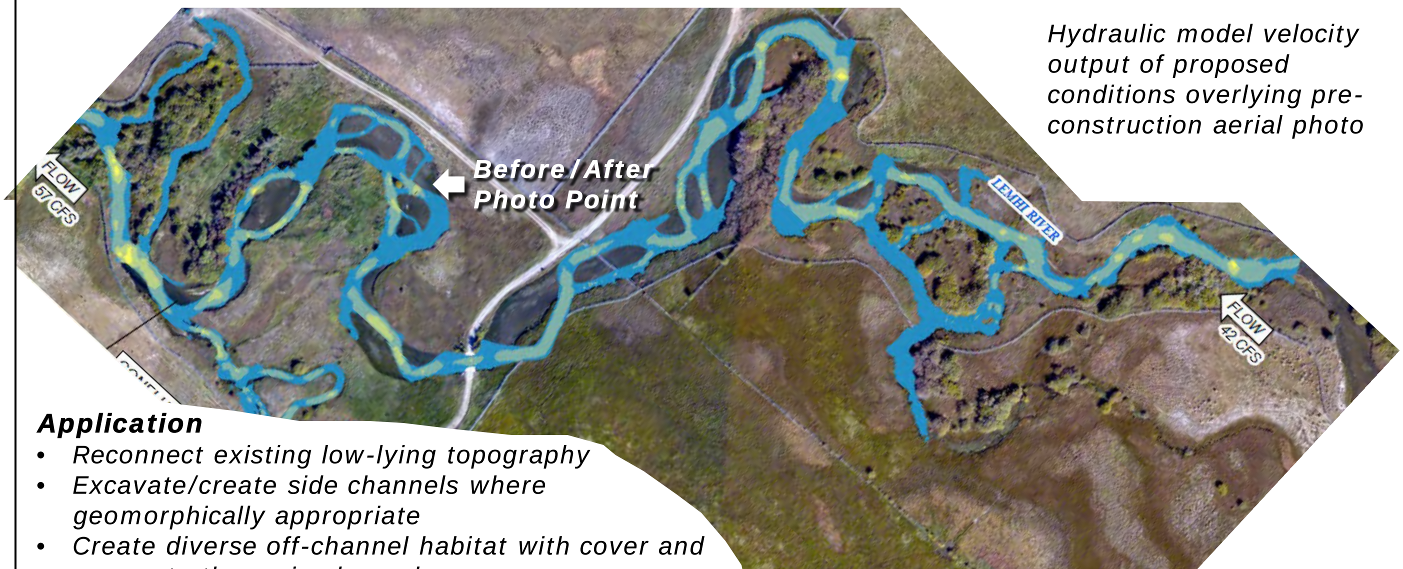
Design Considerations

- *Fencing may be needed to protect, maintain, or improve riparian vegetation and water quality*
- *Applicable on stable areas adjacent to permanent or intermittent streams, wetlands, and areas with groundwater recharge*
- *Supplemental planting may be desired based on overall goals of conservation easement*
- *Tolerant plant species and supplemental watering may be needed in some areas*
- *Can reduce grazing and human impacts to allow riparian vegetation to respond naturally or with assisted planting efforts*

Recent conservation easement illustrating multiple planting strips (dark rectangles); Walla Walla River, OR

Conservation easement 12 years after establishment and riparian planting; Walla Walla River, OR

Treatment: Side Channels
Type: Reconnection and Restoration



Hydraulic model velocity output of proposed conditions overlying pre-construction aerial photo

Application
- *Reconnect existing low-lying topography*
- *Excavate/create side channels where geomorphically appropriate*
- *Create diverse off-channel habitat with cover and access to the main channel*

Biological Considerations
- *Frequent, short/narrow side channels (less than 35% flow split, up to 800 ft long) preferred to less frequent, long/wide side channels*
- *Habitat units should be proportionally smaller and more frequent compared to the primary channel*
- *Provides off-channel rearing habitat for salmonids*

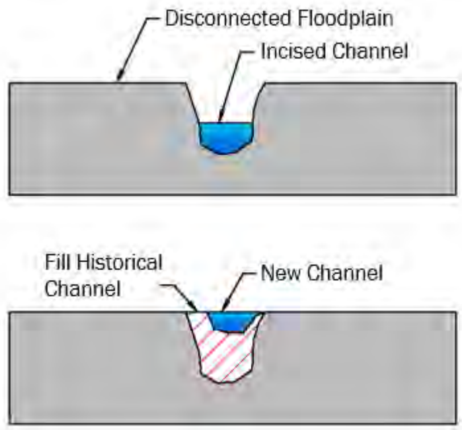
Geomorphic Considerations
- *Spring-fed hydrology and/or limited bedload systems tend toward lower width-to-depth, sinuous, side channels with few/no exposed bars maintained by dense riparian vegetation*
- *Snowmelt hydrology and/or high bedload systems tend toward less sinuous, island-braided systems maintained by instream structure (esp. log jams)*
- *Side channels tend to occupy shorter flow path than the primary channel.*

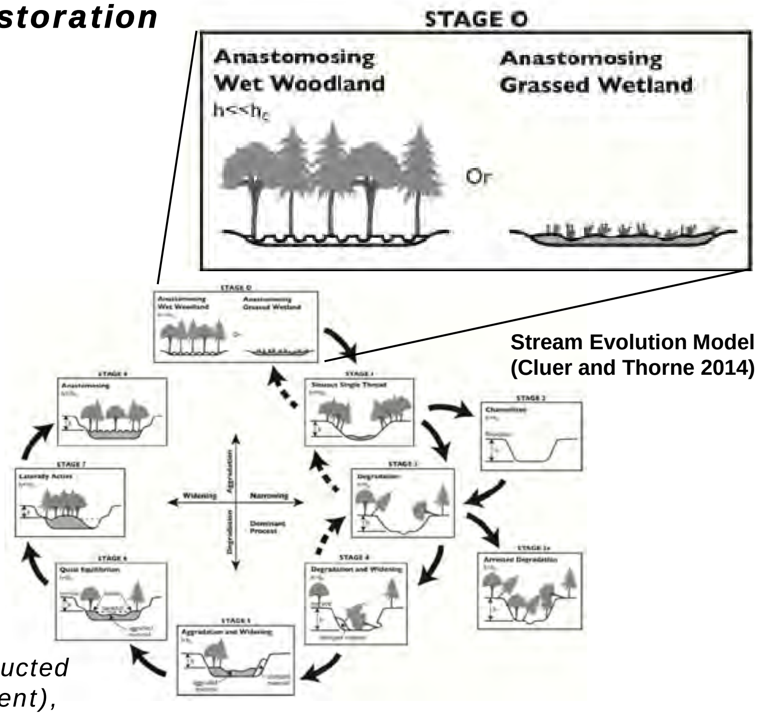
Design Considerations
- *Channel inlet/outlet located in pools or glides*
- *Inlet roughly 2/3 along the outside of a bend may limit bedload entrainment*
- *Use natural scour/deposition to form side channels with limited earthwork where geomorphic processes and risk allow*

Lemhi River, ID; Over-widened, single-thread channel; average channel width over 100 ft.

Above: *Lemhi River, 1.5 years after construction of multi-threaded channel network using various bank and instream structure to split flow into many, short, narrow side channels.*
Left: *Side channel complex on the Lemhi River, ID*

Treatment: Floodplain Reconnection – Fill or Raise the Channel
Type: Reconnection and Restoration





Stream Evolution Model (Cluer and Thorne 2014)

Application
- *Raise water surface with channel fill, constructed riffles, increased sinuosity (i.e., lower gradient), narrower channel, increased roughness and/or other means to inundate the floodplain more frequently*

Biological Considerations
- *Provides high-flow refuge for juvenile salmonids*

Geomorphic Considerations
- *Dissipates flood energy*
- *Deposits fine sediment in the floodplain*
- *Improves hydrologic connectivity for riparian areas and wetlands*

Design Considerations
- *Promote over-bank flow in densely vegetated areas*
- *Significant roughness and structure is often required in frequently inundated floodplain areas to prevent avulsion and undesired channel response resulting in low sinuosity and/or channel incision*
- *Complete channel fill is commonly referred to as "stage-zero restoration" after Cluer and Thorn (2013) stream evolution model*

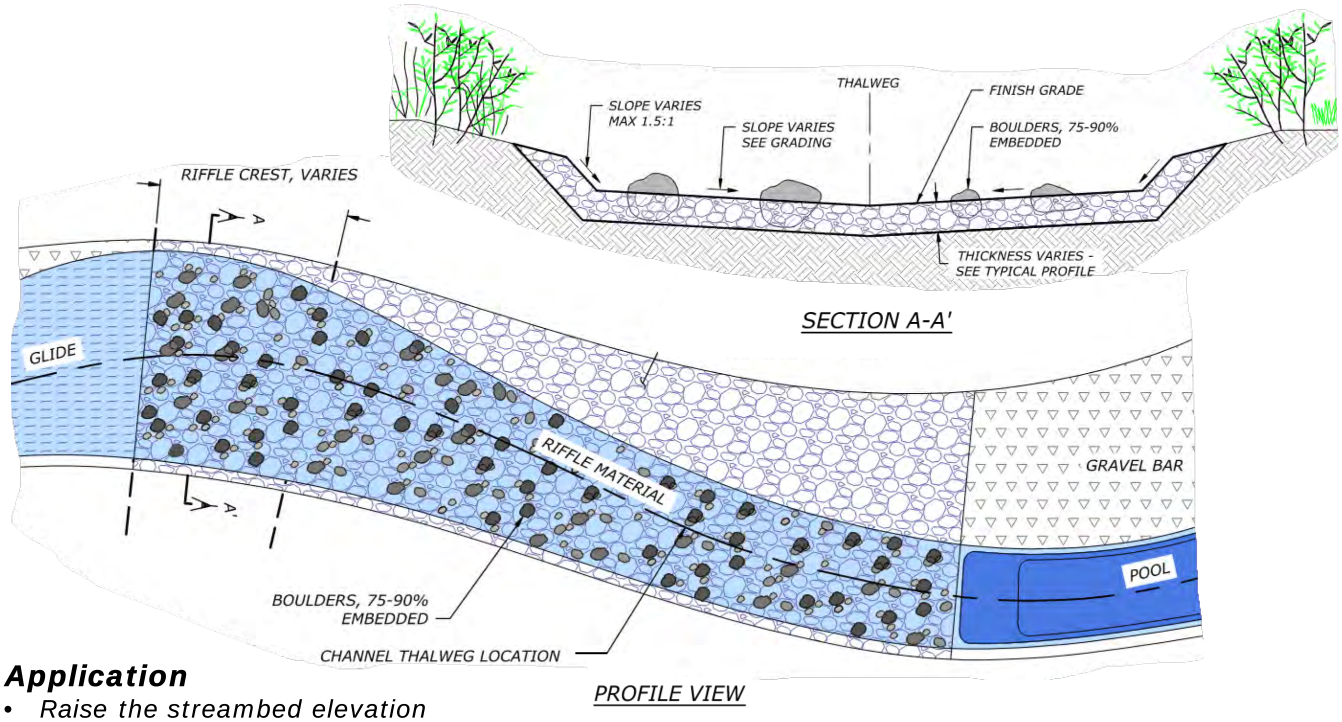
Lost Creek, OR, before channel fill

5-yr flood model of Lemhi River and Big Springs Creek, ID

Narrower channel, increased sinuosity, and riffles increased floodplain connection in restored channel

Channel fill on Jackson Creek, OR

Treatment: Grade Control Features
Type: Reconnection and Restoration



Application
- Raise the streambed elevation
- Abate channel incision and/or knickpoint

Biological Considerations
- Adult and juvenile fish often feed in riffles due to macroinvertebrate abundance
- Proximity to cover and pool refuge is an important consideration

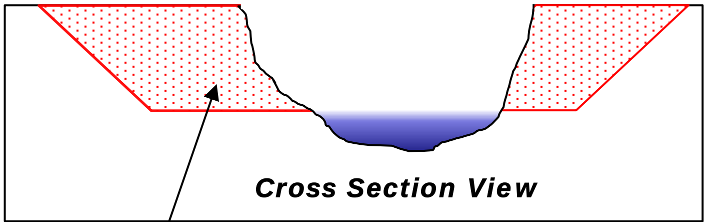
Geomorphic Considerations
- Can be used to backwater floodplain and/or side channel areas, activating off-channel habitat
- Flow passes over the riffle crest perpendicular to the crest angle; a high-angle riffle crest can be used to direct flow toward the bank
- Temporary storage of transient bedload

Design Considerations
- Must understand channel migration trends to ensure channel does not migrate off the riffle before the system has stabilized
- Material sizes should be comparable to the native substrate and should be keyed into the bank to prevent short-term flanking
- Constructed riffles are elongated features that can range in slope from 0.1–5%, while drop structures (step pools) are singular features that control vertical grade and can be used to develop pool habitat
- Roughened chutes are a combination of step pools incorporated into longer reinforced riffles and are typically placed in channels with steeper slopes (>5%)
- Selection of material is important to stability
- A concave cross section may be necessary to focus low-flow water sufficiently to provide adequate depth for seasonal fish passage
- Downstream pool formation and upstream backwater conditions often occur

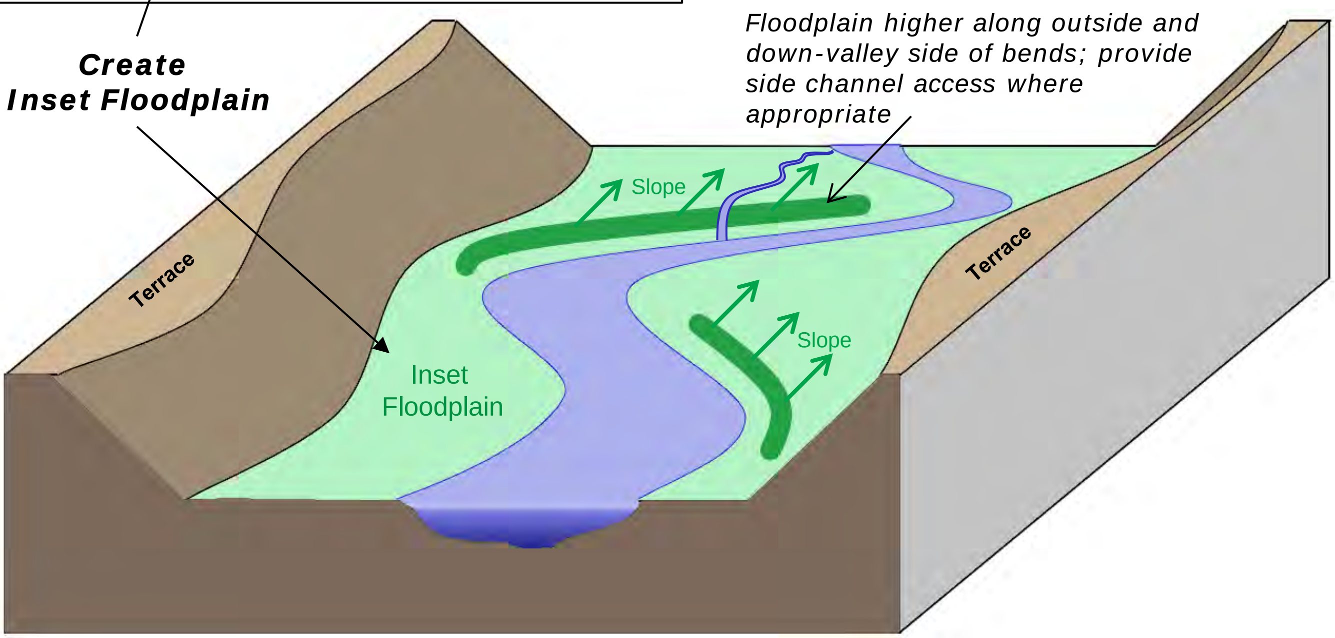
Constructed riffle during construction with wood structure installed on left bank (right side of photo); Lemhi River, ID

Constructed riffle immediately after construction; Lemhi River, ID

Treatment: Floodplain Reconnection – Create Inset Floodplain
Type: Reconnection and Restoration



Note - Floodplain connection should be achieved by removing levees and/or by raising the channel where possible. Excavating an inset floodplain should only be used as a last resort.



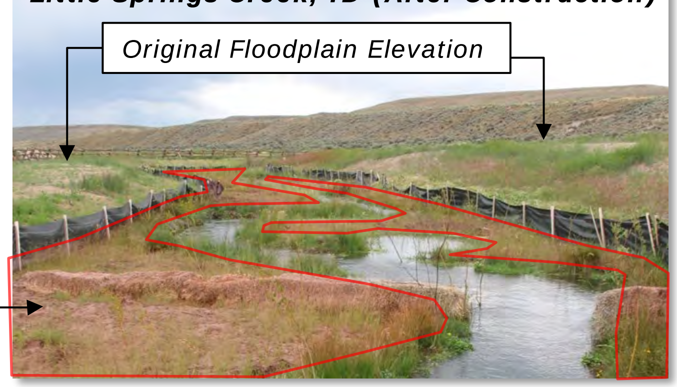
Application
- Selective earthwork to create a new, lower, inset floodplain to enable more frequent inundation

Biological Considerations
- Provides high-flow refuge for juvenile salmonids
- Creates a floodplain surface near the groundwater table to enable riparian vegetation

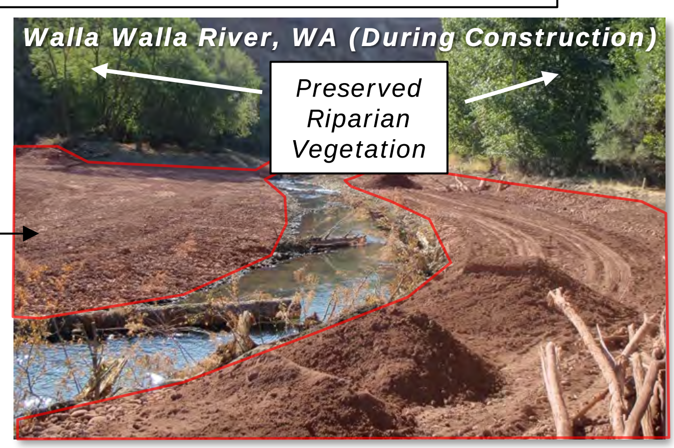
Geomorphic Considerations
- Dissipates flood energy
- Deposits fine sediment in the floodplain
- Improves hydrologic connectivity for riparian areas
- Reduces flooding elevations by increasing capacity within the inset floodplain
- Does not address the cause of incision
- Results in “Arrested Degradation” stage of channel evolution (Stage 3s – Cluer and Thorne 2014)

Design Considerations
- Consider constructing new banks and floodplain surfaces slightly higher on the outside and down-valley side of bends and islands, sloping slightly down-valley to limit avulsion risk while still providing large areas of backwater inundation
- Floodplain width (i.e., meander belt width) should be at least as wide as the maximum calculated meander amplitude
- Can often require disposal site for excavated floodplain material

Little Springs Creek, ID (After Construction)

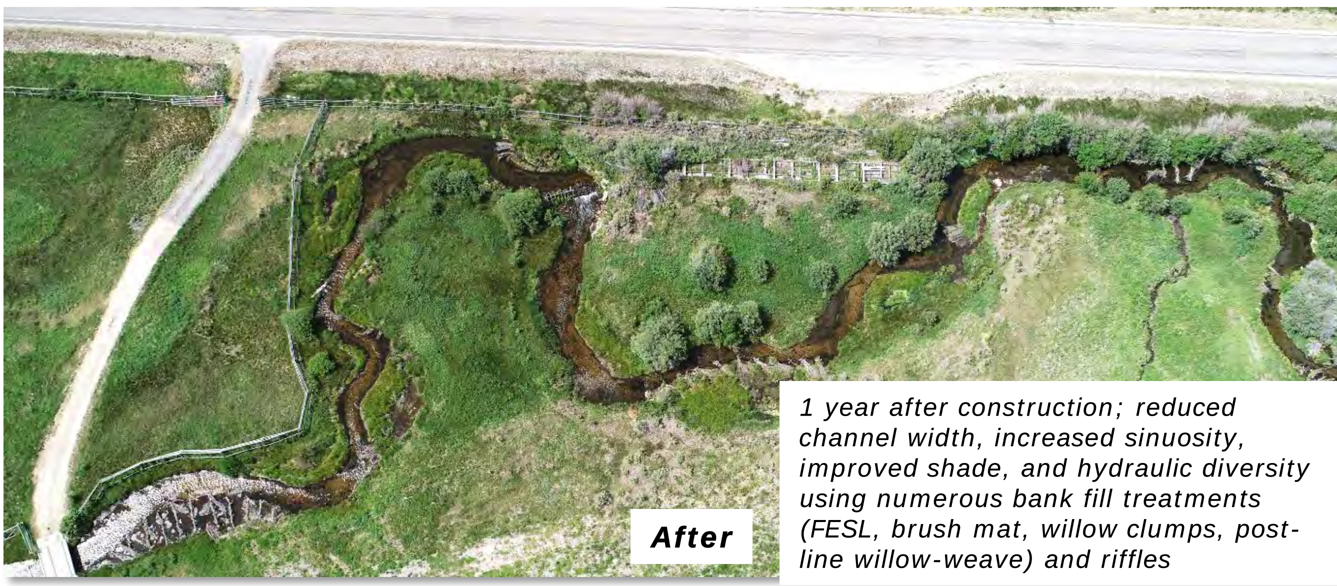


Limits of inset floodplain excavation (in red)



Treatment: Reduce Channel Width
Type: Restoration

Over-widened channel with plane-bed and poor habitat diversity; Big Springs Creek, ID



1 year after construction; reduced channel width, increased sinuosity, improved shade, and hydraulic diversity using numerous bank fill treatments (FESL, brush mat, willow clumps, post-line willow-weave) and riffles

Application

- Reduce channel width where over-widened to meet geomorphic targets
- Excavate new channel(s) and/or fill portions of the existing channel

Biological Considerations

- Install habitat structures and cover; plant riparian vegetation to maintain habitat diversity and shade

Geomorphic Considerations

- Relocate the channel against existing, mature vegetation where possible to provide immediate structure, cover, and shade

Design Considerations

- Add sinuosity, side channels, and/or floodplain connection to compensate for increased velocity associated with narrower channel width to achieve desired instream conditions across a variety of flows
- Detailed hydraulic modeling required; compare existing vs. proposed hydraulic diversity using histogram outputs of velocity and depth area distributions to confirm increased hydraulic variability and habitat suitability
- Provide variability in width by providing areas of contraction and expansion
- Use a variety of bank treatments; provide topographic variability in floodplain areas

Treatment: Channel Realignment
Type: Restoration

Channel realignment and side channel creation during construction, Catherine Creek, OR

Application

- *Create a new, more geomorphically appropriate channel network with improved habitat*
- *Used to relocate a new channel away from negative response areas and/or toward positive response areas*

Biological Considerations

- *Redirect channel to areas with improved floodplain connection, mature riparian vegetation, and/or greater habitat potential*
- *Optimize channel form and structure to meet habitat objectives, including habitat unit frequency and diversity*

Geomorphic Considerations

- *Create channel (cut and fill earthwork) where geomorphic processes will not naturally restore conditions within a reasonable period of time*
- *Integrate process-based restoration where feasible by identifying dominant processes and enabling a response around them (e.g., where deposition is a likely response, add strategic structure to capture sediment forming new bars, islands, and floodplain areas; where erosion is a likely response, excavate a narrow "pilot channel" with strategic structure enabling the river to cut new channels where directed).*

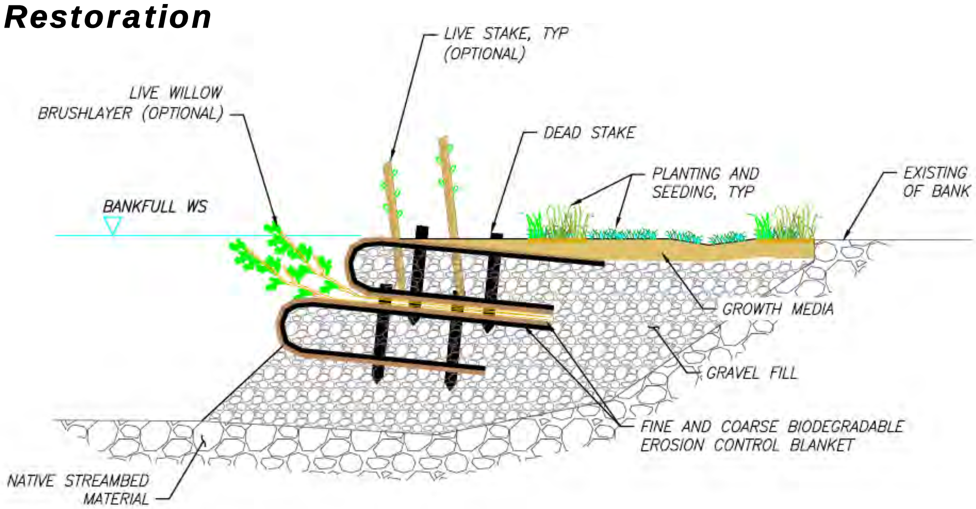
Design Considerations

- *Determine target planform, side-channel character, and channel geometry conceptually based on reach geomorphic and biological targets/objectives*
- *Multiple iterations of design and 2-dimensional hydraulic modeling recommended to evaluate likely response and make appropriate adjustments*
- *Use bank treatments and instream structure appropriately based on potential stream energy and habitat needs*
- *Incorporate cross sectional and plan form geometry variability, especially compound radius bends*
- *May increase floodwater and groundwater elevations*

Channel realignment and floodplain creation immediately after construction; East Fork South Fork Salmon River, ID

New channels with bank treatments and increased floodplain activation 6 months after construction at spring runoff; Lemhi River, ID

Treatment: Bank Fill – Fabric Encapsulated Soil Lift (FESL)
Type: Restoration



Application
- *Temporarily stabilize banks (typically outside bends) until riparian vegetation is established*
- *Used to retain soil to fill over-widened channel*

Biological Considerations
- *Integrate brush, willow clumps, and/or large woody material (LWM) to increase cover and interstitial spaces for juvenile salmonids*
- *Integrate live vegetation to improve riparian conditions and enhance root mat development*

Geomorphic Considerations
- *Can create stable, near vertical banks*

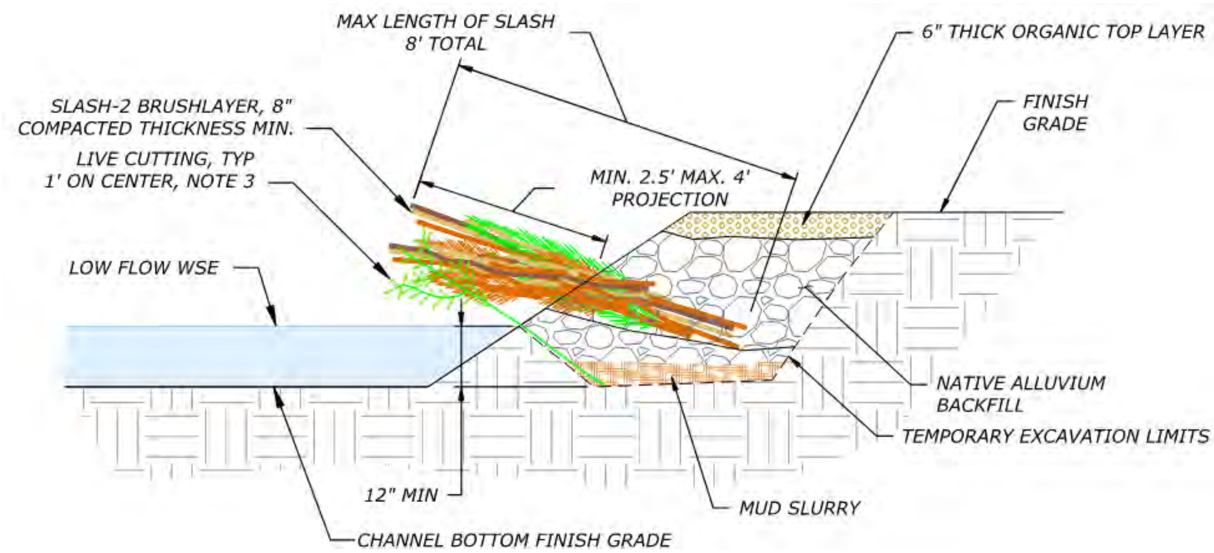
Design Considerations
- *Select appropriate geotextile fabric to withstand anticipated hydraulic forces*
- *Useful with otherwise unstable fill material (silt/sand)*
- *Use narrow sheets of fabric to reduce the overall width of the FESL treatment*
- *Install top lift several inches below final design elevation to allow space for sod mat if proposed*
- *Consider planting container plants directly into FESL*
- *Install with an irregular final surface elevation to provide topographic complexity*
- *Do not fill fabric with soil or leave gaps where LWM will be placed to provide space for the LWM*

Over-widened channel; Big Springs Creek, ID

Big Springs Creek 1 year after construction; Width-to-depth ratio reduced by over 50% using FESL on both banks

Big Springs Creek during construction; Fill placed behind the FESL with potted plants; Sod mat and potted plants within FESL not yet installed

Treatment: Bank Fill – Brush Layer
Type: Restoration



Application
- *Temporarily stabilize banks (typically outside bends) until riparian vegetation is established*
- *Used to dissipate energy in high-energy areas*
- *Can be used with or without other treatments to retain soil to fill over-widened channels*

Biological Considerations
- *Provides increased cover and interstitial spaces for juvenile salmonids*
- *Integrate live vegetation to improve riparian establishment and enhance root mat development*

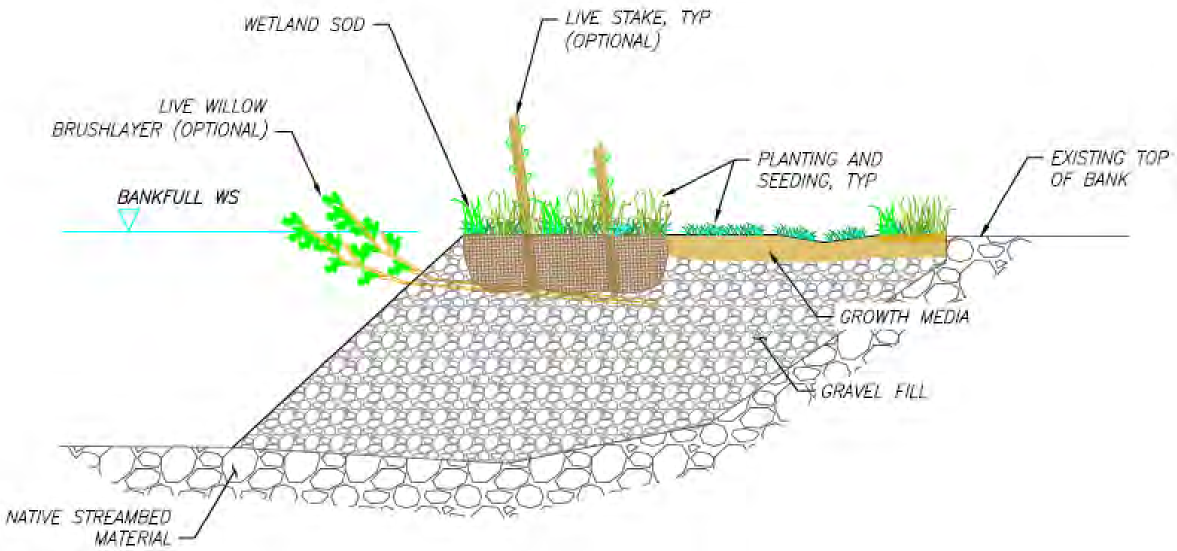
Geomorphic Considerations
- *Creates significant bank roughness that can accumulate fine sediment in low-energy areas*

Design Considerations
- *Specify min/max protrusion to match roughness conditions from hydraulic model*

Willow brush layer during construction (Above) and immediately after construction (Below); Lemhi River, ID

Slash brush layer 1 year after construction; Catherine Creek, OR

Treatment: Bank Fill – Wetland Sod
Type: Restoration



Application
- *Used with or without other treatments to retain soil to fill over-widened channels*
- *Used for short- and long-term bank stabilization*

Biological Considerations
- *Increases rates of vegetative establishment*
- *Integrate woody vegetation (potted plants and/or live stakes) to increase riparian diversity, structure, cover, and shade*
- *Provides high flow cover and refuge for juvenile fish*

Geomorphic Considerations
- *Creates bank roughness and promotes the formation of a root mat providing long-term bank structure*

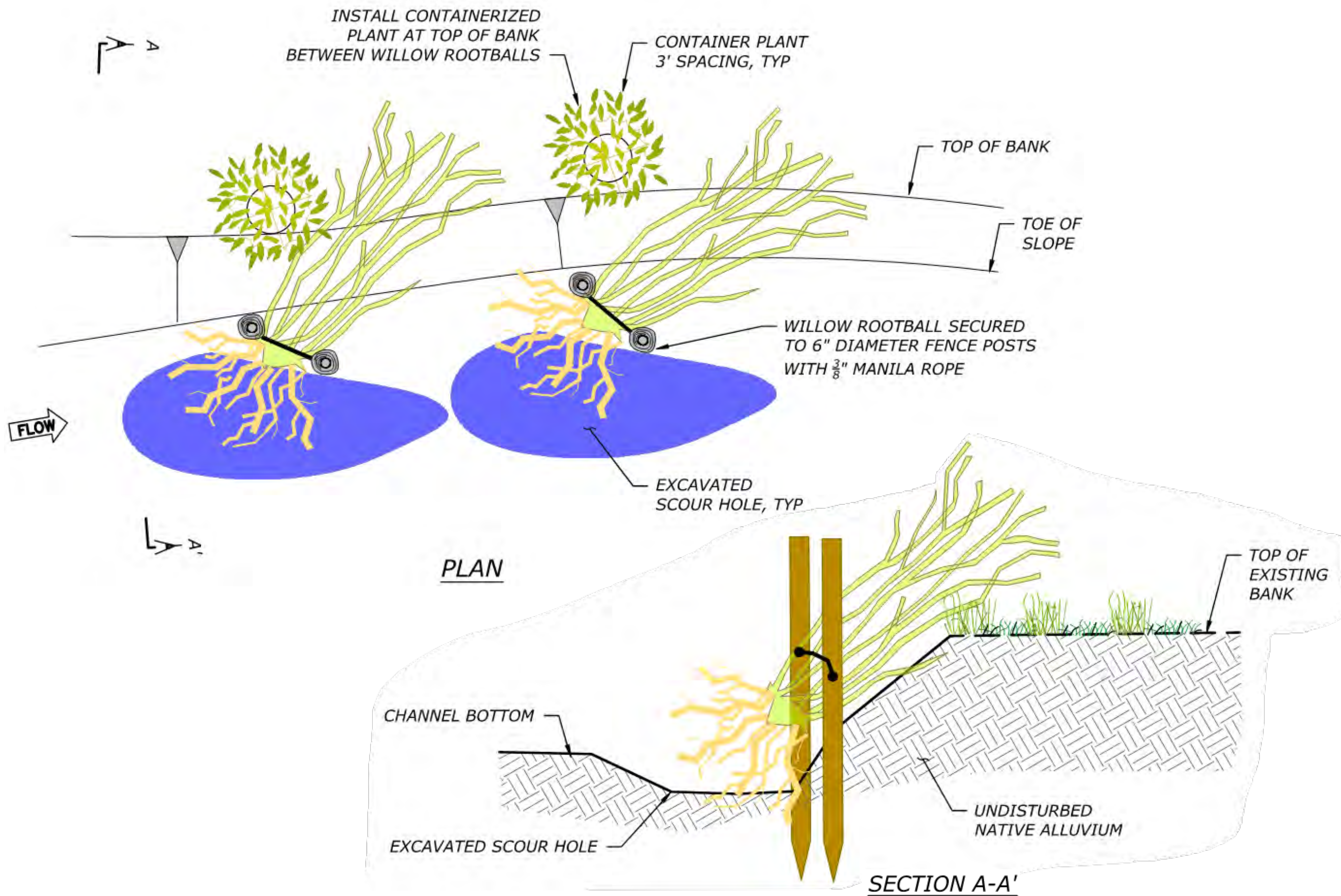
Design Considerations
- *Can use nursery stock or harvest sod mats on-site*
- *Specify thickness and ensure final grade elevations are sufficiently low to accommodate the sod mats*
- *Prioritize directly adjacent the bank, but consider strips of sod with woody plantings in between*

Strips of wetland sod harvested on-site used to retain unstable sandy bank fill immediately after construction; Big Springs Creek, ID

Bank fill stabilized with on-site harvested wetland sod immediately after construction; Big Springs Creek, ID

Strips of nursery-grown wetland sod placed over FESL bank treatment with potted willows between strips 1 year after construction; Big Springs Creek, ID

Treatment: Bank Fill – Willow Clumps
Type: Restoration



Application
- *Used to reduce effective channel width and create instream structure*
- *Used with or without other treatments to retain and stabilize soil to fill over-widened channels*
- *Used for short- and long-term bank stabilization*

Biological Considerations
- *Provides cover, structure, and interstitial spaces for juvenile salmonids*
- *Creates instream velocity and habitat complexity across a range of flows*

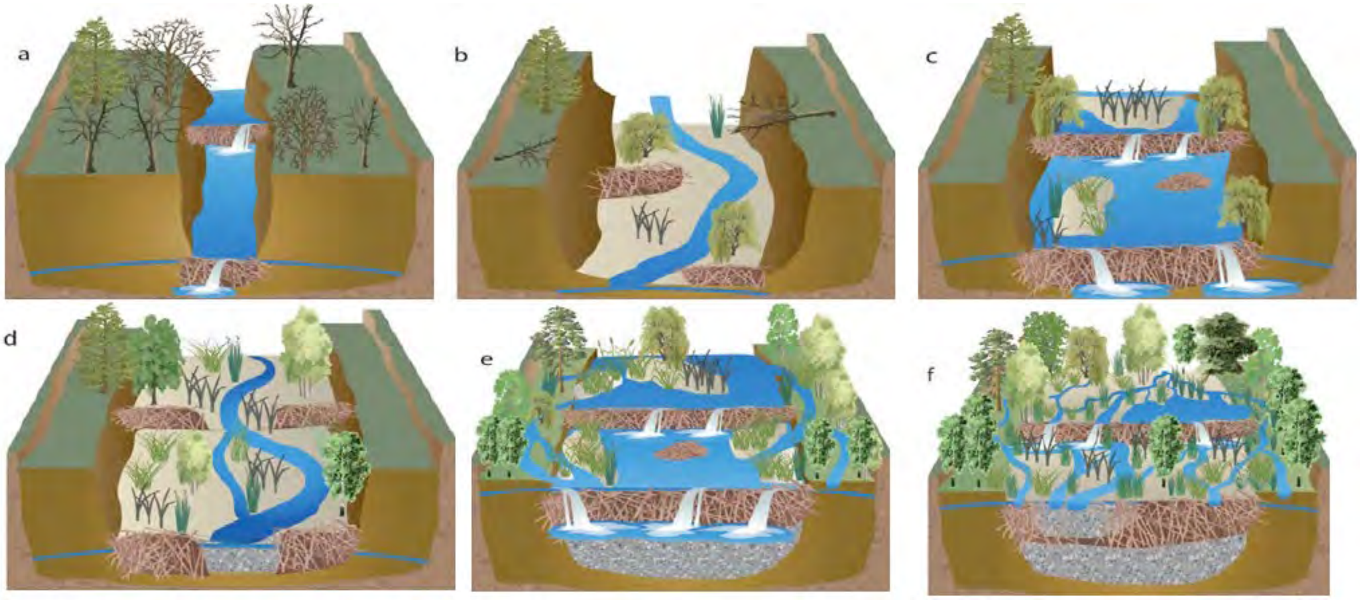
Geomorphic Considerations
- *Creates bank roughness and structure until riparian vegetation can be established*
- *Can be used to obstruct flow and provide sharp hydraulic gradients sorting bedload and directing flow*

Design Considerations
- *Place rootwad into channel for greater rigidity (i.e., outside of bend) and consider placing willow branches into channel where hydraulic forces are less severe (i.e., inside of bend)*
- *Consider use of live willow clumps to increase vegetative establishment*

Willow clumps installed at head of island several years after construction; Lemhi River, ID.

Willow clumps placed along the outside of a newly constructed meander bend to provide bank stability, instream structure, and cover immediately after construction; Big Springs Creek, ID.

Treatment: Beaver Dam Analogues (BDAs)
Type: Reconnection and Restoration



Conceptual model of how beaver dams help a stream to progress from an incised trench to an aggraded channel. Beaver attempting to build dams within narrow incision trenches resulting in blowouts (a), which help to widen the incised channel allowing an inset floodplain to form, as illustrated in (b). The widened channel more readily dissipates energy, enabling beaver to build wider, more stable dams (c). Beaver ponds fill with sediment, facilitating the growth of riparian vegetation (d). The process repeats itself until the beaver dams raise the water table sufficiently to reconnect the stream to its former floodplain (e). Eventually the stream ecosystem develops a high level of complexity (f). Figure from Pollock et al. 2014.

Application
- *Intended to mimic beaver dams obstructing flow, capturing sediment, raising the water table, inundating the floodplain, attenuating high flows, and creating habitat diversity*

Biological Considerations
- *Backwater pools and interstitial spaces within the beaver dam provide juvenile salmonid rearing habitat*
- *May create partial passage barriers to certain species/life stages depending on conditions*

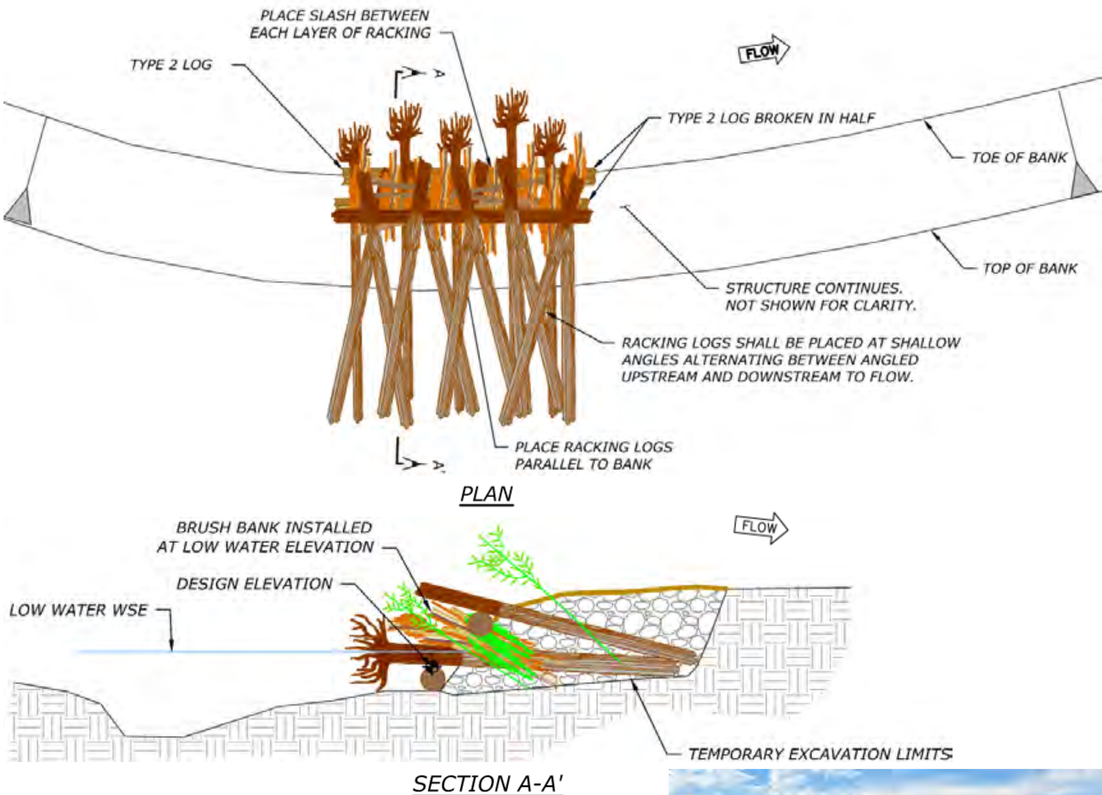
Geomorphic Considerations
- *Channel-spanning structures capture sediment and raise the water elevation*
- *Partial spanning structures capture sediment forming point bars enhancing sinuosity (see post-line willow-weave treatment)*

Design Considerations
- *Construction of in-stream structures requires minimal machinery and disturbance*
- *More robust, floodplain-spanning structures can be used to distribute flow broadly*
- *Can be used to initiate complex stage-0 habitat conditions (Cluer and Thorne 2014)*
- *Typically requires annual monitoring, maintenance, and additional structures to achieve goals, especially if there are no live beavers supporting the structures over time*
- *Generally, only suitable in smaller streams and/or side channels of large rivers*

BDA series capturing sediment and raising the water surface immediately after construction; Hawley Creek, ID

Floodplain spanning structure designed to emulate a relic beaver dam; Lemhi River, ID

Treatment: Bank Roughening Structure
Type: Reconnection and Restoration



Application
- *Used to create in-channel habitat complexity with velocity and depth variability*
- *Can be used for habitat and/or bank stabilization*

Biological Considerations
- *Creates contraction scour pools and provides cover with many interstitial spaces for rearing salmonids*

Geomorphic Considerations
- *Can reduce local hydraulic energy and/or obstruct stream flow*
- *Creates instream roughness*

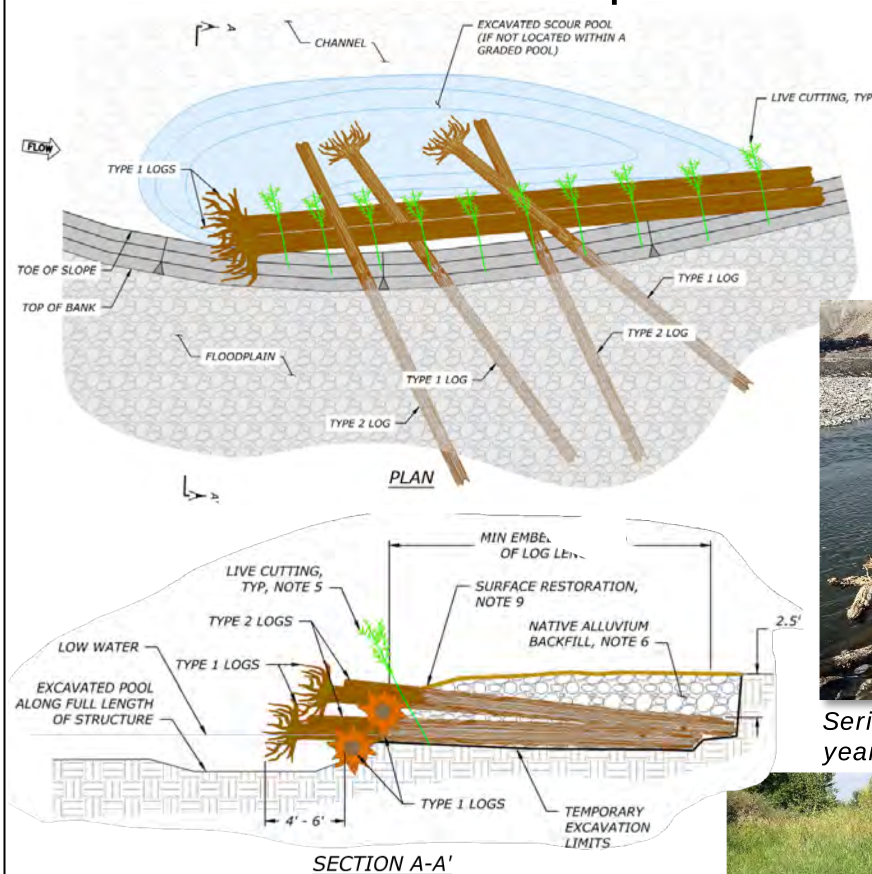
Design Considerations
- *For bank stabilization – overlap wood material structure and/or place in series along an eroding bank to buffer the bank soils from erosive stream forces; obstruct flow with the wood material creating the appropriate overall width-to-depth ratio; create an inset floodplain (if necessary) along the bank to establish riparian vegetation for long-term stability and shade*
- *For in-channel habitat – place an individual structure or structures on opposite banks to interact with and obstruct flow creating areas of contraction (scour) and expansion (sediment deposition and gravel sorting) with cover*
- *Incorporate slash and retain appropriate interstitial space for habitat cover*
- *Consider incorporating an excavated scour pool to expedite habitat response*

Bank roughening structure immediately after construction; Lemhi River, ID

Bank roughening structure on newly created side channel 1 year after construction; Lemhi River, ID

Treatment: Large Wood Material (LWM) Habitat Structure
Type: Reconnection and Restoration

Example Structure



Series of large wood habitat structures 1 year after construction; Lemhi River, ID

Large wood habitat structure 1 year after construction; Lemhi River, ID

Series of large wood habitat structures 1 year after construction; Lemhi River, ID

Application

- *Used to create in-channel complexity and velocity and depth variability*
- *Can be used in series for bank stabilization to buffer bank soils from erosive stream forces*
- *Can be used individually or on opposite banks to create channel constrictions*
- *Can be used to obstruct and/or block flows*

Biological Considerations

- *Create habitat diversity including scour pools with instream cover suitable for adult and juvenile salmonids*

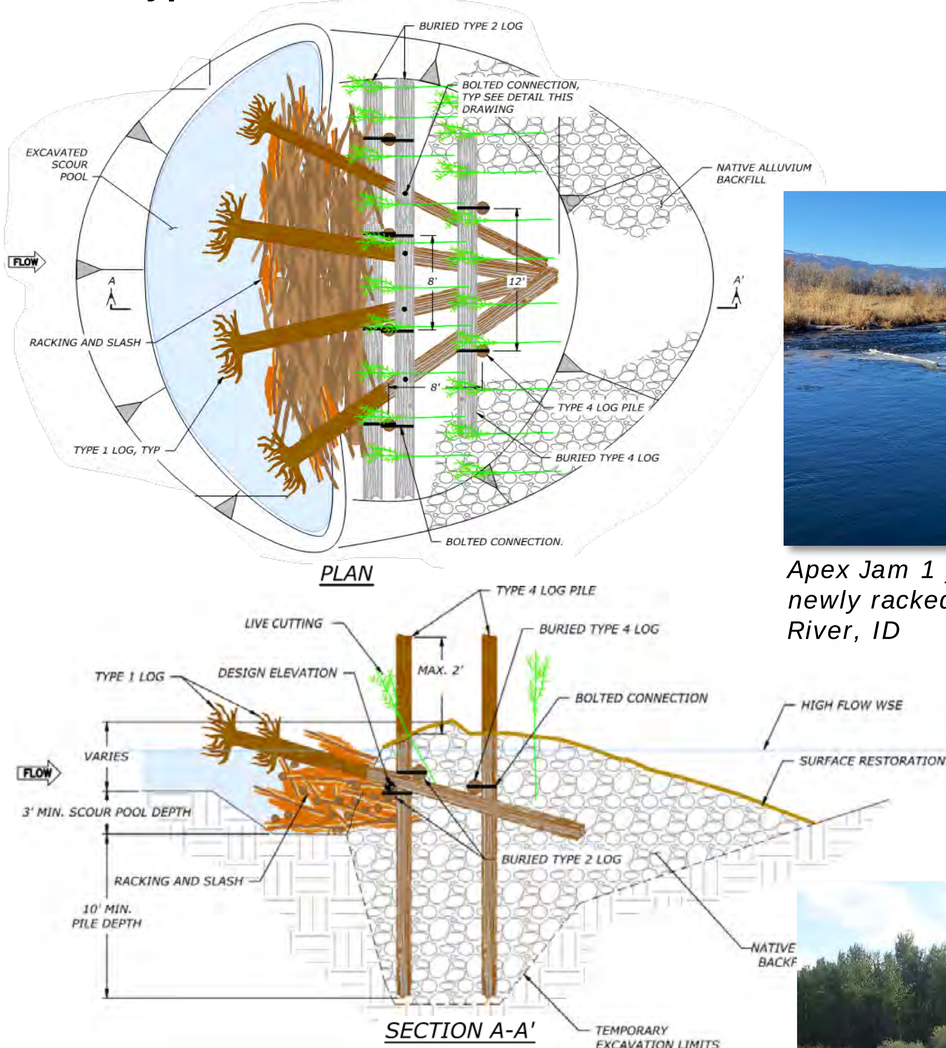
Geomorphic Considerations

- *Can be used to obstruct flow to create backwater areas, sort gravel, and improve floodplain connection*

Design Considerations

- *Hydraulic modeling should be used to calculate the appropriate size and frequency of structure(s) to evaluate likely hydraulic response and change to habitat*
- *Incorporate small woody material and slash between key LWM members to provide interstitial cover*
- *Greater protrusion into stream can improve habitat and hydraulic response*

Treatment: Apex Log Jam
Type: Reconnection and Restoration



Apex Jam 1 year after construction with newly racked wood accumulation; Lemhi River, ID

Application
- *Used to split or obstruct flow and create in-channel complexity with velocity and depth variability*

Biological Considerations
- *Split flow into multiple channels to double margin habitat*
- *Incorporate excavated scour pool and cover*
- *Creates diverse habitat for adult and juvenile salmonids*

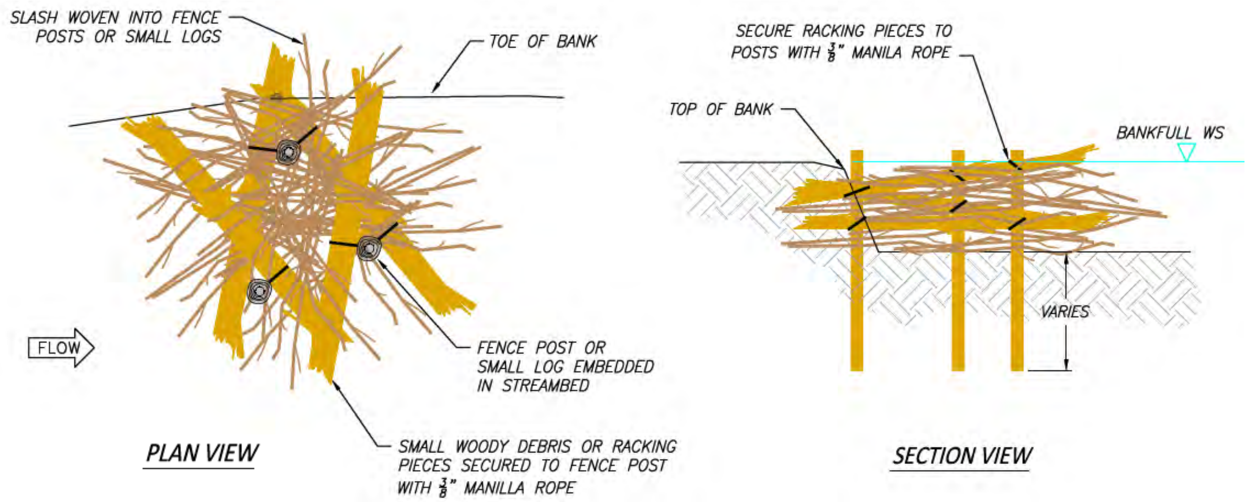
Geomorphic Considerations
- *Evaluate bed and banks to determine if a mid-channel obstruction is likely to erode the banks or scour the bed*
- *Use obstruction to activate new or relic side channels*
- *Evaluate reach-scale sediment transport and deposition to inform bar formation expectations*

Design Considerations
- *Consider use of piles where depth of alluvium is sufficient to enable adequate embedment*
- *Use ballast where piles are not feasible*
- *Design key structures assuming additional racking material will be retained over time*
- *Provide adequate log protrusion into channel for cover*
- *Willow clumps may be substituted for logs in certain environments where stream size and power allow*

Apex Jam 1 year after construction; Lemhi River, ID

Apex Jam 1 year after construction; Lemhi River, ID

Treatment: Small Wood Material Structure
Type: Reconnection and Restoration



Application
- *Used to create in-channel complexity, velocity, and depth variability*
- *Can be used to create channel constrictions promoting scour and gravel sorting*
- *Create cover for improved habitat*

Biological Considerations
- *Promotes velocity gradients and habitat diversity suitable for juvenile and adult salmonids*
- *Provides instream cover and interstitial spaces for juvenile salmonids*

Geomorphic Considerations
- *Increasing frequency and size of structures has a proportional affect on channel roughness*
- *Encourages sorting of bedload sediment*

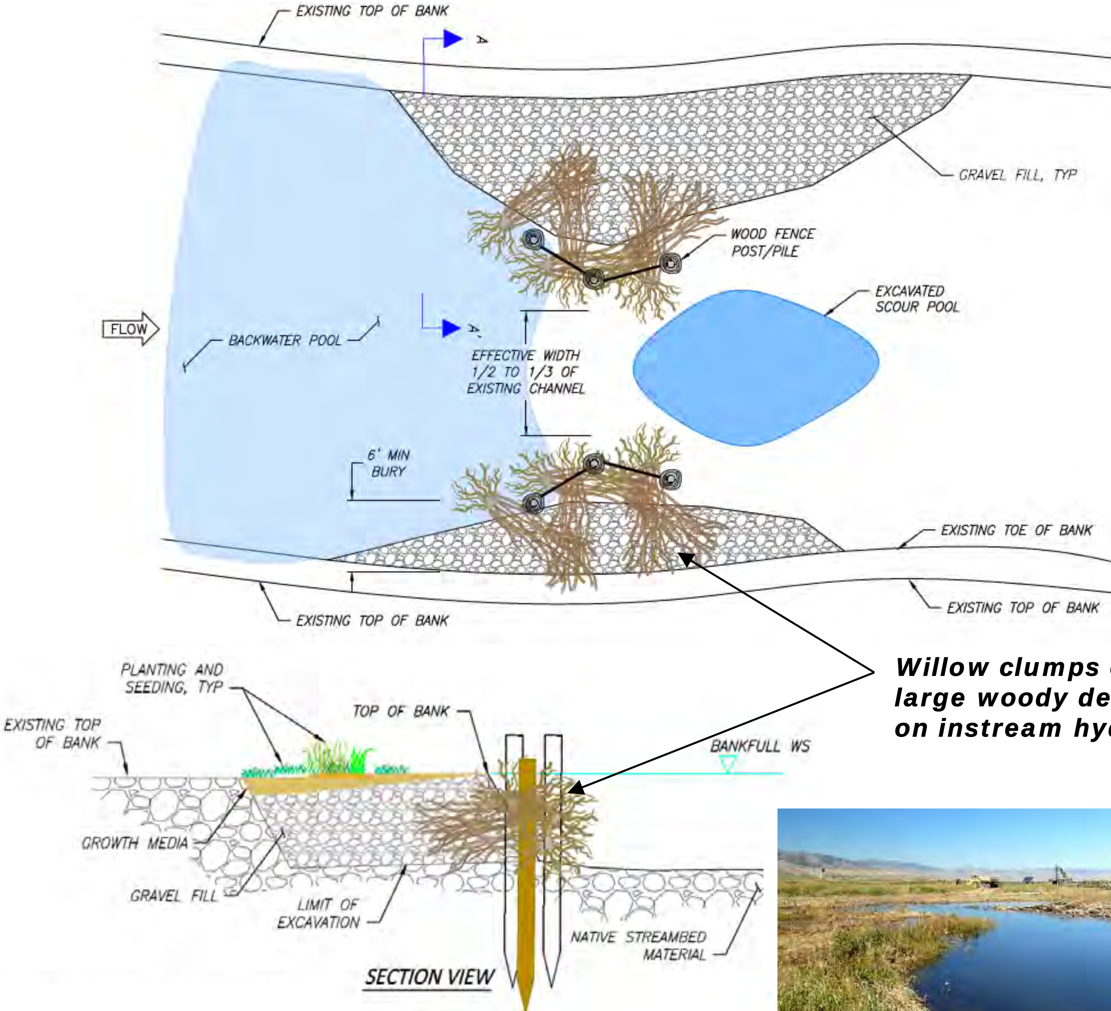
Design Considerations
- *Incorporate LWD for increased stability and habitat diversity*
- *Consider excavating a scour pool to increase rate of channel response*
- *Anticipate channel response to determine size and frequency of structures*

Small wood material structures 1 year after construction; Big Springs Creek, ID

Small and large wood material bank structures immediately after construction; Big Springs Creek, ID

Small wood material bank structures with excavated scour pool immediately after construction; Big Springs Creek, ID

Treatment: Channel Constriction
Type: Reconnection, Restoration



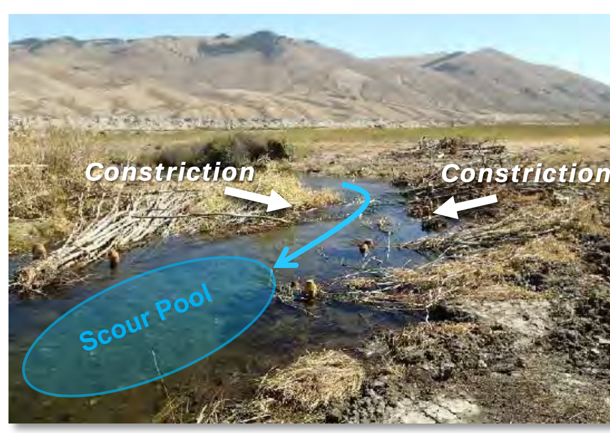
Application
- Create channel constriction to force upstream backwater and/or downstream scour pool
- Reduce effective channel width locally

Biological Considerations
- Increases habitat unit frequency near suitable areas for spawning and rearing salmonids
- Can create backwater and scour pools
- Provides in-channel complexity, velocity and depth variability
- Incorporating LWM or similar structure may increase structural diversity and habitat value

Geomorphic Considerations
- Hydraulic contraction and expansion creates velocity gradients that can sort sediment and create geomorphic complexity
- The greater the contraction the greater the hydraulic effect

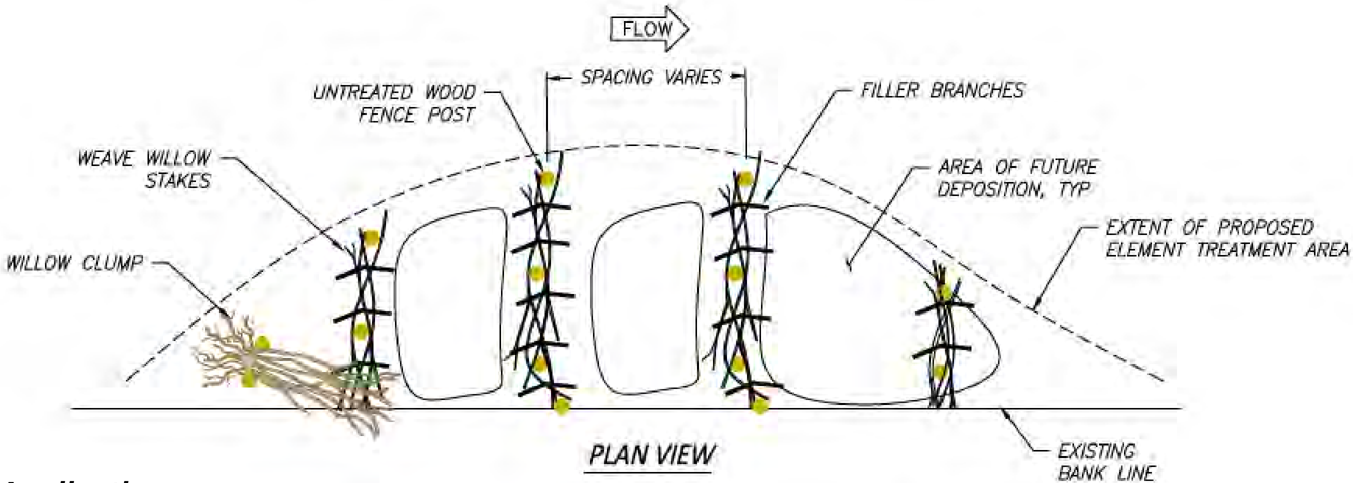
Design Considerations
- Allow an appropriate width within the conservation easement (minimum of one channel width from existing banks).

Backwater pool above flow constriction; Big Springs Creek, ID



Flow acceleration and scour pool downstream of flow constriction; Big Springs Creek, ID

Treatment: Post-Line Willow-Weave
Type: Reconnection and Restoration



Application
- Used to reduce effective channel width and capture sediment forming point bars
- Primarily used to form or enhance the inside of bends
- Can be used with or without other treatments to capture sediment to fill over-widened channel areas

Biological Considerations
- Provides short-term cover and low-velocity refuge for juvenile salmonids
- Creates long-term vegetated point bar increasing habitat diversity, cover, and shade

Geomorphic Considerations
- Narrows effective channel width forming areas of contraction and expansion creating hydraulic diversity
- Captures fine sediment forming point bars, increasing sinuosity, and reducing overall width-to-depth ratio
- To be used in streams with moderate to high sediment supply

Design Considerations
- Consider adding willow clumps, LWM, or other structure to the upstream and/or outer ends of the willow-weave to dissipate energy
- Using live willows in the weave may increase the rate of point bar vegetation establishment

Over-widened channel before construction; Big Springs Creek, ID

6 months after construction; fine sediment deposition observed between willow weaves; effective channel width reduced by approximately 50%

Treatment: Riparian Planting
Type: Reconnection and Restoration

Riparian vegetation 5 years after restoration (left photo) and 14 years after restoration (right photo); Meadow Creek, ID

Application
- *Create appropriate, long-term streambank conditions, bank stability, and shade through root structure and overhead canopy*
- *Increase rate of colonization of native species and reduce non-native species*

Biological Considerations
- *Provides instream structure and cover for multiple life stages of salmonids*
- *Channel erosion into dense riparian vegetation provides undercut banks, instream structure, and cover*

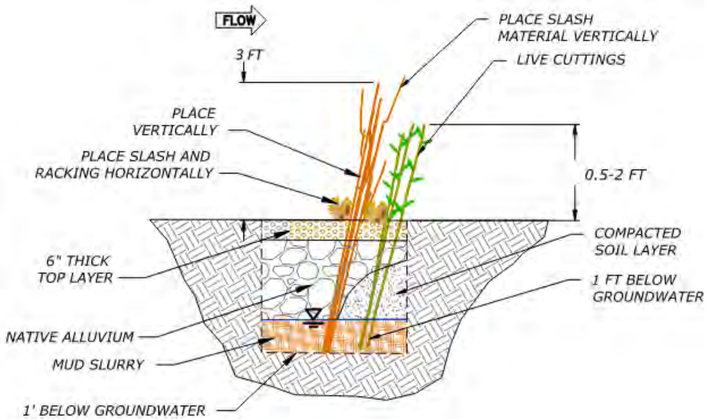
Geomorphic Considerations
- *Promotes woody debris recruitment*
- *Enables appropriate rates of channel migration*
- *Dense riparian vegetation provides floodplain structure promoting side-channel formation and maintenance versus channel avulsion during periods of floodplain activation*

Design Considerations
- *Requires many years to achieve desired outcomes*
- *May require temporary short-term bank stabilization to facilitate vegetative establishment*
- *Can be used to promote long-term bank stabilization*
- *Surface and groundwater elevations must be appropriately near the bank and floodplain surface to promote riparian establishment*
- *Species selection, spacing, and density depend on site conditions, riparian management strategy, and land use; temporary irrigation may improve establishment*

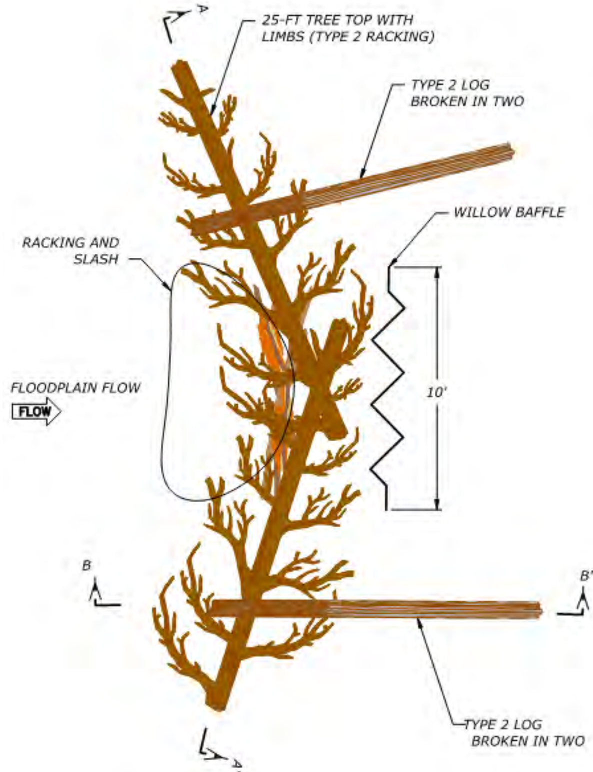
During construction and prior to riparian revegetation; Big Springs Creek, ID

1 year after riparian revegetation; Big Springs Creek, ID

Treatment: Floodplain Roughness
Type: Restoration



Willow Baffle Floodplain Structure



Large Wood Floodplain Structure

Application
- Used to create roughness on the floodplain to provide velocity and depth variability, trap sediment, topographic complexity
- Can be used to create backwatering
- Create cover for improved habitat

Biological Considerations
- Promotes cover, interstitial space, low velocity gradients, and habitat diversity for juvenile salmonids
- Can be designed to impound water on the floodplain prolonging floodplain inundation

Geomorphic Considerations
- Increasing frequency and size of structures has a proportional affect on floodplain roughness
- Encourages deposition of sediment

Design Considerations
- Specify at locations where bank migration, channel avulsion, and/or floodplain scour might occur

Large wood floodplain roughness structure immediately after construction; Lemhi River, ID

Willow Baffle structure 1 year after construction; Lemhi River, ID

Willow Baffle structure immediately after construction; Lemhi River, ID

3.0 REFERENCES

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