Muck Creek Salmon and Steelhead Habitat Assessment Report

September, 2022

ACKNOWLEDGEMENTS

This document was made possible with funding and support from numerous organizations, technical experts, and contributors.
Many thanks to those who provided their time and dedication to this project.

Washington Recreation and Conservation Office (RCO)

Washington Department of Ecology

Nisqually Indian Tribe, Natural Resources Department

Nisqually River Foundation

Nisqually Land Trust

Joint Base Lewis McChord, Fish and Wildlife

Anchor QEA

Coho Water Resources

Quantum Spatial Incorporated

Recommended Citation:
South Puget Sound Salmon Enhancement Group. 2022. Muck Creek Salmon and Steelhead Habitat Assessment Report. Olympia, Washington.

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1. Introduction and Project Overview

This Muck Creek Salmon and Steelhead Habitat Assessment Report was prepared by the South Puget Sound Salmon Enhancement Group (SPSSEG) in support of a Muck Creek streamflow and watershed strategy initiative (Strategy), a multi-partner effort focused on developing a comprehensive approach to improving watershed health, streamflow, and fish and wildlife habitat in the Muck Creek basin, a major tributary to the Nisqually River in Pierce County, Washington. Basin planning programs over the past two decades have recognized general and specific ecological changes in the Muck Creek basin including reduced salmon abundance, diminished streamflow, increased water withdrawals, and expanded distribution of invasive plant species, spurring attention in 2005 towards the protection of aquatic resources and environmentally sensitive areas (Pierce County 2005a). More recently, watershed salmon recovery groups have set goals to address the impact of low and intermittent streamflow on stream connectivity and salmon habitat, the prevalence of invasive plant species such as reed canary grass, and, a general need for increased quality and quantity of wetland and stream habitats have been called out as desirable actions (NSRT 2014; Nisqually Salmon Recovery Lead Entity 2021).

Muck Creek is a large and important tributary for salmon and steelhead in the Nisqually River watershed, hosting Puget Sound DPS winter steelhead (ESA-listed as threatened), coho salmon (ESA candidate species), Nisqually winter chum salmon, and coastal cutthroat trout. Historically, Muck Creek supported approximately 25% of the total production of winter chum salmon in the Nisqually watershed (May 2002; Williams et al. 1975), however annual returns of chum have significantly declined in Muck Creek as well as in the larger Nisqually watershed. Wild steelhead populations have declined substantially throughout Puget Sound over the past 30 years, and, while steelhead spawning numbers in Muck Creek were not tracked consistently or thoroughly through the early 2000s, they were likely to be lower than the levels counted in the 1970s (Pierce County 2005a). Although Muck Creek’s low gradient character is atypical of many steelhead streams, there were considerable numbers of steelhead in the creek up until the early 1990s (Dorner, personal communication, 2003). Declines in salmon and steelhead populations in the basin are hypothesized to be due, in part, to the combined effects of landscape-scale anthropogenic impacts (e.g. land development, ditching and draining within the floodplain, removal of riparian vegetation, the spread of invasive vegetation, water withdrawals, and alterations to the stream’s hydrologic character) coupled with the basin’s natural geologic characteristics which influence seasonal periods of reduced streamflow.

The development and advocacy for this project has been supported by the Nisqually watershed stakeholders including the Nisqually Indian Tribe, Nisqually River Foundation, Nisqually Land Trust, Watershed Resource Inventory Area 11 (WRIA 11) Lead Entity, and allied organizations. Professional consultants providing technical elements for this project include Coho Water Resources (Coho WR), Anchor QEA (Anchor), and Quantum Spatial Incorporated (QSI). Funding for this project largely came from a Recreation and Conservation Office (RCO) salmon grant (#16-1449), with additional contributions from Nisqually River Foundation and the Nisqually Indian Tribe’s Natural Resources Department.

1.1. Project Goals and Objectives

The goals of this assessment were to document current habitat conditions, identify habitat improvement needs and, ultimately, to develop recommendations for prescriptive stream and riparian habitat improvement project opportunities within the Muck Creek basin that could benefit salmon and steelhead populations. The following objectives were completed to support the achievement of the project goals:

- Documentation and analysis of stream habitat conditions for salmon and steelhead using a combination of rapid assessment, field data collection methods and office-based analysis including review of aerial imagery and prior studies
- Synthesis of past basin studies, literature, and oral histories
- Development of a desired conditions ranking matrix and a restoration opportunities matrix
- Mapping of reach-scale habitat restoration project opportunities

Restoration and conservation recommendations have been developed for each of fourteen reaches delineated within the basin. Additional elements being considered for the broader Strategy initiative include opportunities to enhance streamflow and aquatic habitat through hydrologic improvement and conservation projects such as wetland restoration, aquifer recharge, water resource planning, and beneficial uses of storm water, which are currently being developed by other project partners. We envision this habitat assessment piece to become integrated with those other elements as part of the unified Strategy.

2. Basin Characterization and Watershed Conditions

Numerous prior reports and studies have documented the historical, ecological, and physical conditions of the Muck Creek basin, including descriptions of impacts to the basin's natural resources over the last 100+ years since the arrival of Euro-American settlers. Supporting documents specifically contracted for this assessment or allied initiatives provide updated, detailed summaries of physical and ecological conditions within the basin, drawing from the broader body of literature sources and reports. These include:

- *Hydrogeological Influences on Streamflow in Muck Creek Basin Literature Review & Data Integration* (Wilhelm and Pitre 2021). This report was completed by Coho Water Resources in support of this habitat assessment.
- An Annotated Bibliography by Wilhelm (2022) summarizes the body of literature compiled to inform the development of the allied streamflow and watershed strategy initiative (Appendix A).
- *Muck Creek Literature Review and Strategy Framework* (Martz et al. 2022). This report was completed by Anchor QEA in support of the allied streamflow and watershed strategy initiative.

Because there is such a well-developed, existing body of background literature for the Muck Creek basin we provide only a brief characterization of the basin's historic conditions herein to provide context for the habitat assessment covered in this report, utilizing excerpts from Wilhelm and Pitre (2021), Martz et al. (2022), and other key background literature sources for reference.

More detailed descriptions of the basin's historical, ecological, and land use conditions can be found within the numerous prior studies and reports, many of which are listed in the Annotated Bibliography in Appendix A (Wilhelm 2022).

2.1. Basin Characterization

The Muck Creek basin is the largest tributary system by area in the Nisqually River watershed, with a total drainage area of 93 square miles (Pierce County 2005a). The basin includes Muck Creek and three large tributaries: The North Fork of Muck Creek (North Creek), the South Fork of Muck Creek (South Creek), and Lacamas Creek (Figure 1).

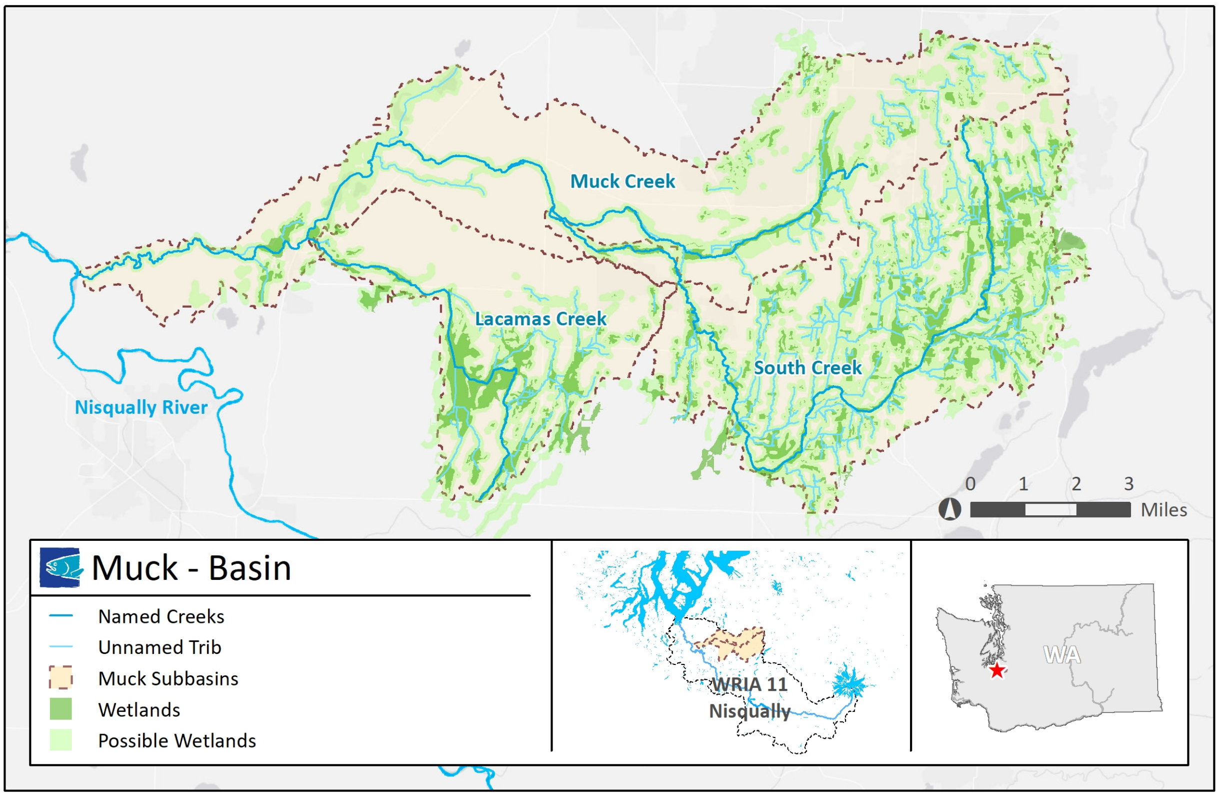

Figure 1. Muck Creek basin

The lower 14 miles of Muck Creek (with the exception of a 1.1-mile stretch in the vicinity of the City of Roy) flows through Joint Base Lewis-McChord (JBLM). Within JBLM's boundary, the creek travels through training areas and along the edge of the Artillery Impact Area, a remote, undeveloped section of the stream corridor. Most of the remaining stream network upstream of JBLM, including the Muck Creek tributaries (i.e. North, South and Lacamas Creeks), is located on privately owned lands with mixed land use including agricultural, residential, rural, and commercial areas. Muck Creek and its tributaries together comprise over 45 miles of stream channel length (Table 1), with over 43 miles of potential steelhead habitat (NSRT 2014).

Table 1. Muck Creek subbasins by area and length

Stream	Basin Area	Length
North Fork	20.5 square miles	7 miles
South Fork (South Creek)	36.6 square miles	17 miles
Muck Creek (mainstem)	20.6 square miles	14 miles
Lacamas Creek	15.2 square miles	7 miles

Muck Creek is a spring- and seep-fed system in the upper basin with two contributing forks. The North Fork is fed by Patterson Springs and other smaller springs. It begins west of the community of Graham and flows westerly, meeting with the South Fork in the north-central portion of the Basin in the prairie landscape on JBLM. The South Fork originates south of Graham and flows southwest for several miles to the south-central portion of the basin where it turns sharply northwest, converging with the North Fork on JBLM in the central portion of the basin. The mainstem of Muck Creek continues downstream of the confluence of the two forks, flowing westerly through the prairie landscape within JBLM to the prominent 'chain of lakes' north of Roy. In this section, the stream channel and lakes form a braided channel wherein the defined stream channel fades in and out of each of the lakes and wetland systems. A well-defined stream channel emerges out of the chain of lakes and flows through the City of Roy. Lacamas Creek, a major tributary, converges with Muck Creek in Roy. Downstream of Roy, the stream system again flows through JBLM in the prairie landscape and along the edge of the Artillery Impact Area. The stream corridor through the chain of lakes and lower Muck Creek receive significant contributions from springs.
Muck Creek empties into the Nisqually River about 10 miles upstream of the river's mouth where it meets with Puget Sound. The Muck Creek basin encompasses approximately 93 square miles, about one-seventh of the entire Nisqually River Watershed.

Streamflow patterns and aquatic habitat features are influenced by the distinctive geologic and topographic areas of the basin and the connectivity, or lack of connectivity, between each of these areas. Notably, patterns of seasonal dryness and no-flow conditions across extensive reaches in the system affect fish and aquatic habitat as well as ecological interactions between reaches.

2.2. Topography

The lower three and a half miles of Muck Creek flows through a forested canyon with a higher gradient than the rest of the basin. This stretch of the stream is more typical of high to moderate gradient streams originating in foothills or mountainous areas; however, the majority of the Muck Creek stream network is predominantly a low-gradient, low-elevation, stream system. Figure 2 illustrates the elevation profiles of the primary stream channels.

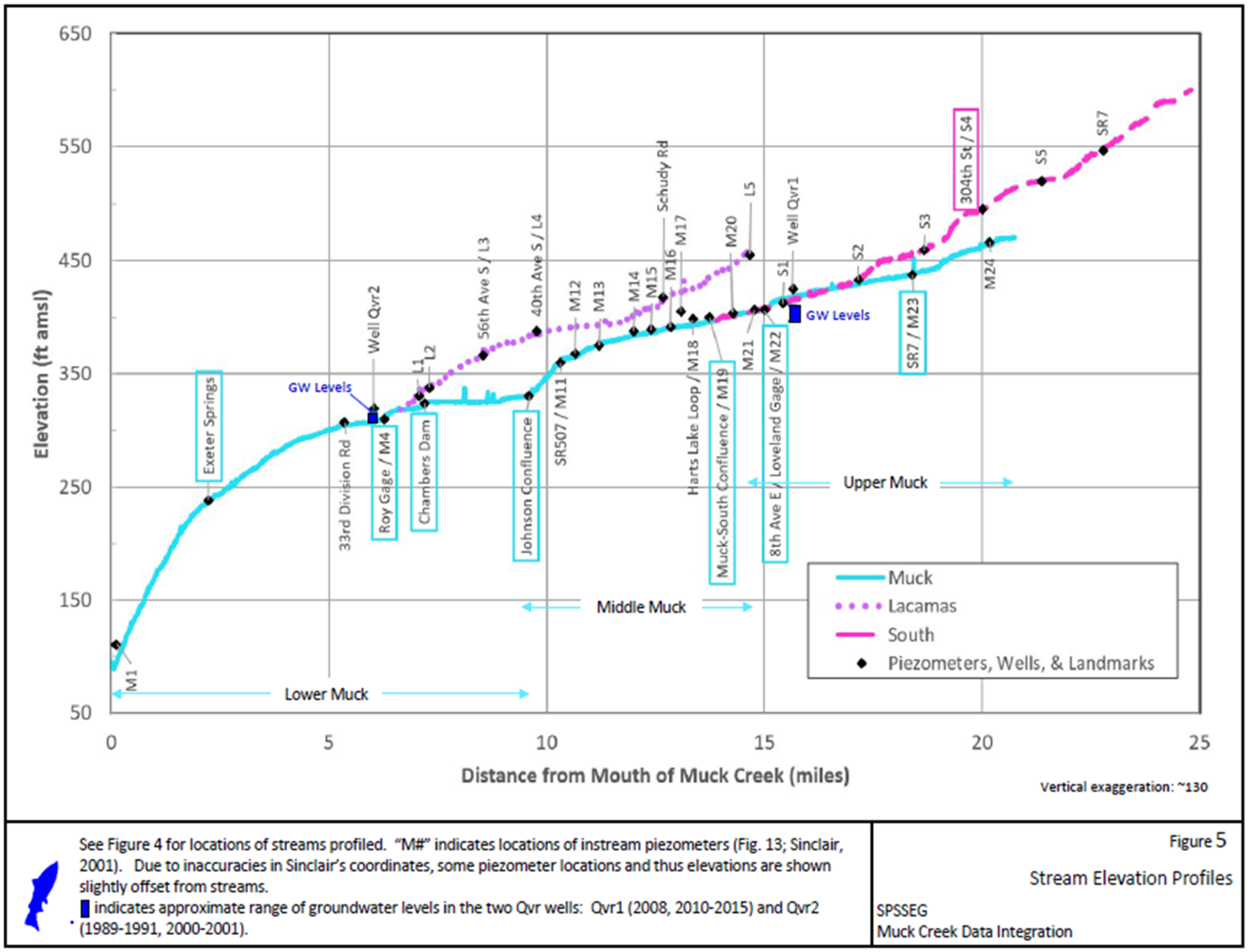

Figure 2. Stream elevation profiles (from Wilhelm and Pitre 2021).

The following excerpt from Wilhelm and Pitre (2021) provides a description of the topography of the basin:

> The topography of Muck Creek Basin has been formed by glacial and post-glacial processes. The basin has indistinct topographic divides at its edges, with a very slight topographic divide in the north, an outward slope of the uplands to the south, and the highest elevations formed by the bluff running along the center of basin. As the stream network illustrates, much of the runoff on the uplands first drains towards the southern edge of basin before turning to the west and north to enter the outwash plain.
>
> Muck Creek climbs about 200' in its lowermost three miles through a valley that connects the Nisqually River valley (elev. ~100' above mean sea level [amsl]) to the outwash plain (elev. ~300' amsl). The streambed rises an additional 200' over the next ~17 miles of its channel upstream. The stream's gradient is almost flat through the lake-and-wetland chain, then rises again to transition onto the outwash plain. The stream then continues to rise gently into its upper reaches.
>
> Lacamas Creek rises more quickly than Muck from the confluence of the two streams. Lacamas traces the northern edge of the divide between the outwash

plain and the uplands, flattening a bit after it crosses 56th Ave S. The stream turns south at 40th Ave S and enters a flat-bottomed valley after about ¾ mile [Figure 5]. The stream gradient then increases periodically as the stream turns generally to the east and crosses glacial striations in the till. The stream section that was profiled rises 130’ in elevation overall, while the whole sub-basin ranges roughly from 300’ to 600’ amsl in elevation.

South Creek travels ~3.5 miles upstream from its confluence with Muck Creek across the outwash plain, roughly paralleling the orientation and elevation of Muck Creek to the north. South Creek then turns to the south-southeast to climb onto an apparent terrace and then has another steeper rise into the uplands. At about river mile (RM) 9 the stream crosses Mountain Highway E (SR7) and turns toward the east-northeast to drain the upper portion of its basin. The stream section that was profiled rises 250’ overall, while the elevation of the whole sub-basin ranges from 400’ to 900’ amsl.

A broad glacial outwash plain is prominent in the central portion of the basin and provides the underlying geologic and soil features associated with the large expanse of Puget lowland prairies on JBLM and surrounding areas (Wilhelm and Pitre 2021). This glacial outwash plain drains much of the basin including most of the North Fork, the main stem of Muck Creek below the confluence with South Creek, and a portion of Lacamas Creek, transitioning to the canyon reach in the lower basin. The remaining areas of the basin including upper Lacamas Creek and upper South Creek cut through a bluff that rises along the edges of the outwash plain. Figure 3 and Figure 4 show a plan view of topographic features and the associated geologic features, respectively, as borrowed from Wilhelm and Pitre (2021).

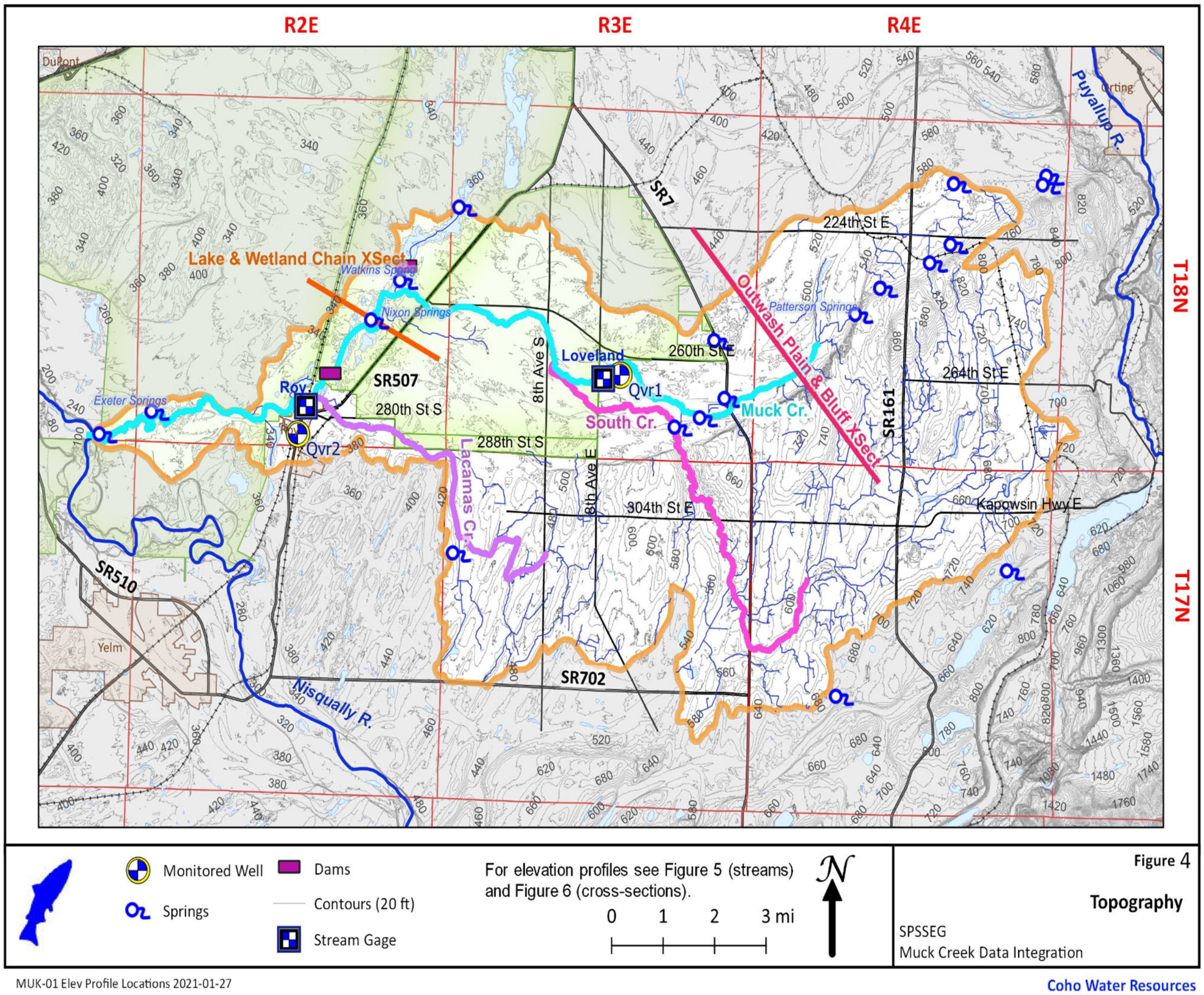

Figure 3. Topographic map of the Muck Creek basin (from Wilhelm and Pitre 2021).

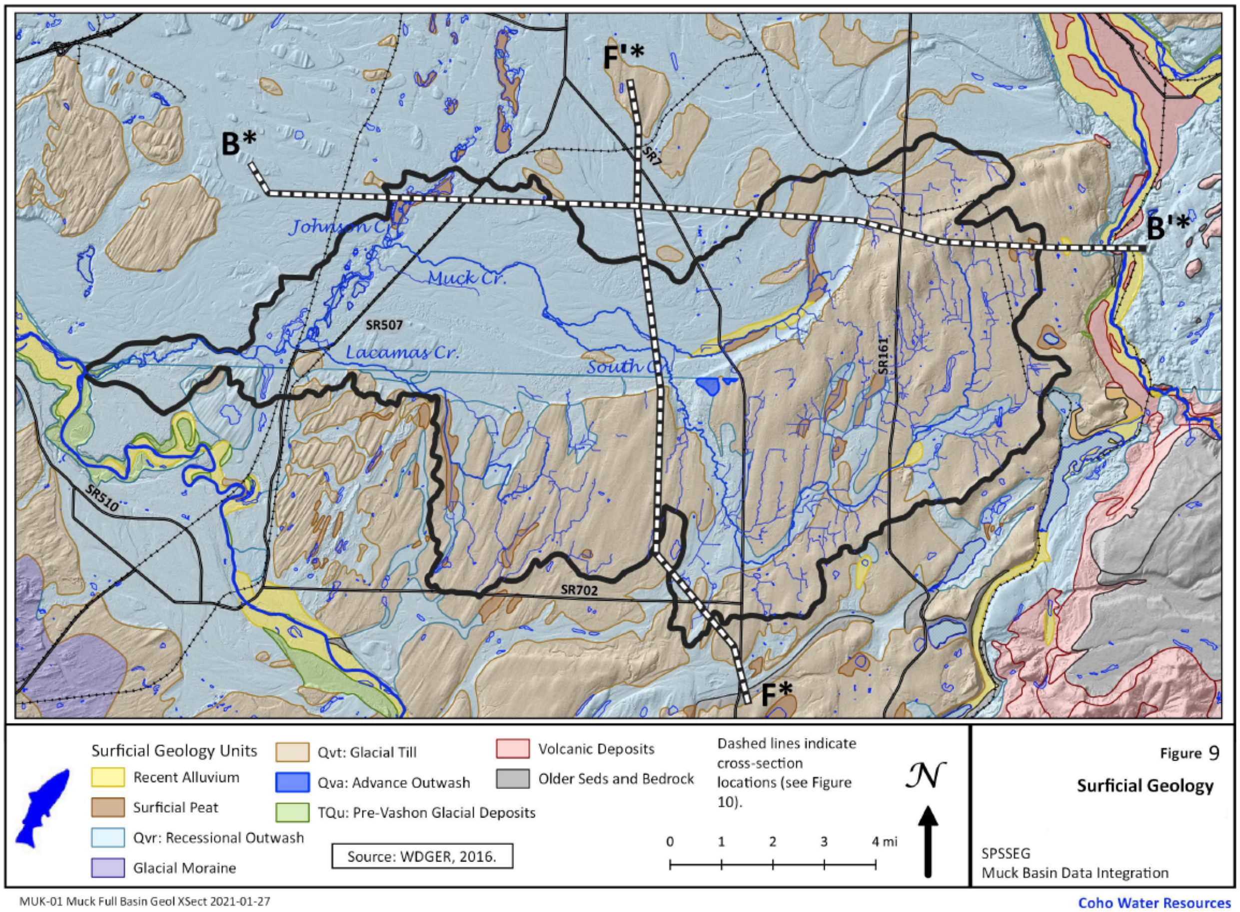

Figure 4. Map of geologic features in the Muck Creek basin (from Wilhelm and Pitre 2021).

The Muck Creek basin's groundwater-surface water interactions are largely influenced by naturally occurring geologic and soil conditions as well as two key topographic features: a chain of lakes and wetlands and the bluff that runs along the midline of the basin (Figure 5). Wilhelm and Pitre (2021) discuss these features:

Chain of lakes and wetlands [Figure 5a]:

- An elevation profile perpendicular to the chain's axis shows that the chain forms a trench-like feature about a quarter mile wide that cuts across the outwash plain. The chain is 10'-25' lower in elevation (decreasing from the north to the south end of the chain) than the surface of the outwash plain on either side. (The elevation difference may be slightly greater when considering the depth of the lakes, but they are reported to be shallow [p. 64 of Sinclair, 2001]).
- A large vertical exaggeration was applied in the profile to highlight this feature. In reality the sides of the chain slope have an approximately 3% grade. This change in elevation is still significant for groundwater-surface water interactions.
- The origin of this chain of lakes and wetlands is post-glacial because the feature cuts across the traces of post-glacial outwash channels that can be seen in the lidar images. The linear orientation of the lakes and wetlands suggests some sort of drainage channel and appears to align with the gap in the hills south of Roy.

Bluff along the horizontal midline of basin [Figure 5b]:

- The elevation profile is taken perpendicular to the bluff near its steepest part.
- The bluff marks the southern boundary of the area from which till was carved away by outwash flows as the most recent glacier receded.
- This carving results in a sharp drop in elevation from the uplands to the outwash plain. The slope of the side of the bluff is as high as 20%.
- The bluff is at its highest (~250' higher than the adjoining outwash plain) and most distinct in the east-central portion of the basin.
- The bluff is softer and lower in the Lacamas drainage, where the original till surface was lower and where some erosion of till is seen where Lacamas Creek leaves the uplands to flow along the southern edge of the outwash plain. (Wilhelm and Pitre 2021)."

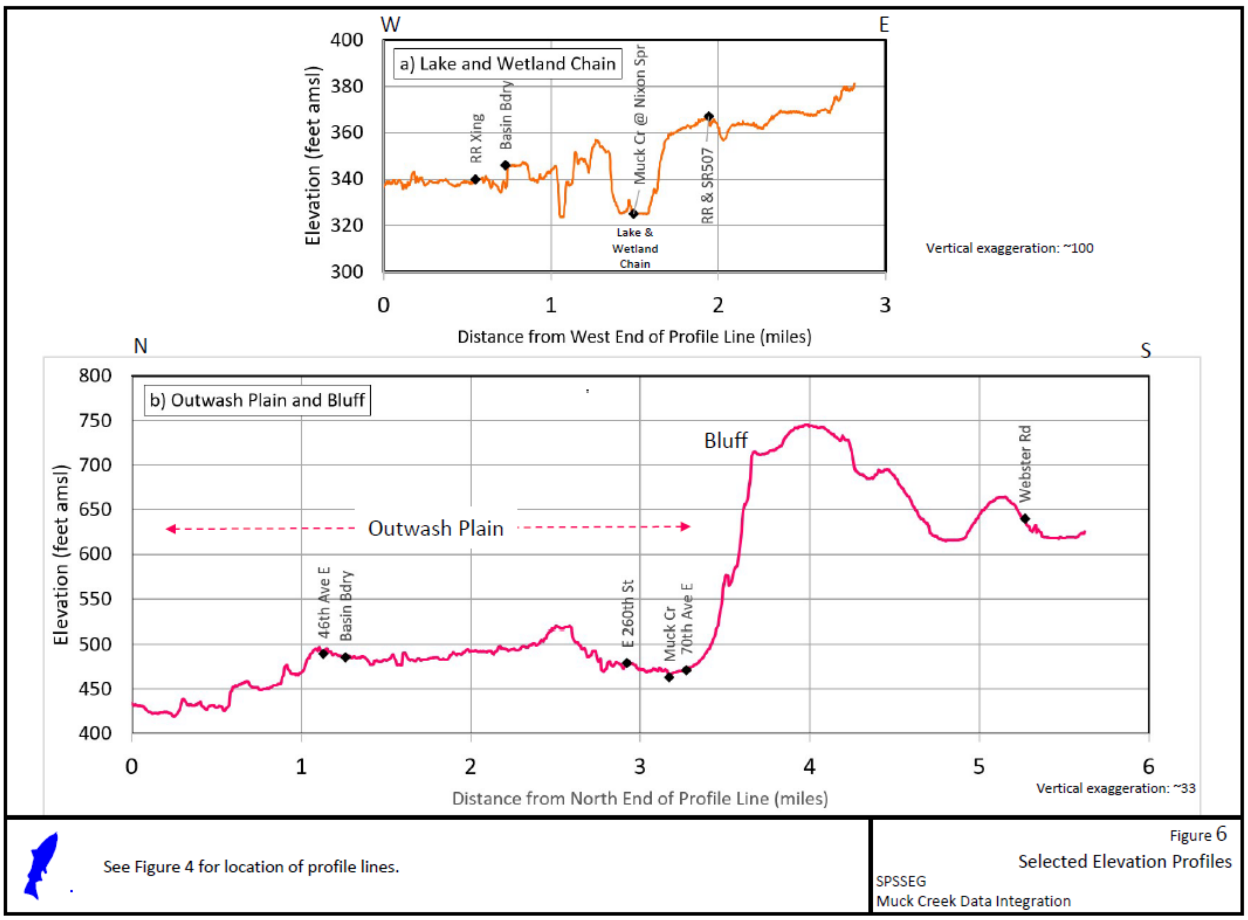

Figure 5. Elevation profiles (from Wilhelm and Pitre 2021).

2.3. Streamflow and Hydrologic Regime

Extended periods of intermittent streamflow occurring in several sections of the Muck Creek system have been well documented and are recognized as an influential characteristic affecting fish migration and hydrologic functional processes in the system (Pierce County [2005a]; May [2002], Sinclair [2001], Savoca and others [2010]).

Regularly dry reaches block juvenile and adult fish migration and limit anadromous fish from accessing large portions of the basin during dry or low-flow periods. This phenomenon is largely due to the permeable nature of glacially derived, gravelly soils which in combination with seasonal precipitation patterns and low groundwater tables cause the 'losing reaches' of the stream to go seasonally dry (Wilhelm and Pitre 2021). Conversely, the entire stream network has flow during, or following, periods of prolonged precipitation, typically occurring between late fall and mid-spring, although periods of intermittent flow do occur in the winter months following precipitation fluctuations. As derived from field observations and prior reports addressing streamflow, most of the dry reaches begin losing flow in May or June and typically do not have flow again until November or December. Data from continuous discharge stream flow monitoring at a U.S. Geological Survey (USGS) gauging station in Muck Creek located in Roy (Station 12090200) between 1956 to 1971 show that there were periods of no flow in that section of the creek for 10 of the 15 years of record (Pierce County 2005a). Over the period of record, zero flow was recorded 9.1 percent of the days (Pearson and Dion 1979). The majority of the no-flow days occurred between August and November. The longest period with zero flow occurred between July 24 and December 7, 1956 (136 days). A peak flow of 600 cubic feet per second (cfs) was recorded on January 21, 1971. Average flow during this period was 64 cfs (45,191 acre-ft/year). If spread evenly across the basin, this would amount to a runoff depth of 9.8 inches, or about 24 percent of the rainfall (as recorded at nearby Fort Lewis) over the basin (Pierce County 2005a).

Lacamas Creek, which drains the southern portion of the Basin, may have a changing flow regime. Pierce County (2005a) reported that the Lacamas system had perennial flow during most years (through 2005), but also occasionally went dry. Sporadic stream flow data have been taken at Lacamas Creek east of Roy from July 5, 1949 to November 11, 1989. There was no flow in the creek on only 5 of the 37 sampling dates, all of which occurred in July-October 1986 and June 1987 (unpublished data, Washington Department of Ecology [Pierce County 2005a]). However, a landowner that has owned property near the mouth of Lacamas Creek for several decades reported that the stream used to have perennial flow in its lower section through the 1960s but since has exhibited a seasonal dry period, usually between September-November (Landowner, personal communication, 2021). SPSSEG biologists observed dry sections in lower Lacamas Creek in September 2021. Lacamas Creek enters Muck Creek a short distance upstream of Roy. Frequently during the summer, flow from Lacamas is the only source of water to Muck Creek along this portion of its channel (Pierce County 2005a).

Fall chum salmon are the most common run in Puget Sound, typically spawning in rivers from late October to early December, peaking in November. The relatively late timing of the winter chum salmon runs in the Muck Creek system (December to January) may be an indicator of their adapted response to the intermittent stream flow condition, as their migration period for spawning coincides with the return of passable stream flows after seasonal dry periods (Pierce County 2005a). Spawning seasons for coho salmon and winter steelhead in the Muck Creek basin also typically coincide with periods of renewed streamflow. In this sense, historical, seasonal flow patterns in the system may be an integral part of the evolutionary and behavioral traits of Muck Creek winter chum. However, some observations suggest historical trends in seasonal flow patterns are changing due to anthropogenic impacts which may further degrade conditions for salmon and steelhead. Severe low streamflow pre-2002 limited salmonid utilization of habitat above Chambers Lake (May 2002). Since 2010 or earlier, a seasonally-dry reach of Muck Creek on the JBLM prairie above Johnson Creek has been both going dry earlier in spring and staying dry longer into the early winter than in years past (JBLM Fish & Wildlife Staff, personal communication, 2020). During steelhead spawning redd surveys in 2021, JBLM Fish and Wildlife staff observed that a section of lower Muck Creek had gone dry earlier than usual (sometime between May 10-17), which could potentially strand steelhead eggs “in the dry.” Further investigation is needed to determine the extent of worsening streamflow losses, their impacts on different salmon and steelhead life stages, and whether direct or indirect streamflow supplementation projects may be beneficial.

Ongoing land cover changes in the basin include residential and commercial land development (particularly in the eastern basin) and the expansion of forest into areas historically maintained as prairie by Native Americans through intentional, managed burning. This loss of prairie habitat due to forest succession may increase water losses in the system due to evapotranspiration. Moreover, incremental changes by humans over time, such as channelization of streams, disruption of stream beds, and draining of wetlands, have likely sped the flow of water through the basin, decreased groundwater recharge, and increased the duration and/or location of dry conditions in streams (Wilhelm and Pitre 2021).

Additional details regarding streamflow trends, prior monitoring data, and flow analysis can be found in numerous supporting documents cited in the Annotated Bibliography (Appendix A) and References for this report.

2.4. Salmonid Utilization in the Muck Creek Basin

At least four salmonid species are known to utilize the Muck Creek system with regularity: winter chum salmon (*Oncorhynchus keta*), coho salmon (*Oncorhynchus kisutch*), winter steelhead/rainbow trout (*Oncorhynchus mykiss*), and both resident and sea-run cutthroat trout (*Oncorhynchus clarki clarki*) (Zimmerman 1995; Kerwin 1999; WDFW SalmonScape 2022) (Table 2). *O. mykiss* (steelhead/rainbow) exhibits multiple life history strategies including various age classes of anadromous and resident forms. Fall Chinook salmon (*Oncorhynchus tshawytscha*) and pink salmon (*Oncorhynchus gorbuscha*) are known to enter the system infrequently only when adequate flow regimes coincide with the run timing for these species. Other native fish species, including lamprey, three-spine stickleback, longnose dace, and sculpins are likely to also be present in Muck Creek (Hiss et al. 1982). Non-native species are also present, including largemouth bass, sunfish, and yellow perch (Zimmerman 1995).

Table 2. Muck Creek salmonid presence (from Martz et al. 2022). Presence of adult life stages are indicated in dark blue and presence of juvenile life stages are indicated in light blue.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Winter Chum Salmon												
Coho Salmon												
Winter Steelhead[1]												
Cutthroat Trout[2]												

1. Winter steelhead juveniles could be present year-round; juvenile outmigration overlaps with adult presence in April and May.
2. Resident cutthroat adults and juveniles present year-round. Sea-run cutthroat trout adults present in spring.

May (2002) reported that coho salmon, chum salmon, steelhead, and coastal cutthroat trout have historically utilized Muck Creek from its mouth to the headwaters, but in the years leading up to 2002, periods of low flow had been severe enough that salmonid utilization (except for resident coastal cutthroat trout use) was limited to the lower segments of the creek below Chambers Lake. However, when streamflow is adequate in late fall and winter, adult chum salmon, adult and rearing juvenile coho salmon, and coastal cutthroat trout make extensive use of the wetlands above Chambers Lake up to the headwaters (May 2002). Still, the most productive spawning habitat has been restricted to the lower and middle sections of Muck Creek below Highway 7 (Pierce County 2005a). These species also utilize the mainstem and wetland habitats of Lacamas and Johnson Creeks (Pierce County 2005a). Steelhead generally utilize Muck Creek in the winter and spring seasons with migration downstream into the Nisqually River early in the summer as flows begin to decrease (Pierce County 2005a).

A handful of landowners contacted for this project indicated they or their relatives had seen, or had knowledge of, spawning salmon returning annually or semi-annually to stream sections upstream of JBLM as late as the 1950s and 1960s but that the runs had ceased to return to the creek at some point. These anecdotal reports applied to parts of the North Fork, middle sections of South Creek, and Lacamas Creek (Landowners, personal communication, 2021).

Winter chum

Oncorhynchus keta

Within the Nisqually River watershed, the most abundant anadromous salmonid is the chum salmon (Williams et al. 1975). Approximately 25% of this winter chum population is produced by the Muck Creek basin (May 2002), with spawning predominantly occurring in the lower half of Muck Creek and in Lacamas Creek (WDFW SalmonScape 2022). Entry to these key spawning areas is restricted by low streamflow until after mid-December (Williams et al. 1975). While adult chum are in the system from December through February, the majority of spawning occurs between late December to mid-January (JBLM Fish & Wildlife Staff, personal communication, 2020).

The glacially derived sediments in the basin provide excellent gravel and cobble sources for spawning habitats (Martz et al. 2022). Winter chum salmon have been documented in Lacamas Creek and in Muck Creek from the mouth to about River Mile 15 (Figure 6), near the east end of JBLM, with presumed presence shown part way up the main forks (WDFW SalmonScape 2022).

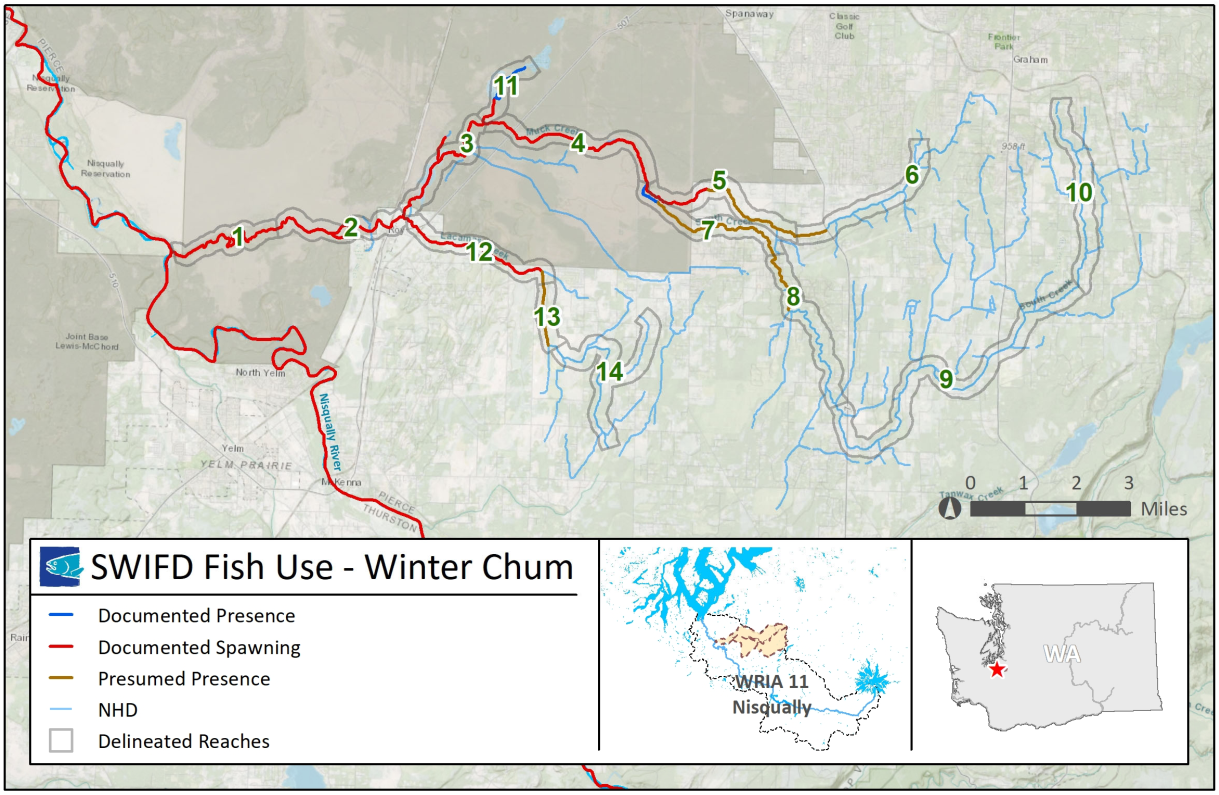

Figure 6. Winter chum map of documented and presumed occurrences. SOURCE: Statewide Integrated Fish Distribution (as shown in WDFW SalmonScape 2022).

There may have been a shift in decades past where chum and other salmon species' usage of the prairie reaches most affected by seasonal flow, and upstream areas, became more limited. Chum salmon were reported to spawn in Muck Creek in the 13th Division prairie area of JBLM (~River Mile 12) up until the 1970s, although they have largely not been seen in that section of the stream since (JBLM Fish & Wildlife Staff, personal communication, 2020). There are anecdotal reports of salmon, spawning far up the Muck Creek basin into the North Fork of Muck Creek in the 1950s or 1960s (Landowners, personal communication, 2021). We are not aware of any reports of chum spawning activity in Lacamas Creek in recent years.

Recent winter chum run sizes in the Nisqually River system have averaged around 30,000 fish with a range from 53,716 in 2014 down to 14,328 in 2016, which is greatly reduced from a 2007-2011 average run size of around 80,000 fish (Nisqually Indian Tribe 2017). It is unclear if the apparent reduction in the size of the chum run and their reduced presence in the mid to upper sections of the Muck basin is attributed to the reduced abundance of returning adults, as seen in many Puget Sound rivers, a lack of flow and connectivity due to the combined natural hydrogeological conditions and worsening flow regime caused by anthropogenic landscape modifications, or some combination of these factors.

Coho Salmon

Oncorhynchus kisutch

Nisqually coho salmon adults typically enter the watershed from September to early December and spawn from November to early February (Kerwin 1999). Adult coho enter Muck Creek usually between December-February, with most spawners observed in January and February. It is likely that early returning coho enter Muck Creek in November, or earlier, if flows are sufficient (JBLM Fish & Wildlife Staff, personal communication, 2020). Puget Sound coho juveniles typically rear for 1 year or more in freshwater and migrate to the estuary and ocean in spring, with a peak in May. Access to high-quality spawning habitat and perennially watered high-quality in-channel and off-channel habitat for rearing are critical elements necessary to support coho salmon. Beaver ponds and other wetlands can provide high-quality rearing habitat and refugia for coho salmon during both summer and winter (Pollock et al. 2004).

Much of the information on the distribution of coho within the Muck Creek basin (Figure 7) is contradictory or speculative. Pierce County (2005a) stated that coho hadn't been seen throughout much of the basin for more than a decade; however, spawning coho have frequently been observed by JBLM Fish and Wildlife biologists (JBLM Fish & Wildlife Staff, personal communication, 2020). There is documented coho spawning from the mouth of Muck Creek up to Highway 7, on the North Fork at Hwy 7, and in Lacamas Creek, and presumed presence of coho throughout much of the upper watershed (WDFW SalmonScape 2022; WDFW SWIFD 2022). In 2021, SPSSEG documented two juvenile coho salmon rearing in Lacamas Creek, which were presumably the progeny of spawners in Lacamas. May (2002) reported that in Muck Creek coho salmon were believed to mainly utilize the middle and upper reaches and Williams et al. (1975) referenced historical documentation that coho have used areas with year-round flow in the upper watershed for spawning and rearing however there are no supporting references listed to support these statements.

Reportedly, as late the 1970s a landowner operated a rearing pond for coho salmon along a tributary to the upper North Fork of Muck Creek and may have stocked or released coho salmon, allowing them to access the stream network (Jeanette Dorner, personal communication, 2021). It is unclear if adult coho salmon returning to the North Fork during that period were of natural origin stocks or if they were partially from the private stocking effort.

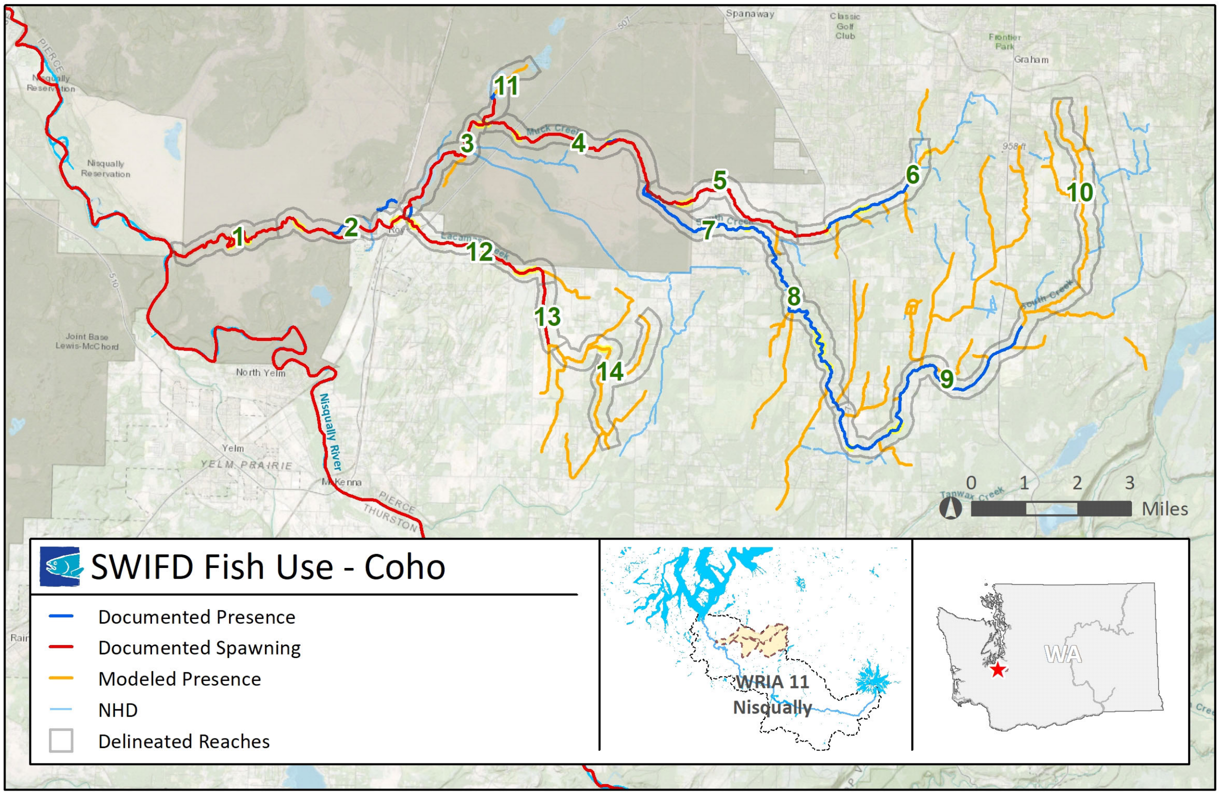

Figure 7. Coho salmon map of documented and presumed occurrences. SOURCE: Statewide Integrated Fish Distribution (as shown in WDFW SalmonScape 2022).

Winter Steelhead

Oncorhynchus mykiss

The winter steelhead of the Nisqually watershed belongs to the Puget Sound Steelhead Distinct Population Segment (DPS), which was listed as threatened under the Endangered Species Act in 2007 (NMFS 2007). Winter steelhead adults enter the Nisqually River watershed from early December to early May and typically spawn from April to early June; however, in Muck Creek, spawning may occur 1 to 2 months earlier (NSRT 2014). Steelhead life histories are highly diverse and juveniles can migrate downstream as fry, parr, or older juveniles (1- to 4-age fish) in the Nisqually River watershed; larger fish typically migrate out earlier, in April and May, and smaller fish migrate out from May to as late as July (Hiss et al. 1982; NSRT 2014).

There are over 43 miles of potential steelhead habitat within the Muck Creek basin (Figure 8) including the upper reaches of its tributaries (NSRT 2014). Resident (rainbow trout) and anadromous (steelhead) forms of this species are presumed to be present in the basin. Genetic interchange between resident and anadromous life history types is not uncommon in sympatric populations (Docker and Heath 2003; McPhee et al. 2007; Pearsons et al. 2007). Thus, the condition of stream habitats supporting resident rainbow trout not regularly accessible to anadromous steelhead may be important to sustaining the genetic integrity of the overall *O. Mykiss* populations in the Muck basin.

From 1980 to 1993, the Nisqually winter steelhead run averaged about 4,400 fish. This number plummeted in the 1990s and has not recovered since. Nisqually winter steelhead runs averaged only about 500 fish from 1998 to 2013; however, the run size in the 2015-2016 spawning season reached over 2,000 fish, the highest number seen in over a decade (Nisqually Indian Tribe 2017; WDFW 2016)

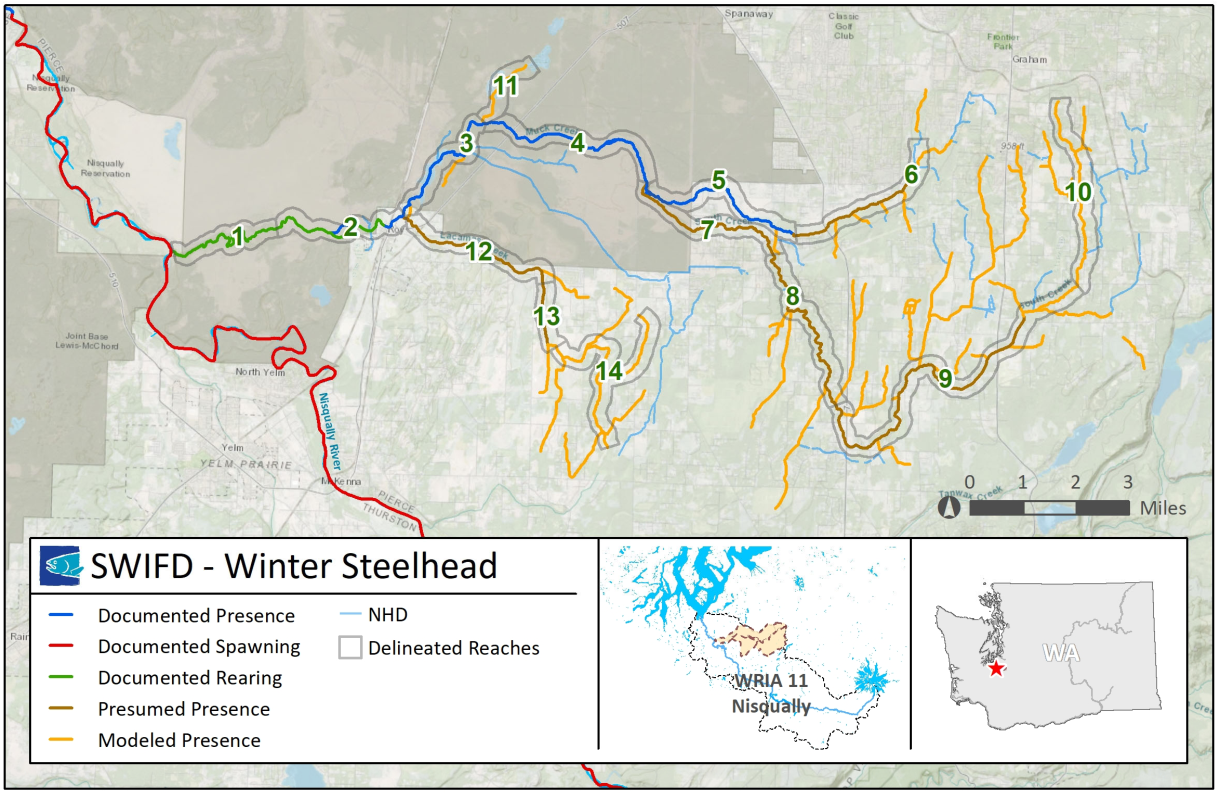

Figure 8. Winter steelhead map of documented and presumed occurrences. SOURCE: Statewide Integrated Fish Distribution (as shown in WDFW SalmonScape 2022).

Cutthroat Trout

Both resident and anadromous cutthroat trout are present in the Muck Creek basin (Figure 9). The former dam at the outlet of Chambers Lake Dam, and dynamic flow conditions, were hypothesized to provide separation between the upper and lower watershed, with resident fish predominant in the upper half of the system and anadromous fish predominant in the lower half of the system below Chambers Lake (Zimmerman 1995). Adults typically spawn from January through June. Access to high-quality spawning habitat with small gravel and perennially watered high-quality in-channel and off-channel habitat for rearing are critical elements necessary to support cutthroat trout.

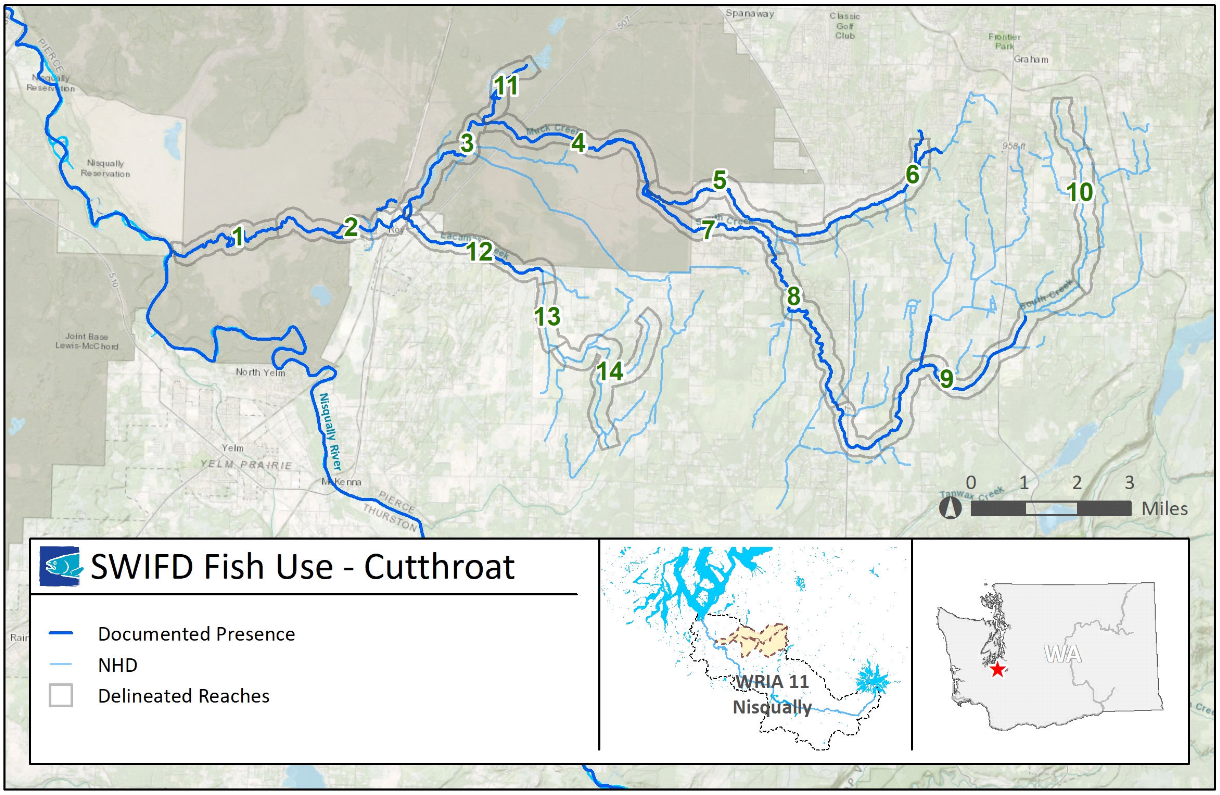

Figure 9. Cutthroat trout map of documented and presumed occurrences. SOURCE: Statewide Integrated Fish Distribution (as shown in WDFW SalmonScape 2022).

3. Assessment Methods

The methods for the habitat assessment and development of restoration opportunities utilized a combination of field data collection protocols and office-based resources to assess baseline habitat conditions, comparative historical conditions, and potential opportunities for habitat restoration actions. The following sections describe the methods used for this assessment.

3.1. Literature Review

A review of literature sources related to stream and watershed conditions, hydrology, fish resources, and other physical and ecological conditions within the Muck Creek basin was conducted to assist in the development of this assessment and the watershed strategy initiative (Strategy). Relevant literature compilations were pulled into two supporting contracted reports and an Annotated Bibliography:

- *Hydrogeologic Influences on Streamflow in Muck Creek Basin Literature Review & Data Integration* (Wilhelm and Pitre 2021).
- *Muck Creek Literature Review and Strategy Framework* (Martz et al. 2022). This report was completed by Anchor QEA in support of the allied streamflow and watershed strategy initiative.
- *Annotated Bibliography* (Wilhelm 2022)

The Annotated Bibliography is provided in Appendix A, while the other reports are available upon request. The supporting literature synthesized for this assessment was used to reference historical and baseline conditions for the basin, known ecological and habitat attributes, documented impairments and challenges for the recovery of aquatic habitat and fish, and technical details relating to physical and biological conditions within the Muck Creek basin and the Nisqually watershed.

The two primary sources of past stream conditions utilized in this report were Pierce County (2005a, 2005b) and May (2002). We compiled available summary data reported for bankfull width, riparian conditions, residual pool depth, pool frequency, maximum pool depth, lengths and widths of habitat units (% pools, % riffles, % runs/glides, % lakes/wetlands, with the last only being reported in Pierce County 2005b), substrate, survey length, and LWD frequency. Additionally, we reviewed and analyzed the raw datasheets from Pierce County (2005b) to compile habitat unit measurements not reported as summarized values. Where necessary, measurements in feet were converted to meters and kilometers for consistency across surveys.
Site maps and survey locations (e.g. roads and landmarks) listed on raw datasheets were used to overlay the locations for past survey efforts with the 14 delineated reaches used in this report.

Restoration opportunities and priorities documented in past reports were also considered and incorporated into the updated restoration opportunities presented in section 4.6. We reviewed all documents listed in Appendix A for mention of restoration and/or conservation opportunities. Additionally, we incorporated recommendations from personal communications with JBLM Fish & Wildlife biologists.

3.2. Landowner Outreach and Survey Access

In order to access the stream for field surveys and data collection, SPSSEG conducted outreach to JBLM Fish and Wildlife personnel for access to Muck Creek within the boundaries of JBLM and to over 200 individual landowners for areas beyond JBLM via mailings and phone calls. The response rate from landowners was about 20% with approximately half of the responses granting permission for field crews to survey stream reaches on their property. Thus, access to targeted stream reaches was limited to those sections with landowner permissions. Landowner outreach constituted a significant portion of the initial survey effort in order to gain access to each stream index area. Through the outreach effort, some landowners provided specific information about historical fish use and/or conditions within the stream at their property, as described in the Summary and Fish Use subsections for each Reach in Section 4.1 of this report.

3.3. Habitat Reaches Designation

The Muck Creek Basin includes the main stem of Muck Creek and its three significant tributaries: Lacamas Creek, the North Fork of Muck Creek, and the South Fork of Muck Creek (aka South Creek). Due to the basin's relatively large size and the unique characteristics of certain sections of the stream, it is helpful to break the basin into discrete reaches for the purposes of characterization and discussion and for presenting recommendations. Numerous stream reaches have been designated as part of prior studies and reports such as those designated by May (2002), NSRT (2014), and Pierce County (2005a; 2005b).

For this assessment, the basin was initially divided into broad reaches, which can still be used for general discussion and analyses:

- Lower basin (primary spawning reaches)
- Middle basin (prairie landscape)
- Upper basin (geologic uplands of each Fork)
- Lacamas Creek

Subsequently, fourteen discrete reaches were delineated by the Anchor QEA team as part of the allied watershed strategy initiative. The reach breaks for the fourteen reaches were based on geologic, geomorphic, streamflow, and habitat considerations and were kept within reasonable size ranges (typically 1.5 to 4 miles in length). These fourteen reaches have been adopted for this assessment and are used for reporting data collection results and analysis and for descriptions and recommendations within each discrete reach (Figure 10). Refer to Table 2 from Martz et al. (2022) for a comparison of the stream reaches with previously delineated reaches.

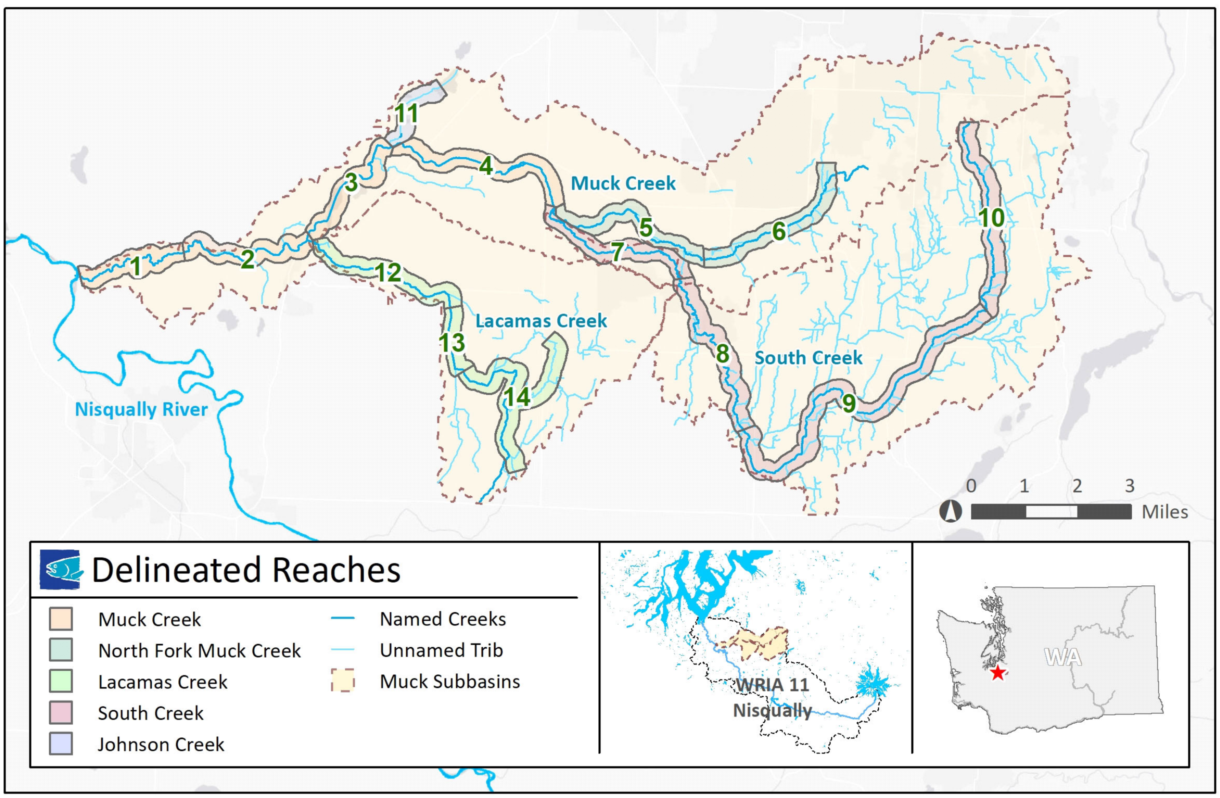

Figure 10. Delineated stream reaches used for this assessment.

3.4. Habitat Survey Data Collection

Habitat surveys were conducted within the stream channel to compliment the office-based assessment methods and to update prior data on habitat condition collected by others. These habitat surveys provided field-collected data on in-stream habitat features including ratios of pool, riffle, and run habitat units and their relative frequencies, in-stream wood sizes and quantities, streambed sediment composition, and the presence of habitat related features such as beaver ponds, reed canary grass, and in-stream wetlands.

3.4.1. Habitat Survey Index Sub-Reaches

Habitat surveys were conducted within select index sub-reaches representative of their respective primary reaches. Additionally, the index sub-reaches were placed in areas where survey access was granted by landowners reach (Figure 11). SPSSEG biologists surveyed 7.35 km of index sub-reaches between 2020 and 2022 (Table 3).

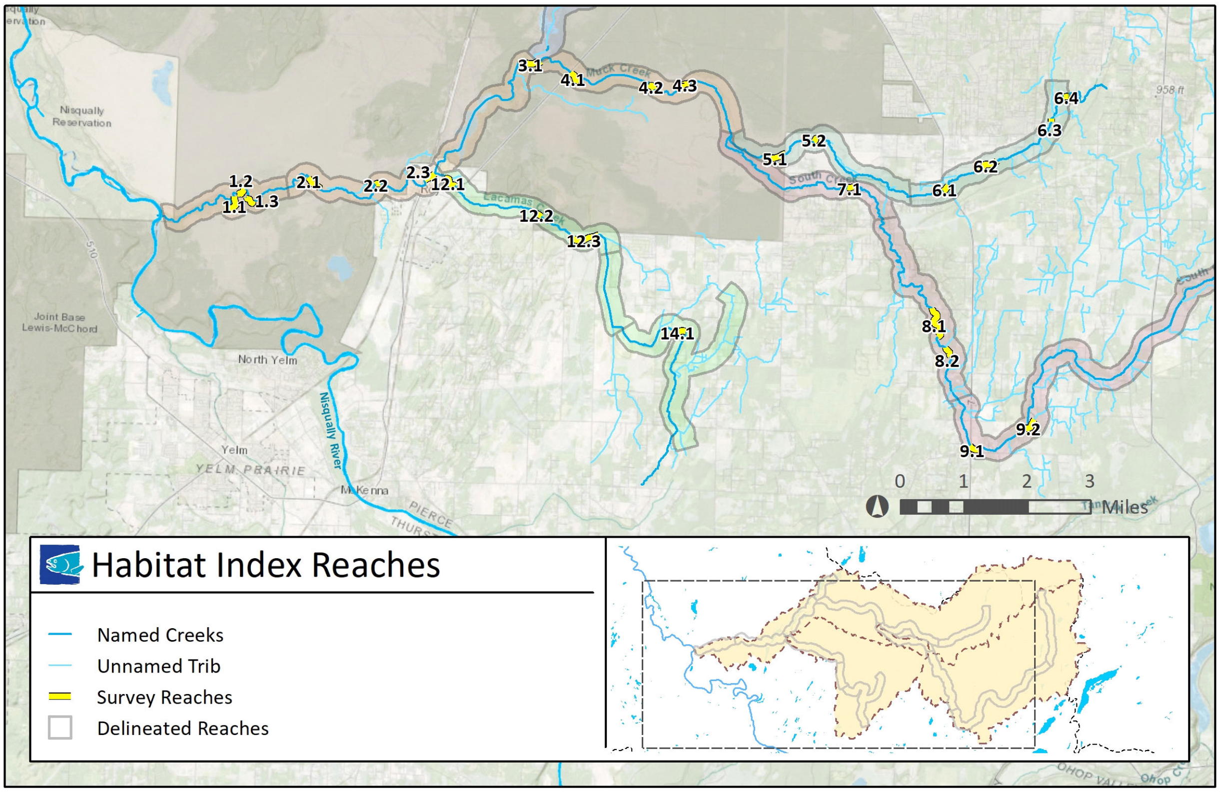

Figure 11. Habitat survey index reaches

Table 3. Habitat survey index lengths per reach.

Reach	Index Survey Total Length (km)
1	1.17
2	1.07
3	0.2
4	0.88
5	0.61
6	0.94
7	0.2
8	0.5
9	0.67
10	No Data
11	No Data
12	0.92
13	No Data
14	0.19

3.4.2. Habitat Rapid Assessment Methods

Methods developed for the habitat surveys were based largely on standard industry protocols from the Timber Fish and Wildlife (TFW) Method Manual for the Habitat Unit Survey (Pleus et al. 1999) and TFW Large Woody Debris (LWD) Survey (Schuett-Hames et al. 1999).

Slight modifications were made to these protocols to maximize efficiency in the field and to focus on the most relevant habitat features for this assessment. Data were collected on core stream habitat unit types including pools, riffles, and runs. Widths (wetted and bankfull), lengths and depths were collected in the field, in both primary and side channels. All distances were measured in meters.

The habitat survey protocols used for this study were also designed to be compatible with the physical habitat survey prescribed in the Washington Department of Fish and Wildlife's (WDFW) Fish Passage Barrier Assessment and Prioritization Manual (WDFW 2019). Additional data collected includes a breakdown of substrate composition into four categories: boulder (>12"), rubble/cobble (3-12"), gravel (0.2-3"), and sand/fines (<0.2").

Data collected for this assessment are also meant to inform future iterations of the Ecosystem Diagnosis & Treatment (EDT) model for Nisqually steelhead.

Field data were collected as a spatial point at the downstream end of each habitat unit using ArcGIS Field Maps or Collector Apps on a MESA 2 and Samsung Cedar tablet, or on an iPhone XR. Photos were also taken for each habitat unit. Data were synced to ArcGIS Online at the end of each field day. After completion of all surveys, a geodatabase was downloaded and opened in ArcMap for review. Data were then migrated to Excel to calculate the final statistics, for comparison to past studies in the basin along with industry targets.

For the large wood surveys, only wood features within the wetted width (Zone 1) were documented; the additional zones as described in the TFW LWD manual (Schuett-Hames et al. 1999) which occur at higher elevations in the channel and floodplain were excluded. This means that our LWD surveys reflect the current wood loading within the wetted channel which are directly accessible to fish at lower flows and which influence stream habitat and morphological functions in the wetted channel. The presence or influence of LWD at higher elevations within the channel or floodplain which would interact with the stream at higher flows were not documented for this study. As a general observation, there is a paucity of wood in most of the Muck Creek system, with streamside trees and shrubs in the riparian corridor either lacking or occurring in small volumes in much of the basin. This may indicate low recruitment potential for wood to enter the stream. There are some exceptions to this trend in locations where there is a well-developed vegetated buffer.

3.5. Fish Presence Surveys

Fish presence observations were documented at nine locations, four targeted sample sites, and five passing observation sites. Formal sampling utilized a backpack electro-shocker sampling method within pools and moderate depth stream sections, with one to several passes conducted at each site. All individual fish encounters were recorded including the species name (or highest known taxonomic level), as well as the length for all salmonids. This was not a systematic or comprehensive fish survey, rather the timing of the surveys and the survey locations were chosen based on opportunistic variables including good flow conditions (low flow and not dry), access permissions, and the availability of Washington Department of Fish and Wildlife (WDFW) staff providing survey permits.

A map of locations and results of fish sampling and observations is presented in Figure 34 in Section 4.5.

3.6. Riparian Buffer Vegetation Model

A riparian buffer vegetation model was developed to illustrate riparian vegetation canopy heights and percentages of vegetated buffer areas within each stream reach. Indicators for canopy height and percentage of vegetated area can serve as a proxy for other riparian indicators such as shade, prey resources, and sources of woody material for the stream.

This riparian model utilized GIS (Esri ArcMap) to compare canopy heights derived from Light Detection and Ranging (LiDAR) datasets. Results were provided for the 50ft and 200ft buffer areas along each side of the stream. Pierce County 2020 LiDAR was used for buffer areas off of Joint Base Lewis-McChord and Puget Lowlands. Pierce County 2005 LiDAR was used for areas on base and where 2020 LiDAR was not available. Digital Surface Model (DSM) and Digital Terrain Model (DTM) datasets were downloaded from the Washington LiDAR Portal.

Methods for developing the model were as follows: Hydro Centerlines from Pierce County were used to create a 200ft and 50ft buffer along each side of the creek. The 200ft buffer area was extracted from each of the LiDAR datasets. The Raster Calculator was used to subtract the DTM (bare ground) from the DSM (highest hit or top surface) buffer area. The result is the approximate height of the vegetation in the buffer area. The 2005 data has a native 6ft resolution. To allow for a similar analysis between the 2005 and 2020 datasets, the 2020 dataset was then resampled down from a 1ft to a 6ft resolution, using the aggregate mean of the contributing cells. The 50ft buffer area was then extracted from the vegetation height model for analysis.

Canopy Height values were categorized into 4 groups: Low (0-5 feet), Medium (5-20 feet), High (20-50 feet), and High >50 feet. The total number of contributing raster cells in each category were used to calculate the percent area of each category within the 50ft and 200ft buffer areas.

Although most of the study area is rural or undeveloped along the creek, it should be noted that the few buildings located in the buffer area, as seen in the reaches that flow through Roy, were not removed from the analysis and were included in the vegetated area calculations. Building areas would fall mostly in the medium vegetation category, <20ft in height.

3.7. Aerial Imagery Review

Aerial imagery of ground conditions was visually reviewed systematically for each stream reach. Observed impairments to stream or riparian conditions shown in the imagery were noted, as were apparent restoration opportunities. The image sets primarily used were the most recent sets from the World_Imagery (MapServer) and Google Earth sources.

Observations of impairments and restoration opportunities were compared with the habitat survey data analysis and recommendations from prior reports to yield restoration opportunities which are discussed in Section 4.6 and displayed in the Project Opportunities Maps (Appendix B).

3.8. Flow Connectivity Study-Reach 4

To inform an understanding of streamflow connectivity in Reach 4 and its potential impacts to fish passage, SPSSEG and Coho Water Resources conducted a study of surface and groundwater trends utilizing continuous water level monitoring with digital water surface loggers placed within piezometer ground wells and in the Muck Creek channel (thalweg). Coho Water Resources created the initial study design, assisted with equipment installation, and assisted with data analysis. SPSSEG conducted data collection, field and GIS mapping, and data analysis.

The piezometers were installed at four study locations (Figure 12):

- Site 1: Adjacent (upstream) to the Johnson/Muck confluence,
- Site 2: Adjacent to Highway 7
- Site 3: Within South Creek, near the confluence of the two forks,
- Site 4: Within Muck Creek, near the confluence of the two forks.

Piezometers (wells) were placed in the floodplain in close proximity to the stream channel (5-20 meters) and consisted of 2” slotted PVC pipe. Well holes were dug with a backhoe to the depth of refusal or to an agreed depth adequate for the study, varying between 2.8 to over 7 feet below ground surface. The well pipe was then placed by hand and the spoils were used to fill the hole around the pipe. Paired loggers captured groundwater elevation data and surface water elevation data at each of the four sites, with the exception of Site 2 where only a groundwater logger was installed. The period of data collection was between November 1, 2019 and April 7, 2020, with additional values collected through June 9, 2020 at Site 3.

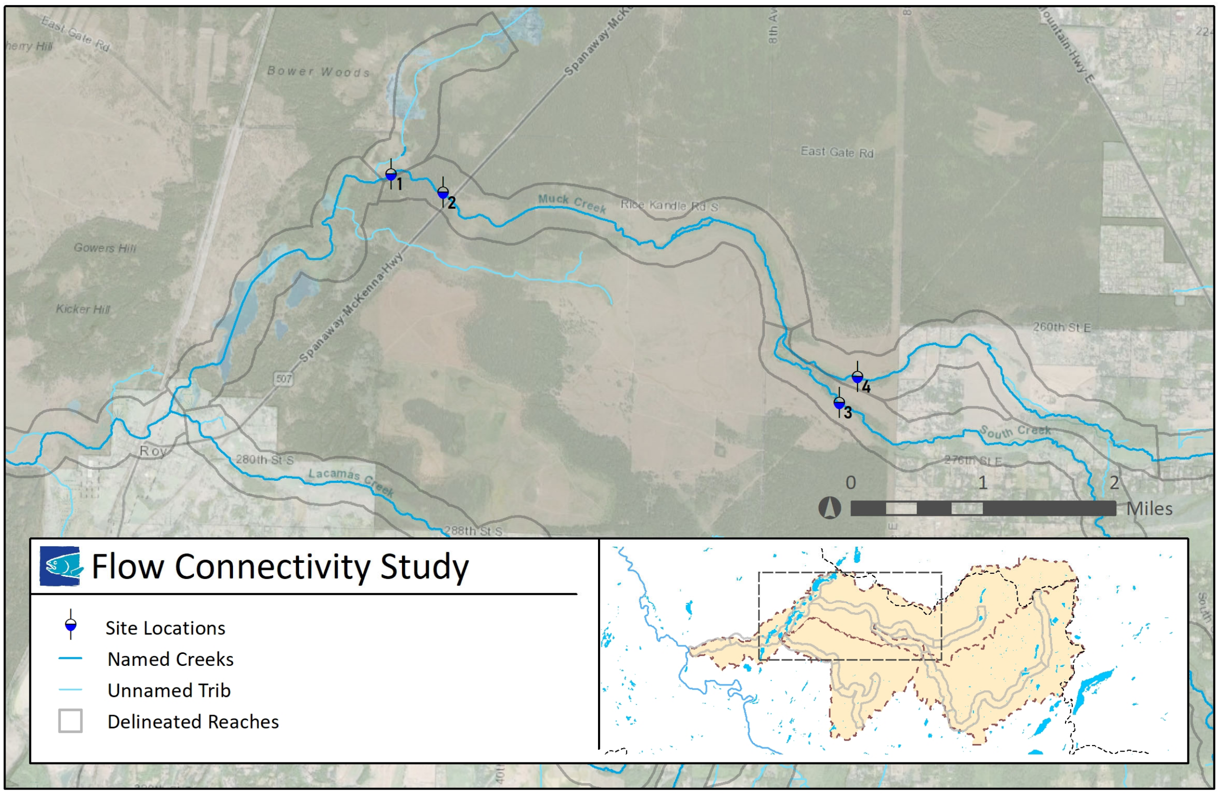

Figure 12. Flow connectivity study sites.

Level Scout water level loggers placed in each of the four piezometers recorded multiple water level readings every fifteen minutes. Additionally, in-stream loggers were installed within the low-flow stream channel thalweg at sites 1, 3, and 4 to allow for comparisons between the groundwater and in-stream water level data.

A subsequent study of surface flow patterns by Coho Water Resources utilizing fixed-location, time-lapse cameras began in 2022 and is currently on-going. Camera 4 (CAM4) is adjacent to Site 1 from the 2019-2020 paired logger site. Time lapse camera results from CAM4 for the period between May 15 – July 5, 2020 show surface flow patterns in relation to precipitation which can be compared with the Site 1 results from the 2019-2020 paired logger study.

Reach 4 was chosen for the flow connectivity study because it is a losing reach with prolonged periods with no stream flow and is also the connecting reach between the lower basin where anadromous fish access occurs annually and the rest of the basin where fish access is limited by flow connectivity. Thus, fish access to the upper half of the basin in a given year is dependent upon flow connectivity in Reach 4. The lack of stream connectivity in this reach was likely always a limiting factor for fish access to the rest of the watershed, with flow connectivity, and thus fish passage, being dependent on precipitation, groundwater and surface flow trends in a given season or year.

Historical, seasonal patterns of flow in this section were likely due to the underlying geologic features and the naturally occurring, well-drained soils across the prairie landscape and gravel outwash plain. However, staff from the JBLM Fish and Wildlife Department (personal communication, 2019) noted a change in the duration and frequency of the streamflow patterns starting sometime between 2005-2010 and continuing to the present time. Notably, three emerging patterns were observed:

1) The duration of continuous, no-flow periods between late-spring and late-fall were becoming longer compared to prior years (observance of dry periods beginning earlier in May in some years and extending longer into December or January)
2) Additional periods of intermittent streamflow loss in winter months following periods of low rainfall were happening earlier than in prior years, in some years (observance of more frequent periods of intermittent flow during winter months)
3) A large pile of stream bed-load cobble began to amass in Muck Creek at the mouth of Johnson Creek during flood events (Figure 13).

These observed trends could have negative impacts on fish passage through Reach 4 in two ways: disconnection of upstream habitat throughout Muck and South Creeks due to reduced flow connectivity, and blockage of fish access to Johnson Creek due to the expanding cobble pile across the mouth of Johnson Creek.

With regard to fish passage and flow connectivity, expanded periods of reduced streamflow, or no streamflow, during the respective late-spring, late-fall, and winter seasons would affect different species in different ways:

- Dec.-Jan.: Delayed replenishment in streamflow after the typical dry summer period of no-flow could block winter chum and early-returning coho salmon from entering and migrating through lower Muck Creek.
- Feb.-March: Expanded periods of reduced flow could impact late-season, spawning coho salmon and migrating juvenile salmon and steelhead.
- March-June: Changes in flow regimes could affect spawning winter steelhead
- May-June: Expanded periods of non-flow could strand eggs or fry of steelhead in the ‘dry’.

Figure 13. Cobble bed load accumulation at mouth of Johnson Creek. Future accumulations in this location could block fish access to Johnson Creek. Photo Credit: Chris Pitre.

3.9. Temperature Sampling and Thermal Infrared Survey of Lacamas Creek

A thermal infrared survey (TIR) of the Lacamas Creek subbasin was performed by Quantum Spatial Incorporated (QSI) to provide a snapshot view of temperature trends in Lacamas Creek during low-flow periods in the summer season (Figure 14). The survey area also included its confluence with Muck Creek at Muck Lake. The goal of this study was to determine 1) if temperatures during the warm, low-flow period fall within optimal, sub-optimal, or lethal ranges for salmonids, and 2) if any cold-water features were present such as springs, seeps, or convergence zones which may be beneficial as thermal refuge for salmonids or otherwise contribute to aquatic habitat.

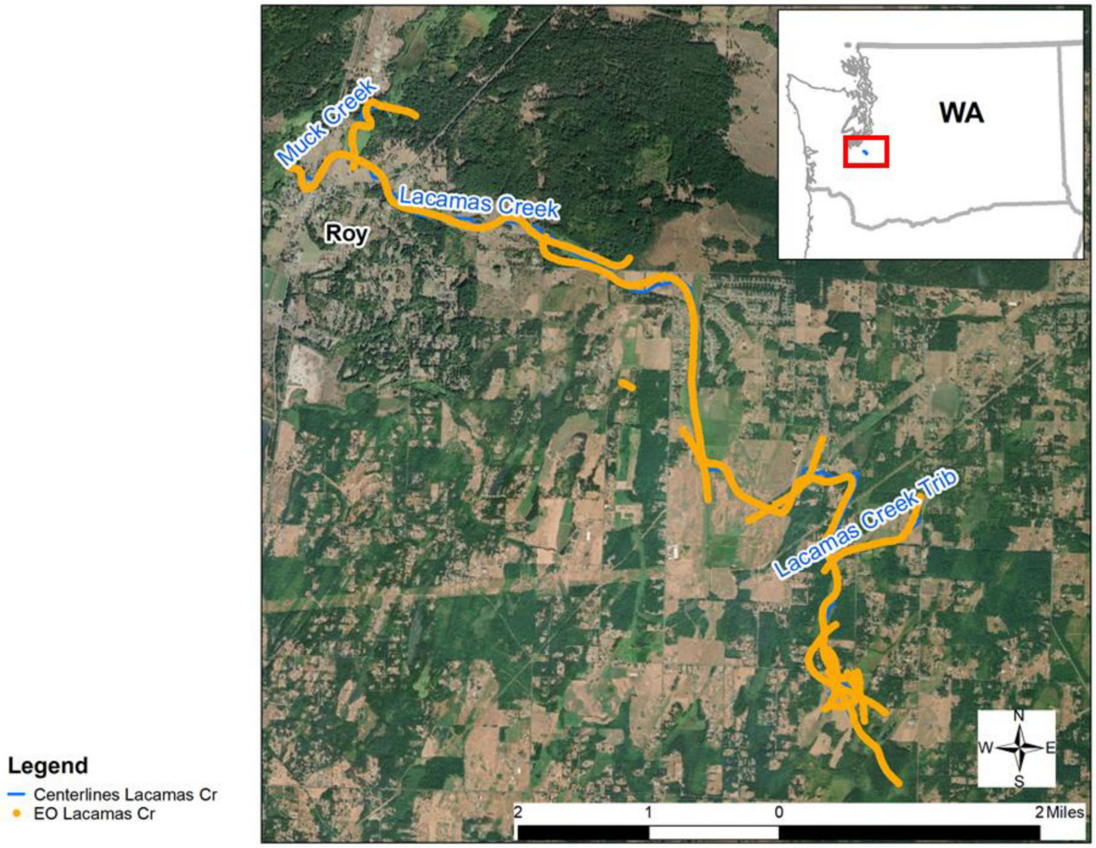

Figure 14. Flight path for the TIR survey along Lacamas and Muck Creeks. From QSI (2020).

The survey was conducted on July 28, 2019 utilizing a helicopter mounted FLIR system SC6000 sensor. In-stream temperature loggers were deployed for calibration purposes.

Sampling the entire Muck Creek basin using TIR would have been cost prohibitive for this project. The Lacamas Creek subbasin was selected for the TIR stream temperature study because sampling of the entire subbasin was achievable, because of the subbasin's importance as a major tributary to Muck Creek which historically hosted all major species of salmonids found across the Muck Creek basin (steelhead, chum, coho, cutthroat), and because of its position in the watershed with a connection to the most anadromous reaches (i.e. downstream of the reaches with the most severe periods of no flow). A small portion of Muck Creek at its confluence with Lacamas Creek was also included in the survey.

The SPSSEG fish presence survey yielded the capture of two juvenile coho salmon in Lacamas Creek at 56th Ave S. confirming that rearing salmonids are using the Lacamas system. Temperature sampling can provide indicators as to whether temperature regimes during low-flow periods and warmer months are in the ranges preferred by various salmonid life history stages and are not exceeding thresholds for sub-optimal or lethal temperature ranges.

Results from the stream habitat surveys were compiled and placed into a data matrix showing current conditions for each habitat attribute, comparative results for the same attributes from prior surveys conducted by other entities (May 2002 and Pierce County 2005), and a Desired Conditions (DC) current ranking (Good, Fair, Poor) based on targets set forth in scientific literature. The DC ranking provides indicators as to which habitat features need improvement to reach optimal, or better, conditions for salmonids. The DC are based on targets suggested in scientific literature—largely from efforts aimed at characterizing the function of salmon habitats (sources are noted in the tables).

Indicators from the DC ranking were then combined with additional quantitative and qualitative summaries derived from the office-based analysis of prior studies, aerial imagery review, field observations, and supplemental field studies including the TIR temperature survey (Lacamas Creek) and the Reach 4 flow connectivity study, to provide a framework for developing project opportunities for habitat restoration and policy or program level achievements for improving aquatic health in the Muck Creek basin. The qualitative metrics are not readily measurable but are included to describe the types of conditions that contribute favorably for salmon.

4. Results and Discussion

Results from the stream habitat surveys were compiled and placed into a habitat results table for each reach showing current conditions for each habitat attribute, comparative results for the same attributes from prior surveys conducted by other entities (May 2002 and Pierce County 2005b), and a Desired Conditions (DC) ranking (Good, Fair, Poor) based on targets set forth in scientific literature. The DC ranking provides indicators as to which habitat features need improvement to reach optimal, or better, conditions for salmonids, based on targets suggested in scientific literature—largely from efforts aimed at characterizing the function of salmon habitats (sources are noted in the tables).

Comparative results for identical or similar data attributes reported in prior studies by May (2002) and Pierce County (2005b) are shown in the habitat results tables as a way to compare results across studies and to show changes in habitat attributes over time. However, it should be noted the habitat survey methods and survey locations used by SPSSEG for this assessment were not identical to those used in the prior studies, although there were some corresponding survey locations and similar field survey methods. Locations of the SPSSEG survey index reaches were largely dictated by access permissions from landowners and the length of each survey index reach varied between reaches. Thus, comparative values and rankings shown between the SPSSEG (2022), May (2002), and Pierce County (2005) studies in the DC ranking column of the habitat results tables likely reflect a range of possible conditions rather than absolute changes in habitat attributes. Additionally, changes in stream condition over the last 20 years likely account for some of the changes in attribute values and rankings.

Indicators from the DC ranking were then combined with additional quantitative and qualitative summaries derived from the office-based analysis of prior studies, aerial imagery review, field observations, and supplemental field studies including the TIR temperature survey (Lacamas Creek) and the Reach 4 flow connectivity study, to provide a framework for developing project opportunities for habitat restoration and policy or program level achievements for improving aquatic health in the Muck Creek basin. The qualitative metrics are not readily measurable but are included to describe the types of conditions that contribute favorably for salmon.

Climate change is expected to negatively impact some of the DC parameters included in the tables. This adds to the challenge of achieving DC while also adding to the urgency of restoring habitats to support salmon populations. DC are aspirational criteria that habitat restoration and conservation efforts should work towards within the context of overall ecosystem health to fully support salmon recovery.

4.1. Habitat Survey Results, Desired Conditions, and Project Opportunities

Separate results for this section are presented for each of the fourteen Reaches in the basin. A summary for each reach highlights the reach's defining characteristics, key attributes, and conditions derived from past and current habitat survey data. This is followed by a matrix showing current data, past data, and Desired Conditions. Results of habitat data collection are also illustrated in the Habitat Survey Maps in Appendix B.

Reach 1: Muck Creek (RM 0-3.0)

Summary
Reach 1 is located entirely within the boundary of Joint Base Lewis-McChord (JBLM). The average gradient of the reach is 3.4% (Martz et al. 2022). The riparian habitat (Figure 15) is characterized as having high riparian integrity, a wide and intact stream buffer with a mix of mature and young conifers, with pockets of deciduous trees such as big-leaf maple along the upland slopes, and mostly deciduous, riparian species along the stream fringe; some areas of the riparian buffer have an open canopy despite mature forest in the lower 2.5 miles, while more of a closed canopy occurs in the upper portion of the reach. LWD presence is poor to fair but with good LWD recruitment potential (May 2002). Sections of the riparian buffer are dominated by deciduous tree species and much of the in-stream logs and woody material is of deciduous species, with conifer logs occurring in low frequencies. Off-channel and rearing habitat is relatively sparse, with some off-channel habitat occurring from RM 2.5 to 3.5 in spring-fed riparian wetlands and beaver ponds (May 2002).

Streamflow often goes dry in sections near the mouth, sometimes with insufficient flows to allow fish access to the main basin until flows recharge (Pierce County 2005a; Kerwin 1999), usually in December or January. Changing flow regimes observed by JBLM Fish and Wildlife in 2021 may be a cause for concern for stranding of steelhead eggs or fry due to loss of flow in areas which typically had enough flow to support these life stages. Streambed substrate is composed of cobble/gravel with minimal embeddedness and few pools present (May 2002)

Reach 1 is known as a key spawning reach spawning reach for steelhead and winter chum, along with reaches 2 and 3, with some coho spawning as well.

Figure 15. Photos of Reach 1 from 5/16/2022 (left) and 6/1/2020 (right).

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 1 (Table 4) found good residual pool depth, poor pool frequency, fair pool quality, fair pool surface area percentage, poor substrate (high amount of fines), gravel-dominated riffles, fair LWD frequency and species composition, and Reed Canary grass (RCG) formations occupying spawning gravel.

Table 4. Habitat survey results for Reach 1. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.66	0.35 (May 2002)	Good	--	Good	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	14.52	37.24 (May 2002)	Poor	--	Good	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	1.30	--	Fair	--	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	31.29	13.60 (May 2002)	Fair	--	Poor	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	58.35	63.37 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	10.36	23.03 (May 2002)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	17.14	--	Poor	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Gravel	primarily large cobble; large gravel; gravel (May 2002)	Good	--	Good	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	195.05	209.33 (May 2002)	Fair	--	Fair	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 1 is high (Table 5). This is an important spawning reach for chum salmon, steelhead, and cutthroat trout (May 2002; Nisqually Indian Tribe, personal communication, 2019; JBLM Fish & Wildlife Staff, personal communication, 2020) and provides some coho spawning habitat (JBLM Fish & Wildlife Staff, personal communication, 2020). Together with Reach 2, this lowest section of Muck Creek provides the majority of remaining spawning habitat for winter chum salmon and winter steelhead, SPSSEG surveys in 2020 and 2022 noted salmonid fry in edge water habitat.

Table 5. Fish use in Reach 1. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho Salmon[1] • Winter Chum Salmon[1] • Winter Steelhead[2] • Cutthroat Trout[2]	• Winter Steelhead[1] • Salmon fry[4]	• Resident Coastal Cutthroat Trout[1]	• Pink (odd year)[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for salmonid habitat in Reach 1 include poor rearing habitat, lack of wetlands and side channels, expanding dry reaches which might threaten redds or young fry, low pool percentage, low pool frequency, low residual pool depth, small bank full width, low LWD frequency, lack of conifer LWD, and prevalence of reed canary grass (RCG).

Reach 2: Muck Creek (RM 3.0-6.1)

Summary

Reach 2 is located primarily on JBLM with the upper portion flowing through the town of Roy. The average gradient of the reach is 0.8% (Martz et al. 2022). Much of the Reach goes dry seasonally. Formerly prairie, the riparian habitat (Figure 16) is characterized as narrow, with sparse cover of mostly young, deciduous trees and shrubs and wetland vegetation, open canopy cover, poor to good LWD present, low riparian integrity, low to good LWD recruitment potential, channelized in several spots, and fragmented by several road crossings as well as the town of Roy (May 2002; Pierce County 2005b).

The streambed is composed primarily of gravel in the lower portion with low embeddedness (May 2002) with silt/gravel/cobble substrate and some hardened banks in the upper portion (Pierce County 2005b). RCG dominates the wetlands in this Reach (May 2002). SPSSEG noted pervasive RCG along much of the stream edges and associated wetlands. JBLM Fish and Wildlife has conducted extensive RCG control efforts in prior years. Flow is intermittent in this reach with dry segments observed in August, September, and October (Pearson and Dion 1979; Wilhelm and Pitre 2021).

Figure 16. Photos of Reach 2 from 5/16/2022.

A 20+ year-old riparian planting project coordinated by the Nisqually Indian Tribe on private land upstream of the Muck Creek bridge in Roy has developed into a well-established riparian buffer, although SPSSEG observed trees showing signs of drought stress in September 2021.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 2 (Table 6) found good residual pool depth, poor pool frequency, poor pool quality, poor pool surface area percentage, good substrate (low amount of fines), gravel-dominated riffles, and very poor LWD frequency.

Table 6. Habitat survey results for Reach 2. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.45	0.91 (PC 2005); 0.47 (May 2002)	**Good**	**Good**	**Good**	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	0.94	1.36 (PC 2005); 14.36 (May 2002)	**Poor**	**Poor**	**Fair**	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	0.5	0.91 (PC 2005)	**Poor**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	0.60	38.98 (PC 2005); 17.2 (May 2002)	**Very Poor**	**Fair**	**Poor**	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	25.96	22.49 (PC 2005); 11.75 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	73.45	0 (PC 2005); 71.05 (May 2002)	--	--	--	--	--
Lakes/wetlands (% Area)	--	38.53 (PC 2005)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	10	--	**Good**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Gravel	small gravel, large gravel (PC 2005); gravel lower, silt upper (May 2002)	**Good**	**Good**	**Fair**	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	56.84	0 (PC 2005); 33.53 (May 2002)	**Very Poor**	**Very Poor**	**Very Poor**	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 2 is high (Table 7). Reach 2 is a known spawning reach for chum salmon, steelhead, and cutthroat trout (May 2002).

Table 7. Fish use in Reach 2. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho Salmon[1] • Winter Chum Salmon[1] • Winter Steelhead[2] • Cutthroat Trout[2]	• Winter Steelhead[1]	• Resident Coastal Cutthroat Trout[1]	• Pink (odd year)[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for salmonid habitat for Reach 2 include shallow residual pool depth, low pool frequency, low pool percentage, low pool quality, high run/glide percentage, summer/fall dry reaches, warm average annual temperatures, low LWD frequency, low riparian integrity, channelization, poor floodplain connectivity, prevalence of invasive species (RCG).

Reach 3: Muck Creek (RM 6.1-9.0)

Summary

Reach 3 extends across private property at the downstream end, including the Muck Lake and Lacamas Creek confluence area, then goes through JBLM upstream of the town of Roy. The average gradient of the reach is 0.3% (Martz et al. 2022). Much of this Reach is dominated by Chambers Lake, Muck Lake, smaller lakes, and a wetland complex. Habitat surveys conducted in this Reach by SPSSEG in 2020 were limited to a small section of the upper Reach; however, an analysis of limiting factors and restoration opportunities was derived from observational and office-based methods and a review of prior identified opportunities, particularly in the lakes region. The riparian habitat is influenced by the large areas of open water in the chain of lakes, with woody vegetation cover being limited to lake-edges in many sections. Riparian cover in streamside areas between the lakes (Figure 17) is relatively intact, mostly consisting of deciduous trees and wetland associated species. LWD recruitment potential is low (May 2002). Pool quantity is low but pool quality is high within this reach (May 2002), although this metric is skewed by the presence of the large, open-water areas. The streambed is composed primarily of silt but with low embeddedness (May 2002). RCG is prevalent within the stream channel (Pierce County 2005b). Flow is perennial in this reach (Wilhelm and Pitre 2021). A former head-gate in structure at the outlet of Chambers Lake was a partial fish barrier and presented issues with flow management. The structure was removed in 2021 allowing for unimpeded passage into the lake.

Figure 17. Photos of Reach 3 from 5/15/2019.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 3 (Table 8) found good residual pool depth, poor pool frequency, poor pool quality, good pool surface area percentage, and poor LWD frequency.

Table 8. Habitat survey results for Reach 3. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.49	1.27 (PC 2005); 0.3 (May 2002)	Good	Good	Good	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	10.21	2.02 (PC 2005); 14.55 (May 2002)	Poor	Poor	Fair	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	0.8	1.78 (PC 2005)	Poor	Fair	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	77.38	18.27 (PC 2005); 10 (May 2002)	Good	Poor	Poor	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	22.62	2.82 (PC 2005); 18.4 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	0	17.30 (PC 2005); 71.60 (May 2002)	--	--	--	--	--
Lakes/wetlands (% Area)	--	61.61 (PC 2005)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	--	--	--	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	--	--	--	--	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	169.16	1.35 (PC 2005); 26.2 (May 2002)	Poor	Poor	Poor	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 3 is moderate (Table 9). There is known presence of chum salmon, steelhead, and cutthroat trout (Martz et al. 2022) and coho salmon (SalmonScape 2022).

Table 9. Fish use in Reach 3. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho Salmon[1] • Winter Chum Salmon[1]		• Resident Coastal Cutthroat Trout[1] • Winter Steelhead[1]	• Pink (odd year)[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for salmonid habitat for Reach 3 include high run/glide percentage, low LWD recruitment potential, low pool percentage, low pool frequency, low pool quality, in the defined stream channels, prevalence of warm-water fish species which are salmon predators, warm temperatures, and potential problems with fish passage through vegetation-choked channels in the lakes and wetlands, and prevalence of invasive species.

Reach 4: Muck Creek (RM 9.0-13.0)

Summary

Reach 4 is located on JBLM upstream of the confluence with Johnson Creek. The lowest section of the reach extends through a fairly well-developed riparian corridor, transitioning to the large prairie-dominated outwash plain above Highway 507. The average gradient of the reach is 0.8% (Martz et al. 2022). Historically, features in this reach may have included extensive riparian wetlands along the edge of the prairie margins, beaver ponds and wetlands, wet and dry prairies in the floodplain, and flow-dependent salmonid use. In 2022, SPSSEG's surveyors observed a lack of fish and aquatic invertebrates, moderate RCG in the stream channel, several ford crossings, and a couple of long riffles with nice spawning gravel and native riparian vegetation (Figure 18). One of the main characteristics of the reach is the presence of dry segments for extended periods of time (Wilhelm and Pitre 2021, Pearson and Dion 1979) which is partially driven by the well-drained soils in the outwash plain. In some years, dry segments have been recorded all months except for April (Pearson and Dion 1979), while in other years, the typical dry period is nonconsecutive with the months of February, May, June, July, September, and November recording zero flow (Wilhelm and Pitre 2021).

Figure 18. Photos of Reach 4 from 4/28/2022.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 4 (Table 10) found good residual pool depth, poor pool frequency, fair pool quality, fair pool surface area percentage, fair substrate (moderate amount of fines), cobble-dominated riffles and glides, and very poor LWD frequency.

Table 10. Habitat survey results for Reach 4. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.43	--	**Good**	--	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	4.54	--	**Poor**	--	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	1.02	--	**Fair**	--	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	42.08	--	**Fair**	--	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	20.53	--	--	--	--	--	--
Runs/Glides (% Area)	37.39	--	--	--	--	--	--
Substrate (SBST)-Average fines % in riffles and glides	16	--	**Fair**	----	----	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)-Dominant Substrate in riffles and glides	Cobble	--	**Good**	--	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	63.96	--	**Very Poor**	--	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 4 is based largely on historical presence with questionable current use (Table 11). There is known presence of coho salmon, chum salmon, steelhead, and cutthroat trout (Martz et al. 2022). Chum salmon were reported to have used this reach for spawning up until sometime in the 1960's and steelhead redds were observed by JBLM Fish and Wildlife Biologist's in the 1970s, although indicators of these species using the reach have been virtually non-existent in the decades since (JBLM Fish & Wildlife Staff, personal communication, 2020).

Table 11. Fish use in Reach 4. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho Salmon[1] • Winter Chum Salmon[1]		• Resident Coastal Cutthroat Trout[1] • Winter Steelhead[1]	• Pink (odd year)[1] • Sockeye[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for salmonid habitat for Reach 4 include absence of flow for large portions of the year in multiple locations and an expanding regime of streamflow loss, prevalence of invasive species, low pool percentage and frequency, high amount of fines in spawning gravel, and low LWD frequency. Loss of historical wetlands may be a limiting factor for restoring salmon habitat.

Reach 5: Muck Creek (RM 13.0-16.6)

Summary

The lower ⅓ of Reach 5 is on JBLM and extends east to the base boundary. The remaining sections of the Reach are primarily on privately owned parcels, with some parcels owned by Pierce County. The average gradient of the reach is 0.8% (Martz et al. 2022). The riparian habitat (Figure 19) is narrow and open, dominated by prairie on JBLM and pasture with sparse deciduous trees and a few 50-year old cedar trees on private properties, low in LWD abundance, very low pool frequency, and abundant RCG (May 2002, Pierce County 2005b). Many of the pasture portions have no riparian vegetation with a silty streambed with moderate embeddedness (Pierce County 2005b). SPSSEG's 2021 survey found that flow is hyporheic in portions of this reach. This reach is characterized by consistently poor habitat with heavy stream channelization and widespread establishment of RCG. Stream sections flowing through the privately owned parcels are mostly channelized and livestock are not excluded from the stream in many places; riparian buffers are sparse. This reach typically has perennial flow (Pearson and Dion 1979).

Figure 19. Photos of Reach 5 from 10/7/2021 (left) and 10/14/2021 (right).

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 5 (Table 12) found good residual pool depth, poor pool frequency, fair pool quality, good pool surface area percentage, poor substrate (high amount of fines), cobble/gravel-dominated riffles, and very poor LWD frequency.

Table 12. Habitat survey results for Reach 5. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.68	0.25 (PC 2005)	**Good**	**Good**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	6.54	3.73 (PC 2005)	**Poor**	**Poor**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	1.20	0.57 (PC 2005)	**Fair**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	64.51	23.58 (PC 2005)	**Good**	**Poor**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	10.38	33.17 (PC 2005); 13.77 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	25.11	43.25 (PC 2005)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	22.00	--	**Poor**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Cobble/Gravel	cobble, large gravel, small gravel (PC 2005)	**Good**	**Good**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	76.04	7.99 (PC 2005); 45.05 (May 2002)	**Very Poor**	**Very Poor**	**Very Poor**	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Anadromous fish use in Reach 5 is questionable, but there is historic documentation of use (Table 13). SPSSEG conducted targeted fish sampling in two sections of stream within this reach. On JBLM, a small beaver dam has provided a pocket of year-round water but no fish of any species were found in the pools or riffles above the dam. Fish sampling at another site in this reach did produce 1 Cutthroat Trout (77mm), but no other salmonids.

Table 13. Fish use in Reach 5. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho Salmon[1] • Winter Chum Salmon[1] • No spawning adult salmon ever[5]	•	• Resident Coastal Cutthroat Trout[4] • Winter Steelhead[1]	• Pink (odd year)[1] • Sockeye[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for Reach 5 include low LWD frequency on private land, low pool frequency, high amount of fine sediment in spawning gravel (embeddedness), high run/glide percentage, narrow riparian, prevalence of invasive species, and channelization.

Reach 6: Muck Creek (RM 16.6-20.0)

Summary

Reach 6, the uppermost portion of North Muck Creek, is comprised of privately owned parcels as well as conservation parcels. The average gradient of the reach is 0.6% (Martz et al. 2022). The riparian habitat (Figure 20) is highly varied in this reach and includes beaver ponds, flooded wetland forests, channelized streams through cattle pastures, and large patches of reed canary grass. SPSSEG located one small man-made rock dam on private property in this reach. Ponded wetlands lower in the reach are formed by beaver dams and have high occurrence of RCG. Stream-wetland complexes in mid-reach sections have diverse riparian assemblages and braided off-channel areas with high water storage potential. This reach has perennial flow (Pearson and Dion 1979).

Figure 20. Photos of Reach 6 from 9/16/2021 (left) and 9/13/2021 (right). Analog section at river mile 19 (left photo) with good in-stream cover, high frequency of wood, and frequent assemblages of native riparian and wetland plants.

A relatively intact stream network within a green space in the lower sections of Reach 6 at River Mile 19 may be an analog for high functioning stream habitat in this reach. A series of flow-through, riverine and palustrine wetlands in this section have an abundance of in-stream wood and woody cover, diverse native plant assemblages, and contributing tributaries from surrounding hillsides. Large, former beaver ponds near River Mile 19 formerly created areas of open water, killing large swaths of older riparian forests. The beavers were subsequently removed and the stream has reverted back to more of a defined channel with some wetland presence, although riparian cover is still impacted by previous flooding caused by the beaver dams. Elsewhere in this reach where shading from riparian vegetation is absent, RCG has taken hold. Several small wetlands offer deep pools but are dominated by RCG.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 6 (Table 14) found good residual pool depth, poor pool frequency, poor pool quality, good pool surface area percentage, poor substrate (high amount of fines), gravel-dominated riffles and glides, and poor LWD frequency.

Table 14. Habitat survey results for Reach 6. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.32	0.24 (PC 2005)	**Good**	**Fair**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	9.53	4.82 (PC 2005)	**Poor**	**Poor**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	0.8	0.71 (PC 2005)	**Poor**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	70.81	13.87 (PC 2005)	**Good**	**Poor**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	16.06	12.98 (PC 2005)	--	--	--	--	--
Runs/Glides (% Area)	13.13	64.70 (PC 2005)	--	--	--	--	--
Lakes/wetlands (% Area)	--	8.46 (PC 2005)	--	--	--	--	--
Substrate (SBST)-Average fines % in riffles and glides	26.67	--	**Poor**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)-Dominant Substrate in riffles and glides	Gravel	sand, silt, small gravel, large gravel, one section mostly pea gravel with medium sand, some cobble (PC 2005)	**Good**	**Good**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	179.34	6.37 (PC 2005)	**Poor**	**Very Poor**	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Reports of historical salmonid usage in Reach 6 are varied (Table 15). Two landowners have observed salmon once each in the past 50 years: one dead salmon after flooding in the late 1970s and one chum salmon in the early 1980s (Landowners, personal communication, 2021). One landowner reported frequent sightings of trout in the stream at night. Coho salmon have historically been documented in this reach (Martz et al. 2022), although informal stocking efforts by residents may have contributed to salmon presence in this reach. The SPSSEG habitat survey in 2021 observed a 12" cutthroat trout, 5" trout, freshwater mussels, sticklebacks, and signal crawfish.

Table 15. Fish use in Reach 6. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Cutthroat Trout[3] • Salmon seen only twice in last 50 years[5]	•	• Resident Coastal Cutthroat Trout[4] • Winter Steelhead[1] (presumed) • Coho Salmon[1]	• Pink (odd year)[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for Reach 6 include low pool frequency, low pool quality, low LWD frequency, high run/glide percentage, prevalence of invasive species, several fish passage barriers, and high embeddedness.

Reach 7: South Creek (RM 0.0-3.5)

Summary

Reach 7's lower section extends from the confluence with Reach 5 (Muck Creek) easterly to the JBLM boundary, then continues upstream across privately-owned parcels. The average gradient of the reach is 1.0% (Martz et al. 2022). A riparian corridor is absent in several stretches of agricultural land and where it is present (Figure 21), it is narrow with scattered deciduous trees including mature maple, cottonwood, and alders (Pierce County 2005b). RCG is prevalent in areas not shaded by trees. This reach is largely characterized by channelized runs/glides with low habitat complexity for long stretches through pasture lands. Cutthroat redds have been observed in ½"-1" sized gravel, however much of the reach is poor habitat with heavy amounts of fine sediment substrate, moderate embeddedness, hardened banks, limited LWD, and low to moderate presence of shallow pools (Pierce County 2005b). In segments where cedar trees or other large riparian trees (e.g. 3-6' diameter maples) are present, habitat improves dramatically (Pierce County 2005b). Historically, this reach had perennial flow (Pearson and Dion 1979); however, recent observations have recorded dry segments in the months of June, July, August, September, October and November (Wilhelm and Pitre 2021).

Figure 21. Photos of Reach 7 from 5/4/2022 (left) and 6/10/2020 (right).

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey efforts in Reach 7 (Table 16) were limited due to lack of access; however, SPSSEG found good substrate (low amount of fines), gravel-dominated riffles and glides, and very poor LWD frequency.

Table 16. Habitat survey results for Reach 7. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	--	1.76 (PC 2005)	--	**Good**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	--	13.05 (PC 2005)	--	**Fair**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	--	2.05 (PC 2005)	--	**Good**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	--	44.85% (PC 2005)	--	**Fair**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	20.26	28.18 (PC 2005)	--	--	--	--	--
Runs/Glides (% Area)	79.74	26.96 (PC 2005)	--	--	--	--	--
Substrate (SBST)-Average fines % in riffles and glides	10	--	**Good**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)-Dominant Substrate in riffles and glides	Gravel	Large gravel, cobble, small gravel, sand (PC 2005)	**Good**	**Good**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	0.00	5.66 (PC 2005)	**Very Poor**	**Very Poor**	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Anadromous fish use in Reach 7 (Table 17) is not well documented. Salmonscape (2022) lists winter steelhead and winter chum as presumed presence, while coho salmon are documented but specific life stages are not. Pierce County (2005b) noted cutthroat redds and numerous 2-3" trout and sticklebacks have been observed in areas associated with a wide, meandering channel, deep corner pools, point bars, side channels, mayfly larva on rocks in riffles, and good spawning gravel.

Table 17. Fish use in Reach 7. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Cutthroat Trout[3]	•	• Resident Coastal Cutthroat Trout[1] • Coho Salmon[1]	• Pink (odd year)[1] • Sockeye[1] • Fall Chinook Salmon[1] • Winter Chum Salmon[1] • Winter Steelhead[1]

Reach Challenges

The key challenges for Reach 7 include narrow riparian buffers, channelization, extended dry stretches through summer and fall throughout the reach, low LWD frequency, loss of historical wetlands.

Reach 8: South Creek (RM 3.5-7.6)

Summary

Reach 8 is primarily within privately owned parcels, with one large parcel owned by the Shoalwater Bay Tribe. The average gradient of the reach is 1.2% (Martz et al. 2022). The riparian habitat (Figure 22) in this reach is largely deciduous with abundant alders (some 70+ years old) and willows (Pierce County 2005b). RCG is prevalent throughout the reach. The streambed is largely gravel with sand and fines, highly embedded in the channelized slough-like segments, but excellent spawning gravel in riffle segments; LWD is limited and pool presence is moderate (Pierce County 2005b). SPSSEG surveyors noted that this reach is intermittently dry in late summer with subsurface flow connecting wetted pools and dry reaches of over 150 meters in the upper portion of the reach. Landowners note that flow is perennial, however, and it will be just a trickle between the pools in late summer. During periods of high rain in winter, the creek jumps its banks and floods the lowland forest. One landowner states that the stream is perennial with minimal flow on their property but dries up around 304th Street near the power lines (Landowners, personal communication, 2021). Past surveys located a large, flooded wetland with 36+" cedars, dense riparian vegetation, and unusually high-quality pool-riffle habitat with cobble riffle steps and side channels with islands (Pierce County 2005b). Wildlife is abundant in this reach, likely owing to the occurrence of connected green corridors. RCG invasion is extremely high where power lines cut through the riparian corridor, obscuring the streambed. The upper third of this reach has a history of intermittent flow with dry segments occasionally observed in the months of September and November (Wilhelm and Pitre 2021).

Figure 22. Photos of Reach 8 from 9/14/2021.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 8 (Table 18) found good residual pool depth, poor pool frequency, fair pool quality, fair pool surface area percentage, fair substrate (moderate amount of fines), gravel-dominated riffles and glides, and very poor LWD frequency. SPSSEG surveyors noted signs of beaver activity but no indications of well-developed beaver ponds in the survey areas.

Table 18. Habitat survey results for Reach 8. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.51	0.92 (PC 2005)	**Good**	**Good**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	20.09	9.17 (PC 2005)	**Poor**	**Poor**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	1.10	1.25 (PC 2005)	**Fair**	**Fair**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	50.87	34.20 (PC 2005)	**Fair**	**Poor**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	25.89	20.47 (PC 2005)	--	--	--	--	--
Runs/Glides (% Area)	23.24	45.33 (PC 2005)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	15.00	--	**Fair**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Gravel	Large gravel, cobble, small gravel, sand, silt (PC 2005)	**Good**	**Good**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	59.13	10.20 (PC 2005)	**Very Poor**	**Very Poor**	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 8 (Table 19) is mostly limited to resident fish with the potential for anadromous fish. The pools could offer good refuge habitat for salmonids, but no fish were observed during the 2021 survey. A landowner's grandfather recalled that salmon used to run up the creek and they would find post-spawn carcasses on the riverbanks but that salmon stopped coming in subsequent generations (around 1960s).

Table 19. Fish use in Reach 8. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible or Presumed Presence (2)
• Anecdotal evidence of spawning salmon[5]	•	• Resident Coastal Cutthroat Trout[1] • Coho Salmon[1]	• Pink (odd year)[1] • Sockeye[1] • Fall Chinook Salmon[1] • (2) Winter Chum Salmon[1] • Winter Steelhead[1]

Reach Challenges

The key challenges for Reach 8 include high run/glide percentage, summer/fall dry stream areas, low pool frequency, moderate embeddedness, low LWD frequency, and prevalence of invasive species.

Reach 9: South Creek (RM 7.6-15.4)

Summary
Reach 9 is comprised of large, privately-owned parcels with many used for agriculture at various scales. The average gradient of the reach is 1.0% (Martz et al. 2022). This reach is characterized by moderate livestock use, with some direct creek access for stock animals, prevalence of RCG, eroding banks, slough-like runs, limited LWD, large cobble-gravel with sand and fine sediment, low embeddedness, and a few pool-riffle sequences (Pierce County 2005b). Livestock ranches have minimal riparian vegetation (Figure 23) and allow for direct access to the stream for the cattle. Stream bank full width is quite wide and transports high flow in winter, however, the stream is dry for much of the spring and summer in this reach, typically drying up in May or June. This reach has recorded dry segments in the months of July, September, and November (Wilhelm and Pitre 2021). Many of the longer tributaries in this reach have been channelized, effectively reducing surface storage and groundwater recharge, and in stream habitat. Many historical wetlands in Reach 9 have likely been reduced or impacted by changes to the stream network.

Figure 23. Photos of Reach 9 from 5/4/2022 (left) and 9/14/2021 (right).

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 9 (Table 20) found good residual pool depth, poor pool frequency, fair pool quality, poor pool surface area percentage, good substrate (low amount of fines), cobble-dominated riffles and glides, and very poor LWD frequency.

Table 20. Habitat survey results for Reach 9. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.66	0.57 (PC 2005)	**Good**	**Good**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	5.94	11.08 (PC 2005)	**Poor**	**Poor**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	1.01	0.71 (PC 2005)	**Fair**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	14.65	23.62 (PC 2005)	**Poor**	**Poor**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	85.35	23.21 (PC 2005)	--	--	--	--	--
Runs/Glides (% Area)	0.00	45.33 (PC 2005)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	10.00	--	**Good**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Cobble	Large gravel, cobble, small gravel (PC 2005)	**Good**	**Good**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	0.00	2.01 (PC 2005)	**Very Poor**	**Very Poor**	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use in Reach 9 is primarily restricted to resident fishes (Table 21). However, potential genetic interchange between resident rainbow trout and anadromous steelhead life history types of *O. mykiss* is poorly understood. One landowner and their family have owned properties along the stream for several decades; the current owner reported having not seen salmon or steelhead in his lifetime (other than escaped fish from a reported fish stocking operation that flooded in 1996), however cutthroat trout have regularly been seen (Landowner, personal communication, 2021). While there is cutthroat trout presence, fish sampling at the upper end of Reach 9 in 2021 revealed sculpin and stickleback, but no salmonids.

Table 21. Fish use in Reach 9. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• No spawning adult salmon ever seen[5]	•	• Resident Coastal Cutthroat Trout[1] • Coho Salmon[1]	• Pink (odd year)[1] • Sockeye[1] • Fall Chinook Salmon[1] • Winter Steelhead[1]

Reach Challenges

The key challenges for Reach 9 include stream channelization, high run/glide percentage, low pool frequency, low pool percentage, low LWD frequency, summer-fall dry stream areas, prevalence of invasive species, lack of riparian vegetation, impacts from livestock use of streams, and lost or impacted floodplain wetlands.

Reach 10: South Creek (RM 15.4-19.3)

Summary
Reach 10 is located primarily within privately-owned parcels at the uppermost end of South Creek. The average gradient of the reach is 2.8% (Martz et al. 2022). This reach has recorded dry conditions in the months of September and November (Wilhelm and Pitre 2021). No habitat surveys were conducted in this reach by SPSSEG in 2020-2022. Past survey efforts did not cover this reach either (Pierce County 2005a).

Similar to Reach 9, salmonid usage in Reach 10 is likely limited to resident salmonids. However, potential genetic interchange between resident rainbow trout and anadromous steelhead life history types of *O. mykiss* is poorly understood.

Habitat Survey Results
No data is available.

Fish Use
Fish use in Reach 10 is questionable (Table 22).

Table 22. Fish use in Reach 10. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
•	•	•	• Pink (odd year)[1] • Fall Chinook Salmon[1]

Reach Challenges
The key challenges for Reach 10 include several fish passage barriers and late summer/fall dry segments. Loss of historical wetlands and channelized stream sections may impact watershed functional processes.

Reach 11: Johnson Creek (RM 0.0-1.7)

Summary

Reach 11 is located upstream of the Chambers Lake wetland-lake complex and includes Johnson Creek and Johnson Marsh. The average gradient of the reach is 0.9% (Martz et al. 2022). Stream substrate below Johnson Marsh (Finch Lake) is primarily gravel with low embeddedness; pool quantity and quality are low (May 2002). There is perennial flow in this reach (Wilhelm and Pitre 2021). No habitat surveys were conducted in this reach by SPSSEG in 2020-2022 due to the limited length of this reach and relatively known conditions.

Habitat Survey Results

Prior habitat survey efforts in Reach 11 (Table 23) found poor residual pool depth and frequency and low LWD frequency. JBLM Fish and Wildlife provided suggestions for habitat improvement projects.

Table 23. Habitat survey results for Reach 11. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	--	0.08 (May 2002)	--	--	**Poor**	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	--	28.57 (May 2002)	--	--	**Fair**	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	--	--	--	--	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	--	25.8 (May 2002)	--	--	**Poor**	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	--	53.1 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	--	21.10 (May 2002)	--	--	--	--	--
Substrate (SBST)-Average fines % in riffles and glides	--	--	--	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)-Dominant Substrate in riffles and glides	--	gravel (May 2002)	--	--	**Good**	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	--	85.7 (May 2002)	--	--	**Very Poor**	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Fish use potential in Johnson Creek is moderate to high (Table 24). There is documented chum salmon spawning and coho salmon presence in this reach (Martz et al. 2022).

Table 24. Fish use in Reach 11. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Winter Chum[1] • Coho Salmon[1]	•	• Resident Coastal Cutthroat Trout[1]	• Pink salmon (odd year)[1] • Sockeye salmon[1] • Fall Chinook Salmon[1] • Winter Steelhead[1]

Reach Challenges

The key challenges for Reach 11 include shallow residual pool depth, low pool quantity, a disconnection of springs to the main channel, and reduced fish passage through the channel throughout Johnson Marsh due to vegetation blockages.

Reach 12: Lacamas Creek (RM 0.0-3.4)

Summary

Reach 12 consists of primarily large, privately-owned properties with a small section located on JBLM. The average gradient of the reach is 1.2% (Martz et al. 2022). The riparian habitat (Figure 24) in this reach is generally poor with RCG highly prevalent and cattle grazing access to the stream. One segment was dredged in the 1970s while many others have been channelized through agricultural parcels (Pierce County 2005b). Long runs/glides dominate the stream channel with moderate embeddedness of gravel/cobble underneath an organic/silt veneer of 6-12" (Pierce County 2005b). Vegetated riparian segments are sparsely populated with deciduous trees, specifically alders of 12-15" diameter, with low quantity of LWD but fair LWD recruitment potential (Pierce County 2005b; May 2002). SPSSEG observed orange-brown sediment and moderately warm stream temperatures (15.6 deg C) in a shallow, mucky, section of the stream at 280th Street. RCG was particularly prevalent in wetlands. Pools were few, shallow, and of low quality in agricultural segments. Lack of exclusion fencing allows livestock to directly access the stream in many sections; channelized sections are also prevalent. Riparian buffers are non-existent, narrow, or in poor condition. SPSSEG noted an absence of observed fish and aquatic invertebrates. Landowners have noted that some segments are dry from September to November. There is additional documentation of no flow in July of some years (Wilhelm and Pitre 2021).

Figure 24. Photos of Reach 12 from 10/7/2021 (left) and 9/15/2021 (center and right).

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 12 (Table 25) found good residual pool depth, poor pool frequency, poor pool quality, fair pool surface area percentage, poor substrate (high amount of fines), gravel/cobble-dominated riffles and glides, and poor LWD frequency.

Table 25. Habitat survey results for Reach 12. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.42	0.15 (PC 2005); 0.24 (May 2002)	**Good**	**Poor**	**Good**	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	11.98	7.66 (PC 2005); 20 (May 2002)	**Poor**	**Poor**	**Poor**	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	0.90	0.48 (PC 2005)	**Poor**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	40.95	22.25 (PC 2005); 36.7 (May 2002)	**Fair**	**Poor**	**Poor**	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	42.07	28.41 (PC 2005); 5.7 (May 2002)	--	--	--	--	--
Runs/Glides (% Area)	16.98	49.34 (PC 2005); 57.60 (May 2002)	--	--	--	--	--
Substrate (SBST)- Average fines % in riffles and glides	23.33	--	**Poor**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)- Dominant Substrate in riffles and glides	Gravel/ Cobble	small gravel, large gravel (PC 2005); gravel (May 2002)	**Good**	**Good**	**Good**	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	105.64	5.93 (PC 2005); 20 (May 2002)	**Poor**	**Very Poor**	**Very Poor**	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

Anadromous and resident fish use of Reach 12 is high (Table 26). One landowner noted historical presence of trout and salmon near the mouth of Lacamas Creek until sometime in the 1970s.

There is documented chum and coho salmon spawning and potential steelhead and cutthroat trout presence (Martz et al. 2022). Fish sampling in fall 2021 with WDFW at 56th Ave captured 2 juvenile coho salmon (78mm and 89mm FL) (Figure 26) and 10 cutthroat trout (65-249mm FL) indicating the anadromous connectivity and importance of Lacamas Creek for salmonids. The stream segment above the captured coho salmon had 6-12" of suspended orange-brown sediment.

Table 26. Fish use in Reach 12. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Winter Chum[1] • Coho Salmon[1] • Salmon and trout regularly use[5] • One dead chum salmon after flooding in 1970s[5]	• Coho salmon[4] • Cutthroat Trout[4]	• Resident Coastal Cutthroat Trout[1]	• Pink salmon (odd year)[1] • Sockeye salmon[1] • Fall Chinook Salmon[1] • Winter Steelhead[1]

Figure 25. Photo of juvenile coho salmon captured in Reach 12 on 10/7/2021.

Reach Challenges

The key challenges for Reach 12 include shallow residual pool depth, high run/glide percentage, low pool frequency, low pool quality, summer dry stretches, high prevalence of invasive species, low LWD frequency, channelization, narrow or nonexistent riparian buffer, livestock in the stream, and high embeddedness/fines in spawning gravel.

Reach 13: Lacamas Creek (RM 3.4-4.7)

Summary

Reach 13 is comprised of privately-owned parcels. The average gradient of the reach is 0.04% (Martz et al. 2022). It is characterized by a sparse deciduous/shrub riparian, low quantity of LWD, and limited riparian buffer in grazed areas (Pierce County 2005b). No dry reaches were noted in past research efforts (Wilhelm and Pitre 2021). No habitat surveys were conducted in this reach by SPSSEG in 2020-2022.

Habitat Survey Results

No data is available.

Fish Use

There is documented coho spawning and potential chum salmon, steelhead, and cutthroat trout presence in this reach.

Table 27. Fish use in Reach 13. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
• Coho salmon[1] • Winter chum[1]	• Coho salmon, presumed	• Resident Coastal Cutthroat Trout[1]	• Pink salmon (odd year)[1] • Sockeye salmon[1] • Fall Chinook Salmon[1] • Winter Steelhead[1]

Reach Challenges

The key challenges for Reach 13 include minimal riparian buffer, low LWD quantity, livestock impacts from direct access to the stream, and impacts to historical wetlands.

Reach 14: Lacamas Creek (RM 4.7-8.7)

Summary

Reach 14 is a mix of agricultural and forested privately-owned parcels. The average gradient of the reach is 1.1% (Martz et al. 2022). The agricultural sections include channelized segments of stream in heavily grazed pasture with cut banks and cattle access to the stream as well as check dams and log weirs on one property (Pierce County 2005b). This reach has very high embeddedness (Pierce County 2005b). Forested segments surveyed by SPSSEG in 2021 were characterized by shallow water depth, large cobble substrate, and very few pools. Segments of dense deciduous riparian vegetation were interrupted by open pasture and open RCG choked wetlands with deep pools (Figure 26). No dry segments were noted in this reach as part of past survey efforts (Wilhelm and Pitre 2021).

Figure 26. Photos of Reach 14 from 9/23/2021.

Habitat Survey Results

SPSSEG's 2020-2022 habitat survey effort in Reach 14 (Table 28) found good residual pool depth, poor pool frequency, poor pool quality, poor pool surface area percentage, poor substrate (high amount of fines), cobble-dominated riffles and glides, and fair LWD frequency.

Table 28. Habitat survey results for Reach 14. Data show current conditions from SPSSEG's 2020-2022 surveys, past conditions from prior survey efforts, and the current rating of each parameter compared to target desired conditions. Data sources: [1] Pleus et al. 1999, [2] NOAA-NMFS 1996, [3] Schuett-Hames et al. 1996, [4] WFGC 1997, [5] WFPB 1997, [6] NOAA-Fisheries 1996, [7] HCCC 2005, [8] Fox and Bolton 2007.

	Current Conditions	Prior Surveyed Conditions	Desired Conditions Ranking			Target	Source
			2022	2005	2002		
Residual pool depth (RPD)	0.43	0.16 (PC 2005)	**Good**	**Fair**	--	if BFW 2.5-5.0 m, then 0.20 m if BFW 5-10 m, then 0.25 m if BFW 10-15 m, then 0.30 m	1
Average #Pools/km	10.09	12.11 (PC 2005)	**Poor**	**Poor**	--	if BFW 5-6m, >34 (pools per km) if BFW 6.01-7.5m, >29 if BFW 7.51-10m, >16 if BFW 10.01-15m, >16	2
Pool Quality (Maximum Pool Depth)	0.61	0.51 (PC 2005)	**Poor**	**Poor**	--	pools >1 m deep with good cover and cool water Poor: no deep pools and inadequate cover or temperature, major reduction of pool volume by sediment Fair: few deep pools or inadequate cover or temperature, moderate reduction of pool volume by sediment Good: sufficient deep pools	4 5 6
Pools (%Area)	16.74109294	72.22 (PC 2005)	**Poor**	**Good**	--	if <2% gradient, then >55% of surface area is pools if 2%-5% gradient, then >40% of surface area is pools if >5% gradient, then >30% of surface area is pools	3
Riffles (% Area)	65.15	9.03 (PC 2005)	**--**	**--**	--	**--**	**--**
Runs/Glides (% Area)	18.11	18.75 (PC 2005)	**--**	**--**	--	**--**	**--**
Substrate (SBST)-Average fines % in riffles and glides	28.57	**--**	**Poor**	--	--	<11% fines (<0.85 mm) within spawning habitat units such as riffles, pool tails, and glides. Poor >17% Fair 11-17% Good <11%	4 5 6 7
Substrate (SBST)-Dominant Substrate in riffles and glides	Cobble	sand, silt, minimal amount of small gravel (PC 2005)	**Good**	**Poor**	--	gravel (2.5 mm - 76 mm) or cobble (76 mm - 305 mm) within spawning habitat units such as riffles, pool tails, and glides.	2
LWD Frequency (#/km)	200.74	2.79 (PC 2005)	**Fair**	**Very Poor**	--	LWD size: diameter>10cm, length>2m if BFW 5-6 m, then>380 pieces if BFW 6-10 m, then 630 pieces if BFW 10-20 m, then 630 pieces	8

Fish Use

There is potential cutthroat trout presence in Reach 14 with a low enough gradient that salmonids could theoretically be present as well (Table 29).

Table 29. Fish use in Reach 14. Data sources: [1] WDFW SalmonScape 2022, [2] May 2002, [3] Pierce County 2005b, [4] SPSSEG fish sampling, [5] Landowners, personal communication, 2021

Spawning	Rearing	Documented Presence	Gradient Accessible Presence
•	•	•	• Pink salmon (odd year)[1] • Sockeye salmon[1] • Fall Chinook Salmon[1]

Reach Challenges

The key challenges for Reach 14 include shallow residual pool depth, very high embeddedness/fines in spawning gravel, low pool frequency, low pool area, low pool quality, prevalence of RCG, channelization, low LWD frequency, cattle stream use, several fish passage barriers, and impacts to historical wetlands.

4.2. Riparian Buffer Vegetation Model

The Riparian Buffer Vegetation Model illustrates the riparian vegetation conditions for canopy height and percent vegetated buffer within both the 50ft and 200ft buffer areas along the stream network. With closer inspection, the map results can also be used as a tool for restoration practitioners to visually target planting areas lacking in riparian vegetation. Results from the Riparian Buffer Vegetation Model are shown on individual maps for each reach and accompany the Habitat Survey Index Reach Maps in Appendix B.

Practitioners developing riparian planting plans may want to set differing, target vegetation communities to match riparian ecosystem or habitat types. Notably, riparian plant communities within the large prairie landscapes in the basin historically consisted of prairie-stream vegetation assemblages, differing from other riparian habitat types, such as upland forests or wetlands. Suggested analog sites are presented for matching good-quality riparian conditions for prairie-type and upland forest-type riparian zones. Figure 27 shows a prairie riparian analog site in survey reach 12.1. The riparian zone within this analog site consists of older trees (greater than 50 feet in height), of species associated with historical prairie-edge riparian zones (E.g. Oregon ash, black hawthorne, black cottonwood).

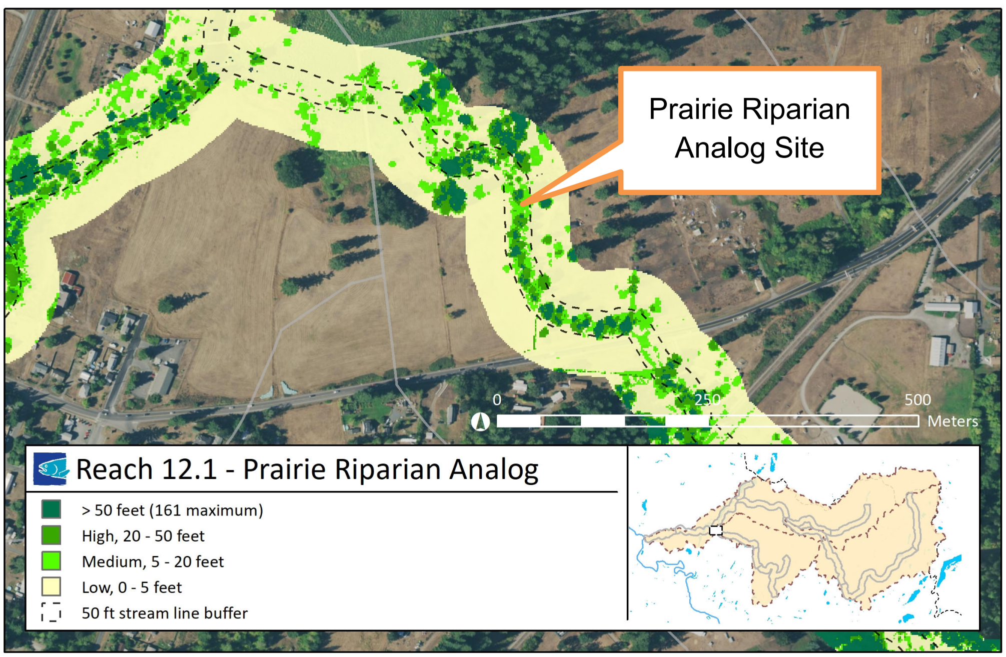

Figure 27. Prairie Riparian Analog Site.

Figure 28. shows an upland forest riparian analog site. The riparian zone within this analog site consists of older trees (greater than 50 feet in height), of species associated with upland forest riparian zones (E.g. Douglas fir and bigleaf maple).

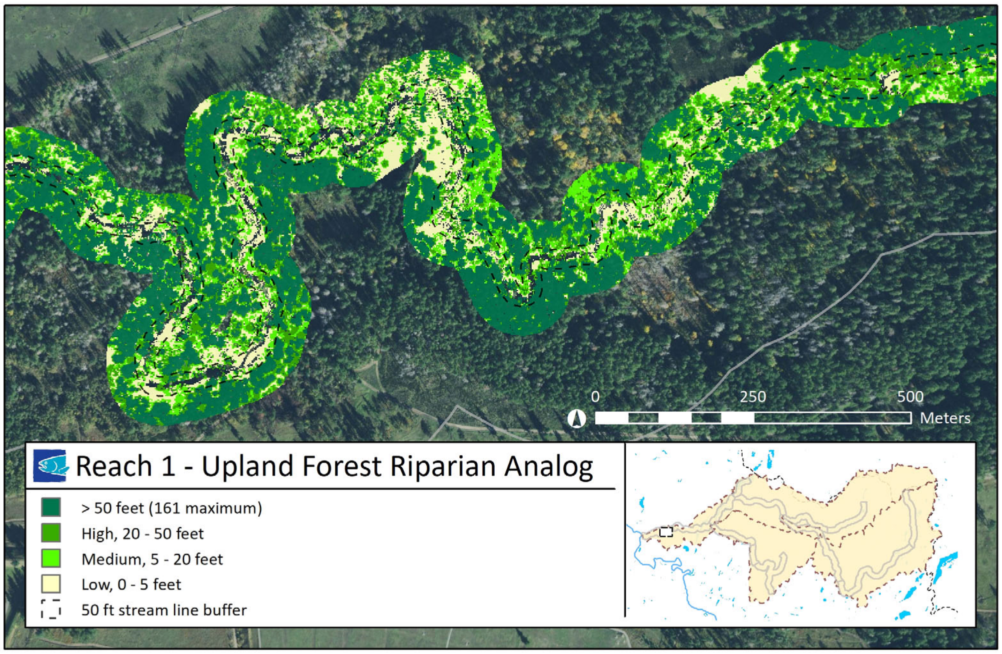

Figure 28. Upland Forest Riparian Analog Site.

4.3. Flow Connectivity Study-Reach 4

For the 2019-2020 study, groundwater and surface water trends at each of the four sites shared some similarities, with some distinct differences. There was a strong correlation between precipitation and groundwater at all four sites. Groundwater levels were several feet below ground surface (GS) and the elevation of the piezometer loggers were thus undetectable at all four sites through November, 2019, with levels sharply rising in late December at sites 1, 3 and 4 after a significant rain event.

Results from the paired piezometer-thalweg data loggers showing the relationship between precipitation, groundwater, and surface water for 2019-2020 are shown in Figure 27. The initial groundwater elevation rise at Site 2 occurred several days later than at the other sites. Groundwater levels crested GS at Site 3 (South Creek) in late December and stayed above or near GS for much of January and February, fluctuating up or down after rain events or periods of low precipitation. Groundwater levels at Site 4 (North Muck Creek) never crested GS or spilled into the floodplain however trends for both groundwater and surface water were similar between Sites 3 and 4, with both sites having high groundwater and surface flow for extended periods in January and February. While groundwater levels were influenced by precipitation, surface flow at sites 3 and 4 likewise correlated with high groundwater. Surface flow emerged into the dry stream channels following the rise in groundwater levels and the subsequent periods of high groundwater near or above the thalweg elevations. Site 4 exhibited similar trends as sites 3 and 4 but had shorter durations of surface flow.

Data capture for the groundwater wells at Site 1 and 4 was effectively cut short due to the logger being unintentionally pulled up high in the well column. We surmise this was caused by a deer or some type of animal which pulled the logger cable. However, based on the trends in precipitation, and groundwater data from the other study sites, there is some inference that groundwater levels were generally decreasing from April through May, 2020 with short duration spikes following rain events.

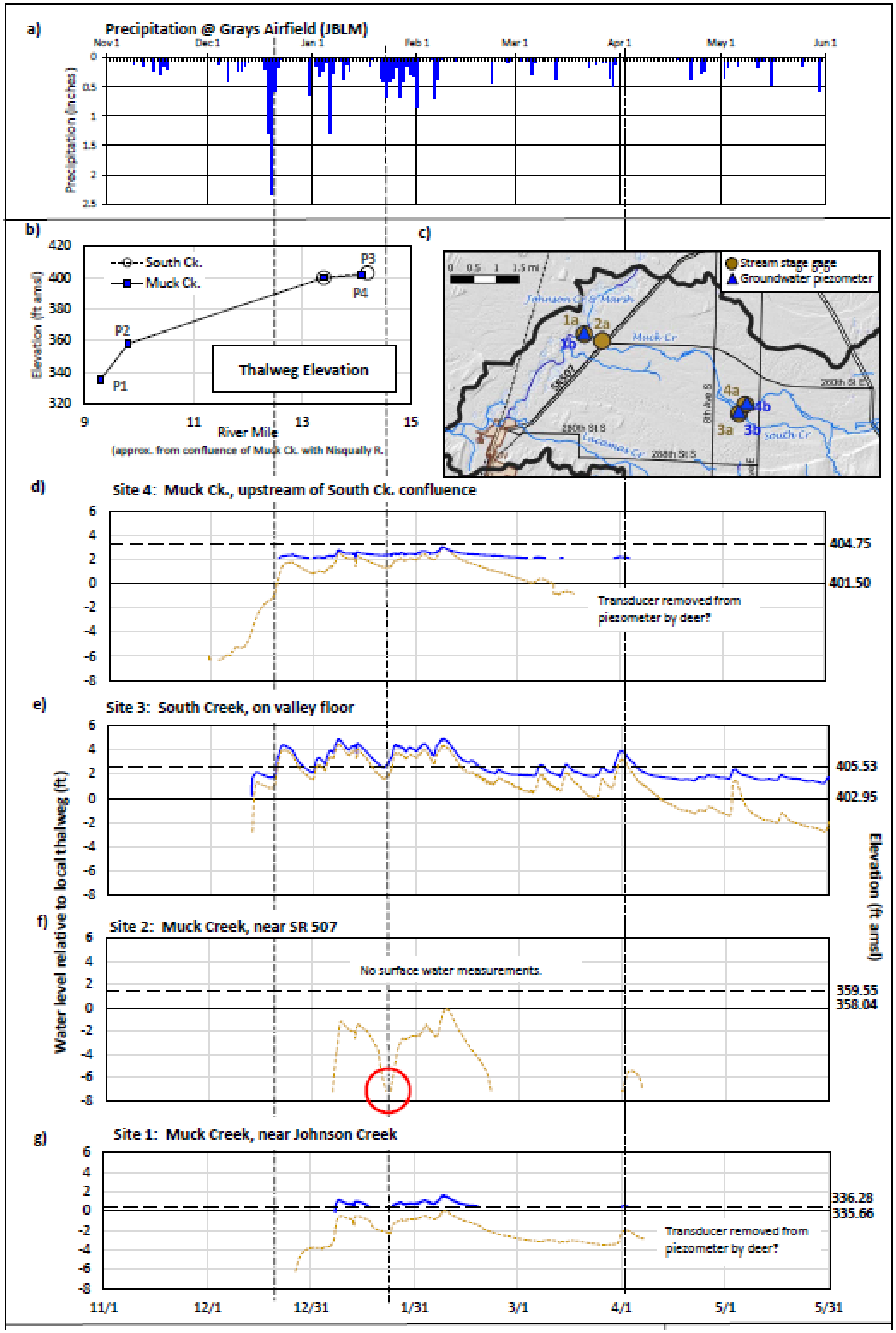

Figure 29. Relative groundwater and surface water elevations from paired piezometer and thalweg (surface) loggers, and precipitation at sites 1-4 between November 2019 and May 2020. Site 2 only shows groundwater elevations (from Wilhelm and Pitre 2021).

Site 2 differed from the other sites in exhibiting a sharp decrease in groundwater levels following periods of relatively low precipitation in mid-January and then again in February, 2020. Groundwater levels at Site 2 displayed a tendency to both respond slower to rising water levels following rain events and a tendency to drop faster following periods of low precipitation. Because of the large fluctuations in groundwater levels and the associated surface water levels at Site 2, this site may be a sink for ground and surface water flowing from the upstream areas to the downstream Site 1, possibly influencing flow connectivity at Site 1 and the downstream reaches.

From the 2022 camera study, surface flow occurred in Muck Creek near Site 1 for several days in mid-May, went sub-surface in Late-May, then exhibited additional periods of flow and dryness in June, correlating closely with precipitation trends (Figure 28). Precipitation trends during the 2020 ground-surface water study and the 2022 streamflow, camera study differed during each respective year, with inverse precipitation trends from April through May (i.e. spring of 2020 was a relatively dry period while spring of 2022 was a relatively wet period). Subsequently, there was no surface flow at Site 1 in May or June, 2020, while there was flow during that same period in 2022. The data for precipitation and streamflow correlations suggest that streamflow and groundwater trends are strongly influenced by precipitation.

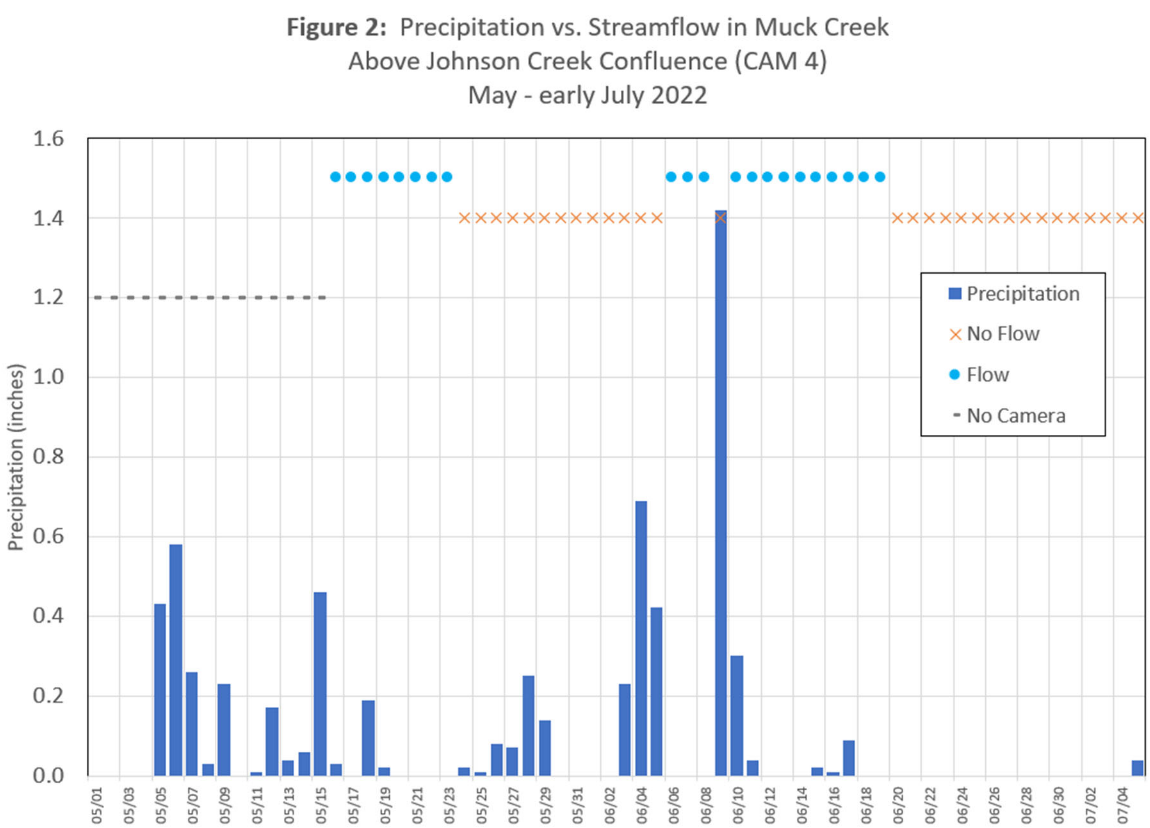

Figure 30. Preliminary results from the CAM4 camera study site showing periods of surface flow, no flow (dry), and precipitation (from Wilhelm and Pitre 2021).

Surface flow which would allow fish passage at Site 1 is highly variable from year-to-year and can be limited in depth and duration. For the 2020 results, Muck Creek at the stream logger location had streamflow only between January 8th to January 17th and January 24th to February 18th. This time period would typically be near the end of the winter chum and coho salmon spawning migration period (JBLM Fish & Wildlife Staff, personal communication, 2020). The depth of flow during these periods was less than 1-foot deep for the majority of time, when there was any flow at all, often only inches deep, reaching a maximum depth of 1.27 feet for only a few days around February 8th. Thus, in winter 2020 fish passage through Site 1 was likely limited to short durations when there was adequate flow and only to species migrating at the same time there was flow connectivity (potentially chum and/or coho). In spring 2020, access for migrating steelhead through Reach 4 during the peak migration period (April-June) was likely blocked due to a lack of flow connectivity. Conversely, for 2022, the CAM4 camera photos show periods of flow connectivity between May 16th-21st, possibly providing adequate flow connectivity for anadromous steelhead or migrating salmonid juveniles.

No flow conditions in Reach 4 can very quickly change. In June 2022, flow near Site 1 changed from no flow to substantial surface streamflow over only two consecutive days (Figures 29 and 30).

Figure 31. CAM4 photo showing no flow on June 9, 2022 near Site 1(from Wilhelm and Pitre 2021).

Figure 32. CAM4 photo showing stream flow on June 10, 2022 near Site 1 (from Wilhelm and Pitre 2021).

Based on these results, we infer that surface flow connectivity through Reach 4 is variable from year to year, limiting or allowing fish passage for different salmonid species and life stages depending on the precipitation, groundwater and flow conditions for a given time period. Reach 4 is the gateway for fish access between the upper and lower watershed, with its flow patterns and connectivity regulating access to and from the anadromous sections of the basin. Thus, salmonid migrations between the lower and upper watershed are largely affected by flow connectivity in Reach 4. Sites 1 and 2 below Highway 507 appear to have the most fluctuating water tables and more limited streamflow connectivity compared to Sites 3 and 4, which demonstrate more prolonged periods of streamflow following the initial surcharge of the groundwater table following rain events.

Quantitative monitoring was not conducted for the observed mass of streambed cobble being deposited at the confluence of Johnson Creek and Muck Creek (Figure 31), rather this phenomenon is noted as needing additional monitoring. If the mass of cobble and streambed material continues moving in the current trajectory, it could block fish passage into Johnson Creek. Additional monitoring may be needed to determine the rate of movement and change with the pile and whether it poses a threat to fish passage. Manual removal of the material may be needed to open up the creek channel again. The factors affecting the movement and deposition of this fairly large sized streambed material are unknown; increases in flooding caused by stormwater influxes may be one potential factor.

Figure 33. Mass of cobbles deposited at the mouth of Johnson Creek. JBLM Fish and Wildlife have observed the pile growing and impinging the channel of Johnson Creek. Over time the mass could block fish passage into Johnson Creek.

4.4. Lacamas Creek Thermal Infrared Survey

Temperatures in the main stem of Lacamas Creek ranged from 14.8℃ to 25.3℃ on July 28, 2019. Results from the thermal infrared survey (TIR) are shown as color-coded sample points on the sampled points map (Figure 32). Most of the sampling points had temperatures above 18℃ with many points reading greater than 20℃, thus exceeding optimal temperature ranges for salmonid Core Rearing designated in WAC 173-201A-200. As established in WAC 173-201A-200, Washington Department of Ecology (WDOE) designates Aquatic Life Temperature Criteria based on the 7-day average of the daily maximum temperatures (7-DADMax). Temperature thresholds for Core Summer Rearing and Salmon Spawning, Rearing, and Migration are 16℃ and 17.5℃, respectively. Similarly, the United States Environmental Protection Agency (EPA) 7-DADMax thresholds for Core Juvenile Rearing, Non-core Rearing and Migration are 16°C, 18°C, and 20°C, respectively (EPA 2003).

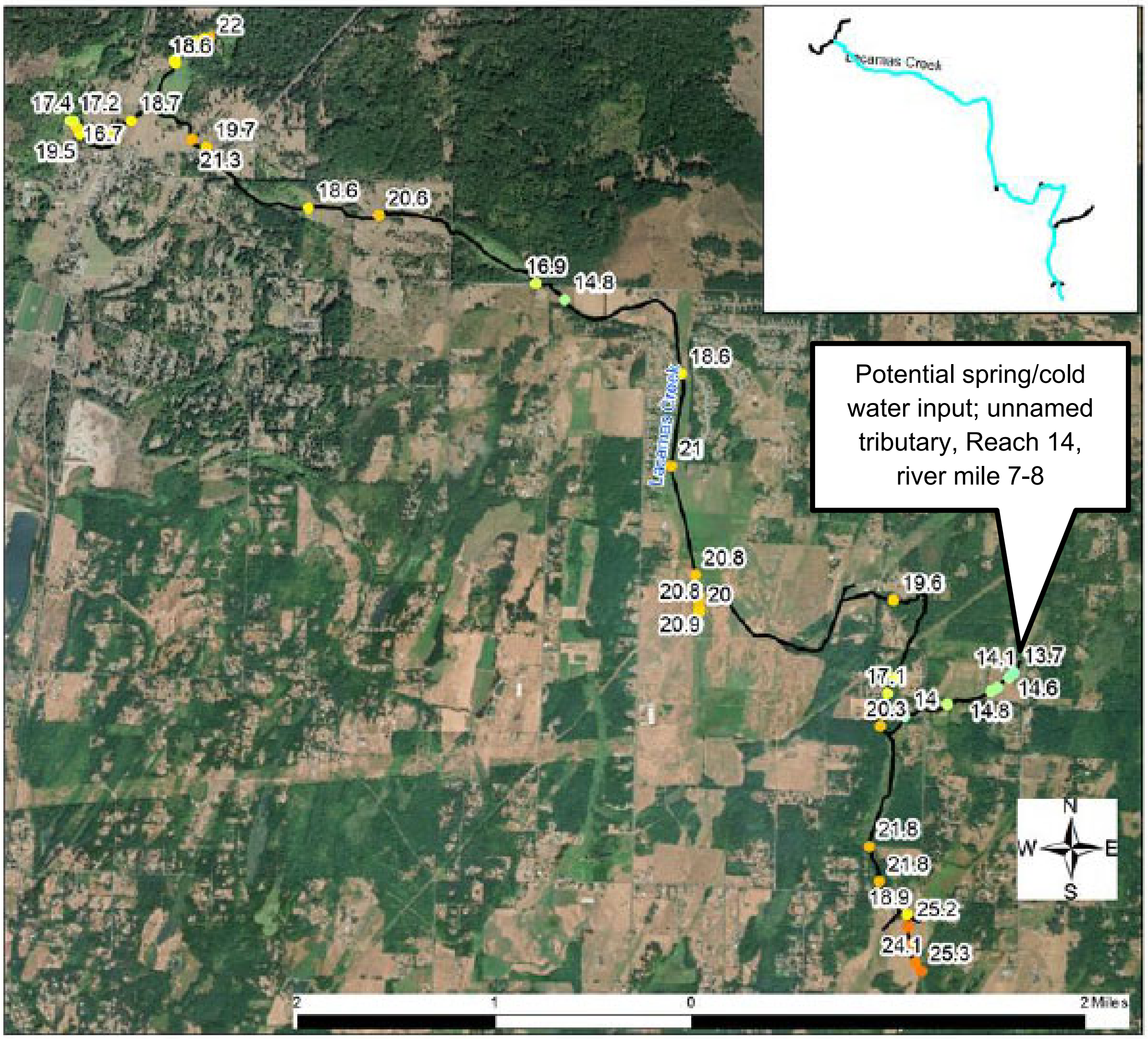

Figure 34. Lacamas Creek TIR sampling point results (from QSI 2019). The callout shows a potential spring/cold water input along an unnamed tributary of Lacamas Creek in Reach 14.

While the regulatory thresholds for stream temperatures are based on the seven-day averages of stream temperatures (7-DADMax), the TIR survey only provides a snapshot of temperature ranges on a single day. However, the TIR survey provides an indication of temperature trends during the summer-time base flow period. Based on the results of the TIR survey, much of the main stem of Lacamas Creek appears to have elevated water surface temperatures which would be in exceedance of the designated optimal thresholds for salmonid life stages if the 7-DADMax at the sampled locations were similar to the ranges shown in the TIR results. Similarly, sample points in Muck Creek near Muck Lake had temperatures greater than 18°C, exceeding optimal thresholds for rearing salmonids (Figure 33). Presumably, late-summer surface water temperatures would typically be higher than the July 28th TIR sampling period and would be more likely to exceed the 7-DADMax optimal salmonid temperature thresholds within stream sections exhibiting high sampled temperatures.

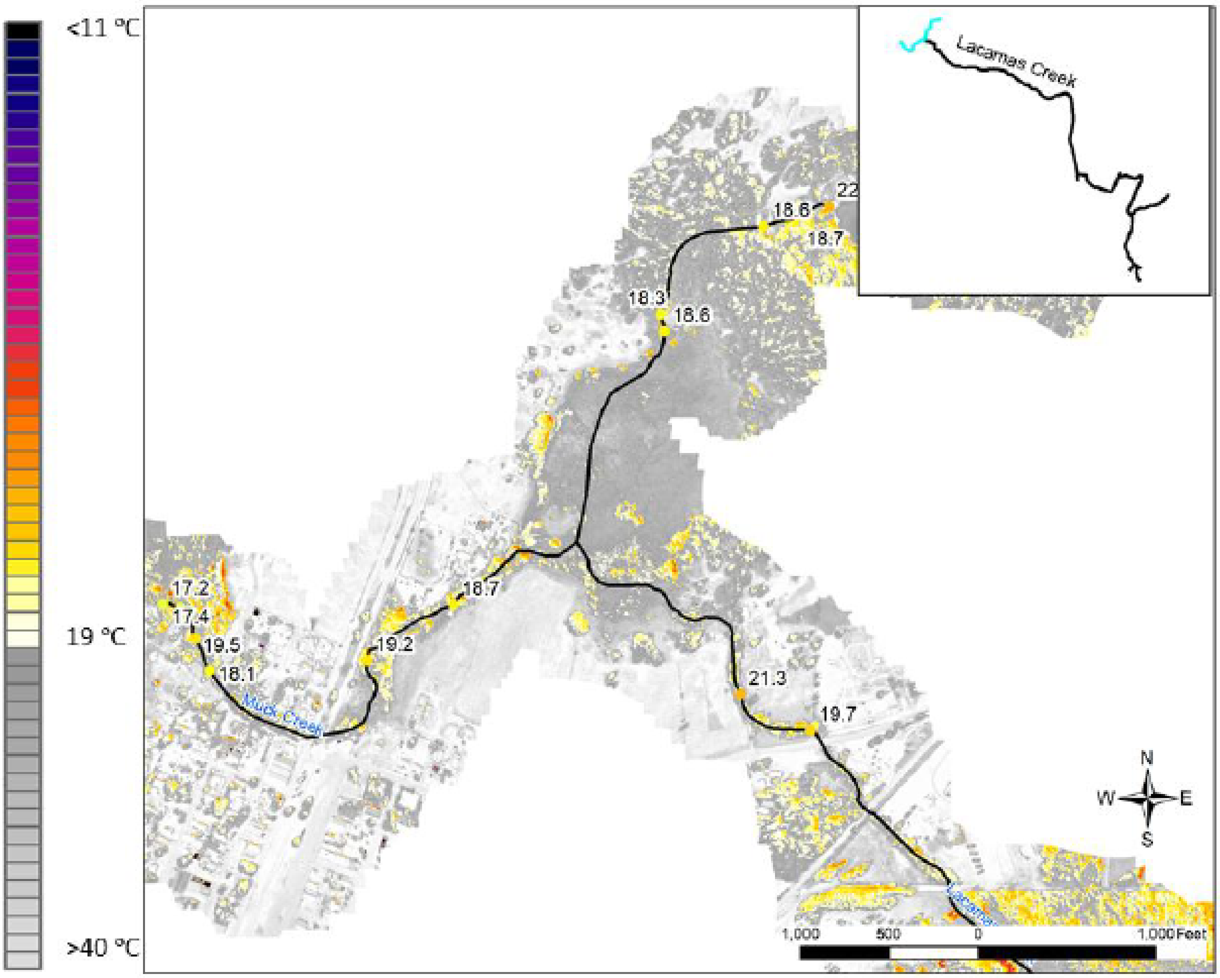

Figure 35. Muck Creek TIR sampling point results (from QSI 2019).

An unnamed tributary to Lacamas Creek in the southeast portion of the basin between river mile 7-8 (Reach 14) had sampled temperatures within optimal ranges for salmonids (13.7°C – 14.8°C) although it is unclear from the TIR report if this may be due to a cold-water input such as a spring, or if it may be an errant reading due to an evapotranspiration signature from aquatic vegetation. However, the colder temperatures shown along that section of the unnamed tributary correspond with a spring input location identified by Sinclair (2001; page 60 and Figure 5). Sinclair's findings from a peizometer-groundwater study noted the following:

"An instream piezometer at site L5, the upper-most monitoring site, exhibited positive hydraulic gradients that ranged from +0.0 to +0.04 and averaged +0.02 (Figure 21-S). Based on the gradient pattern, groundwater discharge to the stream was greatest during the winter and spring (January to mid-June) and lowest during the summer and fall (mid-June through December) (Appendix B). This corresponds with annual fluctuations in area groundwater levels which are generally highest in the spring and lowest in the fall (Figure 17)."

The correlating, lower temperature ranges from the TIR study and the positive hydraulic gradient identified by Sinclair are indicators of spring-fed, colder water inputs along the unnamed tributary in Reach 14 where the stream alignment turns from a north-south orientation to a more westerly orientation and runs along the till-covered low-bluff to the south (Figure 34). Additional temperature and habitat sampling of this tributary may be warranted.

Much of the stream corridor in the Lacamas subbasin is lacking in riparian forest cover, with much of the subbasin having been converted to agricultural and residential land uses. Long sections of the stream exhibit an open, exposed stream surface and are lacking in shade. Riparian enhancement projects in areas lacking shade and cover could contribute to reducing stream temperatures to ranges more suitable for salmonids.

4.5. Fish Presence

This section documents observations of fish presence from four specific sampling efforts as well as passing observations during habitat surveys at a handful of sites. The results from the sampling and observations were tabulated and linked to spatial locations (Figure 34).

The presence of juvenile coho salmon and cutthroat trout at Site 1 (Lacamas Creek) is noteworthy. If the coho juveniles were natal to Lacamas Creek this would indicate the system is supporting spawning coho and is still accessible to anadromous salmon. The presence of cutthroat trout in North Muck Creek in Reach 5 (Site 3) and Reach 6 was not unexpected, as this species has been documented in much of the basin. The presence of juvenile salmonids in Reaches 1 and 2 was to be expected, as these areas have high salmon and steelhead usage.

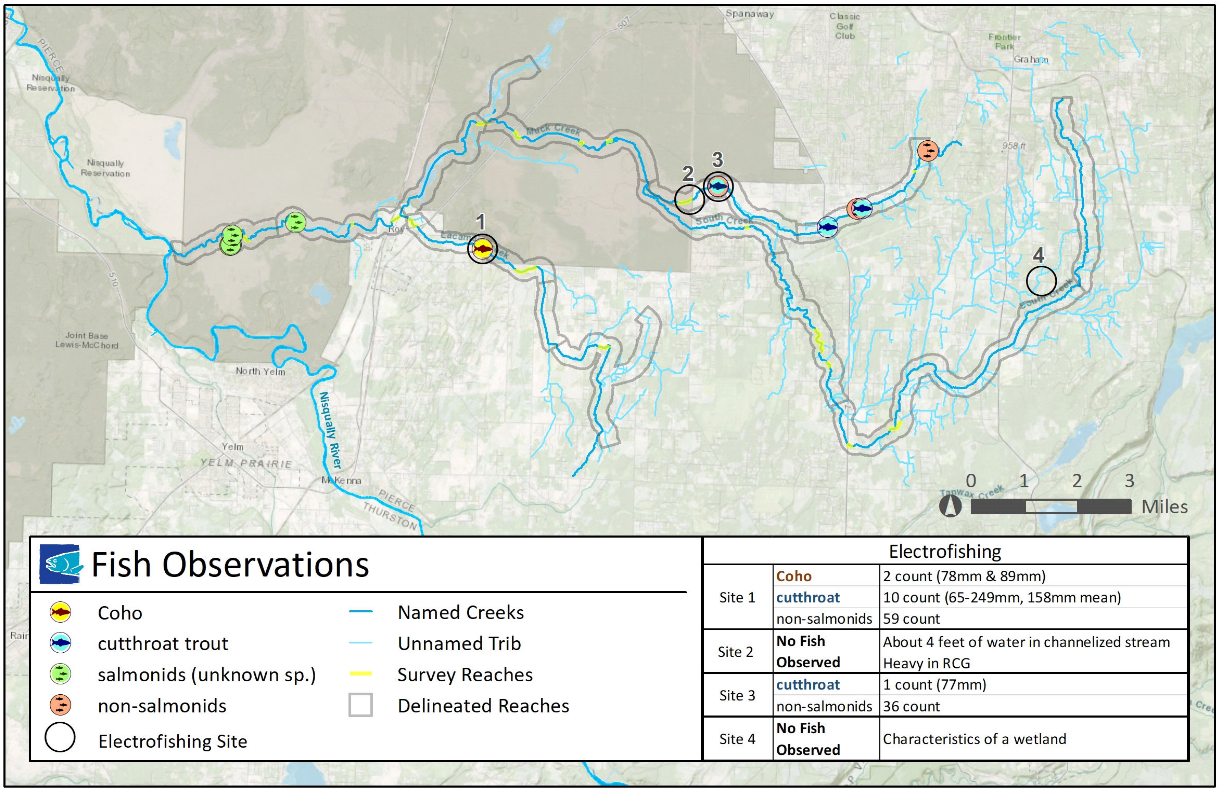

Figure 36. Map of fish sampling locations and observations.

4.6. Project Opportunities Section

Potential opportunities to improve in-stream, riparian, and floodplain habitat for salmonids within the Muck Creek basin developed as part of this assessment were combined with recommendations from prior studies and basin planning reports into an updated opportunities list presented in this section.

Project opportunities are listed for each reach in table form, followed by an Opportunities Map (Figures 35-48). These opportunities are intended to help show the types of restoration actions in the Muck Creek basin, including visual depictions of example projects, that can contribute meaningfully to salmon recovery. The level of specificity for proposed restoration opportunities varies between reaches and within each reach and includes general, specific, or reach-wide options. Refer to the table for a list of all reach-scale and specific project opportunities; the Opportunities Maps do not include every reach opportunity, rather they show example projects and site-specific actions where they have been identified.

Reach	Challenge	Project Opportunities
1	Prevalence of Invasive Species	• Create an invasive species and RCG removal plan to include the frequency of treatments required, preferred treatment types, and costs. • Remove/manage invasive species, particularly RCG in spawning gravel

	Low Diversity and Quality of Stream Habitats	• Protect off-channel spring-fed wetland habitat (e.g. RM 2.5 to 3.5)
		• LWD enhancement: anchor key pieces of large wood and strategically place logs or clusters of logs
		  ○ Improve pool frequency and condition
		  ○ Improve covered pool area
		• Enhance spawning gravel- lower the % of fine sediment
		• Improve side channel and/or off-channel rearing habitat

	Riparian Buffers	• Add supplemental conifer plantings in riparian areas where conifer recruitment is low, or where shade is lacking, either as tree seedlings or as tree seeds ○ Plantings requiring ground disturbance or digging are limited by restrictions in the Artillery Impact Area
	Expanding Dry Reaches	• Protect off-channel spring-fed wetland habitat (RM 2.5 to 3.5) • Improve flow for duration of salmon and steelhead spawning and egg incubation periods (Dec-July) using MAR or other appropriate streamflow enhancement projects
	Fish Passage Barriers	• Remove and restore non-essential stream crossings

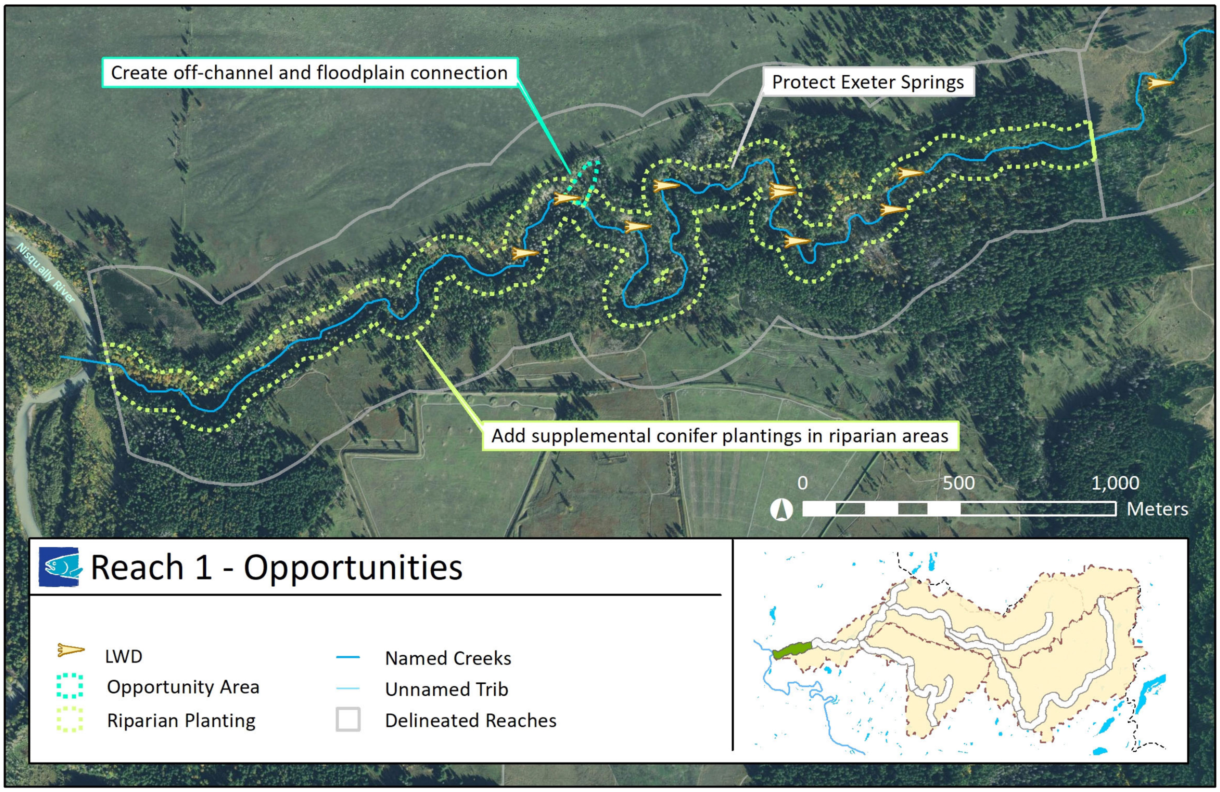

Figure 37. Project opportunities for Reach 1

Reach	Challenge	Project Opportunities
2	Prevalence of Invasive Species	• Create an invasive species and RCG removal plan to include the frequency of treatments required, preferred treatment types, and costs. • Remove/manage RCG and other invasive species in stream channels and wetlands.

	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation, install key pieces of large wood and clusters of logs
		• Reduce stream channelization
		• Enhance spawning gravel
		• Stabilize eroding stream banks in City of Roy
		• Create Muck Lake Management Plan:
		  ○ Control RCG
		  ○ Enhance buffers with native riparian vegetation
		  ○ Improve salmon habitat

	Riparian Buffers	• Enhance riparian vegetation and increase buffers: Plant native riparian species associated with prairie streams. • Muck Lake riparian management (See Reach 3)
	Expanding Dry Reaches	• Install BDAs and promote beaver use • Enhance and reconnect wetlands • Manage quality and quantity of stormwater runoff • Improve flow for duration of salmon and steelhead spawning and egg incubation periods (Dec-July) using MAR or other methods
	Fish Passage Barriers	• Remove and/or restore non-essential stream crossings and man-made barriers to fish passage • Maintain fish passage channel of Preacher Creek • Maintain fish passage channel of Halverson Marsh • Maintain fish passage channel Lacamas Creek • Maintain fish passage channel Muck Creek-Muck Lake

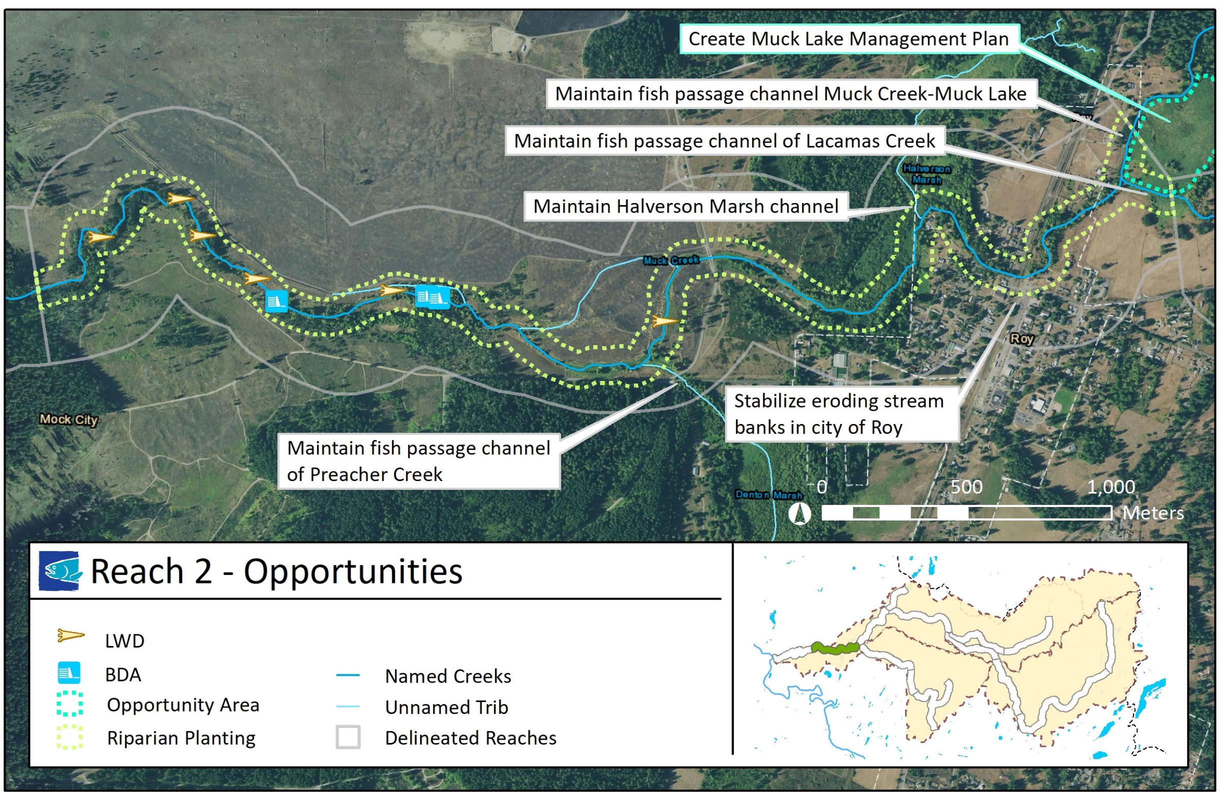

Figure 38. Project opportunities for Reach 2

Reach	Challenge	Project Opportunities
3	Prevalence of Invasive Species	• Remove/manage RCG and other invasive species • Create RCG management plan
	Low Diversity and Quality of Stream Habitats	• Protect and enhance springs in Chambers Lake (JBLM) • Native riparian plantings • LWD enhancement/installation; install logs or clusters of logs and key pieces • Promote/restore wetland connectivity, channel, and storage • Chambers Lake Enhancement Plan: Enhance and define stream channel through Chambers Lake; add Logs and wood in beaded channel, plant riparian and wetland species in Chambers Lake along Muck Creek • Connect two lobes (East/West) of Watkins Springs to Johnson Creek for rearing habitat access.

	Riparian Buffers	• Enhance riparian vegetation within and around lakes and wetlands: Plant native riparian species associated with wetland and lake-edge assemblages.
		• Muck Lake riparian management
		  ○ Manage RCG
		  ○ Plant native trees and shrubs on islands or hummocks

	Expanding Dry Reaches	• Install BDAs, promote beaver use, protect large beaver dam complexes • Restore floodplain function and stream channel migration zone • Conserve native forest and prairie cover and minimize impervious surfaces • Design wetland expansion and water storage areas
	Fish Passage Barriers	• Maintain fish passage channel Lacamas Creek • Maintain fish passage channel Muck Creek-Muck Lake ○ WDFW Fish Passage Barrier: 999243 • Maintain fish passage channel in marsh downstream of Johnson Creek (RM 9.1) • Remove gravel avulsion berm blocking mouth of Johnson Creek

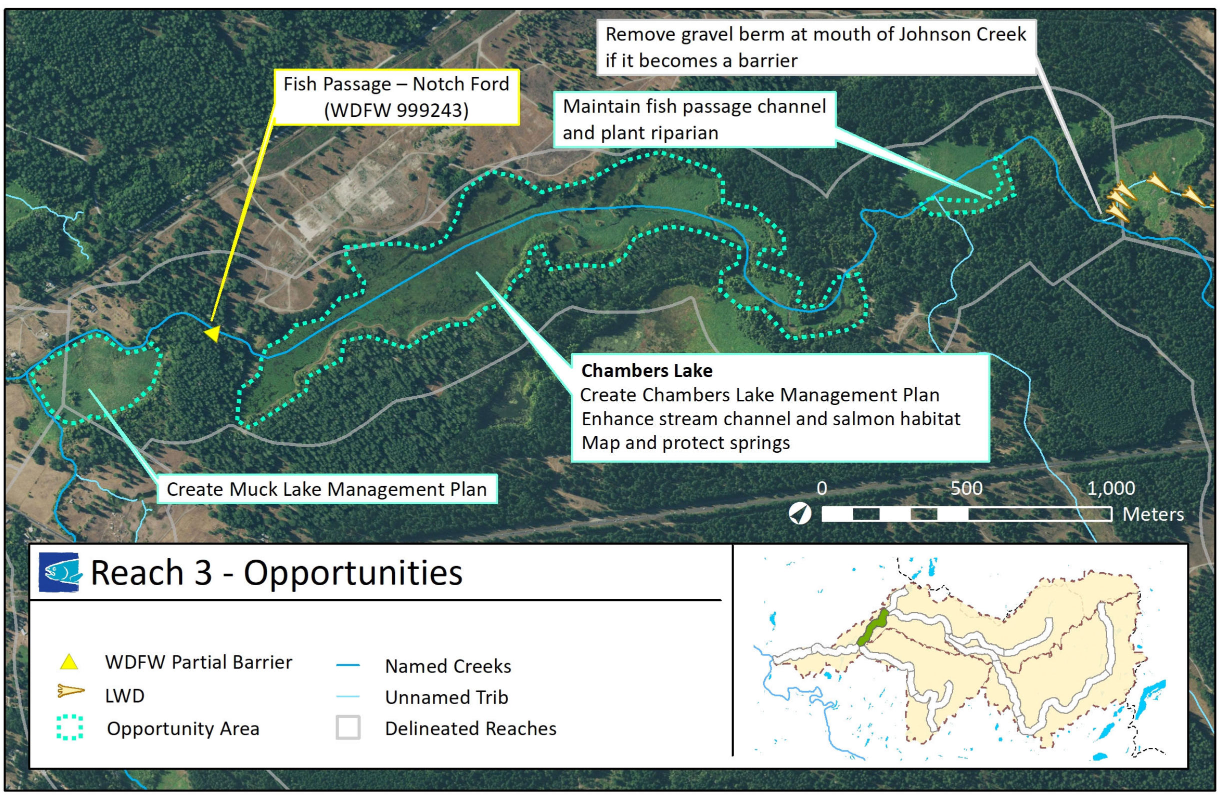

Figure 39. Project opportunities for Reach 3

Reach	Challenge	Project Opportunities
4	Prevalence of Invasive Species	• Remove/manage invasive species including RCG • Create RCG management plan • Remove Douglas fir stands to prevent conversion of prairie environment to forest; reduce evapotranspiration water loss
	Low Diversity and Quality of Stream Habitats	• Install large wood as logs or log clusters to increase pool frequency, area, and quality; this could also include redistribution of accumulated sediment • Enhance or create flow-through wetland habitat by encouraging beaver activity, installing BDAs, and wood placement
	Riparian Buffers	• Enhance riparian vegetation and increase buffers: Plant native riparian species associated with prairie streams • Plant species preferred by beavers
	Expanding Dry Reaches and Flow Management	• Install BDAs and promote beaver use • Improve floodplain connectivity and high flow storage/recharge • Use relict channels and overflow channels to divert peak stormflow • Restore prairie stream-wetland ecosystem upstream of SR-507 • Expand and create flow-through and floodplain wetlands • Reverse channel incision by adding complexity and restoring floodplain connectivity • Identify opportunities for aquifer recharge
	Fish Passage Barriers	• Remove unnecessary ford crossings • Consider fish passage improvements at ford crossings

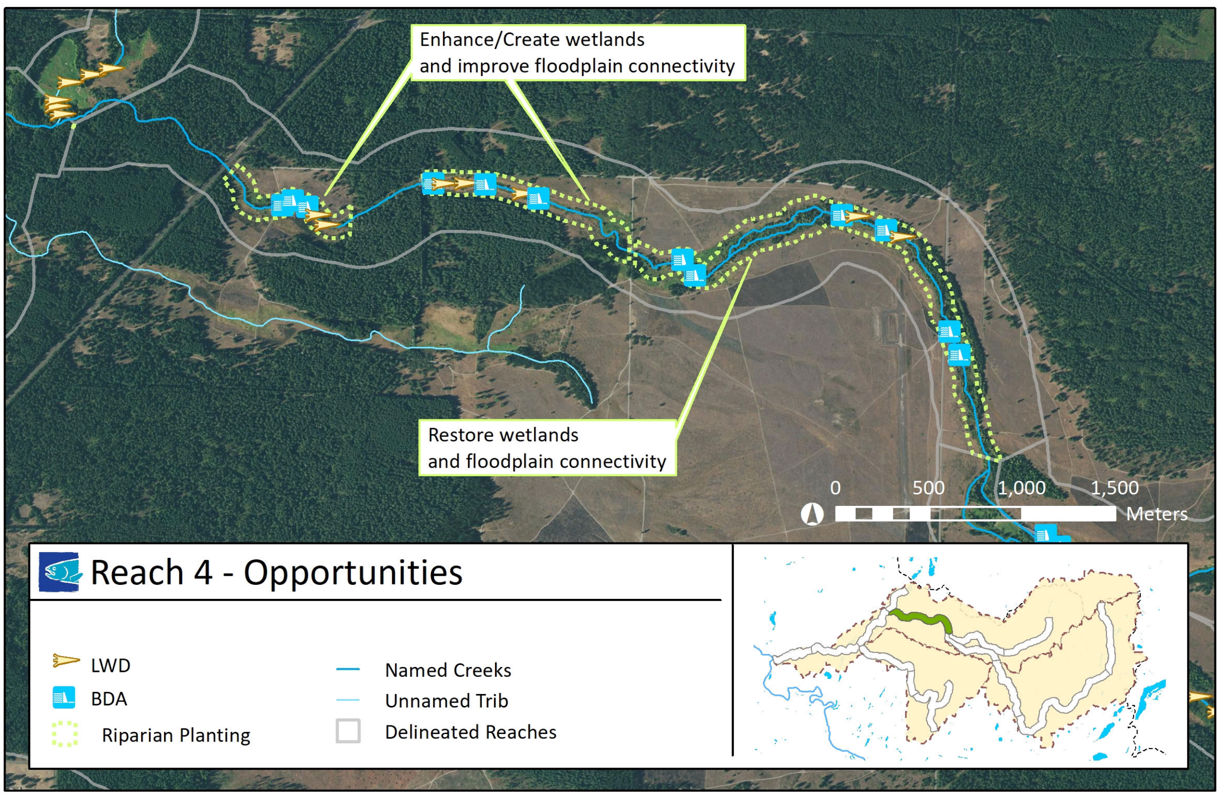

Figure 40. Project opportunities for Reach 4

Reach	Challenge	Project Opportunities
5	Prevalence of Invasive Species	• Remove/manage invasive species, particularly RCG • Create RCG management plan
	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation to increase pool frequency and quality • Native riparian and wetland plantings • Reduce stream channelization • Identify and mediate sources of excess sediment in stream causing embeddedness • Exclude livestock from the stream and riparian buffer using exclusion fencing, easement restrictions, or other methods
	Riparian Buffers	• Enhance riparian buffers and increase buffer widths: Plant native riparian species associated with prairie streams and species preferred by beaver in open areas. • Conserve areas with high-quality riparian buffers
	Expanding Dry Reaches	• Install BDAs and promote beaver use • Identify opportunities for groundwater recharge • Identify if any water rights could be returned to stream flow

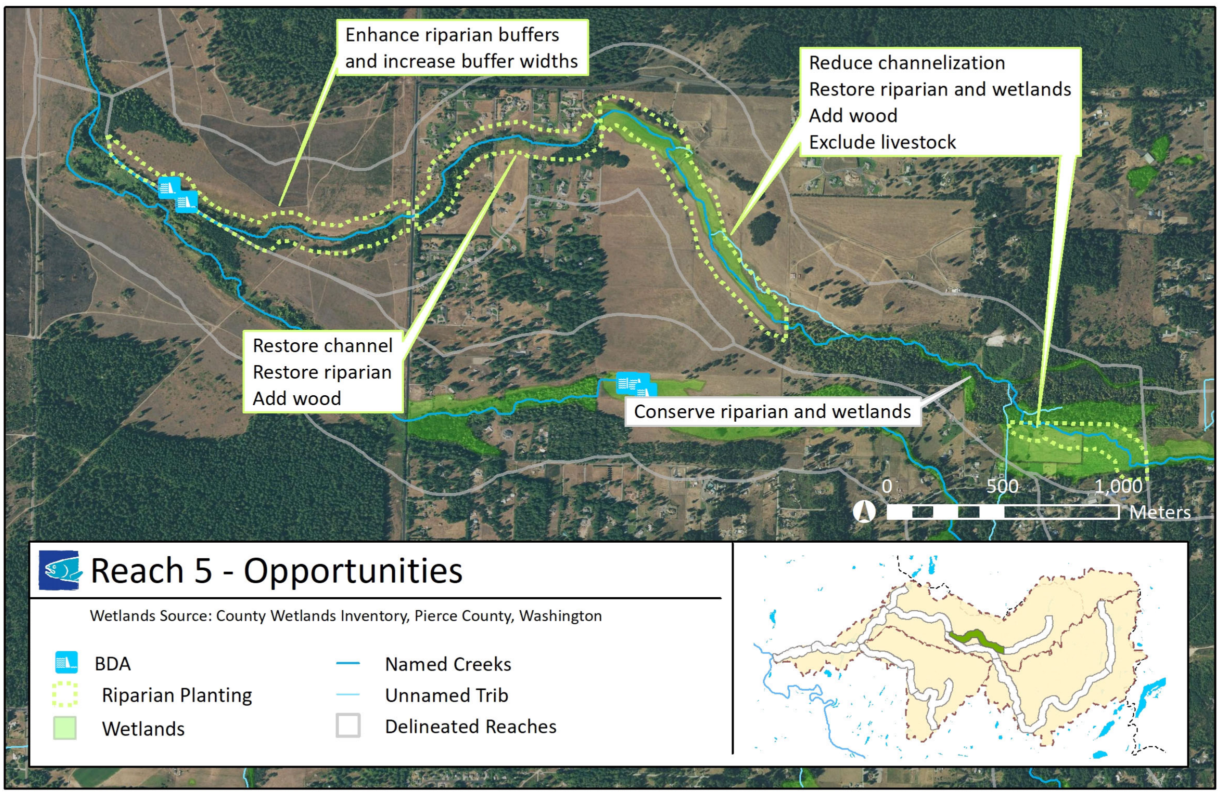

Figure 41. Project opportunities for Reach 5

Reach	Challenge	Project Opportunities
6	Prevalence of Invasive Species	• Remove/manage invasive species, particularly RCG in wetlands
	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation to increase pool frequency and quality • Native riparian and wetland plantings • Promote beaver activity and wetland restoration where land use is favorable for these actions
	Riparian Buffers	• Enhance riparian buffers and increase buffer widths: • Plant native riparian species including conifers. • Conserve areas with high-quality riparian buffers
	Expanding Dry Reaches	• Protection of wetlands • Install BDAs and promote beaver use • Identify potential enhancement of spring flow inputs • Identify opportunities for groundwater recharge
	Fish Passage Barriers	• Address man-made rock dam at RM 17.5 • WDFW Fish Passage Barriers: ○ 997905 ○ 997906 ○ 997907 ○ 997908

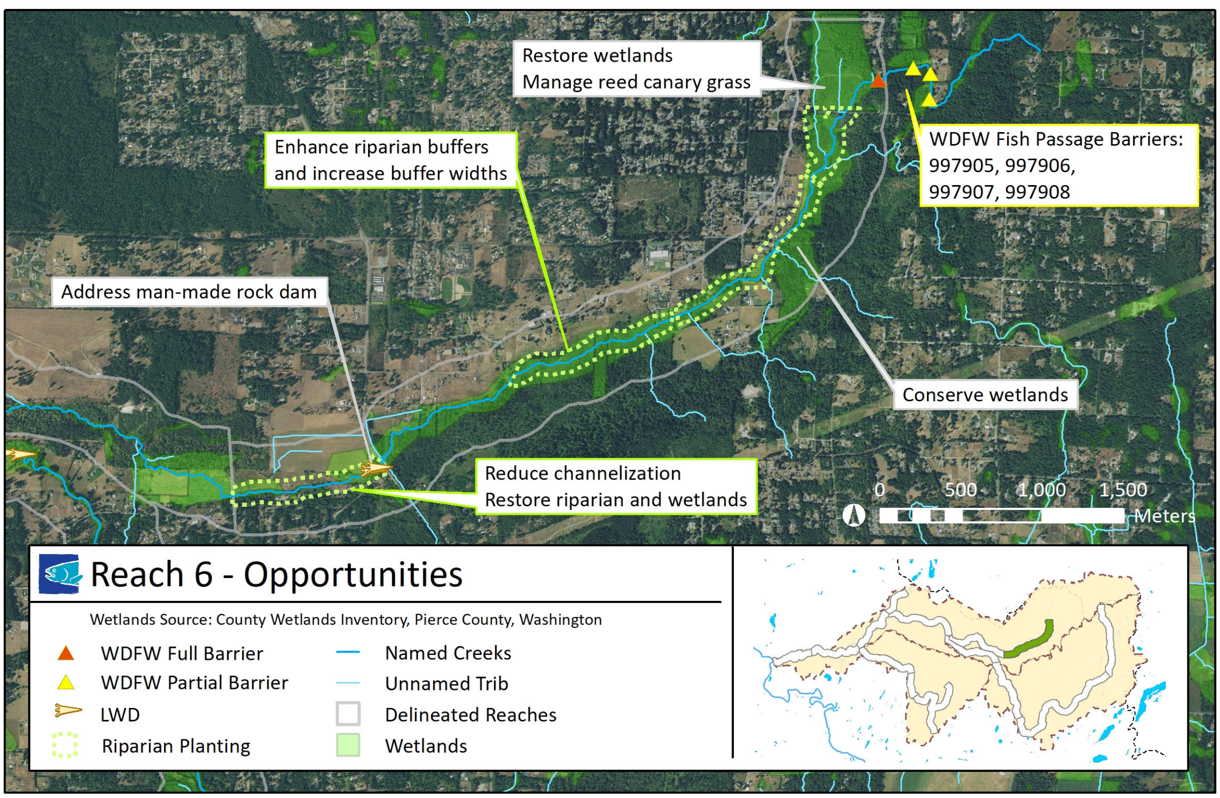

Figure 42. Project opportunities for Reach 6

Reach	Challenge	Project Opportunities
7	Prevalence of Invasive Species	• Remove/manage invasive species, particularly RCG
	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation • Remove armoring and reduce creek channelization • Possible conservation of moderate to high-quality wetlands with native vegetation (e.g. the complex on the east side of 8th Ave E)
	Riparian Buffers	• Enhance riparian buffers and increase buffer widths: • Plant native riparian species associated with prairie streams • Conserve areas with high-quality riparian buffers
	Expanding Dry Reaches	• Install BDAs • Identify opportunities for groundwater recharge • Identify if any water rights could be returned to stream flow

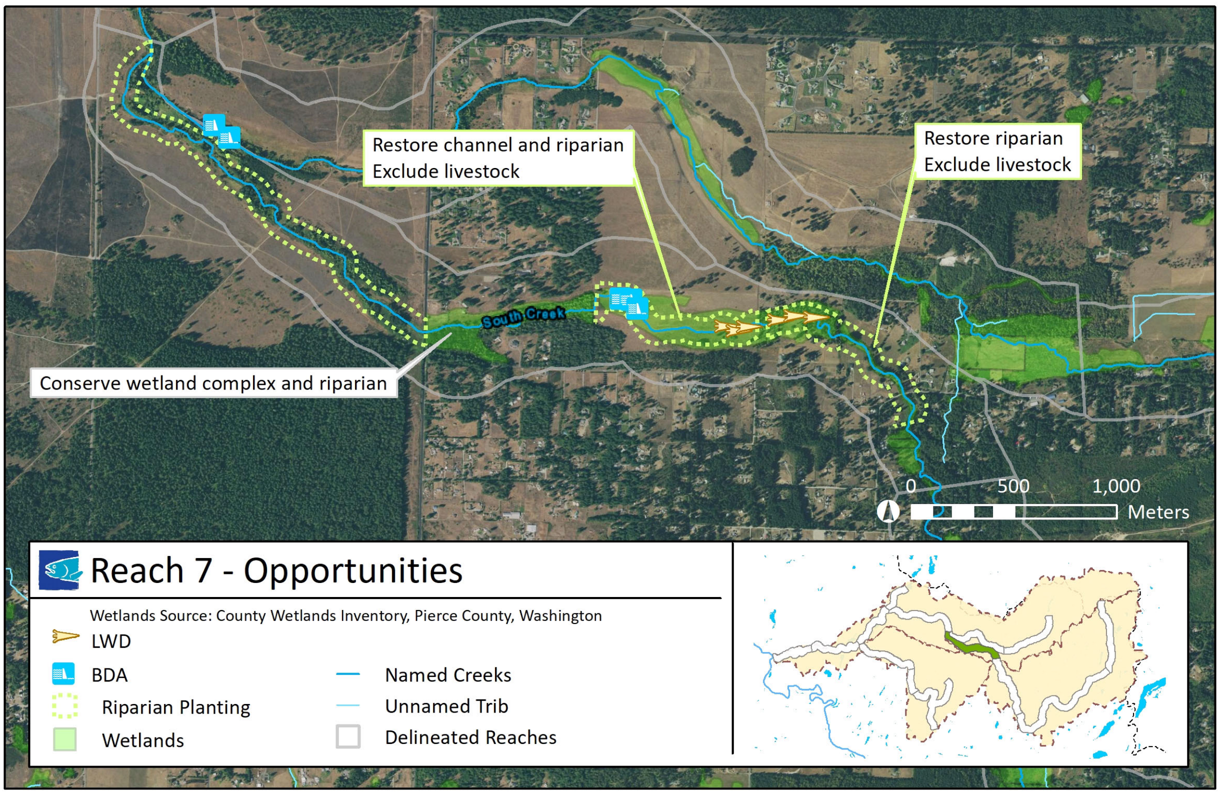

Figure 43. Project opportunities for Reach 7

Reach	Challenge	Project Opportunities
8	Prevalence of Invasive Species	• Remove or manage RCG, especially in open zones along power lines and cleared areas
	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation to increase pool frequency and quality • Enhance wetlands where feasible
	Riparian Buffers	• Enhance riparian buffers and increase buffer widths: ○ Plant native riparian species in low-quality areas ○ Under plant conifers in appropriate soil types ○ Conserve areas with high-quality riparian buffers
	Expanding Dry Reaches	• Enhance wetland connectivity and habitats • Install BDAs and promote beaver use • Identify potential enhancement of spring flow inputs • Identify opportunities for groundwater recharge • Identify opportunities to redirect stormwater facilities for Managed Aquifer Recharge (MAR) or through swales and filtration to wetlands

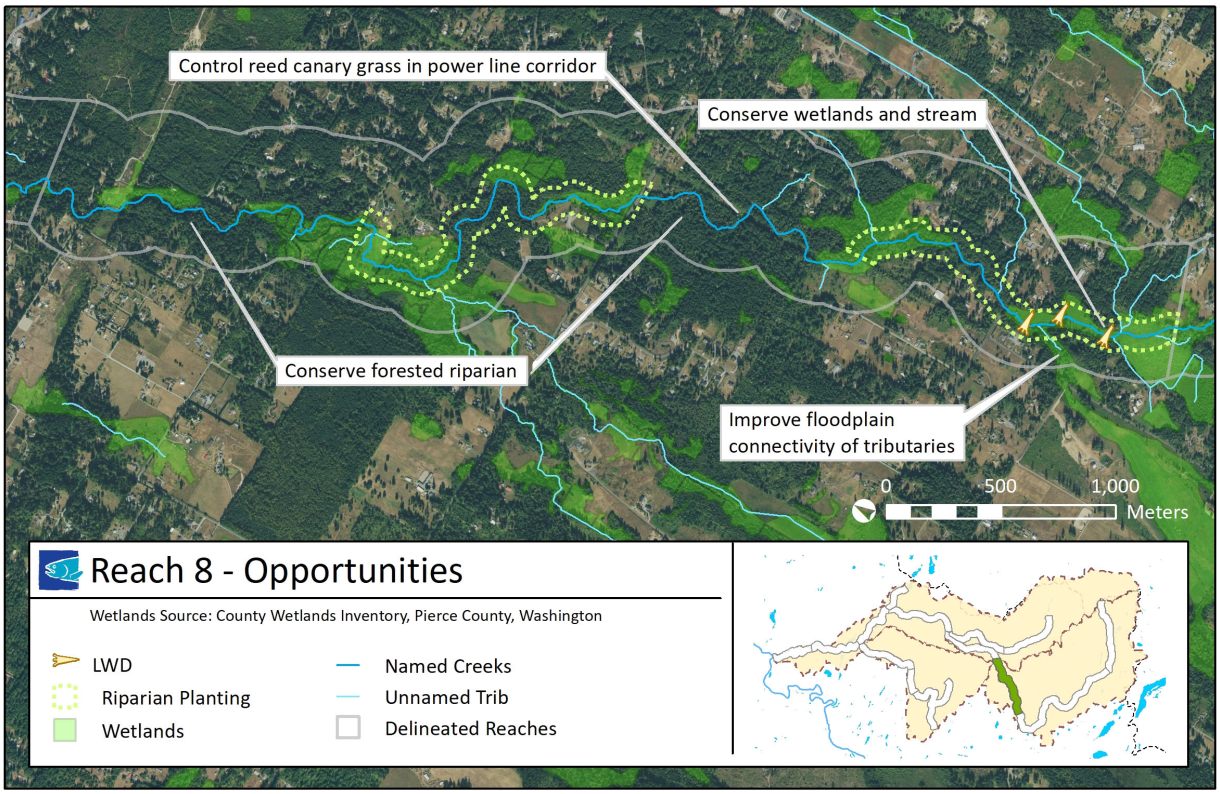

Figure 44. Project opportunities for Reach 8

Reach	Challenge	Project Opportunities
9	Prevalence of Invasive Species	• Remove/manage invasive species, particularly RCG
	Low Diversity and Quality of Stream Habitats	• LWD enhancement/installation to increase pool frequency, area, and quality • Restrict cattle access to stream • Reduce channelization
	Riparian Buffers	• Native riparian and wetland plantings
	Expanding Dry Reaches	• Restore wetland habitats • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands • Reduce or meter stormwater inputs; improve storage

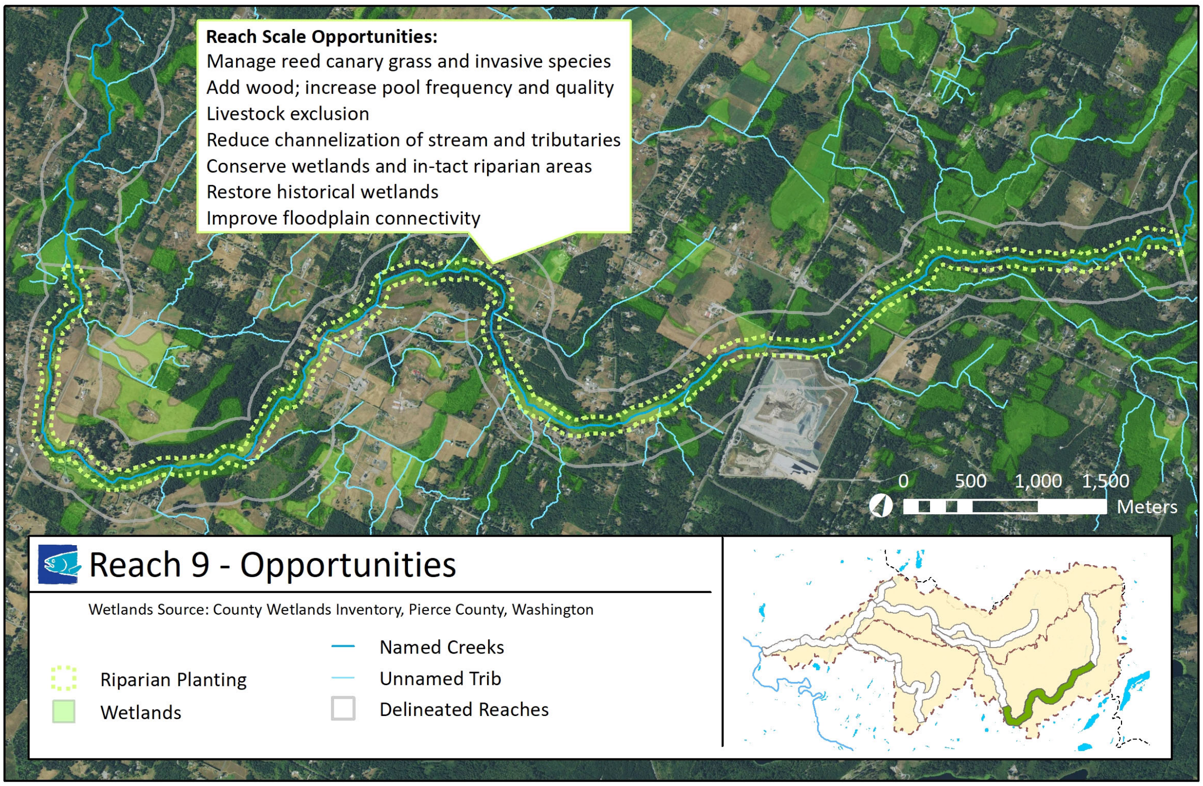

Figure 45. Project opportunities for Reach 9

Reach	Challenge	Project Opportunities
10	Prevalence of Invasive Species	• Remove/manage invasive species (e.g. RCG)
	Low Diversity and Quality of Stream Habitats	• Install large wood • Native riparian and wetland plantings
	Expanding Dry Reaches	• Restore wetland habitats • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands
	Fish Passage Barriers	• WDFW Fish Passage Barriers: ○ 933101 ○ 932679 ○ 932685 ○ 933233 ○ 933232

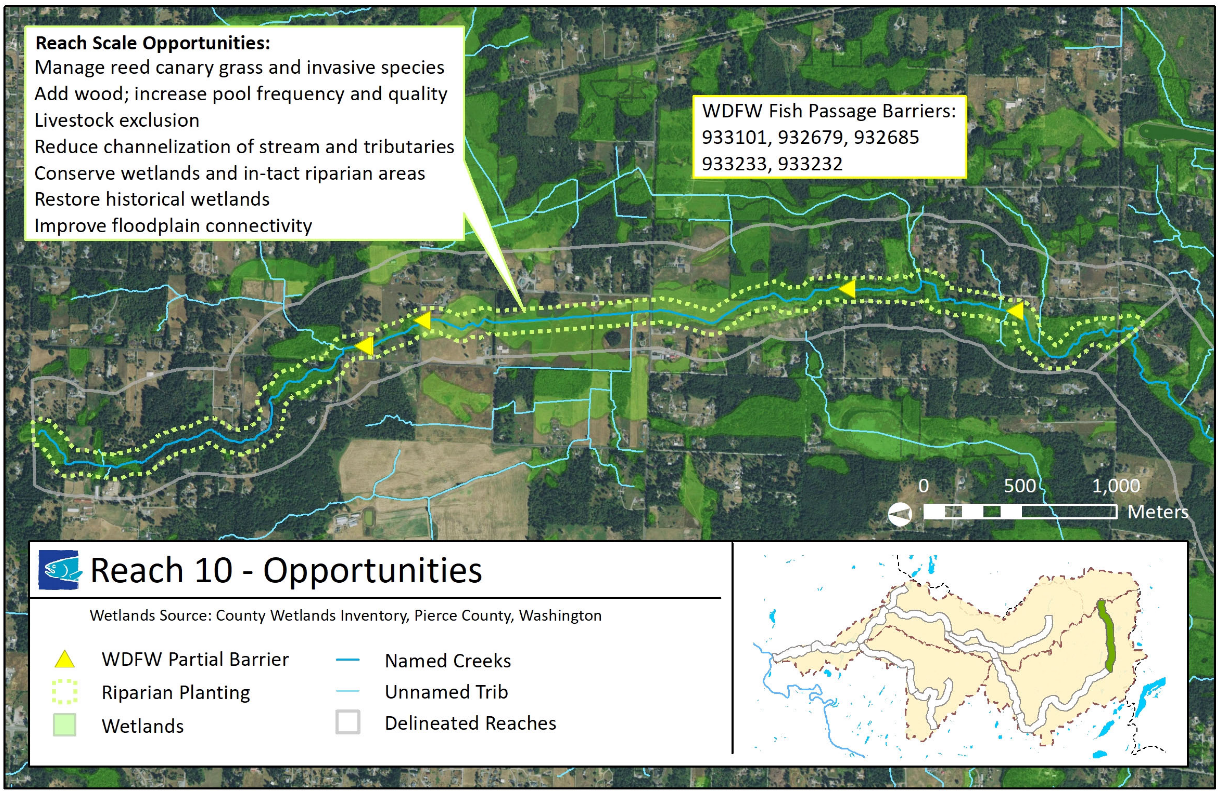

Figure 46. Project opportunities for Reach 10

Reach	Challenge	Project Opportunities
11	Prevalence of Invasive Species	• Create invasive species management plan • Remove/manage invasive species (e.g. RCG)
	Low Diversity and Quality of Stream Habitats	• Add woody cover in Johnson Creek below East Gate Rd. • Connect Off-channel and wetland habitat
	Influence of this Reach on Expanding Dry Reaches Downstream	• Protect Johnson Marsh and maintain open channel from vegetation in-fill (JBLM) • Protect beaver dam impounding Johnson Marsh; promote beaver activity; add BDAs as necessary
	Fish Passage Barriers	• Remove berm both sides of Johnson Creek to reconnect with east and west sections of Watkin Spring (JBLM) • Investigate opportunities to modify dam on Johnson Creek • Maintain fish passage channel in Johnson Marsh

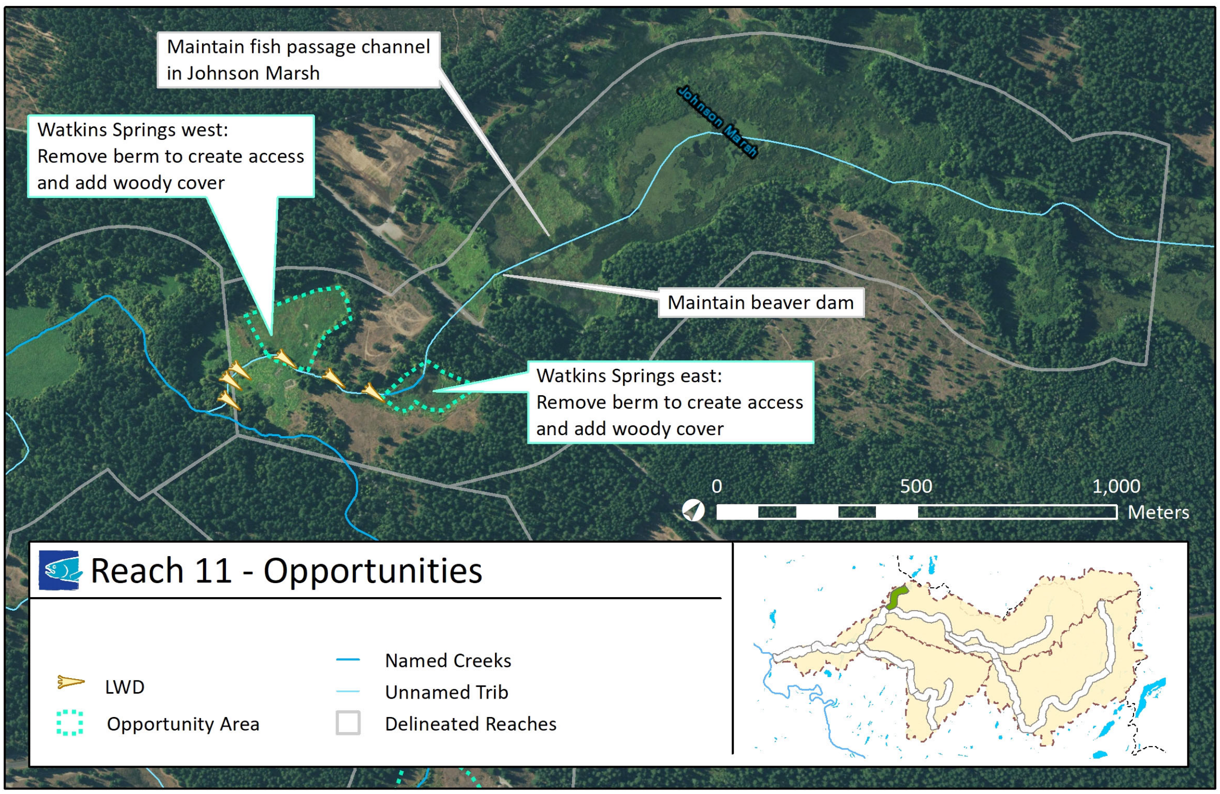

Figure 47. Project opportunities for Reach 11

Reach	Challenge	Project Opportunities
12	Prevalence of Invasive Species	• Remove/manage invasive species (e.g. RCG, Himalayan Blackberry)
	Low Diversity and Quality of Stream Habitats	• Reduce stream channelization • Restrict livestock access to stream • LWD enhancement/installation to increase pool frequency, area, and quality
	Riparian Buffers	• Increase riparian buffer width • Native riparian and wetland plantings
	Water Quality	• Create and implement water quality monitoring plan • Identify and mediate excess sediment and nutrient inputs
	Expanding Dry Reaches	• Install BDAs and promote beaver use • Restore wetlands; improve surface water storage • Identify opportunities to improve streamflow and reduce dry periods, promote water storage, and aquifer recharge • Identify opportunities to return water rights to streamflow • Inventory and address water diversions
	Fish Passage Barriers	• Inventory any unknown stream crossings

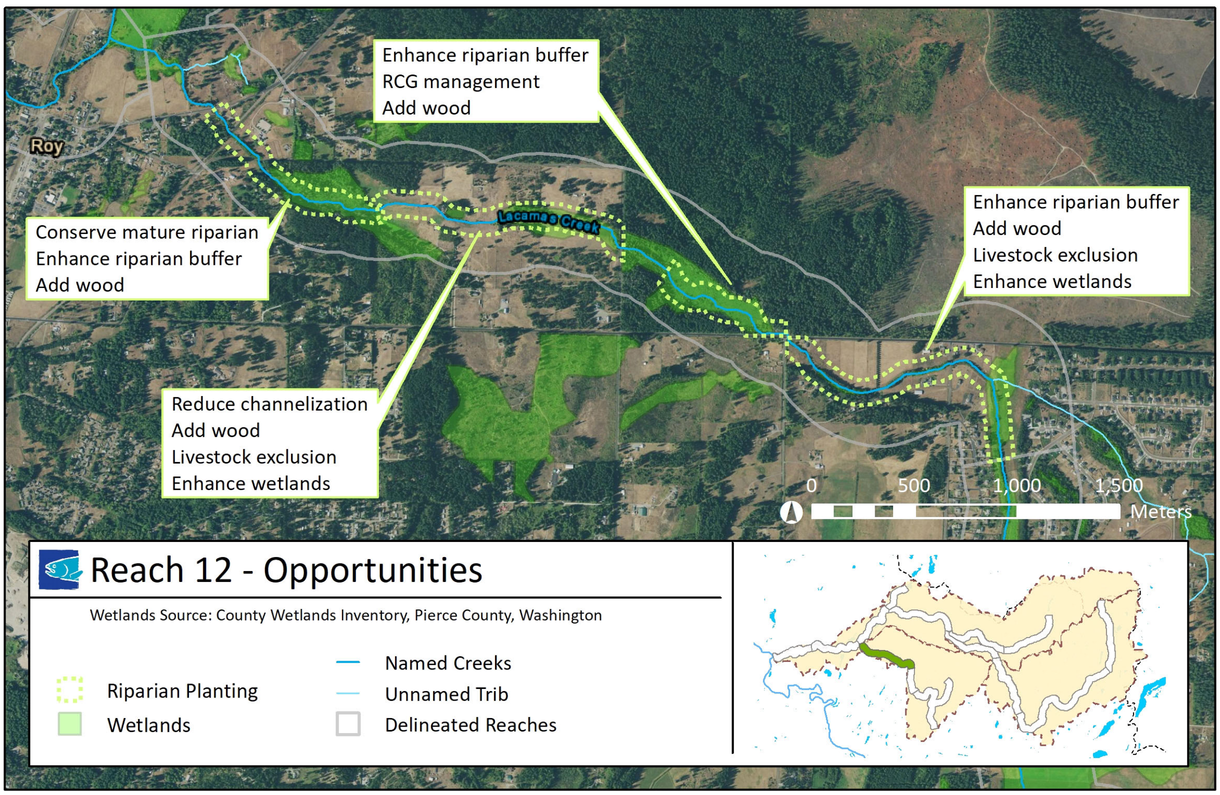

Figure 48. Project opportunities for Reach 12

Reach	Challenge	Project Opportunities
13	Prevalence of Invasive Species	• Remove/manage invasive species (e.g. RCG)
	Low Diversity and Quality of Stream Habitats	• Install livestock exclusion fencing or other exclusion techniques • LWD enhancement/installation
	Riparian Buffers	• Install native riparian and wetland plantings
	Expanding Dry Reaches	• Install BDAs and promote beaver use • Restore wetland habitats • Identify opportunities for groundwater recharge • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands • Identify if any water rights could be returned to stream flow

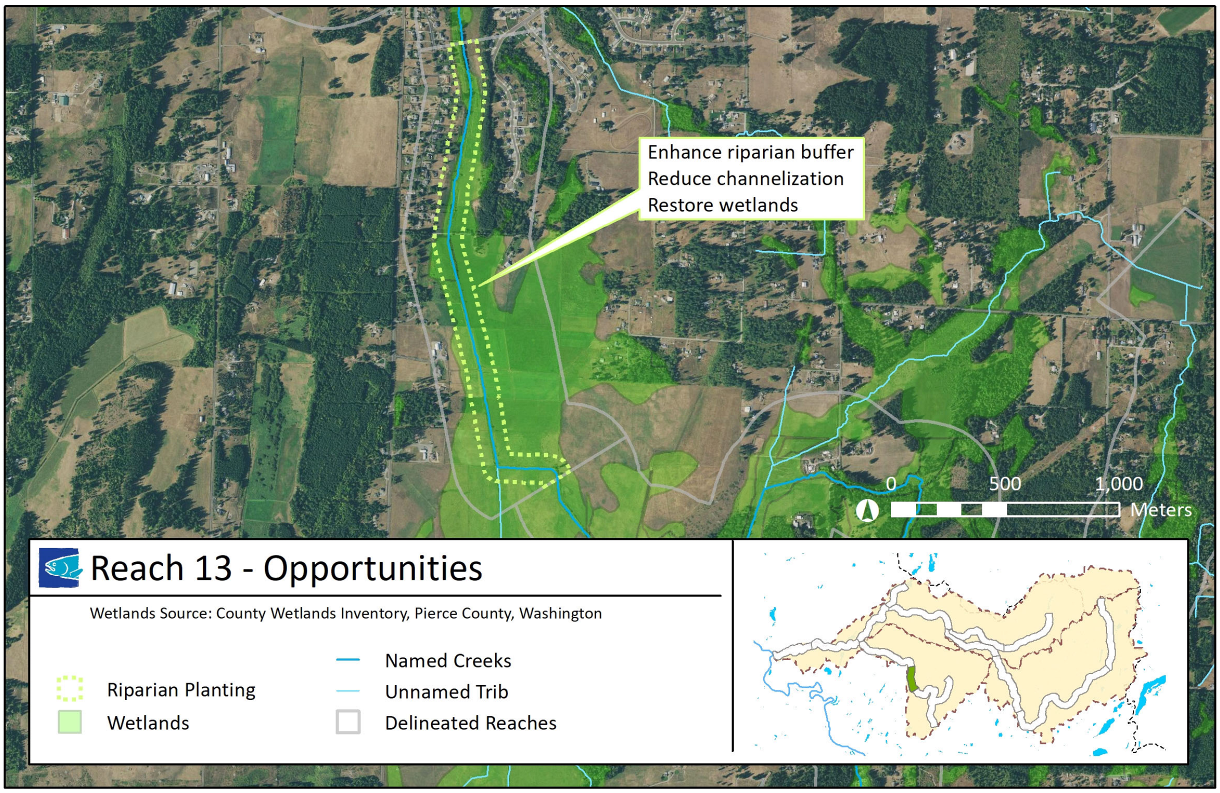

Figure 49. Project opportunities for Reach 13

Reach	Challenge	Project Opportunities
14	Prevalence of Invasive Species	• Remove/manage RCG, especially in wetlands
	Low Diversity and Quality of Stream Habitats	• Restrict cattle access to stream • Reduce stream channelization • LWD enhancement/installation to increase pool frequency, area, and quality • Native riparian and wetland plantings
	Expanding Dry Reaches	• Install BDAs and promote beaver use • Restore wetland habitat • Identify opportunities for groundwater recharge • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands
	Fish Passage Barriers	• WDFW Fish Passage Barriers: ○ 999130 ○ 999131 ○ 999132 ○ 999133 ○ 999156 ○ 999140 ○ 999149 ○ 997800 ○ 999147 ○ 997797

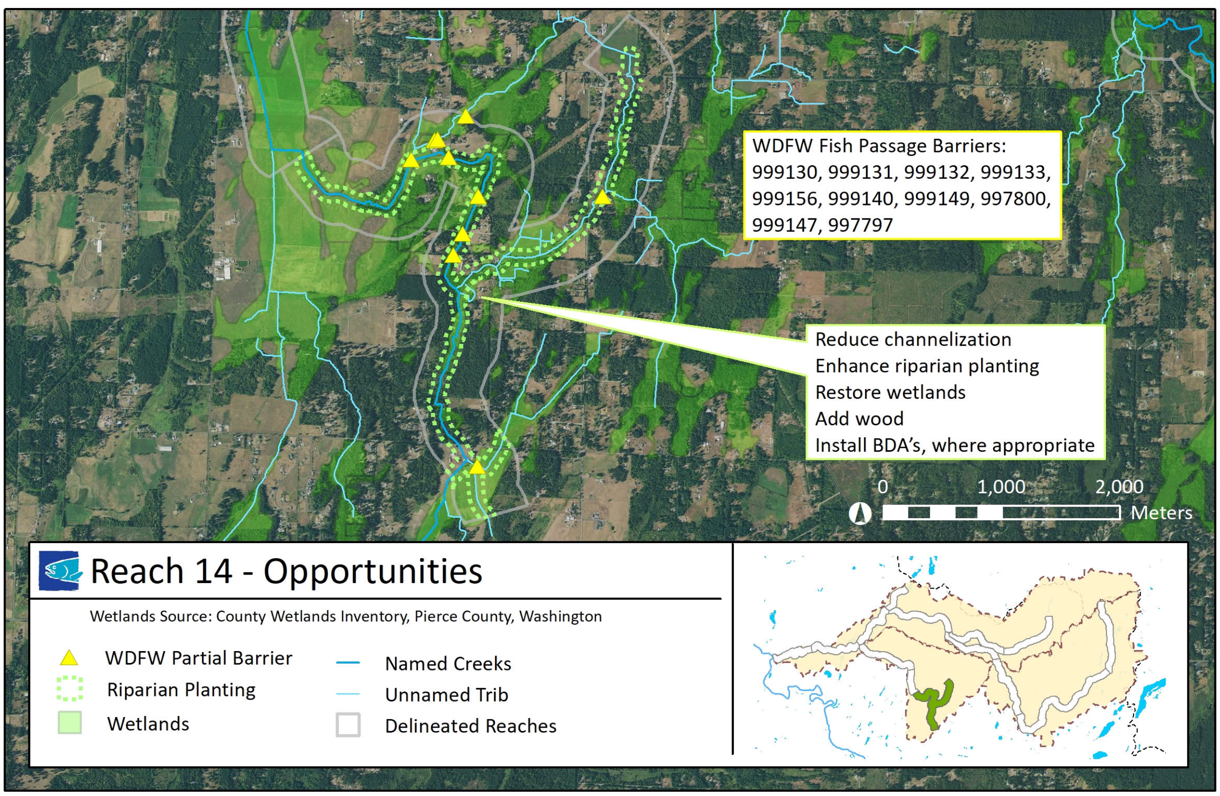

Figure 50. Project opportunities for Reach 14

5. Data Gaps and Next Steps

A number of data gaps were identified through this assessment, the supporting, contracted studies, and within prior studies cited within this report, which may limit the collective understanding of key physical and ecological processes affecting stream functions, species-specific fish use patterns within each reach, inter and intra-specific hydrologic functions that influence streamflow, and the potential of large-scale restoration or enhancement projects to improve streamflow, fish habitat, or ecosystem functions. Filling these data gaps may inform future planning of restoration projects as well as policy level decisions related to stream and habitat management. Identified data gaps are presented below. This section also includes suggested 'next step' planning and policy items which might improve the efficacy and efficiency of implementing watershed enhancement actions.

5.1. Hydrology and Streamflow

Additional groundwater and surface water monitoring may provide additional insight into seasonal patterns of streamflow loss which have direct or indirect impacts on fish or fish habitat. Direct impacts might include stranding of salmonid eggs or fry in dry reaches, barriers to fish migration due to loss of flow connectivity, high stream temperatures partially caused by low-flow, and other conditions. Indirect impacts might include cumulative changes to stream channels or streamflow caused by stormwater management actions.

Additional data collection and analysis can be considered for the following list of data gaps:

- Examine the correlation of dry stream periods with probable causes such as antecedent precipitation, upstream flow volumes, or nearby groundwater levels; study relative contributions of streamflow per reach, or sub-reach, and the respective impacts to streamflow caused by land change and water withdraws and potential streamflow restoration opportunities.
- Identify additional locations to compare groundwater and surface water elevations to understand the feasibility of either extending flow distance or flow timing, particularly in Reaches 2, 4, 5, and 7. Install stream gages or flow monitoring devices at Roy, Muck Creek at Chambers Lake outlet, Muck Creek at 8th Avenue E, Lacamas Creek at 280th Street, and South Creek at 8th Avenue East.
- Calculate comparative precipitation data and evapotranspiration rates for vegetation that did not naturally occur in the prairie reaches, especially Douglas-fir, to determine if reducing tree canopy area will reduce the impacts of evapotranspiration on streamflow and increase infiltration of precipitation.
- Evaluate the potential for the USGS Chambers-Clover Creek modeling effort (now named the Southeast Sound Groundwater Flow Model) to simulate and predict conditions in the Muck Creek basin and inform Muck Creek streamflow management efforts (e.g. reducing dry reaches, reducing peak flows).
- Create a monthly water balance for the basin and use the water balance as a tool to explore the possible impacts of long-term changes in land cover (loss of wetlands, vegetation change from prairie to forest, increase in developed areas), and precipitation patterns on the basin's groundwater and streamflow patterns.
- Conduct an analysis of historical wetland loss and potential restoration: consider the potential for restoring wetland area and functions, restoring hydrologic

storage via wetland restoration and floodplain connections. These features can also supply fish rearing and refugia habitat.
- Managed Aquifer Recharge analysis: identify potential reaches where MAR may improve water storage and/or streamflow.
- Stormwater management planning: manage stormwater to encourage recharge rather than runoff. Techniques include replacing stormwater ditches with infiltration features. Encourage responsible stormwater management and low-impact development in the basin. Reduce irregular, episodic sedimentation events causing embeddedness or bed load accumulations caused by flooding.
- Examine the possibility that peak stormflow events are regularly mobilizing and shifting large bed load across the prairie through Reach 4 and into the chain of lakes in Reach 3.
- Study the impacts of recent or expanding streamflow losses in Reaches 1 and 2 which might threaten steelhead or salmon redds or fry.
- Collaborate with water trusts, landowners, and watershed partners to identify if beneficial water rights which could be retired or managed to improve streamflow.

5.2. Water Quality

Water quality impairments in the basin may have negative effects on stream conditions relative to salmonid habitat, including impacts to temperature, dissolved oxygen, and prey resources such as invertebrate diversity or abundance. Additional water quality monitoring and improvement programs should be considered as part of future watershed management and planning.

- The Lacamas Creek sub-basin is one example of an area where water quality may be negatively impacted. Thick accumulations of colored sediment high in organic matter previously reported by Pierce County (2005) were observed during the SPSSEG habitat surveys, although the source of the sediment and any potential impacts to water quality are not clearly known. Additional water quality monitoring could help to fill this data gap. Sub-basins or reaches where further water quality studies might be important include Lacamas Creek, Muck Lake and Chambers Lake, Reaches 2 and 3, and reaches with high livestock and agricultural use.
- Develop a water quality monitoring program with specific goals for each sub-basin or reach.
- Study the effects of water quality impairments on aquatic habitat features associated with salmonid habitat.

5.3. Monitor fish migration and extent of use in each reach

Fish movement and seasonal presence studies could provide qualitative and quantitative data to determine the extent and preferential use patterns of salmonid species and life stages within each reach. This would improve understanding where juvenile and adult salmonids are rearing during each season, whether they are moving above seasonally dry areas during periods with surface flow, and help refine the high priorities for restoration.

Data on fish use patterns are particularly lacking in the mid and upper basin, including Reaches 4 and 5 through the prairie sections, the north and south forks, and Lacamas Creek.

- Monitor migration and use patterns within each reach; determine which species and life stages are using each reach to inform which priority actions are appropriate within each reach.
- Monitor salmon and steelhead movements to determine if there are potential fish migration barriers in the channels through Muck Lake (Muck and Lacamas Creek channels) and Chambers Lake.

5.4. Invasive Species Management

The prevalence and aggressiveness of reed canary grass (RCG) is perhaps one of the biggest threats to maintaining healthy, productive salmon habitat in the Muck Creek basin. RCG is extremely challenging to control in aquatic habitats. Efforts to remove or manage RCG have occurred in the past or are on-going; however, a unified management plan outlining goals, achievable objectives, and priority treatment areas per subbasin or reach has not been developed.

- Develop an invasive species management plan and RCG management plans per subbasin or reach. Focus on most practical and critical areas first; make priorities; identify innovative and effective techniques.

5.5. Coordination, Outreach and Education, Implementation Planning

Due to the multiple landowners and stakeholders present in the Muck Creek basin, a unified approach is likely necessary to ensure the long-term health and protection of salmonids and water resources.

- Strengthen partnerships across resource organizations, JBLM, municipalities, and the public.
- Create a Muck Creek Basin Planning Team; identify organizations specializing in public education, water quality, restoration, and water resource planning, which can fill data gaps, create management plans, conduct outreach, and continue adaptive management.
- Develop landowner incentive programs; encourage stream habitat friendly practices by private property owners in the watershed.
- Identify landowners willing to participate in land acquisitions, incentive programs, or voluntary restoration projects.

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7. Appendices

Appendix A

Annotated Bibliography of Documents Relevant to Muck Creek Watershed Restoration

Appendix B

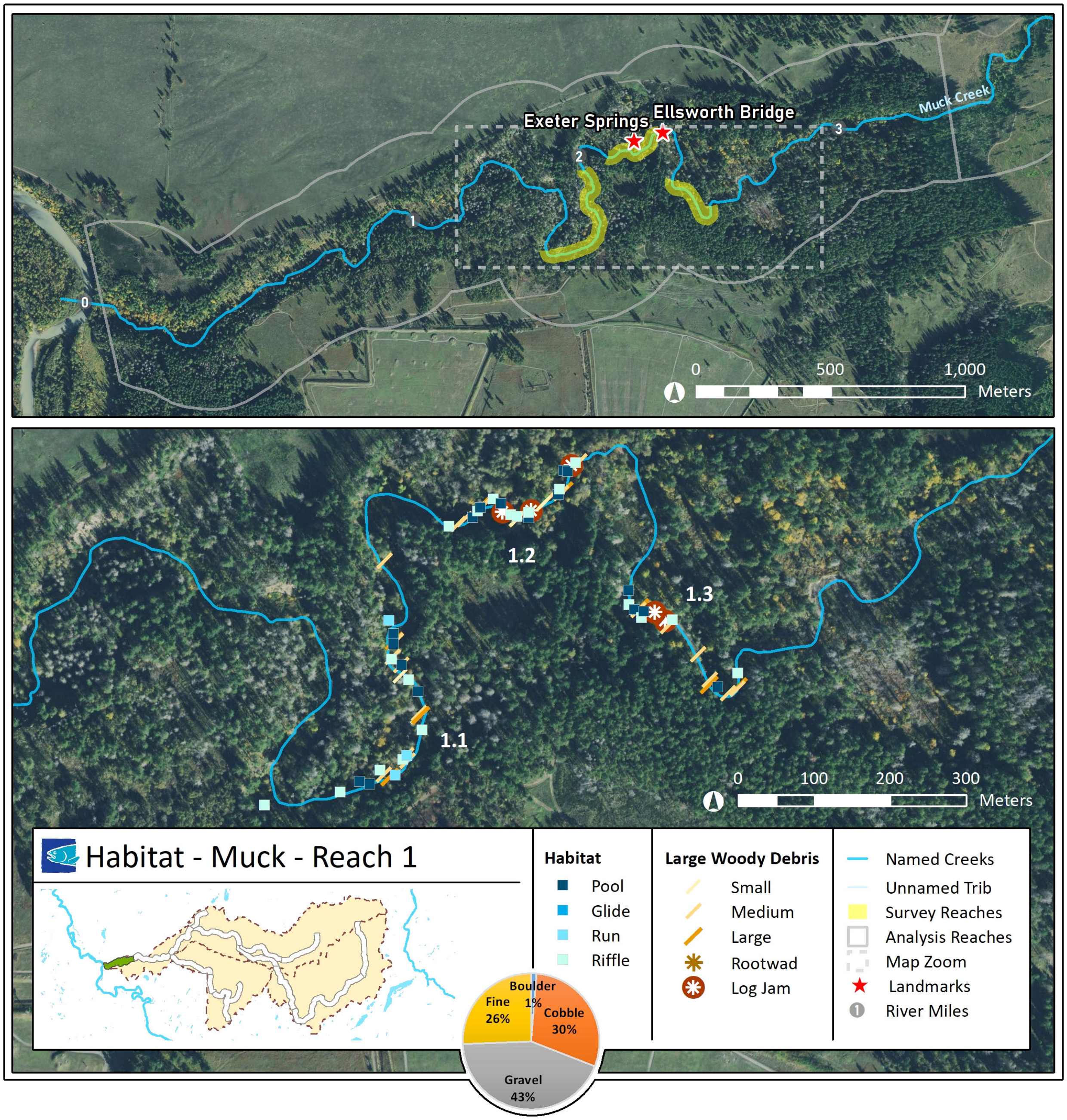
Habitat Survey Index Reach Maps

Reaches 1-14, excluding reaches 10,11,13

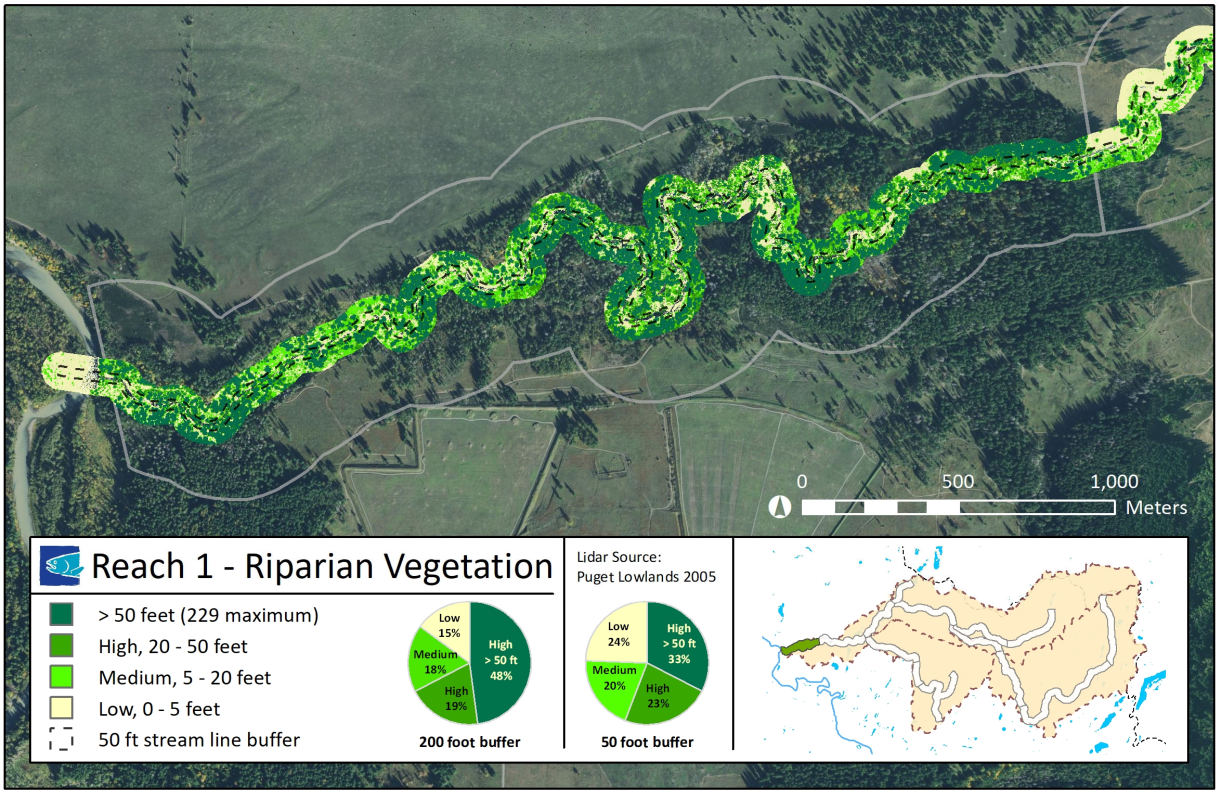
and

Riparian Canopy and Buffer Maps

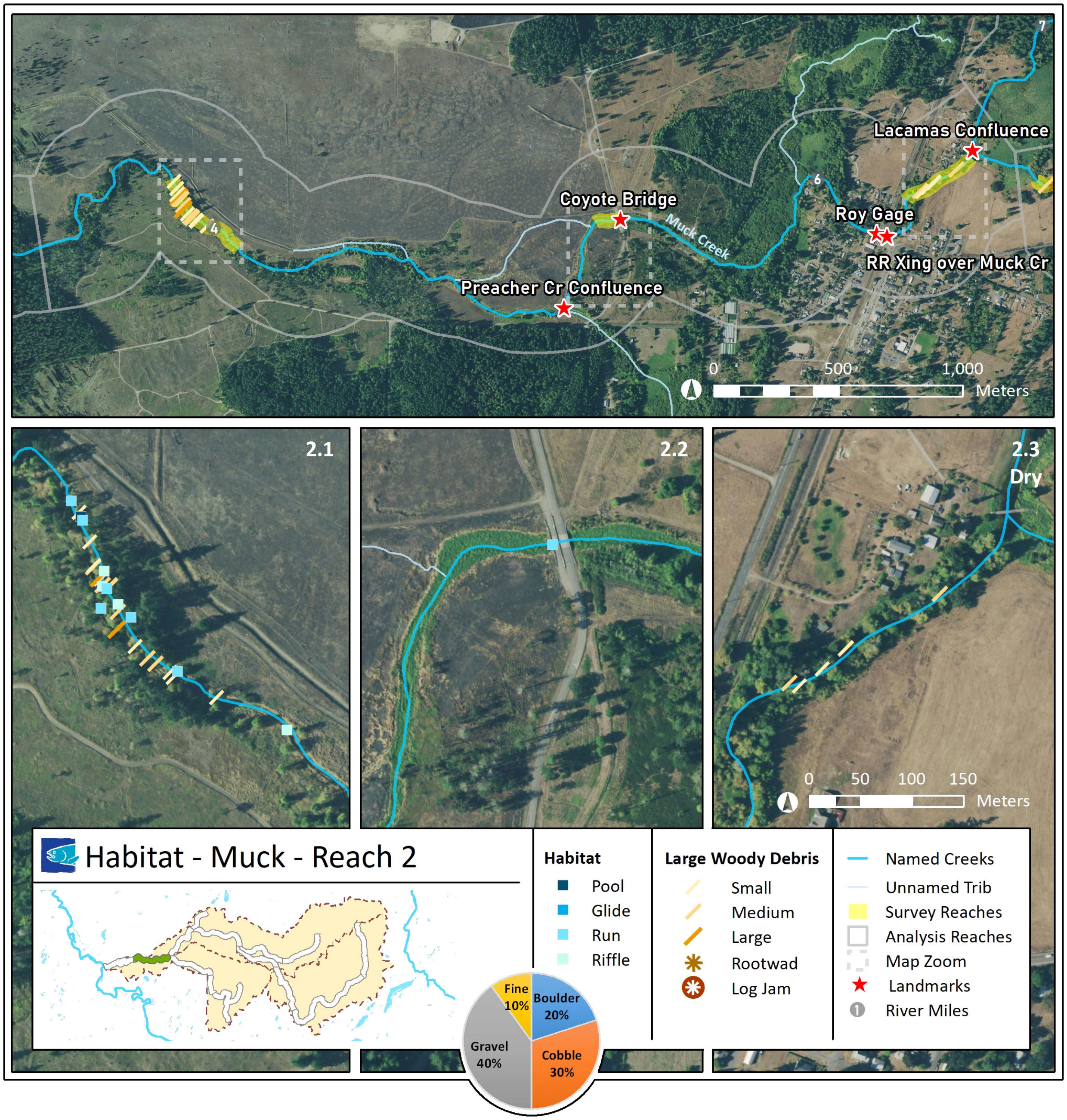
Reaches 1-14

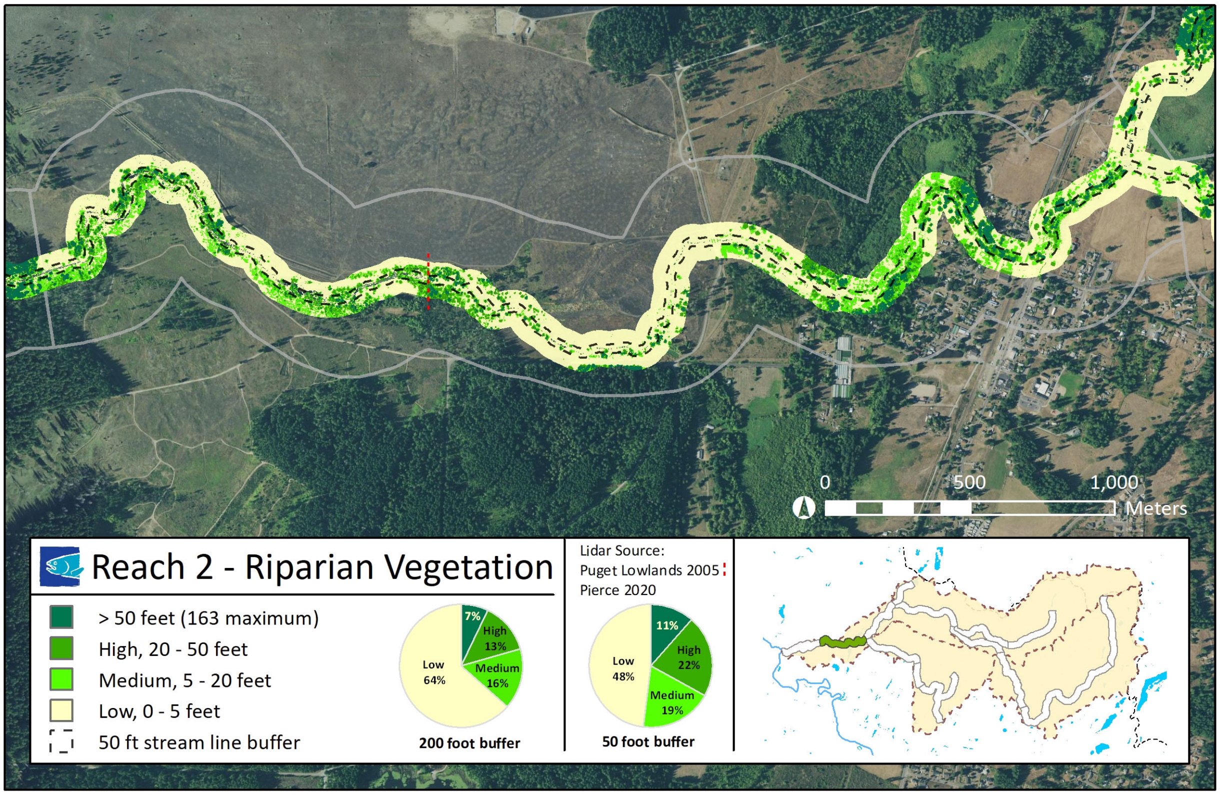


Exeter Springs
Ellsworth Bridge
Muck Creek
0
1
2
3
0
500
1,000
Meters
1.1
1.2
1.3
0
100
200
300
Meters
Habitat - Muck - Reach 1
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 1%
Fine 26%
Cobble 30%
Gravel 43%

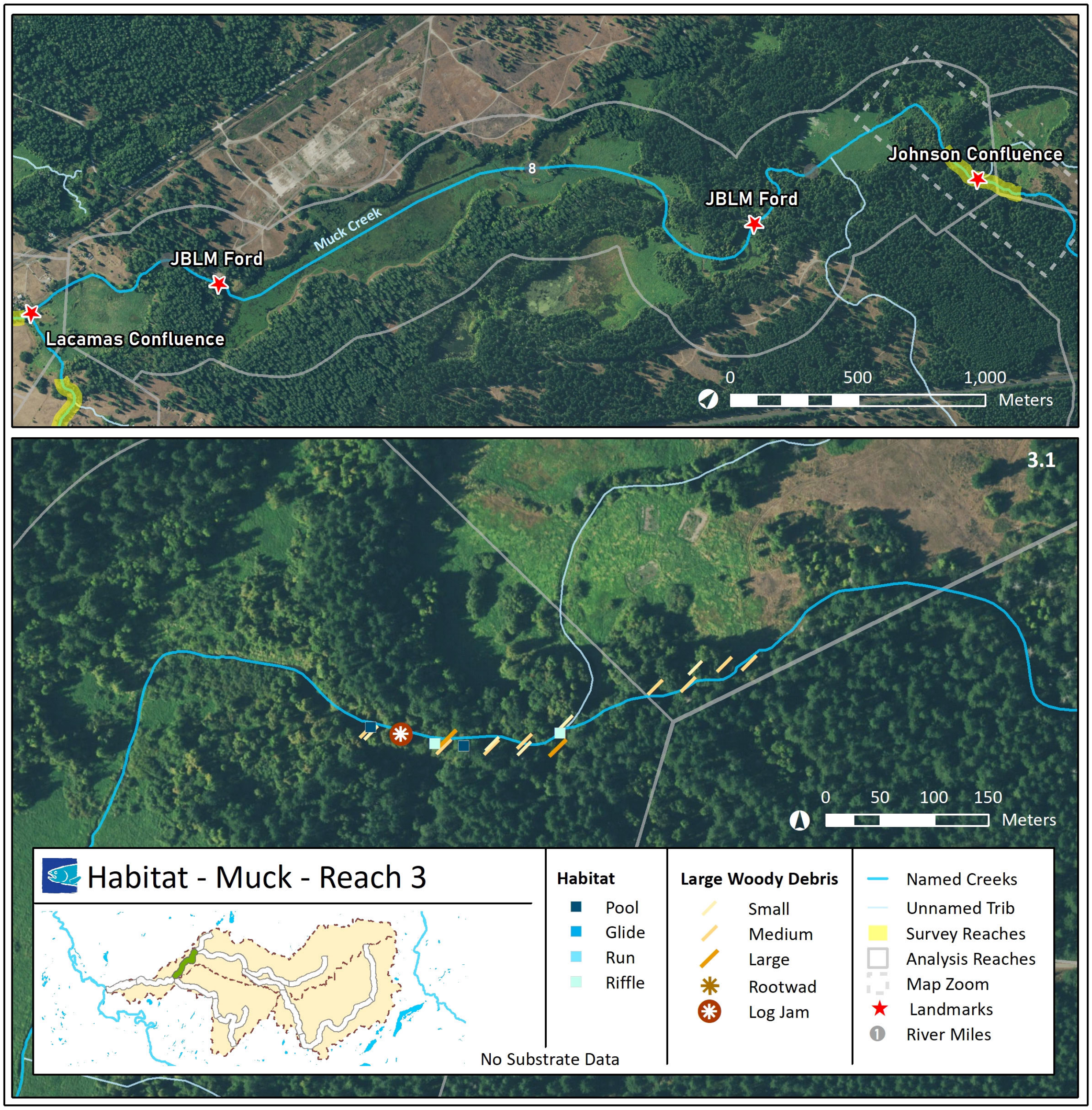


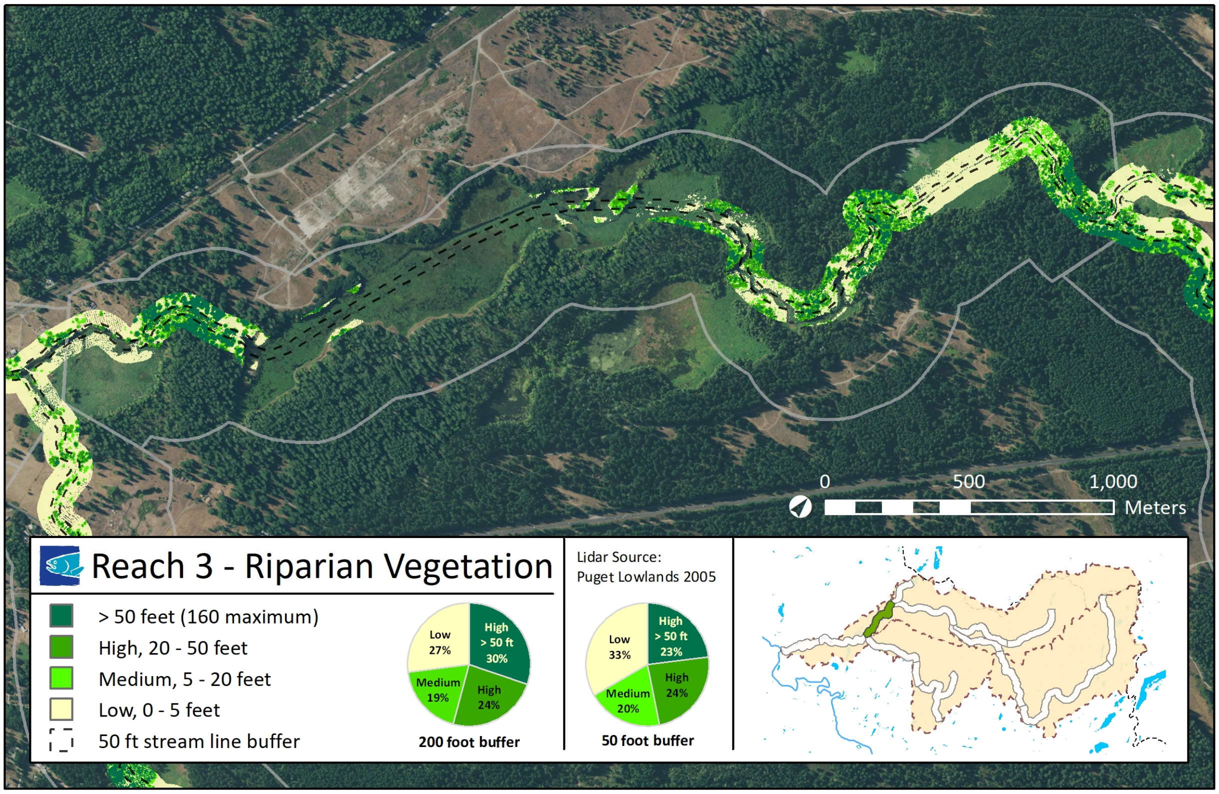
0
500
1,000
Meters
Reach 1 - Riparian Vegetation
> 50 feet (229 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 15%
Medium 18%
High 19%
High > 50 ft 48%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Low 24%
Medium 20%
High 23%
High > 50 ft 33%
50 foot buffer

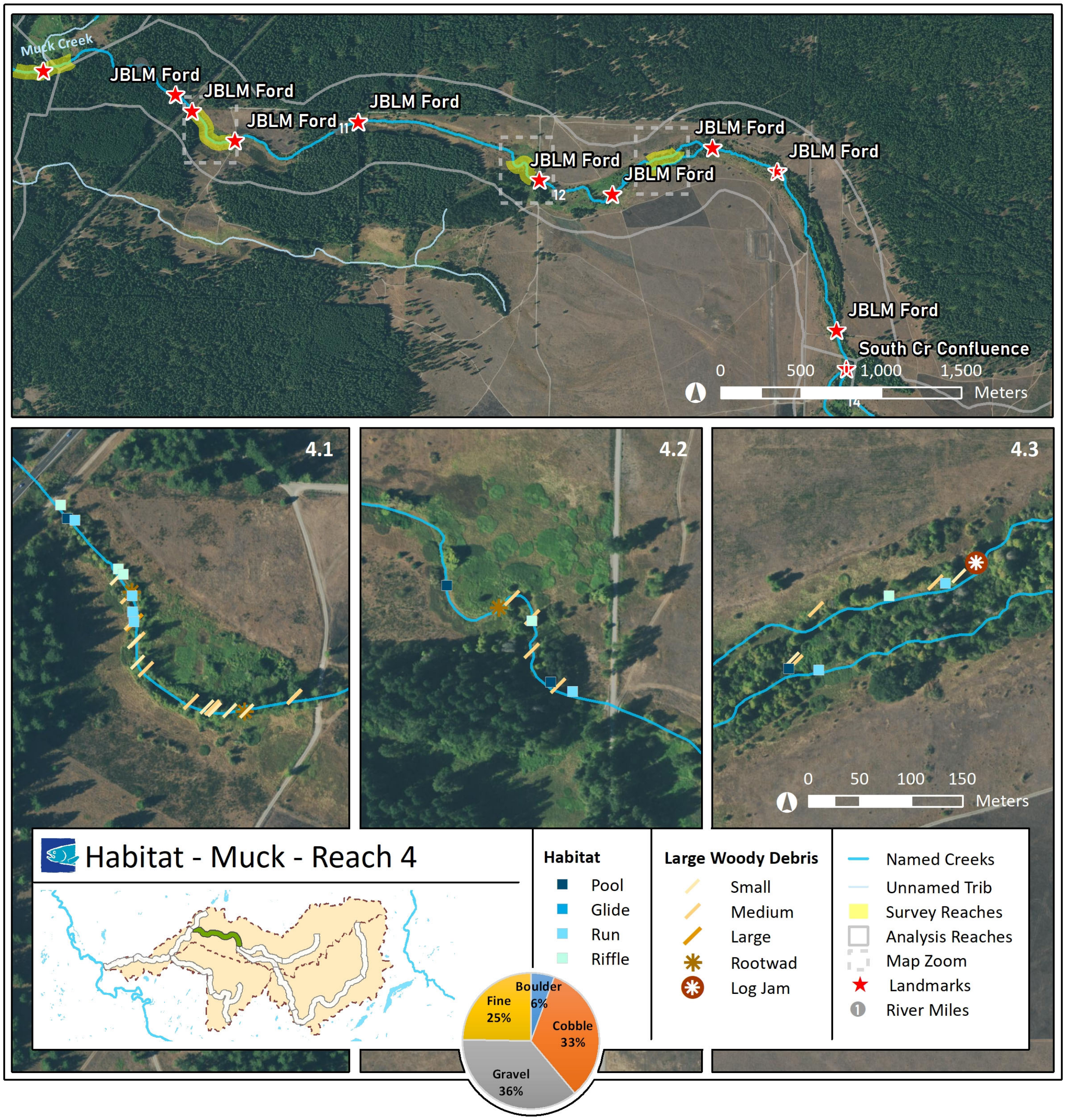

Lacamas Confluence
Coyote Bridge
Muck Creek
Roy Gage
RR Xing over Muck Cr
Preacher Cr Confluence
0 500 1,000 Meters
2.1
2.2
2.3
Dry
0 50 100 150 Meters
Habitat - Muck - Reach 2
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Fine 10%
Boulder 20%
Gravel 40%
Cobble 30%

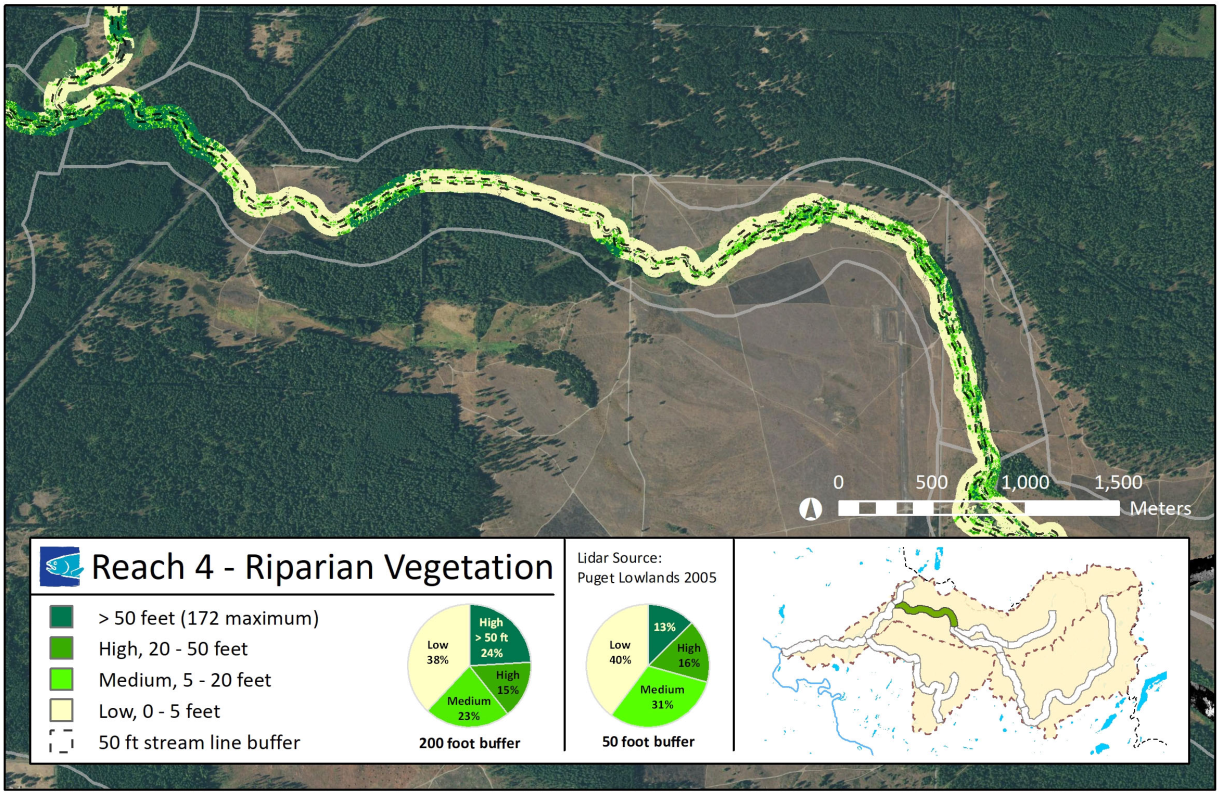


0
500
1,000
Meters
Reach 2 - Riparian Vegetation
> 50 feet (163 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
7%
High 13%
Medium 16%
Low 64%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Pierce 2020
11%
High 22%
Medium 19%
Low 48%
50 foot buffer

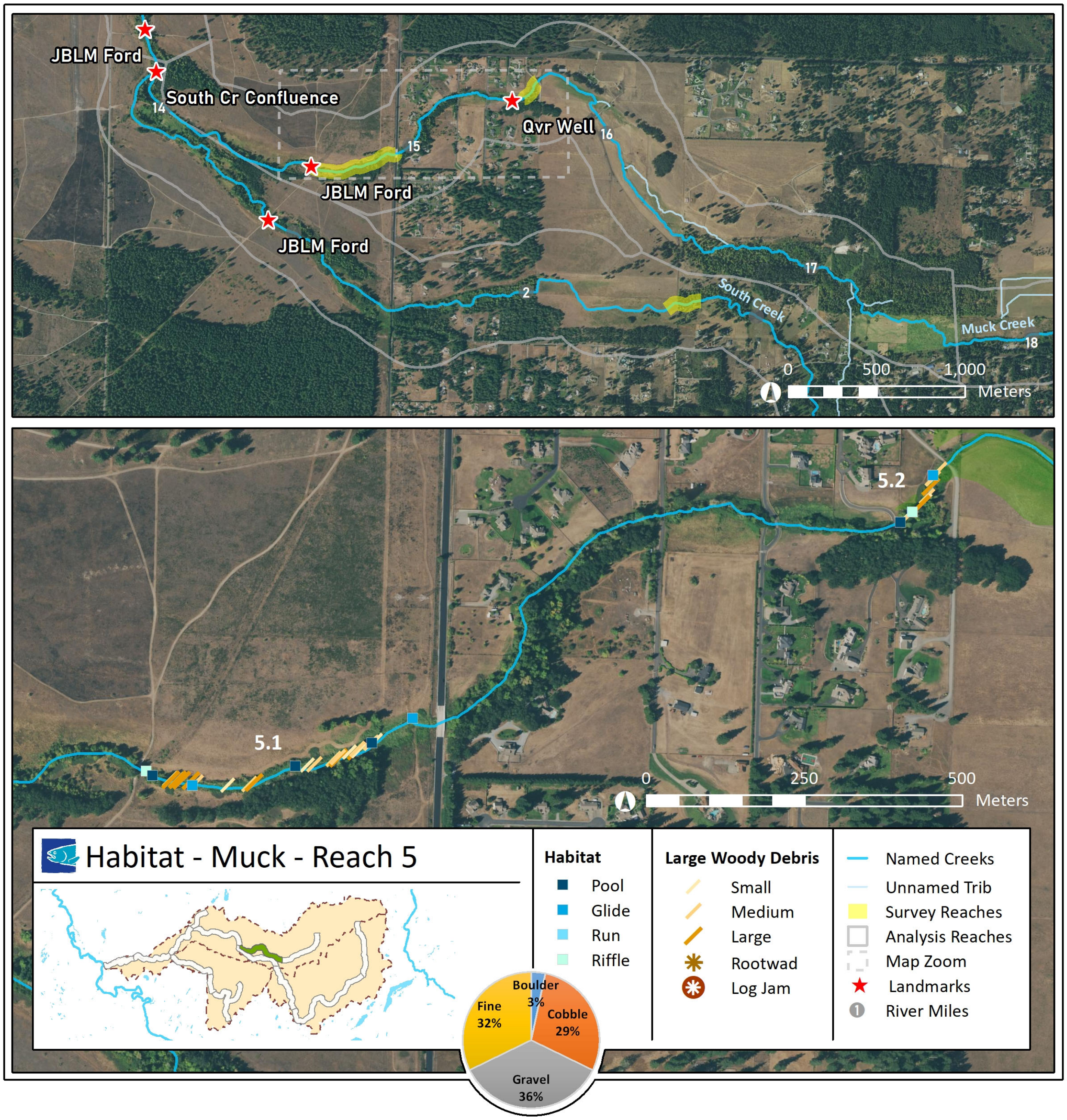

Johnson Confluence
JBLM Ford
8
Muck Creek
JBLM Ford
Lacamas Confluence
0
500
1,000
Meters
3.1
0
50
100
150
Meters
Habitat - Muck - Reach 3
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
No Substrate Data

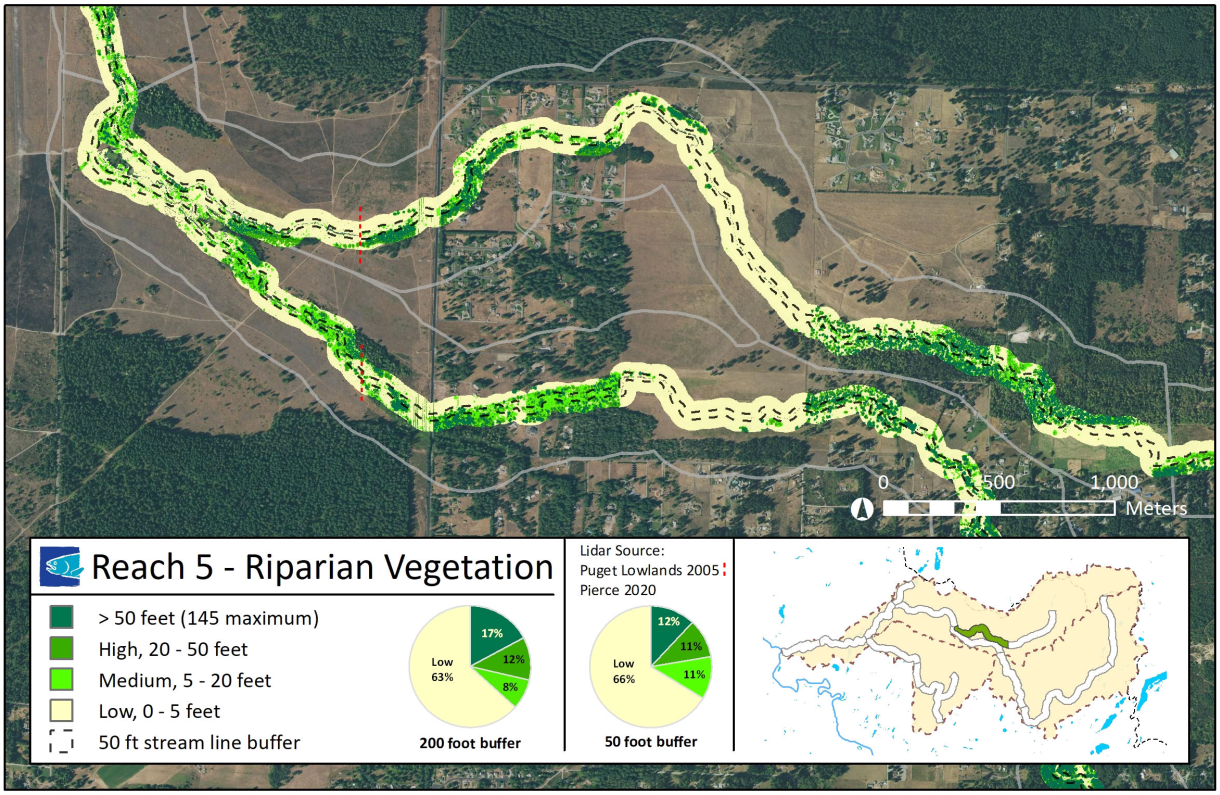

0
500
1,000
Meters
Reach 3 - Riparian Vegetation
> 50 feet (160 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 27%
High > 50 ft 30%
Medium 19%
High 24%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Low 33%
High > 50 ft 23%
High 24%
Medium 20%
50 foot buffer

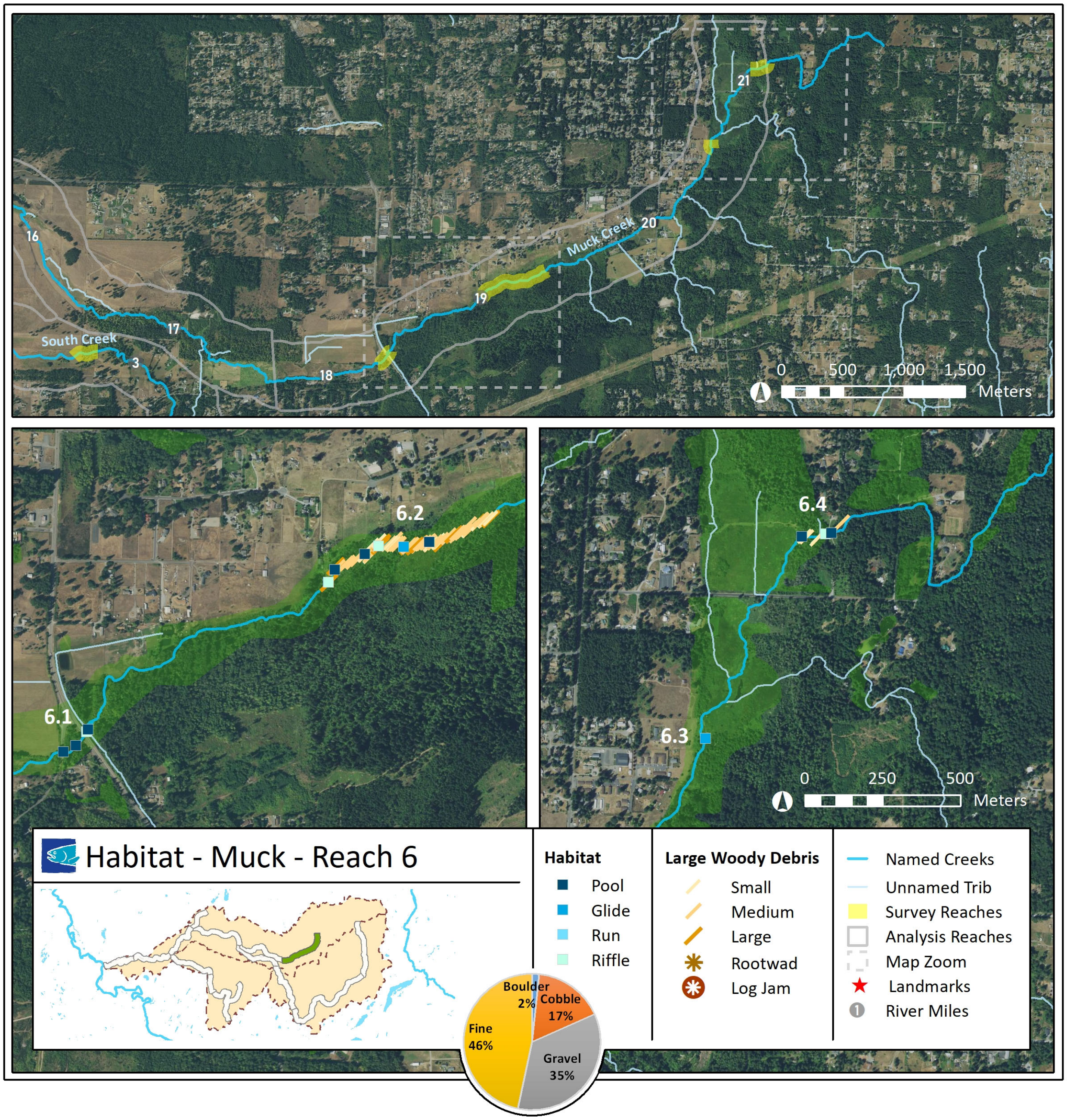

Muck Creek
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
JBLM Ford
South Cr Confluence
0 500 1,000 1,500
Meters
4.1
4.2
4.3
0 50 100 150
Meters
Habitat - Muck - Reach 4
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 6%
Fine 25%
Cobble 33%
Gravel 36%

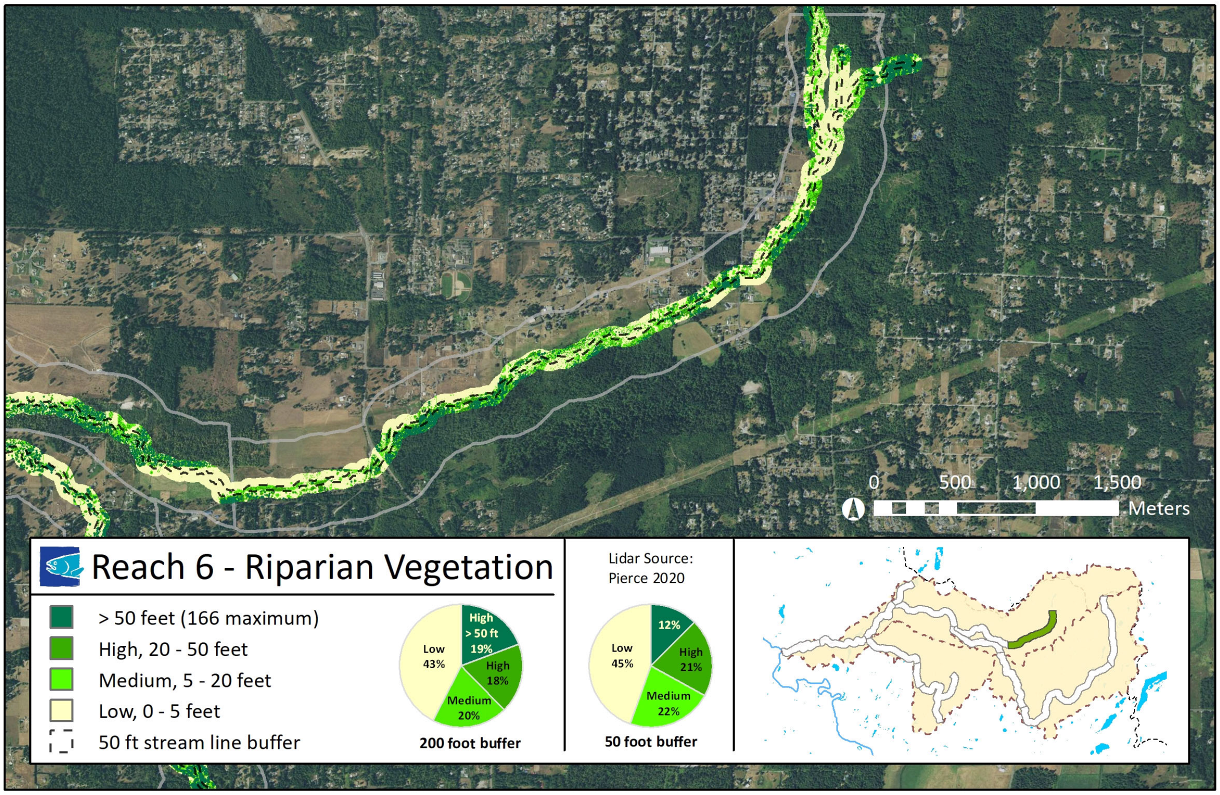


0
500
1,000
1,500
Meters
Reach 4 - Riparian Vegetation
> 50 feet (172 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 38%
High > 50 ft 24%
High 15%
Medium 23%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Low 40%
13%
High 16%
Medium 31%
50 foot buffer

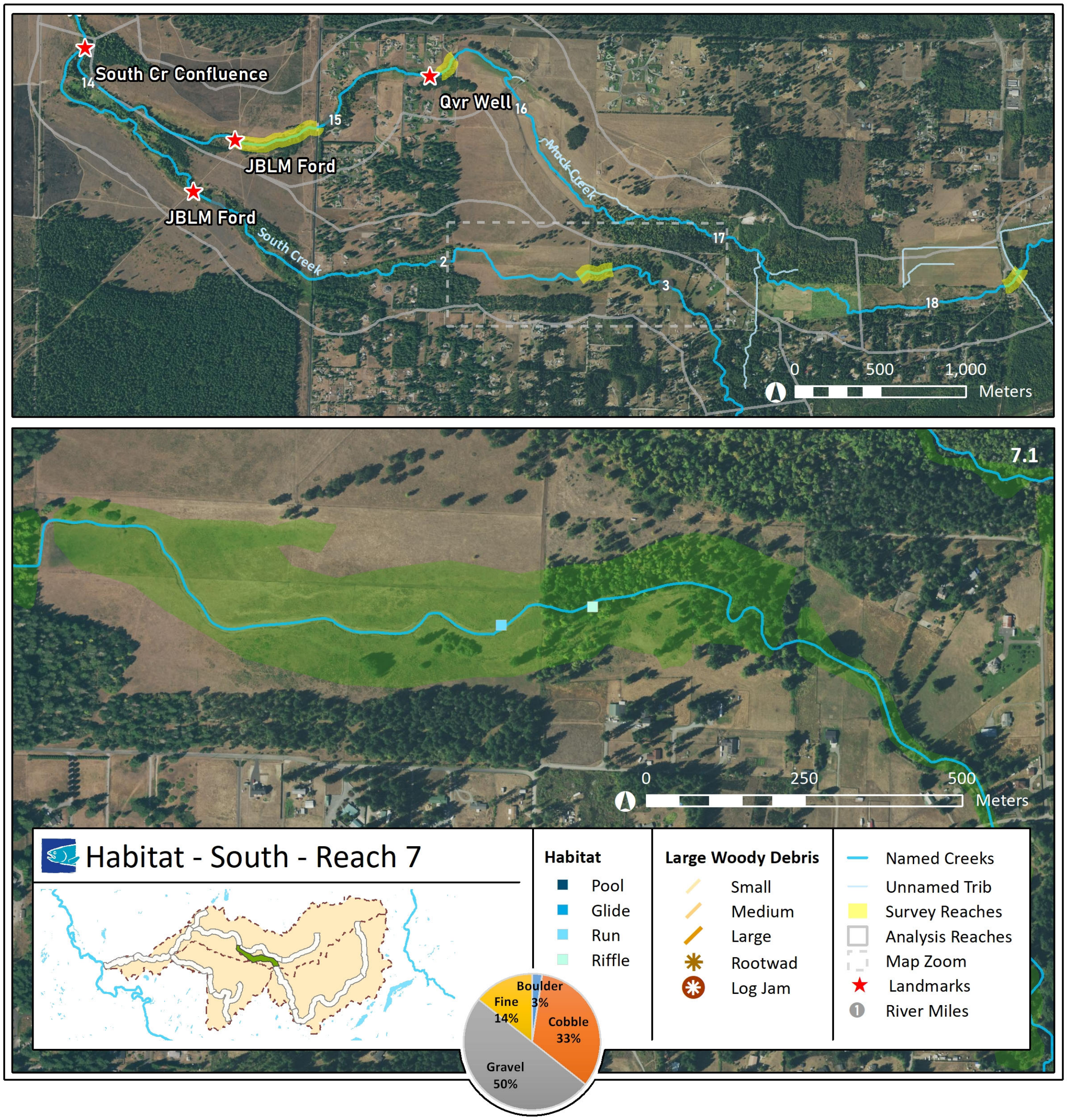

JBLM Ford
South Cr Confluence
JBLM Ford
JBLM Ford
Qvr Well
South Creek
Muck Creek
14
15
16
17
18
2
0
500
1,000
Meters
5.1
5.2
0
250
500
Meters
Habitat - Muck - Reach 5
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 3%
Cobble 29%
Gravel 36%
Fine 32%

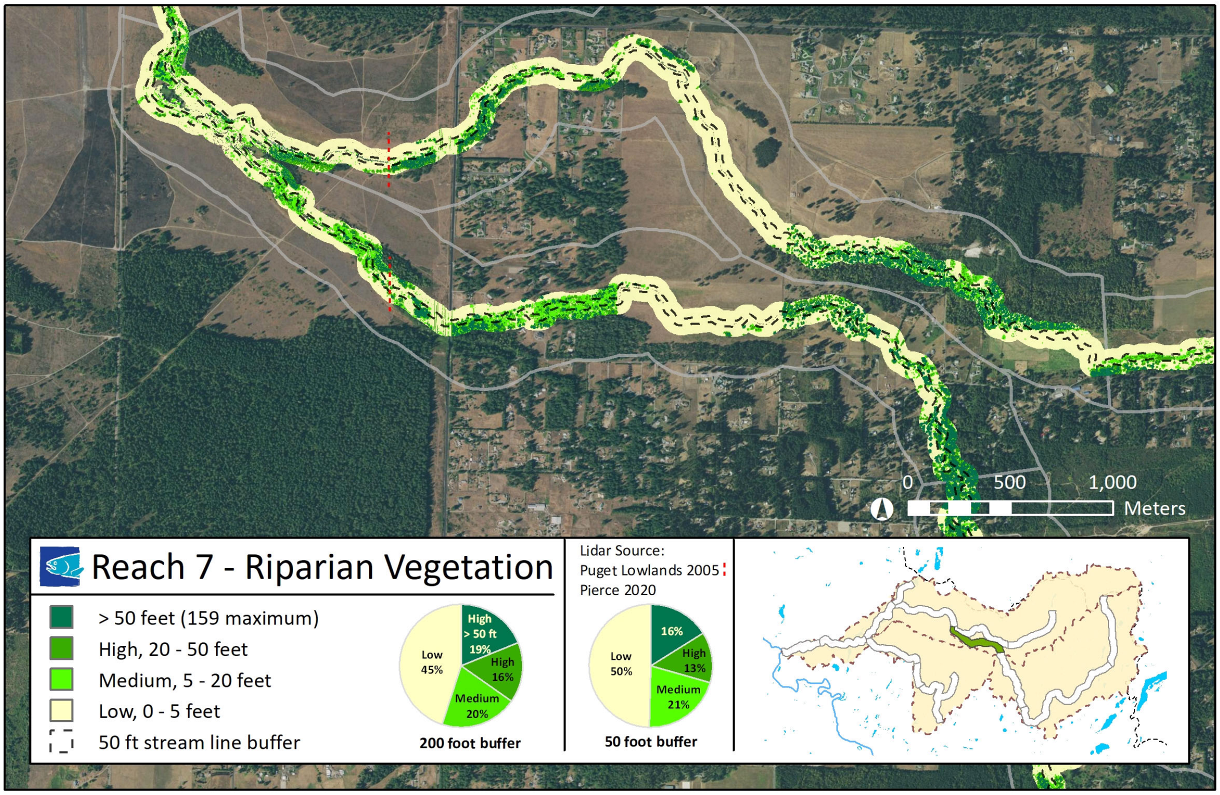

0
500
1,000
Meters
Reach 5 - Riparian Vegetation
> 50 feet (145 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
17%
12%
8%
Low 63%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Pierce 2020
12%
11%
11%
Low 66%
50 foot buffer


Habitat - Muck - Reach 6
Muck Creek
South Creek
16
17
18
19
20
21
3
0 500 1,000 1,500 Meters
6.1
6.2
6.3
6.4
0 250 500 Meters
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 2%
Cobble 17%
Gravel 35%
Fine 46%

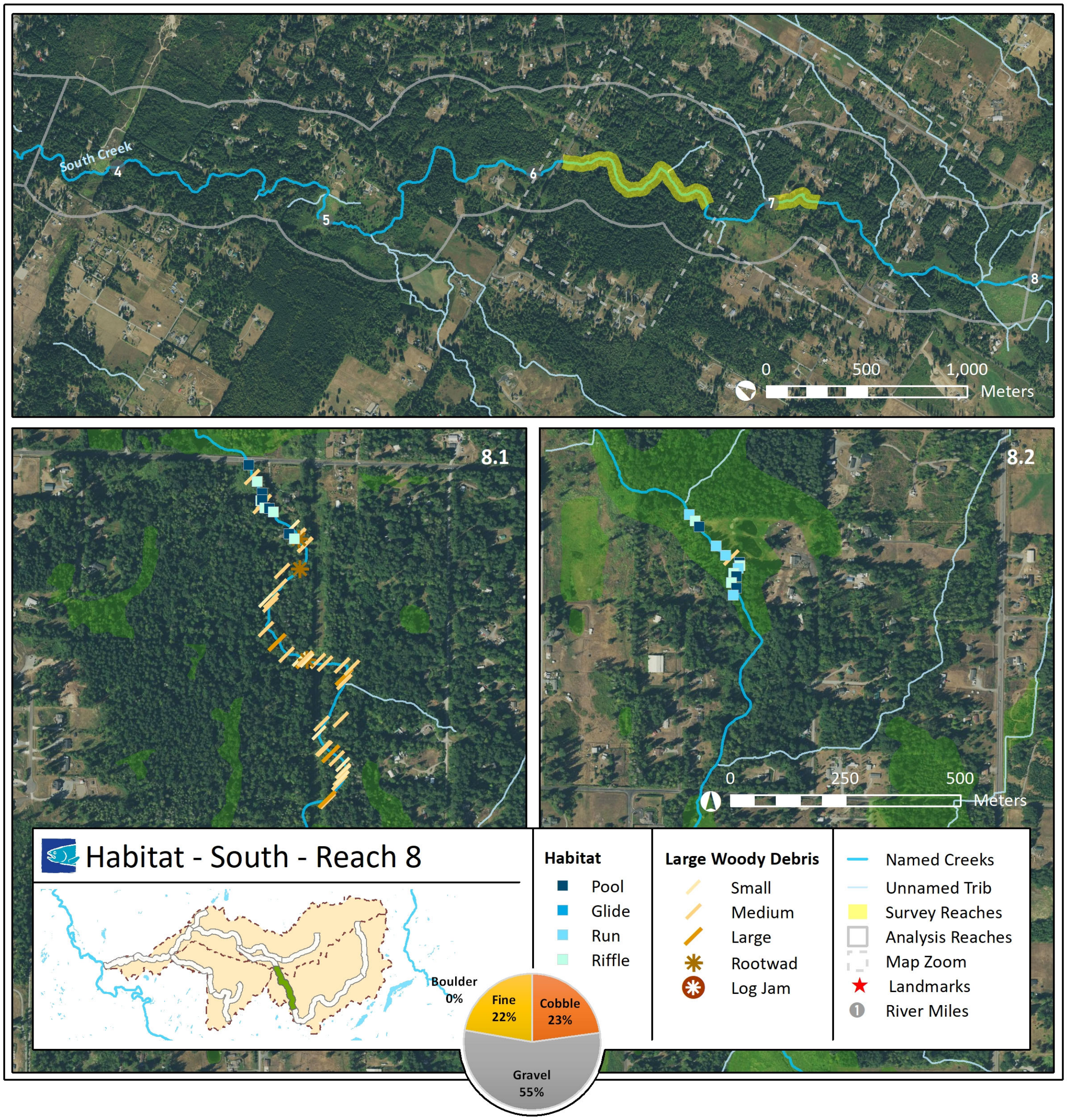


0
500
1,000
1,500
Meters
Reach 6 - Riparian Vegetation
> 50 feet (166 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
High > 50 ft 19%
High 18%
Medium 20%
Low 43%
200 foot buffer
Lidar Source: Pierce 2020
12%
High 21%
Medium 22%
Low 45%
50 foot buffer

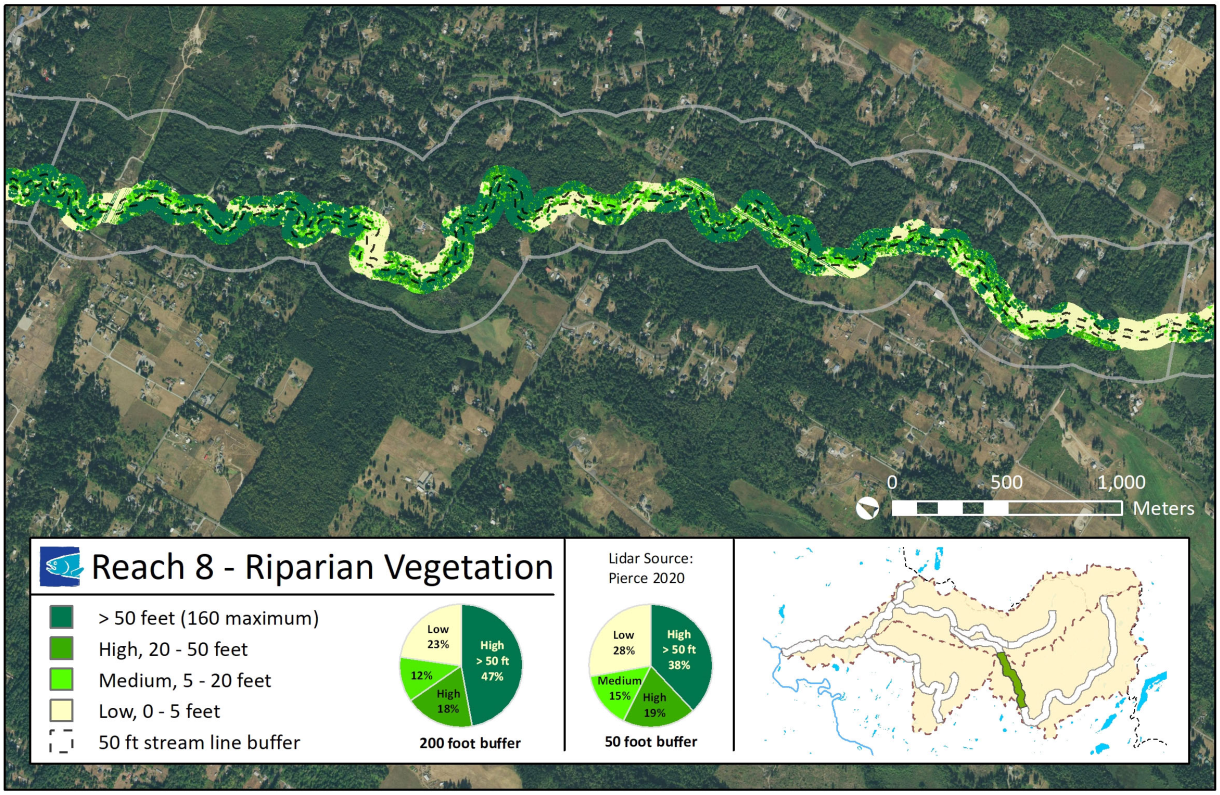

South Cr Confluence
14
15
16
17
18
2
3
JBLM Ford
JBLM Ford
Qvr Well
Muck Creek
South Creek
0
500
1,000
Meters
7.1
0
250
500
Meters
Habitat - South - Reach 7
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 3%
Fine 14%
Cobble 33%
Gravel 50%



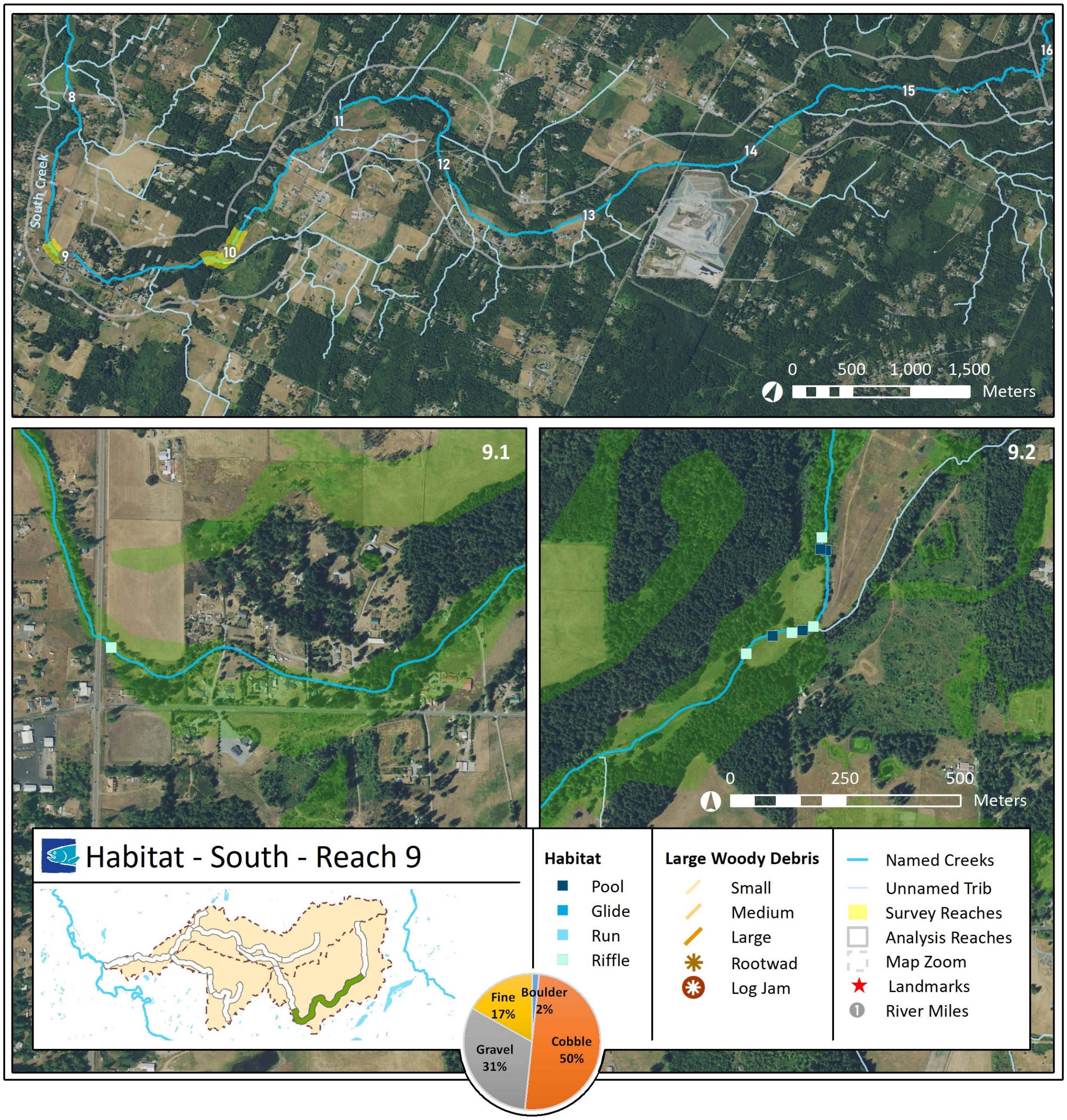
0
500
1,000
Meters
Reach 7 - Riparian Vegetation
> 50 feet (159 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
High > 50 ft 19%
High 16%
Medium 20%
Low 45%
200 foot buffer
Lidar Source:
Puget Lowlands 2005
Pierce 2020
16%
High 13%
Medium 21%
Low 50%
50 foot buffer

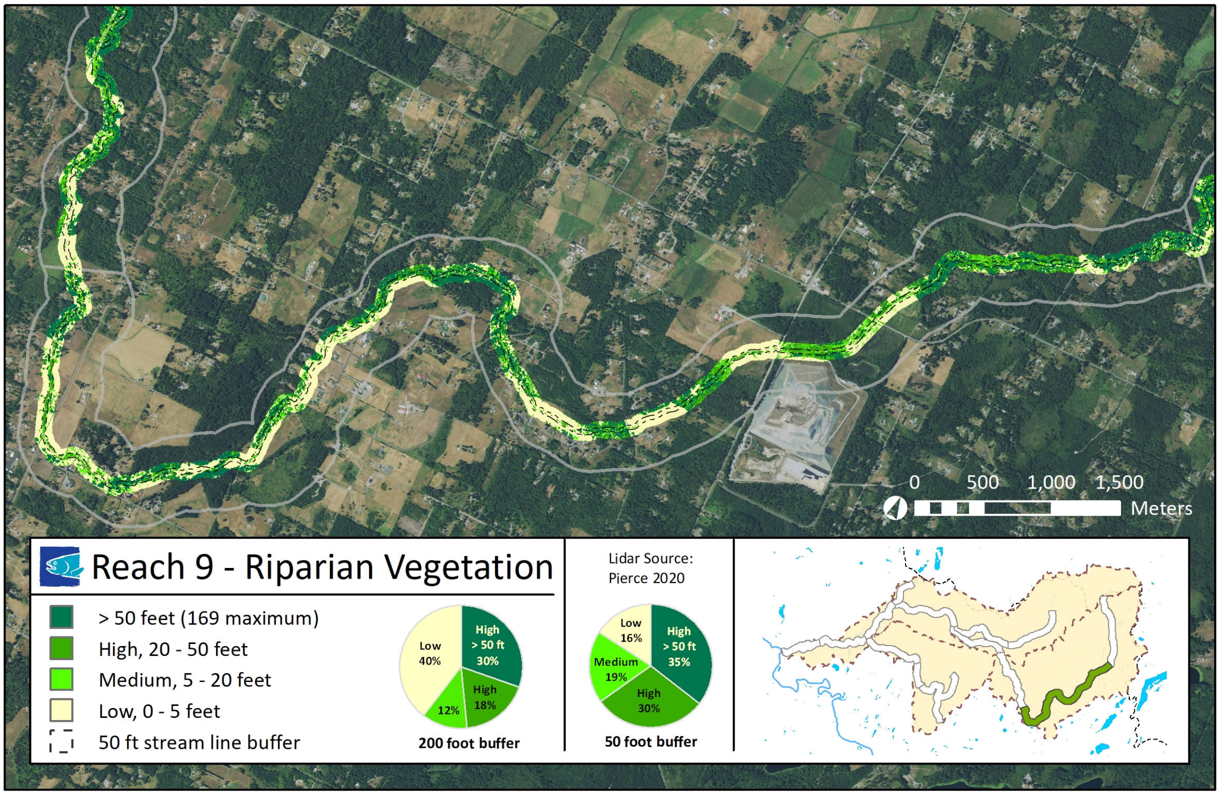


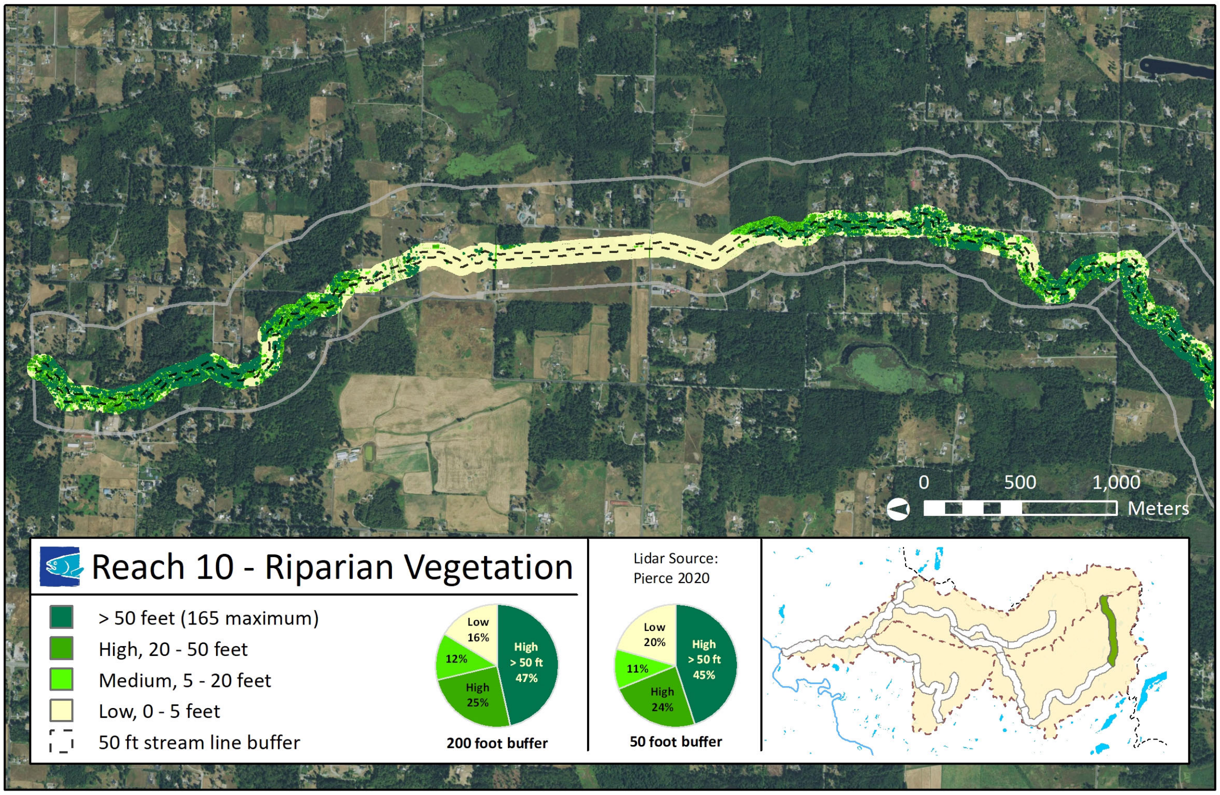
South Creek
4
5
6
7
8
0
500
1,000
Meters
8.1
8.2
0
250
500
Meters
Habitat - South - Reach 8
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 0%
Fine 22%
Cobble 23%
Gravel 55%



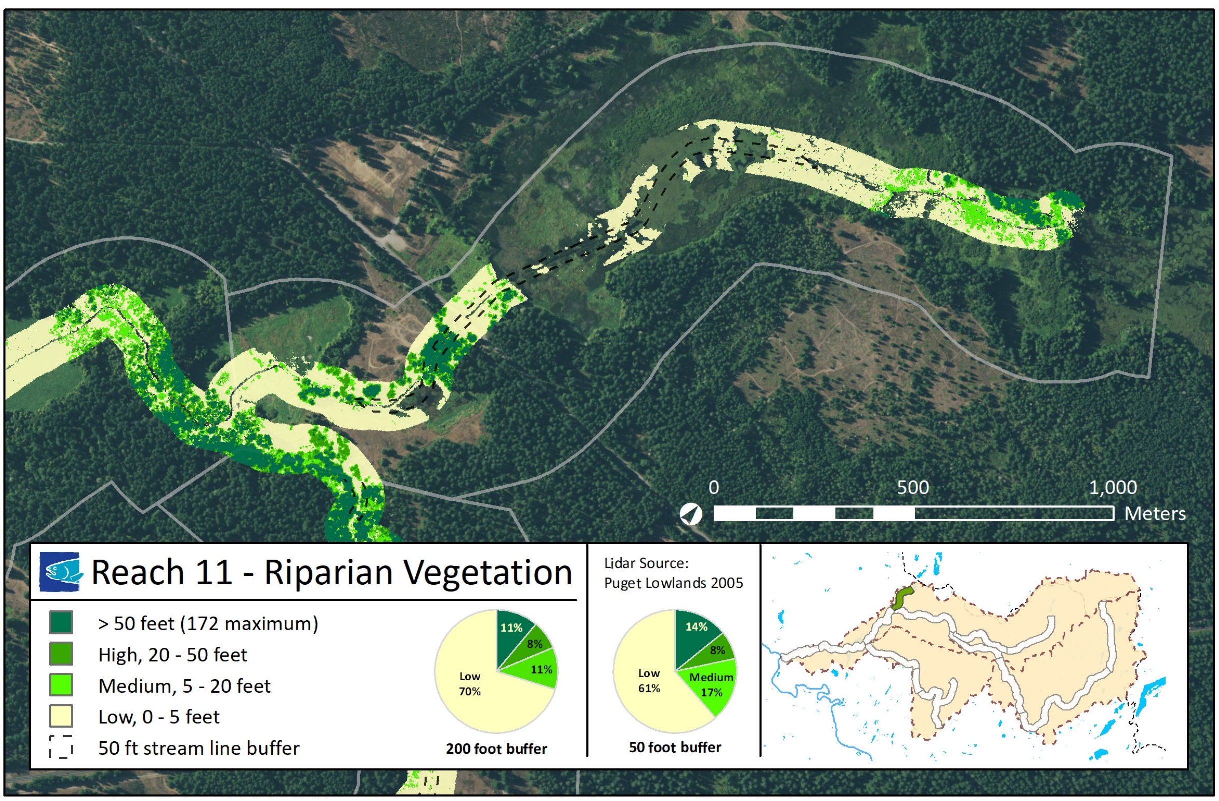
0
500
1,000
Meters
Reach 8 - Riparian Vegetation
> 50 feet (160 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 23%
High > 50 ft 47%
12%
High 18%
200 foot buffer
Lidar Source: Pierce 2020
Low 28%
High > 50 ft 38%
Medium 15%
High 19%
50 foot buffer


South Creek
8
9
10
11
12
13
14
15
16
0 500 1,000 1,500
Meters
9.1
9.2
0 250 500
Meters
Habitat - South - Reach 9
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Fine 17%
Boulder 2%
Gravel 31%
Cobble 50%

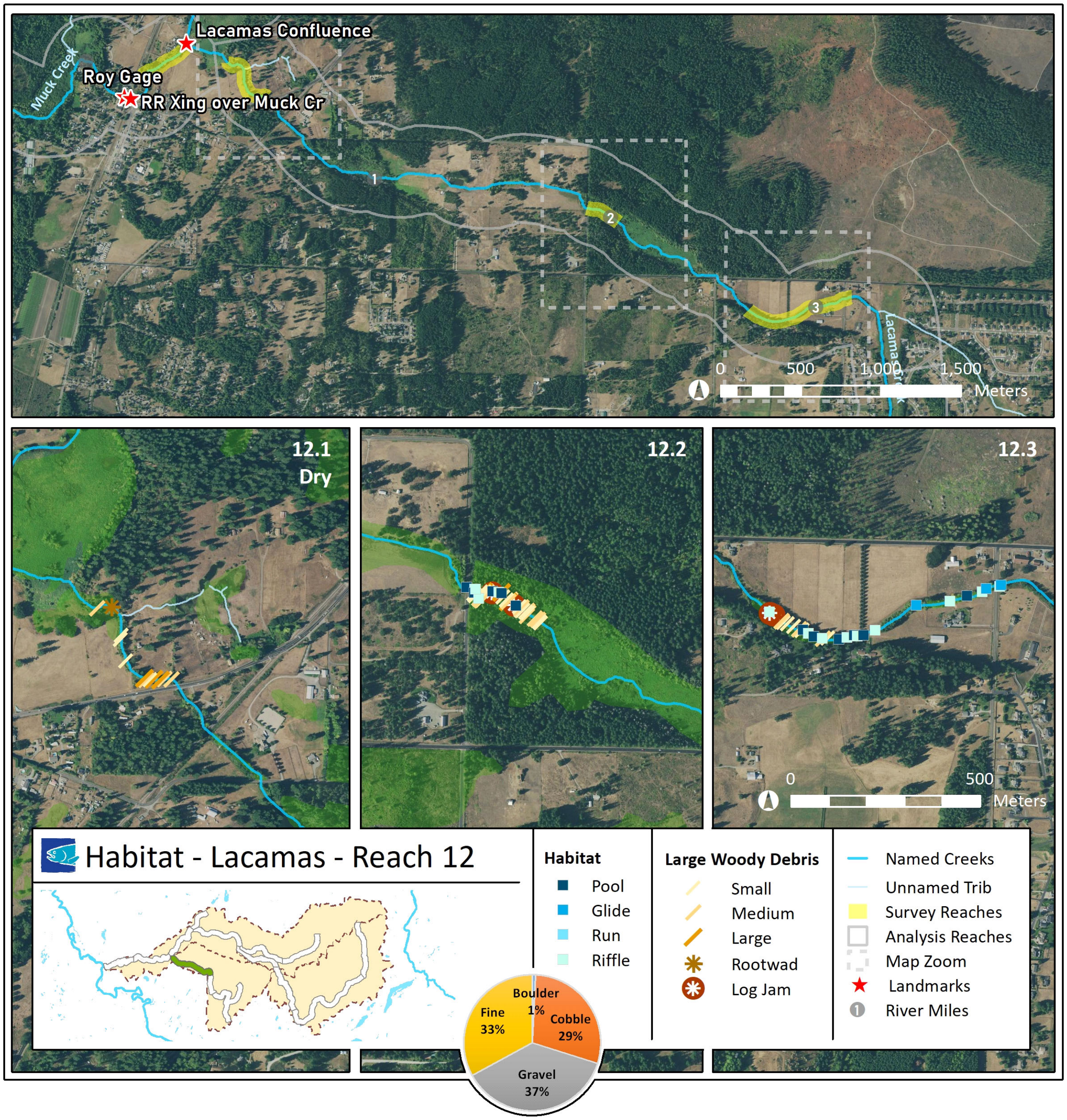

0
500
1,000
1,500
Meters
Reach 9 - Riparian Vegetation
> 50 feet (169 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 40%
High > 50 ft 30%
High 18%
12%
200 foot buffer
Lidar Source: Pierce 2020
Low 16%
High > 50 ft 35%
Medium 19%
High 30%
50 foot buffer



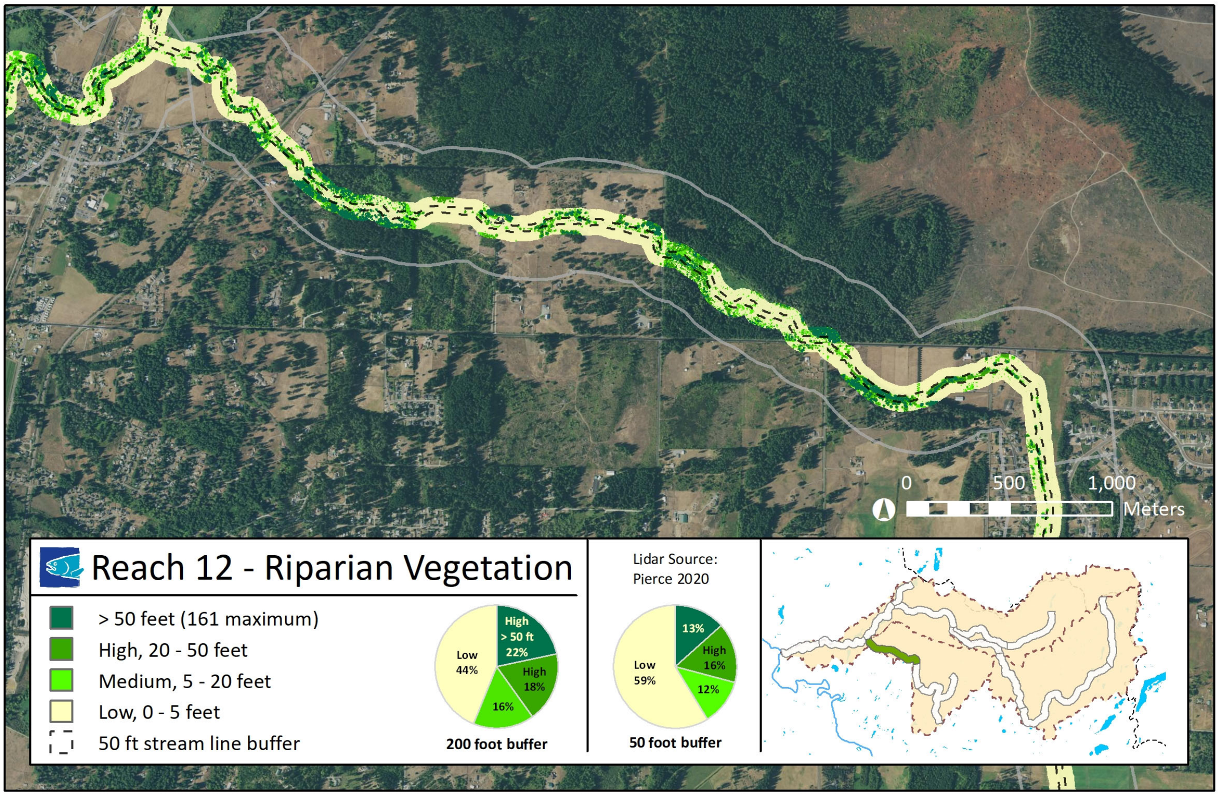
0
500
1,000
Meters
Reach 10 - Riparian Vegetation
> 50 feet (165 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
Low 16%
12%
High > 50 ft 47%
High 25%
200 foot buffer
Lidar Source: Pierce 2020
Low 20%
11%
High > 50 ft 45%
High 24%
50 foot buffer

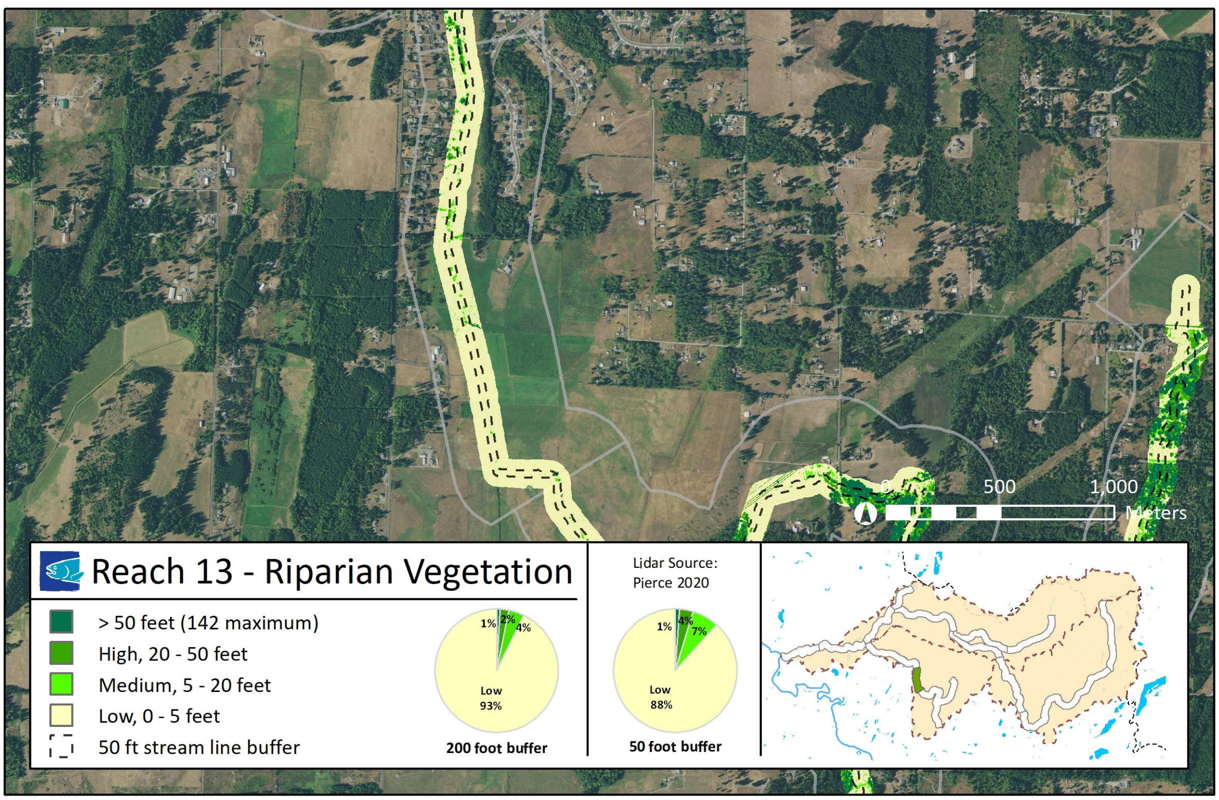


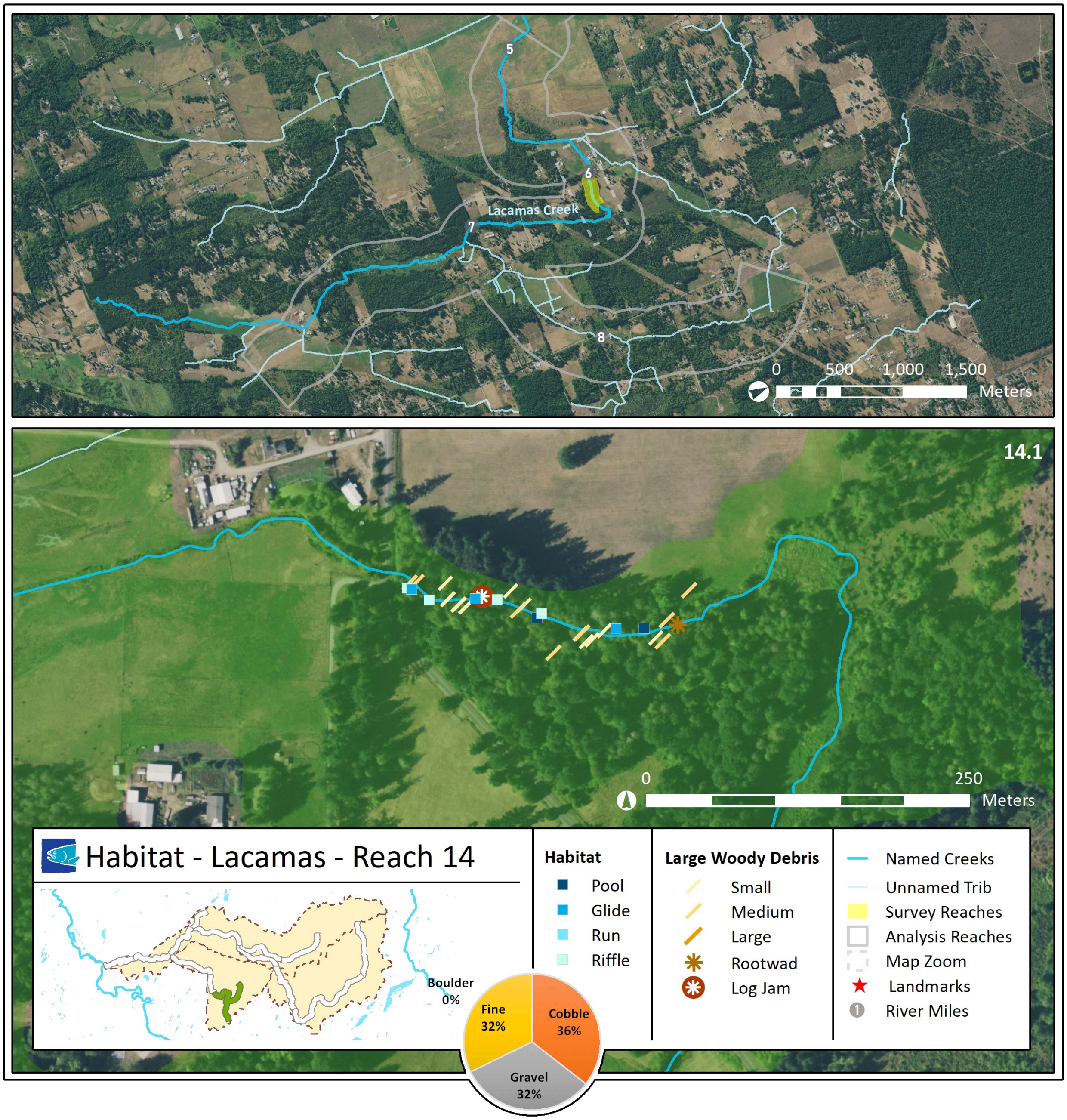
0
500
1,000
Meters
Reach 11 - Riparian Vegetation
> 50 feet (172 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
11%
8%
11%
Low 70%
200 foot buffer
Lidar Source: Puget Lowlands 2005
14%
8%
Medium 17%
Low 61%
50 foot buffer

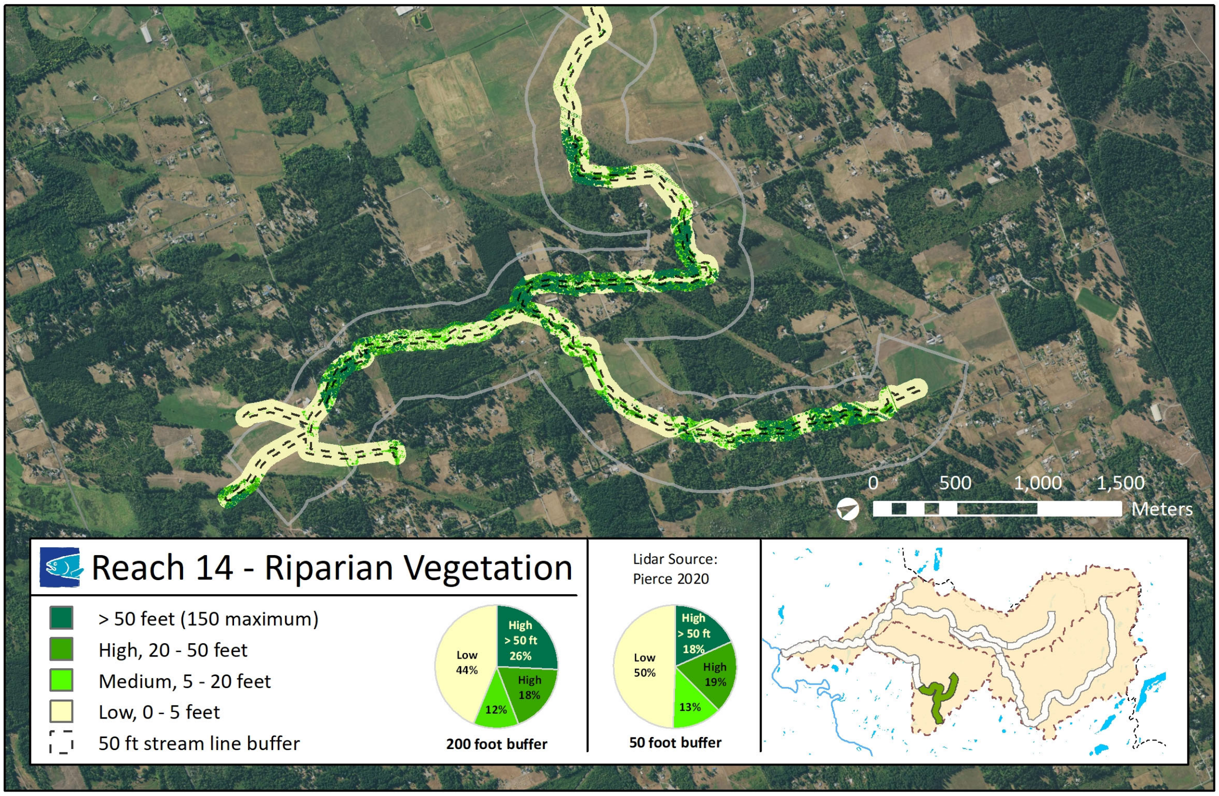


Lacamas Confluence
Roy Gage
RR Xing over Muck Cr
Muck Creek
Lacamas Creek
0 500 1,000 1,500 Meters
12.1
Dry
12.2
12.3
0 500 Meters
Habitat - Lacamas - Reach 12
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder 1%
Fine 33%
Cobble 29%
Gravel 37%


0
500
1,000
Meters
Reach 12 - Riparian Vegetation
> 50 feet (161 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
High > 50 ft 22%
High 18%
16%
Low 44%
200 foot buffer
Lidar Source: Pierce 2020
13%
High 16%
12%
Low 59%
50 foot buffer


0
500
1,000
Meters
Reach 13 - Riparian Vegetation
> 50 feet (142 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
1%
2%
4%
Low 93%
200 foot buffer
Lidar Source: Pierce 2020
1%
4%
7%
Low 88%
50 foot buffer


5
6
7
8
Lacamas Creek
0
500
1,000
1,500
Meters
14.1
0
250
Meters
Habitat - Lacamas - Reach 14
Habitat
Pool
Glide
Run
Riffle
Large Woody Debris
Small
Medium
Large
Rootwad
Log Jam
Named Creeks
Unnamed Trib
Survey Reaches
Analysis Reaches
Map Zoom
Landmarks
River Miles
Boulder
0%
Fine
32%
Cobble
36%
Gravel
32%



0
500
1,000
1,500
Meters
Reach 14 - Riparian Vegetation
> 50 feet (150 maximum)
High, 20 - 50 feet
Medium, 5 - 20 feet
Low, 0 - 5 feet
50 ft stream line buffer
High
> 50 ft
26%
High
18%
12%
Low
44%
200 foot buffer
Lidar Source:
Pierce 2020
High
> 50 ft
18%
High
19%
13%
Low
50%
50 foot buffer