



March 2024
Muck Creek Watershed Strategy



Coho Water Resources

Integrated Water Resource Management

Muck Creek Watershed Restoration Strategy

Prepared for Nisqually River Foundation

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APPENDICES

Appendix A	Revised Muck Creek Literature Review and Strategy Framework
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ABBREVIATIONS

afy	acre feet per year
BDA	beaver dam analogs
BLM	Bureau of Land Management
cfs	cubic feet per second
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
GLO	General Land Office
GSI	Green Stormwater Infrastructure
JBLM	Joint Base Lewis-McChord
MAR	managed aquifer recharge
NPDES	National Pollutant Discharge Elimination System
NWPU	Nisqually Watershed Planning Unit
PAL	post-assisted log structure
PCD	Pierce Conservation District
SPSSEG	South Puget Sound Salmon Enhancement Group
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WRIA	water resource inventory area
WWT	Washington Water Trust
WWTP	wastewater treatment plant
WY	water year

1 Introduction

The Nisqually River Foundation and South Puget Sound Salmon Enhancement Group (SPSSEG) are leading the Muck Creek Watershed Restoration Strategy and Project Prioritization study in collaboration with multiple partners, including the Nisqually Indian Tribe, Nisqually Land Trust, Joint Base Lewis-McChord (JBLM), Pierce County, and the Washington Departments of Ecology (Ecology) and Fish and Wildlife (WDFW). This study was funded by a streamflow restoration grant from Ecology with supplemental funding from SPSSEG for the design of a project selected in this study. The purpose of this study is to develop a comprehensive watershed restoration strategy for Muck Creek that addresses the requirements of the Streamflow Restoration Act (RCW 90.94.020), specifically for the Prairie Tributaries to the Nisqually River, and also restores habitats for salmonids and other native aquatic species.

This report builds on the *Nisqually Watershed Management Plan* (NIT 2003) and the *Addendum to the 2003 Watershed Management Plan* (NWPU 2019), along with the recently completed *Muck Creek Salmon and Steelhead Habitat Assessment Report* (SPSSEG 2022). This study included a compilation of previous plans and studies for the Muck Creek watershed, additional surface and groundwater data collection to support identification of key streamflow needs and opportunities, and development of the restoration strategy that includes reach and site-specific opportunities and an evaluation of the potential benefits of those opportunities to fully offset the projected consumptive water use from future permit-exempt wells while simultaneously improving salmonid habitats.

In the course of completing this study Anchor QEA and its subconsultant Coho Water Resources completed technical memoranda for review by Nisqually River Foundation, SPSSEG and project partners. The technical memoranda provide important background and foundational information for this strategy. The technical memoranda, along with a description of their contents are listed below:

Appendix A: Task 1: Revised Muck Creek Literature Review and Strategy Framework (Anchor QEA 2022)

This memorandum summarizes information produced by numerous previous studies to set the context for historical and current watershed conditions and the key needs and opportunities for watershed restoration, and provides a strategy framework for high priority reaches, data gaps, and the types of projects that are further developed in this strategy document. Included in the memorandum are an annotated bibliography, a timeline of key events for the watershed, and a list of geospatial data layers available for the basin.

Appendix B: Field Data Results—Streamflow Observations and Groundwater Levels (Coho 2024a)

This technical memorandum presents field data on streamflow and groundwater levels in reaches of the Muck Creek drainage network. Coho Water Resources installed eight time-lapse cameras at

points along 12 miles of stream to collect daily photographs of stream conditions and measured shallow groundwater levels at four piezometers adjacent to Muck and South Creeks on the prairie. The daily photographs establish specific times when surface flow was present in Muck Creek.

Appendix C: Muck Creek Basin Water Balance Component Estimates (Coho 2024b)

This technical memorandum presents estimates of water balance components in the Muck Creek basin. The memorandum documents land cover changes that have occurred since the 1800s and uses recent estimates of evapotranspiration (ET) by vegetation type to extrapolate to associated changes in ET across the basin over time. The memorandum also summarizes monthly precipitation (water years 1950 to 2023) and streamflow (water years 1952 to 1972) and estimates total and consumptive water use by the residential population of the basin as of 2010. The water balance information provides context for the investigation of noted trends towards longer stretches of low/dry streamflow in key locations on Muck Creek.

Appendix D: Managed Aquifer Recharge Technical Memorandum (Coho 2024c)

This technical memorandum presents a summary of possible managed aquifer recharge (MAR) opportunities in the Muck Creek watershed with a focus on the Lacamas Creek subbasin. The lack of wastewater treatment plants (WWTPs) in the Muck Creek watershed reduces the potential scale for MAR. There are, however, locations in the Muck Creek watershed where stormwater could be infiltrated.

2 Existing Conditions

2.1 Watershed Characterization

The Muck Creek watershed is an approximately 93-square-mile basin located in southwestern Pierce County and is the largest tributary basin within the lower Nisqually River watershed (Coho 2021; May 2002; Pierce County 2005). The Muck Creek watershed occupies the majority of the Prairie Tributaries subbasin within the Nisqually River watershed (NWPU 2019). The topography is primarily flat or low rolling hillslopes ranging from approximately 140 to 960 feet in elevation (Pierce County 2005). Four primary streams drain the Muck Creek watershed (Muck Creek, South Creek, Lacamas Creek, and Johnson Creek), and the watershed has four main subbasins (Figure 1, Table 1).

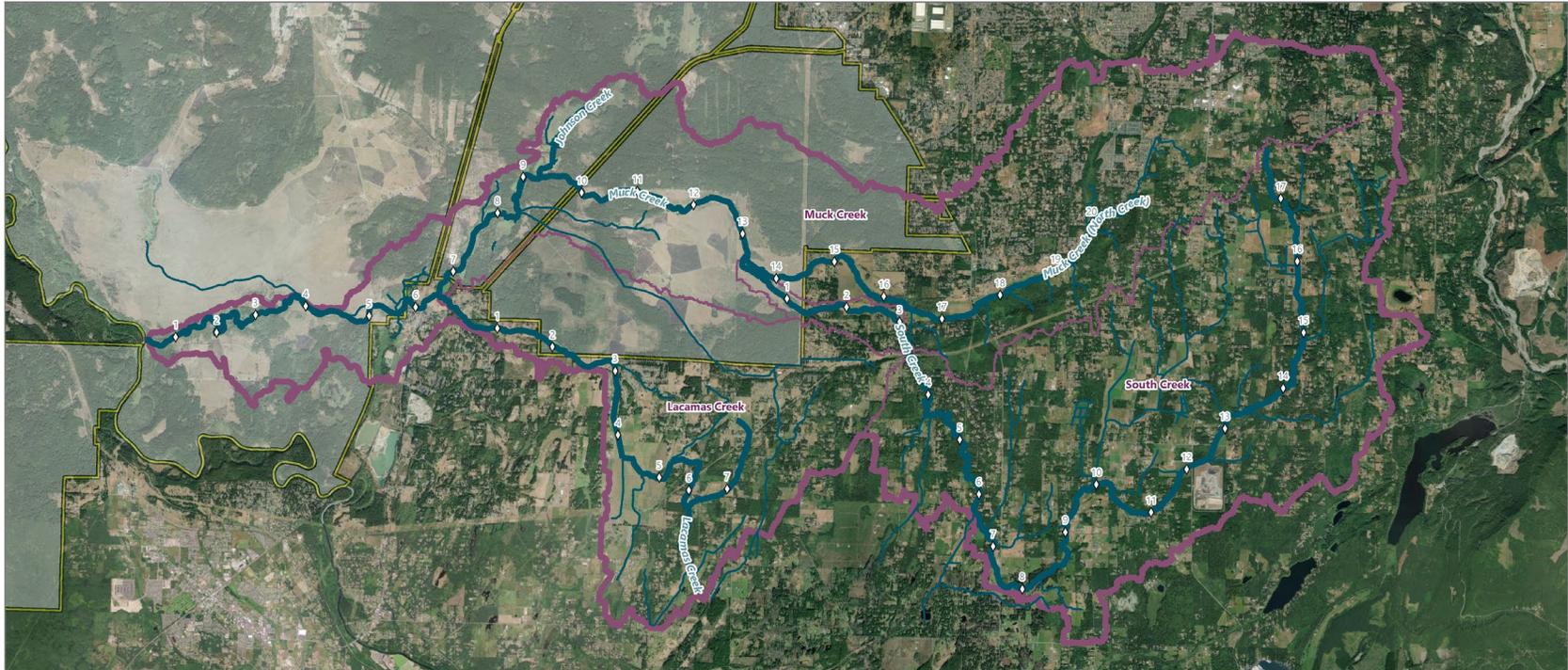
Table 1
Muck Creek Subbasins

Subbasin Stream	Area (square miles)	Length (miles)	Description
Upper Muck Creek	20.5	7	Reaches of Muck Creek upstream of the South Creek confluence
South Creek	36.6	17	South Creek upstream of confluence with Muck Creek
Muck Creek Mainstem	20.6	14	Reaches of Muck Creek downstream of South Creek confluence, including Johnson Creek
Lacamas Creek	15.2	7	Lacamas Creek upstream of confluence with Muck Creek

Streamflow in the Muck Creek watershed is supplied by precipitation, both directly via surface runoff and indirectly via groundwater recharge that is later released in wetlands, springs, and seeps. Upper Muck Creek begins west of Graham where it is fed by Patterson Springs and other smaller springs. Upper Muck Creek flows south and west and joins South Creek in the prairie lowlands on JBLM lands.

South Creek and Lacamas Creek drain the higher elevation foothill portions of the watershed, while Muck Creek and Johnson Creek primarily drain the lower elevation glacial outwash portions of the watershed. Within the low elevation watershed, there is about a 200-foot gain in the lowermost 3 miles of Muck Creek and an additional 200-foot gain over the next 17 miles of its channel upstream (Coho 2021).

Figure 1
Muck Creek Watershed

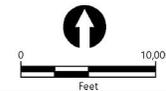


LEGEND:

- Unnamed Stream
- Johnson Creek; Lacamas Creek; Muck Creek; Muck Creek (North Creek); South Creek
- Muck Creek Watershed Subbasin
- Joint Base Lewis-McChord

NOTES:

1. Online basemap acquired from Esri (2021).
2. Stream miles acquired from Coho Water Resources and are based on WDF (Washington Department of Fisheries), 1975. A Catalog of Washington Streams and Salmon Utilization, WRIA 11. Accessed on: March, 2022.
3. Stream flow line acquired from U.S. Geological Survey National Hydrography Dataset (NHD). Accessed on: March, 2022.
4. Joint Base Lewis-McChord boundary acquired from Pierce County GIS. Accessed on: March, 2022.
5. Watershed basins acquired from Pierce County GIS (2017).



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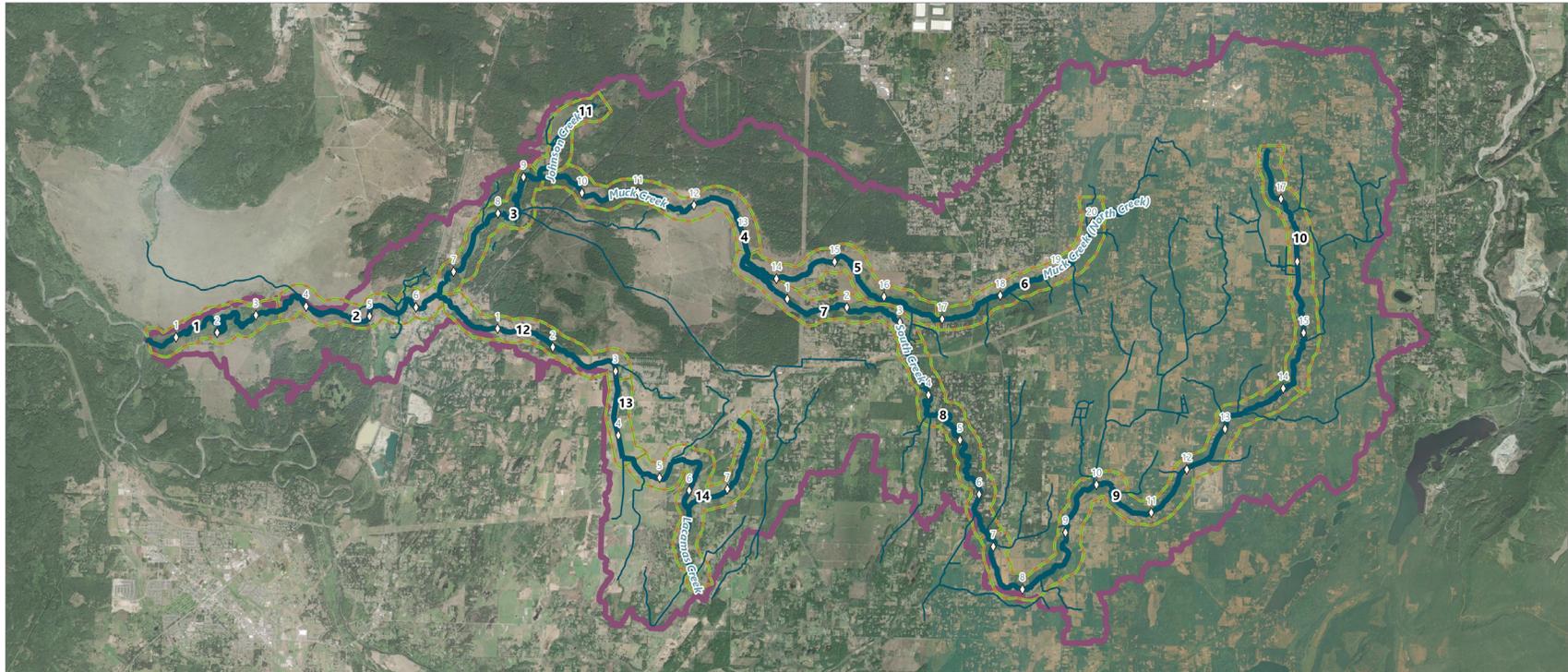
South Creek begins south of Graham and flows southwest for several miles before turning northwest to join Upper Muck Creek. The lower approximately 3.5 miles of South Creek are on the glacial outwash plain, roughly paralleling the orientation and elevation of Muck Creek to the north. The middle and upper reaches of South Creek are located on the glacial till hillslopes. South Creek has an approximately 250-foot elevation gain from its confluence with Muck Creek (Coho 2021).

Downstream of its confluence with South Creek, Muck Creek flows west through the prairie landscape within JBLM to the confluence with Johnson Creek and through the prominent “chain-of-lakes” where the defined channel flows through a series of lakes and wetlands north of Roy. Downstream of Roy, the stream system continues through the prairie landscape and then cuts down through the outwash terrace to join the Nisqually River near river mile 10. The lower 3.5 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 low-moderate gradient Puget Sound streams, whereas the majority of the Muck Creek stream channel is very low gradient.

Lacamas Creek drains foothills along the southern portion of the watershed and meets Muck Creek in Roy. The Lacamas Creek subbasin ranges from 300 to 600 feet, with an overall steeper gradient than Muck Creek. Lacamas Creek flows south and then west, eventually turning northwest toward Roy.

Reaches were delineated for this plan and are based on geologic, geomorphic, streamflow, and habitat considerations (these reaches are also used in the habitat assessment prepared by the SPSSEG [2022]). Each of the reaches comprise a reasonable distance (typically 1.5 to 4 miles in length) and also facilitate the identification of streamflow and habitat restoration actions. Figure 2 shows the designated stream reaches.

Figure 2
Muck Creek Watershed Reaches

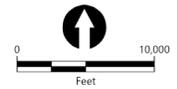


LEGEND:

- ◇ Stream Miles
- Unnamed Stream
- Johnson Creek; Lacamas Creek; Muck Creek; Muck Creek (North Creek); South Creek
- Muck Creek Basin
- Reaches

NOTES:

1. Online basemap acquired from Esri (2021).
2. Stream miles acquired from Coho Water Resources and are based on WDF (Washington Department of Fisheries), 1975. A Catalog of Washington Streams and Salmon Utilization, WRIA 11. Accessed on: March, 2022.
3. Stream flow line acquired from U.S. Geological Survey National Hydrography Dataset (NHD). Accessed on: March, 2022.
4. Watershed basins acquired from Pierce County GIS (2017).



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2.2 Land Use and Population Growth

Land use within the watershed is predominantly residential, military, and agriculture (May 2002). JBLM is a large (approximately 23 square miles) military base located within the Muck Creek watershed but is relatively undeveloped within the watershed, including primarily training areas or protected habitats in upland prairies, upland forest, riparian forest, wetlands, lakes, and in-channel habitats. There are numerous gravel and paved roads and road crossings of Muck Creek and tributaries. The remaining watershed area is dominated by agriculture, residential and commercial areas, highways, and undeveloped land and open space.

Land cover within the Muck Creek watershed is approximately 38% forested (evergreen, deciduous, and mixed forest); 26% grasslands, herbaceous, pasture, and hay cover; 25% developed; 7% wetland; and 4% shrub (NLCD 2021). Impervious surface cover is estimated at 15% in the Upper Muck Creek subbasin, 5% in the South Creek subbasin, and 3% in the remainder of the watershed. (Coho 2024; see Appendix C).

The population within the Muck Creek watershed has been steadily increasing, with the watershed population estimated at 33,000 in 2010 (Coho 2024; see Appendix C). The rural unincorporated Pierce County population increased by 23% from 2000 to 2020 (Pierce County 2023), and the Roy population is anticipated to grow by 29% over the 20-year planning horizon to the year 2040 (NWPU 2019).

2.3 Geology and Soils

The geology within the Muck Creek watershed is heavily influenced by the region's glacial history, with the northern half of the watershed dominated by glacial outwash deposits (classified as Quaternary [Vashon glaciation] Recessional Outwash [Qvr]) and the southern half of the watershed dominated by upland glacial till deposits (Quaternary [Vashon] Till [Qvt]; Figure 3; WDNR 2016). The glacial till and outwash were deposited during the Vashon Stade of the Fraser glaciation (Pierce County 2005). Soils formed in the glacial outwash are rapidly draining and underlain by highly permeable gravel and cobble deposits. Soils formed in the glacial till are typically underlain by a low-permeability compacted till layer. The low permeability of till can result in perched groundwater in the wetter months, as well as greater stormwater runoff. Although more recent mapping indicates the till layer may be more permeable than typical conditions in the South and Lacamas creek subbasins (DNR 2024). There are also isolated peat deposits (some that cover a large area), which are relatively slow draining and associated with wetlands and ponding water. The stream channels in the basin also have developed layered alluvial deposits on the surface of the glacial materials.

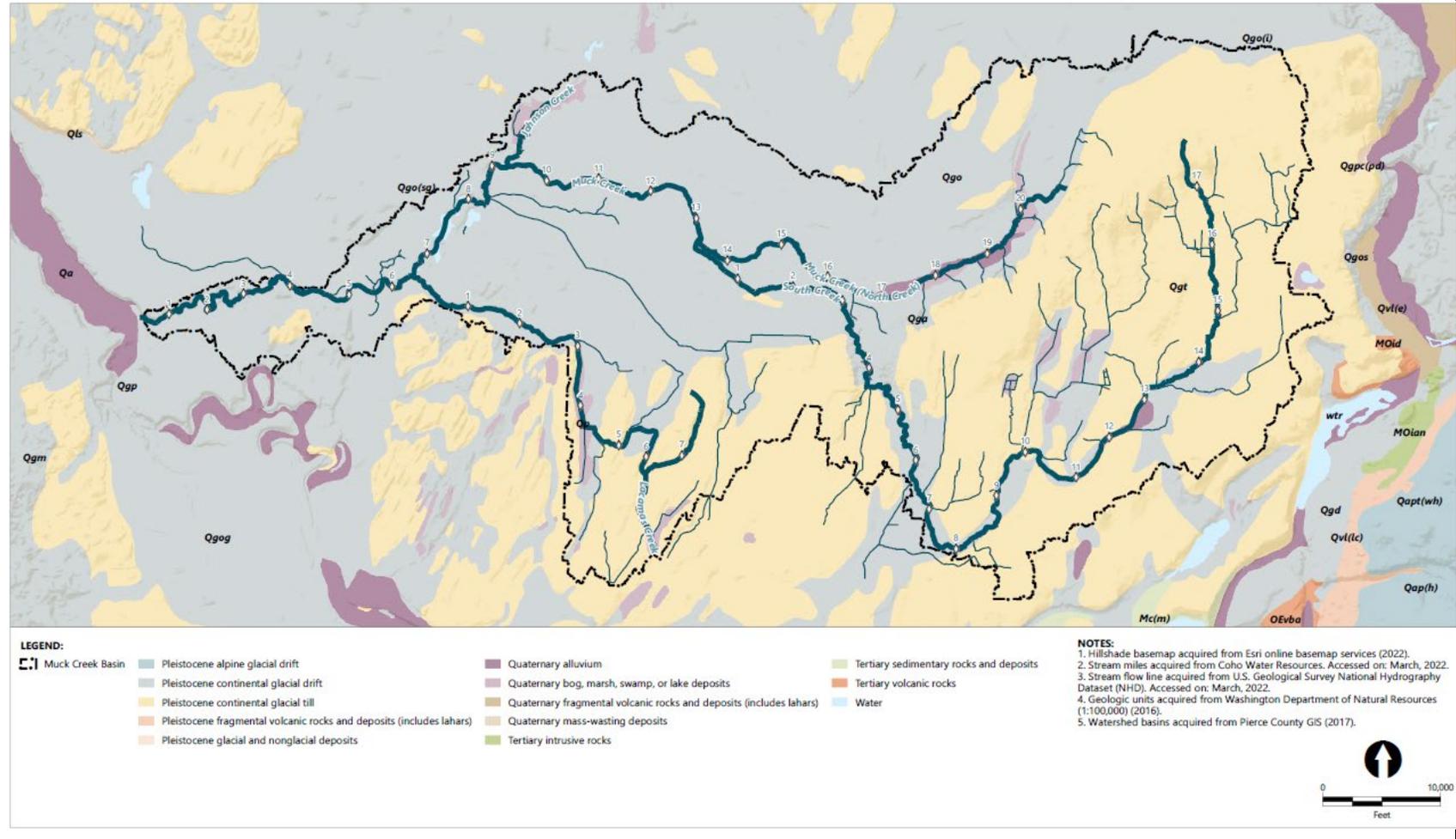
Muck Creek below the South Creek confluence predominantly flows through Spanaway soils formed from glacial outwash that are excessively drained, have a depth of over 80 inches to the water table, and a low available water supply (USDA 2023). Through the "chain-of-lakes" reach, Muck Creek flows

in a deep trough through the outwash, and the soils transition to Semiahmoo muck that is poorly drained, formed from ponding and wetlands, and has a high available water supply (USDA 2023).

Soils at the confluence of Muck and South Creeks are Spanaway soils (glacial outwash derived), but Upper Muck Creek flows through sandy loam, muck, and silt till material. South Creek flows through glacial till. These soil types are consistent with the increased number of wetlands documented along Upper Muck and South Creeks and tributaries (USFWS 2023).

The lower reaches of Lacamas Creek also flow through the Spanaway soil complex and loam (USDA 2023). A long segment in the middle reaches of Lacamas Creek flows through muck soils, corresponding with a large wetland historically present and still currently present, although drained and used for agricultural purposes (USFWS 2023), while the upper reaches flow through sandy and gravelly loams (USDA 2023).

Figure 3
Watershed Geology



2.4 Hydrology, Streamflow, and Groundwater Conditions

The Muck Creek watershed has been known for decades to experience seasonally dry stream reaches, and several studies have investigated the patterns and potential causes for this condition (Sinclair 2001; Pierce County 2005; Savoca et al 2010; Coho 2021). It appears that seasonally dry reaches may have always occurred naturally due to the highly permeable glacial outwash conditions through which lower Muck Creek flows and the presence of groundwater well below the creek bed. However, the frequency and duration of these seasonal dry periods also appears to be increasing.

Sinclair (2001) characterized the hydrogeology of the Muck Creek watershed, and three hydrogeologic units are of most relevance to streamflow. At the land surface, two main hydrogeologic units make up most of the watershed: glacial recessional outwash (Qvr) and till (Qvt). Qvr is the most expansive unit, covering most of the northwest portion of the watershed, including the Muck Creek drainage and areas along both the Lacamas Creek drainage and South Creek drainage. This surface unit is composed of Steilacoom gravels and is considered a productive aquifer in much of the watershed due to its high permeability (Sinclair 2001). Due to the high permeability in this unit, some locations where Qvr is exposed at the land surface are unable to maintain drainage networks because water infiltrates and moves through the unit so quickly (Coho 2021).

Glacial till underlays the glacial outwash but is also exposed at the land surface throughout much of the watershed, particularly within the southern and eastern uplands where South Creek and Lacamas Creek originate (Coho 2021; Sinclair 2001). This unit has an average thickness of 60 feet and is composed of compacted, poorly sorted till. The compact and poorly sorted nature of this unit, combined with the presence of clay and silt, give this unit a low permeability and hydraulic conductivity, making Qvt typically a confining unit. More recent geologic mapping indicates the till in the Lacamas and South creek subbasins may not be as highly compacted as other locations, making this layer somewhat more permeable than typically encountered (DNR 2024).

Below the land surface, underlying the confining Qvt unit, is Quaternary (Vashon) Advance Outwash (Qva) (Coho 2021). This unit is composed of sands and gravels with some lenses of silt and clay throughout. Qva has an average thickness of 15 feet and exists below Qvt across most of the watershed. Though this unit is confined by the low-permeability Qvt unit above it, Qva itself is an aquifer. In areas where Qvt is present at the land surface, excavation through this unit has the potential to expose the underlying Qva aquifer, depending on the thickness of Qvt.

2.5 Vegetation Conditions

The historical conditions of the Muck Creek basin are not fully understood, but based on General Land Office (GLO) mapping from the mid-to-late 1800s (BLM 2024; Plummer 1889), a significant area of the basin was dominated by prairies, and large areas of wetlands were also mapped along Lacamas, Muck, and South Creeks (Figure 4). Areas not historically mapped as prairie or

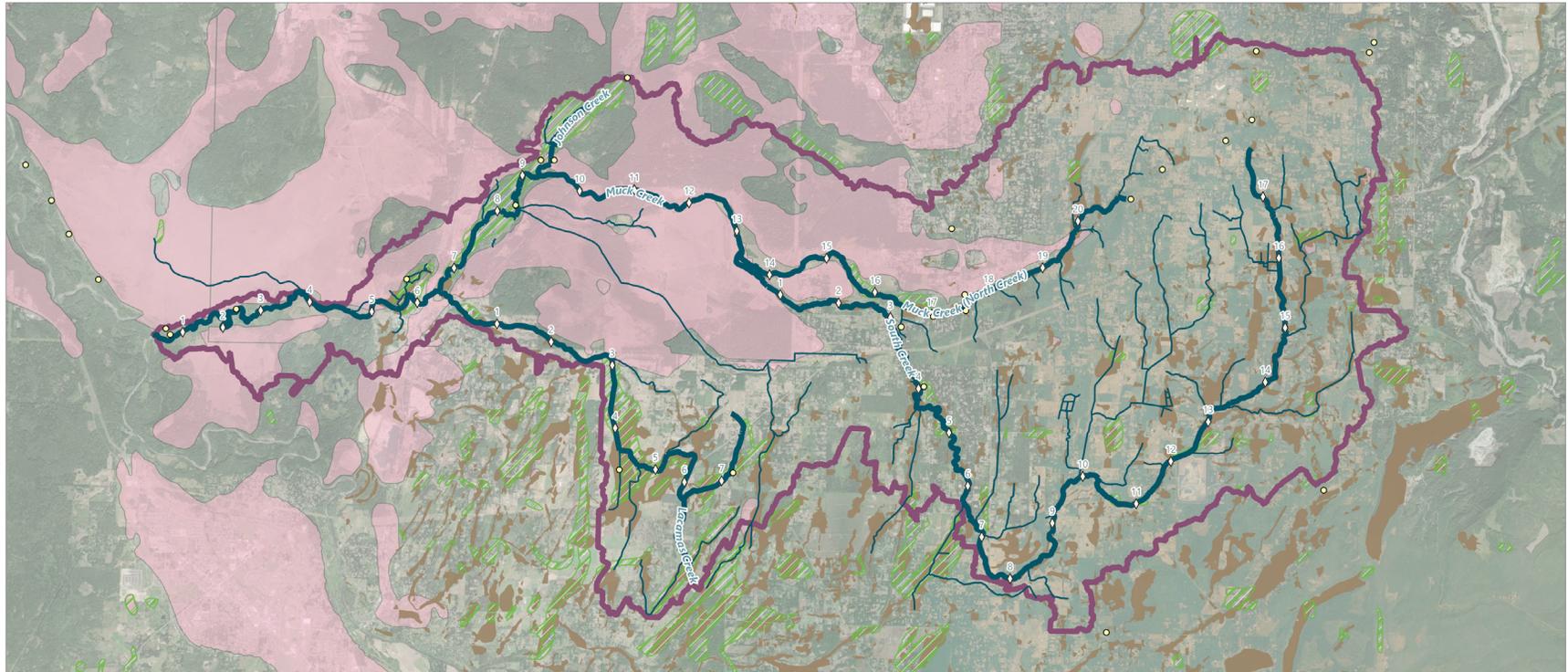
wetlands/waterbodies are presumed to have been dominated by woodland or forest that may have included oak savanna and woodland, evergreen forest, and other deciduous forest such as maple or mixed cottonwood, ash, alder, and willow riparian forest. GLO survey notes indicated that oak savanna or woodland occurred as a buffer between prairie and coniferous forest (Peter & Harrington 2014).

Prairie habitats were maintained from periodic burning by Native Americans to reduce encroachment by trees, such as Douglas fir, and promote edible or otherwise useful plants, such as camas, and game (Minsch 2002; Kruckeberg 1991). By the mid-1800s, forest began encroaching on prairies as diseases and displacement of Native Americans reduced the burning regime (Peter & Harrington 2014). In the early 1900s, before a sizable portion of the Muck Creek watershed was established as a military base, wetlands and forest areas were altered by settlers including draining, ditching, or filling wetlands, as well as converting forests to agricultural land (May 2002). Since the northwestern portion of the subbasin became used for military purposes, the vegetation has continued to change from the historical prairies to many areas that are now forested. Estimates from JBLM indicate over 16,500 acres of prairie have been colonized by forest, which represents about half of the estimated historical prairie within the Muck Creek basin (J. Foster pers. comm. cited in Peter & Harrington 2014).

Early settlement records reveal significant use of Muck Creek and the surrounding areas by the Hudson Bay Company, which established Muck Station within the watershed (Coho 2022; Easterly et al. 2005). As there was a likely expansive population of beaver pre-settlement, Muck Creek would have been in easy proximity for harvesting beaver.

Channelization has occurred in numerous reaches of the streams, including much of Muck Creek upstream of the South Creek Confluence (Pierce County 2005), Muck Creek west of Roy (May 2002), Muck Creek through Chambers Lake, Johnson Creek downstream of Johnson Lake (Richardson 2022) and in the middle reaches of Lacamas Creek (Coho 2021). Many miles of stormwater ditches are also present throughout the subbasin. Two dams were also installed in the chain-of-lakes reach (Reach 3) to raise the water levels in existing wetlands for sport fishing in the 1960s and 1970s: Chambers Lake Dam and Johnson Lake Dam (Sinclair 2001; Hiss et al 1982). Chambers Lake Dam was removed in 2021 by JBLM.

Figure 4
Muck Creek Historical and Current Wetlands

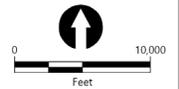


LEGEND:

- ◇ Stream Miles
- Unnamed Stream
- Johnson Creek; Lacamas Creek; Muck Creek; Muck Creek (North Creek); South Creek
- Muck Creek Basin
- Approximate Historical Prairie Location
- ▨ Approximate Historical Wetland Location
- Current Wetlands

NOTES:

1. Historic General Land Office (GLO) maps acquired from Bureau of Land Management (BLM). Accessed on: May 5, 2022.
2. Watershed basin acquired from Pierce County GIS (2017).
3. Approximate historic wetland areas are digitized from georeferenced GLO maps.



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2.6 Stream Reach Conditions

The overall quality of stream and wetland habitat is currently generally fair or poor, with conditions directly related to adjacent land uses, quality of riparian vegetation, invasive species, and dry segments. Many historical wetlands have been reduced or degraded, in turn affecting stream hydrology and quality. Livestock grazing and uncontrolled access to stream habitat has increased erosion, degraded water quality, and reduced riparian vegetation. Additionally, segments of the channel periodically go dry during summer and fall, and the duration of dryness appears to be increasing and expanding to include segments of the channel that were previously perennial. These dry segments block anadromous adult and juvenile fish from many parts of the watershed.

Reach 1 of Muck Creek is the steepest gradient section in the system (average 3.4%) that extends for approximately 3 miles, as Muck Creek down cuts through the plateau in a canyon to meet the Nisqually River. This reach is a primary salmonid spawning reach (SPSSEG 2022), although dry conditions at the mouth can prevent fish from entering the creek altogether if the stream is not flowing by early January. Streambed materials are primarily cobble and gravel. Habitat is limited by few pools or side channels, which reduces the rearing habitat for juvenile salmonids (SPSSEG 2022). Riparian conditions are high quality with mature evergreen and deciduous forest and some mature shrub patches. Large wood is in low to moderate quantities, but future recruitment potential from the mature riparian zone is good (May 2002). Flows in this reach are sustained by Exeter Springs, although the mouth of the creek does go dry in some years.

Reach 2 of Muck Creek is a low gradient (average 0.8%) prairie reach on the glacial outwash plateau that extends for approximately 3 miles to the confluence of Lacamas Creek in Roy, Washington. This reach was historically prairie but now has a long stretch of mature evergreen and deciduous forest, which then transitions into younger deciduous riparian forest. Wetlands are prevalent in this reach; however, there is a high prevalence of reed canary grass, and reed canary grass encroachment in the channel is a major issue in this reach. Streambed materials include stretches of gravel as well as silt-dominated sections (May 2002). Pools are very few and there is limited large wood (SPSSEG 2022). A substantial portion of this reach goes dry in some years (Sinclair 2001).

Reach 3 is the chain-of-lakes reach of Muck Creek that extends for approximately 3 miles to the Johnson Creek confluence with a very low gradient (average 0.3%). Muck and Chambers lakes are significant components of this reach. Riparian habitats fringe the lakes and wetlands and are composed of young deciduous forest and shrubs, with reed canary grass and blackberries in the understory in many areas. Reed canary grass encroachment in the channel is a major issue in this reach. Large wood is sparse, and recruitment potential is low (SPSSEG 2022, May 2002), and the concept of pools is not very applicable to this reach dominated by lake and wetland habitat. This reach has perennial water in Chambers Lake, and the water temperatures are cold, indicating groundwater or spring inputs. The creek segments above and below Chambers Lake go seasonally

dry. The dam at Chambers Lake was removed in fall 2021, but the lake has remained to a similar extent prior to dam removal.

Reach 4 of Muck Creek flows through the glacial outwash prairie area to its confluence with South Creek, a distance of about 4 miles with low gradient (average 0.8%). This reach is nearly always dry in summer/fall and lack of flow here blocks potential fish access to the upper half of the watershed. The bed is generally coarse gravel and cobble. Riparian habitats are mixed deciduous and coniferous and generally older forest that has encroached on prairie habitats in a significant part of this reach. Few pools are present; large wood is sparse, but recruitment potential is good in the segments with older trees (May 2002).

Reach 5 of Muck Creek starts at the confluence with South Creek and continues for approximately 0.7 mile within JBLM and then extends for approximately 3 miles with low gradient (average 0.8%) through primarily agricultural areas. This reach typically has perennial flow, which may be sustained by spring flow from the uplands to the south, and springs in the upper reaches of Muck Creek, as well as a confining layer that reduces losses into the glacial outwash. Riparian conditions vary from essentially no riparian (pasture and reed canary grass) to younger deciduous forest (although with some small patches of conifers), with armoring present in some areas. Livestock frequently accesses the channel, and reed canary grass encroachment in the channel is a significant issue in this reach (SPSSEG 2022). Substrate is mixed sand, gravel, and cobble, with a high percent of fines; limited wood and a few beaver dams are present (Pierce County 2005).

Reach 6 is the uppermost reach of Muck Creek and extends for approximately 4 miles with low gradient (average 0.6%) through predominantly residential areas. Springs and wetlands provide perennial flow to this reach. Riparian habitat is highly varied depending on landowner and the stream includes beaver ponds, wetlands, segments encroached by reed canary grass, and some channelized segments (SPSSEG 2022). A green space segment near RM 19 was noted as high-quality stream through wetlands that was formerly a series of beaver ponds, with large wood and diverse plant assemblages (SPSSEG 2022). Overall, this reach has few pools and limited large wood.

Reach 7 of South Creek extends from its confluence with Muck Creek for approximately 3.5 miles through the glacial outwash prairie with moderate gradient (average 1.0%). Riparian conditions include mixed older deciduous forest and stretches through agricultural land with reed canary grass or no riparian vegetation and steep banks and cattle access. Substrate is gravel with limited wood present (SPSSEG 2022). There is a low to moderate presence of shallow pools (Pierce County 2005).

Reach 8 of South Creek extends for approximately 4 miles up into the foothills (although still in glacial outwash) with moderate gradient (average 1.2%) through residential areas. Riparian conditions include deciduous forest and some patches of conifers, although reed canary grass has a significant presence in the reach. Substrate is gravel, with significant fines in runs and glides (SPSSEG

2022). There are few pools and limited large wood. Wetlands are present in several locations and there are several greenspace corridors (SPSSEG 2022). The downstream half of this reach can go dry for several months, and flows in winter/spring can be flashy with precipitation (SPSSEG 2022).

Reach 9 of South Creek extends for approximately 8 miles through the glacial till uplands with moderate gradient (average 1.0%) through agricultural areas. This reach is generally dry in summer. Most of the tributaries that enter this reach have been channelized. Riparian conditions include patches of mixed deciduous forest, and occasional cedars, but also pasture and reed canary grass. Substrate is gravel, with few pools and limited wood presence (SPSSEG 2022).

Reach 10 of South Creek extends for approximately 4 miles through the glacial till uplands with higher gradient (average 2.8%) through agricultural and residential areas. Little information is known about stream conditions, but this reach has been observed to be dry in fall months (Coho 2021).

Reach 11 on Johnson Creek extends only for approximately 1.7 miles from its confluence with Muck Creek with low gradient (average 0.9%), is located entirely on JBLM in the glacial outwash prairie and includes Johnson Marsh/Lake. A dam is present at Johnson Lake, but is often open, although beavers also build a small dam at the outlet. Watkins Springs is present in the upper half of the reach. Riparian conditions include both mature coniferous forest patches and more open areas with limited tree cover. Substrate is generally gravel with few pools and low levels of large wood, with good recruitment potential (May 2002). Water is perennial in Johnson Marsh/Lake, but the creek channel downstream can go dry.

Reach 12 of Lacamas Creek extends from its confluence with Muck Creek for approximately 3.5 miles with low to moderate gradient (average 1.2%) through the glacial outwash prairie on large private parcels and one segment on JBLM. Riparian conditions include younger deciduous forest and shrubs, with areas of little to no riparian vegetation and cattle access. Invasive species, such as reed canary grass and blackberries, are prominent. Substrate is mixed sand, gravel, and cobbles, with few pools and limited wood presence (SPSSEG 2022; Pierce County 2005). Flow was historically perennial in the lower reach, but in recent years has experienced dry periods (Coho 2021).

Reach 13 of Lacamas Creek extends for a little over 1 mile through primarily agricultural land and was historically mapped as a large wetland (still mapped by Pierce County as wetland) with very low gradient (average 0.4%). Riparian vegetation is extremely limited, and the reach is highly channelized; livestock access the creek, and reed canary grass may encroach on the creek throughout this reach. Substrate is mixed fines, sand, and gravel with limited large wood (Pierce County 2005). This reach appears to have perennial flow (Coho 2021).

Reach 14 of Lacamas Creek extends for approximately 4 miles in the glacial till uplands with low to moderate gradient (average 1.1%) through both agricultural and residential areas. Substrate is highly

embedded with fines except in riffles, and there are few pools and limited large wood (SPSSEG 2022). In upstream areas, mussel beds were noted (Pierce County 2005) along with older riparian vegetation, moderately large wood, and pools.

Table 2 provides a summary of how key functions have changed over time for each of the stream reaches.

Table 2
Historical and Current Functions of Stream Reaches in the Muck Creek Watershed

Stream	Reach No.	Geology/Geomorphology	Seasonal Streamflow Pattern	Groundwater/Surface Water Connections	Fish Habitat Function	Human-Caused Constraints
Muck Creek	1	Glacial drift and outwash; transports locally derived sediments; likely historically, this could have been a spot where wood accumulated from hillslopes with high roughness in stream and numerous short side channels	Low flow in late summer and fall, some dry segments, typically adequate flow for chum passage returns in December or January	Exeter Springs enters in middle of reach; springs from outwash above impervious layers, both historical and current hydrologic function to collect groundwater	Known key spawning reach for chum, steelhead, cutthroat; likely historically good rearing habitat, but now reduced wood and side channels	This reach frequently burns from artillery exercises; Native Americans would have burned historically, but intensity much greater now; loss of beaver
	2	Glacial drift and outwash; prairie mostly on north side, may have been woodland on south side historically; likely numerous beaver dams/ponds and associated wetlands in larger floodplain	Regular dry periods, especially in fall, documented at Roy, even in 1960s	Stream channel in contact with groundwater table; springs/wetlands in this reach; groundwater flow from south side, but not enough to sustain flows year-round	Known key spawning reach for chum, steelhead, cutthroat; major issue of reed canary grass occupying portions of reach and off-channel habitats; gravel dominant lower portion; likely historically excellent rearing habitat in beaver ponds and wetlands	Reed canary grass is continuing to degrade reach and likely reducing spawning habitat over time; reduced number of beavers
	3	Glacial drift and outwash, lakes and wetlands formed in trough 10 to 25 feet lower than surrounding plain; likely significant historical beaver presence and still small numbers present; deposition zone for sediment and wood	Water perennial in lakes and wetlands but connecting channels go dry	Significant perennial springs on south bank of lakes; connected to groundwater table for much of year; important reach for contributing to downstream flows because it captures and sends groundwater downstream	Known presence for chum, steelhead, cutthroat; and some coho/chum spawning, open channel with gravel and cold water through Chambers Lake; significant rearing habitat, potentially limited in diversity; would likely have had more wood delivered from hillslopes historically	Early settlers cleared and farmed north side; became Fort Lewis in 1917; reed canary grass is continuing to degrade this reach and covers connecting channels between lakes; reduced number of beavers

Stream	Reach No.	Geology/Geomorphology	Seasonal Streamflow Pattern	Groundwater/Surface Water Connections	Fish Habitat Function	Human-Caused Constraints
Muck Creek (cont.)	4	Glacial drift and outwash; likely significant historical beaver presence and some still present; this reach scours and moves sediment at high flows even though low gradient, major deposition near mouth of Johnson Creek; historically, likely many side channels and wetlands, channel now incised contributing to scour and sedimentation problems	Dry for significant portions of summer and fall, especially at western end	Loses streamflow to groundwater; supplied primarily by surface water from upstream reaches; floodplain connectivity has been lost	Known presence of coho, chum, steelhead, cutthroat, and some historical observations of spawning, but now largely blocked due to extended dry periods; historically, likely many beaver ponds and wetlands for rearing, now no access or rearing habitat	Substantial change from prairie to forested; farmed historically, may have channelized stream and side cast sediments; loss of connection to winter channel; excavation to install ford crossings may have cut into impervious layer under outwash
	5	Glacial drift and outwash; likely significant historical beaver presence; potentially deposition reach for wood and sediment from upper reaches	Mostly perennial except at western end; may be a beaver complex currently that is keeping upper portion wetted	Stream channel may be perched above groundwater table; may also receive groundwater/hyporheic flow from South Creek; historical mapping showed a wetland between Muck and South Creeks	Potential limit for chum and steelhead spawning historically; likely historically beaver ponds and wetlands for rearing; still a high-quality segment at upper end of reach with good gravel and coniferous riparian forest	Channelization through agricultural areas, reduced wetland area; pipeline construction in this reach may have punctured a confining layer below the outwash and promoted rapid infiltration of surface flows; livestock access to stream degrades habitat
	6	Glacial drift and outwash with peat deposits, and alluvium; may be underlain by a shallow till confining layer; historically, wetlands and likely beaver ponds and riffle/pools; now channelized and incised	Perennial flow	May receive significant groundwater contribution from left bank bluff (groundwater levels higher than stream channel); springs noted along base of bluff in earlier studies	Coho historically documented; potential spawning habitat; several protected lands with beaver complexes and good rearing habitat, but fish need to actually get here to use it; may provide good cutthroat spawning and rearing habitat	Reed canary grass significant issue in riparian and in channel; livestock access to stream degrades habitat

Stream	Reach No.	Geology/Geomorphology	Seasonal Streamflow Pattern	Groundwater/Surface Water Connections	Fish Habitat Function	Human-Caused Constraints
South Creek	7	Glacial drift and outwash; deposition area from upper reaches, both wood and sediment; likely significant presence of beaver historically; now incised	Dry for significant portions of summer and fall, most often at western end	Loses surface flow to groundwater but groundwater levels not substantially below stream channel	Potential coho, cutthroat, rainbow; likely historically spawning and rearing habitats with gravel and beaver ponds; wetlands historically mapped at upper end of reach	Flows have become very flashy likely due to impervious surfaces and stormwater runoff; observed several areas of erosion and wood/brush/sediment delivery
	8	Primarily outwash; with alluvium; sediment and wood transport reach; naturally cutting down through outwash; likely historically large wood creating riffle and pool sequences, now incised	Most consistently flowing portion of South Creek but lower portion of reach goes dry; groundwater inputs help sustain flows, but does not make it to next reach	Significant zone of groundwater input mid-reach but also has losing portions; springs noted in roughly same location; fairly large wetlands mapped in this reach and tributary confluences; potential to further increase groundwater recharge?	Potential coho and cutthroat presence; wildlife noted in this reach, spawning and rearing habitats and connectivity with floodplain	Development, although lesser in this reach, has primarily contributed to flashy flows and reduced in-channel wood
	9	Glacial till and outwash segments, minor alluvium; sediment and wood transport reach; likely historically large wood creating riffle and pool sequences and side channel, now fewer pools and single-thread	Regularly dry in summer and fall	Little information on groundwater; historically, several wetlands present in the reach and still present	Potential cutthroat and resident rainbow, spawning habitats; lack of wood and side channels reduces rearing habitat; maintain genetics of isolated rainbow	Timber harvest and agricultural uses have reduced riparian habitat and wood; development has contributed to flashy flows; also reed canary grass significant issue
	10	Glacial till; sediment and wood transport reach; likely historically large wood creating riffle and pool sequences and side channels, now few pools and single-thread	Regularly dry in summer and early fall; large historical wetland on GLO maps, still wetlands; numerous small	Little information on groundwater; wetlands could recharge groundwater	Potential cutthroat presence; potential spawning and rearing habitat; lack of wood and side channels reduces rearing habitat; likely historically many wetlands	Timber harvest and agricultural uses have reduced riparian habitat and wood; development has contributed to flashy flows; loss of wetlands and channelization

Stream	Reach No.	Geology/Geomorphology	Seasonal Streamflow Pattern	Groundwater/Surface Water Connections	Fish Habitat Function	Human-Caused Constraints
			tributaries could contribute flow			
Johnson Creek	11	Glacial drift and outwash with peat deposits; wetlands, sediment deposition zone; likely historically many beaver dams/ponds	Perennial water in marsh/lake, but channel goes dry in some years	Wetlands recharge groundwater; groundwater table and surface water connected much of year in marsh; stream intercepts groundwater table in rainy season, also fed by wetland groundwater	Documented chum spawning, coho presence; likely rearing habitat	Channelization, berms, widespread reed canary grass in channel and wetlands
Lacamas Creek	12	Glacial drift and outwash; edge of till area to south, likely historically many beaver dams/ponds and meandering with riffles/pools; now channelized	Residents report perennial flow in past but more recent observations of dry periods	Limited information on groundwater levels, but less permeable than outwash along Muck Creek	Documented chum and coho spawning, potential steelhead and cutthroat presence; Pierce Co. wetlands still showing wetland presence in this reach; historically, likely rearing habitat, but now few pools or side channels	Channelization, widespread reed canary grass, loss of beaver
	13	Glacial till, outwash, and peat deposits; historical large wetland area; has been significant loss (drainage) of wetlands, although still fairly wet; channelized	Few documented observations; likely to be perennial, wetlands not fully drained	Limited information on groundwater levels, but potentially major opportunity to benefit streamflow from wetland restoration/ water storage	Documented coho spawning, documented chum spawning, modeled potential for steelhead, and cutthroat presence; resident rainbow? Lack of wood, channelized habitat	Channelization and ditching, widespread reed canary grass, loss of beaver
	14	Primarily glacial till and peat, and some outwash sediment; large historical wetlands, both forks; likely historically many beaver dams/ponds	Few documented observations; likely to be perennial, wetlands not fully drained	Groundwater supplies baseflow; opportunity to benefit streamflow from wetland restoration/ water storage	Presumed presence chum, modeled presence coho; modeled potential for steelhead, potential cutthroat presence; lack of wood, channelized habitat	Channelization and ditching, widespread reed canary grass, loss of beaver

2.7 Fish Species

At least four salmonid species are known to be present in Muck Creek, including winter chum salmon, coho salmon, winter steelhead, and both resident and sea-run cutthroat trout (Zimmerman 1995; Kerwin 1999; WDFW 2022). Fall chinook salmon were noted to have been present in Muck Creek in the 1960s (WDF 1975); however, the timing of adult spawning coincides with seasonally dry reaches, likely precluding their presence in most years. The mouth of Muck Creek could be accessible to juveniles for rearing in spring and early summer.

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; native species noted as captured during sampling but not specified if present within Muck Creek or Nisqually River). Non-native species are also present, including largemouth bass, sunfish, and yellow perch (Zimmerman 1995).

Muck Creek is highly important for and supports approximately 25% of the winter chum population in the Nisqually River watershed (May 2002), with spawning predominantly occurring in the lower half of Muck Creek and in Lacamas Creek (WDFW 2022). Nisqually winter chum salmon adults typically enter the watershed from November through February and spawn from January through February (Kerwin 1999). Chum fry emerge from the redds in March and April and migrate to the estuary with limited rearing in freshwater (Table 3). Due to their limited use of freshwater as juveniles, access to and presence of high-quality spawning habitat are critical elements necessary to support chum. The glacially derived sediments in the basin provide excellent gravel and cobble sources for spawning habitats.

Nisqually coho salmon adults typically enter the watershed from September to early December and spawn from November to early February (Kerwin 1999). Juveniles typically rear for 1 year in freshwater and migrate to the estuary and ocean in spring. If suitable rearing habitat is not available in tributaries such as Muck Creek, they migrate to suitable habitat in the mainstem Nisqually or other tributaries. Access to and presence of high-quality spawning habitat and year-round 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 for coho salmon during both summer and winter (Pollock et al. 2004).

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). 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 steelhead.

Both resident and anadromous cutthroat trout are present in Muck Creek, with resident fish predominant in the upper half of the system and anadromous fish predominant in the lower half of the system and the former Chambers Lake (Zimmerman 1995). The Chambers Lake Dam and flow conditions were hypothesized to provide separation between the upper and lower watershed. 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.

Resident rainbow trout may be present in Upper Muck and South Creeks (Svoboda 1978), but whether they are genetically distinct from the anadromous steelhead has not been determined.

Table 3
Muck Creek Salmonid Presence

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

Notes:

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.

Dark blue: adult presence
Light blue: juvenile presence

3 Data Collection and Analysis

3.1 Surface Water Data Collection

Surface water data was collected on Muck Creek, Lacamas Creek, South Creek, and in Chambers Lake. The goal of the surface water data collection effort was to collect sufficient data, and in combination with existing data and literature, to inform the streamflow and restoration strategy described in Section 4. The data was collected by installing piezometers in the surface water bodies that measure the depth of flow at 15-minute intervals. Stream gaging was performed on the creeks to measure flow at different depths. Rugged TROLL 200 data loggers from InSitu, Inc., were used. Two barometric pressure monitoring data loggers (BaroTROLL) were installed: one at Chambers Lake and one downstream of 8th Avenue East. The barometric pressure data was used to compensate for atmospheric pressure fluctuations as the Rugged TROLL data loggers are not vented to the atmosphere. Flow depth-discharge rating curves were developed and applied to the continuous record of depth measurements (corrected to atmospheric pressure) to develop a flow hydrograph during the time period data was collected. The two Chambers Lake gages were used to help understand the fluctuation in lake water levels throughout the year measured.

The surface water gage locations are shown on Figure 5. Data was collected from mid-September 2022 to November 2023. Table 4 summarizes the location of the gages, the type of data collected and period of data collected. The gages were installed at different times due to landowner permissions, required cultural resource evaluations, and in the case of the Muck Creek below 8th Avenue East gage, the need to purchase a new data logger.

Figure 5
Location of Surface Water Gages

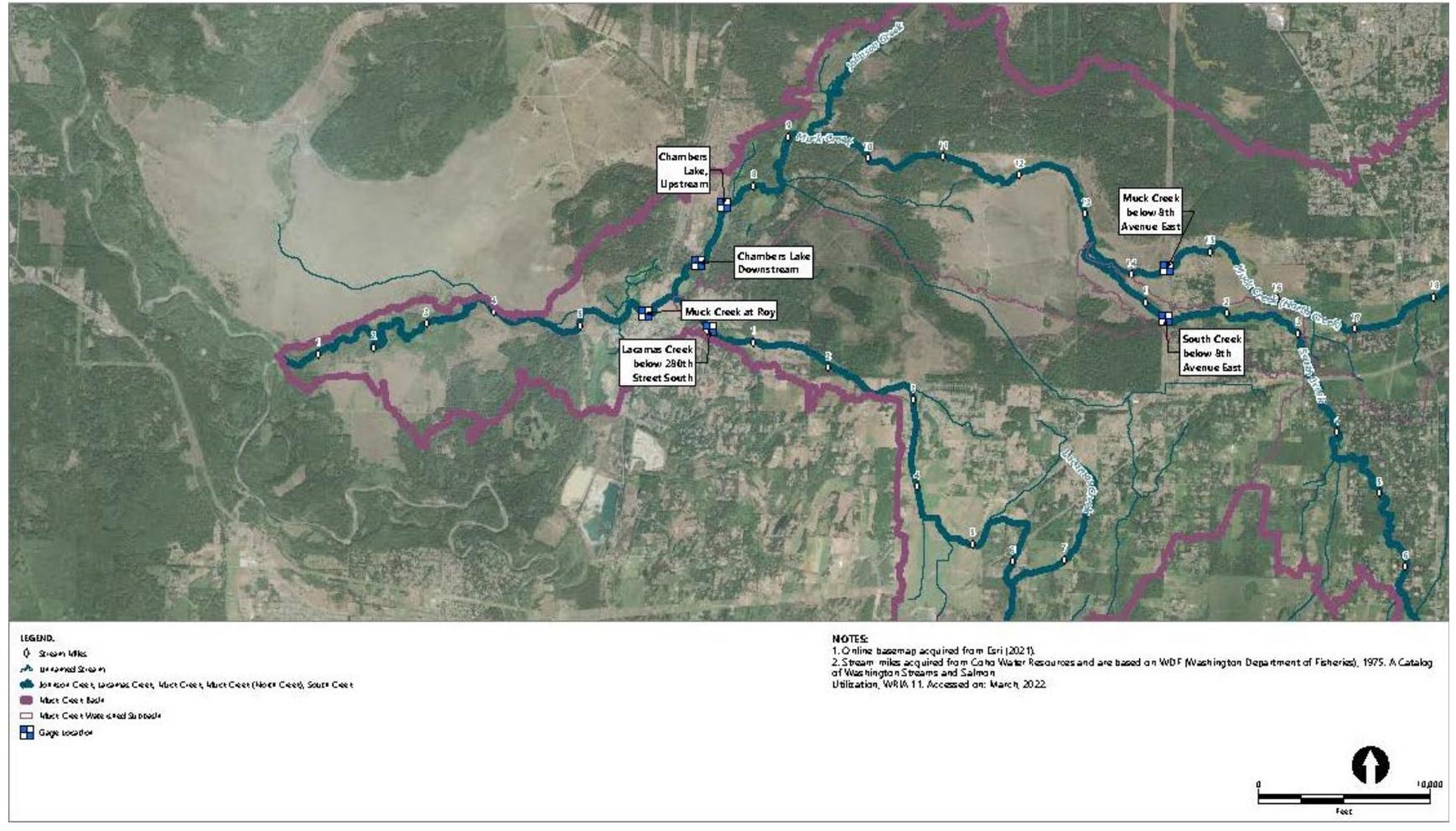


Table 4
Summary of Surface Water Gage Locations and Data Collected

Name of Gage	Location	Type of Gage	Period Data was Collected
Muck Creek at Roy	47° 0.336'N, 122° 32.641'W	Streamflow, Water Temperature	October 26, 2022, to November 22, 2023
Lacamas Creek below 280th Street South	47° 0.204'N, 122° 31.727'W	Streamflow, Water Temperature	October 26, 2022, to November 22, 2023
South Creek below 8th Avenue East	47° 0.413'N, 122° 25.344'W	Streamflow, Water Temperature	September 15, 2022, to November 22, 2023
Muck Creek below 8th Avenue East	47° 0.892'N, 122° 25.346'W	Streamflow, Water Temperature	November 22, 2022, to November 22, 2023
Chambers Lake Upstream	47° 1.398'N, 122° 31.565'W	Lake Level, Temperature	September 15, 2022, to November 22, 2023
Chambers Lake Downstream	47° 0.836'N, 122° 31.909'W	Lake Level, Temperature	September 15, 2022, to November 22, 2023

In addition to continuous measurements of stage that were converted to flow, synoptic flow measurements were made on Muck and Lacamas Creeks. Flows were measured at four locations along Muck and South Creek and three locations on Lacamas Creek on June 14, 2022. The purpose of the measurements was to review the flow-gaining and -losing characteristics of the streams and to compare to measurements performed by others.

The presence or absence of streamflow was observed at eight locations along Muck Creek on JBLM. The data was collected using time-lapse photography with photos taken once per hour, including the entire 2023 water year. A description of the data collection methods is provided in Appendix B (Coho 2024a).

3.2 Historical Streamflow Data

The U.S. Geological Survey (USGS) operated a Muck Creek at Roy stream gage (Station 12090200) that collected daily discharge data from 1956 to 1972 (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=12090200). The location of the gage is within 200 feet of the Muck Creek at Roy stream gage installed for this study. Peak streamflow data was measured until 1975; however, a peak flow estimate for a very large event in 1996 is contained in the records.

Pierce County previously operated two stream gages; Muck Creek at Roy and Muck Creek at 8th Avenue East. Both gages were located close to the gages installed for this plan. The *Muck Creek Basin Plan* (Pierce County 2005) describes the data collected at those gages. The period of record extended from March 2000 to December 2001.

Miscellaneous streamflow measurements collected by USGS in the Muck Creek basin from 1949 to 1977 are listed in *Miscellaneous Streamflow Measurements in The State of Washington, January 1961 to September 1985, Open-File Report 89-380* (USGS 1989).

Streamflow measurements in the Muck Creek basin were collected along with extensive shallow groundwater measurements by Washington Department of Ecology in *Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed Pierce County Publication No. 01-03-037* (Ecology 2001). Within that document, Pierce County and USGS measurements are also provided and discussed.

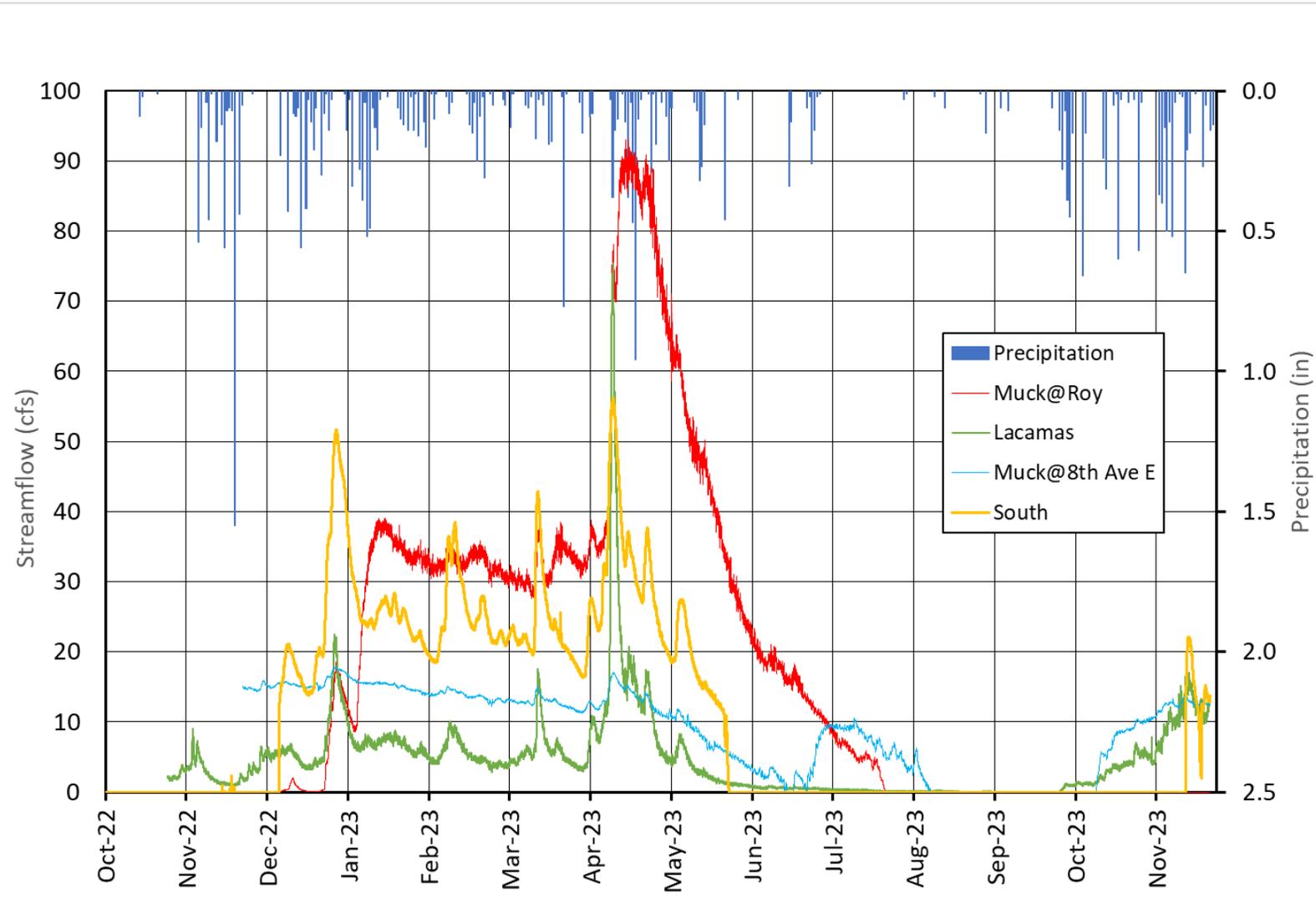
3.2.1 Precipitation

Precipitation records for stations within the Muck Creek basin are available from Pierce County Public Works <https://www.piercecountywa.gov/3024/Weather-Stations>. A precipitation gage named “Christensen/Muck” is located in the Upper Muck Creek basin. Data from the gage was used to compare to gaged streamflow to review the stream response to precipitation. During the 13-month period monitored, 27.8 inches of precipitation was recorded at that gage. That is well below the long-term average annual precipitation for the Muck Creek basin, which is estimated to be 45 inches (Appendix C).

3.3 Surface Water Data Collection Results

Streamflow hydrographs for the surface gages are shown in Figure 6. Hydrographs of Chambers Lake levels are shown in Figures 7 and 8. Daily precipitation volume recorded at the Christensen/Muck station are also plotted on each figure.

Figure 6
Streamflow Hydrographs



The average flow, estimated peak flow, and number of days each stream was dry or had no measurable flow are summarized in Table 5. Muck Creek at Roy and South Creek below 8th Avenue East both had significant periods of no flow or no measurable flow in the 13- to 14-month monitoring period (September or October 2022 to November 2023). However, Muck Creek below 8th Avenue East had ponded water in the stream channel during all the site visits, likely caused by downstream beaver activity. The conversion of stage in the creek to flow is not consistent at that site, likely because of the downstream beaver activity causing fluctuations in water levels. Water levels in late summer 2022 dropped below the level of the data logger, indicating little to no flow at that site.

Table 5 also provides the first day of flow that appeared in those streams during the 2023 water year (starts October 1, 2022).

**Table 5
Streamflow Summary September 2022 to November 2023**

Name of Gage	Average Flow (cfs)	Estimated Peak Flow (cfs)	Number of Days Stream Had No Flow or No Measurable Flow	Date Flow First Appeared in WY2023
Muck Creek at Roy	17.8	93	172	December 7, 2022
Lacamas Creek below 280th Street South	4.6	75	10	Flow was present during beginning of WY2023
South Creek below 8th Avenue East	10.2	56	250	December 7, 2022
Muck Creek below 8th Avenue East	9.0	18	66	Flow was present during beginning of WY2023

The estimated flow volume for the period of October 22, 2022, to November 22, 2023, in Muck Creek at Roy is 13,800 acre-feet, or 3 inches over the 86.6-square-mile tributary basin.

Figure 7
Chambers Lake Upstream Stage Hydrograph

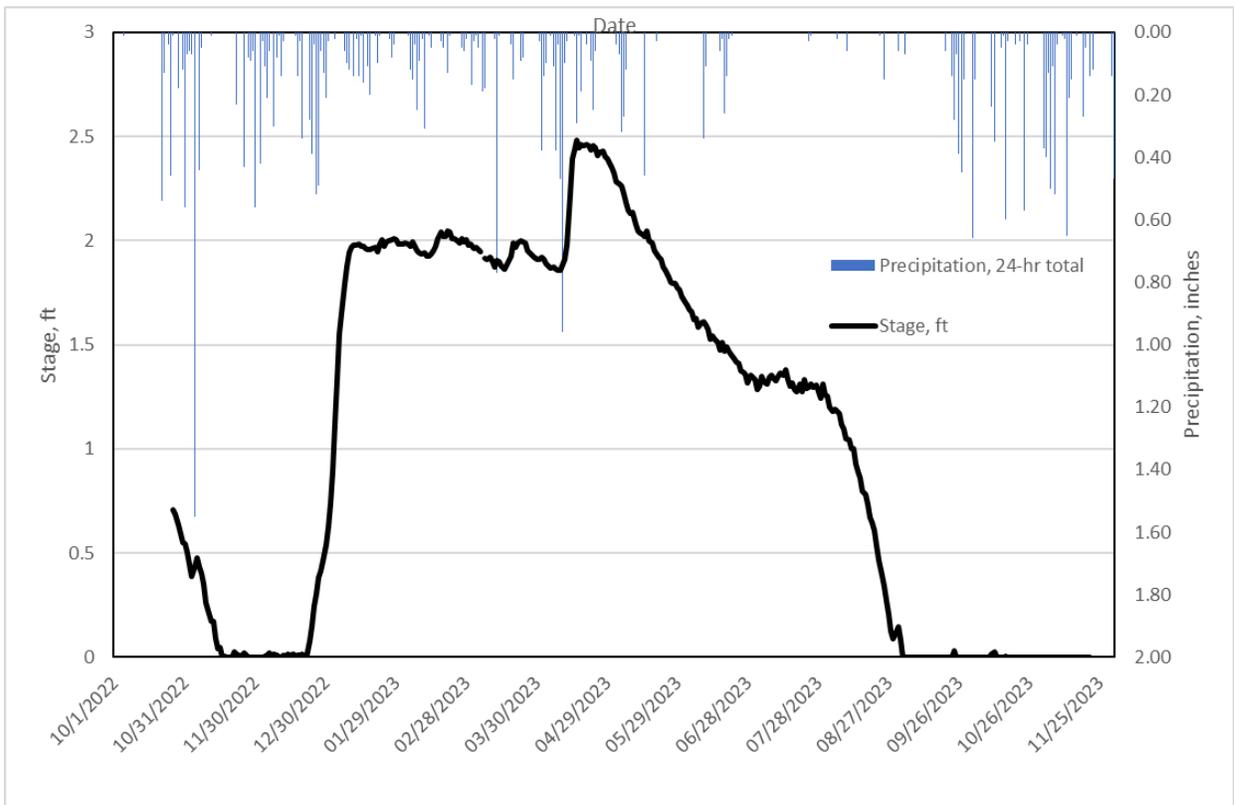
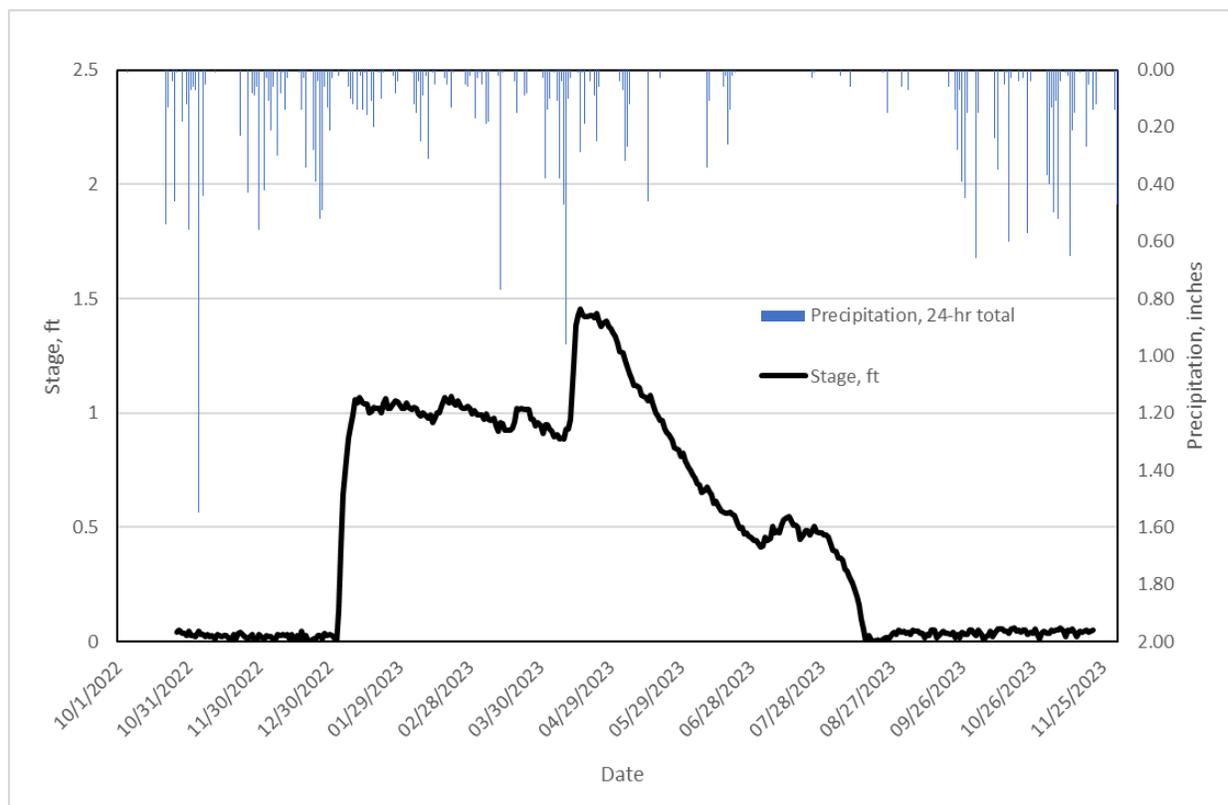


Figure 8
Chambers Lake Downstream Stage Hydrograph



The water level in Chambers Lake varied by over 2.5 feet during the period of time monitored (Figures 7 and 8). The water level gages were installed in mid-September 2022, which was expected to be the time of lowest stage in the lake. However, water levels continued to drop below the level that the water level sensor was installed, so readings between late October and late December are not available. Water levels rose in late December above the sensors allowing recording of water levels until late August 2023 when they dropped again below the water level sensors.

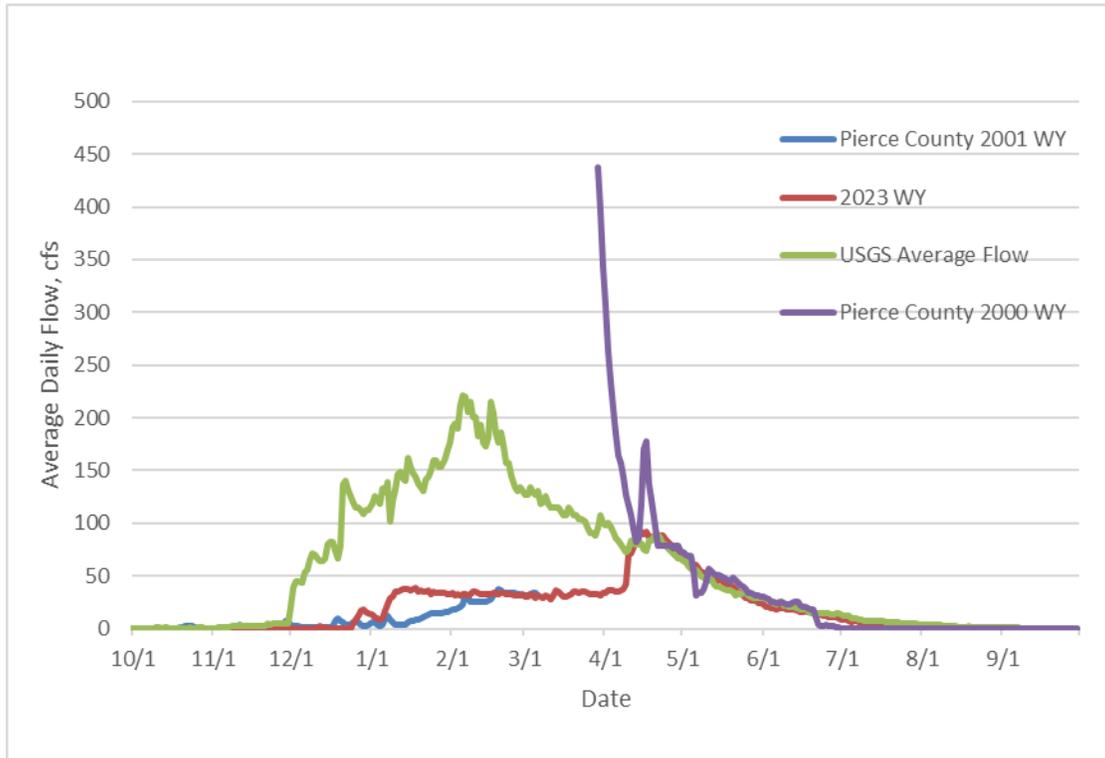
The period of time that Muck Creek at Roy had flow was from December 7, 2022, to mid-July 2023. The lake hydrographs show a leveling off in late June through July, consistent with much less discharge from the lake to Muck Creek. After a month or so of fairly steady lake levels, the levels declined quickly to below the level sensors.

3.4 Comparison to Historical Streamflow Data

Figure 9 presents the median of average daily flow for the period of record for the USGS gage Muck Creek at Roy (1956 to 1972). Also plotted are data from the Muck Creek at Roy gaging station installed for this project for the 2023 water year and data from the Pierce County operated stream

gages Muck Creek at Roy. The Pierce County stream gage was operated for a short time in 2000 and 2001.

Figure 9
Comparison of Stream Gage Records Muck Creek at Roy



Historically, surface water flow would typically start in late November and diminish to very low flow in late July, leaving 3 to 4 months of low to zero flow in Muck Creek at Roy. During the 1956 to 1972 period, the number of days that less than 1 cfs flow was recorded at the Muck Creek at Roy gage ranged from zero to 145, with an average of 58 days.

The average annual flow measured by USGS ranged from 28.8 cfs to 84.9 cfs, with an average of 64.0 cfs. The surface water flow equals a volume of 4.5 inches to 13.3 inches of water over the watershed, with an average of 10.0 inches.

The monitoring performed for this project showed much less flow than the historical measurements from USGS. The annual flow during water year (WY) 2023 for the Muck Creek at Roy gage was 17.8 cfs, equal to a volume of 3 inches of water over the watershed. Muck Creek at Roy had 172 days of no flow, compared to the range of zero to 145, with an average of 58 days in the 1956 to 1972 period.

The data collected by Pierce County is fairly consistent with data collected for this project. Flow recorded by Pierce County at the Roy gage dropped below 1 cfs by late June 2000 with essentially no flow at Roy from mid-July through mid-October. The flow in WY2023 recorded for this project dropped to about zero the third week of July, with no flow up to the end of the monitoring period in late November. In historical conditions, streamflow in Muck Creek at Roy would last until September. A difference in flow also occurs in early winter, with surface water flow appearing about 1 month later on average compared to historical conditions.

At the Muck Creek at 8th Avenue East gage, flow was recorded year-round for this project. Flow generally varied between 5 and 20 cfs from November until mid to late June. It then declined to between 2 and 4 cfs until about November.

For the Muck Creek at 8th Avenue East gage, the streamflow record in WY2023 is generally consistent with measurements performed by Pierce County at the same location in 2000/2001.

The gaging for this project occurred during a dry year, when only 28 inches of precipitation was recorded in the basin. The lesser volume of precipitation reduces groundwater recharge and discharge to Muck Creek. The prior year was wetter, and high flows (104 cfs) were measured in Muck Creek at Roy in mid-June (described in the next section). The measured flow in June 2022 was higher than all flows recorded in WY2023. A site visit was made on September 15, 2022, which noted that water was discharging from Chambers Lake into Muck Creek. The flow rate was not measured but visually estimated to be about 10 cfs. Downstream, at Roy, water was ponded in the Muck Creek channel although no flow was noted. No flow in Muck Creek at Roy was recorded until December 7, 2022.

A long-term flow monitoring program would be helpful to discern patterns and trends in streamflow occurrence and would help track the effectiveness of restoration actions designed to improve streamflow.

3.5 Synoptic Flow Measurements

Table 6 lists the data collected on June 14, 2022, along Muck, South, and Lacamas Creeks. Spring 2022 was very wet and flows were high into June. Muck Creek gained flow down to Roy. Lacamas Creek measurements indicate a gain in flow from 40th Avenue South to 280th Avenue.

Table 6
Synoptic Flow Measurements

Location	Flowrate (cfs)	Loss/Gain (cfs)
<i>Muck Creek</i>		
Muck Creek at Weiler Rd	12.1	
Muck Creek 8th Avenue East	11.4	-0.7 cfs
South Creek 8th Avenue East	59.6	
Lacamas Creek at 280th Street South	18.7	
Muck Creek at Roy	104.3	+ 14.6 cfs from total of Muck Creek at 8th Avenue East plus South Creek at 8th Avenue East plus Lacamas Creek at 280th
<i>Lacamas Creek</i>		
Lacamas Creek 40th Avenue South	17.9	
Lacamas Ck at 56th Avenue South	16.0	-1.9 cfs
Lacamas Creek at 280th Street South	18.7	+2.7 (+0.8 cfs from 40th Avenue South to 280th Street South)

3.6 Time-Lapse Streamflow Observations

The technical memorandum in Appendix B describes monitoring of stream conditions from the mouth of Muck Creek to Reach 6 of South Creek using time-lapse photographs. Eight cameras were installed, and photos taken and downloaded for the period of May 2022 to November 2023 (locations shown in Figure 10). The purpose of using time-lapse photography was to obtain a better understanding of the times Muck Creek and South Creek had no flow, and to obtain that data at more locations than possible by intermittent stream gaging or site visits. The photographic data was also used in tandem with shallow groundwater level data to better understand the relationship of surface water flow to groundwater levels.

The driest area of Muck Creek observed was above the lakes-and-wetlands chain, in Reach 4. In time-lapse photos at Camera 4 located above the confluence of Muck and Johnson Creeks, it was observed that Muck Creek had surface water flow when the camera was installed in May 2022, and surface water was present for a total of 20 days in May and June before drying up for the summer. But only 4 days of surface water flow were observed at this location in WY2023. That flow followed heavy rainfall in early April 2023 and was concurrent with stream hydrograph peaks measured at Muck Creek and South Creek upstream at 8th Avenue East (Figure 6). During WY2023, no surface water flow occurred over the elevated gravel deposit, which has accumulated at Muck Creek's former confluence with Johnson Creek.

The cameras also captured the drying out of stream reaches in Muck Creek between Roy and Exeter Bridge in the summer and fall of both 2022 and 2023, and the arrival of adequate streamflow for fish passage at the mouth of Muck Creek in late January 2023.

3.7 Groundwater Data Collection

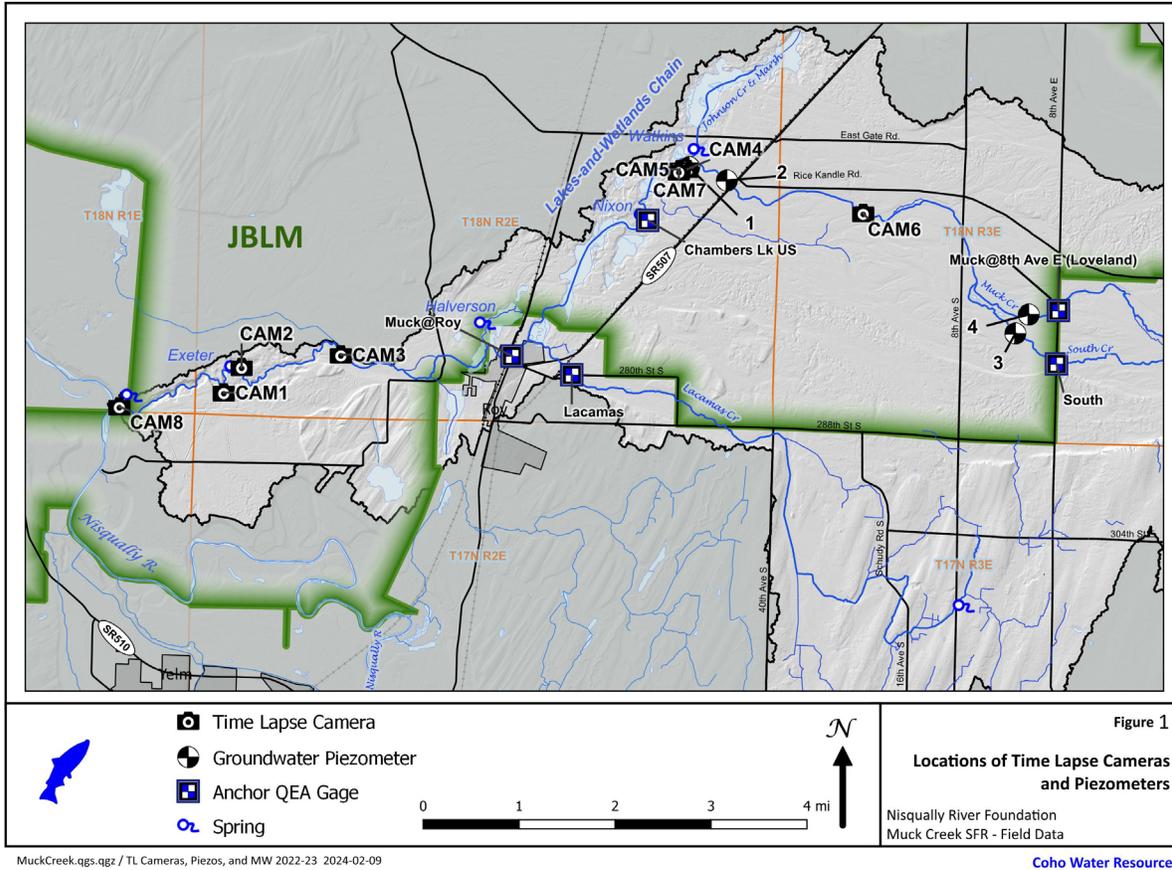
The technical memorandum in Appendix B describes more details of the collection of shallow groundwater data at four existing shallow groundwater piezometers adjacent to Muck and South Creeks on the prairie in Reaches 4, 5 and 6 (Figure 10). The piezometers were installed during a previous phase of work (Coho 2021). The piezometers extend 9 feet to 13 feet below ground surface and approximately 2.5 feet to 7 feet below the thalweg of the adjacent stream section.

The shallow groundwater data combined with the time-lapse photography confirm earlier findings by Coho (2021) that Muck and South Creeks consistently lose water to groundwater on the prairie above the chain-of-lakes (i.e., in Reach 4 and in the downstream portions of Reaches 5 and 7).

The data collected in WY2023 in and near the chain-of-lakes highlight the importance of groundwater in supplying water to the chain-of-lakes and to Muck Creek near Roy. Muck Creek in Reach 4 is the only identified source of surface water to the chain-of-lakes. As described in Section 3.6, streamflow into the chain-of-lakes from Muck Creek occurred for 4 days in WY2023 (April 12 through 15). Meanwhile groundwater levels near Muck Creek's entry into the chain and in Chambers Lake rose sharply in Jan. 2023 and remained high into May 2023 (Figure 7). These increases are primarily from groundwater from the recessional outwash, which enters the chain-of-lakes via springs, seeps, and hyporheic flow.

Streamflow in Muck Creek at Roy is supplied by the chain-of-lakes and by Lacamas Creek. Streamflow at Roy occurred from mid-December 2022 to mid-July 2023 and exceeded the flow of Lacamas Creek by more than a factor of 3 (Figure 6). These findings suggest that in WY2023, groundwater was the largest supplier of streamflow for Muck Creek at Roy. Fluctuations in the groundwater levels in the outwash likely affect the timing and magnitude of winter streamflow in Muck Creek in and below the chain-of-lakes.

Figure 10
Camera and Piezometer Locations



3.8 Water Budget

The technical memorandum in Appendix C describes an analysis of components of the Muck Creek basin’s water balance. The elements of the water balance analyzed are precipitation, ET, water use and streamflow.

Precipitation data was obtained for monthly and water-year totals for recent years and for historical periods matching stream discharge data. Evapotranspiration was estimated on a monthly and water-year basis for major land cover and land use types and current distribution of those types in the basin. Streamflow data was available on a monthly and water-year basis. The findings of the water balance included:

- The average annual ET is estimated to range from 13 inches for prairie to 33 inches for evergreen forest. ET for other land covers cluster between 25 inches and 30 inches.

- Change in land cover from prairie to forest in the outwash plain, which increases ET, has been outweighed across the entire basin by change from forest to agriculture and development, which decreases ET, resulting in an approximately 13% net decrease in ET in the basin. This varies by subbasin from an increase of 31% in middle Muck Creek subbasin to a decrease of 26% in the South Creek subbasin.
- The results of the preliminary water balance indicate precipitation is distributed as: 53% ET, 24% streamflow, and 22% unknown. The unknown component may be attributed to canopy interception and out-of-basin groundwater flow.
- Consumptive domestic water use is 4.7 cubic feet per second (cfs; less than 1 inch per year) based on the 2010 census population of 33,000 people, which is not large in the scale of the water balance but may increase the duration of dry streams, especially during drought years when precipitation and groundwater recharge is reduced.

3.9 Water Rights

In 2018, Washington Water Trust (WWT) examined irrigation water rights in the Prairie Tributaries subbasin of the Nisqually River Basin, identifying rights that may be suitable for acquisition or other water conservation projects to restore stream flows and/or offset future permit-exempt wells (WWT 2018). Muck Creek basin occupies roughly half of the Prairie Tributaries area, and WWT shared its results with this project so that information specific to Muck Creek basin could be summarized.

WWT compiled a list of water rights in the basin with at least 10 acres of irrigation and then assessed the amount of irrigation associated with each water right via examination of growing-season aerial photographs (WWT 2018). In Muck Creek basin, WWT examined almost 900 acres of agricultural fields. Agricultural activity in the basin is concentrated in the Lacamas Creek and South Creek subbasins. Reviewing aerial photographs from the 2015, 2017, and 2019 irrigation seasons, WWT classified an average of 125 acres and 135 acres as having a high and medium likelihood of being irrigated, respectively. Taken together and assuming a crop duty of 1.5 acre feet per year (afy) applied per acre, WWT estimated a water use on the combined 260 acres of 400 afy, equivalent to 0.54 cfs.

In its assessment, WWT grouped the water rights into four tiers to prioritize future efforts in water right review and potential outreach. Its 10 highest priority potential projects include six properties or clusters of adjoining properties with a total of eight Muck Creek basin water rights. Seven of these water rights are groundwater rights, and one is a surface water right. These eight water rights represent almost 900 potentially irrigated acres and an estimated potential 1,400 afy of water use. These quantities likely overestimate current irrigation practices, given that WWT's examination of agricultural fields in Muck Creek basin identified less than 300 acres with a high or medium likelihood of irrigation.

All potential projects require further substantial investigation and ultimately the willingness of landowners/water right holders to participate in a project. These projects may range from full season permanent acquisition to changed irrigation practices, which may prove more efficient, require less withdrawal, and focus agricultural operations on the most productive land. In the case of the surface water right, an actual source switch from a small tributary to a larger stream or from surface to groundwater would not only provide mitigation but also a restoration benefit (WWT 2018).

3.10 Summary of Data Analysis

Sections 2 and 3 provide a summary of hydrologic and physical characteristics of streams in the Muck Creek basin. A combination of stream channelization, loss of floodplain connectivity, and loss of historical wetlands combined with hydrologic changes such as increased stormwater runoff, increased ET in parts of the basin, consumptive water use, and possible breaching of impervious layers in the bed of the stream channels have all contributed to the increased frequency, duration, and extent of dry reaches, and also contribute to increase in peak flows and scouring potential of the streams. A warming climate, which has changed precipitation patterns and increased ET, also likely contributes to hydrologic changes, although climate change effects in the Muck Creek basin are not analyzed in this plan.

Our conclusion is the multiple factors described above need to be addressed to improve streamflow and habitat and reduce the problem of extended periods of dry stream reaches. Sections 4 and 5 lay out the proposed approach to address these multiple factors (and describe their potential benefits) and develop a comprehensive watershed restoration approach.

4 Watershed Restoration Approach

The purpose of the streamflow restoration grant and the development of this plan is to compensate for future consumptive uses of water from permit-exempt wells, which have been projected to be a maximum of 1,098 acre-feet or 1.5 cfs of streamflow for the Prairie Tributaries to the Nisqually River (NWPU 2019). The Prairie Tributaries include Tanwax Creek and other smaller tributaries, but Muck Creek is the largest of the Prairie Tributary systems and the intent is for streamflow restoration in the Muck Creek watershed to fully compensate for all Prairie Tributaries. In addition, Muck Creek already has extended dry periods that appear to have been increasing since the 1960s, so identifying actions that can contribute to streamflow beyond that which is required is desired as part of this watershed restoration plan. Lastly, Muck Creek is extremely important to supporting and sustaining both winter chum and winter steelhead in the Nisqually River watershed, and actions that can be taken to improve habitat conditions that also contribute to streamflow restoration are another important component of this plan.

From the evaluation of historical and current conditions of streamflow, groundwater, and habitat conditions, the following major problems have been identified:

- **Expanding Dry Stream Reaches:** Multiple reaches of Muck Creek, South Creek, and Lacamas Creek go dry annually or occasionally, typically between the months of July through December. While this likely occurred naturally in some reaches within the glacial outwash prairie, the dry reaches appear to be expanding and remaining dry for longer periods. When reaches within lower Muck Creek and lower Lacamas Creek go dry, it can prevent fish entry into either creek.
- **Loss of Large Historical Wetlands:** Approximately 50% of the wetland area has been lost in the South Creek and Lacamas Creek subbasins and slightly less than 50% in the Upper Muck Creek subbasin when comparing GLO mapping to current conditions (see Appendix C). These areas would have historically stored water during the rainy season and recharged the groundwater table and promoted streamflow during the dry season.
- **Succession of Prairie to Forest:** The naturally occurring prairie habitats on the glacial outwash deposits that were maintained by Native Americans through regular burning have transitioned to forest. Over 50% of the prairie habitat in the middle reaches of Muck Creek and over 30% in the lower reaches of Muck Creek have been converted to other vegetation types, primarily coniferous forest (Douglas fir dominated). Douglas fir forest has more than double the evapotranspiration rate as prairie and may be contributing to further reductions in streamflow (see Appendix C; Coho 2023b).
- **Prevalence of Invasive Vegetation:** Both native and non-native invasive species are dominant across the basin, primarily reed canary grass, but also including Scot's broom, and non-native blackberries. Reed canary grass is prevalent both within the stream channels and

wetland and riparian areas and can block fish passage during low flows and may contribute to further reductions in streamflow when it grows directly in the channel.

- **Development and Increase of Impervious Surfaces:** Approximately 25% of the Muck Creek watershed is in development, concentrated in the Upper Muck and South Creeks subbasins, but also prominent in the Lacamas Creek subbasin. Impervious surfaces do not allow infiltration of precipitation into the soil and groundwater table and instead cause higher and flashier stormwater runoff. Combined with the lack of wood and other roughness in the generally channelized and incised stream channels, surface flows rapidly run off causing scour and incision and do not connect to wetlands and floodplains.
- **Low Diversity and Quality of Stream Habitats:** Many stream reaches within the Muck Creek watershed have limited riparian habitat and cover, low quantities of large wood, few pools, and few beaver dams and ponds. These have all resulted from over 150 years of land uses that specifically removed riparian forest, channelized streams, removed beaver from the landscape, and drained or filled wetlands. The historical condition would have included significant quantities of wood in reaches in the forested uplands and many reaches within the glacial outwash prairie would have likely had numerous beaver ponds and associated wetlands and frequent connectivity to a broader floodplain.

These key problems identified are the major reasons that the Muck Creek watershed is experiencing continued loss of streamflow and overall poor- to moderate-quality habitat for native fish and wildlife species.

The types of actions that can help address these problems include the following:

- Restore wetlands, particularly in subbasins that have experienced the largest losses.
- Reverse stream channel incision to promote wetland and floodplain connectivity with installation of large wood and beaver dam analogs (BDAs).
- Promote beaver colonization with BDAs, and restore their food sources along streams (e.g., willows, cottonwoods).
- Manage invasive species, primarily reed canary grass in and adjacent to stream channels, through multi-year plans to include mowing, excavation, solarization, plantings, and continued maintenance.
- Thin Douglas fir forest areas that have encroached on former prairies (and wood can be reused in the channel with other measures).
- Restore riparian habitats as appropriate for the stream reaches (narrower willow/cottonwood in prairie reaches, and coniferous forest in upland reaches).
- Acquire water rights to reduce surface water diversions or improve irrigation efficiencies. Water rights could be purchased outright or leased or acquired for part of the irrigation

season (split season). Investments in more efficient sprinklers could reduce water use and water loss through evaporation.

- Retrofit older stormwater facilities or existing impervious surfaces to provide infiltration into groundwater table.
- Consider large-scale MAR, such as use of treated wastewater from facilities such as JBLM’s Solo Point treatment plant, adjacent to lower Muck Creek where other actions are not feasible in the artillery area of JBLM.

Table 7 summarizes which actions have been identified to address each of the key problems in the watershed.

Table 7
Actions Identified to Address Identified Watershed Problems

Problem	Need	Specific Actions
Expanding Dry Reaches	<ul style="list-style-type: none"> • Reduce evapotranspiration • Recharge groundwater • Reduce loss from streams to groundwater • Return unused (or partial use) water rights to stream flow 	<ul style="list-style-type: none"> • Thin and clear forest patches on prairies adjacent to dry reaches • Install BDAs to slow water to reduce channel scour and promote fine sediment deposition • Promote beaver use by planting suitable forage species • Restore floodplain connectivity with large wood and connection to wetlands and off-channel habitats • Remove or manage invasive species (particularly reed canary grass and Scot’s broom) • Restore wetlands adjacent to channels • Develop sites for MAR • Conserve water • Acquire water rights
Loss of Large Historical Wetlands	<ul style="list-style-type: none"> • Reduce wetland drainage • Restore and reconnect wetlands to stream channels • Enlarge and enhance remnant wetlands 	<ul style="list-style-type: none"> • Install BDAs and wood to reduce channelization/drainage of historical wetlands (particularly on Lacamas and South Creeks) • Reconnect winter channel to promote water storage and groundwater recharge • Remove berms to reconnect wetlands associated with Watkins Springs and other areas isolated from historical ditching/side cast • Fill ditches and remove drain tiles and other drainage features in remnant wetlands (e.g., Stage 0 restoration)

Problem	Need	Specific Actions
Succession of Prairie to Forest	<ul style="list-style-type: none"> • Reduce forest patches on former prairies • Minimize invasive species such as Scot's broom and reed canary grass in prairie habitats • Expand controlled burning and other measures to maintain prairies 	<ul style="list-style-type: none"> • Thin and clear forest patches on prairies adjacent to dry reaches • Manage Scot's broom with continued burning • Develop long-term reed canary management program to focus on stream channels first, then move linearly into riparian buffers, then floodplain wetlands
Prevalence of Invasive Species	<ul style="list-style-type: none"> • Remove species that are most easily managed (e.g., Scots broom, blackberries) • Control reed canary grass in reaches where fish passage is challenging • Reduce forest encroachment on former prairie habitats 	<ul style="list-style-type: none"> • Excavate where necessary to remove reed canary grass blocking stream channels • Mow/spray/solarize reed canary grass moving outwards from stream channels and plant fast-growing native species such as willows to rapidly shade and reduce vigor • Thin Douglas fir forest adjacent to dry reaches and reuse as large wood in the channel • Conduct controlled burning of understory in prairie reaches
Development and Increase of Impervious Surfaces	<ul style="list-style-type: none"> • Increase infiltration of stormwater through retrofits of existing stormwater facilities • Develop local stormwater requirements for Muck Basin to require infiltration as primary solution for all new facilities • Protect groundwater recharge areas for all identified springs 	<ul style="list-style-type: none"> • Install check dams in existing stormwater drainage ditches • Enhance infiltration of stormwater ditches and direct to infiltration zones • Acquire/conserv e existing undeveloped parcels upslope of known springs • Designate Local Areas of More Intense Rural Development and maintain larger lot sizes outside of these
Low Diversity and Quality of Stream Habitats	<ul style="list-style-type: none"> • Increase instream structure • Reconnect wetlands and off-channel areas • Promote beaver ponds • Restore riparian areas 	<ul style="list-style-type: none"> • Install BDAs • Promote beaver use by planting suitable forage species • Install large wood instream • Restore/reconnect adjacent wetlands • Restore/reconnect off-channel and floodplain areas • Revegetate riparian areas with appropriate native species

Because of the importance of maintaining flows in the lower half of the watershed so that anadromous salmon can continue to access and use Reaches 1 to 3 in Muck Creek, as well as Lacamas and Johnson Creeks, prioritization of where to start with streamflow and habitat restoration actions is a key strategy. Typically, when thinking about restoring streamflow, starting in the headwaters and working downstream is the approach to ensure that water can be stored and released as high up in the watershed as possible to benefit as many reaches downstream as possible.

However, Muck Creek has the most frequently dry reaches right in the middle of the watershed (even while upstream reaches in both Upper Muck and South Creeks have more continuous flow) because surface flows discharge rapidly into the highly permeable glacial outwash soils in Reaches 4 and 5 (and Reach 7 of lower South Creek). Very significant volumes of infiltration would be required to raise the groundwater table close to the stream channel beds to maintain flows. Thus, the preferred approach is to prioritize actions in the lower half of the watershed and specifically include near-term actions in Reaches 2, 4 and 5 to address key issues by slowing down flows, promoting wetland and floodplain connectivity, and supporting water storage and sediment deposition in the prairie reaches. Secondly, taking actions to restore and reconnect wetlands to store water in both Johnson and Lacamas Creeks will contribute to supporting longer duration flows both within these creeks and in Muck Creek downstream. Lastly, prioritizing the lower half of the watershed also focuses the work on maintaining flows in the reaches that are currently accessible to and highly important for spawning of anadromous salmonids.

5 Programmatic and Project Actions

Streamflow and habitat restoration in the Muck Creek watershed involves both programmatic actions and site-specific projects. Programmatic actions require collaboration across multiple partners, and site-specific projects will require further detailed site investigations.

5.1 Programmatic Recommendations

P1. Increase water conservation in the Muck Creek watershed. Conservation of both surface water rights and groundwater consumption should be encouraged through outreach and education to watershed residents and businesses. Multiple partners could participate including Washington Department of Ecology, Pierce County, Pierce Conservation District, and non-profit organizations. Surface water rights owners and users can be supported through identification of on-site conservation measures (irrigation equipment upgrades, irrigation best practices, etc.), and other measures.

P2. Protect and restore existing wetlands. Substantial loss of wetlands or wetland functions have occurred, particularly in Upper Muck, South, and Lacamas Creeks. Wetlands are key groundwater recharge features and should be protected, restored, and/or enhanced throughout the watershed, but also particularly those associated with the larger historical wetlands mapped in the 1800s.

P3. Enhance, restore, and reintroduce beaver onto the landscape. The low gradient of nearly all streams within the Muck Creek watershed are highly suitable for beavers and beaver dams and ponds. It is highly likely that beaver dams, ponds, and associated wetlands were a major feature of the historical Muck Creek. While beaver are still present in some areas of the watershed, expanding their presence to all suitable areas within the watershed will slow water velocities and delivery to downstream reaches during storms, promote deposition of fine sediments that may help streams in the outwash plain to hold surface water longer, and promote the long-term storage and infiltration of water into the groundwater table throughout the watershed. Outreach and education to landowners and other residents regarding how to live with beavers should be conducted. Long-term funding of management and maintenance of features that allow beavers to co-exist with human land uses (e.g., pond levelers, beaver deceivers) should be developed.

P4. Protect parcels critical to groundwater infiltration upslope of known springs. Maintaining existing spring flows into the streams of the Muck Creek watershed is critical to maintaining streamflow. Protecting existing undeveloped parcels adjacent to and upgradient from springs will minimize the conversion of these key areas to impervious surfaces and other land uses that restrict infiltration of precipitation into the groundwater table.

P5. Promote infiltration of all stormwater from impervious surfaces. New development is already required to meet current Pierce County stormwater requirements, but older stormwater facilities

should be investigated to identify ways to retrofit the facilities to retain and infiltrate all stormwater up to a specified storm event, such as the 10-year rainfall event. An expanded program of retrofits of individual residences with rain gardens and infiltration facilities should also be started. Newer stormwater facilities that adequately retain stormwater, but may allow discharge to surface water rather than infiltration should also be reviewed to determine methods to include infiltration. A program of stormwater infiltration retrofits should initially be focused in areas that contribute to springs, such as Patterson Springs, which directly feed Upper Muck Creek. A secondary focus area is the Lacamas Creek subbasin, as Lacamas Creek has perennial flow, which supports chum and coho salmon populations. Enhancing flow and temperature conditions would help restoration actions. Appendix D contains a review of the potential for stormwater recharge in the Lacamas Creek subbasin; several locations in the Lacamas Creek subbasin may be appropriate for enhancement of existing stormwater drainage ditches to increase infiltration and recharge to benefit streamflow and stream temperature during low-flow times.

P6. Explore the potential for a large-scale MAR project. The Muck Creek watershed does not have any large-scale water treatment facilities or other large developments that produce sufficient water to be considered for a large-scale MAR project. However, the Solo Point WWTP located northwest of the watershed could be a source of water for a larger scale MAR project that could be situated adjacent to the middle reaches of Muck Creek or up gradient from known springs (such as Exeter Springs) that feed lower Muck Creek. Such a large-scale MAR project could have substantial benefits in maintaining streamflow. While piping water this distance is costly, this option should be considered due to the large potential benefit to streamflow.

P7. Pursue water rights acquisition for streamflow purposes. Currently valid water rights for surface or groundwater should be investigated for opportunities to acquire seasonal or permanent segments of water rights to return to streamflow. Water rights that are not fully utilized or are not needed seasonally could be acquired.

P8. Restore prairie habitats by removal or thinning of Douglas fir forest. There has been a widespread conversion of historical prairies to forest, which has increased the evapotranspiration rates and further contributed to lowering of groundwater. Since over 16,000 acres have been converted, at least 5,000 acres should be considered for removal or thinning, with a focus on areas within 1 mile of streams.

5.2 Potential Projects by Reach

Potential projects have been identified by reach and are shown in Table 8 and described in more detail in Appendix E.

**Table 8
Potential Projects by Reach**

Site ID	Location and Ownership Type	Description
Muck Creek Reach 1		
R1-P1	RM 0-3, JBLM artillery range	Reed canary grass management, placement of unanchored large wood, remove any non-essential stream crossings
R1-P2	RM 2.5-3.5, JBLM artillery range	Protect and enhance spring flows
R1-P3	North of RM 2.5-3.5, JBLM	MAR project using Solo Point treated wastewater piped from plant
Muck Creek Reach 2		
R2-P1	RM 3.5-6, JBLM	Reed canary grass management, placement of log clumps and unanchored large wood, install BDAs where feasible, reconnect to floodplain, riparian plantings where appropriate
R2-P2	RM 5.5-6.2; private and City of Roy	Bioengineering where needed to stabilize eroding streambanks, riparian plantings, retrofit stormwater facilities to infiltrate
R2-P3	RM 5; private	Enhance fish passage to Preacher Creek
R2-P4	RM 5.9; JBLM	Enhance fish passage to Halvorson Marsh
R2-P5	Muck Lake	Enhance fish passage through Muck Lake
Muck Creek Reach 3		
R3-P1	Chambers Lake	Chambers Lake Invasive Species Management Plan; install large wood, plant islands, promote beaver use (e.g., forage species)
R3-P2	Chambers Lake	Identify and protect spring inputs
R3-P3	RM 7; JBLM	Install large wood and BDAs in channel between Muck and Chambers lakes; manage invasives
R3-P4	Muck Lake	Develop long-term Muck Lake Invasive Species Management Plan; install large wood, plant islands, riparian buffer enhancement
Muck Creek Reach 4		
R4-P1	RM 9-13.5; JBLM	Thin forest patches adjacent to stream; install large wood clumps, install BDAs, notch ford crossings for fish access, remove large gravel deposit at mouth of Johnson Creek, reconnect floodplain and wetlands, reconnect winter channel, manage invasive species, riparian and wetland plantings
Muck Creek Reach 5		
R5-P1	RM 13-14.5, JBLM	Install large wood clumps, install BDAs, notch ford crossings for fish access, reconnect floodplain and wetlands, manage invasive species, riparian and wetland plantings as appropriate
R5-P2	RM 14.7-15.55, private	Install BDAs and wood, livestock fencing, manage invasive species, restore wetlands, riparian and wetland plantings
R5-P3	RM 15.55-16.4, private	Preserve existing riparian habitats, install wood or BDAs
R5-P4	RM 16.4-17.2; private	Install BDAs and wood, livestock fencing, manage invasive species, restore wetlands, riparian and wetland plantings
R5-P5	RM 14.5-16.6	Identify and implement water conservation or acquisition opportunities

Site ID	Location and Ownership Type	Description
Muck Creek Reach 6		
R6-P1	RM 17.2-18.7; private and County	Conservation of existing riparian and upland forest; enhance stream habitat with wood or BDAs
R6-P2	RM 17.5; private	Modify or remove rock dam, install large wood
R6-P3	RM 18; private	Conserve existing wetlands and riparian buffer on tributary to Muck Creek; replace undersized culverts at 252nd Street E
R6-P4	18.5-19.4; private	Conserve existing high quality riparian buffers and wetlands
R6-P5	RM 20; private	Remove fish passage barrier (WDFW ID: 997905)
R6-P6	RM 20.1; private	Remove fish passage barrier (WDFW ID: 997906)
R6-P7	RM 20.1; private	Remove fish passage barrier (WDFW ID: 997907)
R6-P8	RM 20.1; private	Remove fish passage barrier (WDFW ID: 997908)
South Creek Reach 7		
R7-P1	RM 0-1.2; JBLM	Install large wood clumps, install BDAs, notch ford crossings for fish access, reconnect floodplain and wetlands, manage invasive species, riparian and wetland plantings as appropriate
R7-P2	RM 1.2-2.2; private	Protect existing high-quality riparian and wetland habitat; install large wood and BDAs, manage invasive species, riparian and wetland plantings
South Creek Reach 8		
R8-P1	RM 2.2-6.0; private	Conserve existing high quality forested riparian buffers and wetlands, install wood or BDAs, identify opportunities to co-exist with beaver
R8-P2	RM 6; private	Restore large historical wetland on tributary to South Creek, install wood or BDAs
R8-P3	RM 3.5-7.6; private	Identify opportunities to increase infiltration of stormwater and reduce ditching/conveyance of tributaries
South Creek Reach 9		
R9-P1	RM 7.6-15.4; private	Manage invasive species, install BDAs and large wood, riparian and wetland plantings, identify opportunities to co-exist with beaver
R9-P2	RM 11-14; private	Restore historical wetlands, install wood or BDAs, enhance riparian buffers
R9-P3	RM 7.6-15.4; private	Identify opportunities to increase infiltration of stormwater and reduce ditching/conveyance of tributaries
South Creek Reach 10		
R10-P1	RM 15.4-19.3; private	Manage invasive species, install BDAs and large wood, riparian and wetland plantings, identify opportunities to co-exist with beaver
R10-P2	RM 15.4-19.3; private	Identify opportunities to increase infiltration of stormwater and reduce ditching/conveyance of tributaries
R10-P3	RM 16.5; private	Remove fish passage barrier (WDFW ID: 933101)
R10-P4	RM 16.8; private	Remove fish passage barrier (WDFW ID: 932679)
R10-P5	RM 18.5; private	Remove fish passage barrier (WDFW ID: 932685)
R10-P6	RM 18.9; private	Remove fish passage barrier (WDFW ID: 933233)
R10-P7	RM 18.9; private	Remove fish passage barrier (WDFW ID: 933232)

Site ID	Location and Ownership Type	Description
Johnson Creek Reach 11		
R11-P1	RM 0-1.7; JBLM	Remove berms to reconnect wetlands/springs to channel; maintain open channel for fish access, manage invasives, install BDAs and large wood, riparian and wetland plantings
R-11-P2	RM 0.5; JBLM	Modify dam to ensure fish accessibility
Lacamas Creek Reach 12		
R12-P1	RM 0-0.5; private	Manage invasive species, install BDAs and large wood, riparian and wetland plantings, livestock fencing, maintain fish passage
R12-P2	RM 0.5-1.8; private	Manage invasive species, install BDAs and large wood, riparian and wetland plantings
R12-P3	RM 2.3-3.4	Manage invasive species, install BDAs and large wood, riparian and wetland plantings
R12-P4	RM 0-3.4; private	Identify opportunities to infiltrate stormwater and water conservation or acquisition
Lacamas Creek Reach 13		
R13-P1	RM 3.4-4.7; private	Reduce stream channelization and restore large historical wetland, manage invasive species, install BDAs and large wood, riparian and wetland plantings, livestock fencing, beaver reintroduction
Lacamas Creek Reach 14		
R14-P1	RM 6-7; private	Reduce stream channelization and restore wetlands, manage invasive species, install BDAs and large wood, riparian and wetland plantings, livestock fencing, identify opportunities for easements
R14-P2	RM 5-8; private	Identify opportunities for water conservation or acquisition of water rights
R14-P3	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999130)
R14-P4	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999131)
R14-P5	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999132)
R14-P6	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999133)
R14-P7	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999156)
R14-P8	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999140)
R14-P9	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999149)
R14-P10	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 997800)
R14-P11	RM 4.9-8.2; private	Remove fish passage barrier (WDFW ID: 999147)

5.3 Evaluation Criteria/Prioritization

A qualitative project evaluation and scoring scheme was developed to identify which projects provide the most potential streamflow and habitat benefits and their level of feasibility to implement to help prioritize the project list within the broader strategy of working in the lower half of the basin first. The scoring was also weighted to emphasize the potential benefits, while reducing the weight

related to challenges, as this is a long-term plan, and challenges can more likely be overcome over a long timeline. Table 9 summarizes the ranking criteria and scoring. Appendix E includes the detailed list of projects and scoring.

**Table 9
Project Evaluation Criteria and Scoring**

Ranking Element	Description	Scoring	Weighting
Streamflow Benefit	Does the project include elements specifically to benefit streamflow (e.g., infiltration, water storage)?	High—5 Medium—3 Low—1 None—0	0.25
Wetland, Floodplain, Riparian Benefit	Does the project include elements specifically to benefit wetlands, floodplains, or riparian zones?	High—5 Medium—3 Low—1	0.25
Stream Habitat Benefit	Does the project include elements specifically to benefit instream habitats or fish access?	High—5 Medium—3 Low—1	0.25
Cost	Relative scale of cost	High—1 Medium—3 Low—5	0.1
Feasibility	Relative scale of technical and implementation feasibility	High—5 Medium—3 Low—1	0.1
Permitting	Relative scale of permitting feasibility	Low complexity—5 Medium complexity—3 High complexity—5	0.05

5.4 Top Ranked Projects

The highest ranked projects are summarized as follows and the concept designs and narrative are included in Appendix F.

Muck Creek Reach 4 (R4-P1). This project is a reach-scale project that would include primarily habitat restoration elements, but would include elements that should contribute to helping hold water for a longer duration in the reach and contribute to groundwater recharge over the long term. Actions would include thinning of Douglas fir forest adjacent to the stream channel to then reuse the wood to be installed as large wood clumps throughout the reach, installation of BDAs throughout the reach, modifying the ford crossings to provide a low-flow notch in each, reconnecting the winter channel at bankfull flows and higher, restoration in the winter channel including spot excavation for flow-through and management of invasive species (primarily reed canary grass) through mowing,

solarization and plantings of rapidly growing native woody species, management of invasive species throughout the reach, riparian/wetland plantings as appropriate for the prairie context and existing forested context.

Muck Creek Reach 5 and South Creek Reach 7 (R5-P1 and R7-P1). This project is a reach-scale project on the lower ends of reaches 5 and 7 (within JBLM property) that would include primarily habitat restoration elements, but include elements that should contribute to helping hold water for a longer duration and contribute to groundwater recharge. Actions would include installation of BDAs and large wood clumps throughout the reach, modifying ford crossings to provide a low-flow notch in each, management of invasive species, riparian/wetland plantings as appropriate for the prairie context and existing riparian and wetland vegetation.

Johnson Creek Wetland and Stream Restoration (R11-P1). This project would restore connectivity between the springs and wetlands and Johnson Creek to promote better water and fish connectivity and restore in-channel habitats and fish access. Actions would include removal of berms along the channel that prevent connectivity to the wetlands, reuse of the excavated material to create planting islands in areas dominated by invasive species, installation of BDAs, management of invasive species, riparian and wetland plantings as appropriate to manage invasives species and in context of existing native vegetation.

Lacamas Creek/Muck Lake Restoration (R12-P1 and portions of R3-P4). This project would improve connectivity through Muck Lake and lower Lacamas Creek to improve fish passage and provide habitat restoration elements. Actions would include excavation as needed to provide a continuous flow-path through Muck Lake and a secondary channel, compost/reuse of excavated material to create planting islands, installation of BDAs and large wood, management of invasive species along the stream routes, riparian and wetland plantings as appropriate to the wetland context.

Lacamas Creek Wetland Restoration (R13-P1). This project could be scaled or accomplished in phases to result over time in the restoration of the large historical wetland mapped in this reach. Wetland restoration would contribute significantly to storing water, groundwater recharge, and helping to sustain perennial flows in lower Lacamas Creek. Actions could include reducing or eliminating channelization of the creek through BDAs, fill to raise the channel bed and create smaller flow paths (for example, Stage 0 restoration), management of invasive species, installation of wood and BDAs, riparian and wetland plantings, and working with landowners to allow for seasonal grazing (during summer/fall) while avoiding wetted winter period. This project evolved from a groundwater recharge only project in the Lacamas Basin which is described in Appendix D Managed Aquifer Recharge (Coho 2024c). The original MAR concept was to infiltrate stormwater from developments located on both the east and west sides of the wetland. However, it was discovered that stormwater infiltration facilities already exist in the developments and fewer suitable MAR locations are available elsewhere in the basin. The proposed wetland restoration project will have a groundwater recharge benefit.

5.5 Potential Streamflow Benefits of Actions

An estimate of streamflow benefits from projects proposed in this plan is provided in this section. The projects entail restoration of stream channels, wetlands, floodplains, installing BDAs or post-assisted log structures (PALs), managing invasive species, thinning forested areas and restoring prairie, and recharging stormwater, streamflow, or recycled water through small- to large-scale MAR-type projects.

Anchor QEA relied on existing literature to estimate the potential streamflow benefits with implementation of restoration projects. Potential benefits to thinning forested areas are based on differences in evapotranspiration (ET) described in the Coho memo in Appendix C. Potential benefits from recharge projects are based on geologic assessments, hydrologic calculations, and existing engineering studies. The potential benefits from each are expressed in terms of volume of water recharged to shallow groundwater and deeper aquifers.

5.5.1 *In-Channel Restoration Streamflow Benefits*

Stream restoration projects may contribute to sustaining flows over longer duration in the later spring and early summer by roughening the channel, slowing down flows during the wet season, retaining sediments which can reduce flow loss through the channel bed, and allowing for infiltration over larger areas adjacent to the mainstream channel. These types of projects may re-engage historical migration zones and hyporheic zones of streams and recreate the natural meandering of streams and mosaic of wetlands, such as stage-0-type projects, which seek to restore initial, pre-disturbance stream conditions (Cluer and Thorne 2014).

5.5.2 *Streamflow Benefits from Beaver Dam Analogs and Beaver Reintroduction*

Addition of structures that mimic beaver dams (BDAs or PALs) along with beaver reintroduction is commonly implemented where restoration efforts seek to reintroduce sinuosity to channels and re-engage adjacent riparian and floodplain areas. The benefits of beaver dams include greater surface water storage, on the order of 200% greater inundation area compared to reaches without beaver activity (Bouwes et al. 2016) and 21% more seasonal flood water stored through the summer (Westbrook et al. 2006). In the Snohomish River Basin, a group of five successful beaver relocation sites stored 22 times as much surface water as control sites without beaver (Dittbrenner et al. 2022). In ponds that are approximately 1 acre-foot in size, subsurface storage typically exceeds volumes observed on the surface by 2 to 3 times (Dittbrenner et al. 2022). Water volumes are not only increased in the area of beaver activity, but also are typically augmented in downstream reaches with an associated delay in attenuation of summer flows occurring due to augmented recharge of aquifers (Pollock et al. 2003; Westbrook et al. 2006).

Assuming each pond complex can provide 1 foot of storage across 1 acre and multiplying by 3 to conservatively account for associated subsurface storage yields a conceptual estimate of 3 acre-feet of storage with each new pond complex. Construction of 10 new pond complexes in a single stream mile (the low end of estimated natural background wood accumulation) could, therefore, result in new storage on the order of 30 acre-feet per mile of stream treated.

The length of stream proposed to be restored along with the potential increase in storage is provided in Table 10.

**Table 10
Potential Increase in Storage from In-Channel Restoration**

Reach	Length (miles)	Potential Benefit (acre-feet)
Reach 4	4	120
Reach 5	1.8	54
Johnson Creek	0.5	15
Lacamas Creek	2.2	66
Totals	8.5	255

The estimated total storage is 255 acre-feet. The contribution of that stored water to improving stream flows depends on many site-specific factors spread across the area restored. Assuming the storage is depleted in a 1- to 2-month period and the stored water enters streams, the potential stream flow increase is in the range of 2 to 4 cfs. Additional, but undefined at this time, stream flow increase would occur from fine sediment sealing the bed of the stream channel.

5.5.3 *Streamflow Benefits from Hydrologic Reconnection of Floodplain Wetlands*

Hydrologic reconnection of floodplain wetlands re-establishes surface and groundwater across areas that historically have been diked, drained, and hydrologically disconnected from streams through stream channel entrenchment. Projects proposed in this plan include reconnecting streams and floodplain wetlands by increasing water levels in streams to allow more overflow into floodplains and removal of hydromodifications like levees, which may have been created when natural stream channels were excavated and straightened.

The projects that will improve hydrologic reconnection to floodplain wetlands are the Johnson Creek and Lacamas Creek projects. The Reach 4 and Reach 5 projects will also improve connection to floodplain wetlands but those reaches have a narrow corridor with less extensive floodplain wetland area than at the Johnson Creek and Lacamas Creek projects. The accounting of water storage

benefits from implementation of BDAs in Reach 4 and Reach 5 would likely cover the water storage benefits.

An estimate of the area of floodplain wetlands that could be inundated more frequently with the restoration projects was made and is provided in Table 11. For this report it is assumed the potential increase in surface water depth in floodplain wetlands averages 1 foot, providing a storage capacity of 1 acre-foot per acre of wetland. The wetland in the Lacamas Creek reach south of 288th Street South is over 500 acres. The Lacamas Creek Stage 0 alternative would restore most of the wetland and increase inundation, but the less intensive alternative would inundate wetland area closer to the stream channel. The accounting of water storage benefits from implementation of BDAs would likely cover the water storage benefit for the less intensive alternative. More detailed site information would be required to better define the potential increase in water depth from more frequent overflow from streams. The additional storage provided in those wetlands is provided in Table 11.

**Table 11
Potential Water Storage Volumes with Reconnection of Floodplain Wetlands**

Project	Inundated Wetland Area (acres)	Increased Water Depth (feet)	Storage Capacity (acre-feet)
Johnson Creek	20	1	20
Lacamas Creek Stage 0	500	1	500
Totals	520	1	520

Another function provided by floodplain wetlands is infiltration of water across larger areas and longer groundwater residence times than if the same volume of water were passing through a linear stream channel. The resulting discharge back to connected stream channels also occurs over longer durations, supporting stream flow over a longer duration. The storage capacity, infiltration, and discharge rates of a given floodplain wetland depend on local features such as gradient, porosity of the substrate, inflow volumes, bed elevation relative to nearby stream channels, and riparian vegetation composition.

The estimated total storage is 520 acre-feet. Assuming the storage is depleted as streamflow in a 1- to 2-month period, the potential stream flow increase is in the range of 4.4 to 8.8 cfs.

5.5.4 Streamflow Benefits from Vegetation Management

The projects propose to manage invasive species, primarily reed canarygrass in and adjacent to stream channels and lakes, and to thin Douglas fir forest areas that have encroached on former prairies. Thinning of Douglas fir from former prairie areas will decrease ET and allow more precipitation to infiltrate. For the Reach 4 project, 10 to 20 acres of forest are proposed to be thinned

with the wood to be used in Muck Creek for the restoration actions. Estimates of ET were made by Coho in its technical memo contained in Appendix C. The average annual ET for prairie is estimated to be 13 inches and for evergreen forest (Douglas fir forest) 33 inches. Applying the difference of those ET values to the acreage of forest thinned the difference in ET is 17 to 34 acre-feet. That should be a conservatively low estimate as the ET calculated for Douglas fir forest does not include interception of rainfall by forest canopy.

A programmatic action to remove or thin 5,000 acres of forested area and restore prairie is also recommended. The potential difference in ET and potential increase in groundwater recharge for that action is estimated to be 8,300 acre-feet.

The streamflow benefit from reducing ET is not known and would need to be analyzed using a basin-wide groundwater model. However, the reduction in ET for the programmatic action is significant compared to the estimated stream flow volume measured in Muck Creek at Roy for this study, which was 13,800 acre-feet for the period of October 2022 to November 2023.

Reed canarygrass will be partially managed through concentrated mowing, mulching, and riparian planting of native vegetation along the streambanks. The estimated ET for reed canarygrass is 28 inches (Appendix D; Coho 2024c). The ET for native vegetation will be less, although not specified in the Coho technical memo. For the calculation of reduction in water demand with restoration, a reduction in ET of 6 inches was assumed when converting from reed canarygrass to native vegetation. Table 12 lists the acreage proposed to be managed and the estimated reduction in ET.

**Table 12
Potential Reduction in Evapotranspiration with Invasive Species Management**

Project	Area Proposed for Reed Canarygrass Management (acres)	Difference in ET (acre-feet)
Reach 4	130	65
Reach 5	45	23
Johnson Creek	9.9	5
Lacamas/Muck Lake	6	3
Lacamas Creek	12	6
Totals	203	102

The estimated difference in ET from Douglas fir forest thinning and reed canarygrass management is 119 to 136 acre-feet. The growing season typically lasts from April through September (183 days). The reduction in ET is estimated to reduce streamflow losses by an average of 0.3 to 0.4 cfs during that time period.

That might be a conservatively low estimate of the reduction in ET from reed canarygrass management. Data from the stream gaging program described in Section 3 indicates the daily fluctuations in flow at the Muck Creek below 8th Avenue East gage during July 2023 were about 1 cfs from nighttime to the middle of the day. The fluctuation is due to water demands from vegetation during daytime. Muck Creek upstream from 8th Avenue East has extensive areas of reed canarygrass infestation in the stream channel. Although a restored riparian corridor will also use water, the vegetation within the stream channel will be reduced, and direct impacts to streamflow will be reduced.

5.5.5 *Streamflow Benefits from Other Types of Projects*

Other types of projects discussed during the preparation of this plan but not carried forward into conceptual designs include:

- Restore wetlands, particularly in the Upper Muck Creek and South Creek subbasins that have experienced the largest losses
- Infiltrate stormwater by retrofitting stormwater facilities or constructing new facilities where they do not currently exist
- Consider large-scale MAR, such as use of treated wastewater from the Solo Point WWTP

5.5.5.1 **Wetland Restoration**

Restoration of wetlands in the Upper Muck, South Creek, and Lacamas subbasins could reduce high winter flows and would extend the duration of medium to low flows in Reaches 5 through 10 in Muck and South Creeks and Reaches 12 through 14 in Lacamas Creek. The water balance technical memo in Appendix C provides an estimate of the loss in wetland from the 1800s to 2021. The accounting of wetland area for 2021 conditions does not indicate if mapped wetlands are impacted by land use changes, ditching or draining or a change in vegetation like growth of invasive species. Table 13 provides the wetland area for Upper Muck, South, and Lacamas Creek subbasins from the 1800s to 2021.

Table 13
Wetland Areas for Upper Muck, South and Lacamas Creek Subbasins

Subbasin	1800s Wetland Area (acres)	2021 Wetland Area (acres)	Change from 1800s to 2021 (acres)
Upper Muck	1,015	525	490
South	4,384	1,818	2,566
Lacamas	1,849	956	893
Total	7,248	3,299	3,949

The loss in wetlands since the 1800s is estimated to be 3,949 acres in the Upper Muck, South, and Lacamas Creeks subbasins. The total acreage of wetlands in 2021 is estimated to be 3,299 acres in those subbasins. Restoration of existing wetlands and recovery of historical wetlands could provide a significant amount of water storage. However, not all the current wetland area could be or needs to be restored nor could all historical wetlands be recovered. Assuming recovery and restoration of 10% to 50% of the wetland loss for this project leads to approximately 400 to 2,000 acres of restored wetlands and additional water storage of approximately 1,200 to 6,000 acre-feet, assuming 3 feet of water stored in the wetlands, which is the estimated volume of storage provided by BDAs.

5.5.5.2 Stormwater Infiltration

The water balance technical memo in Appendix C provides estimates of the amount of impervious area for the period of 1968 to 2021. The growth in impervious area for the Upper Muck, South, and Lacamas Creek subbasin is provided in Table 14. Most of the growth in impervious area is in the Upper Muck and South Creeks subbasins, with an estimated 2,505 acres of impervious area added since 1968. The Lacamas subbasin contains a lower intensity of development and the largest developed area located south of 288th Avenue South has individual infiltration galleries for houses.

Table 14
Growth in Impervious Area 1968 to 2021

Subbasin	Impervious Area in 1968 (acres)	Impervious Area in 2021 (acres)	Growth in Impervious Area (acres)
Upper Muck	236	1,744	1,507
South	228	1,226	998
Lacamas	75	233	158
Total	539	3,202	2,664

The impervious area that drains to stormwater control facilities is not known. In addition, there are extensive wetland areas along the upper reaches of Muck Creek and South Creek. South Creek appears to be the most responsive to stormwater runoff, based upon the stream gaging performed for this study. The peak flow measured in WY2023 on South Creek below 8th Avenue East was 56 cfs on April 11, 2023. The corresponding flow on Muck Creek below 8th Avenue East was 17 cfs. The relative amount of runoff was 1.6 cfs per square mile for South Creek and 0.9 cfs per square mile for Muck Creek. A previous measurement on June 14, 2022, before the gages were installed, had similar results with 59.6 cfs in South Creek and 11.4 cfs on Muck Creek. It is likely stormwater runoff from the Upper Muck Creek subbasin infiltrates through glacial outwash deposits in Reaches 5 and 6, reducing flows in the creek. South Creek also has glacial outwash deposits in Reaches 7 and 8 but are not as extensive as along Muck Creek.

Although flows in Reaches 5 and 6 in Muck Creek are greatly attenuated by infiltration through glacial outwash deposits, implementation of a stormwater infiltration program focused on areas with groundwater recharge tributary to Patterson Springs located at the head of Reach 6 could increase the duration of flow in Muck Creek as well as reduce its temperature. Implementation of a stormwater infiltration program in the South Creek basin could also attenuate stormwater runoff extending the duration of flows in the creek. The aquifer recharge memorandum in Appendix D concluded that surficial till layers in the South Creek subbasin are more permeable and favorable for recharge than previously thought. Site-specific investigations of soils to determine their suitability for stormwater infiltration would be required for this program.

The aquifer recharge memorandum also concluded several locations in Lacamas Creek subbasin may be appropriate for enhancement of existing stormwater drainage ditches to encourage stormwater recharge to benefit streamflow and stream temperature during low-flow times.

Infiltration of stormwater could be achieved through Green Stormwater Infrastructure (GSI) retrofits to existing homes and driveways, roadways, parking lots, and other impervious areas that generate stormwater. The techniques include rain gardens, planter boxes, bio-infiltration swales, permeable pavement and reducing the footprint of roadways or parking lots and replacing with GSI (also described as depaving and green streets).

Pierce Conservation District (PCD) has a program to assist landowners in constructing rain gardens in priority basins. Currently, the Muck Creek basin is not a priority area for PCD, and PCD would need to change its policy to include the Muck Creek basin in its program. PCD has indicated a willingness to expand its program (<https://pierced.org/540/Green-Stormwater>). The *WRIA 10 Watershed Restoration and Enhancement Plan* (Ecology 2021) provides an example of the potential recharge that can be accomplished through GSI. For every 2,000 square feet of impervious area converted to GSI (the average amount of impervious area for a residence), an average annual infiltration volume of 0.15 acre-foot can be accomplished.

A reasonable level of GSI implementation through PCD, provided funding and staff are available, would be 50 residences per year, resulting in 7.5 acre-feet of increased recharge. Although a small amount, over 20 years it could result in 150 acre-feet of increased recharge in the Upper Muck Creek basin. Larger projects such as bio-infiltration swales and green streets would need to be implemented through Pierce County Public Works.

5.5.5.3 Recycled Water Importation and Recharge

The JBLM Solo Point WWTP produces about 3.7 million gallons (11.4 acre-feet) per day of treated effluent. Over one year, that equals about 4,000 acre-feet of water which could be recharged on JBLM. Recharge on JBLM would likely benefit water levels in the lakes-and-wetlands chain on JBLM and increase water levels in the aquifer that discharges to Reach 1 of Muck Creek. Flow in Muck

Creek from Chambers Lake downstream to its confluence with the Nisqually River would likely increase. The potential amount of flow increase and duration was not estimated for this plan as it would entail knowing where recharge would occur and preparing a groundwater model to analyze the effect on groundwater flow. It is worth noting the contribution of recharge may be less than 10% of the total groundwater recharge in the basin, based upon the water balance technical memo (Appendix C; Coho 2024b).

5.5.6 Summary of Potential Streamflow Benefits

Table 15 provides a summary of the potential increase in water storage, recharge, and streamflow from the projects described in this plan. These estimated volumes and rates are preliminary in nature as additional information and an extensive streamflow and groundwater monitoring program would be needed to verify the quantities.

Table 15
Summary of Potential Streamflow Benefits

Project	Description	Water Storage or Recharge Benefit	Streamflow Benefit
Stream channel Restoration	Restore 8.5 miles of Muck, South and Lacamas Creeks	255 acre-feet	2-4 cfs over 30-to-60-day period
Reconnection of Floodplain Wetlands	Reconnect 520 acres of wetlands to floodplain	520 acre-feet	4.4-8.8 cfs over 30-to-60-day period
Invasive Species Management	Treat 203 acres of Reed Canarygrass and remove 10-20 acres of Douglas Fir Forest	119-136 acre-feet	0.3-0.4 cfs over growing season
Wetland Restoration	Restore 400 to 2,000 acres of wetlands in Upper Muck Creek, South Creek and Lacamas Creek Subbasins	1,200 to 6,000 acre-feet	Not calculated
Stormwater Infiltration	GSI in Upper Muck Creek and South Creek subbasins	Total of 150 acre-feet per year in 20 years	Not calculated
Acquire Water Rights	Purchase or lease active irrigation water rights, estimated 260 acres currently irrigated in Lacamas and South Creek subbasins	Up to 400 acre-feet per year	Up to 0.5 cfs
Restore Prairie Habitats	Thin or remove 5,000 acres of Douglas Fir Forest and convert to prairie	8,300 acre-feet per year	Not calculated
Solo Point WWTP	Recharge of Recycled Water on JBLM	4,000 acre-feet per year	Not calculated

The estimated future consumptive uses of water from permit-exempt wells in the Prairie Tributaries to the Nisqually River has been projected to be a maximum of 1,098 acre-feet or 1.516 cfs of streamflow (NWPU 2019). The projects described in this plan can more than offset that quantity and provide greater streamflow and habitat benefits to address existing streamflow concerns.

6 Implementation and Adaptive Management

Implementation of this plan will likely take a 20- to 30-year sustained commitment and funding. Multiple funding sources will need to be leveraged including streamflow restoration grants, Salmon Recovery Funding, Clean Water funding (e.g., for stormwater improvements), federal funding through JBLM's habitat programs, fish passage funding, and national coastal resilience funding, and other sources. Projects can be implemented based on priority as well as strategic opportunities that arise.

Because invasive species management is such a large component of any work occurring in the watershed, it will be important to fund and implement long-term management (5 to 10 years) at most sites to ensure projects are successful. Monitoring of the success of each project will also be an important component to adaptively manage the types of actions undertaken and continue to fund long-term management as needed.

In addition, there are continuing data gaps that could inform the further development or adaptation of streamflow or habitat restoration measures and the prioritization of reaches, as follows:

1. Identify stormwater ditches and facilities that do not currently infiltrate the majority of their flows, and identify localized or regional infiltration locations for retrofitting or rerouting stormwater facilities. Initially focus on areas that contribute groundwater recharge to springs, such as Patterson Springs in the Upper Muck Creek watershed.
2. Collaborate with WWT to identify the volume of conservation, on-farm measures, or water rights leasing or purchases that could return more flow to the streams.
3. Draw on fish movement and seasonal presence studies to provide quantitative data to determine which reaches are being used by salmonids in different seasons and which areas are preferred by salmonids. This would improve understanding where juvenile salmonids are rearing during each season and whether they are moving above seasonally dry areas during periods of flow and help refine the highest priorities for restoration.
4. Identify upgradient parcels of most importance to protect spring flow inputs to the creeks for protection opportunities.
5. Explore the feasibility and cost of bringing Tat Solo treated wastewater and possible locations for MAR.

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Appendix A

Revised Muck Creek Literature Review and Strategy Framework

Memorandum

August 1, 2022

To: Justin Hall, Nisqually River Foundation; Brian Combs, South Puget Sound Salmon Enhancement Group

From: Merri Martz, Alyssa DeMott, Bob Montgomery, Anchor QEA, LLC

cc: Chris Pitre, Sherry Wilhelm, Coho Water Resources

Re: Task 1: Revised Muck Creek Literature Review and Strategy Framework

1 Introduction

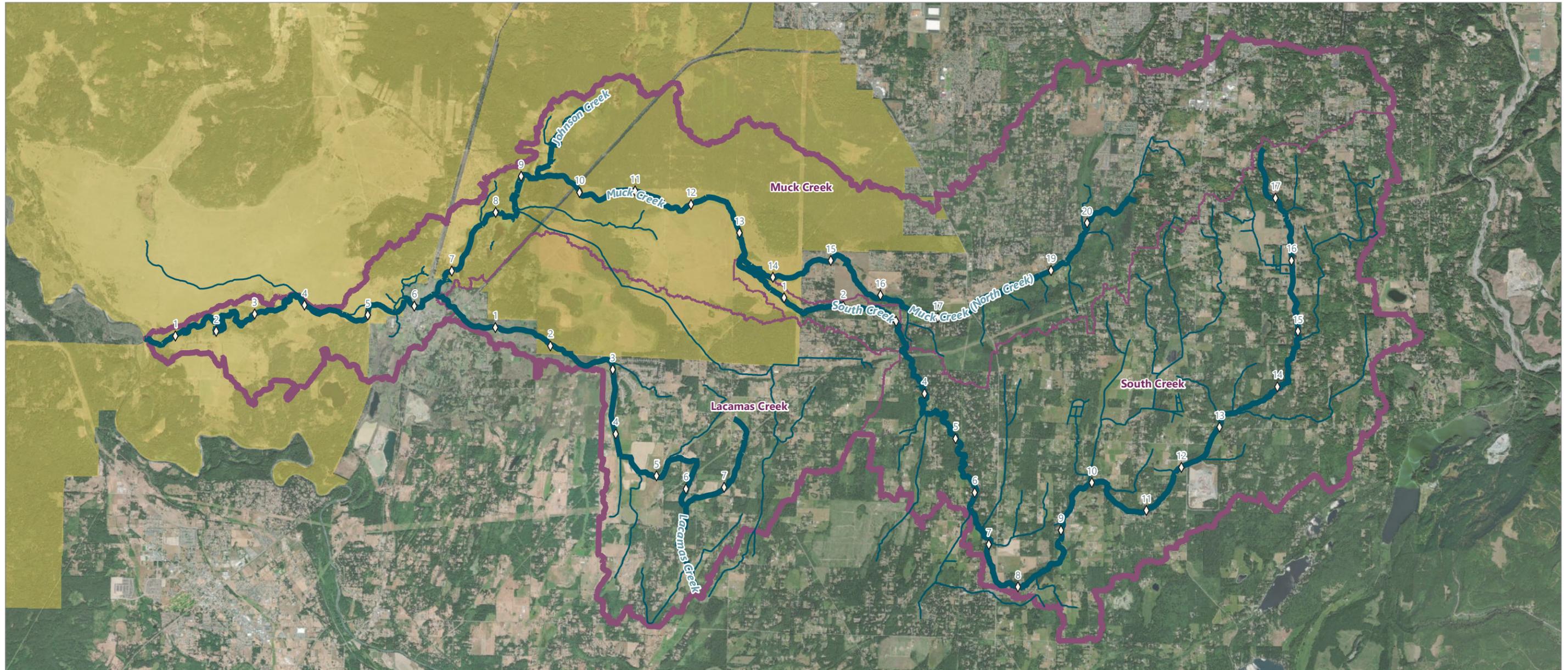
The Nisqually River Foundation and South Puget Sound Salmon Enhancement Group (SPSSEG) are leading the Muck Creek Watershed Restoration Strategy and Project Prioritization study in collaboration with multiple partners, including the Nisqually Indian Tribe, Nisqually Land Trust, Joint Base Lewis-McChord (JBLM), Pierce County, Washington Department of Ecology (Ecology), and Washington Department of Fish and Wildlife. The purpose of this study is to develop a comprehensive watershed restoration strategy that addresses streamflow and aquatic species habitats. The issues of land use, flooding, and water rights are integrally linked to both streamflow and habitats and will be included as appropriate.

This memorandum summarizes the key information produced by numerous previous studies to set the context for historical and current watershed conditions and the key needs and opportunities for watershed restoration, and provides a strategy framework for high priority reaches, data gaps, and the types of projects that will be further developed under future tasks. Attached to the memorandum are an annotated bibliography (Attachment A), a timeline of key events for the watershed (Attachment B), and a list of geospatial data layers available for the basin (Attachment C).

2 Watershed Description

A. General

The Muck Creek watershed is an approximately 92.0 square mile basin located in southwestern Pierce County and is the largest tributary basin within the lower Nisqually River watershed (Coho Water Resources 2021; May 2002; Pierce County 2005). The topography is primarily flat or low rolling hillslope ranging from approximately 140 to 960 feet in elevation (Pierce County 2005). Four primary streams drain the Muck Creek watershed: Muck Creek, South Creek, Lacamas Creek, and Johnson Creek. The watershed is divided into four main subbasins: Muck Creek upstream of the South Creek Confluence, Muck Creek downstream of the South Creek Confluence, South Creek Subbasin, and Lacamas Creek Subbasin. The South Creek and Lacamas Creek subbasins drain the upland portions of the watershed, while the Muck Creek subbasins primarily drain the lowlands (Figure 1).

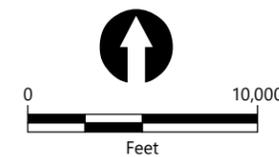


LEGEND:

-  Unnamed Stream
-  Johnson Creek; Lacamas Creek; Muck Creek; Muck Creek (North Creek); South Creek
-  Muck Creek Watershed Subbasin
-  Joint Base Lewis-McChord

NOTES:

1. Online basemap acquired from Esri (2021).
2. Stream miles acquired from Coho Water Resources and are based on WDF (Washington Department of Fisheries), 1975. A Catalog of Washington Streams and Salmon Utilization, WRIA 11. Accessed on: March, 2022.
3. Stream flow line acquired from U.S. Geological Survey National Hydrography Dataset (NHD). Accessed on: March, 2022.
4. Joint Base Lewis-McChord boundary acquired from Pierce County GIS. Accessed on: March, 2022.
5. Watershed basins acquired from Pierce County GIS (2017).

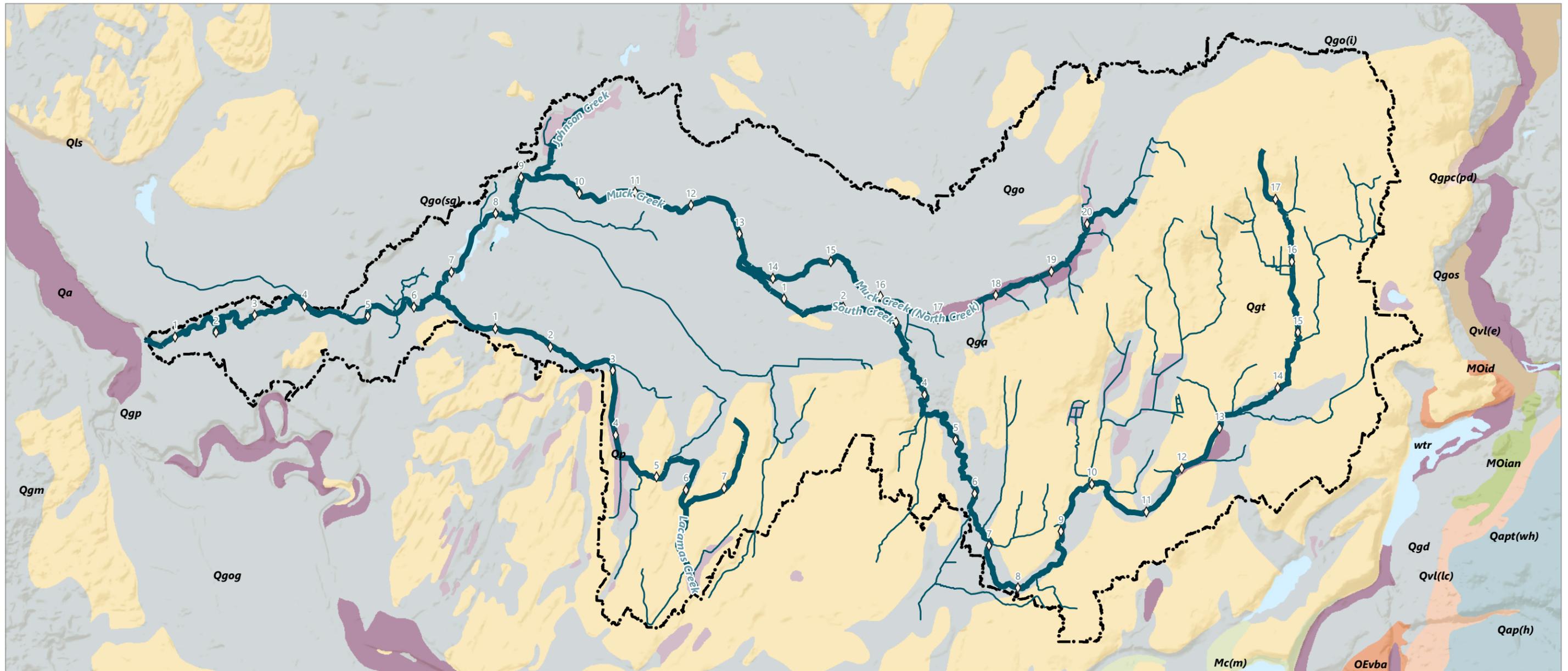


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Forested land (evergreen, deciduous, and mixed forest) comprises approximately 38% of the Muck Creek watershed, while grasslands, herbaceous, pasture, and hay cover makes up approximately 28%. Developed areas make up the remainder, over 30% of the watershed, with a mix of rural residential, commercial town centers, roadways and developed open spaces (Coho Water Resources 2021; Dewitz 2019;). In total, over 60% of the watershed is covered by native vegetation, while less than 20% of the watershed is covered by impervious surfaces (May 2002); although impervious surfaces are continuing to increase as development is also increasing. Land use within the watershed is dedicated primarily to residential (40%) and military use (25%) (May 2002). JBLM is a large military base with a portion located within the Muck Creek watershed that is primarily used for military training and exercises and comprises a large portion of the Muck Creek watershed but is not highly developed. The portion of the watershed within the military base includes upland prairies, upland forest, riparian forest, springs, wetlands, and in-channel habitats, as well as several stream crossings and roads. The remaining watershed area is dominated by agricultural or undeveloped land and open space.

B. Geology

The geology within the Muck Creek watershed is heavily influenced by the region's glacial history; there are two major geologic unit types within the basin: lowland glacial outwash deposits and upland glacial till deposits (WDNR 2016). Muck Creek flows almost entirely through low-lying Pleistocene glacial outwash gravels, specifically the Steilacoom Gravel unit. This unit comprises most of the northwest portion of the watershed and is characterized by stratified pebble, cobble, and boulder deposits. The upstream reaches of Muck Creek and the downstream reaches of South Creek also flow through outwash deposits; however, these deposits are composed of primarily stratified sands and gravels and are part of the Vashon drift unit. In the upper portion of South Creek, the geology transitions to upland glacial till, which is composed of unsorted, unstratified compact clays, silts, sands, gravels, and boulders. This till covers much of the southern and eastern portions of the watershed. Lacamas Creek also flows through this till unit in the uplands, but as the creek approaches its confluence with Muck Creek in the lowlands, the surficial sediment transitions to outwash sediment (WDNR 2016) (Figure 2).

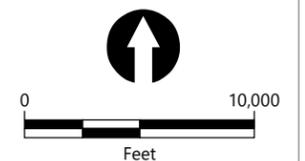


LEGEND:

- | | | | |
|--|--|---|---|
| Muck Creek Basin | Pleistocene alpine glacial drift | Quaternary alluvium | Tertiary sedimentary rocks and deposits |
| Pleistocene continental glacial drift | Quaternary bog, marsh, swamp, or lake deposits | Quaternary fragmental volcanic rocks and deposits (includes lahars) | Tertiary volcanic rocks |
| Pleistocene continental glacial till | Quaternary mass-wasting deposits | Water | |
| Pleistocene fragmental volcanic rocks and deposits (includes lahars) | Tertiary intrusive rocks | | |
| Pleistocene glacial and nonglacial deposits | | | |

NOTES:

1. Hillshade basemap acquired from Esri online basemap services (2022).
2. Stream miles acquired from Coho Water Resources. Accessed on: March, 2022.
3. Stream flow line acquired from U.S. Geological Survey National Hydrography Dataset (NHD). Accessed on: March, 2022.
4. Geologic units acquired from Washington Department of Natural Resources (1:100,000) (2016).
5. Watershed basins acquired from Pierce County GIS (2017).



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Ecology (Sinclair 2001) characterized the hydrogeology of the Muck Creek watershed and noted nine distinct hydrogeologic units: four confining units and five aquifer units. Because this memorandum focuses on streamflow and habitat conditions, only three of the primary hydrogeologic units in the watershed will be discussed. At the land surface, two main hydrogeologic units make up most of the watershed: Quarternary (Vashon) Recessional Outwash (Qvr) and Quaternary (Vashon) Till (Qvt). Qvr is the most expansive unit, covering most of the northwest portion of the watershed, including the Muck Creek drainage and areas along both the Lacamas Creek drainage and South Creek drainage. This surficial unit is composed of the Steilacoom Gravels and is considered a productive aquifer in much of the watershed due to its high permeability (Sinclair 2001). Due to the high permeability in this unit, some locations where Qvr is exposed at the land surface are unable to maintain drainage networks because water infiltrates and moves through the unit so quickly (Coho Water Resources, 2021).

The Vashon till underlays the glacial outwash but is also exposed at the land surface throughout much of the watershed, particularly within the southern and eastern uplands where South Creek and Lacamas Creek originate (Coho Water Resources 2021; Sinclair 2001). This unit has an average thickness of 60 feet and is composed of compacted, poorly sorted till. The compact and poorly sorted nature of this unit, combined with the presence of clay and silt, give this unit a low permeability and hydraulic conductivity, making Qvt a confining unit.

Below the land surface, underlying the confining Qvt unit, is Quaternary (Vashon) Advance Outwash (Qva) (Coho Water Resources 2021). This unit is composed of sands and gravels with some lenses of silt and clay throughout. Qva has an average thickness of 15 feet and exists below Qvt across most of the watershed. Though this unit is confined by the low permeability Qvt unit above it, Qva itself is an aquifer. In areas where Qvt is present at the land surface, excavation through this unit has the potential to expose the underlying Qva aquifer, depending on the thickness of Qvt.

The underlying geology influences both the groundwater and streamflow conditions in the Muck Creek watershed. Muck Creek currently and historically has had seasonally dry reaches. Streamflow is discussed in more detail in Section 2.E.

C. Historical Conditions

Historical land use records for portions of the Muck Creek watershed date back to the mid-1800s when EuroAmerican settlement began. Prior to EuroAmerican settlement, South Puget Sound prairies were maintained by fire used by Native Americans to reduce tree cover and promote useful plants such as camas (Minsch 2002). Early settlement records reveal significant use of Muck Creek and the surrounding areas by the Hudson Bay Company, which established Muck Station within the watershed (Easterly et al. 2005). Historical maps from this time period show buildings and corrals, as well as farms, areas deemed as "good soil," gravel prairies, and oak and pine woods (Easterly et al. 2005). General Land Office survey maps from the 1850s to 1870s show significant portions of Muck Creek and Lacamas Creek with significant wetlands (Figure 3). Many of these wetlands may have

been associated with beaver dams and ponds, with pools and ponds representing 40% to 50% of the stream area (NRST 2014).

In the early 1900s, before a sizable portion of the Muck Creek watershed was established as a military base, wetlands and forest areas were altered by EuroAmerican settlers of the region; these alterations consisted of draining, ditching, or filling wetlands, as well as converting forests to agricultural land (May 2002). Since the northwestern portion of the subbasin became used for military purposes, the vegetation has continued to change from the historical prairies to many areas that are now forested.

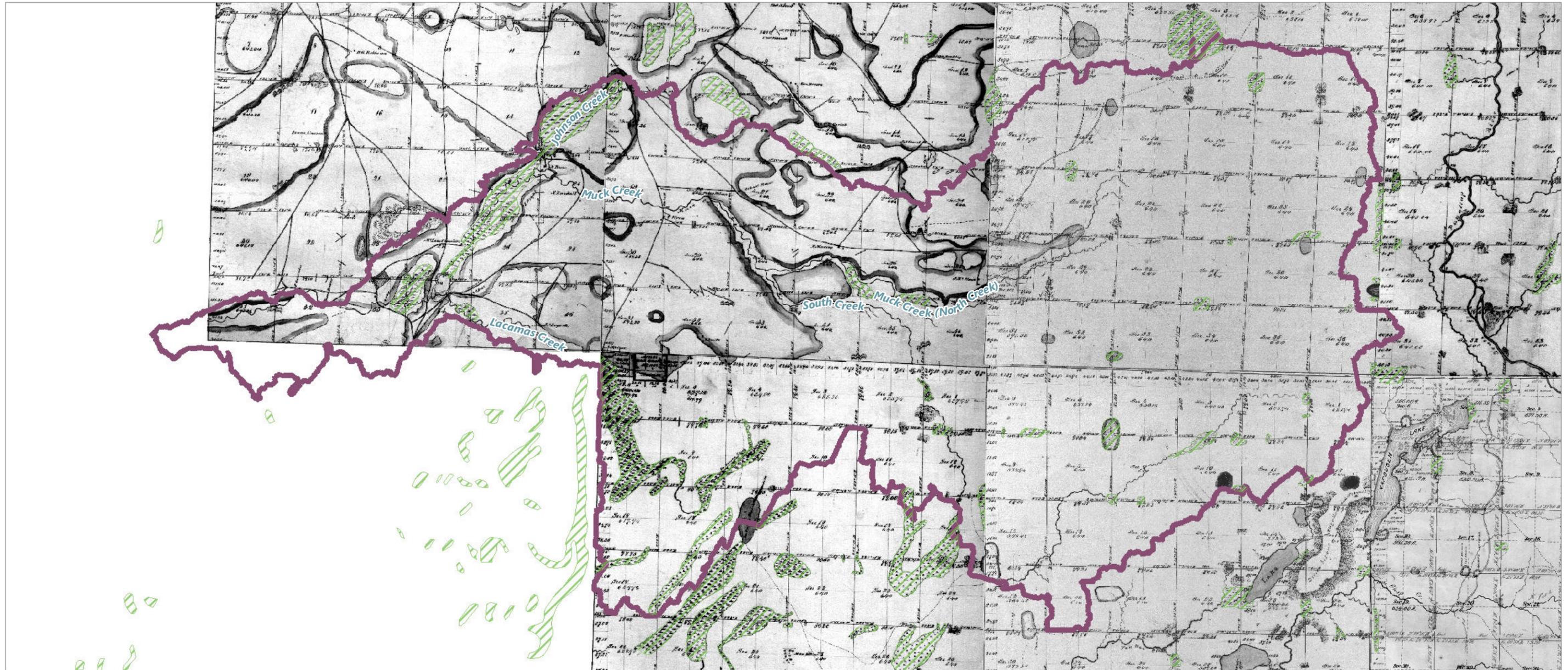
Channelization has occurred in numerous reaches of the streams, including much of Muck Creek upstream of the South Creek Confluence (Pierce County 2005), Muck Creek west of Roy (May 2002), and in the middle reaches of Lacamas Creek (Coho Water Resources 2021). Many miles of stormwater ditches are also present throughout the subbasin. Two dams were also installed in the middle portion of the watershed in the 1960s and 1970s: Chambers Lake Dam and Johnson Lake Dam (Coho Water Resources 2021). Chambers Lake Dam was removed in 2021 by JBLM.

Historical data and observations suggest that precipitation patterns and hydrogeologic conditions (high permeability surficial units), as well as human alterations to the landscape, resulted in intermittent low flows that have been historically observed in the Muck Creek watershed.

D. Aquatic Species and Habitats

At least four salmonid species are known to be present in Muck Creek, including winter chum salmon, coho salmon, winter steelhead, and both resident and sea-run cutthroat trout (Zimmerman 1995; Kerwin 1999; WDFW 2022). Fall chinook salmon were noted to have been present in Muck Creek in the 1960s (WDF 1975). 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) (native species are noted as captured during sampling and not specified if present within Muck Creek or Nisqually River). Non-native species are also present, including largemouth bass, sunfish, and yellow perch (Zimmerman 1995).

Muck Creek supports approximately 25% of the winter chum population in the Nisqually River watershed (May 2002), with spawning predominantly occurring in the lower half of Muck Creek and in Lacamas Creek (WDFW 2022). Nisqually winter chum salmon adults typically enter the watershed from November through February and spawn from January through February (Kerwin 1999). Chum fry emerge from the redds in March and April and migrate to the estuary (Table 1). As chum migrate to rear in the estuary, high-quality spawning habitat and access to spawning habitat are critical elements necessary to support chum. The glacially derived sediments in the basin provide excellent gravel and cobble sources for spawning habitats.

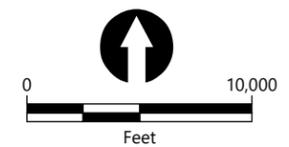


LEGEND:

-  Muck Creek Basin
-  Approximate Historic Wetland Location

NOTES:

1. Historic General Land Office (GLO) maps acquired from Bureau of Land Management (BLM). Accessed on: May 5, 2022.
2. Watershed basin acquired from Pierce County GIS (2017).
3. Approximate historic wetland areas are digitized from georeferenced GLO maps.



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Nisqually coho salmon adults typically enter the watershed from September to early December and spawn from November to early February (Kerwin 1999). Juveniles typically rear for 1 year in freshwater and migrate to the estuary and ocean in spring, with a peak in May. If suitable rearing habitat is not available in tributaries such as Muck Creek, they migrate to suitable habitat in the mainstem Nisqually or other tributaries. 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 for coho salmon during both summer and winter (Pollock et al. 2004).

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) 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 steelhead.

Both resident and anadromous cutthroat trout are present in Muck Creek, with resident fish predominant in the upper half of the system and anadromous fish predominant in the lower half of the system and the former Chambers Lake (Zimmerman 1995). The Chambers Lake Dam and flow conditions were hypothesized to provide separation between the upper and lower watershed. 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.

Table 1
Muck Creek Salmonid Presence

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

Notes:

Dark blue: adult presence

Light blue: juvenile presence

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.

Aquatic and riparian habitats in Muck Creek have been assessed by May (2002) and Pierce County (2005), and NSRT (2014) modeled habitat conditions using the Ecosystem Diagnosis and Treatment (EDT) model based on existing survey data and expert input. The SPSSEG is currently conducting

habitat surveys to update and supplement the older surveys. Habitat conditions on JBLM are generally of higher quality, due to a low level of development, compared to areas outside of JBLM.

The lower 3 to 4 miles of Muck Creek are the steepest gradient section in the system (approximately 3.5%), as Muck Creek down cuts through the plateau in a canyon to meet the Nisqually River. This is the primary area of salmonid spawning, although low flows can prevent fish from entering the creek altogether if the stream has not watered up by early January. Streambed materials are primarily cobble and gravel, with steep banks in many locations and few pools, Riparian conditions are high quality with mature evergreen and deciduous forest and some mature shrub patches. Large wood is in low to moderate quantities, but future recruitment potential from the mature riparian zone is good (May 2002).

As Muck Creek rises out of the canyon and enters the plateau, it enters a low gradient (approximately 0.8%) prairie reach for approximately 3 miles to the confluence of Lacamas Creek and Roy, Washington. This reach was historically prairie but now has a long stretch of mature evergreen and deciduous forest, which then transitions into younger deciduous riparian forest. Wetlands are prevalent in this reach; many dominated by reed canary grass. Streambed materials include stretches of gravel as well as silt-dominated sections (May 2002).

Above Roy, Washington, is the chain of lakes reach that extends for approximately 3 miles to Johnson Creek. Muck Lake and Chambers Lake are present in this section. Riparian habitats are generally young deciduous forest and shrubs, as well as reed canary grass. Few pools are present, although some are of high quality; large wood is sparse (May 2002).

Upstream of Johnson Creek, Muck Creek flows through the glacial outwash prairie area to its confluence with South Creek, a distance of about 4 miles. This reach is the most frequently dry reach in summer/fall and lack of flow here blocks potential fish access to the upper half of the subbasin. The bed is generally coarse, gravel and cobble. Riparian habitats are mixed deciduous and coniferous and generally older forest. Few pools are present; large wood is sparse, but recruitment potential is good with older trees (May 2002).

Muck Creek above the confluence with South Creek continues for approximately 0.7 mile within JBLM and then extends for approximately 6 miles through residential and agricultural areas in Pierce County. The reaches upstream of South Creek typically have perennial flow that may be sustained by spring flow from the uplands to the south, and springs in the upper reaches of Muck Creek, as well as a confining layer that reduces losses into the glacial outwash. Riparian conditions vary from limited riparian to younger deciduous forest, with armoring present in some areas. Substrate is mixed sand, gravel, and cobble, with limited wood present; a few beaver dams are present (Pierce County 2005).

South Creek above its confluence with Muck Creek extends for approximately 3.5 miles through the glacial outwash prairie, then extends for approximately 4 miles up onto an outwash terrace. Several

segments go dry through this reach. Riparian conditions include mixed older deciduous forest and stretches through agricultural land with reed canary grass or no riparian vegetation and steep banks and cattle access; proceeding upstream is primarily younger deciduous (alder and willows); some armoring is present. Substrate is mixed sand and gravel, with limited wood present. There is a low to moderate presence of pools, although they are typically shallow (Pierce County 2005).

Upper South Creek extends for approximately 12 miles through the glacial till uplands. Upper South Creek is primarily dry in summer/fall. The channel has been straightened in many locations. Riparian conditions include shrub wetlands, mixed deciduous forest, and occasional cedars. Substrate is mixed sand, gravel, and cobble with fines, with limited wood presence. There is a moderate presence of pools, although they are typically shallow, and the pools are typically deeper farther upstream (Pierce County 2005).

Lacamas Creek extends from its confluence with Muck Creek upstream for approximately 3.5 miles through the glacial outwash prairie. Riparian conditions include younger deciduous forest and shrubs, with some areas of little to no riparian vegetation and cattle access. Invasive species such as reed canary grass and blackberries are prominent. Substrate is mixed sand, gravel, and cobbles, with limited wood presence (Pierce County 2005). Flow was historically perennial in the lower reach, but in recent years has experienced dry periods. Proceeding upstream for the next 3 miles, Lacamas Creek enters a mixed zone of glacial outwash and glacial till, and flow is perennial in this reach and upper reaches. Riparian conditions include younger deciduous tree species and shrubs, with continued areas of limited riparian vegetation and cattle access. Substrate is mixed fines, sand, and gravel, with some beaver dams and wetland areas with significant reed canary grass expanses. Lacamas Creek continues upstream for approximately 4 miles in the glacial till uplands. In upstream areas, mussel beds were noted (Pierce County 2005) along with older riparian vegetation, moderately large wood, and pools.

Johnson Creek extends only for approximately 1.7 miles from its confluence with Muck Creek, entirely on JBLM in the glacial outwash prairie. Riparian conditions include both mature forest with closed canopy and more open areas with limited tree cover. Substrate is generally gravel with few pools and low to moderate levels of large wood, with good recruitment potential (May 2002).

E. Streamflow Conditions

Muck Creek

Muck Creek discharge data was recorded by the U.S. Geological Survey at a gage near Roy, Washington, in 1949 and from 1956 to 1971, respectively (Sinclair 2001). Gage records at Roy reveal intermittent stream flow during the 1956 to 1971 period, with relatively consistent flow presence from January to June, and absence of streamflow at some points during the remainder of the year; discharge generally follows the precipitation record with a 1- to 2-month lag in timing (Coho Water Resources 2021; Sinclair 2001). More recent discharge data from Roy and Loveland, Washington

(upstream of the South Creek Confluence), collected from 2000 to 2001 (Sinclair 2001), indicate similar seasonal trends in Muck Creek; this data revealed greater reductions in flow during the 2000 to 2001 time period, which was attributed to a drought. Overall, these discharge data show that Muck Creek stream flow has historically been controlled by seasonal fluctuations in precipitation, and intermittent flow in the creek has occurred for decades, with the lowest flows (or no flows) typically recorded from July to December (Sinclair 2001). Observations in the Nisqually Basin from the 1960s and 1970s also cite low flows and no flow in Muck Creek due to the local geology being a limiting factor for fish in the basin (WDF 1975).

The field observations and data collected in upper Muck Creek in June and September of 2000 revealed that Muck Creek upstream of its confluence with South Creek had measurable streamflow, even during months where other reaches were typically dry (Sinclair 2001). The presence of streamflow in this upper reach has been attributed to springs and seeps that supply water to the upstream channel, thus allowing the reach to maintain perennial flow (Coho Water Resources 2021; Sinclair 2001).

The middle reach of Muck Creek, which flows across the glacial outwash prairie from its confluence with South Creek to its confluence with Johnson Creek, had multiple dry reaches that were observed in June and September 2000, as well as in February 2001 (Sinclair 2001). In June 2000, almost the entire lower half of this middle reach was dry and, by September, approximately two thirds of the reach was dry; even in February of 2001, one third of the reach upstream of the Johnson Creek confluence was dry (Sinclair 2001). The streamflow patterns observed in this reach make it "the most consistently dry reach of Muck Creek" (Coho Water Resources 2021).

Field observations from Sinclair's (2001) study revealed that the lower reach of Muck Creek, from the Johnson Creek confluence to confluence with the Nisqually River, had streamflow in June 2000 but had several dry reaches by September 2000. In general, the reach between the Johnson Creek confluence and the Lacamas Creek confluence maintained perennial streamflow due to the presence of the chain of lakes and wetlands along this reach; however, most of the reach downstream of the Lacamas Creek confluence was dry in September 2000 (Sinclair 2001). The Nisqually Tribe conducts spawner surveys in lower Muck Creek and, since 1989, the initiation of flow at the mouth of Muck Creek typically begins in December. In 12 of the 32 years, flow did not begin until after January 1 (Nisqually Tribe [unpublished]).

South Creek

Based on field observations and data collection in 1999 and 2000, summer and early fall streamflow conditions in the upstream reach of South Creek were characterized by long dry reaches and disconnected pools of water (Sinclair 2021). In contrast, perennial flow was observed in the channel farther downstream, where groundwater from unit Qvr (Sinclair 2001) or unit Qva (Coho Water Resources 2021) consistently contributes to base flow. In the lower reach of South Creek through the glacial outwash prairie, field observations revealed a significant loss in streamflow and a dry bed just

above the confluence (Sinclair 2001). Overall, perennial streamflow in South Creek is only present in a short reach where the stream flows over an aquifer (unit Qvr or Qva) and receives groundwater input, and most of the creek is dry in the summer and fall (Sinclair 2001)

Lacamas Creek

The field observations and data collection from 1999 and 2000 revealed that Lacamas Creek had perennial streamflow along the entire creek, even during the low flow period from June through September (Sinclair 2001). Though average discharge was low during this period (1.0 cubic foot per second), streamflow was still sustained. Observations in 2008 showed that Lacamas Creek was dry in two locations (at 288th Street and Highway 507; Savoca et al. 2010). Lacamas Creek was also noted to be dry in 1989 near its mouth (Sinclair 2001). Similar to South Creek, unit Qvr or Qva likely supply baseflow in this creek (Coho Water Resources 2021).

Johnson Creek

Johnson Creek flows through a wetland and lake complex which remains wet throughout the year; however, it has been noted that despite the perennially wet nature of the complex, some reaches of Johnson Creek itself are dry in the summer (Fort Lewis Directorate of Public Works 2010; Coho Water Resources 2021).

3 Stream Reach Delineation

Stream reaches have been delineated in the past for stream habitat surveys and other purposes (May 2002; NSRT 2014; Pierce County 2005). For this watershed restoration study, the team has delineated reaches based on geologic, geomorphic, streamflow, and habitat considerations. Reaches that comprise a reasonable distance (typically 1.5 to 4 miles in length) will allow strategies and actions to be formulated and implemented that address the two key objectives (streamflow restoration and habitat restoration) in high priority reaches with consideration of landownership patterns. Table 2 shows the stream reach delineation and crosswalk with previously delineated reaches and rationale for delineation. Figure 4 shows the stream reaches.

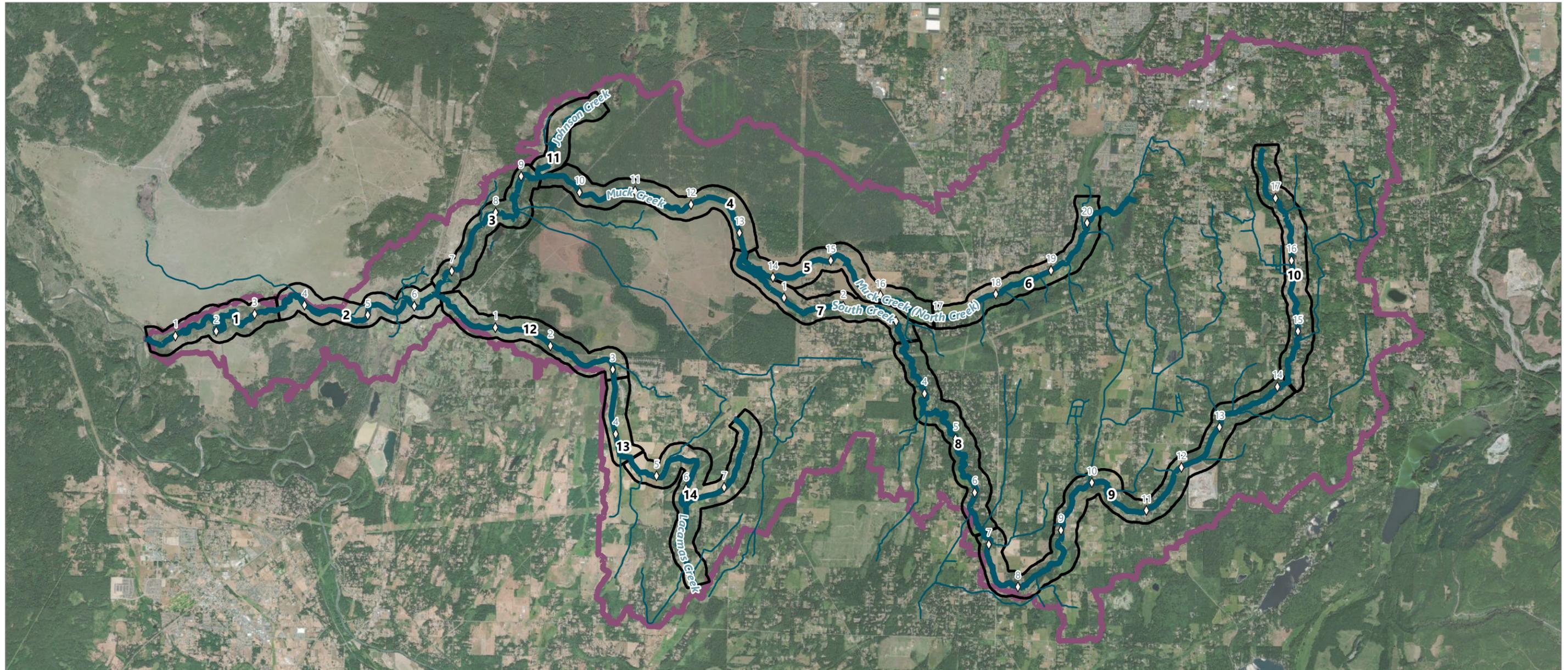
Table 2. Muck Creek Watershed Proposed Stream Reaches and Crosswalk with Prior Reaches

Stream	Reach No.	River Miles ¹	Average Gradient	Geology	Seasonal Streamflow Pattern	Groundwater-Surface Water Connections	Fish Presence/ Use	May (2002) Reaches	Pierce County (2005) Reaches	EDT Reaches (NRST 2014)
Muck Creek	1	0–3.0	3.40%	Glacial drift and outwash	Little or no flow in late summer and fall, adequate flow for chum passage returns in December or January	Exeter Springs flows seasonally, on right bank in middle of reach	Known spawning reach for chum, steelhead, cutthroat	Reaches MCK-1, MCK-2, MCK-3, cobble/gravel bed, mature riparian, few pools, large woody debris (LWD) ranges from poor to good, but good recruitment potential	N/A	Canyon Reaches, Muck 1A-a, 1A-b, and 1B-a
	2	3.0–6.1	0.80%	Glacial drift and outwash	Regular dry periods, especially in Sept. and Oct., documented at Roy, Washington, even in 1960s	In contact with groundwater table (not perched)	Known spawning reach for chum, steelhead, cutthroat	Reaches MCK-3, MCK- 4, MCK-5, MCK-6, MCK-7, lower portion mainly gravel bed, mature riparian, upper portion primarily silt bed, deciduous riparian, beaver ponds and wetlands, LWD ranges from poor to good, with low to good recruitment potential	Reach near Roy, Washington, hardened bank, gravel/ cobble substrate, deciduous and shrub riparian, limited large wood	Upper Canyon Reach, Muck 1B-b and Prairie Reaches, Muck 2A and 2B
	3	6.1–9.0	0.30%	Glacial drift and outwash, features formed in trough 10–25' lower than surrounding plain	Series of lakes and wetlands; water persists in lakes through late summer and fall but connecting channels go dry	Significant perennial springs on left bank of trough; connected to groundwater table for most or all of year	Known presence for chum, steelhead, cutthroat	Includes MCK-8, wetlands dominate, bed is silt, young riparian, few pools but good quality, LWD limited and low recruitment potential	N/A	Lakes Reaches, Muck 3AA, 3AB, 3BA, and 3BB
	4	9.0–13.0	0.80%	Glacial drift and outwash; coarse sediments raising channel at west end	Dry for significant portions of summer and fall, especially at western end	Loses large volumes of streamflow to groundwater; Supplied primarily by surface water from upstream reaches	Known presence of coho, chum, steelhead, cutthroat, depends on water	Mainly gravel bed, mixed older riparian, few pools, LWD quantity is low, but recruitment potential is good	N/A	Upper Reach Muck 4A
	5	13.0–16.6	0.80%	Glacial drift and outwash	Mostly perennial except at western end	May be perched; may receive flow from South Creek via groundwater	Potential limit for chum and steelhead spawning	Encompasses MCK-9, MCK-10, MCK-11, bed is primarily silt, areas of channelization, riparian is narrow and open, prairie dominated, no pools, LWD very low, but may be natural for prairies	Vegetated banks, deciduous/ shrub riparian, no riparian in some areas, gravel/cobble with sand in some areas, limited wood	Upper Reach Muck 4C_a
	6	16.6–20.0	0.60%	Glacial drift and outwash with peat deposits, and alluvium; may be underlain by a shallow till confining layer	Perennial flow according to all observations	May receive significant groundwater contribution from left bank bluff; springs noted along base of bluff in earlier studies; gradients from groundwater to streams at times	Coho historically documented	N/A	Vegetated banks, deciduous/ shrub riparian, no riparian in some areas, gravel/cobble with sand in some areas, limited wood, beaver dams	Upper Reach Muck 4C_b

Stream	Reach No.	River Miles ¹	Average Gradient	Geology	Seasonal Streamflow Pattern	Groundwater-Surface Water Connections	Fish Presence/ Use	May (2002) Reaches	Pierce County (2005) Reaches	EDT Reaches (NRST 2014)
South Creek	7	0–3.5	1.00%	Glacial draft and outwash	Dry for significant portions of summer and fall, most often at western end; often dry when Muck Creek, at same elevation and less than 1 mile to north, is still flowing	Loses flow to groundwater but no signs of perched conditions	Potential coho and cutthroat presence	Not surveyed, outside JBLM	Some hardened banks, deciduous riparian, no riparian in some areas, gravel with sand and fines substrate, limited wood	Upper Reach Muck 4SFA_aa
	8	3.5–7.6	1.20%	Primarily outwash	Most consistently flowing portion of South Creek but has been dry at times	Significant zone of groundwater input mid-reach but also has losing portions; springs noted in roughly same location	Potential coho and cutthroat presence	Not surveyed, outside JBLM	Deciduous riparian, alders, willows, gravel with sand and fines, embedded, limited wood, moderate pool presence	Upper Reach Muck 4SFA_ab and portion of 4SFA_ac
	9	7.6–15.4	1.00%	Glacial till and outwash segments, minor alluvium	Regularly dry in summer and early fall	Few documented observations	Potential cutthroat presence	Not surveyed, outside JBLM	Slough-like, wetlands, shrub vegetation, some stretches of pool and riffle sequences, gravel with sand and fines, limited wood	Upper Reach portions of 4SFA_ac
	10	15.4–19.3	2.80%	Glacial till	Regularly dry in summer and early fall	Few documented observations	Potential cutthroat presence	Not surveyed, outside JBLM	N/A	Upper Reaches Muck 4SFA_ac, 4SFA_b, 4SFB_a, 4SFB_b, 4SFB_c
Johnson Creek	11	0–1.7	0.90%	Glacial drift and outwash with peat deposits			Documented chum spawning, coho presence	Includes JSN-1, primarily gravel bed, mature riparian, few pools, LWD fair but with good recruitment potential	N/A	Johnson Creek and Johnson Marsh
Lacamas Creek	12	0–3.4	1.20%	Glacial drift and outwash	Residents report perennial flow in past but more recently experiences dry periods		Documented chum and coho spawning, potential steelhead and cutthroat presence	Includes JAC-1, primarily gravel bed, deciduous riparian, both mature and young, few pools, LWD low but fair recruitment potential	Vegetated banks, deciduous/shrub riparian, grazed areas limited riparian, gravel/cobble/sand substrate, limited wood	Lacamas Creek_a
	13	3.4–4.7	0.04%	Glacial till, outwash, and peat deposits	Few documented observations		Documented coho spawning, potential chum, steelhead, and cutthroat presence	N/A	Vegetated banks, deciduous/shrub riparian, grazed areas limited riparian, gravel/cobble/sand substrate, limited wood	Lacamas Creek_a
	14	4.7–8.7	1.10%	Primarily glacial till	Few documented observations	Groundwater supplies stream baseflow	Potential cutthroat presence	N/A		Lacamas Creek_a, _b, _c, _d, _e

Note:

1. River miles based on Coho Water Resources (2021).

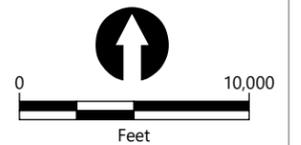


LEGEND:

- ◇ Stream Miles
- ~ Unnamed Stream
- █ Johnson Creek; Lacombs Creek; Muck Creek; Muck Creek (North Creek); South Creek
- █ Muck Creek Basin
- █ Proposed Reaches

NOTES:

1. Online basemap acquired from Esri (2021).
2. Stream miles acquired from Coho Water Resources and are based on WDF (Washington Department of Fisheries), 1975. A Catalog of Washington Streams and Salmon Utilization, WRIA 11. Accessed on: March, 2022.
3. Stream flow line acquired from U.S. Geological Survey National Hydrography Dataset (NHD). Accessed on: March, 2022.
4. Watershed basins acquired from Pierce County GIS (2017).



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4 Watershed Problems and Opportunities

From the evaluation of historic and current conditions within the Muck Creek watershed, the following problems have been identified:

- **Expanding Dry Stream Reaches:** Multiple reaches of Muck Creek, South Creek, and Lacamas Creek go dry annually or occasionally, typically from July to December. While this may have occurred naturally in some reaches within the glacial outwash prairie, the dry reaches appear to be expanding and remaining dry for longer periods. When reaches within lower Muck Creek and lower Lacamas Creek go dry, it can prevent fish entry into either creek.
- **Prevalence of Invasive Vegetation:** The naturally occurring prairie habitats on the glacial outwash deposits that were maintained by Native Americans through regular burning have transitioned to forested or modified habitats (e.g., agricultural, residential). Both native and non-native invasive species are prevalent including reed canary grass, Scot's broom, blackberries, and Douglas fir. Reed canary grass is prevalent both within the stream channels and wetland and riparian areas and may increase evapotranspiration and stream drying as well as reducing fish passage and habitat.
- **Low Diversity and Quality of Stream Habitats:** Many stream reaches within the Muck Creek watershed have limited riparian habitat and cover, low quantities of large wood, few pools, and few beaver dams and ponds. The historical condition would have included many reaches within the glacial outwash prairie that would have had narrow riparian areas dominated by deciduous forest and willows but would have also likely had numerous beaver ponds and associated wetlands.

To address the identified problems, the following opportunities and types of actions shown in Table 3 could be considered.

Table 3. Potential Opportunities and Actions to Address Identified Watershed Problems

Problem	Opportunity	Potential Actions
Expanding Dry Reaches	<ul style="list-style-type: none"> • Reduce evapotranspiration • Promote floodplain infiltration • Recharge groundwater • Reduce loss from streams to groundwater • Return unused (or limited use) water rights to stream flow 	<ul style="list-style-type: none"> • Install Beaver Dam Analogs (BDAs) • Promote beaver use by planting suitable forage species • Promote floodplain connectivity with large wood and connection to wetlands and off-channel habitats • Remove or manage invasive species (see next row) <ul style="list-style-type: none"> - Create/restore wetlands adjacent to channels - Develop sites for managed aquifer recharge (MAR) - Identify if any water rights could be returned to streamflow
Prevalence of Invasive Species	<ul style="list-style-type: none"> • Remove species that are most easily managed (e.g., Scots broom, blackberries) • Control reed canary grass in reaches where fish passage is challenging • Reduce forest encroachment on former prairie habitats 	<ul style="list-style-type: none"> • Cut/spray/dig invasive species in dry reaches and where most affecting riparian habitat quality • Mow/spray/solarize reed canary grass and plant fast-growing native species such as willows to reduce vigor • Grade areas as appropriate to remove reed canary grass root mat and accumulated sediment and vegetate with native species • Thin Douglas fir forest in dry reaches and reuse as large wood in the channel • Conduct controlled burning of understory in prairie reaches
Low Diversity and Quality of Stream Habitats	<ul style="list-style-type: none"> • Increase instream structure • Reconnect wetlands and off-channel areas • Promote beaver ponds • Restore riparian areas 	<ul style="list-style-type: none"> • Install BDAs • Promote beaver use by planting suitable forage species • Install large wood instream • Restore/reconnect adjacent wetlands • Restore/reconnect off-channel and floodplain areas • Revegetate riparian areas with native species

Based on the issues identified for each reach, Table 4 provides a summary of potential actions recommended by reach.

Table 4. Potential Actions by Reach to Address Identified Problems

Stream	Reach	Potential Actions
Muck Creek	1	<ul style="list-style-type: none"> • Anchor key pieces of large wood via helicopter and hand crews to promote natural racking of wood in jams; constraints in this reach are due to artillery use/presence and fish surveying needs • Mow/spray reed canary grass
	2	<ul style="list-style-type: none"> • Remove or manage invasive species, including grading, if appropriate • Revegetate with native riparian species, particularly fast-growing species such as willows • Install BDAs and promote beaver use • Install large wood • Enhance and reconnect wetlands
	3	<ul style="list-style-type: none"> • Restore more natural channel through Chambers Lake and promote floodplain wetland connectivity and storage • Install large wood • Install BDAs and promote beaver use • Revegetate with native riparian and wetland species, particularly fast-growing species such as willows • Remove or manage invasive species, including grading, if appropriate
	4	<ul style="list-style-type: none"> • Install BDAs and promote beaver use • Install large wood; could also include redistribution of accumulated sediment • Revegetate with native riparian and wetland species • Remove or manage invasive species, including grading, if appropriate • Consider fish passage improvements at ford crossings • Identify opportunities for floodplain (high flow) recharge • Identify opportunities for aquifer recharge
	5	<ul style="list-style-type: none"> • Reduce creek channelization where feasible • Install BDAs and promote beaver use • Install large wood • Revegetate with native riparian and wetland species • Remove or manage invasive species • Identify opportunities for groundwater recharge • Identify if any water rights could be returned to stream flow

Stream	Reach	Potential Actions
Muck Creek	6	<ul style="list-style-type: none"> • Install BDAs and promote beaver use • Install large wood • Revegetate with native riparian and wetland species • Remove or manage invasive species • Identify potential enhancement of spring flow inputs • Identify opportunities for groundwater recharge
South Creek	7	<ul style="list-style-type: none"> • Remove armoring and reduce creek channelization where feasible • Install BDAs • Install large wood • Revegetate with native riparian and wetland species • Remove or manage invasive species • Identify potential depths to till • Identify opportunities for groundwater recharge • Identify if any water rights could be returned to stream flow
	8	<ul style="list-style-type: none"> • Enhance wetland connectivity and habitats • Install large wood • 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 MAR or through swales and filtration to wetlands
	9	<ul style="list-style-type: none"> • Restore wetland habitats • Install large wood • Remove or manage invasive species • Revegetate with native riparian and wetland species • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands
	10	<ul style="list-style-type: none"> • Restore wetland habitats • Install large wood • Remove or manage invasive species • Revegetate with native riparian and wetland species • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands
Johnson Creek	11	<ul style="list-style-type: none"> • Investigate opportunities to modify dam on Johnson Creek • Install BDAs and promote beaver use • Install large wood • Remove or manage invasive species, including grading, as appropriate

Stream	Reach	Potential Actions
Lacamas Creek	12	<ul style="list-style-type: none"> • Restore wetland habitats • Install large wood • Install BDAs and promote beaver use • Remove or manage invasive species • Revegetate with native riparian and wetland species • Identify if any water rights could be returned to stream flow
	13	<ul style="list-style-type: none"> • Restore wetland habitats • Install large wood • Install BDAs and promote beaver use • Remove or manage invasive species • Revegetate with native riparian and wetland species • 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
	14	<ul style="list-style-type: none"> • Restore wetland habitats • Install large wood • Install BDAs and promote beaver use • Remove or manage invasive species • Revegetate with native riparian and wetland species • Identify opportunities for groundwater recharge • Identify opportunities to redirect stormwater facilities for MAR or through swales and filtration to wetlands

5 Data Gaps

The following are several key data gaps that could inform the development of streamflow or habitat restoration measures and the prioritization of reaches.

1. Documenting habitat conditions, geology, geomorphology, and spring flow in Reach 1 will help to identify the feasibility of restoration or streamflow actions for this reach. Conducting a reconnaissance walk-through of as much as this reach as can be accessed in low flow conditions is recommended.
2. Understanding the lateral extent and thickness of glacial till in the upland portions of the basin would contribute to the understanding of the potential effectiveness of MAR projects and to prioritize the most effective locations. Compilation of U.S. Geological Survey and Washington Department of Natural Resources geologic mapping and Ecology well log data can be used to estimate thickness and extents.

3. Additional groundwater and surface water monitoring locations and data collection would refine which reaches are dry and provide 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, 5,7. It is recommended to reinstrument the four piezometers that currently exist (near Johnson Creek confluence and above Muck Creek and South Creek Confluence), install stream gages 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. Additionally, cameras could be installed at Muck Creek at 8th Avenue South.
4. Compiling precipitation records and calculating evapotranspiration rates for vegetation that did not naturally occur in the prairie reaches (e.g., reed canary grass, Douglas fir, and Scots broom) will support identifying the best locations for management of invasive species. Managing invasive species in combination with beaver promotion and thinning and burning some prairie segments to reduce tree canopy could reduce evapotranspiration and increase infiltration of precipitation.
5. Refine potential habitat restoration actions by reach based on recent SPSSEG habitat surveys of specific instream and riparian conditions and further identification of landownership opportunities and constraints.
6. Collaborate with Washington Water Trust to identify if any water rights could be returned to stream flow.
7. Fish movement and seasonal presence studies could provide quantitative data to determine which reaches are being used by salmonids in different seasons and which areas are more preferred by salmonids. This would improve understanding where juvenile salmonids are rearing during each season, whether they are moving above seasonally dry areas during periods of flow, and help refine the high priorities for restoration.

6 References

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Attachment A

Annotated Bibliography

Annotated Bibliography of Documents Relevant to Muck Creek Watershed Restoration

See related spreadsheet for simplified, shortened version of this bibliography.
Electronic versions of all reports on hand except those marked with an asterisk (*).

AHBL, 2010. **City of Roy Shoreline Master Program Shoreline Inventory and Characterization.** Prepared for the City of Roy, 50 pp.

Part of fulfilling requirement of RCW 90.58.080 to update Shoreline Master Plan. Compilation of data from other sources. Proposed restoration project for Muck Cr riparian buffer plantings and Muck Lake restoration (note Muck Lake shoreline is on private land). Includes Fig. 4, Stormwater Infrastructure.

AHBL, 2012. **City of Roy Shoreline Master Program – Restoration Plan.** Prepared for the City of Roy, 21 pp.

Summary of objectives of Puget Sound Partnership and Nisqually Watershed Stewardship Plan, repeat of two possible restoration projects.

* Baccus, J.N., 1995. **Roy Area, Pierce County, Washington: an historical overview.** Self-published, 426 pp.

Out of print, available at Seattle Public Library, central branch, in library use only, and at Tacoma Public Library, main branch, available for checkout.

Borden, Richard Knox, and Kathy G. Troost. 2001. **Late Pleistocene Stratigraphy in the South-Central Puget Lowland, Pierce County, Washington.** Olympia, WA: Washington State Department of Natural Resources, 31 pp.

Investigation of stratigraphy of sedimentary sequences encountered in a series of boreholes to east of American Lake on JBLM (and thus to the north of the Muck Creek's lake-and-wetland chain). Radiocarbon dates for some layers. Includes cross-sections showing depth of Vashon outwash. Correlation of layers with sequences in other parts of Puget Sound.

* CH2mHill, 2000. **Muck Creek Basin Study, Phase 1 - Basin Characterization Plan, draft report.** Prepared for Pierce County Public Works and Utilities, Water Programs, June 2000, 34 pp.

Cited for this statement in Sinclair (p. 1; 2001): "Muck Creek and its major tributaries, Lacamas Creek and South Creek, were dredged and channeled at various locations, in the past, to contain flow and alleviate winter flooding problems."

Cole, D.L., R.M. Comstock, and B. Harrington-Tweit, 1986. **The Nisqually Chum Run: A Status Report.** Prepared for the Nisqually Indian Tribe and the US Fish & Wildlife Service, 49 pp.



Initially a post-season evaluation of Nisqually chum run size and escapement. Extended in time to provide base year escapement numbers to correlate with spawning ground counts, carcass deposition on Nisqually mainstem, which were then used to estimate annual escapement in other years.

Crawford, R.C. and H. Hall, 1997. **Changes in the South Puget Sound Prairie Landscape.** In: Ecology and Conservation of the South Puget Sound Prairie Landscape, P. Dunn and K. Ewing, eds. Seattle, WA: Nature Conservancy of Washington, pp. 11-15.

Estimate of areal coverage of native prairie species and general grasslands on soils assumed to have hosted prairie in the past in the South Puget Sound region.

Dittbenner, C., 2018. **Northern Pacific RR Water Tank – Roy – Washington Heritage Register Application.** Submitted to the Washington State Department of Archaeology and Historic Preservation, 19 pp.

Includes historic photos and information on general history of Roy.

Easterly, R.T., D.L. Salstrom, and C.B. Chappell. 2005. **Wet Prairie Swales of the South Puget Sound, Washington.** Prepared for The Nature Conservancy, South Sound Office, Olympia, WA, 32 pp.

Prairie extents from GLO 1853-76 maps (created GIS map), map of vegetation types along 6 miles of Muck Cr and tributaries (also put in GIS map, but no image in report). Note open native vegetation in area between Muck and South Creeks.

Engle, M.A., 1997. **Quaternary Stratigraphy of the Nisqually Watershed and Its Influence on Annual Flow of Muck Creek, Washington.** M.Sc. Thesis, Evergreen State College, 28 pp.

Mostly a review of geologic setting of the entire Nisqually basin. Flow measurements at 12 sites along the Muck Creek stream network in March 1997 and calculation of flow increases and decreases between sites.

ENSR, 2003. **Final Report: Muck Creek Watershed Assessment.** Prepared for U.S. Army Public Works, Fort Lewis, Washington, approx. 30 pp.

Stream components included mapping of streambed substrate (2000), assessing spawning gravels (2000), and spawning surveys (winter 2002). Hydrologic assessment consisted of readings from streambed piezometers and discharge measurements from four dates (Sept. 2000 – Oct. 2002) and consideration of impact of hardened crossings.

Golder Associates, Inc., 2003. **Nisqually Watershed Management Plan.** Prepared for the Nisqually Indian Tribe and WRIA 11 Planning Unit, 165 pp. plus appendices.

Planning document for future management actions. Muck Creek watershed not examined in detail. Management plan was supported by the following studies which we are in the process of obtaining:



- * *Level 1 Technical Assessment (lower basin: Watershed Professionals Network, 2002; Executive summary in Appendix A)*
- * *Final Water Quality Monitoring Report (October 31, 2003; Appendix C)*
- * *Instream Flow Step A Report (only conducted for Mashel River; June 30, 2003)*
- * *Storage Assessment Step A Report (June 30, 2003; Appendix E)*

Griffin, W.C., J.E. Sceva, H.A. Swenson, and M.J. Woodruff, 1962. **Water Resources of the Tacoma Area.** USGS Water Supply Paper 1499-B, 79 pp., 4 plates.

Study area includes northern half of Muck Creek Basin. Includes estimates of Fort Lewis water system and irrigation use in area. Water table contour map. No well log summaries.

Harrington-Tweit, B. and P. Svoboda, 1983. **Estimation of Chum Salmon Escapements in Muck Creek, a Nisqually River Tributary.** Nisqually Indian Tribe Technical Report No. 7, 20 pp.

Reports chum salmon returns and surveys of six spawning areas as far upstream as Johnson Creek.

Hiss, J.M., B. Harrington-Tweit, and R.S. Bonner, 1982. **Downstream migration of juvenile rainbow/steelhead trout in the Nisqually River and Muck Creek, 1980-1981.** Prepared for the US Fish & Wildlife Service and the Nisqually Indian Tribe, March 1982, 60 pp.

Life history of rainbow/steelhead on Muck Cr, smolt emigration on Muck Cr; also steelhead outmigration from Nisqually R.

Johnson, K.H., Savoca, M.E., and Clothier, B., 2011. **Numerical simulation of the groundwater-flow system in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington.** U.S. Geological Survey Scientific Investigations Report 2011–5086, 108 pp.

Presentation of MODFLOW groundwater model that includes Muck Basin. Includes water budget for whole area but not subbasins. Annual recharge and return flow estimates mapped. Simulations aimed at predicting changes in groundwater levels in advanced outwash aquifer, which supplies municipal wells in Tacoma area.

Kerwin, J., 1999. **Salmon and Steelhead Habitat Limiting Factors, Water Resource Inventory Area 11.** Washington State Conservation Commission, 158 pp.

Historic and current salmon distribution in Nisqually Basin. Brief description of Muck Creek (p. 38, pp. 61-62).

* Kunschak, W., 1959. History of Roy, Washington. M.A. Thesis, Pacific Lutheran University, 259 pp.

Available at Tacoma Public Library, main branch, in library use only.

Madel, G. and J.P. Losee, 2016. **2016 Research and Monitoring of Adult *Oncorhynchus mykiss* in the Nisqually River.** Washington Department of Fish and Wildlife, Fish Program FPA 16-06, Sept. 2016, 14 pp.



Covers steelhead in the broader Nisqually basin.

Maris, J.K., 1991. **State of the Environment Report at Fort Lewis and Its Sub-Installations.** Prepared for the Department of the Army, Environmental and Natural Resources Division, Fort Lewis, WA, 96 pp.

Summary of fisheries on JBLM, including cutthroat issues in Muck Cr and Chambers Lake in 1980s. Acres of prescribed burns, 1981-1989.

May, C., 2002. **Measures of Ecological Integrity for Salmonid Streams on Department of Defense facilities in the Pacific Northwest: Current Watershed Conditions and Management Recommendations.** Applied Physics Laboratory, University of Washington Technical Report APL-UW-TR 0104.

Assessments of reaches of Muck Cr. within JBLM woven into explanation of general stream habitat assessment method. Muck-related content was extracted and re-organized by Coho in attachment to Coho (2021).

Meinzer, O.E., L.K. Wenzel, and others, 1946. **Water Levels and Artesian Pressure in Observation Wells in the United States in 1943, Part 5, Northwestern States.** USGS Water Supply Paper 990, 279 pp.

Includes two USGS observation wells to north of Muck basin, in T19NR4E. Also reports water levels from about 3 wells in basin and 8 wells just to north of basin. Water levels from the late 1930s and early 1940s.

Nisqually Indian Tribe, 2020. **2020 State of Our Watersheds Report – Nisqually River Watershed.** Nisqually Indian Tribe, 13 pp.

Includes written and graphical summary of trends in water use, domestic wells, population growth, and impervious surface in Nisqually Basin.

Nisqually Steelhead Recovery Team, 2014. **Nisqually River Steelhead Recovery Plan - Draft.** Prepared for the Nisqually Indian Tribe, Olympia, WA, July 2014, 210 pp.

Thorough summary of data in other reports. Muck Cr Basin is one of eight identified.

Nisqually Watershed Planning Unit, 2019. **Nisqually Watershed Response to the 2018 Streamflow Restoration Act (RCW 90.94): Addendum to the Nisqually Watershed Management Plan.** Olympia, WA, 108 pp. plus appendices.

Response to Hirst decision. Covers Muck Creek Basin as part of Prairie Tributaries sub-basin. Estimates of future water demand from permit-exempt wells. Final appendix (N) is one-page memo about use of BDAs, LWD, and groundwater channels for increasing streamflow and retaining water.

Pearson, H.E. and N.P. Dion, 1979. **Water Resources of the Nisqually Lake Area, Pierce County, Washington.** Tacoma, WA: USGS Water Resources Division. WRI 78-101, 34 pp.

Two-year study of area near mouth of Muck Creek. Measured discharge of Muck Creek at Roy and mouth and less frequently about half mile downstream of Roy. Includes “abnormally dry winter of 1976-77”.



Perdue, V., 1997. **Land Use and Ft. Lewis.** In: Ecology and conservation of the South Puget Sound prairie landscape, P. Dunn and K. Ewing, eds. Seattle, WA: Nature Conservancy of Washington, pp. 17-30.

Summary of native American land management practices and vegetation uses on the prairies, early history and agricultural practices of European settlement (Puget Sound Agricultural Company's activities and the transition to American settlers), and the cessation of agricultural activity with the establishment of Fort Lewis.

Peter, D.H. and T.B. Harrington, **2014. Historical Colonization of South Puget Sound Prairies by Douglas-Fir at Joint Base Lewis-McChord, Washington.** Northwest Science 88(3):186-205.

Pattern of establishment of Douglas-fir stands in former prairie areas on JBLM based on tree ring increments, stem density measurements, etc. Considers fire-free intervals.

Pierce County, 2005a. **Muck Creek Basin Plan: Volume 1 – Basin Plan & SEIS.** As adopted PCC 2003-62s. Pierce County Water Programs Division, Washington, approx. 210 pp.

A basin-wide plan for comprehensive surface water management. Not actively used by county at this point.

- *Summarized basin conditions in the early 2000s, particularly in Chapter 4 (Basin Characterization: Current Conditions), including distribution of wetlands and domestic water use.*
- *Surveyed streamflow conditions (dry or flowing) along major reaches (excluding sections within the Joint Base Lewis McChord [JBLM]) in November 1999 and in a smaller extent in September and December 2000 (Figures 4-6 and 4-7 in Pierce Co., 2005).*
- *Assessed value of stream reaches for salmon habitat (excluding sections within JBLM).*

Pierce County, 2005b. **Muck Creek Basin Plan: Volume 2 – Appendices.** As adopted PCC 2003-62s. Pierce County, Washington.

- *Compiled scattered historical water quality and streamflow measurements (App. C).*
- *Field notes from Urban Stream Baseline Evaluation of stream reaches (App. E).*

Pitre, C.V. and S.R. Wilhelm, 2019. **Muck Creek Field Reconnaissance, May 2019.** Technical memorandum prepared for South Puget Sound Salmon Enhancement Group, Aug. 2019, 12 pp.

Documents observations from field visit by 10 natural resource professionals plus more general observations by field visit participants with experience in the basin.

Savoca, M.E., W.B. Welch, K.H. Johnson, R.C. Lane, B.G. Clothier, and E.T. Fasser, 2010, **Hydrogeologic framework, groundwater movement, and water budget in the Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington.** U.S. Geological Survey Scientific Investigations Report 2010-5055, 46 pp.



Characterized the groundwater-flow system in the Chambers-Clover Creek Watershed and vicinity, including entire Muck Creek Watershed, in preparation for a groundwater flow model.

- *Examined ~450 well logs to describe the geologic framework of study area and construct geologic cross-sections.*
- *Made one-time measurements of groundwater levels in 229 wells in 2006 and 2007.*
- *Measured groundwater levels monthly in 137 wells (a subset of those measured above), including ~15 in Muck Creek Basin, in 2007 and 2008.*
- *Surveyed streamflow at 44 stations, including 14 in Muck Basin, at two low-water times (2007 and 2008).*
- *Estimated groundwater recharge, groundwater discharge, and groundwater flow directions.*
- *Constructed an annual water budget for the study area.*

Sceva, J.E., D.E. Wagner, and others, 1955. **Records of Wells and Springs, Water Levels, and Quality of Ground Water in Central Pierce County, Washington.** Washington Department of Conservation and Development, Division of Water Resources and City of Tacoma, Department of Public Utilities, Water Division: Open-file report, May 1955.

Covers entire Muck Creek Basin. Compilation of groundwater information available to date. Describes “representative” wells and springs. Includes well logs and well hydrographs.

Sinclair, K., 2001. **Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed, Pierce County.** Washington department of Ecology Publication No. 01-03-037.

An overview of the hydrogeologic setting and an evaluation of the potential cause(s) of intermittent flow conditions within the watershed.

- *Examined existing well logs to construct geologic cross-sections. Located springs from existing reports.*
- *Collected new field data in 2000-2001, during a period of relatively low precipitation:*
 - *Monthly groundwater levels from 15 existing wells.*
 - *Two rounds of point-in-time streamflow surveys in June and September 2000, plus a smaller survey in February 2001.*
 - *Instream piezometers installed and monitored monthly to determine gradient between stream and associated groundwater.*

Svoboda, P., 1978. **Juvenile salmonid population estimates in the Nisqually Reservation hatchery stream system and upper Muck Creek drainages.** Prepared for the Nisqually Indian Tribe, USFWS, and NMFS, 28 pp.

Removal method for population estimate. Includes Aug. 1978 channel width, wetted area, depth; fish species counts – steelhead/rainbow trout and cutthroat present, no



coho; fish lengths; description of vegetation in/around each of two study reaches on Muck Cr.

Svoboda, P., 1984. **Nisqually River Winter Steelhead Status Report.** Prepared for the Nisqually Indian Tribe, 3 pp.

Age and abundance of winter steelhead in Nisqually, 1979/80 – 1983/84.

TetraTech, 2021. **Diversion and Care of Water Plan, Joint Base Lewis McChord Chambers Lake Weir Removal, Washington (Preliminary).** Approx. 90 pp.

Engineering options for water control during weir removal, mostly based on topography and seasonal patterns of inundation.

Tobiason, F.L., 2003. **Historic Flows, Flow Problems and Fish Presence in Clover Creek – 1924-1942: Interviews with Early Residents.** Prepared for the Clover Creek Council and WRIA 12 Watershed Planning Committee. 25 pp.

Observations about Clover Creek watershed, to north of Muck Creek. Prompted by a reach which has intermittent summer flow and question of whether this is a natural occurrence or one caused by human activities. Also notes fish presence over time.

Tweit, B., 1990(?). **Nisqually Chum Salmon Escapement and Run Size Estimation Methodologies – Draft.** Washington Dept. of Fisheries, 11pp. (year of issuance is unclear but date of most recent document in the citation list is 1989)

Summary of Nisqually chum fishery, including Muck Creek, as well as discussion of limitations of estimation methods.

U.S. Army Corps of Engineers (Seattle District) and JBLM, 2019. **Environmental Assessment - the Chambers Lake Weir Removal, Joint Base Lewis McChord, Washington.** 45 pp.

Evaluates three different alternative configurations for the final channel after weir removal. Estimates changes in inundated area in Chambers Lake. Considers impacts on fish passage and wetland vegetation.

* U.S. Army Corps of Engineers and Sealaska Environmental, 2017. **2017 Artillery Impact Area Annual Report.**

Includes time series (1999 – 2017) of groundwater levels from 18 monitoring wells in and around the South Impact Area, which is directly north of the lower reaches of Muck Creek. Only data table of times series and map of monitoring wells with selected groundwater levels currently on hand.

* U.S. Army Corps of Engineers, 2019. **Muck Creek/Chambers Lake Weir Removal Hydraulic and Geomorphic Assessment.** USACE, Seattle District, January 2019.

Trying to obtain.



- Walters, K.L. and G.E. Kimmel, 1968. **Ground-Water Occurrence and Stratigraphy of Unconsolidated Deposits, Central Pierce County, Washington.** Washington Department of Natural Resources, Water Supply Bulletin No. 22, 428 pp.
Study area includes entire Muck Creek basin. Groundwater hydrographs with 8 to 15 years of monthly measurements from several wells in/near Muck Cr. basin.
- Washington Water Trust, 2018. **Nisqually Rapid Water Rights Assessment: Prairie Tributaries – CONFIDENTIAL REPORT.** Prepared for the Nisqually Indian Tribe, 15 pp.
Identified water rights with greater than 10 acres of irrigation within Muck Basin and adjacent basins. Determined place of use and assessed which water rights represent actual water use. Ranked 22 water rights according to potential to serve as exempt well mitigation.
- Wilhelm, S.R. and C.V. Pitre, 2021. **Hydrogeologic Influences on Streamflow in Muck Creek Basin.** Prepared for South Puget Sound Salmon Enhancement Group, 147 pp.
Synthesis of data from previous studies and description of surface water patterns and hydrogeologic conditions in basin. Summary of groundwater-surface water interactions in distinct reaches of Muck, Lacamas, and South Creeks.
- Williams, J.R., H.E. Pearson, and J.D. Wilson, 1985. **Streamflow Statistics and Drainage-Basin Characteristics for the Puget Sound Region, Washington.** U.S. Department of the Interior, United States Geological Survey Open-File Report 84-144-A.
Monthly mean discharge for each year for Muck Creek at Roy, 1956-1971.
- Williams, R.W., R.M. Laramie and J.J. Ames, 1975. **A Catalogue of Washington Streams and Salmon Utilization. Volume 1: Puget Sound Region.** Washington Department of Fisheries.
Brief description of Muck Creek geomorphology, salmon utilization, and tributary locations.
- Zimmerman, C.E., 1995. **Population Structure of Coastal Cutthroat Trout (*Oncorhynchus clarki clarki*) in the Muck Creek Basin, Washington.** M.Sc. Thesis, Oregon State University, 56 pp.
Analysis of genetic and physical characteristics of cutthroat from six locations in Muck Creek Basin.



Attachment B

Muck Creek Timeline

**Timeline of Important Events and Observations
Related to Streamflow and Salmonids in the Muck Creek Watershed**

Date	Event or Observation	Source
pre-1833	Native peoples maintain prairie by periodic intentional fires to inhibit conifer encroachment and retain habitat for camas (pre-European contact)	
1833	Fort Nisqually established in modern day DuPont, increased local demand for beaver and other furs. "When the Hudson's Bay Company established Fort Nisqually in 1833, they claimed the lands from the Puyallup River on the north and eastern sides, to the Deschutes River in the south."	HistoryLink article on Hudson Bay Company, David Williams, 2020 (https://www.historylink.org/File/20999); Muck area history on Pacific Highway website (https://www.pacific-hwy.net/muck.htm)
1839	Puget Sound Agricultural Company (PSAC) established within Hudson's Bay Company (HBC).	Hudson Bay Company History Foundation (https://www.hbcheritage.ca/history/ventures/the-puget-sound-agricultural-company)
1839	Fur trade at Fort Nisqually was declining.	HistoryLink article on Hudson Bay Company, David Williams, 2020 (https://www.historylink.org/File/20999)
1841	"The Nisqually Plains has a soil found to be better fitted for pasturage than tillage, it had been appropriated almost exclusively to the flocks and herds, so that now with only 200 acres of cultivated land, it possessed 6,000 sheep, 1,200 cattle, besides horses, pigs, etc."	Observation of Sir George Simpson (https://www.pacific-hwy.net/muck.htm)
1846	Oregon Treaty (15 March 1846) establishes British-American border at 49th parallel, transferring ownership of land in basin to America. Over next two decades American citizens moved into area and gradually took over areas of PSAC land.	
1851	HBC ". . . had 1,500 acres of land under cultivation at Nisqually along with 10,000 sheep and 6,000 cattle."	Muck area history on Pacific Highway website (https://www.pacific-hwy.net/muck.htm)
1851	HBC had to abandon their claim in Thurston County and the Nisqually River became the southern boundary.	Muck area history on Pacific Highway website (https://www.pacific-hwy.net/muck.htm)
1854	Treaty of Medicine Creek - Nisqually reservation established on 1280 acres south of Nisqually R.	Nisqually Indian Tribe website (http://www.nisqually-nsn.gov/index.php/heritage/)
1855	Muck Station present along Muck Creek upstream of wetland chain (date of establishment not clear)	Washington Secretary of State Legacy Washington (https://www.sos.wa.gov/legacy/maps/maps_detail.aspx?m=10)
1855	War of 1855: Armed conflict between native peoples and Americans in the area.	
1856	Nisqually reservation expanded by executive order to 4717 acres, including land north of Nisqually R. and directly to the east of Muck Basin	Nisqually Indian Tribe website (http://www.nisqually-nsn.gov/index.php/heritage/)
1869	Fort Nisqually/PSAC land sold to US government, available for settlers.	

Date	Event or Observation	Source
1873	Northern Pacific Railroad constructed through basin, passing through future site of Roy (year is when Tacoma reached; regular service began in 1874).	
1880	Ditch dug to drain swamps in wetland-and-lake chain	Historic documents unearthed by Surface Water Management Division, Planning and Public Works, Pierce Co.
1884	Town of Roy founded	City of Roy website (https://www.cityofroywa.us/history.html)
1892	Cutting of a drainage channel through Finch's Lake (modern day Johnson Lake)	Historic documents unearthed by Surface Water Management Division, Planning and Public Works, Pierce Co.
1895	Washington State authorizes counties to establish drainage districts to "Straighten, widen, deepen, improve rivers, watercourses or streams, construct dikes"	"Special Purpose Districts In Washington State", Municipal Research and Services Center of Washington, 2003
circa 1900	Roy contained several lumber mills which supplied Tacoma. Date unclear.	City of Roy website (https://www.cityofroywa.us/history.html)
1917	In January Pierce Co. voters approve donation of land for Camp Lewis. Construction begins later that year. This action eliminated farms on the donated land and included the condemnation of 3353 acres of Nisqually reservation to be included in Camp Lewis. Tribal members forced to move.	Nisqually Indian Tribe website (http://www.nisqually-nsn.gov/index.php/heritage/)
1919	Official transfer of land for Camp Lewis, from Pierce Co. to federal government.	Lewis Army Museum website (https://lewisarmymuseum.com/history-of-the-army-at-camp-lewis-fort-lewis-and-joint-base-lewis-mchord/camp-lewis-1917-1919/)
1920-1933	Prohibition caused collapse of hops farming in area.	Early Roy History: Three Mayors and Fort Lewis, Nisqually Valley News, 30 Dec. 2014 (https://www.yelmonline.com/stories/early-roy-history-three-mayors-and-fort-lewis,114430)
circa 1940	13th Division Prairie, approximately 1100 acres, added to Fort Lewis	Perdue, 1997
1948	Muck Cr Basin closed to surface water withdrawals except for domestic and stock watering (affirmed by WAC 173-511 in 1981).	Surface Water Source Limitation (SWSL) letter issued by the Departments of Fisheries and Game.C49
unknown	Jeanette has heard a community story that the reach of the creek between 8th Ave. S and Hwy 507 was "cleaned out" multiple times with a backhoe driving down the channel.	Jeanette Dorner, at stakeholder's meeting, Oct. 21, 2021.
1950s?	A landowner whose family has been in the basin for several generations reports stories of abundant chum in upper Muck Creek. (exact years/period uncertain)	Jeanette Dorner's father, reported by Brian Combs at stakeholder's meeting, Oct. 21, 2021.
1960s?	Long time residents report being able to see from Roy to Spanaway across the prairie, with no trees to block the view. (exact years/period uncertain)	Jeanette Dorner, stakeholders meeting, Oct. 21, 2021
1967	Installation of Chambers Dam on JBLM.	Sinclair, 2001

Date	Event or Observation	Source
1970s	Someone living at the headwaters of the north fork near Patterson Springs stocked and released coho in the 70's. Jeanette theorizes that might have been why people saw more salmon in that part of the creek before the 80's when her family moved in there.	Jeanette Dorner, at stakeholder's meeting, Oct. 21, 2021.
1970s	I was told that sometime in the 1970s before I started here there was a very strong run of chum that made it up into the 13 th Division Prairie section of Muck Creek. During the 1980s we surveyed upper portions of Muck Creek within the 13 th Division sections and counted steelhead redds.	Dave Clouse, 3 Dec. 2021, in response to this question: "Were the salmon or steelhead ever known to get beyond the dry stream areas on the prairie and up farther into the system?"
1972	Installation of flow control structure at outlet of Johnson Creek.	Sinclair, 2001
1973	Rehabilitation of Exeter Springs via replacement of fine sediment with gravel.	Harrington-Tweit and Svoboda, 1983
1976-77	Weir placed at mouth of Muck Creek to count escapement	Cole and others, 1986
1976-77	No flow at mouth of Muck Creek in winter for chum return (duration unclear)	Tweit, 1990(?)
1979	Rehabilitation of short sections of Johnson Creek and Halverson Creek by Fort Lewis	Harrington-Tweit and Svoboda, 1983
1981	Instream flow rule affirms the 1948 closure to further allocation, maintains the stockwatering exemption (except feed loots), and in the case of cumulative impacts of single use domestic diversion/withdrawals causing serious impacts on surface water, limits such use to domestic in-door use if no alternatives are available.	WAC 173-511
1980s?	"When I started here the salmon and steelhead runs were fairly strong every year. The Coho run was never really strong."	Dave Clouse, 3 Dec. 2021, in response to this question: "When you came to the base how were the salmon and steelhead populations doing?"
late 1980s	Fish passage structure added to Chambers Dam	
1987-88	No flow at mouth of Muck Creek in winter for chum return (duration unclear)	Tweit, 1990(?)
circa 1990	JBLM replaced earthen tank crossing points with concrete fords under Dave Clouse. This greatly reduced unauthorized crossings at other locations.	Dave Clouse, 3 Dec. 2021, in response to this question: "There are many anecdotal reports of how the fords negatively impacted salmon when they were first put in. I understand you helped to harden the fords so that the creek bed was not exposed. Were there impacts from the original, muddy fords, and do you think the hardened fords may also be impactful?"

Date	Event or Observation	Source
1995	Initial land donation for Morse Creek Preserve in eastern basin	
1999	LRI landfill begins operation in December.	Pierce County Muck Creek Basin Plan, 2005, p. 4-16
circa 2000	Restoration actions on JBLM - riparian plantings in 1990s and 2000s?	Mentioned by Brian Combs and Dave Clouse in interview of Dec. 2021
circa 2000	13th Division Prairie Natural Resources Area, 712 acres east of lake and wetland chain, established on JBLM. (Pre-2007, when mentioned in Washington Natural Areas Plan)	Pacific Northwest Interagency Natural Areas Network website (http://www.fsl.orst.edu/rna/sites/Thirteenth_Division_Prairie.html)
circa 2000	Project removed reed canary grass from Muck Lake	Reported to Brian Combs by landowner along Lacamas Creek upstream of Muck Lake
2000-2001	During this winter "Muck Creek experienced extremely low flow during the fall and winter of 2000/2001. As a result, escapement to Muck Creek was essentially zero."	Pierce County Muck Creek Basin Plan, 2005, p. 4-21
2001	Creation of a 940' x 15' spawning channel from an existing drainage ditch connected to Muck Creek by Fort Lewis and Nisqually Tribe	Final EIS for Fort Lewis Army Growth and Force Structure Realignment, July 2010 (available on Google Books)
2001-2002	During this winter ". . . the 2001/2002 season produced a record run, with over 20,000 fish returning to Muck Creek (Troutt 2002, personal communication)."	Pierce County Muck Creek Basin Plan, 2005, p. 4-21
2002-2003	"During much of the winter of 2002/2003, flow at the mouth of Muck Creek was insufficient for upstream migration. The situation did not improve until the beginning of February when flows were finally sufficient for fish to enter the creek (Walters, personal communication)."	Pierce County Muck Creek Basin Plan, 2005, p. 4-21
2003	Installation of natural gas pipeline by Williams across prairie. May be a year or so later, but no earlier. "Anecdotal verbal report from Jonathon Richardson that construction of the Muck Creek crossing of the natural gas pipeline resulted in perforating a perching or confining layer, and that all of the flow of Muck Creek entered through that perforation."	Pitre and Wilhelm, 2019; <i>Oil and Gas Journal</i> , 2001 (https://www.ogi.com/pipelines-transportation/pipelines/article/17261767/williams-plans-to-expand-northwest-pipeline-in-washington-state)
2006	Confluence of Muck and Johnson Creeks: "JBLM staff has characterized this confluence as the site of an avulsion, where a discrete event created large-scale movement and deposition of coarse-grained sediments that creates an impassable barrier to fish for parts of the year to upstream portions of Muck Creek. Jonathon [Richardson] hypothesized that this might have occurred about 10 years ago." (2006 is an approximation) / Dave Clouse's description from Dec. 2021: "A few years ago during extreme high flows rock and sediments were deposited at the confluence of Muck and Johnson creeks. This has altered the surface flow in that particular section of Muck."	Pitre and Wilhelm, 2019; Dave Clouse, 3 Dec. 2021, in response to this question: "Do you know if there were changes that stopped salmon from migrating up past the prairie?"

Date	Event or Observation	Source
2011	In Sept. 2011, Muck Creek was unexpectedly flowing in area of a bridge in Roy scheduled to be replaced. JBLM was asked to reduce flow from Chambers Dam and in the process caused the cessation of flow below the dam and stranding of 1000s of fish.	Described in letter from NOAA General Counsel to Foster Pepper, June 29, 2017.
2021	John Richardson observed dry reaches in lower Muck Creek in May 2021, earlier than he had ever seen before, which led to stranding of eggs and fry.	Brian Combs, at Muck Creek stakeholder's meeting, Oct. 21, 2021.
2021	Chambers Dam removed and channel restored in November 2021.	Observed during Nov. 17 field trip by SPSSEG, Anchor, and Coho.
2022	In mid-January the water level in Muck Creek near its confluence with Johnson Creek was the highest in recent memory.	John Richardson, as reported by Brian Combs in email, 11 Jan. 2022

Attachment C

Muck Creek Geospatial Data Layer List

Catalog of Geospatial Data Available for the Streamflow Restoration Study Muck Creek Basin

This is a compilation of available geospatial data relevant to the Muck Creek Basin. It is regularly updated as more information is identified (see footer for date of this version). This compilation began with data gathered for the Muck Creek Hydrogeological Report (Wilhelm and Pitre, 2021) and has been expanded during the Muck Creek Watershed Restoration Study. It has been reviewed by several people, including Jennifer Cutler of the Nisqually Indian Tribe, and they have contributed additional details, data layers, and sources. This document contains three tables:

Table 1: Standard Layers 1
 Table 2: Data Specific to Muck Creek Basin and Nearby Areas..... 4
 Table 3: Historical Maps and Images 8

Note: The Nisqually Indian Tribe and SPSSEG prefer to use Washington State Plane South, NAD 83 HARN projection for their GIS work.

Table 1: Standard Layers

Dataset	Description	Source	Status
Basin boundary (Muck Cr. Basin)	Has obvious errors compared to apparent stream network (see “Muck Cr Basin Needs Revision.jpg”).	Watershed Boundary Dataset – merge of 3 WBDHU12 basins	On hand (Coho)
Basin boundaries (sub-basins for Muck, Lacamas, and South Creeks)	Could be revised to include information from lidar elevations and Pierce Co hydro_centerlines.	Watershed Boundary Dataset WBDHU12	On hand (Coho)

Dataset	Description	Source	Status
Nisqually Subbasins	Derived from the old WADNR Watershed Administrative Units (WAUs) and then modified to both clean up the boundaries and group/name the subbasins to match how NIT 'manages' them. Lidar was used as a guide to manually adjust/improve how the boundaries were mapped between subbasins but the outer Nisqually Watershed boundary matches DOE's WRIA 11 boundary. (J. Cutler, Jan. 2022)	Nisqually Indian Tribe	On hand
Nisqually Watershed Planning Subbasins	Merging of Nisqually Subbasins into larger units for purposes of watershed planning.	Nisqually Indian Tribe	On hand
County parcels		Pierce Co.	On hand (Coho)
County roads		Pierce Co.	On hand (Coho)
County stormwater and drainage features		Pierce Co.	Downloaded but not yet interpreted for usefulness to this study
County floodways	Deep or fast flowing floodways.	Pierce Co.	
Nisqually Basin intrinsic potential	Intrinsic potential data layer for coho, steelhead, and chinook salmon habitat, not sure of source or date. Obtained from SPSSEG in 2019, files dated 2017.		On hand (Coho)
Fish distribution observations		WDFW (includes observations by from Nisqually Indian Tribe submitted via NWIFC)	
Fish passage		WDFW	
Flood Zones	Currently being updated by FEMA, not yet available	Pierce Co. / FEMA	Matt Barnhart will alert us when available

Dataset	Description	Source	Status
Land cover	Classification into general vegetation and landcover, based on Landsat images, 30 m resolution.	National Land Cover Database	2016 data on hand (Coho)
Land surface elevation	From lidar surveys.	Washington Lidar Portal (2005 whole basin and 2011 – non-JBLM); JBLM – 2016, portion near Muck-Johnson confluence	On hand (Coho)
Pipelines	As shown on Nisqually Web Map.	Justin Quinley, Anchor QEA; also see Nat'l Pipeline Mapping System	DOH?
Population	By census tract, available from historical and recent censuses	National Historical GIS (https://www.nhgis.org/)	
Public and conserved lands		State and county databases plus land conservancy websites	
Soils		NRCS WebSoilSurvey	
Stream network	Stream network digitized by Pierce Co. More accurate than WC_Hydro.	Pierce Co. - Hydro_Centerlines	On hand (Coho)
Surficial geology	1:100k layer. 1:24,000 has been “in prep” since 2011, not available.		On hand (Coho)
Tax parcels	Includes “current land use” attribute.	Pierce Co.	
Water system locations and withdrawals		DOH SENTRY online database (USGS may have)	
Well locations	Includes date of installation so can estimate water use trends from about 1980 onward (Plan Addendum looked at 1990 onward?); only located to QQ section	Ecology GIS Data via Well Report Viewer	
Wetlands		Pierce Co.	On hand (Coho)

Table 2: Data Specific to Muck Creek Basin and Nearby Areas

Shapefile Name	Description	Source	Status or Coho Layer Name
Dams	Location of two dams in lakes-and-wetlands chain (estimated from photo points during May 2019 field visit and 2017 aerial photo).		Dams
Geologic cross-section locations and unit elevations and thicknesses		USGS Chambers-Clover and SE Sound GW Model	On hand (Coho)
Groundwater flow direction	Direction of groundwater flow in Qvr and A3 (Qva) aquifers.	Savoca and others, 2010	Savoca_GW_Flow_Directions_2927
Groundwater level contours by geologic unit	Single point in time.	USGS Chambers-Clover and SE Sound GW Model	On hand (Coho)
Groundwater monitoring wells	Location of two wells in Qvr monitored by the USGS.	USGS NWIS	Monitoring_Wells
Groundwater recharge estimates	Revised version will be issued with SES Model paper, possibly by summer 2022.	USGS Chambers-Clover and SE Sound GW Model	Requested
Habitat surveys in streams	SPSSEG (recent) – see types of data in SPSSEG webmap.		
	Pierce Co. spring and early summer, 2000 and 2001.	MCBP, 2003	
	Stream reaches assessed by May, 2002 (approximated from Map G-2 of that report).	May, 2002	May_Survey_Reaches_4602

Shapefile Name	Description	Source	Status or Coho Layer Name
	Approximate locations where May (2002) measured B-IBI (locations estimated from Map G-8 of that report). (see also Pierce Co. B-IBI layer)	May, 2002	May2002_Biol_Monit
Landfill	Location of LRI Landfill (digitized from 2017 aerial photograph).		Landfill
Muck Station	Includes structures, land cover, and water features in area around Muck Station (just above confluence of Muck and Johnson Creeks). Drawn by Tolmie (1847), re-drafted in Larson and Lewarch (1993).	SEE Botanical (Easterly, Salstrom, and Chappell, 2005)	On hand (Coho), not georegistered.
Piezometers	Groundwater-surface water piezometer pairs installed by Coho and SPSSEG in Oct. 2019.	SPSSEG	Piezometers_Muck2019
Prairie Extent (Historical)	Prairie extent as mapped in GLO maps of 1853 to 1876, hand digitized.	SEE Botanical (Easterly, Salstrom, and Chappell, 2005)	GLO_prairie
Puget Sound Agricultural Company Land Claim (1855)	Includes structures, land cover, and water features.	Washington Sec. of State – Legacy Washington (https://www.sos.wa.gov/legacy/maps/maps_detail.aspx?m=10)	On hand (Coho), not georegistered.
River miles (conventional)	River miles based on Williams and others, 1975. Hand digitized by Coho. Muck Cr not in Ecology GIS River Miles layer (nor is Nisqually R.) – as of 2022-02-20.		RiverMiles_StreamsOfWA_Centerlines
River miles (actual)	River miles calculated from Hydro_Centerlines from Pierce Co.		Muck_Lac_South_Mainlines_RM

Shapefile Name	Description	Source	Status or Coho Layer Name
Stream conditions	Reaches of stream network observed to be dry in June 2000, Sept. 2000, and Feb. 2001.	Sinclair (2001)	Hydro_Centerlines_Muck_Dry
	Location of instream piezometers from Sinclair, 2001 (coordinates from Table 1, p. 13 of that report).	Sinclair (2001)	SinclairPiezoStns
	Observed stream conditions (dry or wet) during field visits in May 2019. (SPSSEWG has additional observations, including Oct. 2019, Dec. 2020, and SPSSEG/Anchor/Coho site visit Nov. 2021)		StreamConds_20190515
	Reaches of stream network observed to be dry or flowing in Nov. 1999	MCBP, 2005	MCBP_DryReaches_Nov1999
	Stream stations observed in Sept. 2007 and July 2008.	Savoca and others, 2010; USGS NWIS	Savoca_Streamflow_Stations
Springs	Location of springs from literature and as pointed out by JBLM personnel during May 2019 field trip.	Sceva and others, 1955; Sinclair, 2001; JBLM staff	Springs
Surface water withdrawal locations		ECY Water Rights Map/Database; WWT Rapid Assessment	
Stream gages	Location of stream gages at Roy and at Loveland.	Sinclair, 2001, Apps. E and F	Muck_Gage_Locations
Water rights		WWT project; ECY Water Rights Map/Database	In Anchor's Nisqually Basin webmap

Shapefile Name	Description	Source	Status or Coho Layer Name
Well locations and logs	Subset of well logs in Ecology database precisely located for USGS study, basis for geologic interpretations.	USGS Chambers- Clover and SE Sound GW Model	On hand (Coho)

Table 3: Historical Maps and Images

Data Set	Time Period	Description	Source	Status
General Land Office Plat Maps	1870-74	By townships. Uplands and eastern basin are sparsely mapped.	Color versions with notes online via BLM (“Survey Plats and Field Notes”); georegistered versions on Map Server from WA Dept. of Archaeology and Historic Preservation (currently not available, March 2022)	Coho has color versions (not georegistered)
Plummer Atlas of Pierce Co.	1889	By townships. Shows some marshy/wetland areas, as shown in Pierce Co. example. Wetland locations generally correspond to flat areas shown in recent lidar.	Tacoma Public Library NW Room	Pierce Co. Surface Water Division has scans of at least some townships
Drainage district maps	Varies	Not clear what exists.		Pierce Co. Surface Water Division has a 1917 map from upper South Creek, Drainage District 13 (check)
Nicholson’s Atlas of Tacoma	1910	Only urban, suburban areas around Tacoma, not useful for this study.		--

Data Set	Time Period	Description	Source	Status
Timber Cruise	1915	Mapped by section.	Puget Sound Branch of State Archives	
Kroll's Atlas	1915	Pages by township, shows parcels, some ownership, stream locations but no other natural features	Tacoma Public Library NW Room	
Plan Book, Pierce Co.	1918	By section, only a few near Muck Cr basin (T18R3E Sect. 25, for instance)	Tacoma Public Library NW Room	
White's Atlas of Pierce Co.	1928	Pages by east and west portions of each township, shows parcels, some ownership, stream locations, some indication of wetlands in chain W of SR507 and other areas, but no other natural features	Tacoma Public Library NW Room	Pierce Co. Surface Water Division has scans of at least some townships
Historical aerial photographs (single frames)	1941, 1942	Full coverage of basin with about 10 photographs, B&W. WA DOE has Map Service of orthos. NIT has hard copies of 1942 aerials from JBLM, not georegistered.	USGS EarthExplorer (have downloaded index of these photos as shapefile)	Jennifer Cutler has most knowledge about these
	1952	About 20% of basin in east and southeast		
	1955	Eastern 1/3 of basin		
	1956	Most of basin except northernmost 5%		
	1957	Full basin coverage		
	1968	Full basin coverage, B&W.		



Data Set	Time Period	Description	Source	Status
Historical aerial photographs (single frames)	1969	Western 10% of basin, but not mouth of Muck.	USGS EarthExplorer (have downloaded index of these photos as shapefile)	
	1971	Full basin coverage		
	1972	Northern ¾ of basin		
	1975	Eastern 60% of basin plus mouth of Muck		
	1979	20% of basin, lower SE		
	1982	Less than 10% of basin, easternmost		
	1991	Full basin coverage except southern tip		
	1992	Southern 60% of basin		
Landsat MSS & TM	1975	MSS; 60 m resolution	USGS EarthExplorer	Tribe has on-hand
	1990	TM; 30 m resolution		
	2000	TM; 30 m plus 15 m resolution		
National High Altitude Photography (NHAP)	1980-82		USGS EarthExplorer	
Digital Ortho Quad	1990		USGS EarthExplorer	
National Aerial Photography Program	1990-91		USGS EarthExplorer	
High Resolution Orthoimagery	Have downloaded index of these photos as shapefile.		USGS EarthExplorer	
	2002	North half of basin		
	2003	Mouth of Muck only		
	2005	Full basin coverage		
	2006	Full basin coverage		
	2009	Full basin coverage		
	2012	North half of basin		

Data Set	Time Period	Description	Source	Status
National Agriculture Imagery Program (NAIP)	July 2006		USGS EarthExplorer	
	Aug 2009			
	Late Aug, early Sept 2011			
	July 2013			
	Late July, early Aug 2015			
	Sept 2017	Resolution is 1 – 2 m.		On hand (Coho)
	Aug 2019			
NAIP expanded coverage	NAIP dates above, plus partial coverage of “even” years	Reprojected, tiled version of NAIP images listed above, plus 6” orthos of “urban” areas, which includes mouth of Muck and NE portion of basin.	Via Statewide Imagery Consortium.	Tribe has on-hand or accessible.
Pictometry Imagery	2016, 2021	2016 6” ortho of lower 1.3 mile of Muck Creek “gorge”, downstream from about Exeter Springs. 2021 3” ortho and 360° oblique views of same extent.	EagleView?	Tribe has on-hand.
Hyperspectral Image	2022	Currently being collected for JBLM.		

Also checked UW River History Project, which has georegistered some GLO sheets and aerial photos from the 1930s, but they concentrated on the mainstem Nisqually Rivers and only include a small portion of the mouth of Muck Creek.

Data Sources (incomplete):

NIT, Tribe: Nisqually Indian Tribe

[Pierce Co. GIS](#)

[Washington Geospatial Open Data Portal](#)

References:

- Golder Associates Inc., 2003. Nisqually Watershed Management Plan. Prepared for Nisqually Indian Tribe and Nisqually Watershed Planning Unit. 165 pp.
- May, C., 2002. Measures of ecological integrity for salmonid streams on Department of Defense facilities in the Pacific Northwest: current watershed conditions and management recommendations. Applied Physics Laboratory, University of Washington Technical Report APL-UW-TR 0104.
- Pierce County, 2005 (*nicknamed MCBP*). Muck Creek Basin Plan: Volume 1 – Basin Plan & SEIS. As adopted PCC 2003-62s. Pierce County, Washington.
- Savoca, M.E., W.B. Welch, K.H. Johnson, R.C. Lane, B.G. Clothier, and E.T. Fasser, 2010. Hydrogeologic framework, groundwater movement, and water budget in the Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington: U.S. Geological Survey Scientific Investigations Report 2010-5055, 46 p. Accessed 2019-05-01 from <https://pubs.usgs.gov/sir/2010/5055/>
- Sinclair, K., 2001. Assessment of Surface Water and Groundwater Interchange within the Muck Creek Watershed, Pierce County. Washington department of Ecology Publication No. 01-03-037.
- U.S. Geological Survey, 2016. National Water Information System (NWIS). Data available on the World Wide Web (USGS Water Data for the Nation), accessed Nov. 2019 at URL [<http://nwis.waterdata.usgs.gov/usa/nwis/gwlevels>] [DOI <http://dx.doi.org/10.5066/F7P55KJN>].
- Wilhelm, S.R. and C.V. Pitre, 2021. Hydrogeologic Influences on streamflow in Muck Creek Basin. Prepared for South Puget Sound Salmon Enhancement Group, Feb. 2021. 145 pp.

Notes:

Did not include precipitation and temperature datasets. Will wait to see if helpful for basin understanding and strategy development.

Appendix B

Field Data Results—Streamflow

Observations and Groundwater Levels



Date: 9 February 2024

Coho Ref.: MUK-04.3

To: Merri Martz, Anchor QEA mmartz@anchoragea.com
cc: Bob Montgomery, Anchor QEA rmontgomery@anchoragea.com
From: Sherry Wilhelm & Chris Pitre sherry@cohowr.com, chris@cohowr.com
Re: **Field Data Results - Streamflow Observations and Groundwater Levels in Lower and Middle Muck Creek**

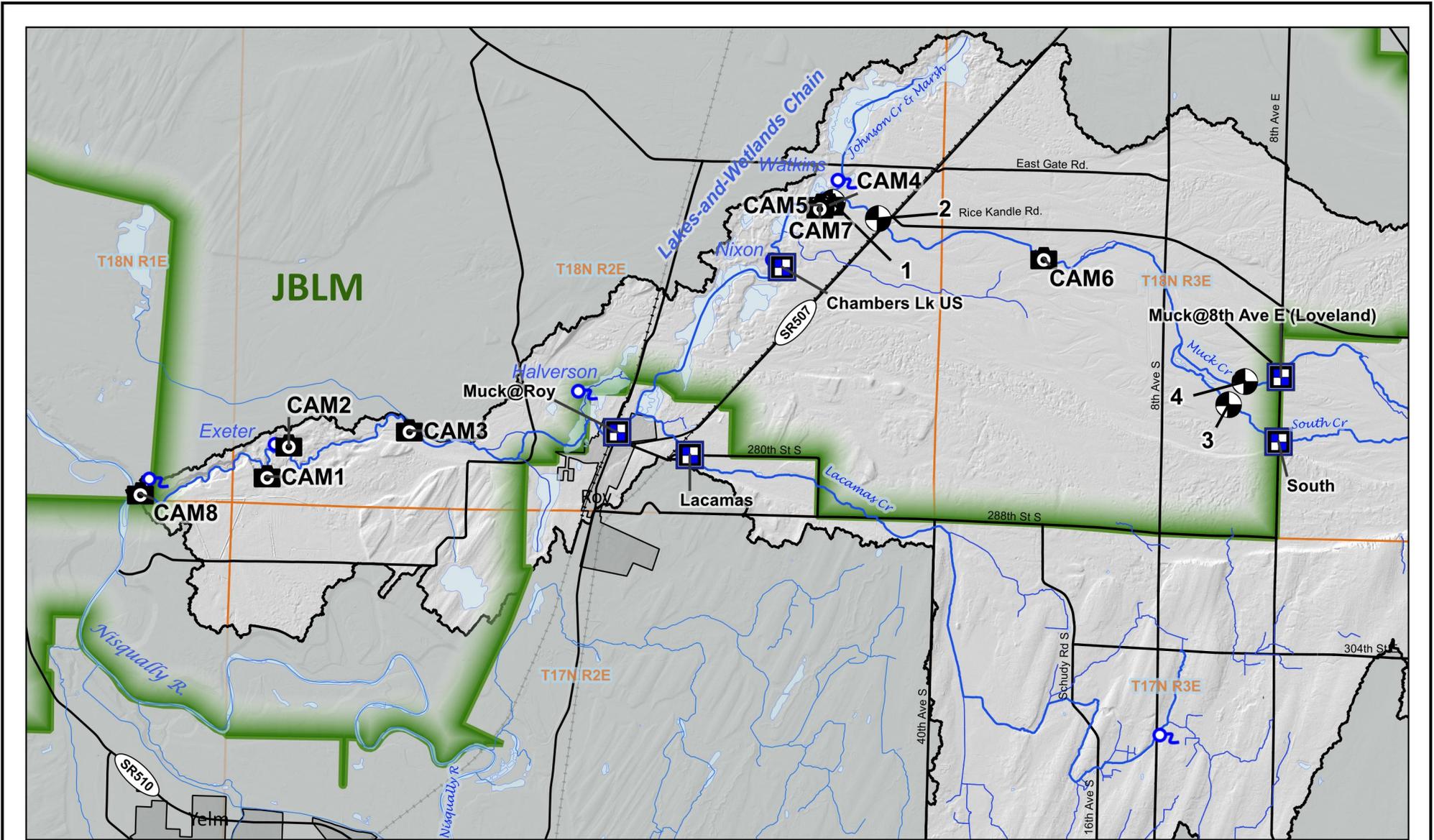
This technical memorandum presents measurements of streamflow and groundwater levels on reaches of the Muck Creek drainage network. Coho Water Resources, LLC (Coho) conducted this work for the Nisqually River Foundation's (NRF) Muck Creek Stream Flow Restoration project as a subconsultant to Anchor QEA, LLC.

1. PURPOSE

The goals of the Muck Creek Stream Flow Restoration project include improving streamflow and hydrologic processes to benefit salmonids. The work presented here characterizes existing conditions by collecting coordinated, fine temporal resolution observations of stream and groundwater dynamics in two reaches of Muck Creek in which frequent low flow or dry conditions impact salmonid passage and/or habitat (Figure 1):

1. Between Exeter Springs and the town of Roy.
2. Between the confluence with Johnson Creek and 8th Ave. East. This reach crosses the largest expanse of prairie in the basin. South Creek below 8th Ave. East was also investigated.

Dry conditions in these reaches in summer and fall have been documented with synoptic streamflow measurements (Engle, 1997; Sinclair, 2001; ENSR, 2003; Savoca and others, 2011) and monthly monitoring at multiple points, mostly on the prairie above the lakes-and-wetlands chain (Sinclair, 2001). The current work records daily stream conditions at multiple points.



-  Time Lapse Camera
-  Groundwater Piezometer
-  Anchor QEA Gage
-  Spring

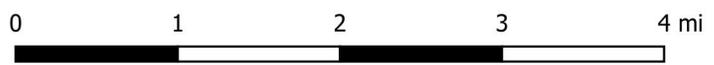


Figure 1
Locations of Time Lapse Cameras and Piezometers
 Nisqually River Foundation
 Muck Creek SFR - Field Data

Field data collection spanned May 2022 to October 2023 and included:

- Installation of eight time-lapse cameras at points along 12 miles of stream to collect daily photographs of stream conditions.
- Instrumentation of four existing shallow groundwater piezometers adjacent to Muck and South Creeks on the prairie.

The collected data can be correlated with each other, precipitation patterns, and with Anchor's stream discharge and lake level data.

2. KEY FINDINGS

- Immediately above the confluence of Muck and Johnson Creeks, streamflow was observed for four days in water year 2023. This lack of flow blocked fish passage to Upper Muck and South Creeks for almost the entire water year. Extensive periods of dry streams were also observed downstream of Roy.
- Exeter Springs provides baseflow to sustain streamflow in the lowermost two miles of Muck Creek when the stream immediately upstream of the springs is dry.
- Winter streamflow at and downstream of Roy, below the lakes-and-wetlands chain, appears to be controlled by the groundwater level in the recessional outwash to the east. Streamflow increases when the groundwater level is high enough to be intercepted by the lakes-and-wetlands chain. This concept is complex and requires further development of explanatory materials.
- The groundwater piezometer data confirmed earlier findings that Muck and South Creeks consistently lose water to groundwater as they cross the prairie above the lakes-and-wetlands chain.

Some of these findings had been previously described and this work characterizes them at higher resolution. Although the precipitation in water year 2023 was approximately 30% lower than the 30-year average, the observations of this study are consistent with other studies, including the 2019-2020 piezometer study (Attachment B).



3. METHODS

All data collection occurred on Joint Base Lewis McChord (JBLM) within the Muck Creek Basin. This work was made possible by the assistance of JBLM Fish & Wildlife staff, who facilitated access and helped with monitoring. In particular, John Richardson of JBLM Fish & Wildlife provided valuable assistance with camera installation, maintenance, and data downloads, and shared his observations of his many years' work in the Muck Subbasin.

This work considers hydrologic patterns within water years (WY), which run from October through the following September and are numbered according to the year in which the period ends (e.g., water year 2023 runs from October 1, 2022, to September 30, 2023). This water-year convention fits the natural precipitation pattern of the Puget Sound region, typically starting and ending in a dry period and encompassing the rainy season.

3.1. Time-Lapse Cameras

Eight locations were chosen for streamflow observation via time-lapse camera (Figure 1; Figure 2). Camera locations are designated as CAM1 through CAM8 (Table 1). CAMs 1-6 were installed from downstream to upstream. CAM7 and CAM8 were added later, so CAM8 is the most downstream of all cameras and CAM7 is located near CAMs 4 and 5. The cameras were especially useful in observing conditions in Muck Creek in the Artillery Impact Area (AIA; extends from river mile [RM] 0.0 to RM 5.3) where no digging is allowed, and which has limited data.

3.2. Camera Equipment

- TechNaxx TX-164 time-lapse cameras, designed for outdoor use and lengthy deployments, were installed. Photographs are saved to micro-SD cards.
- Cameras were programmed to capture photographs every hour at 2 Mb resolution.
- Condensed camera installation and data download instructions were prepared (Attachment A).

3.2.1. Camera deployment

- Cameras were installed during several field visits, ranging from May to October 2022.



- Final data collection for this project occurred in October and November 2023. Cameras were left operating in place so they can continue to collect data. Their maintenance has been handed over to NRF and JBLM staff.
- Some gaps in the record occurred due to a shift in the camera view (CAM2, CAM7) and blockage by vegetation (CAM5).

Table 1: Time-lapse camera descriptions.

River Mile	Camera	Location	Data Collection Period (gaps, if any)
RM ~0.1	CAM8	Mouth of Muck Creek.	2022-10-13 to 2023-12-04
RM ~1.7	CAM1	Muck Creek in the canyon downstream of Exeter Springs.	2022-05-15 to 2023-12-04
RM ~2.3	CAM2	Muck Creek in the canyon upstream of Exeter Springs.	2022-05-15 to 2023-11-27 (2022-11-30 to 2023-01-12)
RM ~3.8	CAM3	Muck Creek on the prairie above the canyon and below Roy and the lakes-and-wetlands chain.	2022-05-15 to 2023-12-04 (2022-10-24 to 2022-12-05)
RM ~9.3	CAM7	Muck Creek in the lakes-and-wetlands chain at its previous (now blocked) confluence with Johnson Creek	2022-07-06 to 2023-10-06 (2022-07-25 to 2022-10-27)
RM ~9.5	CAM5	Muck Creek in the lakes-and-wetlands chain including its current confluence with Johnson Creek.	2022-05-25 to 2023-10-06
RM ~9.7	CAM4	Muck Creek in the lakes-and-wetlands chain above its confluence with Johnson Creek. Near Piezometer 1.	2022-05-15 to 2023-10-06
RM ~12	CAM6	Muck Creek on the prairie above the lakes-and-wetlands chain.	2022-05-15 to 2023-10-06

RM river mile (distance along river's channel from mouth of river) calculated from Pierce Co. version of Muck Creek.

3.2.2. Camera downloads, processing, and interpretation

- Data were collected by swapping out micro-SD cards from the cameras and downloading and processing images in the office. Data downloads were conducted by Coho staff and by John Richardson of JBLM Fish & Wildlife, who also checked on camera conditions between downloads while conducting other work in the area.



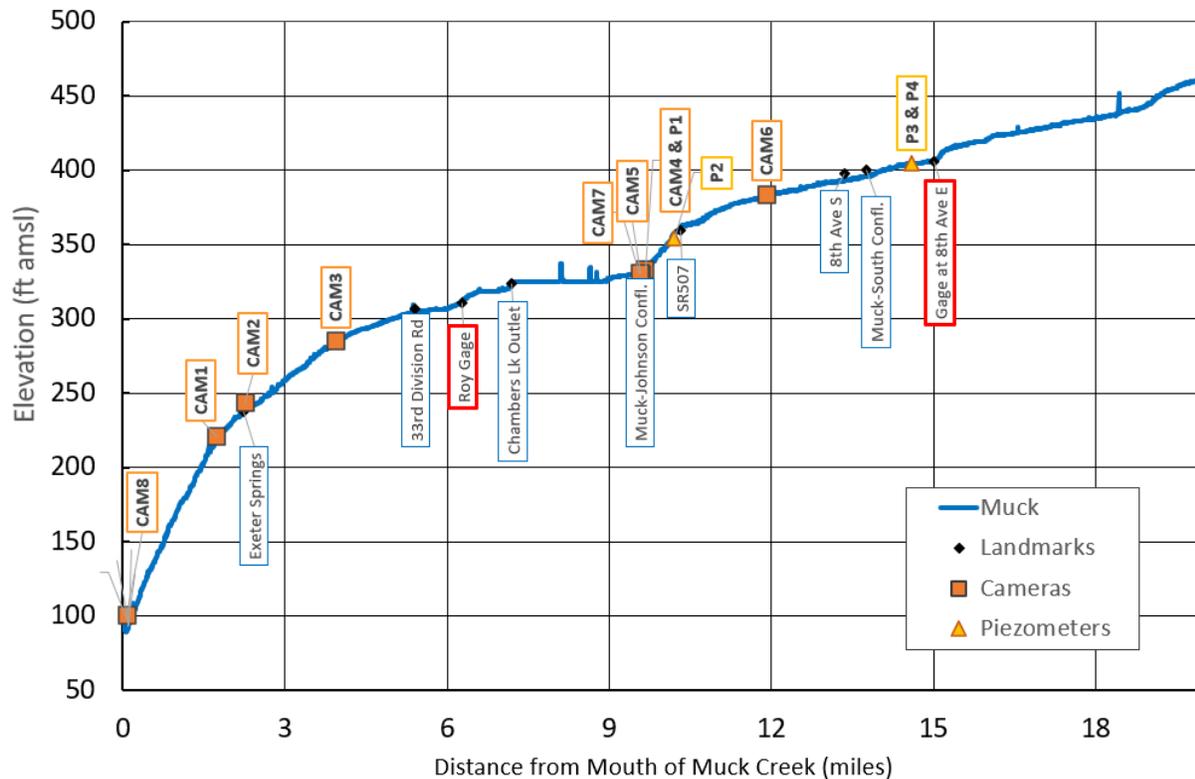


Figure 2: Camera and piezometer locations along Muck Creek elevation profile.

- Photos were re-named from generic names assigned by cameras to include camera number, time and date.
- Videos were created by compiling a single photo from each day via Matlab or Python. Videos were shared with team members via YouTube.
- Videos were visually inspected for the presence or absence of water in the stream channel. Note that actual flow cannot always be positively identified, since the photo might capture standing water instead of flowing water. If the streamflow is fast, ripples and whitewater can be seen around obstacles. At CAM3 and CAM5, the growth of reed canary grass can block the view of stream channel at times.
- Most camera views include features which allow for a rough estimate of stream stage, but this option was not pursued.

3.3. Groundwater Piezometers

Groundwater levels were monitored in four near-stream piezometers beside Muck Creek and South Creek on the main prairie of JBLM (Table 2, Figure 1, Figure 2). These piezometers were installed during a previous phase of work. They extend 9'-13' below ground surface and ~2.5'-7' below the thalweg of the adjacent stream sections. Elevation measurements were made during installation by SPSSEG.



The piezometers are constructed of 1" diameter schedule 80 PVC with a 5'-long screen at the bottom. They were installed into an excavated pit and backfilled with native material. They were installed to below the thalweg of the adjacent stream and close to the stream within the reasonable limits of the installation equipment.

The water levels in the four piezometers were monitored with unvented pressure transducers. Seametrics LevelSCOUT Level Loggers were used with a 30 pounds per square inch (psi) range. Measurements were logged every 15 minutes and corrected for barometric pressure.

- Instrumentation and download dates:
 - 6 July 2022 – instrumentation of piezometers 1-4.
 - 28 Oct 2022, 17 March 2023 – downloads.
 - 6 October 2023 – retrieval of transducers.

Depth-to-water (DTW) was measured manually each time a piezometer or well was visited.

- Processing:

Piezometer data were corrected to remove barometric (air) pressure from total pressure reading of the transducers. Barometric pressure data was initially collected by a dedicated transducer at P1 from 15 May 2022 to 17 March 2023, recording every 15 minutes. This transducer was stolen sometime between the March and October 2023 downloads. For the later data collection period, barometric data from the weather station at McChord Air Force Base was used. These data were collected hourly at least and have 15 gaps of up to 12 hours between March and October 2023. Barometric data are also available from Anchor Anchor QEA, LLC (Anchor) barometric loggers (September 15, 2022 onward) and Pierce County automated weather stations in Muck Basin.
- P4 data loss:

The data record for P4 is only two weeks in July 2022. The transducer is believed to have been pulled out of groundwater by wildlife on 20 July 2023. The transducer was re-installed at the next download visit in October 2022 but did not record any further valid data due to an internal malfunction. In addition, the land around P4 was burnt by wildfire sometime between October and March 2023, melting the aboveground portion of the piezometer.



Table 2: Piezometer locations and placement.

Piezometer	Muck RM	Location	Period of record for this study	Approx. distance to center of stream	Vertical measurements
P1	~9.7	Muck Cr. above Johnson Cr. confluence	2022-07-06 to 2023-07-03	47'	Depth: 6.8 ft bgs Maximum depth below stream thalweg: 6.3 ft Bottom of piezometer: 329 ft amsl
P2	~10.2	Muck Cr. downstream of SR 507	2022-07-06 to 2023-07-03	30'	Depth: 8.7 ft bgs Maximum depth below stream thalweg: 7.2 ft Bottom of piezometer: 351 ft amsl
P3	~14.5 *	South Cr. above confluence with Muck Cr.	2022-07-06 to 2023-07-03	20'	Depth: 5.5 ft bgs Maximum depth below stream thalweg: 2.9 ft Bottom of piezometer: 400 ft amsl
P4	~14.6	Muck Cr. above confluence with South Cr.	2022-07-06 to 2022-07-20	18'	Depth: 9.5 ft bgs Maximum depth below stream thalweg: 6.3 ft Bottom of piezometer: 395 ft amsl

RM: River mile (distance along river's channel from confluence with the Nisqually River)

ft bgs: Feet below ground surface

ft amsl: Feet above mean sea level

* South Creek RM ~0.9 from the confluence with Muck Creek.

Associated data:

- Groundwater levels in piezometers 1-4 and water levels in adjacent streams for piezometers 1, 3, and 4 were collected by Coho from October 2019 to June 2020 (Attachment B).
- Precipitation data from nearby stations and PRISM dataset.
- Data from Anchor's stream gages (stage and discharge) ~~and water level monitors~~, mostly deployed from mid-September 2022 to November 2023. Reported streamflows are included here to compare with camera and piezometer data.



4. RESULTS AND DISCUSSION

The seasonal cycle of streamflow in Muck Basin is determined in large part by the seasonal precipitation pattern. Stream discharge typically rises after rainfall increases in the autumn and falls after rainfall slows in the late spring. During this study (May 2022-October 2023), monthly precipitation amounts were much lower than average in January and February, and March (Figure 3a). In contrast, April precipitation was higher than average. Over a two-week period in late March and early April of 2023 the basin received about three inches of precipitation, and a response to this heavy rainfall was observed at many monitoring points. The total precipitation for WY 2023 was approximately 70% of the 30-year normal (Figure 3b).

For the previous monitoring period of October 2019-June 2020 (WY 2020), the basin experienced an extremely wet January and low rainfall in November and April. Precipitation in WY 2020 was 89% of normal.

The stage and discharge of the major streams in Muck Basin were measured by Anchor over a similar period as the cameras and piezometers measurements (Figure 4). The gage for Muck Creek at Roy is upstream of CAMs 1-3 and 8 and downstream of CAMs 4-7 and Piezometers 1-4. The gages for South Creek and Muck Creek at 8th Avenue East are upstream of CAMs 4-7 and Piezometers 1-4.

Anchor (2024) reports that all the gaged stream locations experienced periods of no measurable flow between October 2022 to November 2023. Lacamas Creek had the fewest days without flow (10 days) whereas South Creek was dry for the longest amount of time (250 days). The hydrograph for South Creek exhibits the strongest response to precipitation, with sharply increasing flow followed by equally sharp decreases. Lacamas has a similar pattern, scaled to its lower average flow. Muck Creek at Roy and at 8th Ave. E has a muted response to precipitation. The hydrography for Muck Creek at 8th Ave E may be affected by a downstream beaver pond. The most noticeable feature of the hydrograph for Muck at Roy is the doubling of flow in April 2023.



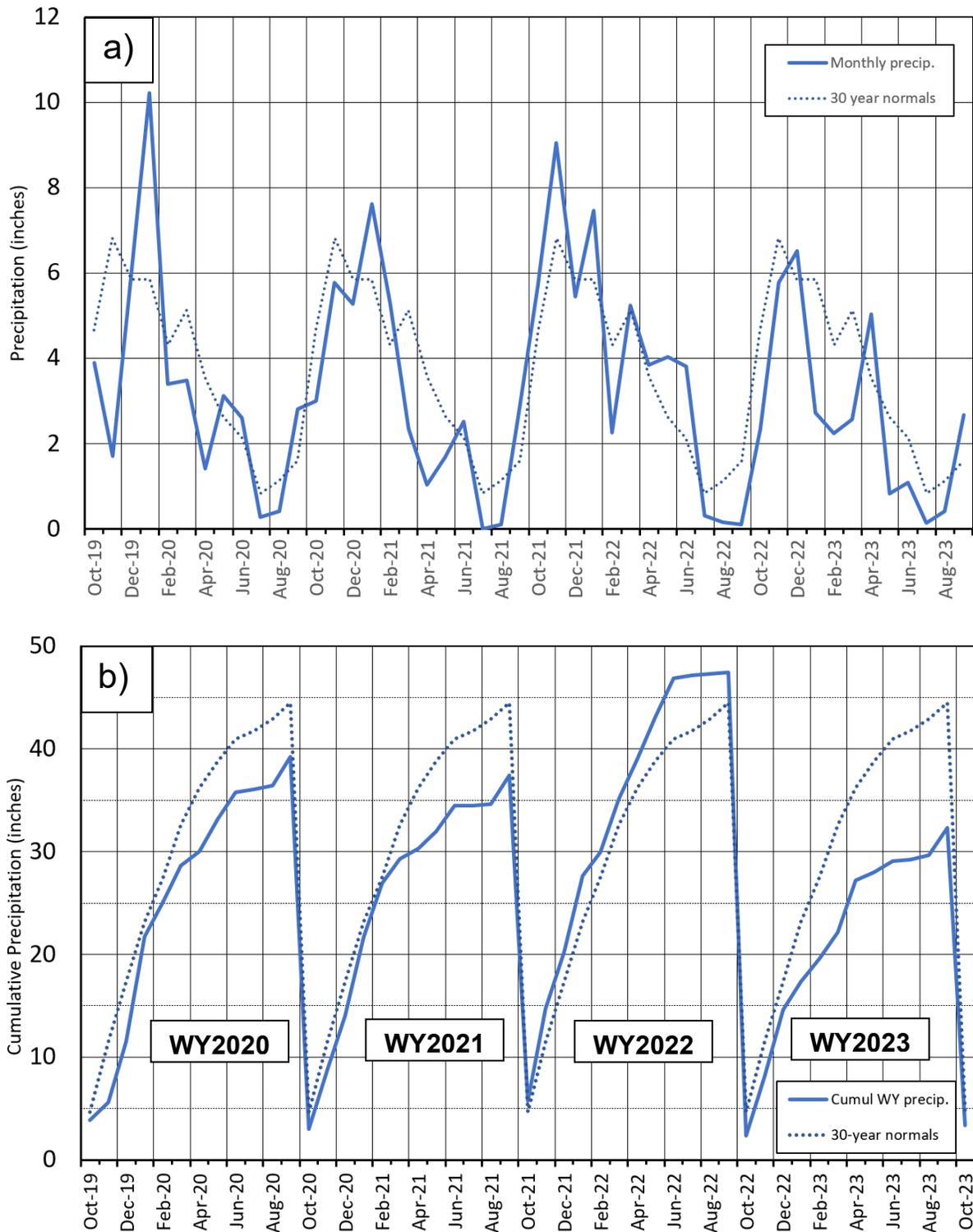


Figure 3: Precipitation estimated by PRISM for Muck Basin for recent water years: a) Monthly estimates. b) Cumulative water year.

(30-year normal shown for comparison.)



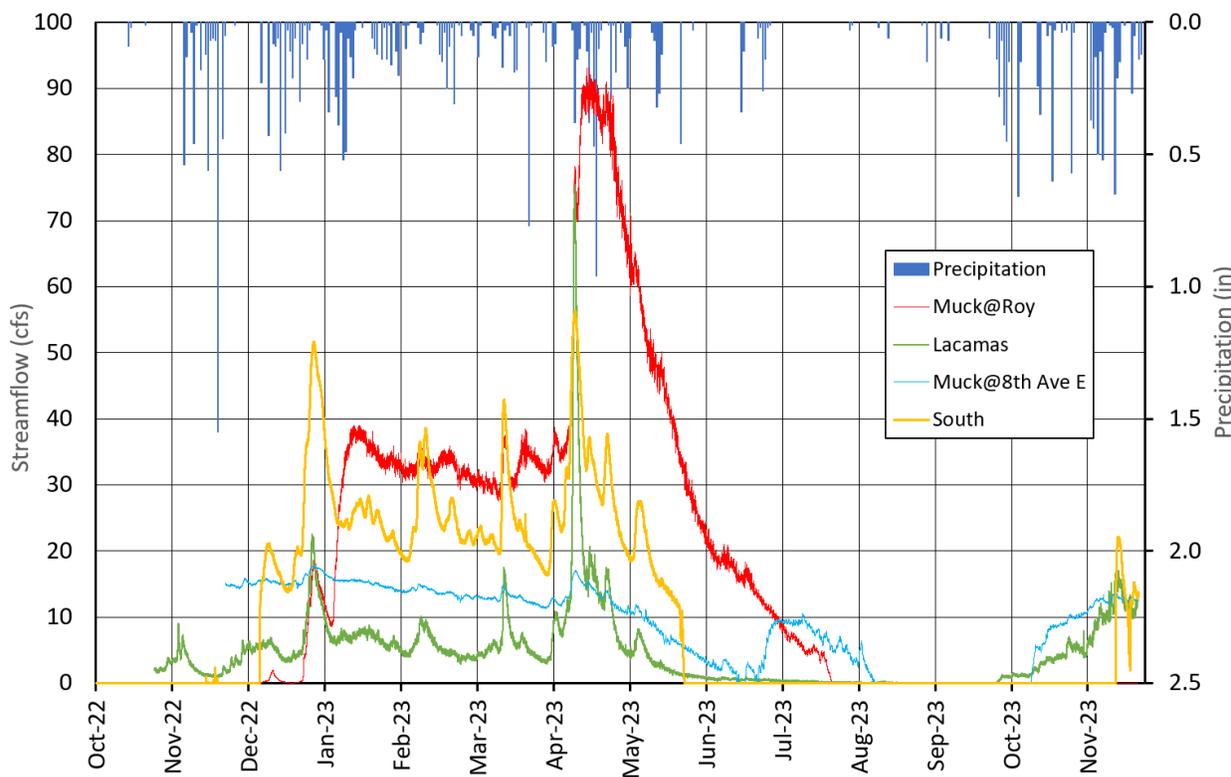


Figure 4: Stream discharge from Anchor gages.
(Inverse scale on righthand axis is for precipitation bars.)

4.1. Streamflow Observations by Time-Lapse Cameras

The time-lapse cameras monitor two different areas of Muck Creek that experience intermittent flow (Figure 1):

1. Lower Muck Creek.
2. Muck Creek on the prairie above the lakes-and-wetlands chain.

4.1.1. Lower Muck Creek (CAMs 1-3 and CAM8)

Below Roy, after leaving the lakes-and-wetlands chain, Muck Creek crosses a section of outwash plain and then cuts down through outwash deposits to reach the Nisqually River. The gradient increases as the stream nears its mouth (Figure 2). Lower Muck includes Exeter Springs.

The stream at the two downstream cameras (CAM8 and CAM1) had continuous flow from the start of monitoring in May 2022 until the fall of 2023 (Figure 5). In qualitative



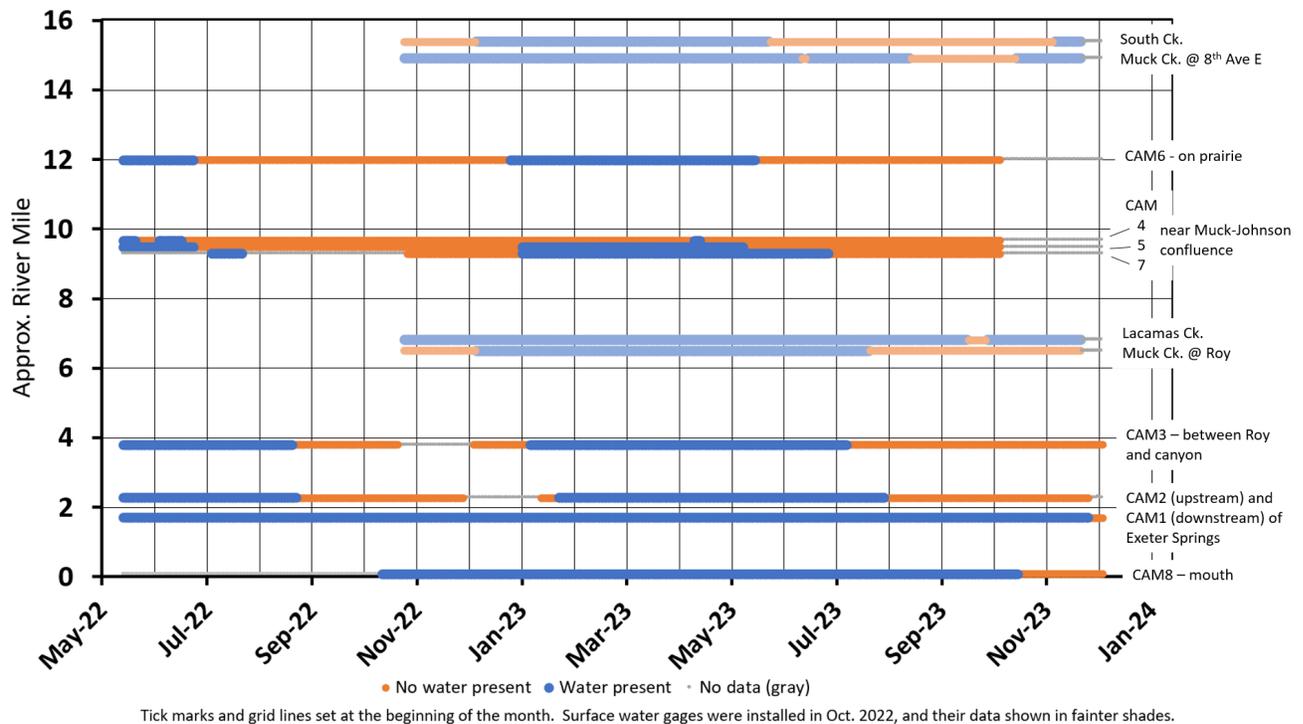


Figure 5: Presence and absence of water at all cameras and gages.

observations of stage, the water level in the stream near the mouth of the creek (CAM8) follows the pattern of the gage at Roy with some delay. The water level rose in late January, steadied for the next two months, then rose from 12 April to early May. It then dropped steadily through the summer and the channel was dry by mid-October. Similarly the water level in the stream near CAM1 peaked around the beginning of May. Water was visible in the channel at this location until the last camera photos were taken in November, but it appears to be in disconnected puddles for the final days of the monitoring period.

The stream at the two upstream cameras (CAMs 2 and 3) experienced several months of dry periods starting in late summer in both 2022 and 2023 (Figure 5). At both locations, the stream was flowing in 2022 until approximately 24 August 2022. Streamflow returned around 8 January 2023 at the upstream camera (CAM3) and around 22 January 2023 at the downstream camera (CAM2). The channel at CAM2 was dry by the end of July 2023, and the channel at CAM3 dried up to 3 weeks before then, although the exact date can't be determined due to the heavy vegetation over the channel.



The impact of groundwater input from Exeter Springs and possibly other nearby locations is seen in the contrast between CAMs 2 and 3 upstream of the springs vs. CAMs 1 and 8 downstream. In both 2022 and 2023, the downstream locations had flow for 2.5 to 4 months in the late summer and fall while the upstream locations were dry.

4.1.2. Muck Creek above the lakes-and-wetlands chain (CAMs 4-7)

The stream sections observed in this area are dry most of the monitoring period (Figure 5). After holding steady across the prairie, the stream's gradient increases as the stream enters the lakes-and-wetlands chain. The stream is underlain by recessional outwash (CAM6) or by a layer of wetland deposits on top of recessional outwash in the lake-and-wetland chain (CAMs 5 and 7). The recessional outwash is coarse-grained and permeable. CAM4 is in the lakes-and-wetlands chain, but the stream channel is composed of outwash carried in from upstream areas.

The driest conditions were observed by CAM4 above the confluence of Muck and Johnson Creeks. This stretch of stream is recognized as the most severe bottleneck limiting fish passage into upper Muck and South Creek subbasins. In the time-lapse photos, the stream was flowing when the camera was installed in May 2022 and flowed for a total of 20 days in May and June 2022 before drying up for the summer. Only four days of flow were observed at this location in WY 2023, which followed heavy rainfall in early April 2023 and were concurrent with stream hydrograph peaks (Figure 4). In the 2019-2020 study, the transducer set in the stream bed detected surface water for almost 40 days in January and February (Attachment B).

Stream sections observed by these cameras (CAMs 4-7) are supplied by two different water sources. The reaches observed by CAMs 4 and 6 rely on streamflow that crosses the prairie. The piezometer study in 2019-20 did not detect any groundwater contributions to streamflow in these areas. Instead, streamflow is lost by infiltration to the subsurface as it crosses the prairie, with stream drying progressing upstream from west to east (Sinclair, 2001; Savoca and others, 2010). In the camera data, streamflow is often present at CAM6 but lacking at CAM4 (Figure 5). During a field visit in March 2023, flow at CAM6 had disappeared within 1.5 miles downstream (Figure 6).





Figure 6: Muck Creek at CAM6 on 17 March 2023, looking downstream. Water depth estimated at 1.5+ feet.

The stream sections observed by CAMs 5 and 7 receive surface water from Johnson Lake and Watkins Spring. These features are fed by groundwater flowing from the east through the outwash deposits into the lakes-and-wetlands chain, and groundwater likely seeps into the stream directly as well.

4.2. Observations of groundwater levels near streams by piezometers

Four piezometers installed in 2019 were re-instrumented for this study (Figure 1, Attachment B). Transducers were installed in July 2022 and recorded data until July 2023. The collected data suggests that groundwater contributes to surface water in the lakes-and-wetlands chain and that surface water flows into groundwater on the outwash plain east of the chain.



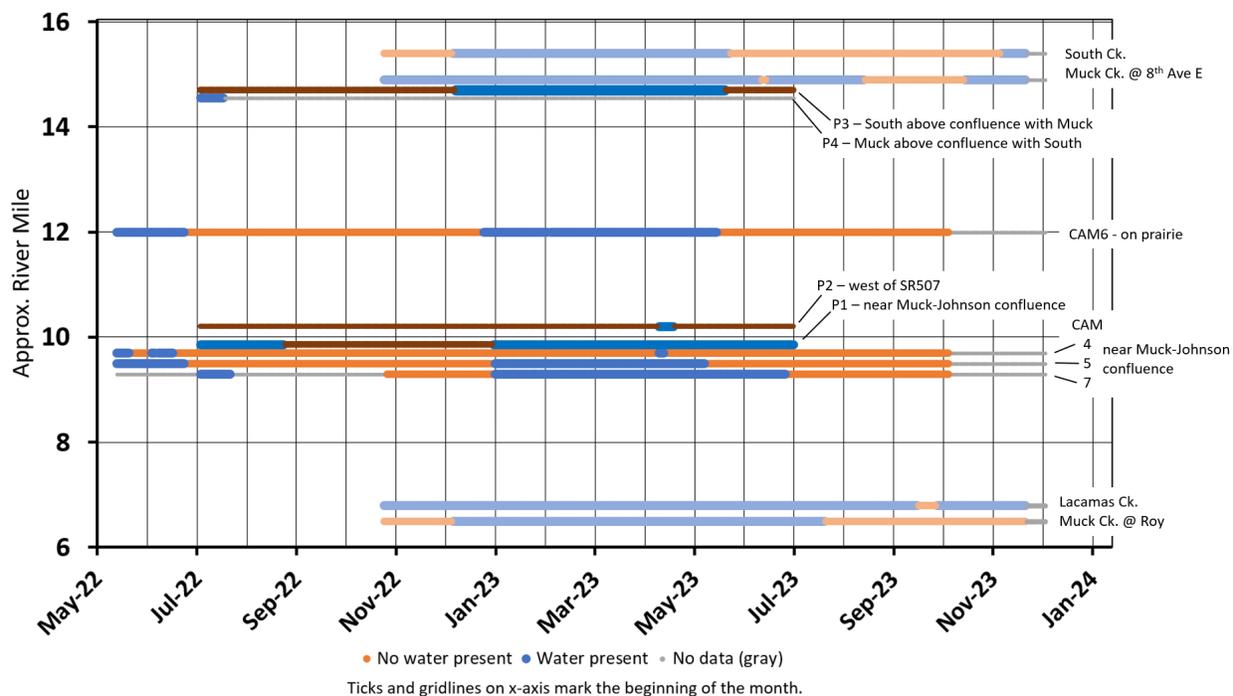


Figure 7: Presence and absence of water at cameras, piezometers, and gages at and above Roy.

(Muck CAMs and Piezo Wet Dry.xlsx)

- **Muck Creek above confluence with Johnson Creek (P1):** Groundwater levels in this piezometer reflect the groundwater table of the lakes-and-wetlands chain. The change of the groundwater over time generally mirrors that of the water level of Chambers Lake (Figure 8). Groundwater levels rise more than surface water levels following concentrated rainfall in early Jan., late Feb., late March, and especially in mid-April. In the vicinity of the Muck-Johnson confluence the groundwater levels rise in early January 2023 within a day of the appearance of streamflow at CAMs 5 and 7.
- **Muck Creek near SR 507 (P2):** Groundwater was detected in P2 for 10 days during the 12-month monitoring period (12-21 April 2023; Figure 9). When present, groundwater levels were more than 2' below the thalweg of the nearby stream channel, so groundwater was not contributing to the stream. The 10-day period brackets the four days during which CAM4 observed streamflow in Muck Creek above the Muck-Johnson confluence. The observed groundwater was likely contributed by surface water in Muck Creek infiltrating into the underlying sediments. As observed elsewhere, conditions at this piezometer were drier than during the 2019-20 study, when groundwater was present for over 2 months.
- **South Creek (P3):** The groundwater level in this piezometer rises above the elevation of the thalweg of the adjacent stream by several feet at times. These data cannot indicate in which direction water moved between



groundwater and surface water, but in 2019-20, gradients at this location always indicated flow from surface water into groundwater.

The groundwater levels over time match those of the surface water stage recorded by the South Creek gage, approximately one-half mile upstream (Figure 10). The general temporal pattern of groundwater levels is similar to that observed in 2019-20. During both studies, ground water levels rose in mid-December, persisted for a few months and then gradually declined.

- **Muck Creek upstream of confluence with South Creek (P4):** Due to a variety of issues, the transducer at P4 recorded data only for two weeks in July 2022. During this period, groundwater levels were more than 2' below the thalweg of the nearby stream channel, so groundwater was not contributing to the stream (Figure 11). More extensive data from this location from 2019-2020 is shown in Attachment B.

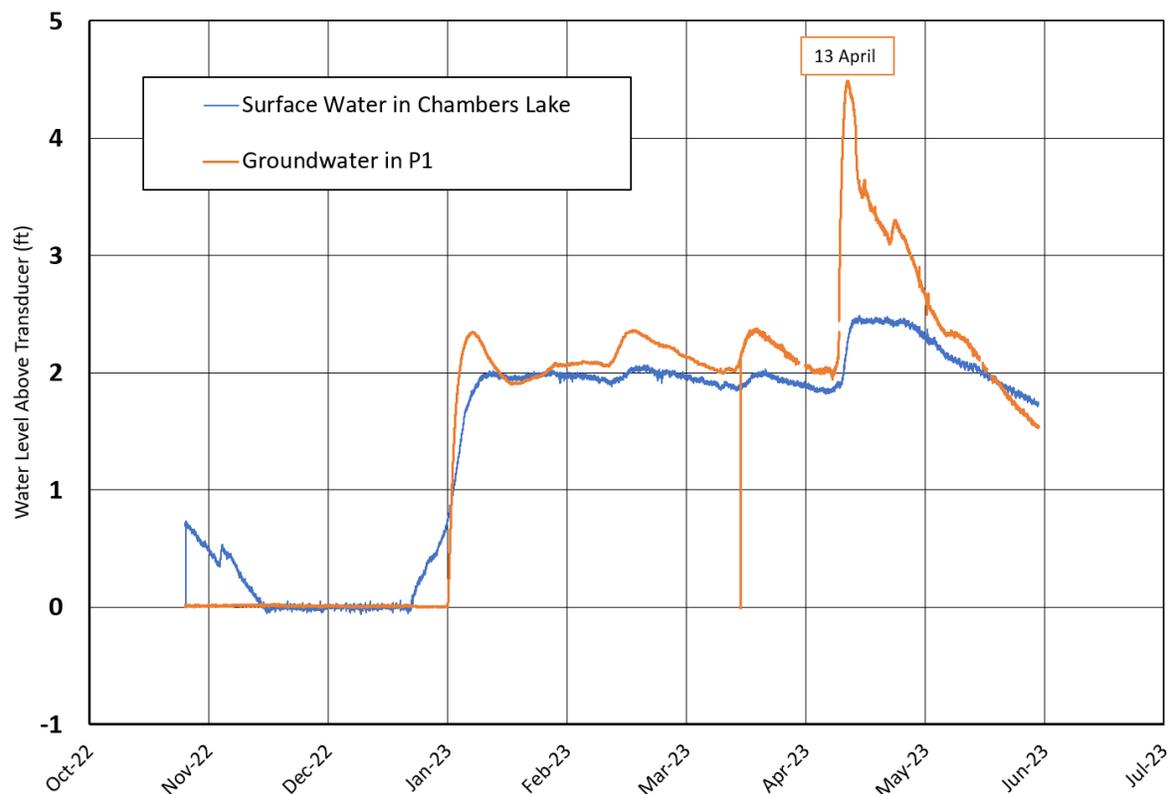


Figure 8: Comparison of groundwater levels in P1 with stage in Chambers Lake.
(Data sets are not to the same datum. Ticks on the x-axis are placed at the beginning of each month.)



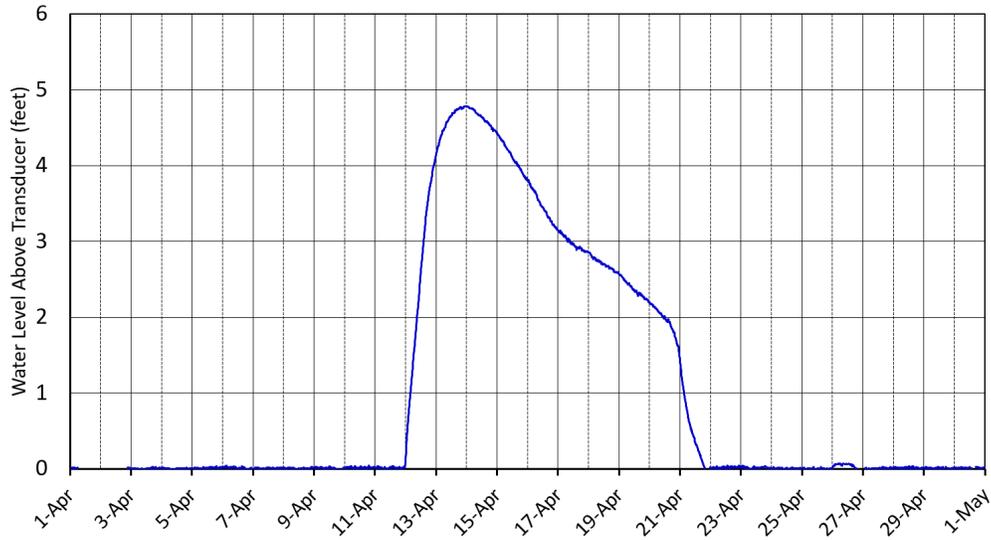


Figure 9: Period of groundwater presence in piezometer P2 between July 2022 and July 2023.
(CORRECTED-Muck P2 2022-07-02 to 2023-07-03.xlsx)

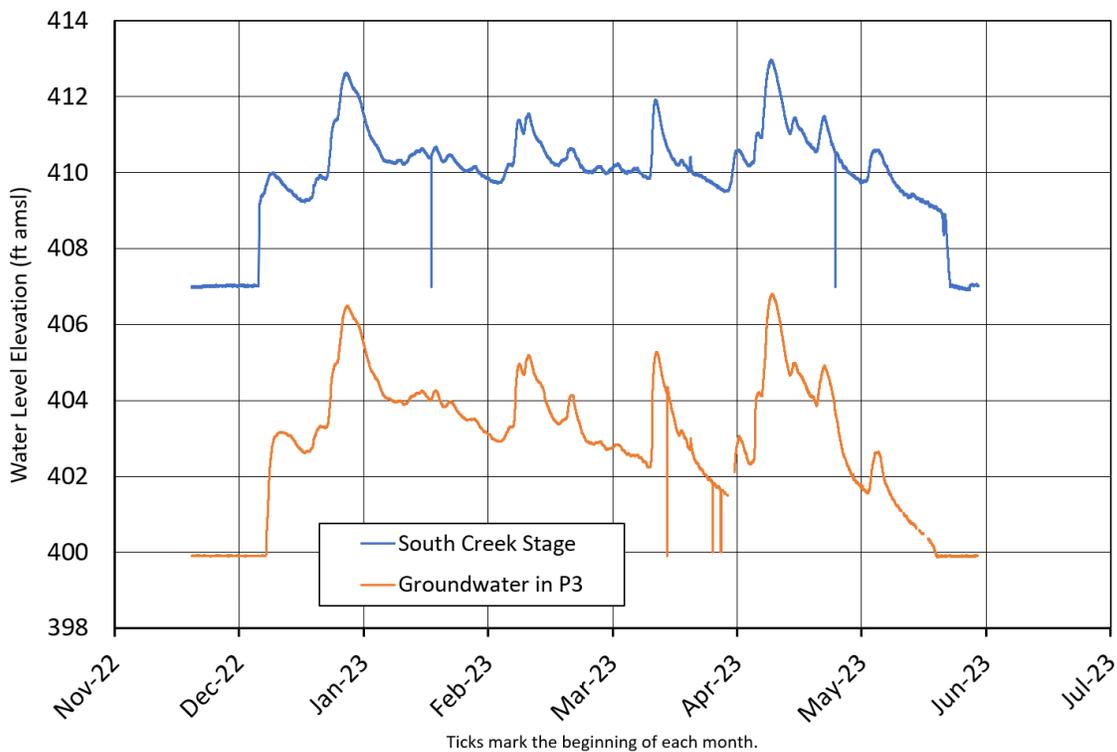


Figure 10: Comparison of groundwater levels in P3 with stage at South Creek gage.

South Creek stage from gage approximately one-half mile upstream of P3. Elevation of the stream thalweg at P3 is approximately 403 ft amsl.
(P3 Piezo and South Creek Stage.xlsx)

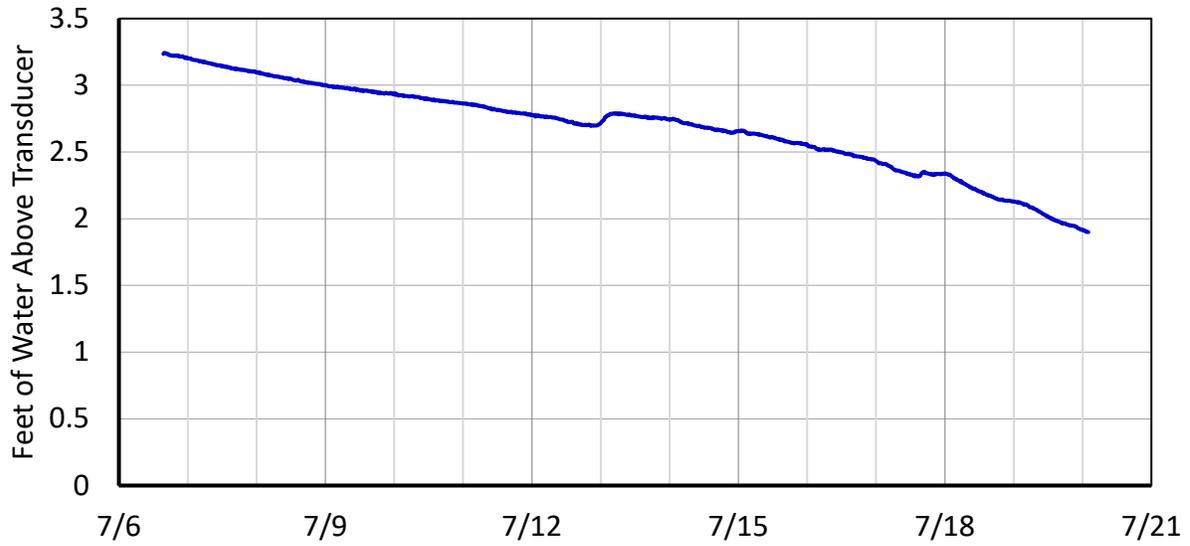


Figure 11: P4 groundwater levels, July 2022.
CORRECTED-Muck P4 2022-07-03 to 2022-10-28.xlsx



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- Savoca, M.E., W.B. Welch, K.H. Johnson, R.C. Lane, B.G. Clothier, and E.T. Fasser, 2010, Hydrogeologic framework, groundwater movement, and water budget in the Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington. U.S. Geological Survey Scientific Investigations Report 2010-5055, 46 pp.
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- Wilhelm, S.R. and C.V. Pitre, 2021. Hydrogeologic Influences on Streamflow in Muck Creek Basin. Prepared for South Puget Sound Salmon Enhancement Group, 147 pp.

ATTACHMENTS:

- Attachment A Time-lapse camera operating instructions.
- Attachment B 2019-2020 groundwater levels and stream stages.

ELECTRONIC DATA:

- Groundwater levels from piezometers (to be posted to EIM).
- Time lapse photos. Long-term repository with NRF.
- Time lapse videos – posted online and to project data collection. Long-term repository with NRF.



ATTACHMENT A

TIME-LAPSE CAMERA OPERATING INSTRUCTIONS



Time Lapse Camera Operation

Date: 15 January 2024

Authors:

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(206) 276-2293

Chris Pitre, chris@cohowr.com

(206) 406-9596

Programming Cameras for Streamflow Observation

(1-hour interval, individual photos)

Parameters here are those used for Muck Creek streamflow project, 2022-23.

Open camera case using latch on the side.

If first use for camera, remove plastic film covering lens and light sensor in front and from view screen inside camera case.

Insert micro-SD card to left of view screen (should hear a distinct “click” when it is fully inserted).

Insert 12 AA batteries (4 below view screen and 8 under opposite panel). Camera turns on automatically when batteries first inserted.

If camera does not turn on automatically, press and hold the POWER button until opening screen appears (“Technaxx/Germany”) and then will see camera view with various icons and numbers in corners.

If micro-SD card not yet inserted or is not fully inserted, will see “Memory card missing” in orange in middle of screen when turned on, as well as orange X through SD card icon in upper right and “00000” as number of available frames in memory.

If it’s the first start-up after batteries inserted, will be asked to choose language – press up or down arrows to choose “English”. Press “OK”.

Note: Camera will turn off automatically 3 minutes after last activity/button-pressing if time lapse video/photo program is not running.

To program:

- Press MENU. Will see title of “Settings” with Mode / Interval / Battery / Storage Available parameters indicated below.
 - General info - Pressing up and down arrows will move to previous or next setting.
-

- Pressing OK will enter menu for a particular setting. Use up and down arrows to scroll through the options. Once desired setting is chosen, press OK to accept current settings and return to higher level.
- Press MENU again to return to view screen.

For specific settings, in order:

- Press down triangle to see Mode options. Select “Timing Photo” with up or down triangles.
- Press OK and will be moved onward to “Time Lapse” settings.
 - Use up and down arrows to change hours and MODE to move onto minutes and seconds.
 - Press OK to return to main MODE screen.

When settings are as desired, exit Settings by pressing MENU. Can now press POWER button briefly to begin photo/video acquisition program or press with a long hold to shut down camera.



Field Deployment of Time-Lapse Cameras

Cameras have been set to collect timed photo series (*.jpg), one per hour, 24 hr per day, at 2 MP resolution. Can only see actual camera view by taking some photos and opening camera to examine.

Find mounting location above seasonal high-water mark. Try to point camera to the north to avoid sun glare in photos at some times of day. This is not crucial because only looking for daily record of streamflow, not hourly. Use straps and wedges to position camera for view of stream. Remove vegetation branches, etc., between camera and stream.

Once camera is mounted, take test image to determine if camera view is correct:

1. Turn camera on (long press of POWER button – upper left button of 6-button control panel). Should see TechNaxx logo then camera's current view on screen.
2. Begin timed photo collection by pressing POWER button briefly.
3. Camera will begin counting down seconds from 15 in red numbers in center of screen and green light will flash on front of camera. Close and latch camera before countdown ends so will capture exact view of mounted camera.
4. After 30 seconds (just to be safe) have passed, open camera while keeping it mounted.
5. Briefly press POWER button. Should see "Timing photo stop" on blue screen, then see camera's current view on video screen. *(If you mistakenly press any other button instead, will have to pull batteries and re-program whole camera – call us for assistance.)*
6. Press MODE two times, so see right-pointing blue triangle in upper left.
7. Look at last photo collected by camera. The numbers in the upper right indicate which photo is displayed out of total photos on the Micro SD card. Make sure you are looking at the highest numbered photo (the two numbers are equal). If not, use the down and up buttons to navigate to it.

If the view is NOT GOOD:

- a. Adjust camera mounting angle, height, position, etc.
- b. Press MODE once to see blue camera symbol in upper left. Will see camera's current view on screen.
- c. Return to step #2.

If the view is GOOD:

- a. Press MODE once to see blue camera symbol in upper left. Will see camera's current view on screen.
- b. Begin timed photo collection by pressing POWER button briefly. Camera will begin counting down seconds from 15 in red numbers in center of screen. Close and latch camera.
- c. Note coordinates. Take photos to document camera location. Take photo from "over the camera's shoulder" to capture approximate camera's view.



- d. Dry camera top if damp. Put plumber's tape over top seam of camera, with some extra at each end.



Switching Micro SD Cards in Time-Lapse Cameras

Muck Creek Restoration 2022-23

Cameras have been set to collect timed photo series (*.jpg), one per hour, 24 hr per day, at 2 MP resolution.

Basic procedure –

1. Evaluate exterior camera condition:
 1. Any vegetation or other objects blocking view? If so, remove vegetation.
 2. Any signs of damage to camera housing? If might affect camera operation, replace camera. See procedure for newly installed cameras (separate sheet of paper).
 3. Any failure of mounting strap or wedge items? Repair, replace, check camera view after replacing micro SD card.
2. Evaluate camera view:
 - a. Remove waterproof tape from top if present and unlatch camera at side to open interior.
 - b. Briefly press POWER/START/STOP button. Should see “Timing photo stop” on blue screen, then see camera’s current view on video screen.
 - c. Press MODE two times, so see right-pointing blue triangle in upper left.
 - d. Look at last photo collected by camera. The numbers in the upper right indicate which photo is displayed out of total photos on the Micro SD card. Make sure you are looking at the highest numbered photo (the two numbers are equal). If not, use the down and up buttons to navigate to it.
 - e. Note results in field notebook. If not satisfied with view, adjust camera mounting angle, height, position, etc. (Will test after swapping micro SD card.)
3. Check battery status (see symbol in lower right). Replace if necessary. Will have to re-program for photo capture. (See other set of instructions.)
4. Clean camera lens with lens cloth.
5. Swap micro SD cards:
 - a. Remove current micro SD card. Note card number in field notes and place card in cardholder marked “To Download”.
 - b. Install new micro SD card from cardholder marked “Blank”. Note card number in field notes.
6. Once new micro SD card installed, take test image to determine if camera view is correct:
 - a. Start new photo collection session by pressing POWER/START/STOP button briefly. Camera will begin counting down seconds from 15 in red numbers in center of screen and green light will flash on front of camera. Close and latch camera before countdown ends so will capture exact view of mounted camera.
 - b. After 30 seconds (just to be safe) have passed, open camera while keeping it mounted.



- c. Briefly press POWER/START/STOP button. Should see “Timing photo stop” on blue screen, then see camera’s current view on video screen.
 - d. Press MODE two times (may have to press third time if double-pressed quickly) to see right-pointing blue triangle in upper left.
 - e. Look at last photo collected by camera. The numbers in the upper right indicate which photo is displayed out of total photos on the Micro SD card. Make sure you are looking at the highest numbered photo (the two numbers are equal). If not, use the down and up buttons to navigate to it.
7. If view is satisfactory, re-start photo collection session:
- a. Press MODE once to see blue camera symbol in upper left. Will see camera’s current view on screen.
 - b. Begin timed photo collection by pressing POWER/START/STOP button briefly. Camera will begin counting down seconds from 15 in red numbers in center of screen.
 - c. Close and latch camera.
 - d. Place waterproof tape over top seam of camera.
8. If view is not satisfactory, adjust camera orientation, possibly using with wooden wedges behind camera to angle downward. If use wedges, it’s best to screw them into tree supporting camera so they don’t slip. May want to pre-drill holes in wedges so they don’t split. After camera position adjusted, return to Step #6.



Time Lapse Camera Field Supplies List

- Spare camera, pre-programmed and labeled
- Micro-SD cards for swap and holder for retrieved cards
- Instructions for swapping cards and re-starting camera
- Lens cloth to clean lens
- Waterproof tape such as 10 mil PVC pipe tape and buck knife to cut it
- Spare set of 12 AA lithium batteries
- Mounting straps – ratchet and fast-clip buckle
- Wood wedges to adjust mounting
- Cordless drill and screws

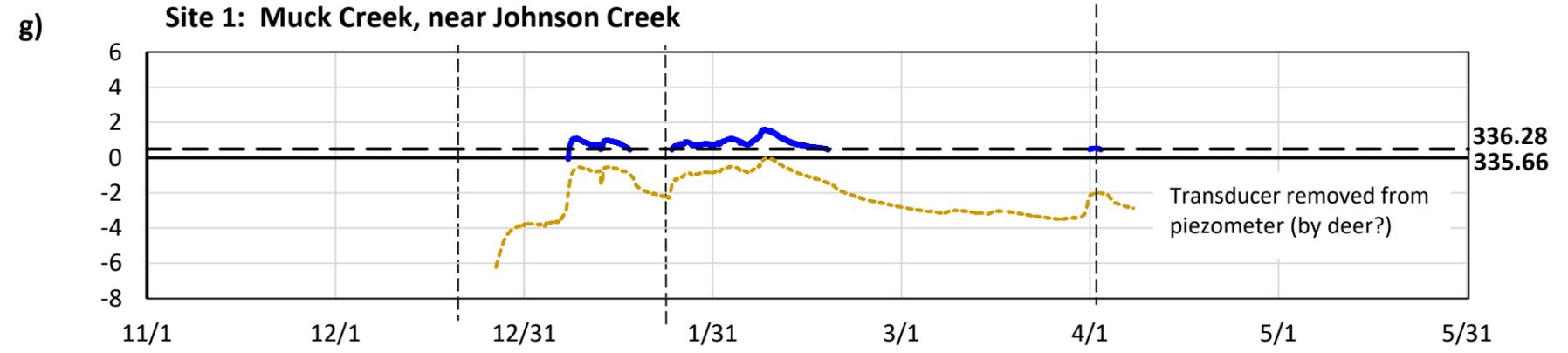
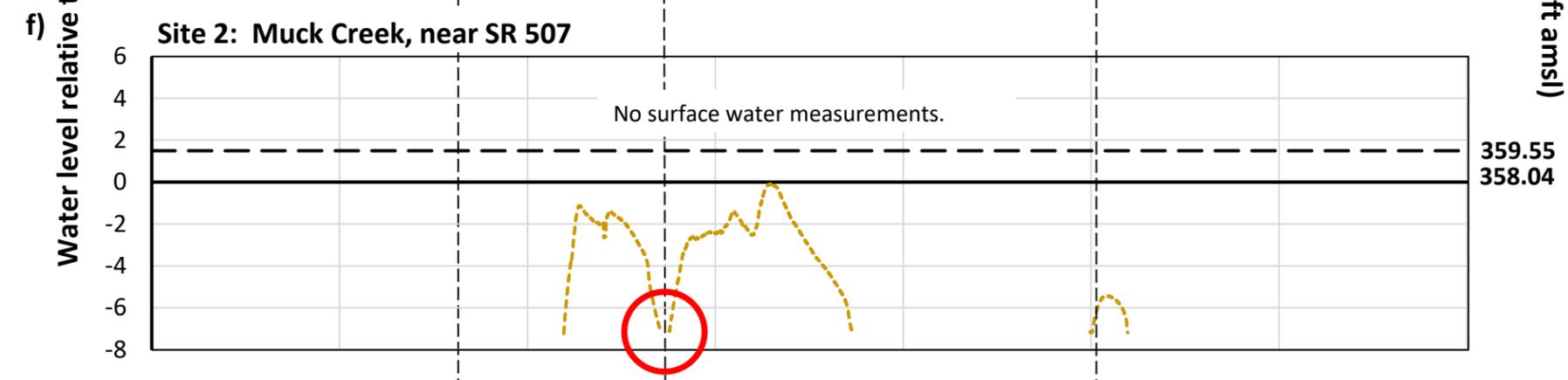
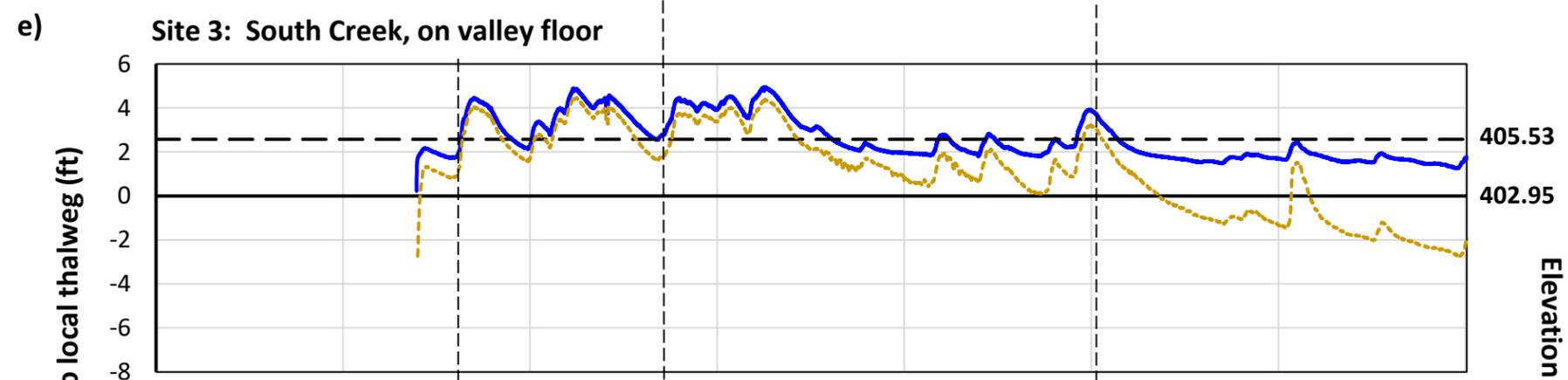
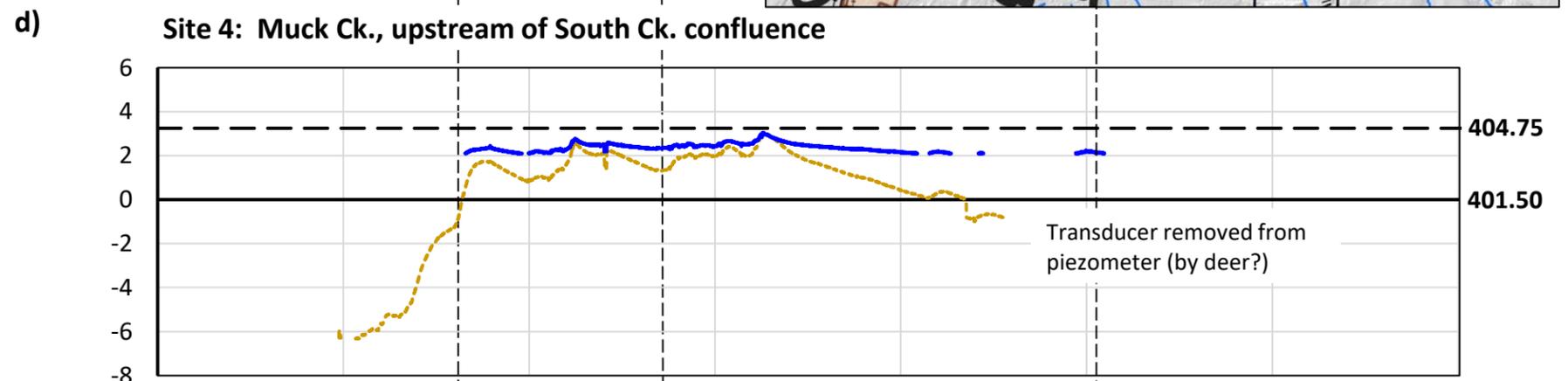
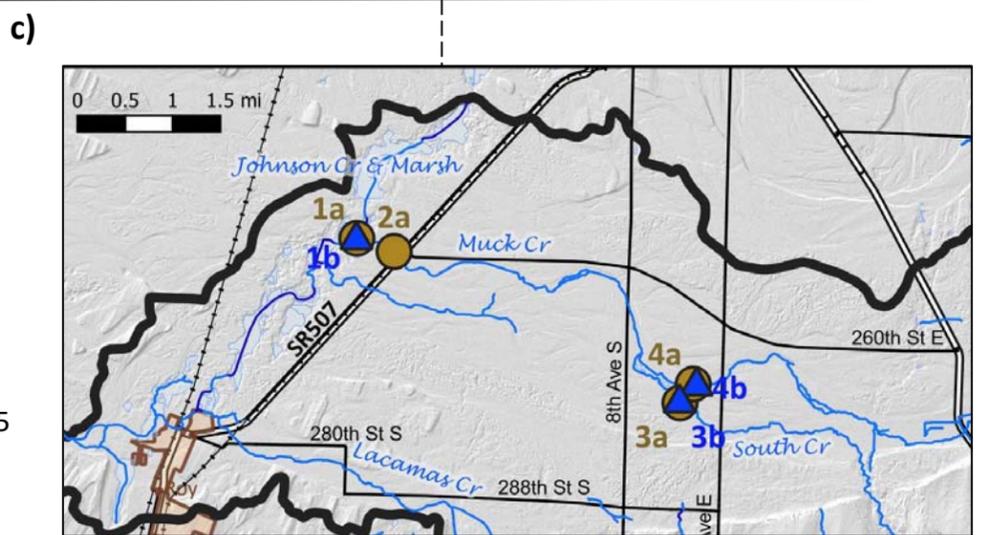
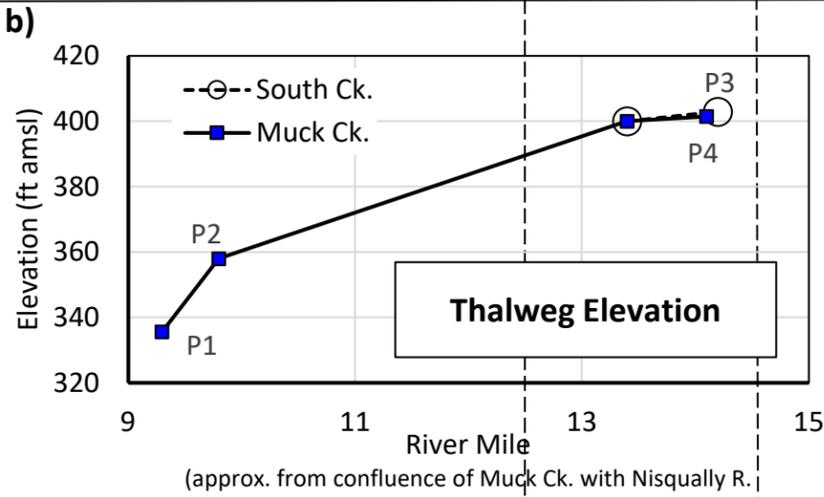
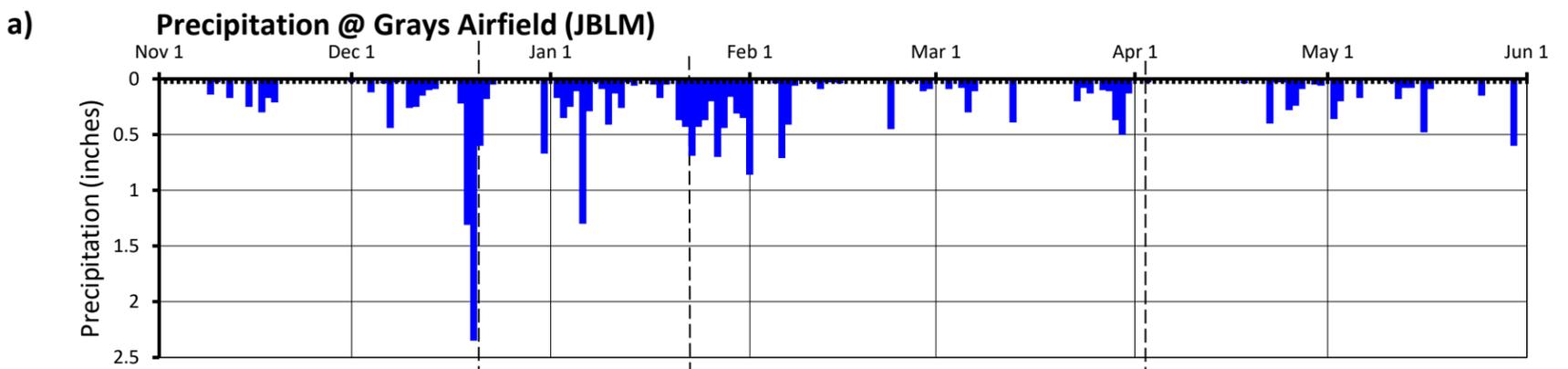
BRING MACHETE and/or PRUNERS to clear brush blocking camera's view.

BRING TABLET or SMARTPHONE to find camera and document conditions.



ATTACHMENT B

2019-2020 GROUNDWATER LEVELS AND STREAM STAGES



- Surface water
- Groundwater
- Ground surface at the piezometer
- Elevation of stream channel thalweg

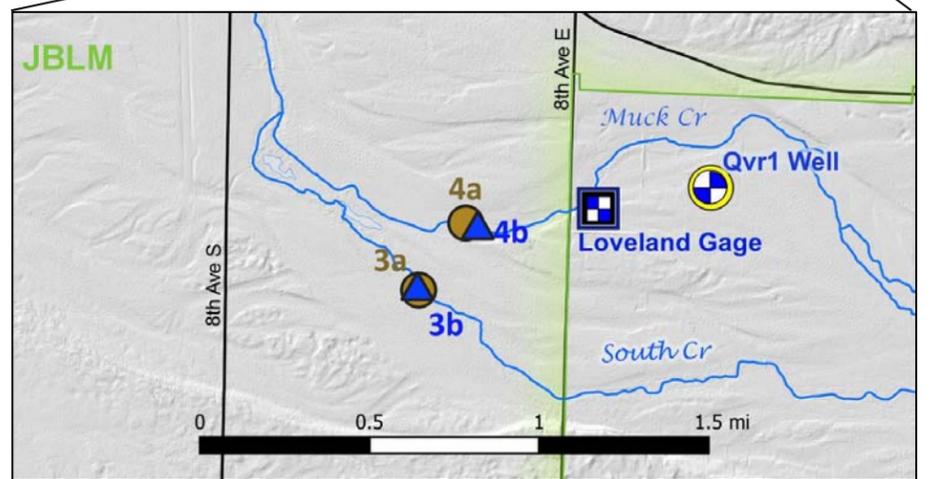
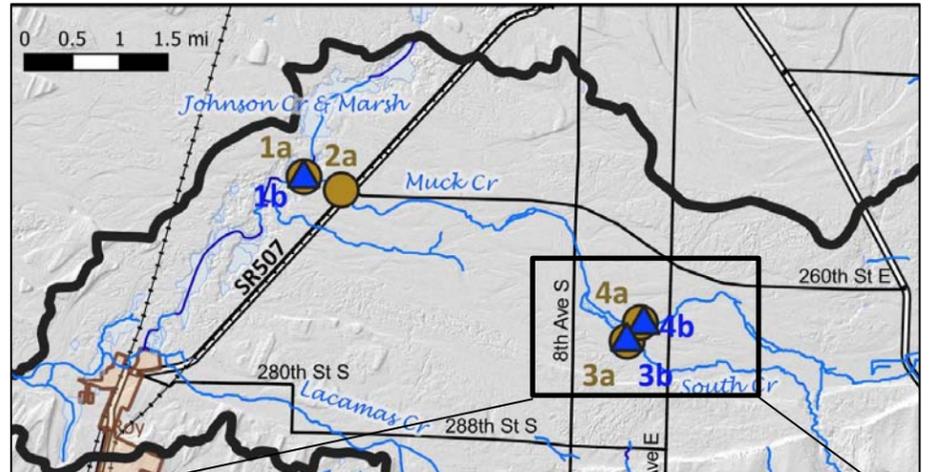
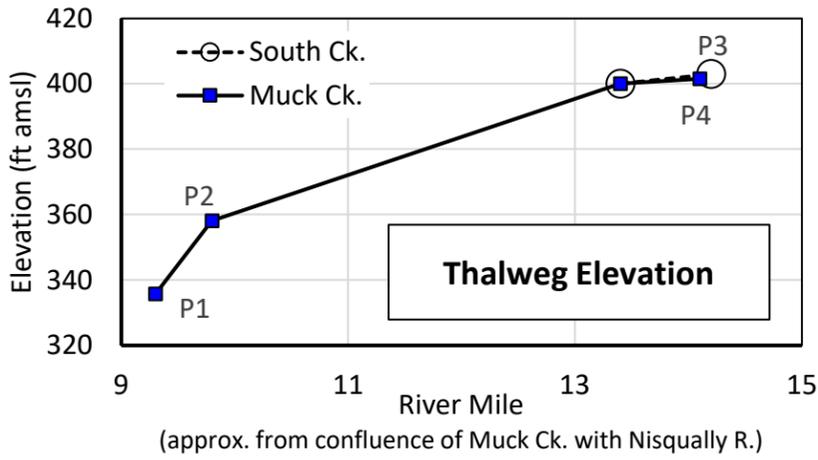
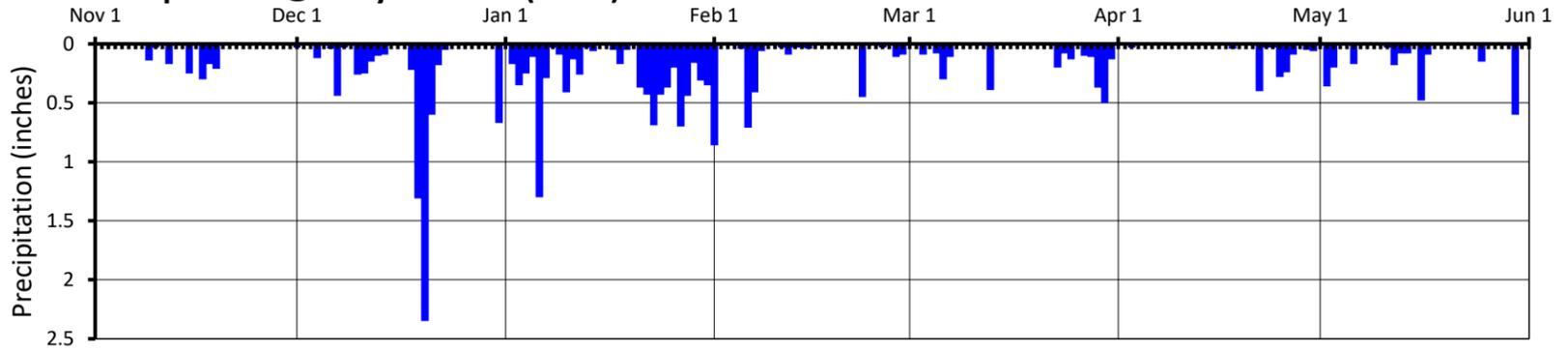
Gaps in the record are caused by deer pulling transducers out of the piezometers (P1 & P4), and water levels dropping below the transducer setting.

Figure 1
Stage and groundwater levels -
DRAFT by site (2019-2020)

Nisqually River Foundation
Muck Creek Restoration

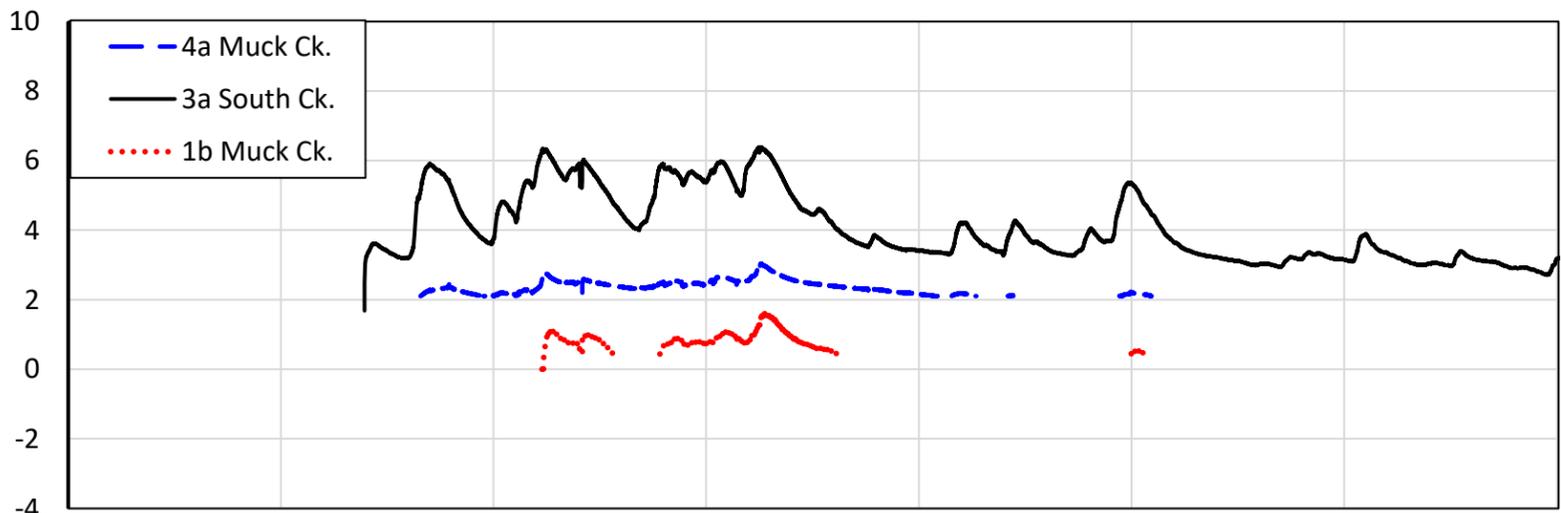


Precipitation @ Grays Airfield (JBLM)

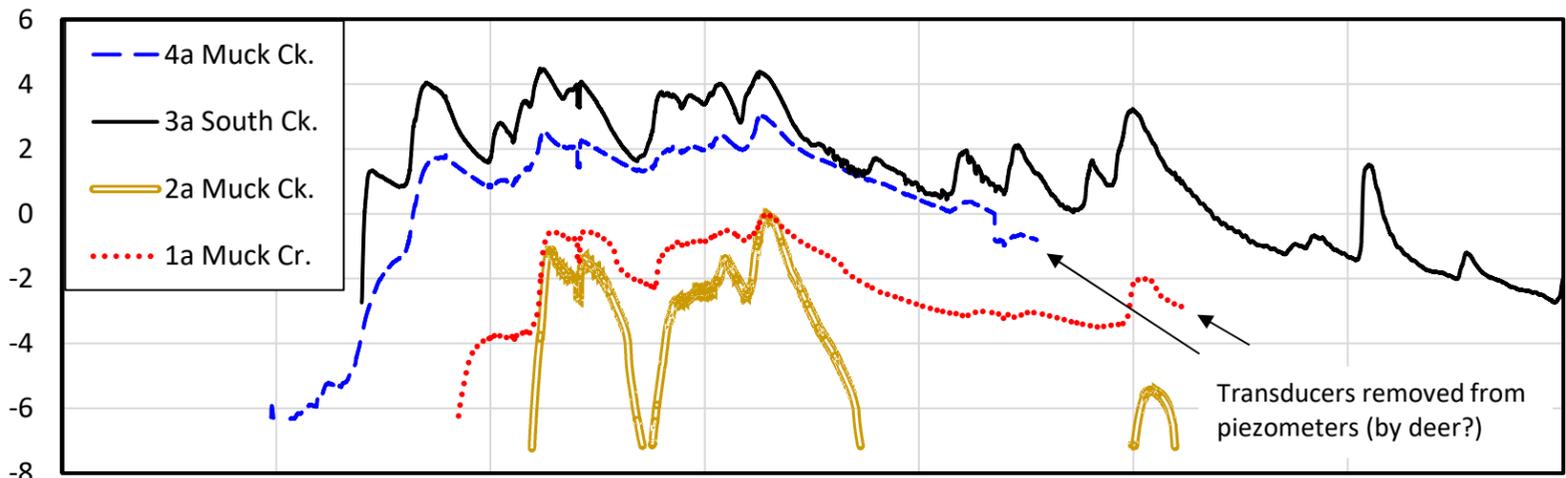


Water level relative to local MUCK CREEK thalweg (ft)

Surface water levels



Groundwater levels



- Surface water
- - - Groundwater
- - - Ground surface at the piezometer
- Elevation of stream channel thalweg

Gaps in the record are caused by deer pulling transducers out of the piezometers (P1 & P4), and water levels dropping below the transducer setting.

Figure 2
Stage and groundwater levels - by surface and groundwater (2019-20)

DRAFT
Nisqually River Foundation
Muck Creek Restoration



Appendix C
Muck Creek Basin Water Balance
Component Estimates



Technical Memorandum

Date: January 29, 2024

Coho Project: MUK-04.4

To: Merri Martz, Anchor QEA

mmartz@anchoragea.com

From: Sherry Wilhelm, Coho Water Resources

sherry@cohowr.com

cc: Robert Montgomery, Anchor QEA
Chris Pitre, Coho Water Resources

rmontgomery@anchoragea.com
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RE: MUCK CREEK BASIN WATER BALANCE COMPONENT ESTIMATES

1 PURPOSE & PRIMARY FINDINGS

This technical memorandum presents estimates of water balance components in Muck Creek basin. Coho Water Resources, LLC (Coho) conducted this work for the Nisqually River Foundation's (NRF) Muck Creek Stream Flow Restoration project as a subcontractor to Anchor QEA, LLC (Anchor QEA).

Low streamflows constrain salmonid access and use of most of Muck Creek Basin. Streamflow at a given location depends on "upstream" inputs. Streamflow observations have indicated interannual differences that affect salmonid access and utilization and have noted trends towards longer stretches of low/dry streamflow in key locations (South Puget Sound Salmon Enhancement Group [SPSSEG], 2022). Possible causes of these variations include:

- Replacement of prairie areas by "thirstier" (higher evapotranspiration [ET]) evergreen forest in western basin.
- Conversion of large areas from prairie and evergreen forest to agriculture and residential uses in eastern basin.
- Channelization of streams and drainage of wetlands.
- Higher air temperatures and more extreme seasonal precipitation patterns.

The purpose of this work is to present the following components of Muck Creek Basin's water balance to develop options to manage streamflow:

- **Precipitation:** monthly and water-year totals for recent years and for historic periods matching stream discharge data.
- **Evapotranspiration:** monthly and water-year estimates constructed from ET rates for major vegetation types and current distribution of those vegetation types in the basin.
- **Streamflow:** monthly and water-year totals from available data (1956-72, 2000-01).

Significant findings are:

- OpenET estimates average annual ET to range from 13" for prairie, to 33" for evergreen forest. ET for other land covers cluster between 25" and 30".
- Change in land cover from prairie to forest in the outwash plain, and from forest to agriculture and development on the uplands, have resulted in an approximately 13% net decrease in ET in the basin. This varies by subbasin from an increase of 31% in Middle Muck Subbasin to decrease of -26% in the South Subbasin.
- In the preliminary water balance precipitation is distributed as: 53% ET; 24% streamflow; and, 22% unknown. The unknown component may be attributed to canopy interception and out-of-basin groundwater flow.
- Consumptive domestic water use is 4.7 cubic feet per second (cfs; <1" per year) based on the 2010 census population of 33,000 people.

2 METHODS

The compilation of data into basin-specific, consistent data sets involved extraction, processing, and analysis of existing data and the compilation of basin and subbasin boundaries, area, and land cover. The analyses used British units (e.g., inches, ft, miles, cubic feet per second) to match those commonly used in the study area and report annual quantities on a water-year basis, which sums data from October through the following September and assigns it to the year in which the period ends (e.g., water year 2023 runs from October 1, 2022, to September 20, 2023). This water-year convention fits the natural precipitation pattern of the Puget Sound region, typically starting and ending in a dry period and encompassing the rainy season. All sources of geospatial and time series data are listed in Section 5.2.



2.1 Basin Boundary and Area

Different versions of the Muck Creek basin boundary have been created over time, including the United States Geological Survey (USGS) Watershed Boundary Dataset (WBD) that use Hydrologic Unit Code (HUC) delineations and the Nisqually Indian Tribe’s revisions to the Washington Department of Natural Resources’ Watershed Administrative Units (WAUs) for subbasins within the Nisqually Basin (Cutler, 2022).

For this work we use a boundary for the Muck Basin based on the work of the Pierce Co. Surface Water Management Division (SWMD) that expands upon the USGS HUC delineations (Figure 1). The SWMD is nearing completion of this project and shared their draft results for Muck Basin with us (Pierce Co. SWM, 2023). This work is consistent with the lidar-based stream network layer created by the SWMD and used in this project.

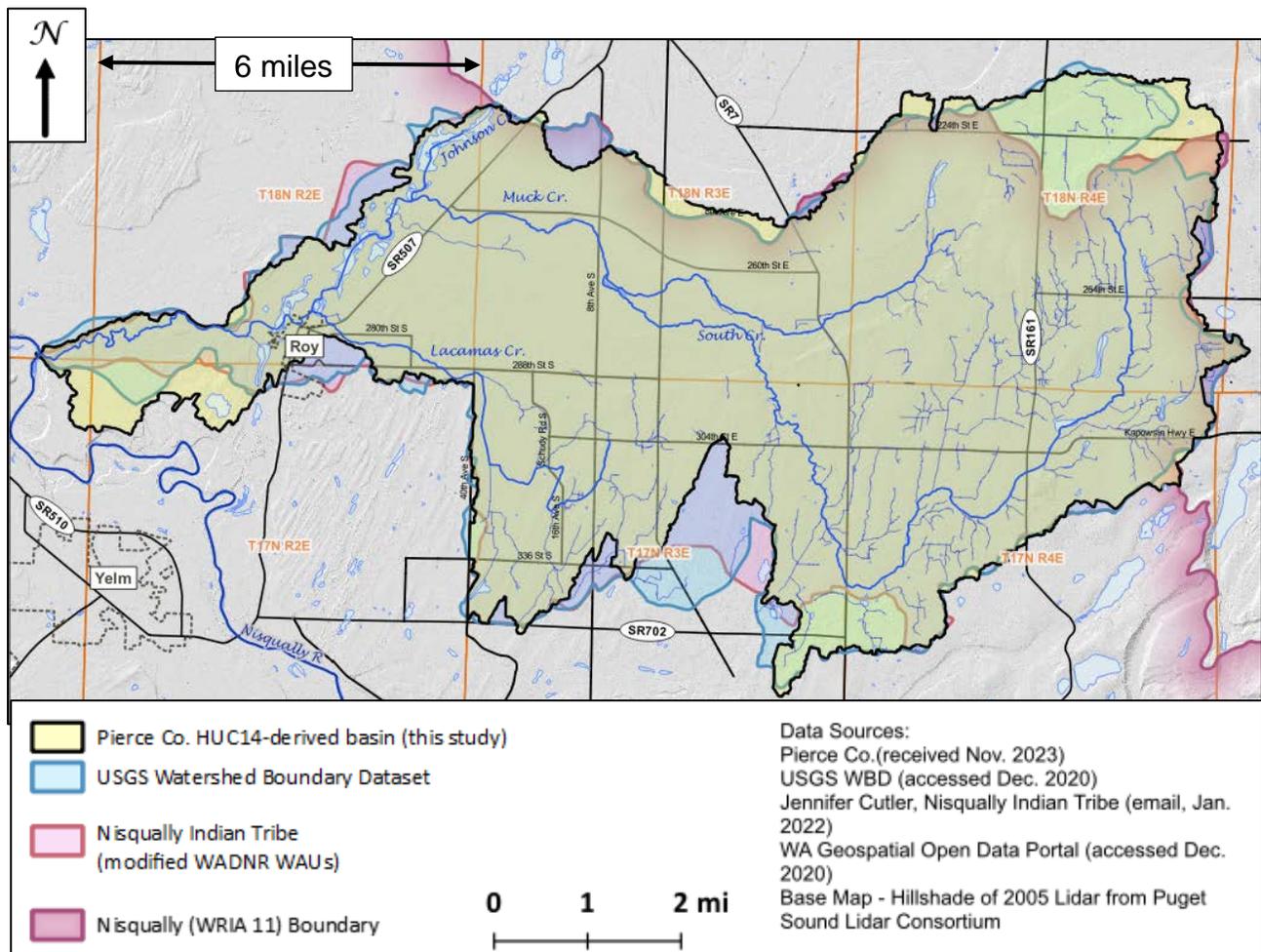


Figure 1: Basin delineation for this study compared to other versions.

The SWMD delineated drainage basins at a resolution finer than that of the existing WBD. These finer-scale drainage basins are referred to as HUC14 basins, identified by their 14-digit HUCs. The project uses 2010 lidar data of Joint Base Lewis McChord (JBLM) and 2020 lidar for the remainder of the basin and incorporates knowledge of stormwater drainage features. We created a boundary for the entire Muck Creek and subbasin boundaries for Lacamas Creek, South Creek, and Lower, Middle, and Upper Muck Creek by merging the appropriate HUC14 basins. We placed the divide between Lower and Middle Muck at the confluence with Lacamas Creek, partly to separate out the portion of the basin downstream of the gage at Roy.

2.2 Land Cover

We compared land cover in the basin at three different times: late 1800s; 1968; and, 2021. We also reviewed accounts of the history of the basin.

2.2.1 1800s land cover

We acquired GIS versions of features from two maps made in the late 1800s. The prairie extent was pulled from the General Land Office (GLO) surveys conducted between 1853 and 1876. The prairie areas of the GLO maps had been digitized for the work of Easterly and others (2005).

For indications of the extent of wetlands we consulted Plummer's Atlas of the County of Pierce, Washington (Plummer, 1889), as well as a 2023 version of the Pierce County Wetland Inventory (CWI) and a 2020 version of the National Wetland Inventory (NWI). Plummer's Atlas indicates several large areas of wetlands, especially in Lacamas, but does not delineate wetlands along stream corridors or in many other locations identified as possible wetlands in the NWI and CWI. For a broader estimate of the extent of wetlands in the basin we combined the NWI and the CWI and assumed that all mapped wetlands existed in the late 1800s. The NWI covers the whole study area while the CWI excludes JBLM.

We intersected these features with the subbasin boundaries to estimate the area of prairie and wetland in the subbasins according to these sources. We assumed areas not covered by prairie or wetland were evergreen forest.



2.2.2 1968 land cover

We geo-registered two 1968 black-and-white aerial photographs that cover more than 90% of the basin. The year 1968 falls within the period of streamflow measurements at Roy (1956-1972) and is about 6 years before the systematic recording of water well installations by the Washington Department of Ecology (Ecology). We made qualitative observations of changes compared to the prairie extent in the GLO surveys and to the vegetation patterns in 2021 National Agricultural Imagery Program (NAIP) air photo mosaic and the 2021 National Land Cover Dataset (NLCD). We estimated land cover classes present in 1968 based on these observations.

2.2.3 2021 land cover

We used the 2021 NLCD to measure the land cover classes in the basin. This dataset is generated from classification of Landsat images, which have a horizontal resolution of 30 m (98 ft). The classes include evergreen forest, herbaceous vegetation, pasture/hay, wetlands, and several intensities of development. A separate product estimates the percent impervious surface. The areal extent of each class was extracted for the whole basin and for each of the five subbasins.

The NWI and the CWI were not used to estimate current wetland cover.

2.2.4 Pace of development

Since the mid-1970s, well installations have been recorded systematically by Ecology. We downloaded all well reports for water supply wells for the 6 townships that cover most of the Muck Creek Basin (Ranges 2E, 3E, & 4E in Townships 17N and 18N). We then identified the sections that cover the basin, using the union of the three possible basin boundaries (Pierce Co., Nisqually Indian Tribe, and WBD; Figure 1). The resulting well list was sorted by installation year to plot wells completed per year.

2.3 Precipitation

Precipitation data were extracted from the work of the PRISM Climate Group at Oregon State University. Their precipitation modeling interpolates from weather station data to



all areas in the continental United States by considering the effects of elevation (orography) and weather patterns (Daly and others, 2008). The PRISM datasets include estimates of monthly and annual precipitation at two resolutions (800 m² and 4 km²). PRISM provides estimates from 1895 to 2023 but notes that values prior to 1981 are based on less extensive observations.

We downloaded monthly precipitation data for October 1949-September 2023 for the 33 4-km² grid cells which cover the Muck Creek Basin. This period includes the available streamflow measurements from the gage at Roy (see below). Precipitation estimates for each month and each water year were created from a weighted average of the grid cell values, based on the percentage of the grid cell lying within Muck Creek Basin. The resulting monthly averages for the basin were combined into water year totals.

We also downloaded annual (calendar year) and monthly averages for the basin for the 30-year period of 1991-2020. These data are reported at 800 m² resolution.

2.4 Evapotranspiration

Evapotranspiration (ET) rates were estimated by combining areal estimates of the land cover classes of the basin with estimates of monthly ET rates for corresponding vegetation classes. The three main steps of this analysis are described below.

2.4.1 Compile ET estimates for major vegetation types from OpenET

OpenET uses remotely sensed and locally collected data to provide estimates of recent ET for the western United States. OpenET applies a suite of surface energy balance (SEB) models, which compare the difference between the energy which reaches the land surface and the energy which is radiated back to estimate the latent heat used by ET. OpenET has parameterized six SEB models to work with Landsat and other available large-scale datasets, and the OpenET team recommends using the “ensemble” estimate of these six models, which is an average of estimates after outliers are removed.

For estimates of ET in the Muck Creek Basin, we selected 3 to 6 representative areas of common vegetation types (Table 1; Figure 2) and extracted monthly time series of the



ensemble ET from OpenET for the last 6 years, the range of available data. Because the resolution of Landsat pixels is 30 m² (0.22 acres), we chose areas of at least 2 acres. We also extracted estimates of ETo, the standard reference ET that is used to scale other ET estimates and that corresponds to the expected ET of well-watered grass. A location specific ETo is reported with every OpenET extraction. Water-year totals were calculated by summing monthly values.

For the late 1800s, the ET of the prairie and evergreen forest were assumed to be equivalent to the prairie and evergreen forest areas sampled in OpenET. The wetlands were assumed to be 75% woody wetlands and 25% herbaceous wetlands.

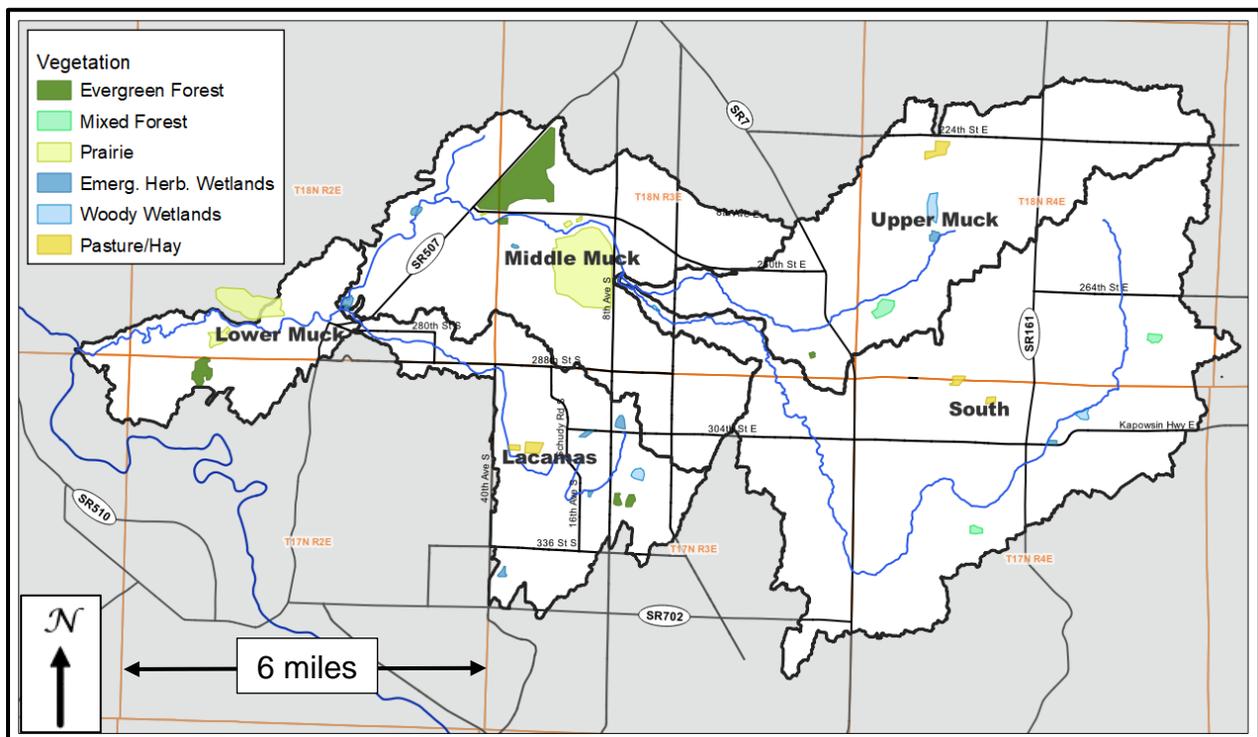


Figure 2: Representative areas of common vegetation sampled in OpenET.

Table 1: Major vegetation types for which ET extracted.

Abbreviation	Description of Vegetation Type
Ag	Pasture/hay
DF	Evergreen forest, primarily Douglas Fir
FM	Mixed evergreen and deciduous forest
Pr	Prairie, including with sparse Scot's broom
ET _o	Reference ET for well-watered grass about 5" tall, for estimating watered lawns.
Imperv	Impervious surface
WLH & RCG	Emergent herbaceous wetland, including reed canary grass
WLW	Woody wetland

2.4.2 Convert land cover estimates into classes to match vegetation types

For conditions in 1968 and 2021, the NLCD includes several classes that are equivalent to the vegetation types that were sampled in OpenET (Table 2). Other NLCD classes contain a mixture of vegetation types as well as non-vegetated surfaces. In the ET calculations we represented these classes as mixtures of simpler vegetation and surface classes:

- **Developed areas:** The NLCD includes three levels of development that are present in Muck Basin: developed open space, low intensity development, and medium intensity development. Their percentages of impervious surfaces, in the form of buildings and paved surfaces, are <20%, 20%-49%, and 50%-79%, respectively, and we used the midpoint of these ranges. We assumed that impervious areas had a constant ET rate of 0.5"/month. Other portions of these areas are covered by a mixture of vegetation including lawns, both irrigated and non-irrigated, and landscaping shrubs and trees. Based on inspection of air photos, we approximated these as 30%-40% forest and 60%-70% herbaceous (prairie), with 25%-33% of the herbaceous vegetation as irrigated and thus having an ET signal similar to ET_o, the reference for well-watered grass.
- **Transition areas:** The NLCD includes areas which are in transition from herbaceous or shrub cover to forest. These areas were treated as a mixture of prairie and forest, with relative proportions based on inspection of corresponding areas on aerial photographs.



Table 2: Correlating NLCD classes and vegetation types to develop ET estimates.

NLCD Class	Vegetation Types with OpenET Estimates
Grassland	Prairie, including with Scot's Broom
Evergreen forest	Evergreen forest
Woody wetlands	Woody wetlands
Emergent herbaceous wetlands	Herbaceous wetlands, including reed canary grass
Pasture/hay	Agricultural

2.4.3 Calculate basin ET

The monthly ET estimates were multiplied by the area of the equivalent vegetation class in each subbasin and combined into monthly and water year ET fluxes.

2.5 Streamflow

Existing daily streamflow measurements were acquired and processed:

- Daily discharge at the Roy gage (“USGS 12090200 Muck Creek at Roy, WA”) from March 1956 – September 1972.
- Daily discharge at the Roy and Loveland gages (located on Muck Creek near the crossing of SR7) for April 2000-Feb. 2001 (Sinclair, 2001).

The daily values, reported in cubic feet per second (cfs), were averaged into flow rates by month and water year. To allow comparison with precipitation and ET estimates, these averages were then converted into inches (cubic inches of precipitation per square inches of basin area) for the area upstream of the measuring point, using the subbasin delineations described above. The area above the Roy gage was estimated as the combined Lacamas, Middle Muck, Upper Muck, and South subbasins. The area above the Loveland gage was estimated as the area of Upper Muck Creek subbasin, about 2% of which is below the gage location.

2.6 Domestic and Irrigation Water Use

To estimate the total and consumptive water use for domestic purposes in the basin, we combined the 2010 population of census blocks in the basin and the Nisqually Watershed Plan’s method for estimating total and consumptive domestic use per connection (Nisqually Watershed Planning Unit, 2019).



3 RESULTS AND DISCUSSION

The results of this work describe basin-wide dynamics and are a complement to the streamflow and aquatic habitat focus of parts of the Muck Creek Stream Flow Restoration project.

3.1 Basin boundary and area

The Muck Creek Basin covers about 93 square miles (Table 3). South Creek is the largest subbasin, covering almost 40% of Muck Creek Basin (Figure 3).

Table 3: Basin and subbasin areas.

Basin	Acres	Miles ²	% of basin	% within JBLM
Whole Basin	59,380	93	100%	26%
Lower Muck	4,263	7	7%	85%
Middle Muck	13,053	20	22%	82%
Upper Muck	11,824	19	20%	3%
Lacamas	7,455	12	13%	12%
South	22,785	36	38%	1%
All but Lower Muck*	55,117	86	93%	

* Approximately equal to drainage area above Roy gage.

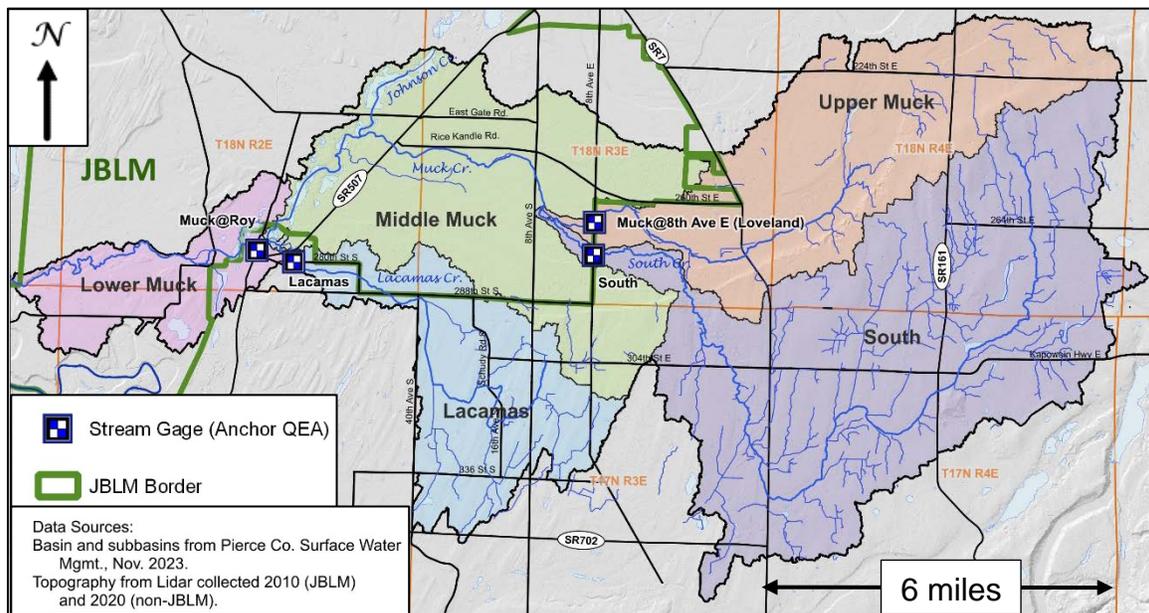


Figure 3: Muck Creek Subbasins.

3.2 Land Cover and Land Use

Land cover is the basis upon which estimates of ET over the last 150+ years is based. Land use changes also provide context to changes in the hydrologic processes. Additional details are included in Wilhelm and Pitre (2022).

Pre-1700s: Before the arrival of Europeans, the major land cover types of the basin were evergreen forest, prairie and wetlands. Native Americans maintained the prairie vegetation through periodic burning to promote the growth of useful plant species such as bracken fern and camas (Perdue, 1997).

1700s: In the late 1700s Native Americans traded with Europeans who visited Puget Sound, including the trading of beaver pelts.

1833: In 1833 Hudson's Bay Company established Fort Nisqually in present-day Dupont, to the west of Muck Creek Basin. Associated farming activities occurred around the fort and on the prairie in the Muck Creek Basin under the direction of the Puget Sound Agricultural Company (PSAC). A map of PSAC claims from 1855 shows several sheep stations across the prairie area and farm plots along Muck Creek at and above its confluence with present-day Johnson Creek (Fig. 3 in Easterly and others, 2005).

1836: The Oregon Treaty, signed by the United States and Great Britain in 1846, opened the area to American settlers. Settlers continued the conversion of land to agriculture, including filling and draining wetlands. In 1892 the outlet from Johnson Lake (called Finch Lake at the time) was ditched and the lake was drained (Plummer, 1892).

1855: Following the signing of the Treaty of Medicine Creek in 1855, Native Americans were moved onto reservation lands south and west of Muck Creek Basin.

Prairie vegetation covered most of the Lower and Middle Muck Subbasins (Figure 4). The three other subbasins contained much less prairie (1% to 14%; Table 4).

Estimates of wetland extents in the basin vary between Plummer's Atlas (Plummer, 1889) and the modern-day NWI and CWI. Generally, Plummer's (1889) individual wetlands are larger and may represent herbaceous wetlands, whereas the NWI and CWI map many



more but generally smaller wetlands along stream corridors (Figure 5). In the Middle Muck Subbasin only, the area and location of the Plummer’s (1889) wetlands and the combined NWI-CWI wetlands are similar. In all other basins, the area of wetlands mapped by Plummer (1889) is less than half of that mapped by the NWI and CWI. According to the NWI and CWI, approximately 25% of Lacamas Creek subbasin and 20% of South Creek subbasin are covered by possible wetlands. Lower, Middle, and Upper Muck Creek Subbasins all have less than 10% wetland coverage.

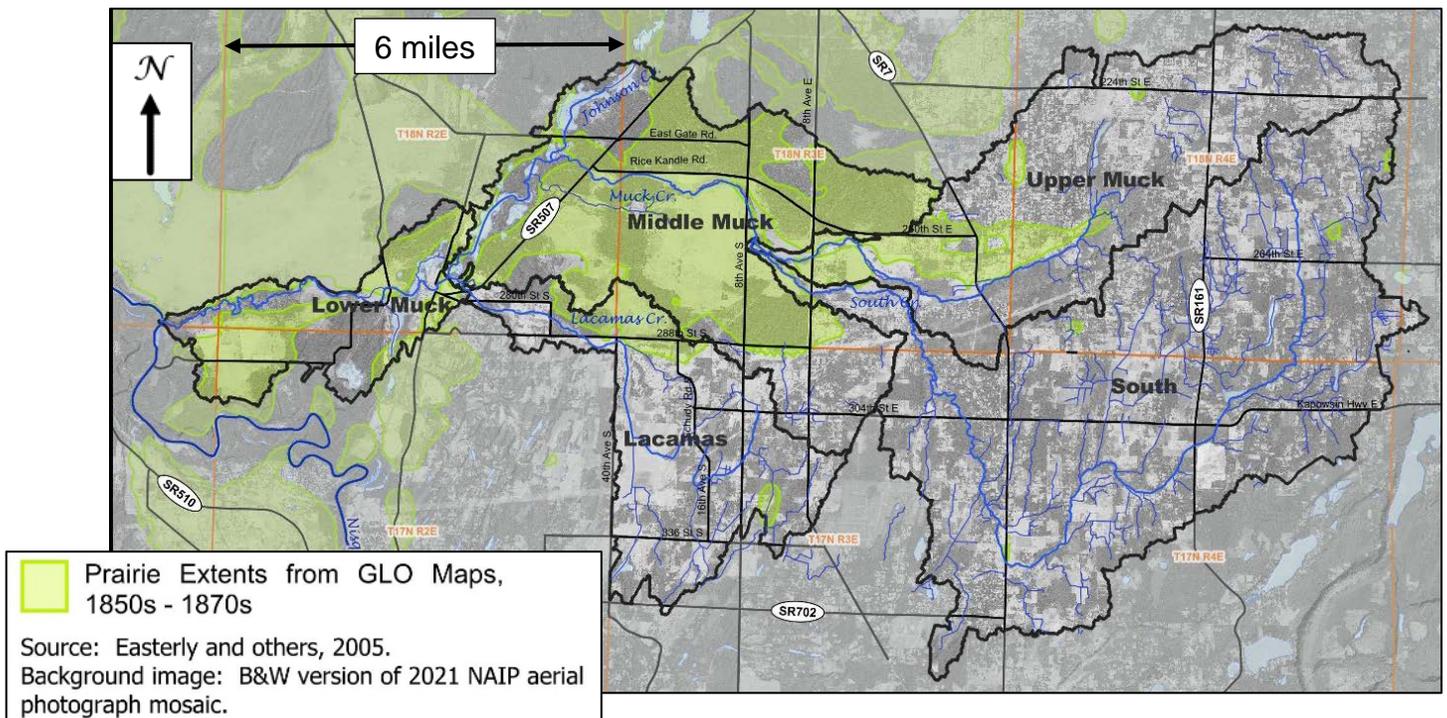


Figure 4: Prairies mapped by the GLO (1853-1876).

Table 4: Estimated vegetation cover in late 1800s.

Subbasin	Prairie	Wetland ^a	Forest ^b
Lower Muck	51%	9%	40%
Middle Muck	66%	7%	27%
Upper Muck	14%	9%	77%
Lacamas	12%	25%	63%
South	1%	19%	80%

^a From combination of present-day NWI and Pierce Co. CWI.

^b Assumed to be remainder of basin that is neither prairie nor wetland.

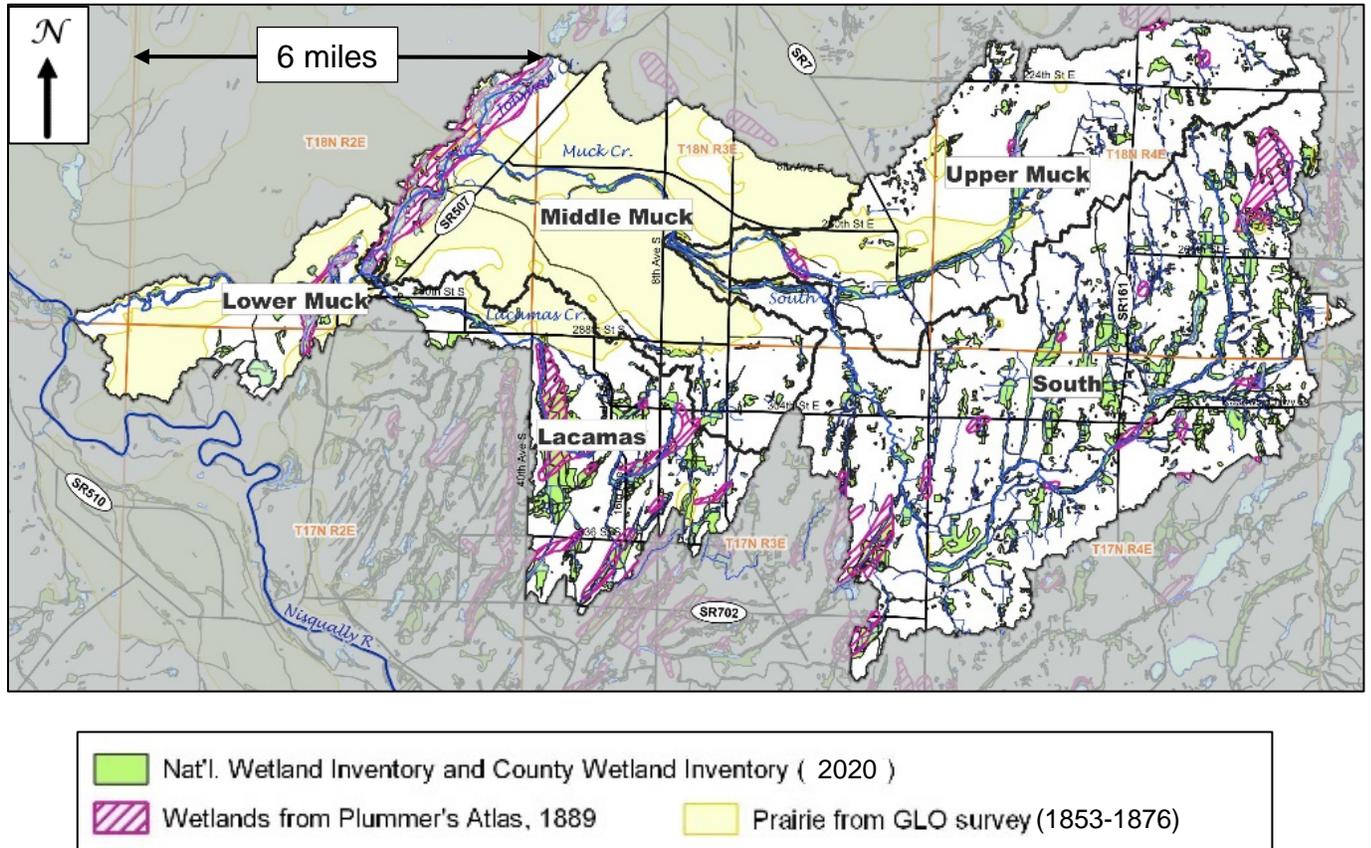


Figure 5: Wetland distributions according to different sources.

The forest coverage in the late 1800s, estimated by difference from the prairie and wetlands estimates, ranged from 27% in Middle Muck Subbasin to 80% in South Subbasin (Table 4).

1900: Timber harvesting likely occurred throughout this period, with associated road carving. Around 1900, the town of Roy contained several lumber mills (City of Roy, 2022).

1917: Between the late 1800s and 1968, the largest change in basin land cover resulted from the establishment of Camp Lewis in 1917 with land north and west of the Muck Creek Basin Lewis donated by the city of Tacoma, including land that was part of the Nisqually Indian Tribe’s reservation. Land has been added to the base over time including about 1,100 acres along Muck Creek around 1940 (Perdue, 1997). When land became part of the military base, farmers and ranchers moved out, and the land reverted to prairie, forest, and wetland.

1968: In 1968, land use outside of JBLM was primarily either agricultural, rural residential, or undeveloped/forested land (Figure 6). Often the agricultural land was mapped as possible wetlands. Rural residential properties were generally 5- to 10-acre lots. Several areas mapped as prairie in the 1880s were forested in 1968. About 40% of the former prairie in Lacamas Subbasin became forested, mostly in areas on Fort Lewis (now JBLM). In Middle Muck, most of the prairie areas mapped by the 1880s GLO survey lay within Fort Lewis, and by 1968 about 30% of these areas had been replaced by young, sparse evergreen forest and another 30% by dense evergreen forest. JBLM's management of its land within Muck Creek Basin has left most of it undeveloped.

2021: From 1968 to 2021, development has been the main change affecting the basin. In the 1980s and 1990s stormwater management policy in Washington State added concerns for water quality and stream health to the original focus on flood reduction. In 1991, the state established the Growth Management Act, which required the development of comprehensive plans to manage growth and preserve open space. Except for the City of Roy, all of Muck Creek Basin lies outside the county's Urban Growth Areas (UGAs).

Land cover and land use patterns on JBLM in 2021 have changed very little since 1968 (Figure 6). The portions of Muck Creek Basin on JBLM are managed to maintain a range of environments for military training purposes. Some prairie areas are protected as habitat for endangered species. The forest cover on JBLM appears more uniformly dense than in 1968, but approximately 60 acres of forest east of Roy was cleared around 2020.

The rest of Muck Creek Basin has experienced an increase in residential use, especially in the northeastern basin. Upper Muck Subbasin contains the highest percentage of developed areas, followed by the South Creek subbasin (Figure 7 and Figure 8). According to the NLCD analysis, the Upper Muck subbasin is estimated to be almost 15% impervious surfaces, South Creek subbasin is about 5%, and the remaining three subbasins are around 3%.



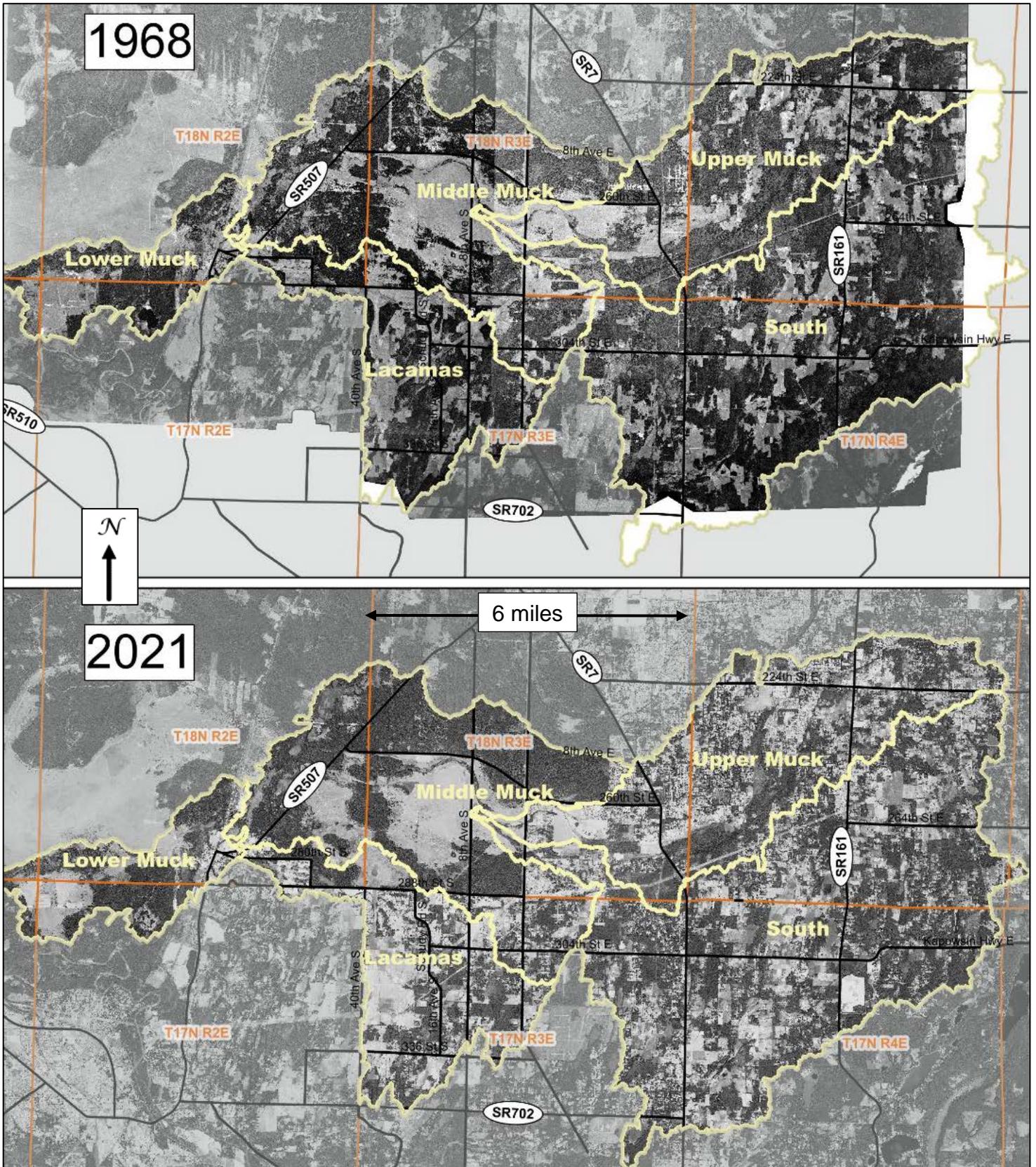


Figure 6: Aerial images (1968, 2021).

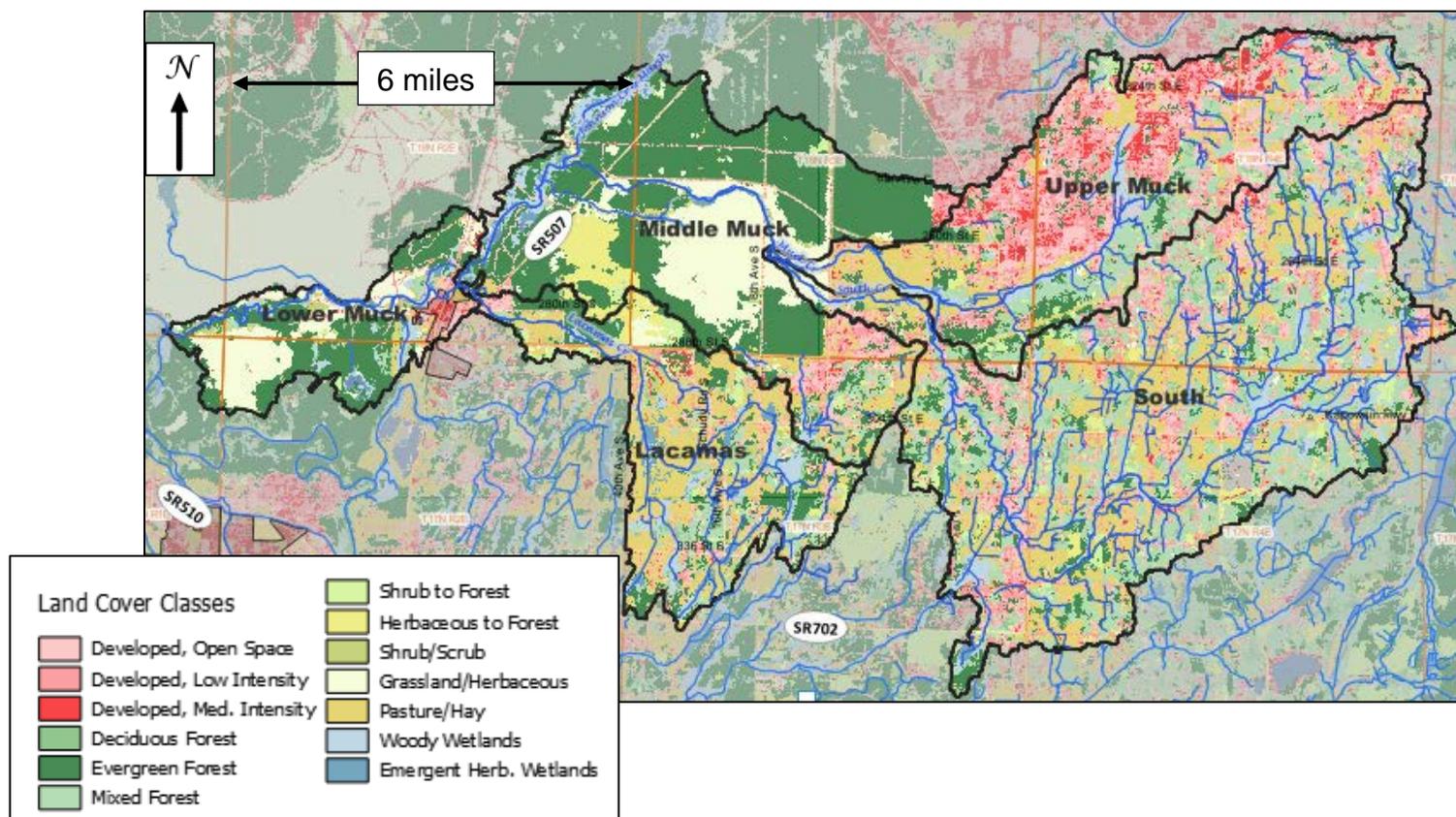


Figure 7: Land cover from NLCD 2021.

MuckCreek.qgs.gqz NLCD 2021 2024-01-04

The 2010 population of the entire basin was about 33,000. Although the basin is outside of the county’s UGA, the developed areas include residential plots of roughly a ¼-acre in size as well as areas of 5- to 10-acre plots. Well installations over time suggest that residential development was steady in the 1970s-1990s and has slowed in the last 20 years (Figure 9). Since 1975 approximately 4,250 water wells have been drilled in the basin.

The residential areas are mostly in areas formerly covered by forest but also on formerly agricultural lands. Compared to conditions in 1968, agricultural fields, primarily for pasture or hay, have expanded in Lacamas and South subbasins at the expense of forested land. The extent of agricultural fields has stayed roughly constant in the Upper Muck Subbasin. Forested areas have decreased in Upper Muck, Lacamas, and South subbasins.

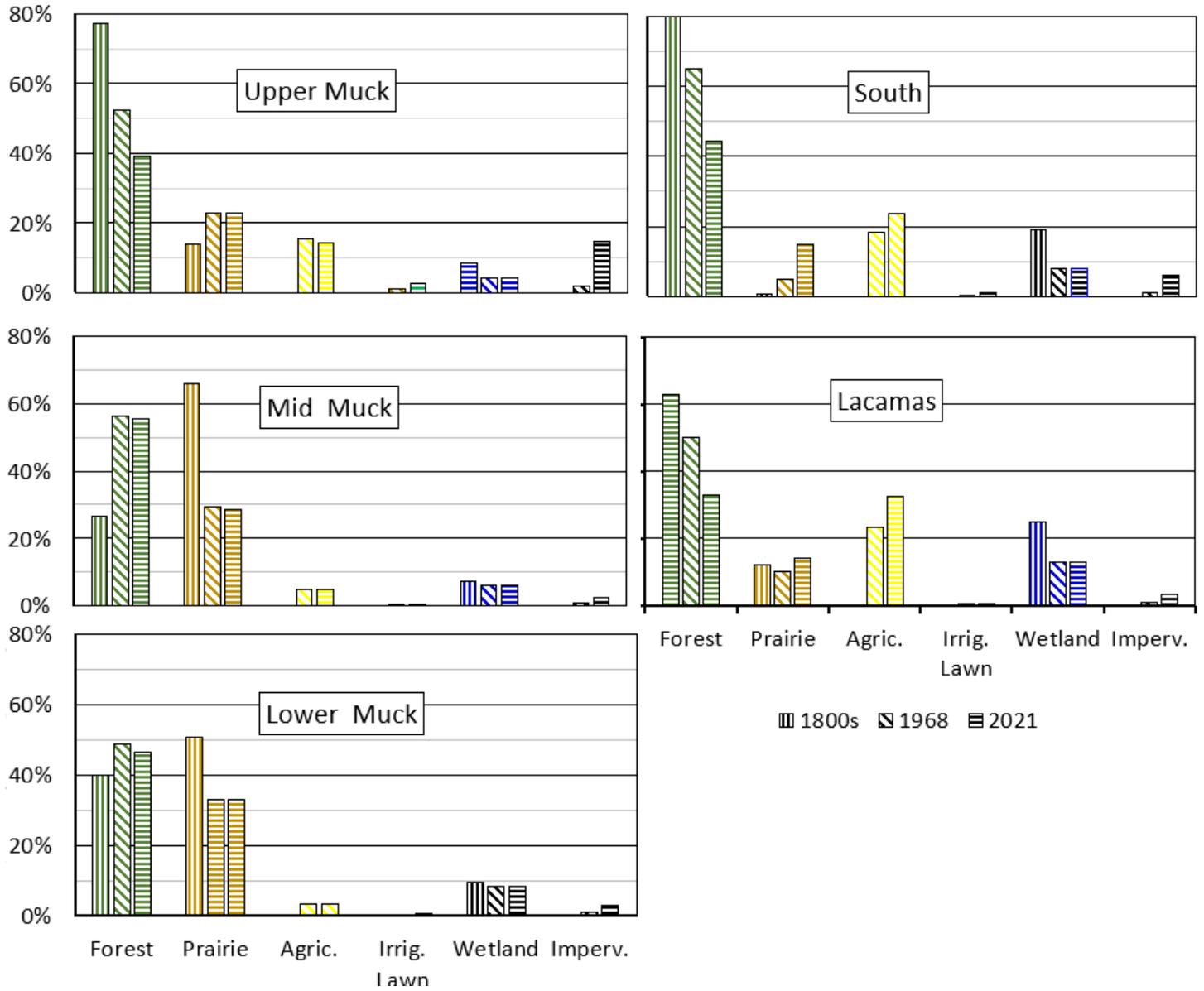


Figure 8: Estimated vegetation types over time.

(Prairie includes non-irrigated lawns.)

(Water Balance Data and Figures 20240122 / Land Cover Over Time Ch(2) 2024-01-27)



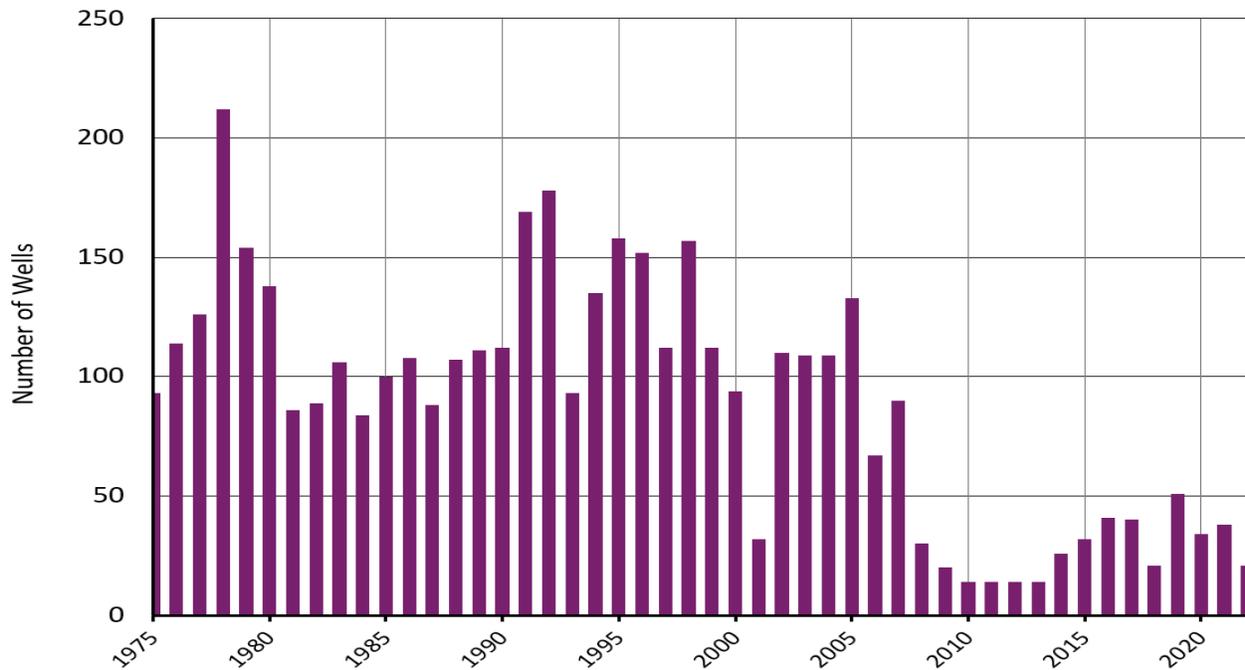


Figure 9: Water wells installed over time in basin.

(Ecy Well Logs Over Time.xlsx)

In summary, the following changes in land cover have occurred in the basin over the last approximately 150 years:

On JBLM:

- Prairie areas have decreased, especially beyond JBLM.
- Evergreen forested areas have increased.
- Agricultural land expanded into the outwash plain and stream valleys during European settlement in the late 1800s. When JBLM was established and later expanded, agricultural use ceased.

Beyond JBLM:

- Prairie areas have decreased.
- Evergreen forests have decreased.
- Developed areas have increased in the last 50 years, especially in the Upper Muck and South Creek Subbasins.
- Agricultural areas have expanded over time.
- The extent of wetlands over time is not well-defined, but the occurrence of agricultural lands on areas mapped as possible wetlands suggests that wetlands have decreased since the late 1800s.



3.3 Precipitation

PRISM modelling for the period of 1991-2020 estimates an average annual precipitation of 45” across the basin. Values are lowest in the central basin and increase to the west and the east (Figure 10). Given the uncertainties in other water balance components, we use the average precipitation for the whole basin, rather than calculating it separately by subbasin. For 1991-2020, monthly precipitation is highest in November and lowest in July (Figure 11).

The last five water years (2019-2023) average 38 inches and contain two years that are in the lowest 10% of precipitation for the past 70 years (Figure 12).

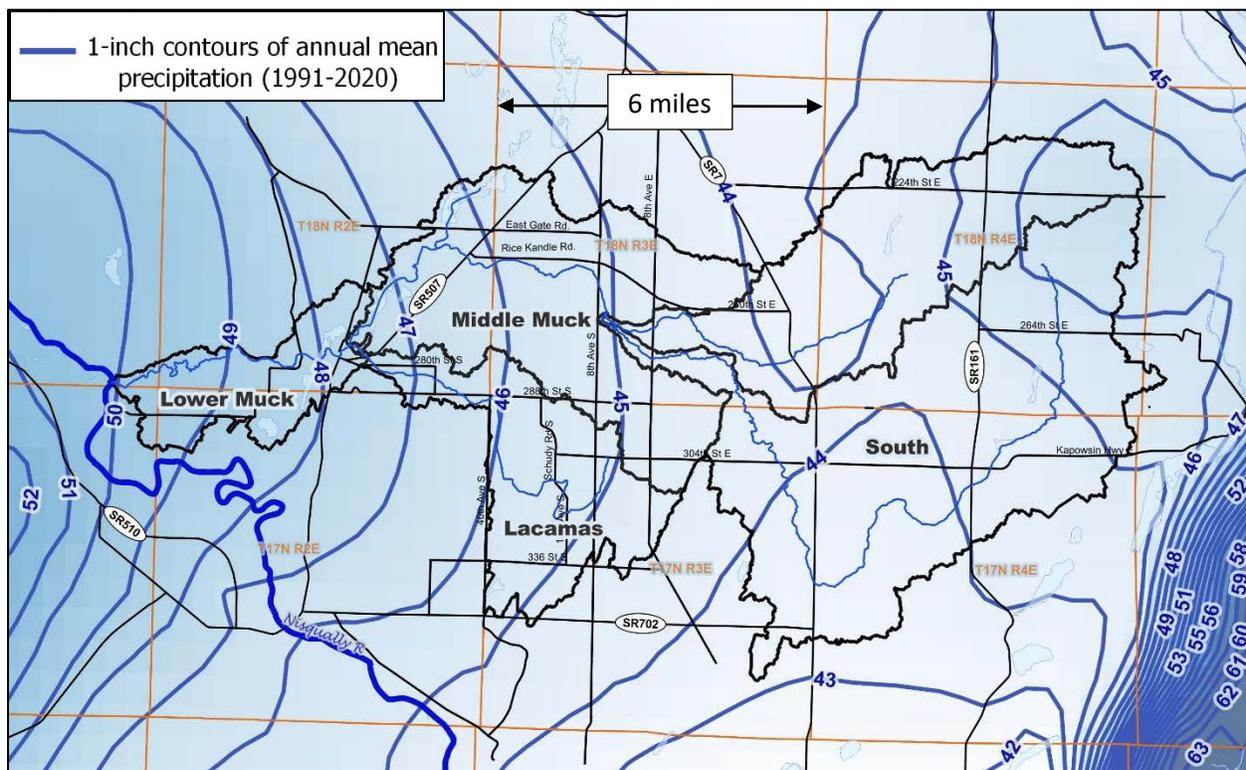


Figure 10: Annual precipitation isopleths, 1991-2020.

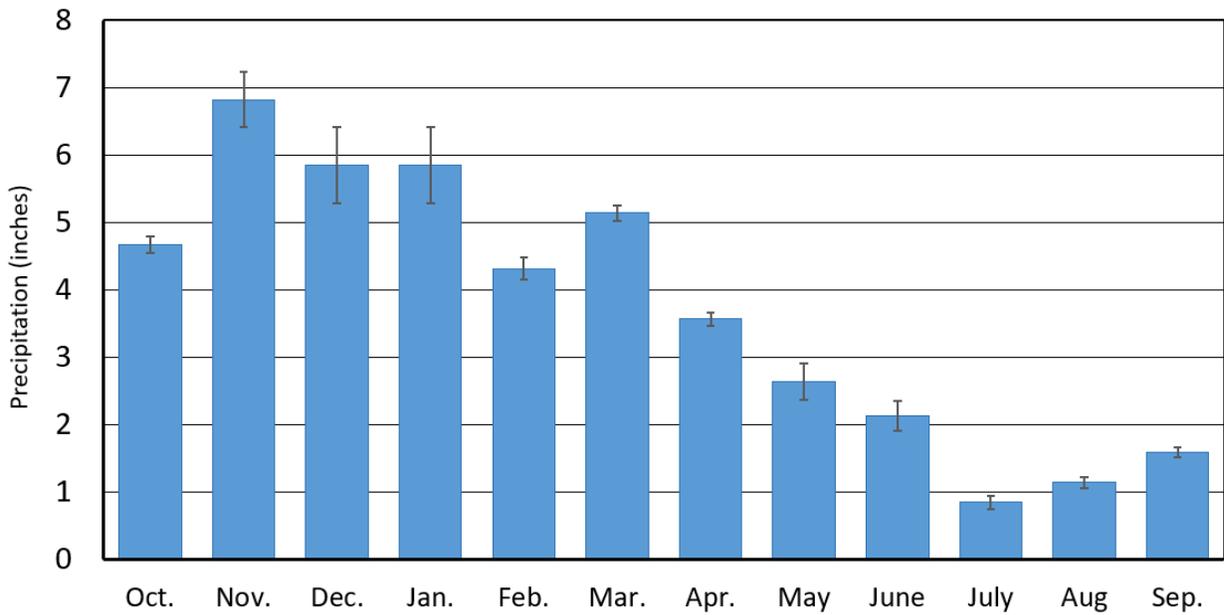


Figure 11: Monthly precipitation (1991-2020; means and standard deviations).

(Water Balance Data and Figures 20240122.xlsx)

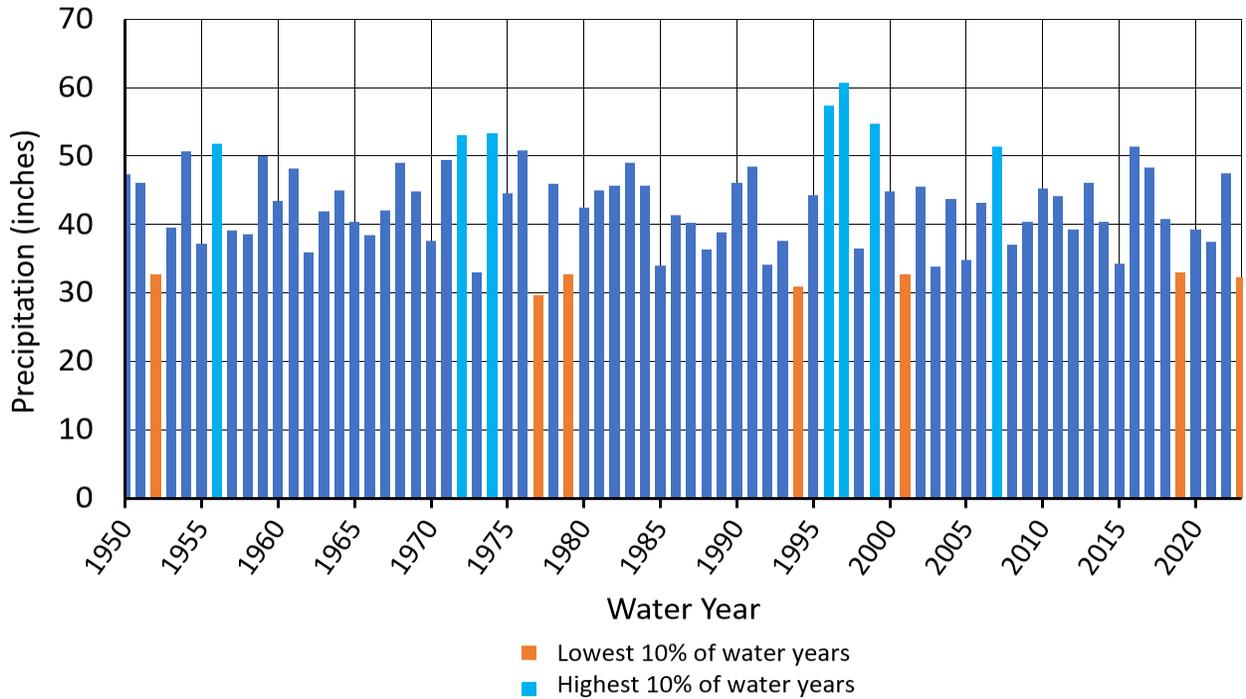


Figure 12: Water year precipitation, 1950-2023.

(PRISM Grid Cells - Basins Etc.xlsx)



3.4 Evapotranspiration

Evapotranspiration is the largest flux of water out of Muck Creek Basin. The magnitude of ET depends on many variables, including the distribution of vegetation types, soil water availability, and meteorological conditions such as precipitation, insolation, wind speed, and humidity. The availability of location-specific energy-based estimates of ET from OpenET and of land cover classes from NLCD allow us to estimate ET without estimating the many contributing variables.

In the sampled polygons (Figure 2), OpenET estimates average annual ET to range from 13" for prairie to 32"-33" for evergreen and woody wetlands (water years 2019-2023; Table 5, Figure 13). ET for other land covers cluster between 25" and 30".

Table 5: Average annual OpenET estimates of ET.
(water years 2019-2023)

Vegetation Type	Average Annual ET
Evergreen forest	33"
Woody wetlands	32"
Grass	30"
Emergent wetlands (reference ETo)	28"
Pasture/hay	25"
Prairie	13"
Impervious	6" ^a
Average precipitation	38"

^a Assumed.



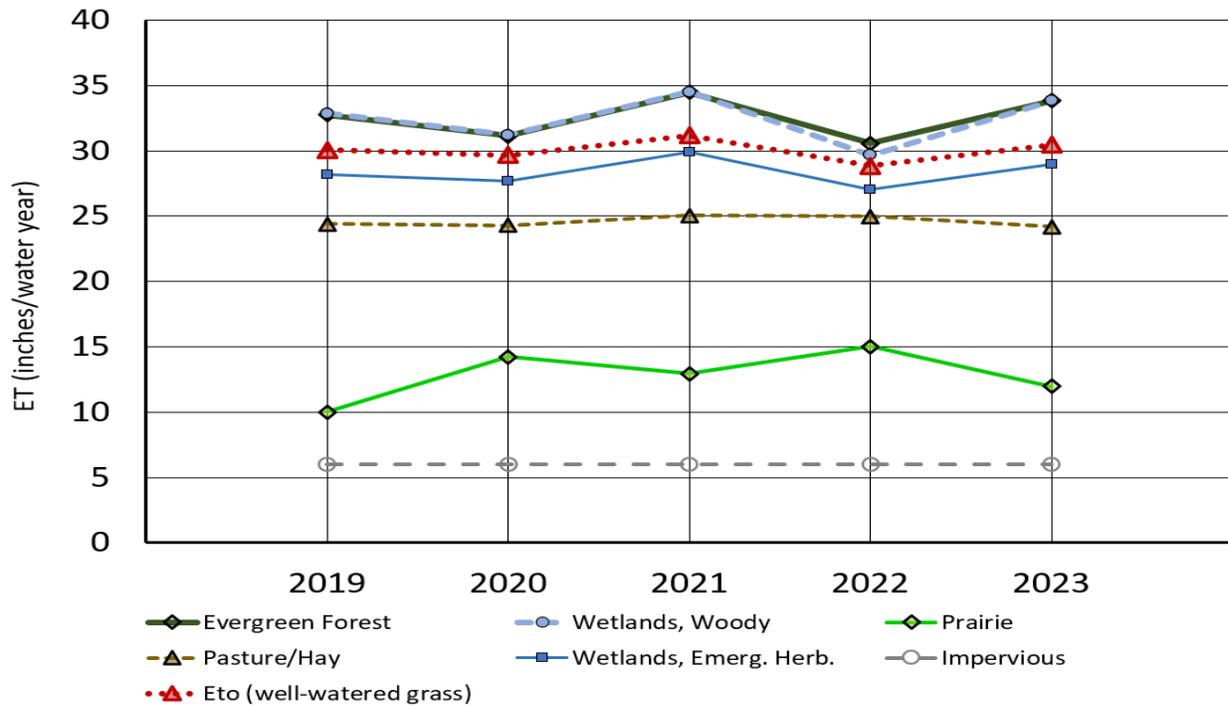


Figure 13: OpenET estimates of water-year ET for major vegetation types.

(Water Balance Data and Figures 20240122.xlsx)

OpenET is based on the loss of energy, which it assumes is directed into ET, adjusted by several algorithms. Interception is the evaporation of precipitation landing on plant surfaces and can be 10%-30% of precipitation for evergreen forest (Zhong and others, 2022). In Douglas fir stands in Kitsap County, researchers measured 2"-4"/month of interception loss during winter months (Bauer and Mastin, 1997) and 20% of precipitation lost to interception (Bidlake and Payne, 2001). Wintertime ET from OpenET is uniformly low for all vegetation types at about half an inch, which suggests that OpenET does not adequately account for interception losses (Figure 14). While OpenET is a good tool for illustrating the general differences between vegetation types, its handling of interception should be further examined.

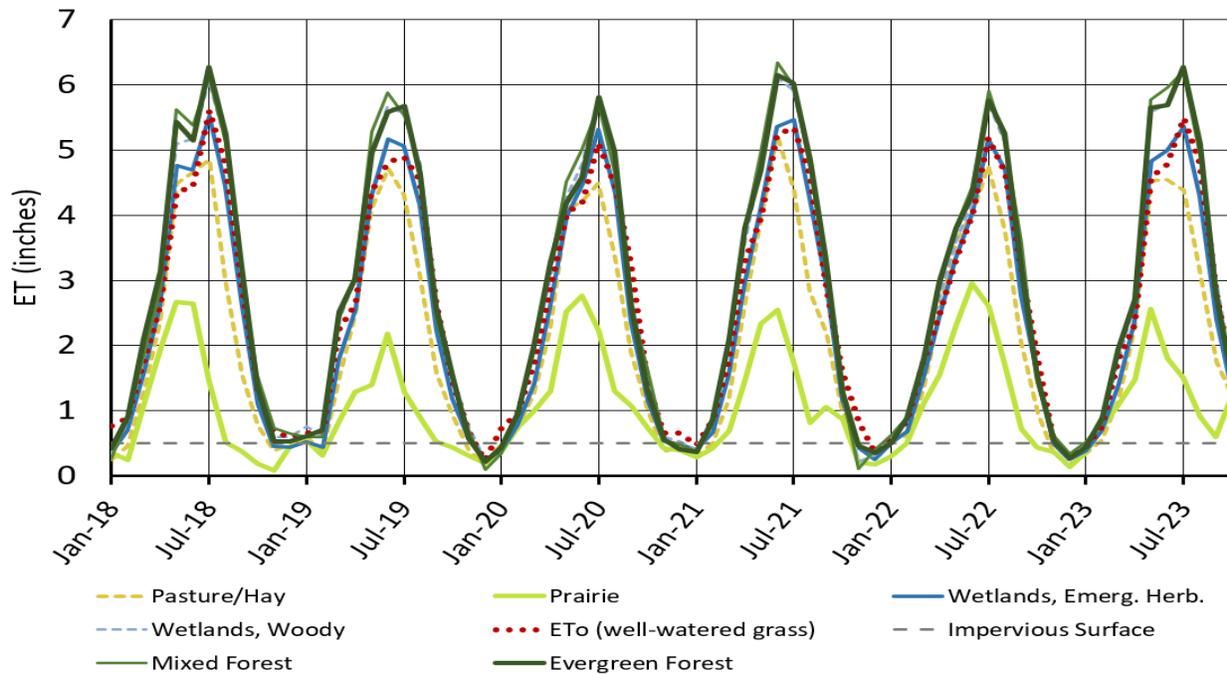


Figure 14: Monthly OpenET estimates of ET for vegetation types.

(Water Balance Data and Figures 20240122.xlsx)

The ET by subbasin and over time is shown in Table 6.. In the 1800s, Middle Muck had the lowest ET because of the dominance of prairie, and South Subbasin had the highest ET because of the dominance of forest. Over time, ET has been low and relatively constant in Lower Muck because its original conditions from the 1880s have been largely preserved by the presence of JBLM, with some encroachment from forestation (Figure 8). South Subbasin has seen the largest decrease in ET because agriculture and development have replaced forest.

The current estimates of ET do not differ much between subbasins (Figure 15) because forest has encroached on former prairie in Lower and Middle Muck subbasins and raised the ET in these subbasins, and agricultural land, lawns, and impervious surfaces have replaced forest in Upper Muck, Lacamas, and South subbasins and lowered the ET in these subbasins. Interannual variation in precipitation does not have a direct correlation with ET for a number of reasons including roots continuing to access deep soil moisture and more sun in a dry year.

For the basin as a whole, the estimated ET flux has decreased over time (Table 6; Figure 16).

Table 6: Annual ET estimates by subbasin.

Subbasin	Late 1800s	1968	2021	Late 1800s-2021 Change
Lower Muck	22.4"	24.9"	24.3"	8%
Middle Muck	19.5"	25.8"	25.6"	31%
Upper Muck	29.7"	26.1"	23.1"	-22%
Lacamas	29.8"	28.4"	25.7"	-14%
South	32.2"	29.6"	23.7"	-26%
Whole Basin	27.9"	27.6"	24.3"	-13%

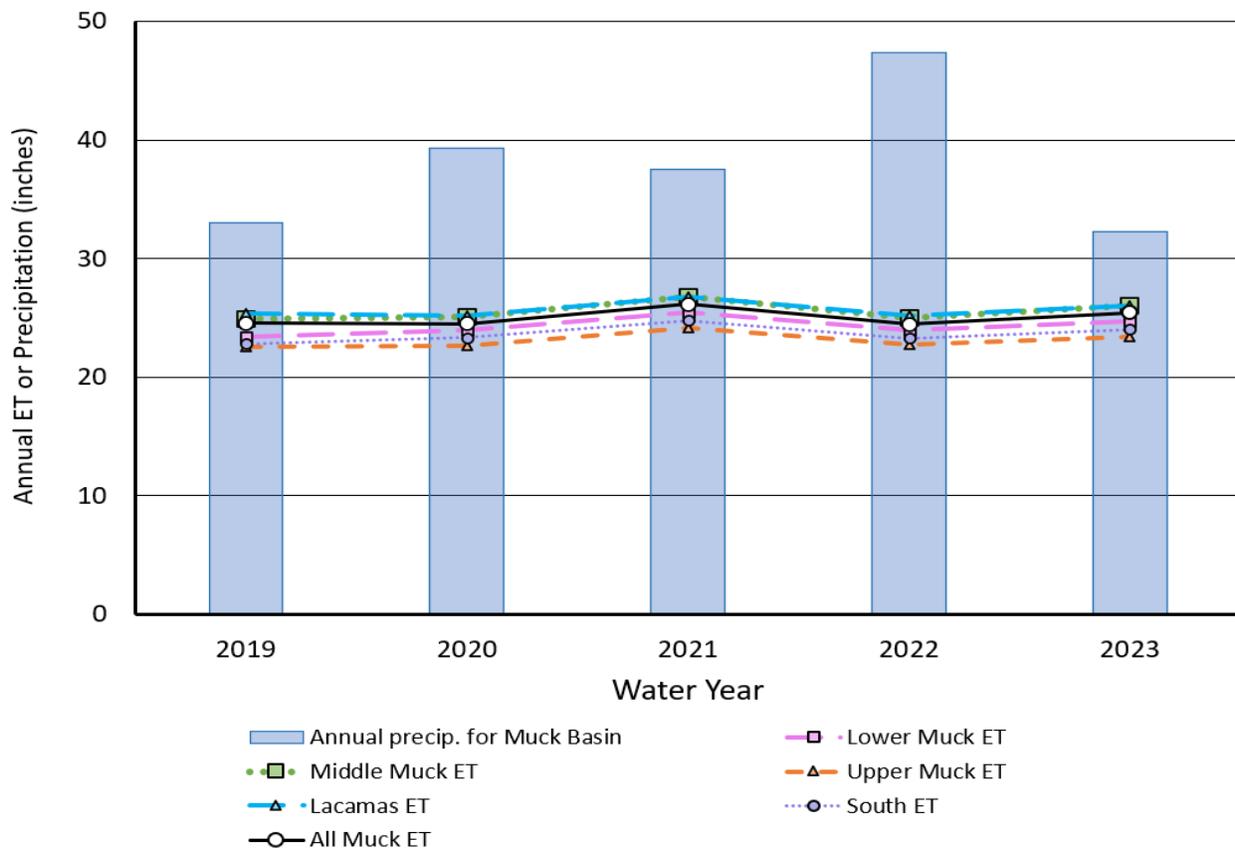


Figure 15: OpenET estimates by subbasin.

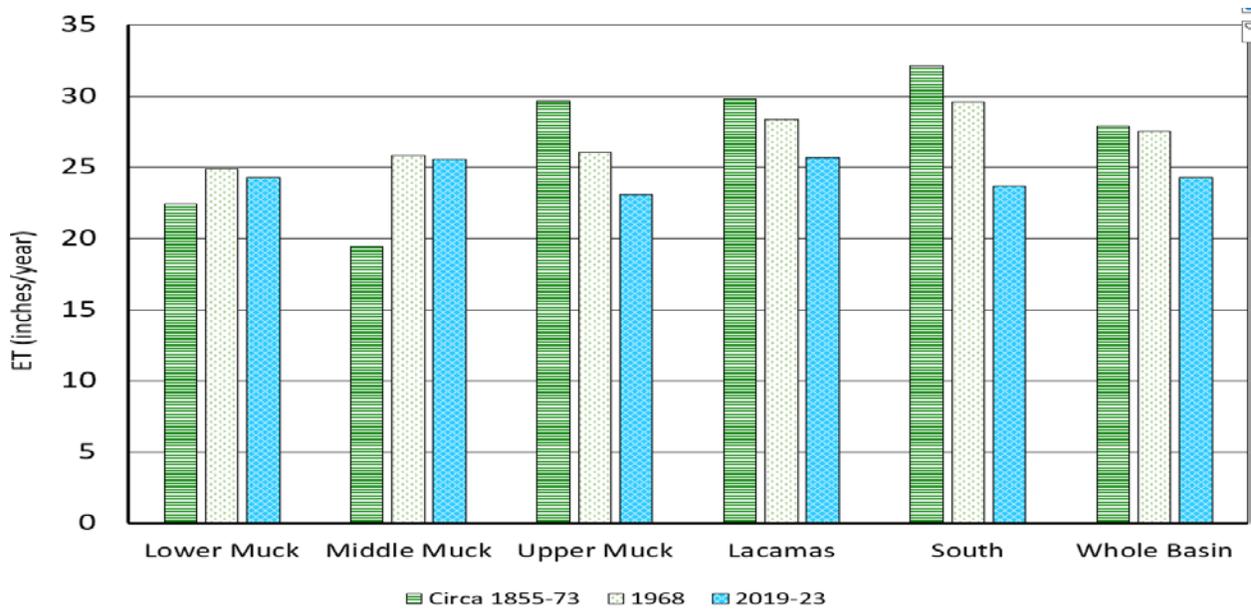


Figure 16: Annual ET estimates of Muck Basin based on land cover over time.

3.5 Streamflow

The most complete record of streamflow was collected from 1957-72 when the basin had much less residential development. At that time, streamflow upstream of the Roy gage averaged 10.7” per water year, ranging from a low of 4.5” in 1962 to a high of 20.3” in 1972 (Figure 17). A flow control device was installed at the mouth of Chambers Lake in 1967. This location is upstream of the Roy gage, and the device may have affected streamflow measurements at Roy after that time.

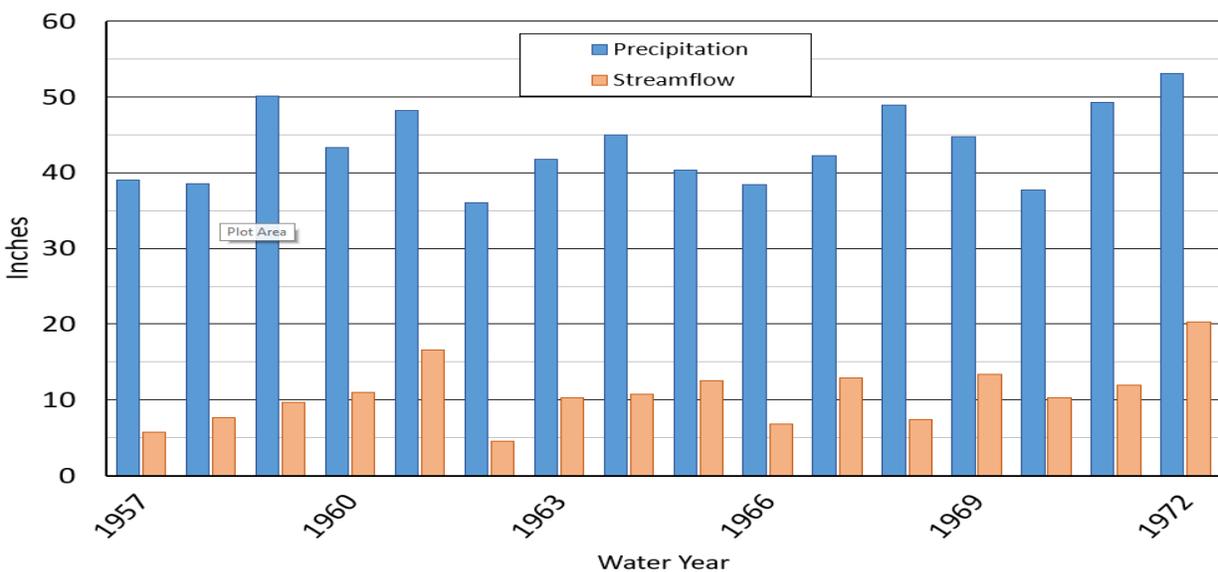


Figure 17: Precipitation across basin vs. streamflow at Roy, WYs 1957-1972.

Over the period of 1957-72 streamflow at Roy was 13% to 38% of precipitation. None of these water years had precipitation totals in the lowest 10% of water years. The months with the highest streamflows were January and February, with more variability than in precipitation record (Figure 11 and Figure 18). A comparison of the monthly averages of precipitation and streamflow shows a temporal lag of about a month in streamflow relative to precipitation (Figure 19). This pattern reflects the need to fill soil moisture capacity and groundwater “reservoirs” at the end of the dry season before significant surface water flow is generated.

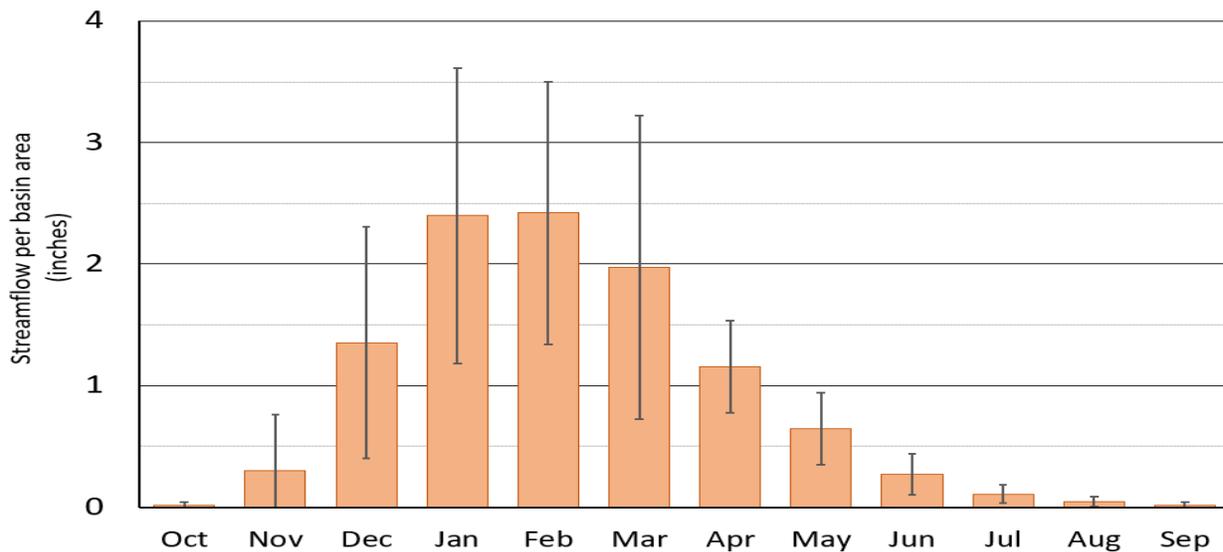


Figure 18: Monthly streamflow at Roy (1956-1972; means and standard deviations).

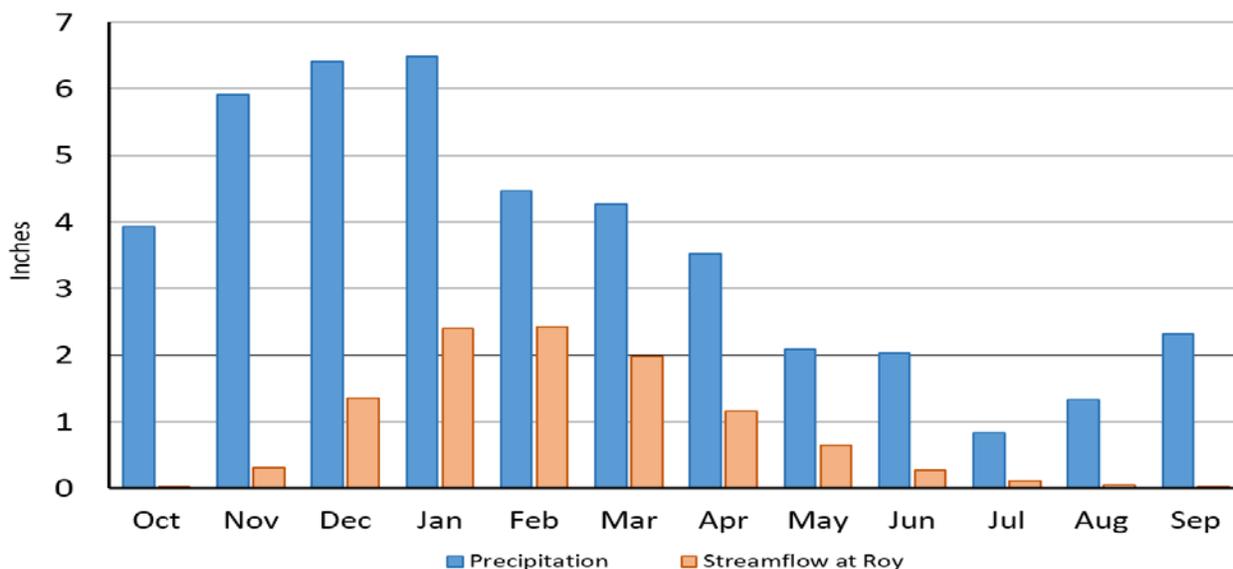


Figure 19: Monthly precipitation across basin vs. streamflow at Roy, 1956-1957.

(Water Balance Data and Figures 20240122)

Streamflow measurements were collected by Sinclair (2001) over 11 months from April 2000 to February 2001 at Roy and Loveland/8th Ave. E. These measurements are missing the month of March and span parts of two water years, including WY 2001, which was one of the lowest on record for precipitation (Figure 12). Therefore, further analysis of that dataset was not conducted.

3.6 Domestic Water Use

Based on the 2010 basin population, the total domestic use in the basin is estimated at roughly 9 cfs and the consumptive use at almost 5 cfs (Section 2.6). These rates convert to 1.3 and 0.7 inches/year respectively over the entire basin and are within the ranges of uncertainty of other water balance variables.

4 PRELIMINARY WATER BALANCE

The estimates of selected water balance components are summarized in Table 7. ET is the largest flux of water out of the basin, equal to approximately half of the precipitation, and approximately 10" of water input by precipitation is not accounted for with the outputs which quantified in this study.

Table 7: Estimated annual water fluxes for Muck Creek Basin.

Component	Time period	inches	afy *	%
Average precipitation	1991-2020	45"	206,700	100%
Average ET	WYs 2019-2023	24"	110,500	53%
Average streamflow at Roy	WYs 1957-1972	11"	50,500	24%
Consumptive domestic water use	2010	<1"	3,300	2%
Balance (to be accounted for):		~10"	46,000	22%

* afy calculated for area above the gage in Roy.



Adjustments to values in Table 7 may be made with further analysis considering the following:

- Interception: Evaporation may higher than accounted in this study.
- Groundwater flow out of the basin: This study did not estimate groundwater that bypasses the stream gage at Roy, either flow into Muck Creek downstream of Roy, to marine waters, or out of the basin to the west and north.
- Datasets of different periods: Estimates of precipitation, ET, and water use come from the past 5 to 35 years, but streamflow data are from 1956-1972 – before most of the development in the eastern and southern basin had occurred.

We estimate the net ET has decreased in the Muck Basin over the last approximately 160 years due to the removal of forest and the growth of developed areas in Upper Muck, Lacamas, and South Subbasins. This decrease has been partially offset by an increase in ET by the expansion of forest into prairie lands in the Lower and Middle Muck subbasins (Table 6). Existing data does not allow us to say whether the decrease in ET at the level of the whole basin has resulted in an increase in streamflow in the lower reaches. Anecdotal reports of increasingly dry periods in streams in summer and early fall over the past 40 years suggest this is not the case.

At the subbasin scale, the increase of forest cover and associated ET in Lower and Middle Muck may have impacted streamflow. Converting forest areas back to prairie would increase groundwater recharge, but it's not clear where this additional groundwater would discharge to surface water. Forest removal would not benefit Muck Creek on JBLM upstream of the confluence with Johnson Creek because this is a losing reach. Removal of forest from southern prairie areas near Lacamas Creek may increase recharge to support Muck Creek downstream of Roy, but more information on groundwater dynamics in the area is needed to better define the possible benefits.



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Appendix D
Managed Aquifer Recharge Technical
Memorandum



Technical Memorandum

Date: 28 March 2024

Coho Project: MUK-04.5

To: Merri Martz, Anchor QEA

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From: Sherry Wilhelm, Coho Water Resources
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cc: Robert Montgomery, Anchor QEA

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**RE: POTENTIAL FOR AQUIFER RECHARGE
IN LACAMAS SUBBASIN OF MUCK CREEK BASIN**

1 PURPOSE & PRIMARY FINDINGS

This technical memorandum presents an evaluation of potential stormwater recharge locations in the Lacamas Creek subbasin of Muck Creek Basin. Coho Water Resources, LLC (Coho) conducted this work for the Nisqually River Foundation's (NRF) Muck Creek Watershed Restoration Strategy as a subcontractor to Anchor QEA, LLC (Anchor).

Muck Creek Basin experiences low or no streamflow in key reaches during times of salmonid passage, spawning, and rearing. Managed Aquifer Recharge (MAR) projects can retain water in groundwater then can later discharge to surface water to augment streamflows. This work considers the potential of MAR projects to capture and recharge stormwater runoff generally across the basin and in more detail for Lacamas Basin, which has most consistent streamflow conditions but also vulnerable to low or no streamflow at important times.

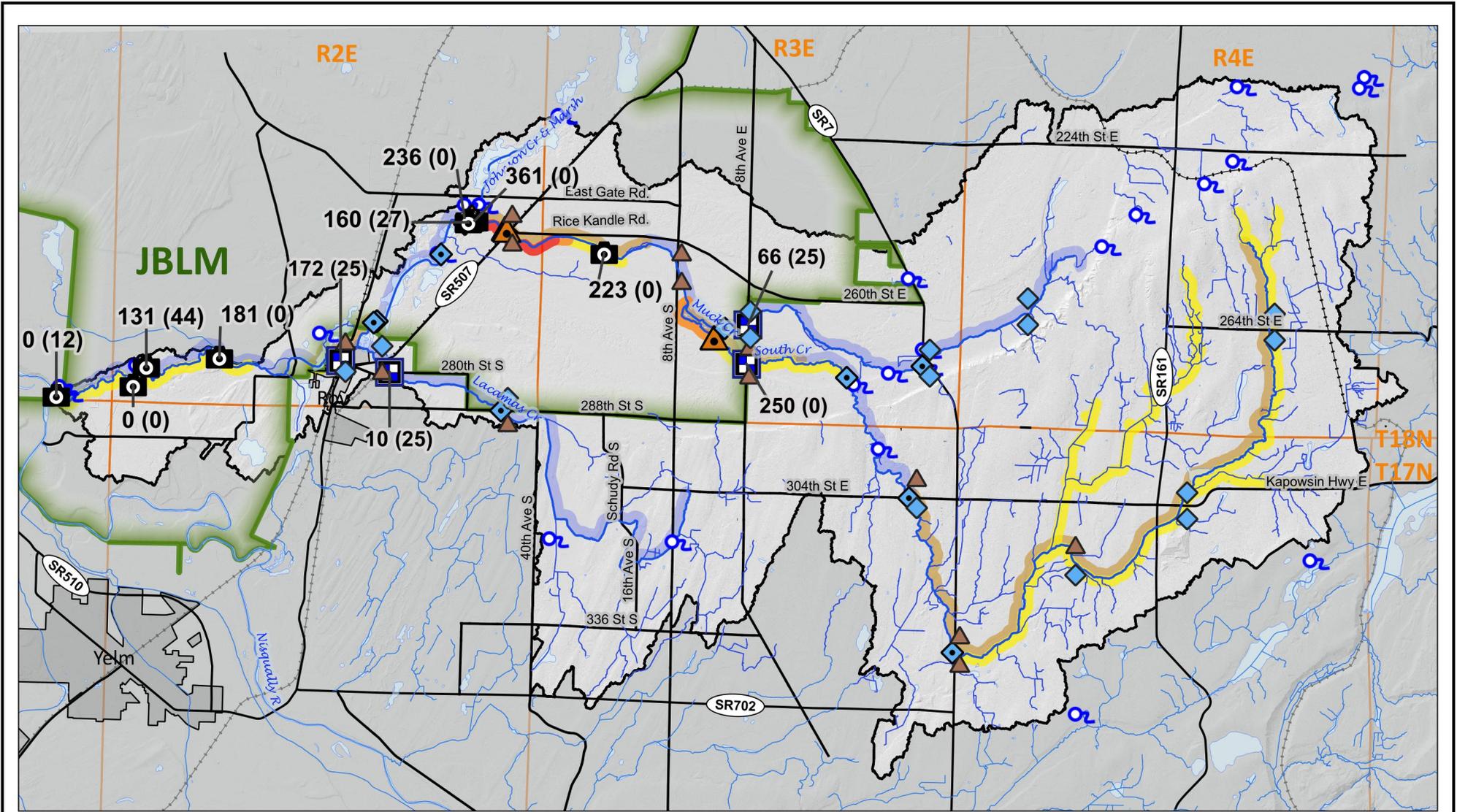
Significant findings of this work are:

- Muck Creek Basin does not contain water sources for a high-volume MAR project, leaving stormwater as the best water source for recharge to groundwater.
- Recent geologic mapping in Lacamas Creek Subbasin suggests that the surficial "till" deposits in the subbasin and by extension in South Creek

Subbasin are more permeable and favorable for recharge than previously thought.

- Several locations in Lacamas Creek Subbasin may be appropriate for enhancement of existing stormwater drainage ditches to encourage stormwater recharge to benefit streamflow and stream temperature during low-flow times.





<p>Stream Conditions Nov. 1999</p> <p> Dry</p> <p> Flowing</p> <p> Springs</p>	<p>Dry Stream Reaches</p> <p> Sept. 2000</p> <p> Sept. & June 2000</p> <p> Sept. & June 2000, Feb. 2001</p>	<p>Stream Conditions Upper: Sept. 2007 Lower: July 2008</p> <p> Dry</p> <p> Flow</p>	<p>Stream Conditions 15 May 2019</p> <p> Dry</p> <p> Wet</p>	<p>Days of dry stream in WY2023 (days without data in parentheses):</p> <p> Streamflow gage (Anchor QEA)</p> <p> Time-lapse camera</p>
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Data Sources (from L to R): Pierce Co. (2005), Sinclair (2001), Savoca and others (2010), Coho (2019), and Coho (2024).

Figure 1

Observed Occurrence of Dry Reaches and Springs

Nisqually River Foundation
Muck Creek SFR - Lamas MAR

2 BACKGROUND

2.1 Reaches of concern in Muck Creek Basin

In Muck Creek Basin, many stream reaches experience periods of low or absent flows that impact salmonid development and passage (Figure 1). Low flow conditions most often impact these critical times in the salmonid life cycles (Figure 2; Anchor QEA 2022):

- Late fall and winter for return and spawning of anadromous species.
- Late winter and spring for rearing and outmigration of anadromous species.
- Summer and early fall for species present year-round.

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

Notes:
 Dark blue: adult presence
 Light blue: juvenile presence
 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.

Figure 2: Muck Creek salmonid presence

(Anchor QEA 2022)

Important reaches with little or no flow at critical times include (Coho 2021, Coho 2024 and Anchor QEA 2024):

- Several reaches of Muck Creek:
 - At the mouth and in the lower canyon.
 - Between the lakes-and-wetlands and the canyon, both above and below Roy.
 - On the prairie between the confluence with Johnson Creek and 8th Ave E.
- Lower reach of South Creek as it crosses the prairie. Portions of upper South Creek have also been observed to be dry in the summer.
- Lower reach of Lacamas Creek as it crosses outwash deposits. This reach is rarely dry, but observations suggest dry periods may be increasing.



2.2 Importance of groundwater discharge to streams

Groundwater discharge is an important source of streamflow at key times and locations in the basin. This is seen most clearly in concentrated areas of groundwater discharge to streams, such as at Exeter Springs in Muck Creek canyon, but also significant in other reaches. Observations of sustained streamflow during times of little or no precipitation indicate that several stream reaches, including much of Lacamas Creek, parts of South and upper Muck Creeks, and Muck Creek below Exeter Springs, are sustained by groundwater baseflow in the summer and early fall. Groundwater also supplies much of the winter streamflow pulse from the lakes-and-wetlands chain that results in fish passage flow in lower Muck Creek.

2.3 Suitable MAR options for Muck Creek Basin

Among other applications, MAR techniques can be used to store “surplus” water in groundwater aquifers for later release to streams. In addition to increasing streamflow quantity, MAR can have the added benefit of providing cool water to streams. At its simplest, a MAR project in support of streamflow requires these components:

- A source of “surplus” water for recharge.
- An aquifer that:
 - Can receive and store additional water.
 - Can deliver recharged water to the targeted stream reach.
 - Provides a storage interval that delivers recharged water to the stream during a low flow time. Ideally several months in Muck Creek Basin.
- A means of transferring water from the source to the aquifer, such as surface application or injection via wells.

In Muck Basin some of the typical sources of “surplus” water for MAR are not available:

- Highly treated wastewater, i.e., reclaimed water, is often used for MAR, but no wastewater treatment plants (WWTPs) exist in the basin. The nearest WWTP is the Solo Point facility near the shore of Puget Sound.
- Concentrated sources of stormwater from large stormwater management features, such as stormwater retention ponds. No such features exist in the basin.



Stormwater runoff represents the most available source of surplus water in Muck Creek Basin. Runoff in the basin is typically managed with a distributed network of ditches and culverts. Increasing the recharge of stormwater can also reduce peak winter flows and the damage, such as scouring and incision, that they can do to stream channels.

Stormwater can be recharged via Green Stormwater Infrastructure (GSI) projects such as retention swales in roadside ditches and rain gardens on private properties (Simmons and others 2022). Individually these projects may recharge small volumes of water, so their impact builds as multiple projects are added to a basin.

2.4 Focus of this report

To examine the potential for GSI projects in Muck Creek Basin, this work focuses on the Lacamas Creek Subbasin for the following reasons:

- Lacamas Creek has almost-perennial streamflow. These favorable conditions should be protected and enhanced, especially because signs of streamflow decreases have been observed recently.
- Salmonid presence is documented in this subbasin, including some evidence of coho.
- Lacamas Creek does not dry out as it crosses the outwash gravels, though the stream does apparently lose some flow to this highly permeable unit in its lower reach. Thus increased streamflow in the upper subbasin due to GSI projects will not be completely erased in the lower subbasin.
- Lacamas Creek lies downstream of the main prairie reach of Muck Creek that is the greatest barrier to fish passage due to its extensive dry periods.

The findings of this work may be applicable to the South Creek Subbasin as well, given its similar stream network, geology, and hydrogeology compared to Lacamas Creek Subbasin.

3 METHODS

Potentially favorable locations for GSI projects are identified by characterizing the likely recharge areas for groundwater units which discharge to Lacamas Creek and then evaluating these locations for their suitability for additional recharge of stormwater. This approach involves evaluating the land cover, geology, and hydrogeology with which the



stream interacts and filtering the existing drainage network for appropriate underlying geology, slopes, etc.

3.1 Characterize relevant aspects of Lacamas Subbasin

The following features of the subbasin are described, based on examination of available data sources.

3.1.1 Basin boundary and land cover

- Basin boundary from combination of recently defined fine-scale surface water basins (Dun 2022).
- Description of land cover characteristics as extracted in Coho (2024).

3.1.2 Hydrology

- Pierce County “hydro_centerlines” dataset for stream network. This stream network is a version of the National Hydrology Dataset revised with channel features visible on recent lidar.
- Streamflow pattern from previous studies and a stream gage operated in WY2023 by Anchor (Montgomery 2024).

3.1.3 Stormwater system

- Stormwater drainage network from Pierce County Surface Water Management (2021).

3.1.4 Geology

- Surficial geology from Washington Geological Survey:
 - Hart’s Lake Quadrangle (1:24,000 scale; Contreras and others 2023): Covers most of Lacamas basin.
 - Surficial geology spatial dataset (1:100,000 scale; Washington Department of Natural Resources 2016): Used for northern and western portions of the basin not covered by the finer-scale Hart’s Lake Quadrangle.
- Subsurface geology:
 - Existing descriptions of basin geology, including two cross-sections, in Sinclair 2001.
 - Cross-section of geology SE-NW across Lacamas Creek, constructed by spatially locating and interpreting existing well logs (Washington State Department of Ecology 2023).



3.1.5 Hydrogeology

- Existing descriptions of basin hydrogeology (Savoca and others 2010; Sinclair 2001).
- Static water levels from well logs in cross-section.

3.1.6 Groundwater-surface water interactions

- Locations of groundwater contributions to streams based on:
 - Thermal infrared (TIR) survey of Lacamas Creek which measured stream temperature during low water conditions (July 2019; QSI 2020). Used an August 2019 aerial photograph to identify reaches where tree canopy covered the stream, then identified areas where stream temperature was consistently below 18 C.
 - Observations from instream piezometer in upper Lacamas subbasin (Sinclair 2001).

3.2 Evaluate possible locations for recharge projects

The basin characterization is used to identify criteria favorable for stormwater recharge to benefit streamflow, and spatial analysis is used to identify possible locations.



4 RESULTS AND DISCUSSION

4.1 Characterize relevant aspects of Lacamas Subbasin

4.1.1 Basin boundary and land cover

Based on the recent Pierce Co. basin delineation, Lacamas Basin covers almost 12 square miles (Figure 3). Before settlement by European Americans, the basin was approximately 63% forest, 25% wetlands, and 13% prairie (Coho 2024). Currently the main land cover classes are agriculture (primarily pasture and hay; 33%), forest (28%), and wetlands (13%) (Coho 2024). Undeveloped portions of Joint Base Lewis McChord (JBLM) cover much of the northern portion of the basin.

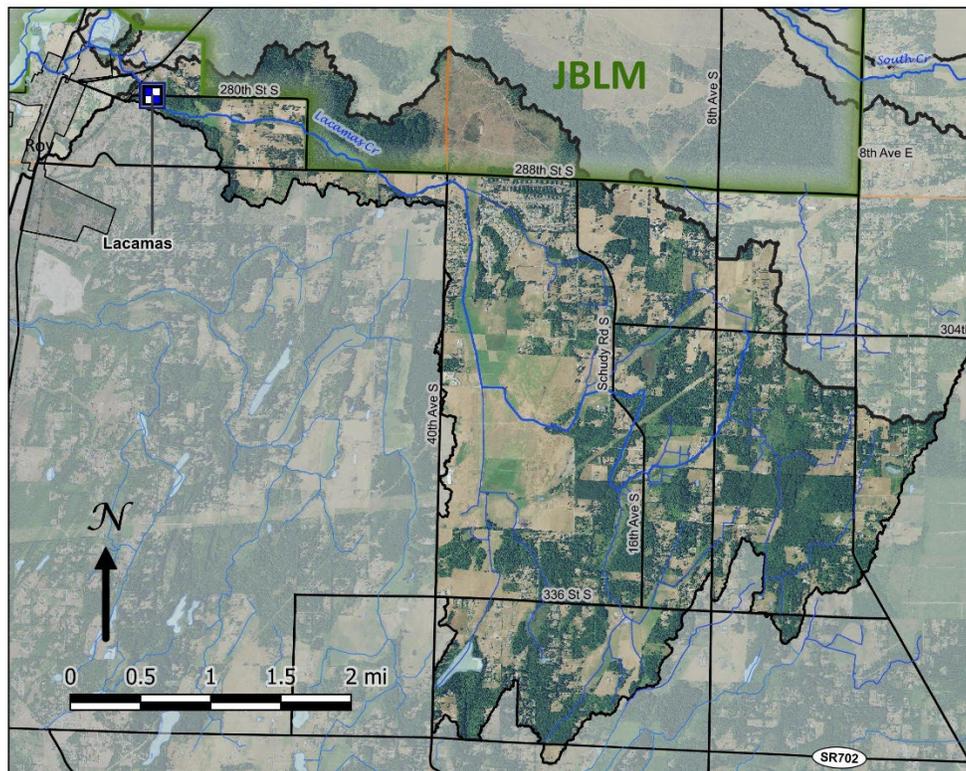


Figure 3: Lacamas Creek Subbasin (2021 air photo).

(Data source: USDA NAIP, 2020; figure source: MuckCreek.qgs – Lacamas Basic Airphoto)

4.1.2 Hydrology

Lacamas Creek joins Muck Creek near the town of Roy, at the northwestern end of the Lacamas Subbasin. The restoration strategy for Muck Creek (Anchor QEA 2022) divides Lacamas Creek into three reaches: 12, 13, and 14. The lower portion of Lacamas Creek (~Reach 12) crosses the level outwash plain and enters Muck Lake, where it joins Muck Creek. The middle portion of the creek (~Reach 13) flows northward across a flat valley floor. This reach has been channelized into straight sections (Figure 4). The upper portion (~Reach 14) is constrained by ridges of glacial deposits that run roughly northeast to southwest. At points the stream cuts across these ridges to follow the overall topographic gradient of the basin to the northwest.

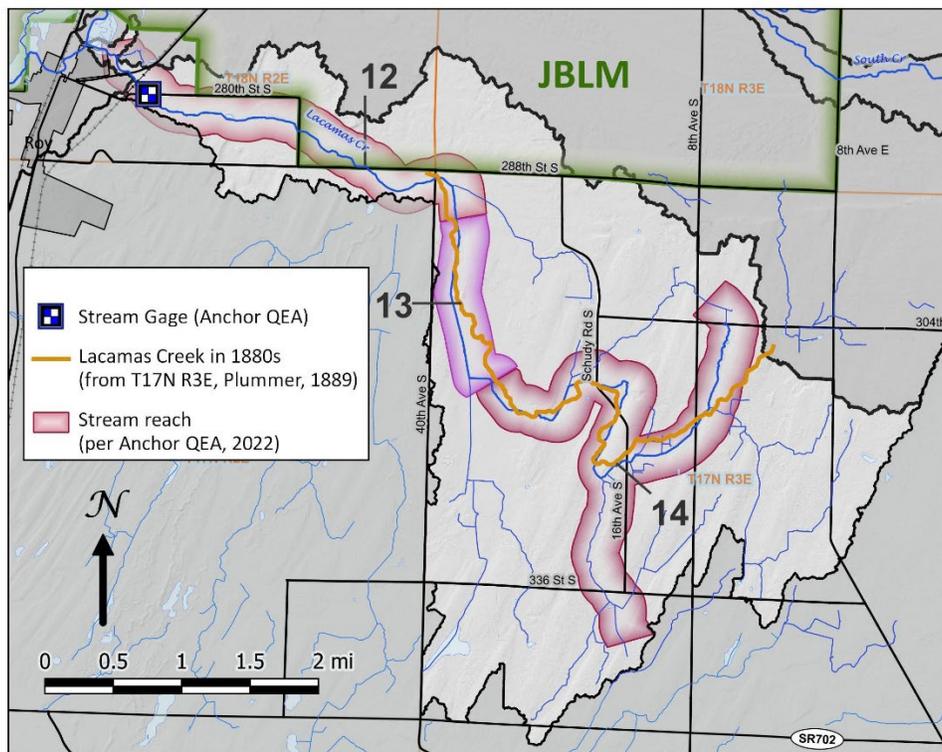


Figure 4: Stream network, with topography and reaches for restoration strategy.

(figure source: MuckCreek.qgs-Lacamas lidar and stream network)

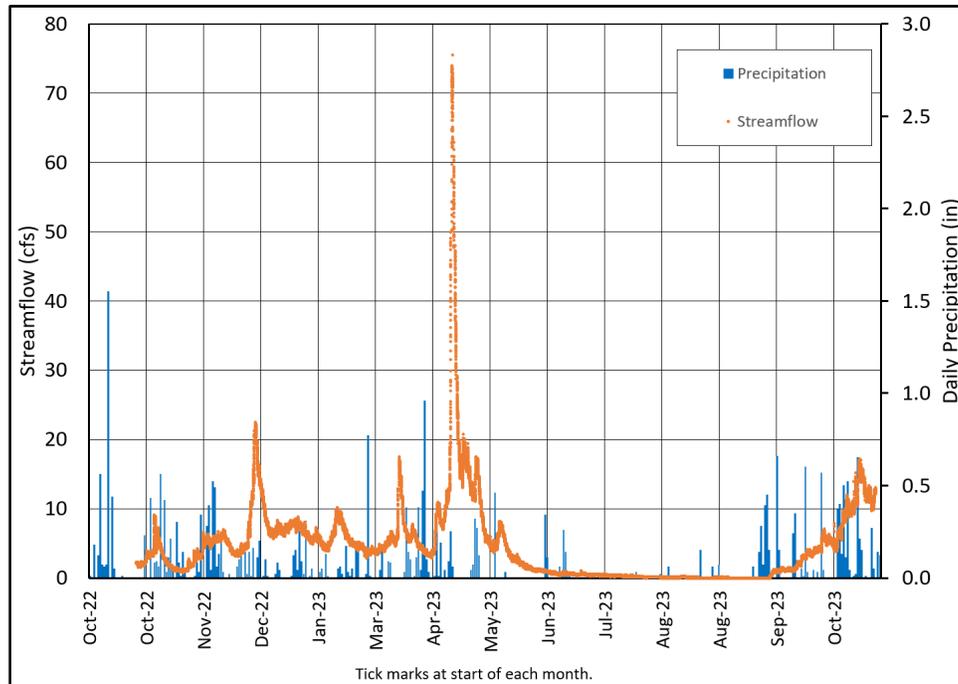


Figure 5: Streamflow at Lacamas Creek gage vs. precipitation, Oct. 2022-Oct. 2023

(data source: Anchor QEA;

figure source: SF_Rating_Curves_Stitched_Corrected_Data_V1 srw_values.xlsx)

The hydrograph for Lacamas Creek for water year 2023 (WY2023; Oct. 2022-Sept. 2023) exhibits several peaks in streamflow occurring after heavy rainfall (Figure 5). These stormwater peaks represent water that could be captured for groundwater recharge.

Lacamas Creek generally flows even during the dry summer season. In WY2023, one of the five driest water years in the last 70 years, Lacamas Creek at its gage had flow for all but 11 days (Sept. 18-28), while Muck Creek at Roy, less than a mile downstream, was dry for 172 days (gage locations in Figure 1; Anchor QEA 2024). Although Lacamas Creek has only been monitored sporadically, periods of no streamflow have occasionally been observed in lower Lacamas:

- July 21 and August 19, 1986, and June 24, 1987, during roughly monthly flow measurements (Eylar and others 1990, as reported in Sinclair 2001, App. G). The creek was always flowing during similar measurements in 1988 and 1989.
- July 9, 2008, during a single-day survey of flow conditions throughout the Muck Creek and Chambers-Clover Creeks basins (Savoca and others 2010).



to oldest (Figure 7). The descriptions and geologic map include the symbols used by Contreras and others (2023), which is the most recent and detailed mapping of the study area:

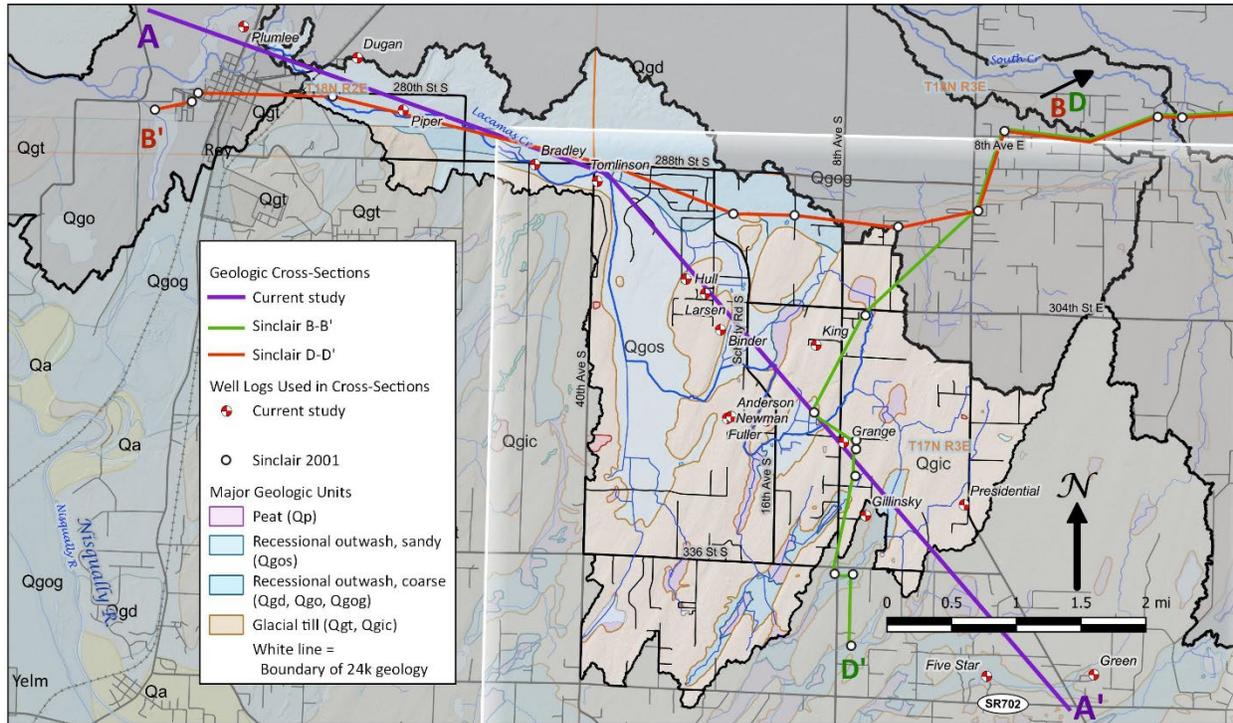


Figure 7: Surficial geology and location of cross-sections.

(figure source: MuckCreek.qgs-Lacamas geology)

- Peat deposits (Qp): Post-glacial deposits of organic and organic-rich sediment.
- Recessional outwash deposits (Qgo and Qgd): Fluvially sorted sediments deposited by melt-water streams during the retreat of the last glaciers. Two important types present in Lacamas Basin:
 - Recessional outwash sand (Qgos): Moderately to well-sorted sand with minor silt and rare pebble-gravel; found in low-lying areas between glacial ridges, overlying finer-grained glacial deposits.
 - Recessional outwash gravel (Qgog): Gravelly; found on the broad outwash plain at the northern edge of Lacamas basin.
- Glacial till deposits (Qgt and Qgic): Poorly sorted deposits of glacially carried sediments including grain sizes from cobbles to clays. In the Lacamas Basin, Contreras and others (2023) describe this unit as “ice contact deposits” (Qgic), indicating that the deposits are less compacted than typical glacial till (Qgt). This unit will be referred to as glacial till in this document.

The soils which have developed on top of these deposits since the glacial retreat share the characteristics of the underlying geologic unit (USDA 2023):

- Spanaway gravelly sandy loam has developed on top of outwash gravel.
- Gravelly to fine-sandy loams have developed on top of outwash sand and glacial till.
- Finer-grained soils including Dupont muck and Tisch silt have developed in moist low-lying areas such as along stream channels, where peat deposits are found.

The subsurface geology consists of the units present at the surface plus additional underlying units (Figure 8). The deposits of the most recent glacial cycle are usually identifiable, but the deposits of preceding glacial cycles are less clear and classified under a more general descriptor such as “pre-Vashon glacial and nonglacial undifferentiated sediment” (Qguc; Contreras and others 2023). From surface downward the geologic units in Lacamas Basin include:

- Recessional outwash deposits (Qgo), with grain sizes that increase with depth:
 - Recessional outwash gravel (Qgog): less than 40' thick, only present on outwash plain.
 - Recessional outwash sand (Qgos): up to 100' thick, not present in many upstream portions of basin.
- Glacial till (Qgt): typically 40-100' thick, but observed to be very thin or absent in the west end of the cross-section constructed for this work, where it might have been completely eroded by outwash waters.
- Older glacial and inter-glacial deposits, with a range of textures. May include:
 - Advance outwash deposits (Qga) of the most recent glacial deposit, which are coarse-grained, with grain sizes that decrease with depth. This unit was not mapped as present in Lacamas basin by Sinclair 2001, nor was it identified in the deeper layers exposed in Muck Creek canyon to the west (Polenz and others, 2023).
 - Pre-Vashon coarse- and fine-grained layers (i.e., Qguc): Sinclair identified 2 aquifers and one aquitard within 100' below till in Lacamas Basin. Difficult to identify more specifically due to age and heterogeneity.



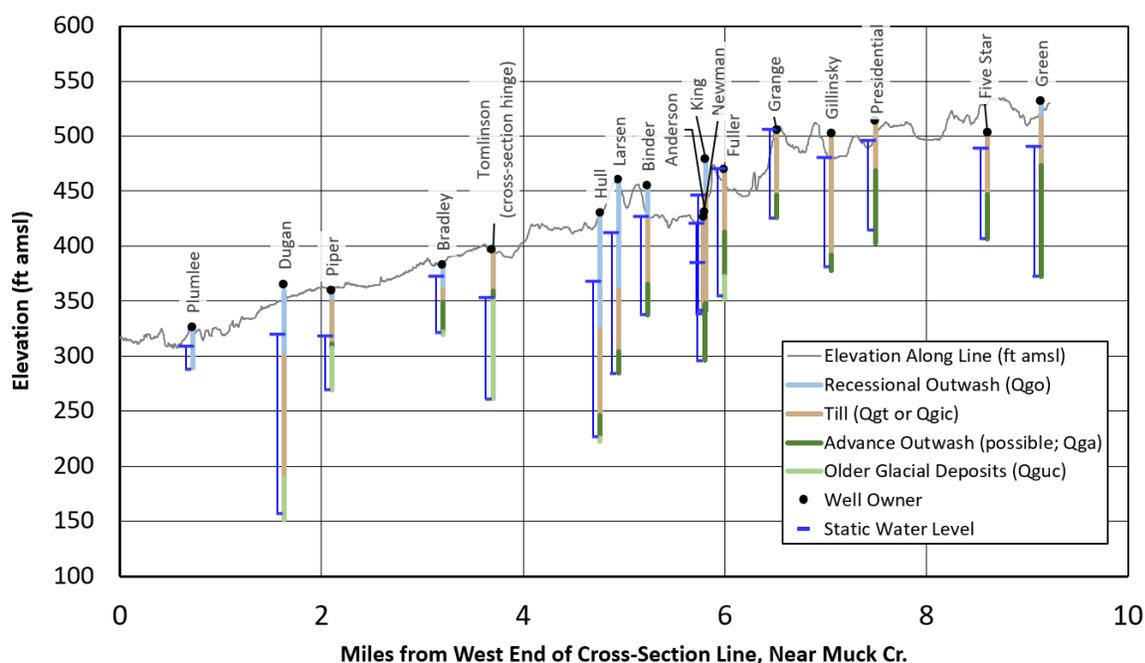


Figure 8: Geologic and hydrogeologic cross section.

(figure source: Muck Basin Geol XSects.xlsx)

4.1.5 Hydrogeology

The geologic setting defines the basin’s ability to store and transport groundwater. In northern basin, the surficial unit, the recessional outwash, is a productive aquifer, and older domestic wells around Roy such as Plumlee’s tap this unit for water supply. In the main part of the basin, roughly below 288th St. S., geologic units below the till, either the recent advance outwash or older, coarse-grained glacial deposits, form aquifers that are tapped for domestic supply (Figure 8; Sinclair 2001).

Since the recessional outwash sand and glacial till are not used for water supply, little information has been collected on their groundwater levels or hydraulic properties for estimating available storage or transport times. The recessional outwash sand is expected to be permeable, given its deposition by fluvial processes. Although glacial till is usually expected to have low permeability, the less-compacted texture of the till-equivalent “ice contact deposits” (Qgic) in the Lacamas basin may be more “permeable”. The soils which have developed on these deposits are mapped as moderately well drained (USDA 2023). An area of ice-contact deposits to the east of Lacamas Basin and



south of 304th St. has no visible surface water drainage channels, suggesting that recharge dominates over surface runoff in this area (Figure 7).

Groundwater flow directions suggested by water levels in the cross-sections are consistent with other work that suggests that groundwater flows to the west and northwest in Muck Creek Basin (Savoca and others 2010; Sinclair 2001). These water levels are those recorded during well installation, which span decades and in a variety of seasons, lending uncertainty to their use in defining groundwater gradients. The water table in surficial aquifers often follows the general land surface topography, which would again be to the northwest. Vertical gradients between aquifers are not well-defined but seem to be downward (Sinclair 2001).

4.1.6 Groundwater-surface water interactions

As described earlier, the successful application of MAR techniques to improve streamflow depends on the presence of a hydrogeologic unit that can receive, store, and discharge surplus water to streams. In the Lacamas Basin, the existing connections between groundwater and surface water suggest possible foci for MAR projects.

The ability of groundwater to supply streamflow to Lacamas Creek is demonstrated by the stream's perennial flow through times of little or no rainfall. Stream baseflow during low flow times may be supplied by groundwater recharged to and transported through the glacial till as well as the recessional outwash. Till is generally thought of as an aquitard with a low ability to transport water, but as discussed above, the ice-contact deposits in Lacamas may be a more permeable cousin of till.

The 2019 Thermal Infrared (TIR) survey of Lacamas Creek was flown at the end of July 2019 (QSI 2020). The survey detected areas of cool water in the stream that might indicate the local input of groundwater (Figure 9). One area matches the location at which groundwater input to upper Lacamas Creek was observed via an instream piezometer (Sinclair 2001). The TIR signal can be confounded if cool groundwater has recently been applied as irrigation water, which might be the cause of the cool patch in the center of Reach 13.



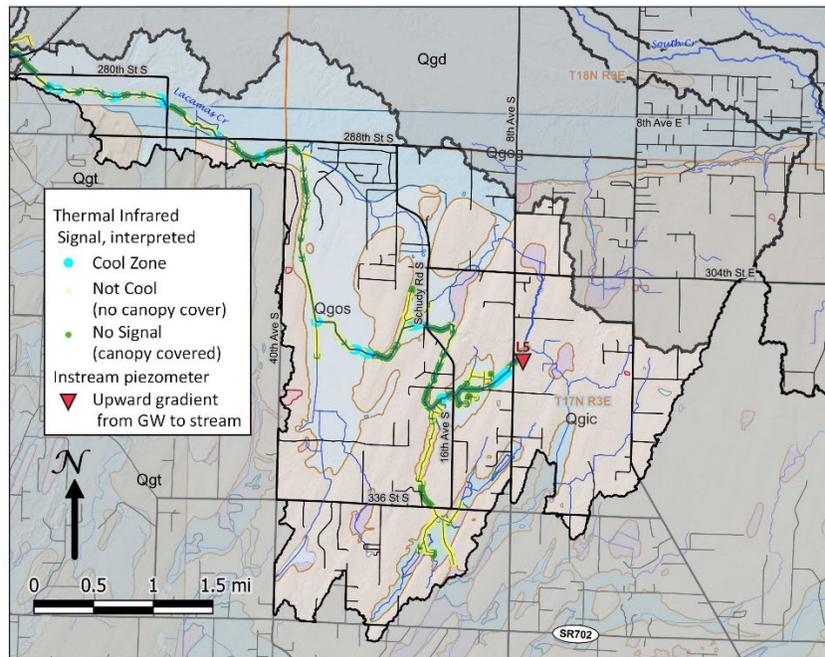


Figure 9: Possible zones of groundwater input to Lacamas Creek from TIR survey

(figure source: MuckCreek.qgs-Lacamas TIR and Canopy)

4.2 Possible locations for recharge projects

In Lacamas Subbasin, winter stormwater flow provides an available source of water for recharge. Of the two hydrogeologic units which connect with surface water, recharge to the till, a.k.a. the ice-contact deposits, may provide longer retention times than the recessional outwash. However the hydrogeologic properties of the till are unknown and should be determined if recharge to the till is considered further. Longer retention times are also likely if recharge locations are further from streams.

Characteristics of 250' lengths of open drainage channels in the basin, namely slope, underlying geology, distance to a stream, and land ownership, were compiled in a GIS project and then filtered for the best locations for recharge to benefit Lacamas Creek. In this initial analysis these criteria were used:

- Along-channel slope of 1%-6% (Simmons and others 2022)
- Underlain by glacial ice-contact deposits.
- Distance to nearest stream of at least 800'.
- Publicly owned.

Different criteria could be applied as understanding evolves or as different GSI configurations are proposed.

Clusters of drainage ditches fitting the above criteria were found in the following locations, listed from east to west (roughly upstream to downstream; Figure 10):

1. 8th Ave S between 304th St and 310th St
2. 16th Ave S near 327th St
3. 40th Ave S. (several sections) on west edge of Lacamas Subbasin. From north to south:
 - a. Between 328th St and 336th St., as well as areas on 336th St.
 - b. At same latitude as 304th to 314th St.
 - c. At same latitude as 296th St

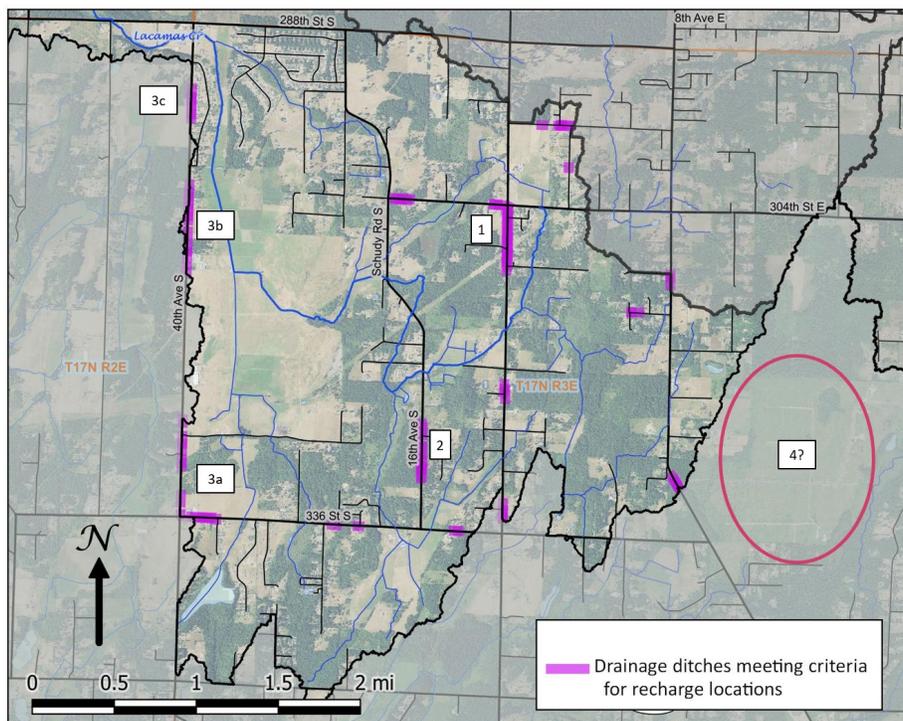


Figure 10: Locations of drainage ditches meeting criteria for possible enhanced recharge.

(figure source: MuckCreek.qgs-Lacamas Target Drain Channels)

An area to the east of Lacamas Subbasin (#4 in Figure 10) may also be a recharge area for Lacamas Creek, considering the regional groundwater flow directions. This area is currently being developed into residential lots of 15+ acres in size, and roads are being installed. Given the large lot size and current county regulations on stormwater management, the development may not generate significant stormwater runoff.

This exploratory “desktop” evaluation of possible GSI siting, based on existing knowledge of Lacamas Basin, would be strengthened if combined with field observations and the input of stormwater managers for the area.



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ATTACHMENT A
WELL LOGS USED IN CONSTRUCTING
A-A' GEOLOGIC CROSS-SECTION

Owner's Last Name	Well Report Id	Distance from "A" along cross-section line (miles)	Depth of well (ft)
Plumlee	01868658	0.72	38
Dugan	00022434	1.63	208
Piper	00031506	2.10	90
Bradley	00032149	3.20	61
Tomlinson	00481470	3.70	135
Hull	00311229	4.77	202.5
Larsen	00031765	4.95	175
Binder	00477487	5.24	117
Newman	00026415	5.79	87
Anderson	00339438	5.80	135
King	00535982	5.81	137
Fuller	00029268	6.00	114
Grange	00026745	6.52	80
Gillinsky	01924238	7.06	121
Presidential	01904209	7.49	99
Five Star	00413488	8.61	96
Green	00638128	9.14	159



(1) OWNER NAME: **RUSSELL PLUMLEE**
 (2) LOCATION OF WELL: County **PIERCE**
 (2a) STREET ADDRESS OF WELL (or nearest address): **427 WARREN ST**

ADDRESS: **P.O. BOX 164 ROY WA 98580**
NW 1/4 NW 1/4 SEC 34 TWP 18N R 2E
PARCEL 0218346706

(3) PROPOSED USE: **DOMESTIC**
 (4) TYPE OF WORK: **NEW WELL**
 METHOD: **ROTARY**

(10) WELL LOG OR DECOMMISSIONING PROCEDURE DESCRIPTION

(5) DIMENSIONS: Diameter of well inches.
 Drilled **38** feet. Depth of completed well **35** ft.

MATERIAL	FROM	TO
DARK BROWN SANDY SILT, GRAVEL, COBBLES	0	2
BROWN VERY SILTY SAND, GRAVEL, COBBLES AND BOULDERS	2	18
DARK BROWN SANDY CLAY	18	19
BROWN SANDY SILT AND CLAY, W.B.	19	23
BROWN VERY SILTY SAND, GRAVELS, AND COBBLES, WATER BEARING	23	28
LIGHT BROWN SILT, SAND, SOME CLAY, GRAVEL, WB	28	29
BROWN VERY SILTY SAND, GRAVEL, COBBLES, WB	29	36
GREY BROWN SANDY SILT, SOME GRAVEL	36	38

(6) CONSTRUCTION DETAILS
 Casing instld: **6"** " Diam. From **+1** ft. to **35'** ft.
 Welded " Diam. From ft. to ft.
 Liner " Diam. From ft. to ft.
 Threaded

Perforations: Yes No
 Type of perforator used
 Size of perforations in. by in.
 perforations from ft. to in.
 perforations from ft. to in.
 perforations from ft. to in.

Screens: Yes No
 Manufacturer's Name: Model No.
 Type Diam Slot size from ft. to ft.
 Diam Slot size from ft. to ft.

Gravel packed Yes No Size of gravel? ft.
 Gravel packed from ft. to ft.

Surface seal: Yes No To what depth? **18** ft.
 Material used in seal **BENTONITE CHIPS**
 Did any strata contain unusable water? Yes No
 Type of water? Depth of Strata ft.
 Method of sealing strata off

(7) PUMP: Manufacturer's Name Type H. P.

(8) WATER LEVELS: Surface elev above mean sea level ft.
 Static level **17'** below top of well Date **06/18/18**
 Artesian pressure lbs. Per sq. in. Date
 Artesian pressure is controlled by

(9) WELL TESTS: Pump test made? By Whom
 Yield gal./min with ft. drawdown after hrs.
 Yield gal./min with ft. drawdown after hrs.
 Yield gal./min with ft. drawdown after hrs.
 Recovery data:
 Time Wtr Lvl. Time Wtr Lvl. Time Wtr Lvl.

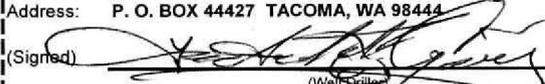
Date of test:
 Bailer test gal./min with ft. drawdown after
 Airstest **32** gal/min stem set at **35** ft. for 1 hrs.
 Artesian flow gal/min Date
 Temperature of water Was chemical analysis made? **NO**

Work Started **06/18/18** Completed: **06/18/18**

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Name: **RICHARDSON WELL DRILLING COMPANY INC.**
 Address: **P. O. BOX 44427 TACOMA, WA 98444**

(Signed)  Lic No. **2081**
 (Well Driller)
 Contractor's Registration No. **RICHAW*3210B** DATE **6/26/18**

RECEIVED

06/22/2018

WA State Department of Ecology (SWRO)

The Department of Ecology does NOT warrant the data and/or the information on this Well Report

File Original with Department of Ecology
Second Copy - Owner's Copy
Third Copy - Driller's Copy

7751 WATER WELL REPORT

STATE OF WASHINGTON

Notice of Intent W 129053
UNIQUE WELL ID # AFT-212
Water Right Permit No _____

(1) OWNER Name Michael & Susan Hull Address 30103 28th Ave. So., Roy, Wa. 98580

(2) LOCATION OF WELL County Pierce SW 1/4 NE 1/4 Sec 6 T 17 NR 3E WM

(2a) STREET ADDRESS OF WELL (or nearest address) 30103 28th Ave S., Roy, Wash 98580

TAX PARCEL NO 0317064019

(3) PROPOSED USE Domestic Industrial Municipal
 Irrigation Test Well Other
 DeWater

(10) WELL LOG or DECOMMISSIONING PROCEDURE DESCRIPTION
Formation Describe by color, character, size of material and structure and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. Indicate all water encountered

(4) TYPE OF WORK Owner's number of well (if more than one) AFT 212
 New Well Method
 Deepened Dug Bored
 Reconditioned Cable Driven
 Decommission Rotary Jetted

MATERIAL	FROM	TO
Top soil	0'	1'
Brown Silty Sand	1'	4'
Brown Silty gravel	4'	24'
Brown silty gravel	24'	60'
Brown silt w/ gravel	60'	105'
Hard brown till	105'	114'
Brown Silty Sand	114'	136'
Brown Silt	136'	160'
Brown Clay	160'	174'
Cemented Sand & gravel	174'	184'
Brown Silty Sand	184'	190'
Brown Sand & gravel, waterbearing	190'	204'
Gray silt w/ wood chips	204'	207'

(5) DIMENSIONS Diameter of well 6 inches
Drilled 207 feet Depth of completed well 202'-6" ft

(6) CONSTRUCTION DETAILS
Casing installed
 Welded 6 " Diam from 12 ft to 202'-6" ft
 Liner installed " Diam from " ft to " ft
 Threaded " Diam from " ft to " ft

Perforations Yes No
Type of perforator used _____
SIZE of perforations _____ in by _____ in
_____ perforations from _____ ft to _____ ft

Screens Yes No K-Pac Location _____
Manufacturer's Name _____
Type _____ Model No _____
Diam _____ Slot Size _____ from _____ ft to _____ ft
Diam _____ Slot Size _____ from _____ ft to _____ ft

Gravel/Filter packed Yes No Size of gravel/sand _____
Material placed from _____ ft to _____ ft

Surface seal Yes No To what depth? 18 ft
Material used in seal benonite chips
Did any strata contain unusable water? Yes No
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

(7) PUMP Manufacturer's Name _____
Type _____ HP _____

(8) WATER LEVELS Land-surface elevation above mean sea level _____ ft
Static level 62'-2" ft below top of well Date 11/3/00
Artesian pressure _____ lbs per square inch Date _____
Artesian water is controlled by _____ (Cap valve, etc)

RECEIVED

NOV 08 2000

Washington State
Department of Ecology

Work Started 11/1 2000 Completed 11/3 2000

(9) WELL TESTS Drawdown is amount water level is lowered below static level
Was a pump test made? Yes No If yes by whom? Hokkaido
Yield 15 gal/min with 11'-2" ft drawdown after 1/2 hrs
Yield 15 gal/min with 13'-4" ft drawdown after 1/2 hrs
Yield 15 gal/min with 14'-9" ft drawdown after 2 hrs
Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)
Time Water Level Time Water Level Time Water Level
0 76'-11" 3min 69'-5" 20min 65'-1"
1min 74'-1" 5min 68'-3" 25min 64'-9"
2min 72'-3" 10min 66'-9" 30min 64'-9"
Date of test 11/3/00
Bailer test _____ gal/min with _____ ft drawdown after _____ hrs
Airtest _____ gal/min with _____ ft drawdown after _____ hrs
Artesian flow _____ g p m Date _____
Temperature of water _____ Was a chemical analysis made? Yes No

WELL CONSTRUCTION CERTIFICATION
I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief
Type or Print Name STEVE SAENZ License No 2217
(Licensed Driller/Engineer)
Trainee Name _____ License No _____
Drilling Company HOKKAIDO DRILLING, INC.
(Signed) [Signature] License No 1146
(Licensed Driller/Engineer)
Address P.O. BOX 100, GRAHAM, WA 98338-0100
Contractor's Registration No HOKKAD1017M8 Date 11/6/00
(USE ADDITIONAL SHEETS IF NECESSARY)

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

File Original and First Copy with Department of Ecology
Second Copy - Owner's Copy
Third Copy - Driller's Copy

WATER WELL REPORT

STATE OF WASHINGTON

Start Card No. W 058645

UNIQUE WELL I.D. # ACA 205

Water Right Permit No.

(1) OWNER: Name Dale Larsen Address 30200 24th Ave. S Roy

(2) LOCATION OF WELL: County Pierce SE 1/4 SE 1/4 Sec 6 T.17 N. R. 3E W.M.

(2a) STREET ADDRESS OF WELL (or nearest address) 30200 24th Ave. S Roy

(3) PROPOSED USE: [X] Domestic [] Irrigation [] DeWater [] Industrial [] Test Well [] Municipal [] Other []

(4) TYPE OF WORK: Owner's number of well (if more than one)
Abandoned [] New well [X] Deepened [] Reconditioned [] Method: Dug [] Cable [] Rotary [X] Bored [] Driven [] Jetted []

(5) DIMENSIONS: Diameter of well 6 inches. Drilled 175 feet. Depth of completed well 175 ft.

(6) CONSTRUCTION DETAILS: Casing installed: 6" diam. from 0 ft. to 175 ft. Welded [X] Liner installed [X] Threaded []

Perforations: Yes [] No [X] Type of perforator used SIZE of perforations in. by in. perforations from ft. to ft.

Screens: Yes [] No [X] Manufacturer's Name Type Model No. Diam. Slot size from ft. to ft.

Gravel packed: Yes [] No [X] Size of gravel Gravel placed from ft. to ft.

Surface seal: Yes [X] No [] To what depth? 20 ft. Material used in seal Bentonite Grout Did any strata contain unusable water? Yes [X] No []

(7) PUMP: Manufacturer's Name Type: H.P.

(8) WATER LEVELS: Land-surface elevation above mean sea level ft. Static level 48 ft. below top of well Date Artesian pressure lbs. per square inch Date Artesian water is controlled by (Cap, valve, etc.)

(9) WELL TESTS: Drawdown is amount water level is lowered below static level Was a pump test made? Yes [] No [] If yes, by whom? Yield: gal./min. with ft. drawdown after hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level) Time Water Level Time Water Level Time Water Level

Date of test Bailer test gal./min. with ft. drawdown after hrs. Airtest 40 gal./min. with stem set at 160 ft. for 1 hrs. Artesian flow g.p.m. Date Temperature of water Was a chemical analysis made? Yes [] No []

(10) WELL LOG or ABANDONMENT PROCEDURE DESCRIPTION

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information.

Table with columns MATERIAL, FROM, TO. Entries include: Silty brown sand & cobbles (0-20), Gray silty sand & gravel (20-60), Gray & brown silty sand & gravel (60-100), Olive silty with coarse gravel (100-155), Gray sand with very coarse gravel (155-175).

RECEIVED 95 AUG -1 P1:32 DEPARTMENT OF ECOLOGY STATE OF WASHINGTON

Work Started 19. Completed 19

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

NAME Tacoma Pump & Drilling Co., Inc. (PERSON, FIRM, OR CORPORATION) (TYPE OR PRINT)

Address 30316 Mountain Hwy Graham

(Signed) [Signature] License No. 2230 (WELL DRILLER)

Contractor's Registration No. TACOMPD203PF Date July 31, 19 95

(USE ADDITIONAL SHEETS IF NECESSARY)

Ecology is an Equal Opportunity and Affirmative Action employer. For special accommodation needs, contact the Water Resources Program at (206) 407-6600. The TDD number is (206) 407-6006.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

00535982

WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle) 302008

Construction
 Decommission ORIGINAL CONSTRUCTION Notice of Intent Number _____

PROPOSED USE: Domestic Industrial Municipal
 DeWater Irrigation Test Well Other

TYPE OF WORK: Owner's number of well (if more than one) _____
 New Well Reconditioned Method: Dug Bored Driven
 Deepened Cable Rotary Jetted

DIMENSIONS: Diameter of well 6" inches, drilled 137 ft.
Depth of completed well 137 ft.

CONSTRUCTION DETAILS
Casing Welded 6" Diam. from +3 ft. to 137 ft.
Installed: Liner installed _____ ft. to _____ ft.
 Threaded _____ ft. to _____ ft.

Perforations: Yes No
Type of perforator used _____
SIZE of perfs _____ in. by _____ in. and no. of perfs _____ from _____ ft. to _____ ft.

Screens: Yes No K-Pac Location _____
Manufacturer's Name _____
Type _____ Model No. _____
Diam. _____ Slot Size _____ from _____ ft. to _____ ft.
Diam. _____ Slot Size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: Yes No Size of gravel/sand _____
Materials placed from _____ ft. to _____ ft.

Surface Seal: Yes No To what depth? 18' ft
Materials used in seal BEADONITE CHIPS
Did any strata contain unusable water? Yes No
Type of water? _____ Depth of strata _____
Method of sealing strata off _____

PUMP: Manufacturer's Name _____
Type: _____ H.P. 1/2

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
Static level 33' ft. below top of well Date 3-20-2008
Artesian pressure _____ lbs. per square inch Date _____
Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level.
Was a pump test made? Yes No If yes, by whom? AQUA FLO INC.
Yield: 12 gal./min. with 30' drawdown after 1 hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level

Date of test 3-20-2008
Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
Airstest _____ gal./min. with stem set at _____ ft. for _____ hrs.
Artesian flow _____ g.p.m. Date _____
Temperature of water _____ Was a chemical analysis made? Yes No

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller Engineer Trainee Name (Print) _____
Driller/Engineer/Trainee Signature Willy Halset
Driller or Trainee License No. 1469
If trainee, licensed driller's Signature and License no. Willy Halset

CURRENT Notice of Intent No. W233017
Unique Ecology Well ID Tag No. AAT 395
Water Right Permit No. _____

Property Owner Name MATTHEW KING
Well Street Address 1012 308th ST. S.

City ROY County: PIERCE

Location SE 1/4- 1/4 NE 1/4 Sec. 8 Twn 17N R3E ^{EWM} circle one ^{or} WWM

Lat/Long: (s, r still REQUIRED) Lat Deg _____ Lat Min/Sec _____
Long Deg _____ Long Min/Sec _____

Tax Parcel No. 0317081019

CONSTRUCTION OR DECOMMISSION PROCEDURE
Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. Indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
SAND, GRAVEL + COBBLES	0	13'
SAND, GRAVEL + COBBLES	13'	15'
W/WATER		
SAND, GRAVEL + COBBLES	15'	30'
CEMENTED SAND + GRAVEL	30'	52'
SILTY GRAY SAND + WATER	52'	71'
GRAY SAND, TRACES GRAVEL	71'	79'
W/WATER		
SILTY WET BROWN SAND + GRAVEL	79'	121'
SILTY SAND	121'	122'
FINE BROWN SAND	122'	130'
W/WATER		
BROWN SAND, GRAVEL + WATER	130'	137'

RECEIVED RECEIVED
MAR 26 2008 JUN 24 2008
DEPARTMENT OF ECOLOGY WELL DRILLING UNIT Washington State Department of Ecology
Start Date 3-17-2008 Completed Date 3-19-2008

Drilling Company AQUA FLO INC.
Address P.O. Box 141
City, State, Zip KAPOWISIN, WASH 98344
Contractor's Registration No. AQUA FLO 9806 Date 3-20-2008
Ecology is an Equal Opportunity Employer. ECY 050-I-20 (Rev 4/01)

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 062151
Water Right Permit No.

(1) OWNER: Name FULLER, SAM Address 5712 117TH AVE CT E PUYALLUP, WA 98372-

(2) LOCATION OF WELL: County PIERCE - SE 1/4 SW 1/4 Sec 8 T 17 N., R 3E WM
(2a) STREET ADDRESS OF WELL (or nearest address) 1726 318TH ST SO

(3) PROPOSED USE: DOMESTIC

(10) WELL LOG

(4) TYPE OF WORK: Owner's Number of well (If more than one) Method: ROTARY
NEW WELL

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change in formation.

(5) DIMENSIONS: Diameter of well 6 inches
Drilled 117 ft. Depth of completed well 114 ft.

MATERIAL	FROM	TO
BROWN TILL	0	12
BROWN SAND & GRAVEL	12	17
GRAY TILL	17	23
DAMP BROWN SILTY SAND & GRAVEL	23	40
BOULDERS	23	40
BROWN SILTY SAND GRAVEL & WATER	40	42
BROWN SILT	42	47
BROWN SILTY SAND & GRAVEL	47	53
DAMP GRAY SILTY SAND & GRAVEL COARSE	53	72
BROWN SILTY SAND & GRAVEL	72	97
BLACK GRAY BEDROCK	97	114
	114	117

(6) CONSTRUCTION DETAILS:
Casing installed: 6 Dia. from +1 ft. to 114 ft.
WELDED/LINER IN Dia. from ft. to ft.
Dia. from ft. to ft.

Perforations: YES
Type of perforator used ROTARY STAR
SIZE of perforations 1/2 in. by 1 in.
140 perforations from 80 ft. to 105 ft.
perforations from ft. to ft.
perforations from ft. to ft.

Screens: NO
Manufacturer's Name Type Model No.
Diam. slot size from ft. to ft.
Diam. slot size from ft. to ft.

Gravel packed: NO Size of gravel
Gravel placed from ft. to ft.

Surface seal: YES To what depth? 18 ft.
Material used in seal BENTONITE CLAY
Did any strata contain unusable water? NO
Type of water? Depth of strata ft.
Method of sealing strata off N/A

RECEIVED
 90 NOV 16 A9:32
 WASHINGTON STATE DEPARTMENT OF ECOLOGY

(7) PUMP: Manufacturer's Name Type N/A H.P.

(8) WATER LEVELS: Land-surface elevation above mean sea level ... ft.
Static level 28 ft. below top of well Date 11/09/90
Artesian Pressure lbs. per square inch Date
Artesian water controlled by N/A

Work started 11/07/90 Completed 11/09/90

(9) WELL TESTS: Drawdown is amount water level is lowered below static level.
Was a pump test made? NO If yes, by whom?
Yield: gal./min with ft. drawdown after hrs.

WELL CONSTRUCTOR CERTIFICATION:
I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Recovery data
Time Water Level Time Water Level Time Water Level

NAME ORLKE DRILLING, INC.
(Person, firm, or corporation) (Type or print)

Date of test / /
Bailer test gal/min. ft. drawdown after hrs.
Air test 3.5 gal/min. w/ stem set at 114 ft. for 01 hrs.
Artesian flow g.p.m. Date
Temperature of water 52 Was a chemical analysis made? NO

ADDRESS 4312 166 AV E SUMNER, WA

[SIGNED] License No. 0837

Contractor's Registration No. ORLKEDI 136QC Date 11/13/90

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.

WATER WELL REPORT
STATE OF WASHINGTON

Start Card No. 002168
Water Right Permit No.

(1) OWNER: Name LACANUS GRANGE Address 33616 25TH AVE ROY, WA 98580-
(2) LOCATION OF WELL: County PIERCE - NW 1/4 NW 1/4 Sec 16 T 17N N., R 3E WM
(2a) STREET ADDRESS OF WELL (or nearest address) 320TH & 8TH AVE SO

(3) PROPOSED USE: COMMUNITY

(10) WELL LOG

(4) TYPE OF WORK: Owner's Number of well (If more than one) 001
NEW WELL Method: ROTARY

Formation: Describe by color, character, size of material and structure, and show thickness of aquifers and the kind and nature of the material in each stratum penetrated, with at least one entry for each change in formation.

(5) DIMENSIONS: Diameter of well 6 inches
Drilled 80 ft. Depth of completed well 80 ft.

MATERIAL	FROM	TO
BROWN SANDY TILL	0	7
GRAY GLACIAL TILL	7	24
BLUE SANDY SILT	24	35
BLUE SILTY SAND GRAVEL	35	60
BOULDERS	60	63
BROKEN GRAVEL BOULDERS	63	80

(6) CONSTRUCTION DETAILS:
Casing installed: * Dia. from ft. to ft.
WBLED * Dia. from ft. to ft.
* Dia. from ft. to ft.

Owner requested well to be capped

Perforations: NO
Type of perforator used
SIZE of perforations in. by in.
perforations from ft. to ft.
perforations from ft. to ft.
perforations from ft. to ft.

Screens: NO
Manufacturer's Name
Type Model No.
Diam. slot size from ft. to ft.
Diam. slot size from ft. to ft.

Gravel packed: NO
Gravel placed from ft. to ft. Size of gravel ft.

Surface seal: NO To what depth? ft.
Material used in seal
Did any strata contain unusable water? NO
Type of water? Depth of strata ft.
Method of sealing strata off

RECEIVED
 07/17/90
 10:00 AM
 STATE OF WASHINGTON
 DEPARTMENT OF ECOLOGY

(7) PUMP: Manufacturer's Name Type N/A H.P.

Work started 07/12/90 Completed 07/17/90

(8) WATER LEVELS: Land-surface elevation above mean sea level ... ft.
Static level ft. below top of well Date 07/17/90
Artesian Pressure lbs. per square inch Date
Artesian water controlled by N/A

(9) WELL TESTS: Drawdown is amount water level is lowered below static level.
Was a pump test made? NO If yes, by whom?
Yield: gal./min with ft. drawdown after hrs.

WELL CONSTRUCTOR CERTIFICATION:
I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Recovery data
Time Water Level Time Water Level Time Water Level

NAME OELKE DRILLING, INC.
(Person, firm, or corporation) (Type or print)

Date of test / /
Bailer test gal./min. ft. drawdown after hrs.
Air test gal./min. w/ stem set at ft. for hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? NO

ADDRESS 4312 166 AVE SUMNER, WA
[SIGNED] *D. Blum* License No. 1842
Contractor's Registration No. OELKEDI 136QC Date 10/05/90

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report.



WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

DEPARTMENT OF
ECOLOGY
State of Washington

Construction/Decommission ("x" in circle)

Construction

Decommission ORIGINAL INSTALLATION

Notice of Intent Number _____

PROPOSED USE: Domestic Industrial Municipal
 DeWater Irrigation Test Well Other _____

TYPE OF WORK: Owner's number of well (if more than one) _____
 New well Reconditioned Method: Dug Bored Driven
 Deepened Cable Rotary Jetted

DIMENSIONS: Diameter of well 6" inches, drilled 124' ft.
 Depth of completed well 121' ft.

CONSTRUCTION DETAILS
 Casing Welded 6" Diam. from +1.5' ft. to 85' ft.
 Installed: Liner installed 4.5" Diam. from 121' ft. to 81' ft.
 Threaded _____ Diam. From _____ ft. to _____ ft.

Perforations: Yes No
 Type of perforator used saw cut
 SIZE of perfs 1/16 in. by 6 in. and no. of perfs 120 from 121' ft. to 85' ft.

Screens: Yes No K-Pac Location _____
 Manufacturer's Name _____
 Type _____ Model No. _____
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.
 Diam. _____ Slot size _____ from _____ ft. to _____ ft.

Gravel/Filter packed: Yes No Size of gravel/sand _____
 Materials placed from _____ ft. to _____ ft.

Surface Seal: Yes No To what depth? 18' ft.
 Material used in seal 3/8" bentonite chips
 Did any strata contain unusable water? Yes No
 Type of water? _____ Depth of strata _____
 Method of sealing strata off _____

PUMP: Manufacturer's Name Grundfos
 Type: S.S. Sub. H.P. 1/2HP

WATER LEVELS: Land-surface elevation above mean sea level _____ ft.
 Static level 21'11" ft. below top of well Date 06/19/2019
 Artesian pressure _____ lbs. per square inch Date _____
 Artesian water is controlled by _____ (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level
 Was a pump test made? Yes No If yes, by whom? Bison
 Yield: 2.5 gal./min. with 52.6 ft. drawdown after 3.5 hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Yield: _____ gal./min. with _____ ft. drawdown after _____ hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Date of test _____
 Bailer test _____ gal./min. with _____ ft. drawdown after _____ hrs.
 Airstest 2 gal./min. with stem set at 100' ft. for 1.0 hrs.
 Artesian flow _____ g.p.m. Date _____
 Temperature of water _____ Was a chemical analysis made? Yes No

CURRENT

Notice of Intent No. WE35130

Unique Ecology Well ID Tag No. BAF-140

Water Right Permit No. _____

Property Owner Name Lance Gilinsky

Well Street Address 415 - 330th St. S.

City Roy County Pierce

Location sw 1/4-1/4 ne 1/4 Sec 16 Twn 17N R 03E EWM
 (s, t, r Still REQUIRED) Or WWM

Lat/Long
 Lat Deg _____ Lat Min/Sec _____
 Long Deg _____ Long Min/Sec _____

Tax parcel No. (Required) 0317163009

CONSTRUCTION OR DECOMMISSION PROCEDURE
 Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
brown silt bound sand/gravel w/cobbles	0	13
boulder	13	15
brown/grey marbled silt bound sand/gravel w/cobbles	15	23
grey til	23	26
grey silty sand/gravel	26	35
grey silt bound cobbles	35	42
grey silty sand/gravel	42	56
brown silty sand w/gravel layers	56	77
brown silt bound sand/gravel w/cobbles	77	85
brown silt bound sand/gravel w/layers h20	85	110
boulders	110	114
brown silty sand/gravel - layered h20	114	121
boulders	121	124

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OCT 21 2019

WA State Department of Ecology (SWRC)

Start Date 05/29/2019 Completed Date 06/14/2019

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller Engineer Trainee Name Darrell Feavel
 Driller/Engineer/Trainee Signature _____
 Driller or trainee License No. 2398
 IF TRAINEE: Driller's License No: _____
 Driller's Signature: [Signature]

Drilling Company Bison Well Drilling
 Address PO Box 5142
 City, State, Zip Spanaway, WA 98387
 Contractor's Registration No. BISONWD945R9 Date 07/13/2019

ECY 050-1-20 (Rev 02-2010) To request ADA accommodation including materials in a format for the visually impaired, call Ecology Water Resources Program at 360-407-6872. Persons with impaired hearing may call Washington Relay Service at 711. Persons with speech disability may call TTY at 877-833-6341.

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

(1) OWNER NAME: **PRESIDENTIAL HOMES** ADDRESS: **1212 39TH AVE SW PUYALLUP, WA 98373**
 (2) LOCATION OF WELL: County **PIERCE** NE 1/4 SE 1/4 SEC 16 TWP 17N R 3E
 (2a) STREET ADDRESS OF WELL (or nearest address): **32726 8TH AVE E PARCEL #0317161005**

(3) PROPOSED USE: **DOMESTIC**
 (4) TYPE OF WORK: **NEW WELL**
 METHOD: **ROTARY**

(10) WELL LOG OR DECOMMISSIONING PROCEDURE DESCRIPTION

(5) DIMENSIONS: Diameter of well **6** inches.
 Drilled **100.5** feet. Depth of completed well **99** ft.

MATERIAL	FROM	TO
DARK BROWN SOIL, GRAVE LOOSE DRY	0	3
LIGHT BROWN CLAY MUD & GRAVEL, DENSE DRY	3	19
DARK GRAY SILTY SAND & GRAVEL, DENSE DRY	19	31
DARK GRAY GRAVEL, SAND VERY DENSE, WET	31	44
GRAY CLAY & GRAVEL, HARD, WET	44	46
LIGHT GRAY GRAVEL, VERY DENSE (W.B.)	46	53
LIGHT BROWN GRAVEL, SILTY SAND, DENSE (W.B.)	53	85
BROWN GRAVEL, LITTLE SAND, VERY DENSE (W.B.)	85	100.5

(6) CONSTRUCTION DETAILS
 Casing instld: **6** " Diam. From ft. to **99** ft.
 Welded " Diam. From ft. to ft.
 Liner " Diam. From ft. to ft.
 Threaded

Perforations: Yes No
 Type of perforator used
 Size of perforations in. by in.
 perforations from ft. to in.
 perforations from ft. to in.
 perforations from ft. to in.

Screens: Yes No
 Manufacturer's Name:
 Type Model No.
 Diam Slot size from ft. to ft.
 Diam Slot size from ft. to ft.

Gravel packed Yes No Size of gravel?
 Gravel packed from ft. to ft.

Surface seal: Yes No To what depth? **18** ft.
 Material used in seal **BENTONITE CHIPS**
 Did any strata contain unusable water? Yes No
 Type of water? Depth of Strata ft.
 Method of sealing strata off

(7) PUMP: Manufacturer's Name
 Type H. P.

(8) WATER LEVELS: Surface elev above mean sea level ft.
 Static level **18** below top of well Date **05/31/19**
 Artesian pressure lbs. Per sq. in. Date
 Artesian pressure is controlled by

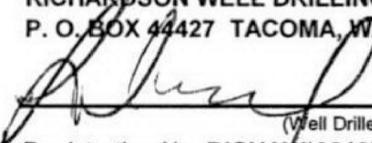
(9) WELL TESTS: Pump test made? By Whom
 Yield gal./min with ft. drawdown after hrs.
 Yield gal./min with ft. drawdown after hrs.
 Yield gal./min with ft. drawdown after hrs.
 Recovery data:
 Time Wtr Lvl. Time Wtr Lvl. Time Wtr Lvl.

Work Started **05/30/19** Completed: **05/31/19**

WELL CONSTRUCTOR CERTIFICATION:

I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Name: **RICHARDSON WELL DRILLING COMPANY INC.**
 Address: **P. O. BOX 44427 TACOMA, WA 98444**

(Signed)  (Well Driller)
 Contractor's Registration No. **RICHAW*3210B**

Lic No. **3292T/2432**

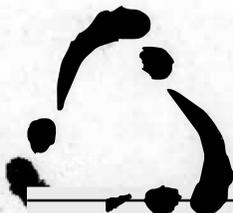
DATE **6/4/19**

Date of test:
 Bailer test gal./min with ft. drawdown after hrs.
 Airtest **80+** gal./min stem set at **96** ft. for **1** hrs.
 Artesian flow gal./min Date
 Temperature of water Was chemical analysis made? **NO**

RECEIVED

JUN 07 2019

WA State Department
of Ecology (SWRO)



Tacoma-Pierce County Health Department

Unique Well ID Number AEP355
X Y Z 1 2 3

WELL TAGGING FORM

All shaded areas must be completed.

Date of Field Visit 3-2-99 By Matt + Scott

ADDITIONAL WELL IDENTIFIERS

Department of Health System ID Number 15483F Source # SO 1

USGS Site Identification _____
Other _____

RECORD VERIFICATION

Well Report available (please attach)
 Well Report not available
 Verification inconclusive

WELL OWNERSHIP, IF DIFFERENT FROM WELL REPORT

Name COUNTRY GREEN ESTATES
Street Address P.O. Box 399
City oak harbor State WA 98277-0399

LOCATION OF WELL, IF DIFFERENT FROM WELL REPORT

Well Address 2005 347th St E
City ROY County PIERCE
T. 17 N. R. 03 E W.M. Sec. 22 SE 1/4 of the SE 1/4

Latitude 46 ° 56 ' 24.0 "
Longitude 122 ° 23 ' 56.7 "

- GPS (raw data)
- GPS (corrected)
- Topographic Map
- Survey
- Computer Generated
- Other _____

Elevation at land surface _____ feet/meters (circle one)

- Digital Altimeter
- Topographic Map
- Other _____

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

Additional information, if available:

Location marked on topographic map (please attach)

Location marked on air photo (please attach)

Water right #

Priority Date

Circle One: Application Permit Certificate Claim Exempt

WELL CHARACTERISTICS

Physical Description of Well (size of casing, type of well, housing, etc.): *8" Cased well in the well house near the pump house*

Location of Well Identification Tag: *on the 8" casing*

Was supplemental tag needed for ease of identifying well?

NO YES

If yes, where was tag placed?

Scale 1:24,000 (1"=2,000')

Indicate the location of the well within the Section by drawing a dot at that point.

SECTION 22

TOWNSHIP 17

RANGE 03E

D	X	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

COMMENTS: _____

The Department of Ecology does NOT Warranty the Data and/or the Information on this Well Report

Appendix E

Project List and Scores

Site ID	Reach	Waterbody	Boundary (RM)	Property Ownership	Restoration Opportunity/Element	Challenge Addressed	Groundwater/	Wetland, Floodplain,	Stream Habitat	Cost	Feasibility	Permitting	Unweighted Total Score	Average Score	Weighted Scoring						Weighted Total Score	Weighted Average Score
							Stream flow	Riparian Habitat									0.25	0.25	0.25	0.1		
							high (5)/medium (3)/low (1)/none (0)	high (5)/medium (3)/low (1)	high (5)/medium (3)/low (1)	L(5)>=100k, M(3)=100k-1mil, H(1)=>1mil	high (5)/medium (3)/low or difficult (1)	easy (5)/medium (3)/complex (1)										
R1-P1	1	Muck Creek	0.0 to 3.0	JBLM	Invasive spp management and RCC removal/management; enhance spawning gravel to decrease the % of fine sediment; improve side channel and/or off-channel rearing habitat by placing wood (no excavation in artillery area); remove and restore non-essential stream crossings.	Prevalence of invasive spp; low diversity and quality of stream habitat; fish passage barriers	1	1	5	3	3	5	18	3.0	0.25	0.25	1.25	0.3	0.3	0.25	2.6	0.4
R1-P2	1	Muck Creek	2.5 to 3.5	JBLM	Protect and enhance spring flows and off-channel spring-fed wetland habitat	Low diversity and quality of stream habitat; enhance dry reaches	3	3	1	3	3	5	18	3.0	0.75	0.75	0.25	0.3	0.3	0.25	2.6	0.4
R1-P3	1	Muck Creek	2.5-3.5	JBLM	Pipe Tef Sol Point treated wastewater to discharge into glacial outwash soils to enhance and recharge spring flows into Muck Creek.	Enhance dry reaches	5	1	5	1	1	1	14	2.3	1.25	0.25	1.25	0.1	0.1	0.05	3	0.5
R2-P1	2	Muck Creek	3.0 to 5.5	JBLM	Invasive spp management plan and long-term management; place individual key pieces of LWD and log clusters to enhance gravel sorting and floodplain connectivity; no anchoring of LWD in artillery area, BDAs where feasible.	Prevalence of invasive spp; low diversity and quality of stream habitat; enhance dry reaches; fish passage barriers	1	3	5	1	3	5	18	3.0	0.25	0.75	1.25	0.1	0.3	0.25	2.9	0.5
R2-P2	2	Muck Creek	5.5 to 6.2	Private	Stabilize eroding stream banks in City of Roy with bioengineering; riparian plantings, retrofit stormwater drainage to infiltrate	Low diversity and quality of stream habitat	1	3	3	3	3	3	16	2.7	0.25	0.75	0.75	0.3	0.3	0.15	2.5	0.4
R2-P3	2	Muck Creek	5	Private	Enhance fish passage channel of Preacher Creek	Fish passage barriers	0	1	3	5	3	5	17	2.8	0	0.25	0.75	0.5	0.3	0.25	2.05	0.3
R2-P4	2	Muck Creek	5.9	Private	Enhance fish passage channel of Haverson Marsh	Fish passage barriers	0	1	3	5	3	5	17	2.8	0	0.25	0.75	0.5	0.3	0.25	2.05	0.3
R2-P5	2	Muck Creek	6.5	Private	Enhance fish passage channel Muck Creek-Muck Lake	Fish passage barriers	0	1	5	5	3	5	19	3.2	0	0.25	1.25	0.5	0.3	0.25	2.55	0.4
R3-P1	3	Muck Creek	7.0-9.0	JBLM	Chambers Lake Management Plan. Long-term invasive species management plan/implementation; enhance riparian vegetation within and around lakes and wetlands; place logs for more beaded channel flow; install BDAs, promote beaver use, protect large beaver dam complexes; restore floodplain function; conserve native forest	Prevalence of invasive spp; low diversity and quality of stream habitat; riparian buffer	1	5	5	1	3	5	20	3.3	0.25	1.25	1.25	0.1	0.3	0.25	3.4	0.6
R3-P2	3	Muck Creek	7.0 to 7.8	JBLM	Identify and protect/enhance springs on Chambers Lake	Low diversity and quality of stream habitat	3	1	3	5	3	5	20	3.3	0.75	0.25	0.75	0.5	0.3	0.25	2.8	0.5
R3-P3	3	Muck Creek	7	JBLM	Install large wood and BDAs in channel between Muck and Chambers lakes	Low diversity and quality of stream habitat	1	3	5	3	5	1	18	3.0	0.25	0.75	1.25	0.3	0.5	0.05	3.1	0.5
R3-P4	3	Muck Creek	6.5	Private	Muck Lake Management Plan; manage invasive species, plant riparian buffer and plant islands	Riparian buffer	1	5	3	1	3	5	18	3.0	0.25	1.25	0.75	0.1	0.3	0.25	2.9	0.5
R4-P1	4	Muck Creek	9.0 to 13	JBLM	Thin and clear Douglas fir patches, reuse wood and install as log clumps in stream channel; install BDAs, modify ford crossings (notch); reconnect floodplain and wetlands, restore connection to winter channel, invasive species management, willow and other riparian plantings	Prevalence of invasive spp; enhance dry reaches; fish passage barriers	5	5	5	1	3	5	24	4.0	1.25	1.25	1.25	0.1	0.3	0.25	4.4	0.7
R5-P1	5	Muck Creek	13.0 to 14.1	JBLM	Remove/manage invasive spp including RCC; LWD enhancement/installation to increase pool frequency and quality; native riparian and wetland plantings; reduce stream channelization; identify and mediate sources of excess fine sediment; enhance riparian buffers and increase buffer widths; plant native riparian spp associated with prairie streams and spp preferred by beaver in open areas; install BDAs and promote beaver use	Prevalence of invasive spp; low diversity and quality of stream habitat; riparian buffer; enhance dry reaches	5	5	5	1	3	5	24	4.0	1.25	1.25	1.25	0.1	0.3	0.25	4.4	0.7
R5-P2	5	Muck Creek	14.7 to 15.55	Private farm and agriculture	Remove/manage invasive spp including RCC; LWD enhancement/installation to increase pool frequency and quality; fencing to reduce livestock access; reduce stream channelization; restore riparian buffer; plant native riparian spp associated with prairie streams and spp preferred by beaver in open areas; install BDAs and promote beaver use	Prevalence of invasive spp; low diversity and quality of stream habitat; degraded riparian buffer; enhance dry reaches	5	5	5	1	1	3	20	3.3	1.25	1.25	1.25	0.1	0.1	0.15	4.1	0.7
R5-P3	5	Muck Creek	15.55 to 16.4	Private farm and agriculture	Conserve high quality forested riparian zone; install LWD and/or BDAs	Conserve existing functional riparian buffer; enhance stream habitat and dry reaches	1	3	5	3	1	5	18	3.0	0.25	0.75	1.25	0.3	0.1	0.25	2.9	0.5
R5-P4	5	Muck Creek	16.4 to 17.2	Private hobby farm and residential	Remove/manage invasive spp including RCC; LWD enhancement/installation to increase pool frequency and quality; fencing to reduce livestock access; reduce stream channelization; reconnect to floodplain wetlands; enhance riparian buffers and increase buffer widths; install BDAs and promote beaver use	Prevalence of invasive spp; low diversity and quality of stream habitat; degraded riparian buffer; enhance dry reaches	5	5	5	1	1	3	20	3.3	1.25	1.25	1.25	0.1	0.1	0.15	4.1	0.7
R5-P5	5	Muck Creek	14.5-16.6	Private farm and agriculture	Identify water rights conservation and opportunities for leases/acquisitions	Streamflow	5	1	3	3	1	5	18	3.0	1.25	0.25	0.75	0.3	0.1	0.25	2.9	0.5
R6-P1	6	Muck Creek	17.2 to 18.7	County and residential	Long-term conservation target, protect existing forested riparian, wetlands, and upland forest to protect seasonal streams and possible spring inputs, enhance stream habitat with LWD and/or BDAs	Conserve existing functional riparian buffer; enhance stream habitat and dry reaches	1	3	5	3	3	5	20	3.3	0.25	0.75	1.25	0.3	0.3	0.25	3.1	0.5
R6-P2	6	Muck Creek	17.5	Private residential	LWD enhancement/installation to increase pool frequency and quality; address man-made rock dam at RM 17.5	Prevalence of invasive spp	1	1	5	5	3	5	20	3.3	0.25	0.25	1.25	0.5	0.3	0.25	2.8	0.5
R6-P3	6	Muck Creek Tributary	~18.0	Private vacant	Conserve existing wetlands and forested buffer, replace undersized culverts at 252nd St E to reduce flooding while also maintaining wetlands	Conserve existing functional riparian buffer; enhance stream habitat and dry reaches	1	5	3	1	3	5	18	3.0	0.25	1.25	0.75	0.1	0.3	0.25	2.9	0.5
R6-P4	6	Muck Creek	18.5-19.4	Private residential	Conserve areas with high-quality riparian buffers.	Riparian buffer	1	5	3	1	3	5	18	3.0	0.25	1.25	0.75	0.1	0.3	0.25	2.9	0.5
R6-P5	6	Muck Creek	20	Tahoma Land Conservancy	Address WDFW Fish Passage Barrier: 997905	Fish passage barriers	0	1	5	3	5	3	17	2.8	0	0.25	1.25	0.3	0.5	0.15	2.45	0.4
R6-P6	6	Muck Creek	20.1	Tahoma Land Conservancy	Address WDFW Fish Passage Barrier: 997906	Fish passage barriers	0	1	5	3	5	3	17	2.8	0	0.25	1.25	0.3	0.5	0.15	2.45	0.4
R6-P7	6	Muck Creek	20.1	Tahoma Land Conservancy	Address WDFW Fish Passage Barrier: 997907	Fish passage barriers	0	1	5	3	5	3	17	2.8	0	0.25	1.25	0.3	0.5	0.15	2.45	0.4
R6-P8	6	Muck Creek	20.1	Tahoma Land Conservancy	Address WDFW Fish Passage Barrier: 997908	Fish passage barriers	0	1	5	3	5	3	17	2.8	0	0.25	1.25	0.3	0.5	0.15	2.45	0.4
R7-P1	7	South Creek	0.0 to 1.2	JBLM	Remove/manage invasive spp, particularly RCC; enhance riparian buffer and increase buffer widths; plant native riparian spp associated with prairie streams; conserve areas with high-quality riparian buffers; install BDAs	Prevalence of invasive spp; low diversity and quality of stream habitats; riparian buffer; enhance dry reaches	5	5	5	1	1	5	22	3.7	1.25	1.25	1.25	0.1	0.1	0.25	4.2	0.7
R7-P2	7	South Creek	1.2 to 2.2	Private farm and agriculture	Install large wood and BDAs; manage invasive species, remove armoring and reduce creek channelization, enhance riparian buffer	Low diversity and quality of stream habitats	3	3	3	1	1	3	14	2.3	0.75	0.75	0.75	0.1	0.1	0.15	2.6	0.4
R8-P1	8	South Creek	2.2 to 6.0	Multiple private farm and residential	Conserve high quality riparian forest buffer and wetlands; enhance wetlands where feasible; install LWD and/or BDAs; identify potential enhancement of spring flow inputs	Conserve existing functional riparian buffer; enhance stream habitat and dry reaches	3	3	5	1	1	5	18	3.0	0.75	0.75	1.25	0.1	0.1	0.25	3.2	0.5
R8-P2	8	South Creek Tributary	~6.0	Multiple private	Restore historical wetland and riparian buffer; look for opportunities for easements; reduce stream channelization; install LWD and/or BDAs	Conserve and restore historical wetlands for streamflow support; enhance stream and wetland habitat	3	3	3	1	1	5	16	2.7	0.75	0.75	0.75	0.1	0.1	0.25	2.7	0.5
R8-P3	8	South Creek	3.5 to 7.6	Multiple private farm and residential	Identify opportunities to reduce ditching of tributaries; identify opportunities to infiltrate stormwater (retrofits, etc.)	Streamflow	3	3	3	3	1	5	18	3.0	0.75	0.75	0.75	0.3	0.1	0.25	2.9	0.5
R9-P1	9	South Creek	7.6 to 15.4	Multiple private farm and residential	Remove/manage invasive spp, particularly RCC; install LWD and/or BDAs; restrict cattle access to stream; reduce channelization; native riparian and wetland plantings	Prevalence of invasive spp; low diversity and quality of stream habitats; riparian buffer; enhance dry reaches	3	3	5	1	1	5	18	3.0	0.75	0.75	1.25	0.1	0.1	0.25	3.2	0.5
R9-P2	9	South Creek	11 to 14	Multiple private farm and residential	Restore historical wetlands and riparian buffers; look for opportunities for easements; reduce stream channelization; install LWD and/or BDAs	Prevalence of invasive spp; low diversity and quality of stream habitats and riparian buffers; store water to enhance streamflow	3	3	3	1	1	5	16	2.7	0.75	0.75	0.75	0.1	0.1	0.25	2.7	0.5
R9-P3	9	South Creek	7.6 to 15.4	Multiple private farm and residential	Identify opportunities to reduce ditching of tributaries; identify opportunities to infiltrate stormwater (retrofits, etc.)	Streamflow	3	3	3	1	1	5	16	2.7	0.75	0.75	0.75	0.1	0.1	0.25	2.7	0.5
R10-P1	10	South Creek	15.4 to 19.3	Multiple private farm and residential	Remove/manage invasive spp (e.g., RCC); install LWD; native riparian and wetland plantings; restore wetland habitats	Prevalence of invasive spp; low diversity and quality of stream habitats; riparian buffer; enhance dry reaches	3	3	5	1	1	5	18	3.0	0.75	0.75	1.25	0.1	0.1	0.25	3.2	0.5

Site ID	Reach	Waterbody	Boundary (RM)	Property Ownership	Restoration Opportunity/Element	Challenge Addressed	Groundwater/	Wetland, Floodplain,	Stream Habitat	Cost	Feasibility	Permitting	Unweighted Total Score	Average Score	Weighted Scoring						Weighted Total Score	Weighted Average Score
							Stream flow	Riparian Habitat									0.25	0.25	0.25	0.1		
							high (5)/medium (3)/low (1)/none (0)	high (5)/medium (3)/low (1)	high (5)/medium (3)/low (1)	L(5)>=100k, M(3)=100k-1mil, H(1)>=1mil	high (5)/medium (3)/low or difficult (1)	easy (5)/medium (3)/complex (1)										
R10-P2	10	South Creek	15.4 to 19.3	Multiple private farm and residential	Identify opportunities to reduce ditching of tributaries, identify opportunities to infiltrate stormwater (retrofits, etc.)	Streamflow	3	3	3	1	1	5	16	2.7	0.75	0.75	0.75	0.1	0.1	0.25	2.7	0.5
R10-P3	10	South Creek	16.5	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 933101	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R10-P4	10	South Creek	16.8	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 932679	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R10-P5	10	South Creek	18.5	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 932685	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R10-P6	10	South Creek	18.9	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 933233	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R10-P7	10	South Creek	18.9	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 933232	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R11-P1	11	Johnson Creek	0 to 1.7	JBLM	Remove berms to reconnect Watkins Springs to channel, add wood and BDAs, manage invasives, maintain open channel for fish access, riparian and wetland plantings	Influence of this reach on enhancing downstream dry reaches	5	3	3	3	5	5	24	4.0	1.25	0.75	0.75	0.3	0.5	0.25	3.8	0.6
R11-P2	11	Johnson Creek	0.5	JBLM	Investigate opportunities to modify dam on Johnson Creek	Fish passage barriers	1	1	3	3	3	5	16	2.7	0.25	0.25	0.75	0.3	0.3	0.25	2.1	0.4
R12-P1	12	Lacamas Creek	0.0 to 0.5	Multiple private farm and residential	Remove/manage invasive spp; install LWD and/or BDAs; increase riparian buffer width; native riparian and wetland plantings; reconnect wetlands	Prevalence of invasive spp; low diversity and quality of stream habitats; riparian buffer; water quality; enhance dry reaches; fish passage barriers	5	5	5	1	3	5	24	4.0	1.25	1.25	1.25	0.1	0.3	0.25	4.4	0.7
R12-P2	12	Lacamas Creek	0.5 to 1.8	Multiple private farm and residential	Remove/manage invasive spp; install LWD and/or BDAs; reduce channelization; increase riparian buffer width; native riparian and wetland plantings; reconnect wetlands; opportunities for easements	Prevalence of invasive spp; low diversity and quality of stream habitats and riparian buffers; store water to enhance streamflow	5	5	5	1	1	5	22	3.7	1.25	1.25	1.25	0.1	0.1	0.25	4.2	0.7
R12-P3	12	Lacamas Creek	2.3 to 3.4	Multiple private farm and residential	Remove/manage invasive spp; install LWD and/or BDAs; reduce channelization; increase riparian buffer width; native riparian and wetland plantings; reconnect wetlands; opportunities for easements	Prevalence of invasive spp; low diversity and quality of stream habitats and riparian buffers; store water to enhance streamflow	5	5	5	1	1	5	22	3.7	1.25	1.25	1.25	0.1	0.1	0.25	4.2	0.7
R12-P4	12	Lacamas Creek	0 to 3.4	Multiple private farm and residential	Identify opportunities to infiltrate stormwater and water conservation or acquisition of water rights	Streamflow	5	1	3	3	1	5	18	3.0	1.25	0.25	0.75	0.3	0.1	0.25	2.9	0.5
R13-P1	13	Lacamas Creek	3.4 to 4.7	Multiple private farm and residential	Remove/manage invasive spp (e.g., RCG); install livestock exclusion fencing or other exclusion techniques; LWD enhancement/installation; install native riparian and wetland plantings; install BDAs and promote beaver use; restore large historical wetland	Prevalence of invasive spp; low diversity and quality of stream habitats; riparian buffer; enhance dry reaches	5	5	5	1	3	5	24	4.0	1.25	1.25	1.25	0.1	0.3	0.25	4.4	0.7
R14-P1	14	Lacamas Creek	6 to 7	Multiple private farm and residential	Remove/manage RCG, especially in wetlands; restrict cattle access to stream; reduce stream channelization; install LWD and/or BDAs; restore large historical wetland; opportunities for easements	Prevalence of invasive spp; low diversity and quality of stream habitats; enhance dry reaches	5	5	5	1	1	5	22	3.7	1.25	1.25	1.25	0.1	0.1	0.25	4.2	0.7
R14-P2	14	Lacamas Creek	5 to 8	Multiple private farm and residential	Identify opportunities for water conservation or acquisition of water rights	Streamflow	5	1	3	3	1	5	18	3.0	1.25	0.25	0.75	0.3	0.1	0.25	2.9	0.5
R14-P3	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999130	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P4	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999131	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P5	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999132	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P6	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999133	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P7	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999156	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P8	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999140	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P9	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999149	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P10	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 997800	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4
R14-P11	14	Lacamas Creek	4.9 to 8.2	Multiple private farm and residential	Address WDFW Fish Passage Barrier: 999147	Fish passage barriers	0	1	5	1	5	5	17	2.8	0	0.25	1.25	0.1	0.5	0.25	2.35	0.4

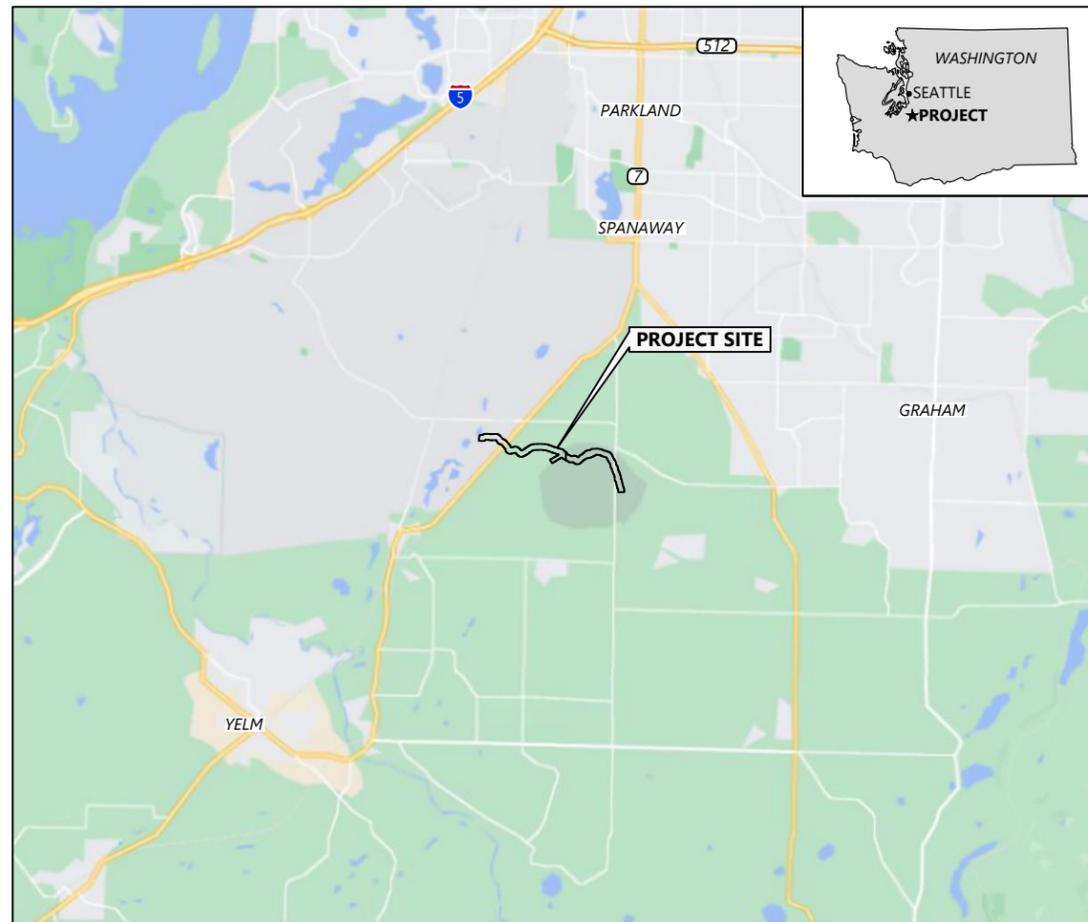
Appendix F
Concept Designs

PRELIMINARY DESIGN SUBMITTAL

MUCK CREEK REACH 4

STREAMFLOW AND HABITAT RESTORATION PROJECT

NISQUALLY RIVER FOUNDATION



SOURCE: ESRI WORLD STREET MAP

VICINITY MAP



SCALE IN MILES



NORTH



SOURCE: ESRI IMAGERY

SITE MAP



SCALE IN FEET



NORTH

DRAWING LIST		
SHEET #	DRAWING #	TITLE
1	G-01	COVER SHEET
2	G-02	GENERAL NOTES, ABBREVIATIONS, AND LEGENDS
3	C-01	OVERALL SITE PLAN
4	C-02	RESTORATION PLAN (1 OF 3)
5	C-03	RESTORATION PLAN (2 OF 3)
6	C-04	RESTORATION PLAN (3 OF 3)
7	C-05	STREAM PROFILE (1 OF 2), 0+00 TO 116+00
8	C-06	STREAM PROFILE (2 OF 2), 116+00 TO 225+00
9	C-07	WINTER CHANNEL STREAM PROFILE
10	C-08	RESTORATION DETAILS - BDAs
11	C-09	RESTORATION DETAILS - LWD
12	C-10	GENERAL DETAILS

PROJECT DATA

PROJECT LOCATION: JOINT BASE LEWIS-McCHORD
PIERCE COUNTY, WA
SECTION 24, TOWNSHIP 18N, RANGE 2E
SECTIONS 19, 28, 37, AND 38, TOWNSHIP 18N, RANGE 3E

CONTRACTING AGENCY: DAVID TROUT, CHAIR
NISQUALLY RIVER FOUNDATION
620 OLD PACIFIC HIGHWAY SE,
OLYMPIA, WA 98513

DESIGN ENGINEER: ROBERT MONTGOMERY, P.E.
ANCHOR QEA, LLC
71201 3RD AVENUE, SUITE 2600
SEATTLE, WA 98101
(206) 219-5901

PLAN INTENDED TO BE VIEWED
IN COLOR. ADJACENT BLOCK IS
"BLUE"

ONE INCH
AT FULL SIZE. IF NOT ONE
INCH SCALE ACCORDINGLY

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION



NISQUALLY RIVER
FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
DRAWN BY: J. SEXTON
CHECKED BY: M. MARTZ
APPROVED BY: R. MONTGOMERY
SCALE: AS NOTED
DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

COVER SHEET

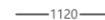
G-01

SHEET # 1 OF 12

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Mar 12, 2024 3:14pm jsexton

LEGEND

-  1120 EXISTING LIDAR CONTOURS
-  EXISTING STREAMS
-  PROPOSED LWD
-  PROPOSED BDA
-  EXISTING GROUND SURFACE, LIDAR (PROFILES)
-  EXISTING GROUND SURFACE, FIELD COLLECTED (PROFILES)

GENERAL CONSTRUCTION NOTES

1. CONTRACT DOCUMENTS REFER TO THESE DRAWINGS, THE PROJECT SPECIFICATIONS, THE BIDDING DOCUMENTS, AND THE CONSTRUCTION CONTRACT. ALL COMPONENTS OF THE CONTRACT DOCUMENTS SHALL FULLY APPLY TO THE WORK WHETHER SPECIFICALLY REFERENCED ON THE DRAWINGS OR NOT. ANY ITEMS NOT SPECIFICALLY REFERENCED IN THE NOTES ON THE DRAWINGS SHALL BE AS DESCRIBED IN THE SPECIFICATIONS.
2. THE CONTRACTOR SHALL HAVE A COPY OF THE APPROVED CONTRACT AND PERMIT DOCUMENTS ON THE JOBSITE AT ALL TIMES.
3. THE CONTRACTOR SHALL VISIT THE JOB SITE PRIOR TO CONSTRUCTION AND SHALL BE RESPONSIBLE FOR VERIFYING FIELD CONDITIONS AND DIMENSIONS, AND CONFIRMING THAT THE WORK CAN BE ACCOMPLISHED AS SHOWN ON THESE CONTRACT DOCUMENTS. ANY DISCREPANCIES BETWEEN THE EXISTING FIELD CONDITIONS AND THE DRAWINGS OR ANY INCONSISTENCIES OR AMBIGUITIES BETWEEN THE DRAWINGS AND OTHER CONTRACT DOCUMENTS SHALL BE REPORTED IN WRITING TO THE CONTRACTING ORGANIZATION PRIOR TO PROCEEDING WITH THE WORK. WORK DONE BY THE CONTRACTOR INVOLVING SUCH DISCREPANCIES WITHOUT A WRITTEN REPORT AND RESPONSE FROM THE CONTRACTING ORGANIZATION SHALL BE DONE AT THE CONTRACTOR'S SOLE RISK AND EXPENSE.
4. THE CONTRACTOR SHALL RECEIVE, IN WRITING, AUTHORIZATION TO PROCEED BEFORE STARTING WORK ON ANY ITEM NOT CLEARLY DEFINED OR IDENTIFIED BY THE CONTRACT DOCUMENTS.
5. ALL WORK SHALL BE IN ACCORDANCE WITH EXISTING LABOR LAWS, SAFETY REQUIREMENTS, AND OTHER REGULATIONS, AS REQUIRED BY PIERCE COUNTY, THE STATE OF WASHINGTON, AND THE FEDERAL GOVERNMENT. THE CONTRACTOR SHALL ASSUME SOLE AND COMPLETE RESPONSIBILITY FOR JOB SITE CONDITIONS DURING THE COURSE OF CONSTRUCTION, INCLUDING THE SAFETY OF ALL PERSONS AND PROPERTY. THIS REQUIREMENT SHALL APPLY CONTINUOUSLY AND IS NOT LIMITED TO NORMAL WORKING HOURS.
6. THE CONTRACTOR SHALL BE SOLELY RESPONSIBLE FOR ALL CONSTRUCTION MEANS, METHODS, TECHNIQUES, SEQUENCES, AND PROCEDURES AND FOR COORDINATING ALL PORTIONS OF THE WORK UNDER THIS CONTRACT.
7. THE DETAILS PROVIDED ON THE CONTRACT DOCUMENTS ARE INTENDED TO SHOW THE FINAL RESULT OF THE DESIGN. MINOR MODIFICATIONS MAY BE REQUIRED TO SUIT JOB SITE DIMENSIONS OR CONDITIONS. SUCH MODIFICATIONS SHALL BE CONSIDERED INCIDENTAL TO OTHER ITEMS INCLUDED IN THE BID SCHEDULE FOR THE WORK.
8. THE CONTRACTOR SHALL MAKE ALL NECESSARY PROVISIONS TO PROTECT EXISTING STRUCTURES, IMPROVEMENTS, GROUNDWATER WELLS, SIGNS, FENCES, GATES, CURBS, ROADWAYS, DRAINAGE WAYS, BRIDGES, CULVERTS, AND VEGETATION UNTIL SUCH ITEMS ARE TO BE DISTURBED OR REMOVED AS INDICATED ON THE CONTRACT DOCUMENTS. IF SUCH ITEMS ARE DAMAGED OR NEED TO BE REMOVED OR MODIFIED TO FACILITATE CONSTRUCTION, THE CONTRACTOR SHALL FIRST NOTIFY THE CONTRACTING ORGANIZATION AND THEN REPLACE OR REPAIR THE ITEMS TO EQUAL OR BETTER CONDITION AT THE CONTRACTOR'S EXPENSE AND TO THE SATISFACTION OF THE CONTRACTING ORGANIZATION.
9. THE CONTRACTOR SHALL NOT DISTURB OR DESTROY ANY EXISTING SURVEY MONUMENT OR BENCHMARK. ANY SURVEY MONUMENT OR BENCHMARK DISTURBED OR DESTROYED BY THE CONTRACTOR SHALL BE REPLACED AS DIRECTED BY THE CONTRACTING ORGANIZATION AT THE CONTRACTOR'S SOLE EXPENSE.
10. REPRESENTATIONS OF TRUE NORTH SHALL NOT BE USED TO IDENTIFY OR ESTABLISH THE BEARING OF TRUE NORTH AT THE JOB SITE. THE CONTRACTOR IS ADVISED THAT NORTH ARROWS AND ORIENTATION OF THE PLAN VIEW SHEETS VARY TO ALLOW FOR LEFT-TO-RIGHT STATIONING AND STATIONING IN THE DIRECTION OF FLOW.
11. WHERE A CONSTRUCTION DETAIL IS NOT SHOWN OR NOTED, THE DETAIL SHALL BE THE SAME AS FOR OTHER SIMILAR WORK.
12. THE NOTES, DETAILS AND SPECIFICATIONS ON THE CONTRACT DOCUMENTS SHALL TAKE PRECEDENCE OVER THESE GENERAL NOTES.
13. DIMENSION CALL-OUTS SHALL TAKE PRECEDENCE OVER SCALES SHOWN ON THE CONTRACT DOCUMENTS.
14. STATIONING, DISTANCES, AND LENGTHS SHOWN ON THE DRAWINGS

- ARE BASED ON HORIZONTAL MEASUREMENTS ALONG THE CREEK CENTERLINE.
15. THE CONTRACTOR SHALL BE REQUIRED TO CONTROL ON-SITE STORM WATER RUNOFF BY USING TEMPORARY OR PERMANENT DRAINAGE EROSION/SILTATION CONTROL PROCEDURES. TEMPORARY EROSION AND SEDIMENT CONTROL (TESC) SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS INCLUDED IN THE CONTRACT DRAWINGS.
 16. THE CONTRACTOR SHALL MAINTAIN HAND DRAWN REDLINES, FIELD NOTES AND PHOTOGRAPHS ("FIELD DOCUMENTATION") OF ALL IMPROVEMENTS AS THE WORK PROGRESSES. THE CONTRACTOR SHALL ALSO TAKE PHOTOGRAPHS AND VIDEO TO DOCUMENT CONDITIONS PRIOR TO CONSTRUCTION. THE CONTRACTOR'S FIELD DOCUMENTATION SHALL BE MAINTAINED ON SITE AND SHALL BE AVAILABLE FOR REVIEW BY THE CONTRACTING ORGANIZATION AT ALL TIMES. THE CONTRACTOR SHALL PROVIDE CERTIFIED RECORD DRAWINGS PRIOR TO PROJECT ACCEPTANCE.

STANDARD CIVIL NOTES

1. ALL MATERIALS SHALL BE NEW AND UNDAMAGED, UNLESS OTHERWISE APPROVED BY THE CONTRACTING ORGANIZATION'S REPRESENTATIVE AND THE ENGINEER. THE SAME MANUFACTURER OF EACH ITEM SHALL BE USED THROUGHOUT THE WORK UNLESS OTHERWISE APPROVED BY THE CONTRACTING AGENCY AND THE ENGINEER.
2. ALL SITE WORK SHALL BE AS INDICATED ON THE CONTRACT DOCUMENTS. DO NOT EXCAVATE AND DISTURB BEYOND THE CLEARING LIMITS SHOWN ON THE CONTRACT DOCUMENTS UNLESS OTHERWISE APPROVED BY THE CONTRACTING ORGANIZATION.
3. RUBBISH, DEBRIS, AND GARBAGE SHALL BE REMOVED FROM THE JOB SITE AND DISPOSED OF LEGALLY, AS REQUIRED BY THE PROJECT SPECIFICATIONS.
4. THE AREAS OF THE JOB SITE DISTURBED BY THE WORK SHALL BE GRADED SMOOTH AND PROTECTED AND/OR REVEGETATED AS SPECIFIED HEREIN.

UTILITY NOTES

1. THE LOCATIONS OF EXISTING UTILITIES SHOWN ON THESE DRAWINGS ARE APPROXIMATE.
2. UTILITY SERVICES HAVE NOT BEEN SHOWN ON THE PLAN AND PROFILE DRAWINGS. THE CONTRACTOR SHALL TAKE CARE NOT TO DISRUPT BURIED UTILITY SERVICES.
3. THE CONTRACTOR SHALL BE RESPONSIBLE FOR LOCATING ALL EXISTING UTILITIES PRIOR TO CONSTRUCTION. THE CONTRACTOR SHALL CONTACT THE UTILITY LOCATION REQUEST CENTER (ONE-CALL CENTER) AT 1-800-424-5555 FOR UTILITY LOCATIONS NOT LESS THAN TWO (2) BUSINESS DAYS BEFORE THE SCHEDULED DATE FOR EARTHWORK OR TRENCHING THAT MAY IMPACT EXISTING UTILITIES.
4. ALL ABANDONED UTILITIES WHICH INTERFERE WITH THE EXECUTION OF THE WORK SHALL BE VERIFIED BY THE CONTRACTING ORGANIZATION'S REPRESENTATIVE AND THE UTILITY OWNER PRIOR TO DISTURBANCE OR MODIFICATION. ONLY AFTER WRITTEN APPROVAL HAS BEEN RECEIVED FROM THE UTILITY OWNER BY THE CONTRACTING ORGANIZATION, MAY THE CONTRACTOR TAKE ACTION.
5. THE SIZE, LOCATION, AND TYPE OF UNDERGROUND UTILITIES EXPOSED OR MODIFIED BY THE CONTRACTOR SHALL BE ACCURATELY NOTED AND PLACED ON THE CONTRACTOR'S AS-BUILT DRAWINGS. SEE GENERAL CONSTRUCTION NOTES FOR ADDITIONAL REQUIREMENTS RELATED TO THE CONTRACTOR'S AS-BUILT DRAWINGS AND FIELD DOCUMENTATION.
6. THE CONTRACTOR SHALL ENSURE THAT OPERATION OF EXISTING DRAINAGE, POTABLE WATER, POWER, COMMUNICATIONS, AND OTHER UTILITY SYSTEMS IS NOT DISRUPTED DURING CONSTRUCTION WITHOUT PRIOR AUTHORIZATION OF THE UTILITY OWNER AND CONTRACTING ORGANIZATION'S REPRESENTATIVE.

ABBREVIATIONS

- ' FEET, MINUTES
- " INCHES, SECONDS
- ° DEGREES
- ∅ DIAMETER
- # NUMBER
- ASTM AMERICAN SOCIETY FOR TESTING AND MATERIALS
- BM BENCHMARK
- BMP BEST MANAGEMENT PRACTICE
- CFS CUBIC FEET PER SECOND
- CL CENTERLINE
- CONC CONCRETE
- CSBC CRUSHED SURFACING BASE COURSE
- CSTC CRUSHED SURFACING TOP COURSE
- CY CUBIC YARDS
- DIA DIAMETER
- DWG DRAWING
- E EAST, EASTING
- ELEV ELEVATION
- EX EXISTING
- FG FINISHED GRADE
- FPS FEET PER SECOND
- GALV GALVANIZED
- GPM GALLONS PER MINUTE
- HOR HORIZONTAL
- ID INSIDE DIAMETER
- IE INVERT ELEVATION
- L LENGTH
- LF LINEAR FEET
- MAX MAXIMUM
- MIN MINIMUM
- N NORTH, NORTHING
- NAD NORTH AMERICAN DATUM
- NAVD NORTH AMERICAN VERTICAL DATUM
- NTS NOT TO SCALE
- P POWER
- P.E. PROFESSIONAL ENGINEER
- PED PEDESTAL
- R, RAD RADIUS
- REINF REINFORCED, REINFORCEMENT
- RM RIVER MILE
- ROW RIGHT-OF-WAY
- S SLOPE, SOUTH
- ST STORM
- STA STATION
- TESC TEMPORARY EROSION AND SEDIMENT CONTROL
- T TELEPHONE
- TYP TYPICAL
- W WEST, WATER
- W/ WITH
- WFDW WASHINGTON STATE DEPARTMENT OF FISH AND WILDLIFE
- WSDOT WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
- WSEL WATER SURFACE ELEVATION
- YR YEAR

SOURCE OF DATA: TOPOGRAPHIC DATA OBTAINED FROM DNR LIDAR DATABASE, 2005 PUGET LOWLANDS DATASET, COLLECTED FEBRUARY 2005.

AERIAL PHOTOGRAPHY - 2023 BING MAPS

HORIZONTAL DATUM: WASHINGTON STATE PLANE NORTH ZONE, NORTH AMERICAN DATUM OF 1983 (NAD 83), U.S. SURVEY FOOT.

VERTICAL DATUM: ELEVATIONS BASED ON WASHINGTON STATE REFERENCE NETWORK (WSRN), THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).

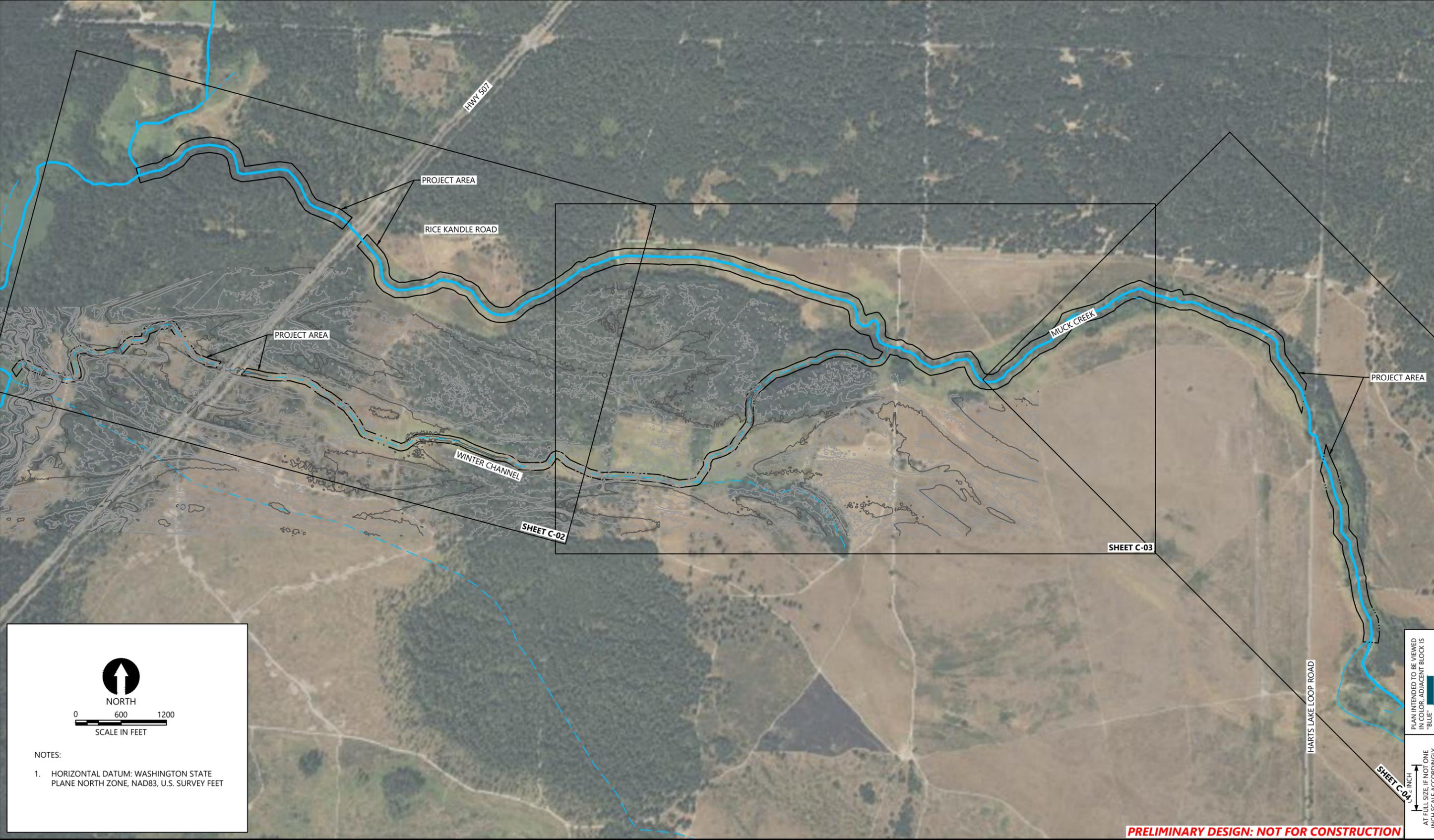
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PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

	NISQUALLY RIVER FOUNDATION		REVISIONS					DESIGNED BY: <u>J. SEXTON</u> DRAWN BY: <u>J. SEXTON</u> CHECKED BY: <u>M. MARTZ</u> APPROVED BY: <u>R. MONTGOMERY</u> SCALE: <u>AS NOTED</u> DATE: <u>JANUARY 2024</u>	MUCK CREEK REACH 4 PRELIMINARY DESIGN	G-02																						
			<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 5%;">REV</th> <th style="width: 10%;">DATE</th> <th style="width: 5%;">BY</th> <th style="width: 5%;">APP'D</th> <th style="width: 75%;">DESCRIPTION</th> </tr> </thead> <tbody> <tr><td> </td><td> </td><td> </td><td> </td><td> </td></tr> </tbody> </table>	REV	DATE	BY	APP'D		DESCRIPTION																							
REV	DATE	BY	APP'D	DESCRIPTION																												

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NORTH



SCALE IN FEET

NOTES:

- 1. HORIZONTAL DATUM: WASHINGTON STATE PLANE NORTH ZONE, NAD83, U.S. SURVEY FEET

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"

1/4" = 1" INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION



NISQAULLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

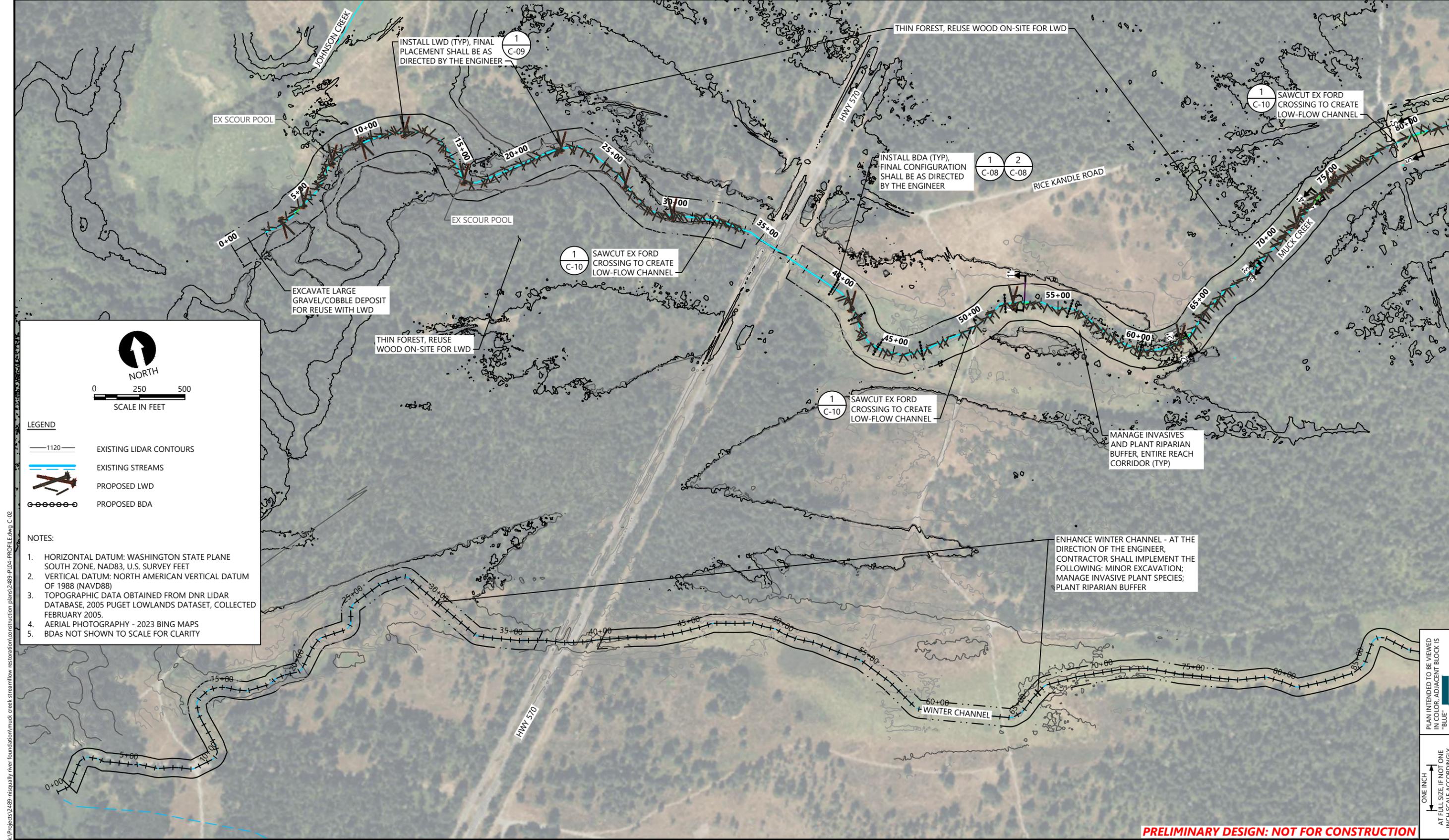
MUCK CREEK REACH 4 PRELIMINARY DESIGN

OVERALL SITE PLAN

C-01

SHEET # **3** OF **12**

Mar 12, 2024 3:23pm jsexton



LEGEND

- 1120— EXISTING LIDAR CONTOURS
- EXISTING STREAMS
- PROPOSED LWD
- PROPOSED BDA

NOTES:

- HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, NAD83, U.S. SURVEY FEET
- VERTICAL DATUM: NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)
- TOPOGRAPHIC DATA OBTAINED FROM DNR LIDAR DATABASE, 2005 PUGET LOWLANDS DATASET, COLLECTED FEBRUARY 2005.
- AERIAL PHOTOGRAPHY - 2023 BING MAPS
- BDAs NOT SHOWN TO SCALE FOR CLARITY

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE" SCALE ACCORDINGLY



NISQAULLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

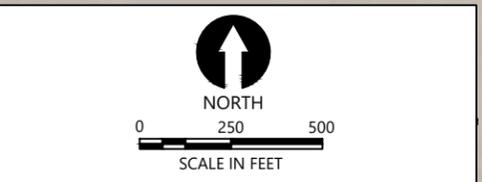
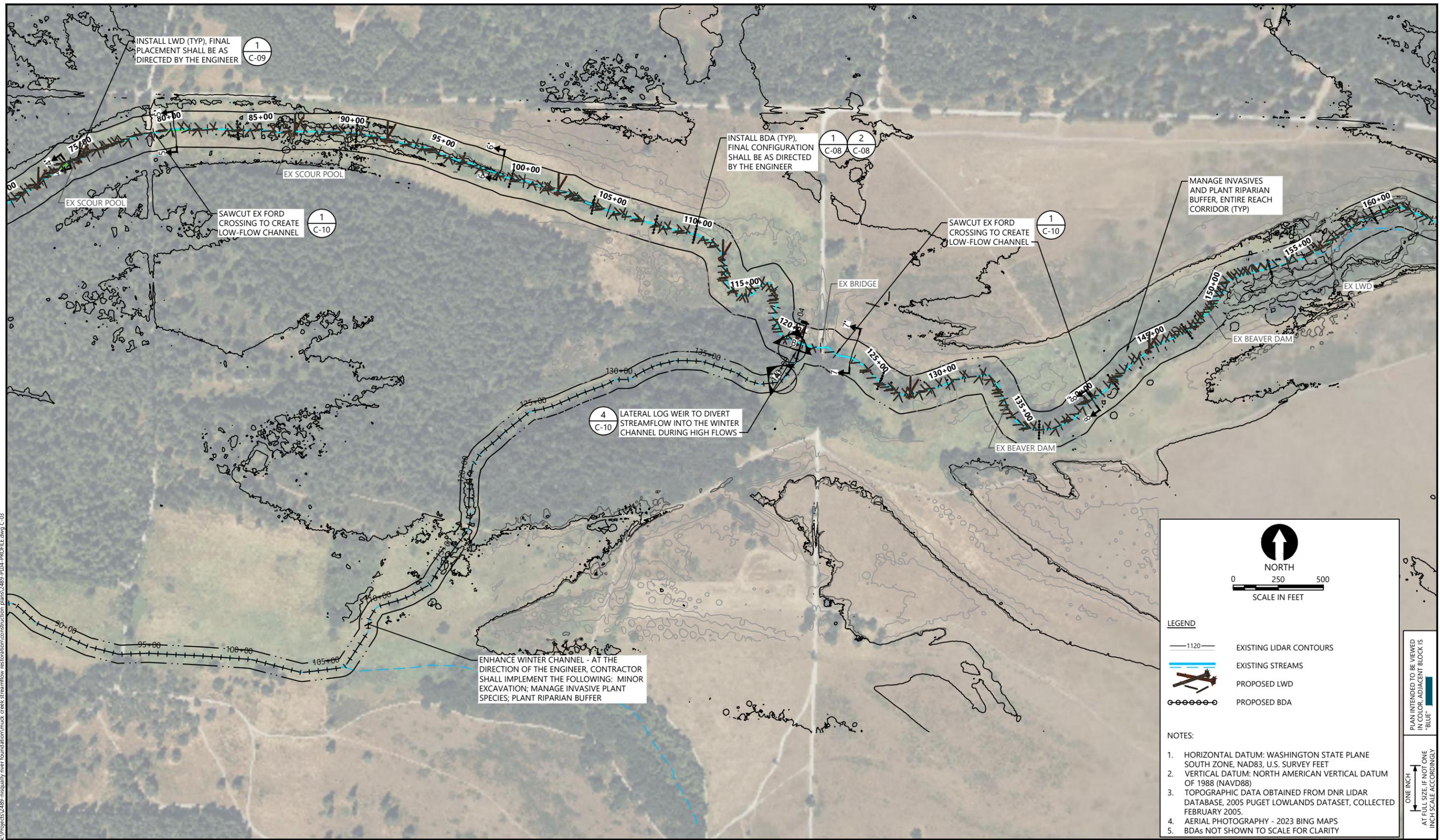
RESTORATION PLAN (1 OF 3)

C-02

SHEET # 4 OF 12

k:\Projects\2488-nisqually_river_foundation\muck_creek_streamflow_restoration\construction_plans\2488-P104-PROFILE.dwg C-02 Mar 12, 2024 3:23pm jsexton

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Mar 12, 2024 3:24pm jsexton



LEGEND

	EXISTING LIDAR CONTOURS
	EXISTING STREAMS
	PROPOSED LWD
	PROPOSED BDA

- NOTES:**
- HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, NAD83, U.S. SURVEY FEET
 - VERTICAL DATUM: NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)
 - TOPOGRAPHIC DATA OBTAINED FROM DNR LIDAR DATABASE, 2005 PUGET LOWLANDS DATASET, COLLECTED FEBRUARY 2005.
 - AERIAL PHOTOGRAPHY - 2023 BING MAPS
 - BDAs NOT SHOWN TO SCALE FOR CLARITY

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"
ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY



NISQUALLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

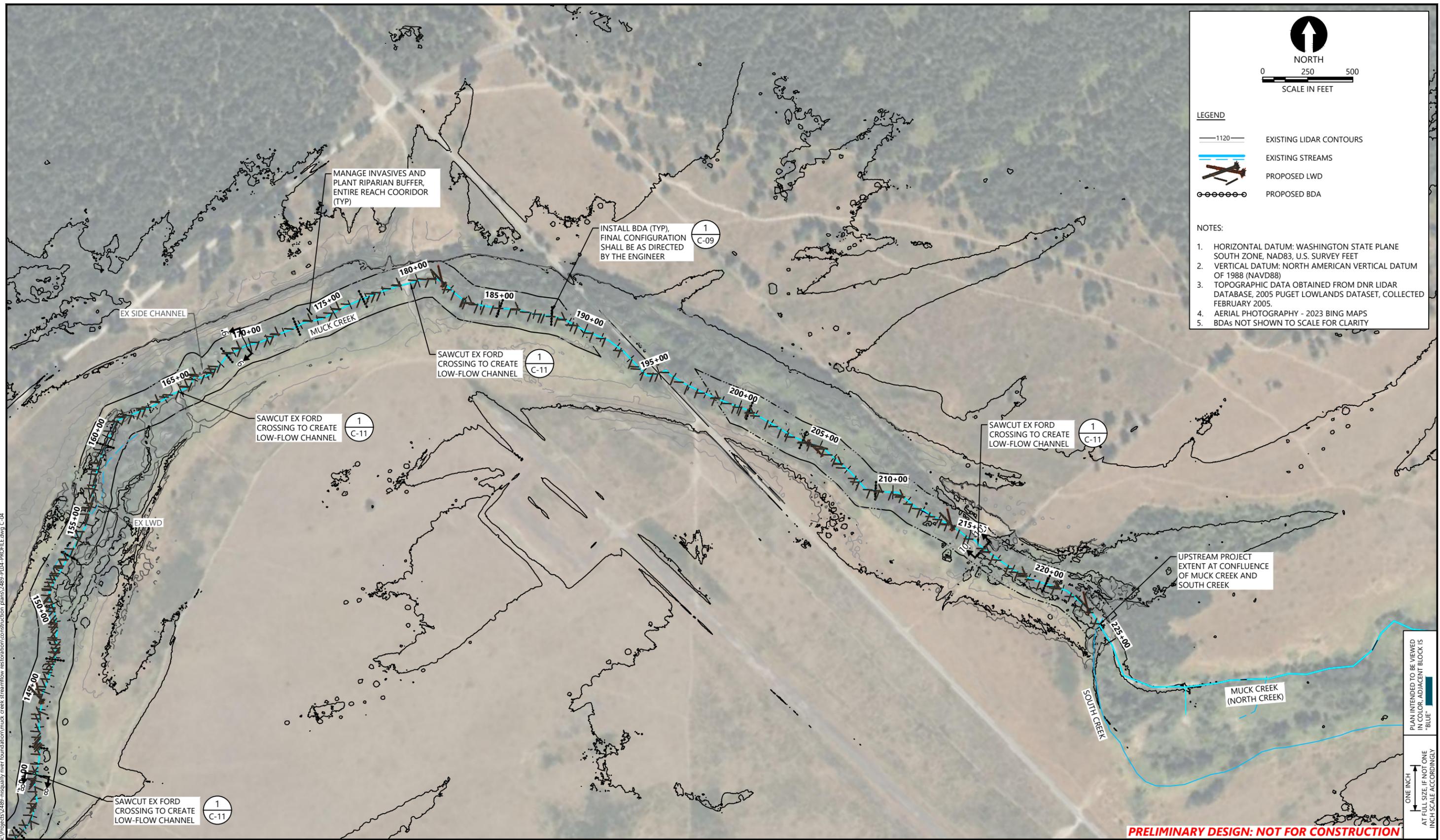
MUCK CREEK REACH 4 PRELIMINARY DESIGN

RESTORATION PLAN (2 OF 3)

C-03

SHEET # **5** OF **12**

K:\Projects\2488-nisqually_river_foundation\muck_creek_streamflow_restoration\construction_plans\2488-P104-PROFILE.dwg C-04
Mar 12, 2024 3:24pm jsexton



NORTH
0 250 500
SCALE IN FEET

LEGEND

- EXISTING LIDAR CONTOURS
- EXISTING STREAMS
- PROPOSED LWD
- PROPOSED BDA

NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, NAD83, U.S. SURVEY FEET
2. VERTICAL DATUM: NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)
3. TOPOGRAPHIC DATA OBTAINED FROM DNR LIDAR DATABASE, 2005 PUGET LOWLANDS DATASET, COLLECTED FEBRUARY 2005.
4. AERIAL PHOTOGRAPHY - 2023 BING MAPS
5. BDAs NOT SHOWN TO SCALE FOR CLARITY

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"
ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY



NISQUALLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

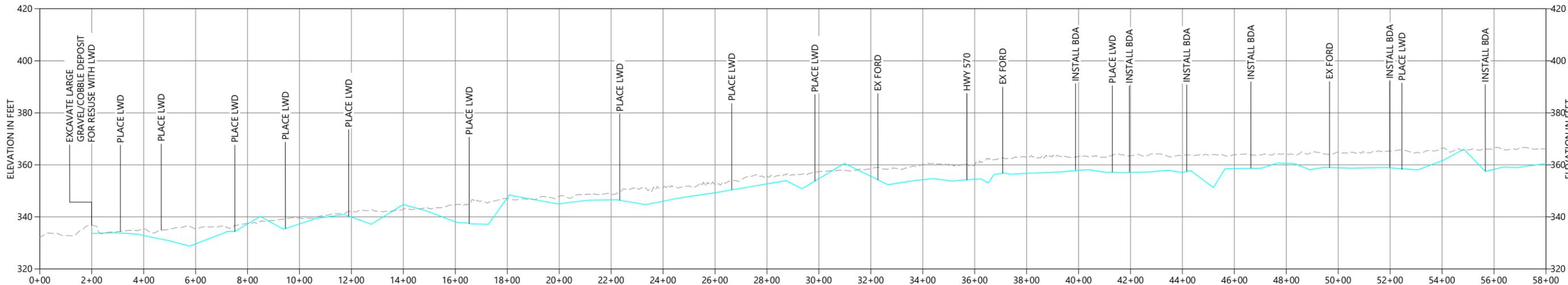
DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

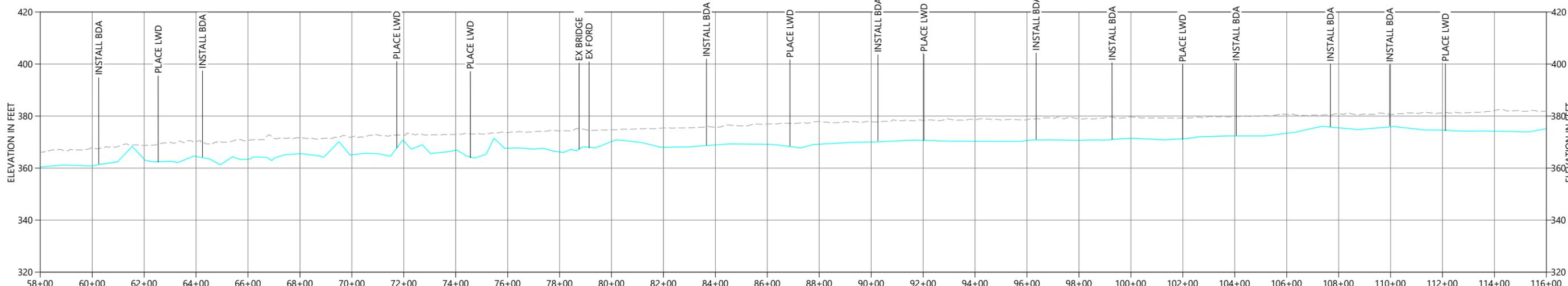
RESTORATION PLAN (3 OF 3)

C-04

SHEET # **6** OF **12**



STREAM PROFILE, STATION 0+00 TO 58+00
 HORIZONTAL SCALE: 1" = 200'
 VERTICAL SCALE: 1" = 20'



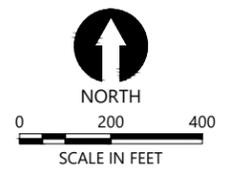
STREAM PROFILE, STATION 58+00 TO 116+00
 HORIZONTAL SCALE: 1" = 200'
 VERTICAL SCALE: 1" = 20'

LEGEND:

- 2005 LIDAR SURFACE
- FIELD COLLECTED TOPOGRAPHIC DATA AND CHANNEL PROFILE

NOTES:

1. HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, HARN, U.S. SURVEY FEET
2. VERTICAL DATUM: NAVD88



PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

k:\projects\2488-nisqually_river_foundation\muck_creek_streamflow_restoration\construction_plans\2488-P104-PROFILE.dwg C-05



NISQUALLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

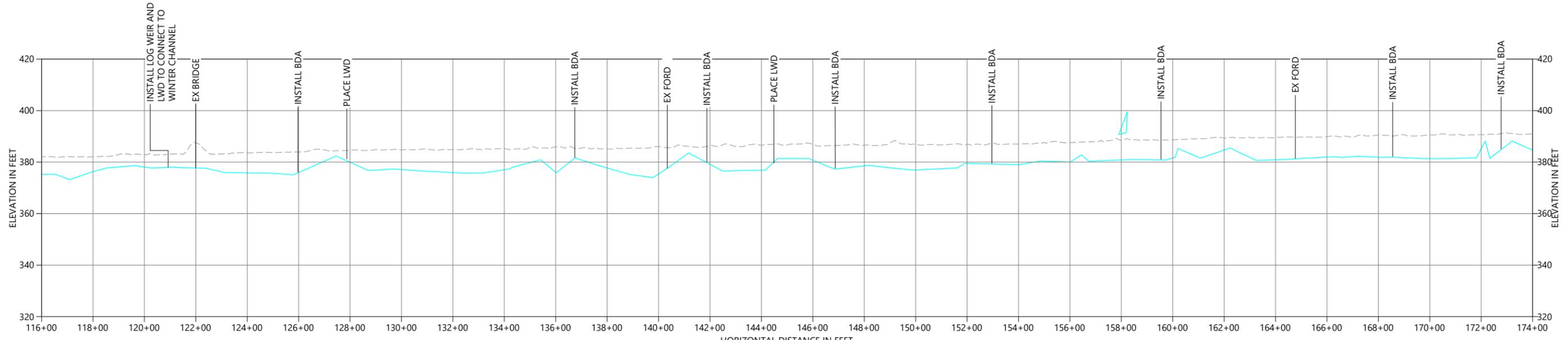
STREAM PROFILE (1 OF 2), 0+00 TO 116+00

C-05

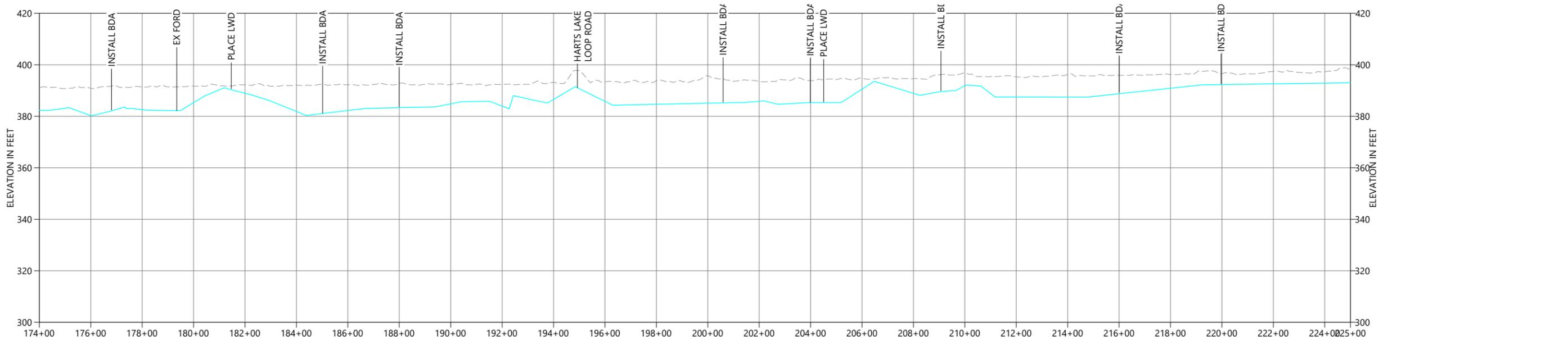
SHEET # **7** OF **12**

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE" INCH SCALE ACCORDINGLY

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 Mar 12, 2024 3:24pm jsexton



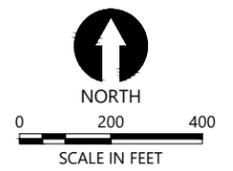
STREAM PROFILE, STATION 116+00 TO 174+00
 HORIZONTAL SCALE: 1" = 200'
 VERTICAL SCALE: 1" = 20'



STREAM PROFILE, STATION 174+00 TO 225+00
 HORIZONTAL SCALE: 1" = 200'
 VERTICAL SCALE: 1" = 20'

LEGEND:
 - - - 2005 LIDAR SURFACE
 ——— FIELD COLLECTED TOPOGRAPHIC DATA AND CHANNEL PROFILE

NOTES:
 1. HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, HARN, U.S. SURVEY FEET
 2. VERTICAL DATUM: NAVD88



PRELIMINARY DESIGN: NOT FOR CONSTRUCTION



NISQUALLY RIVER FOUNDATION

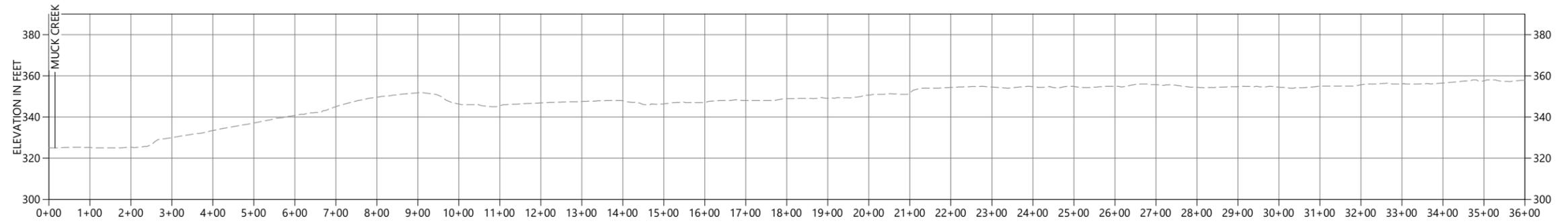
REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

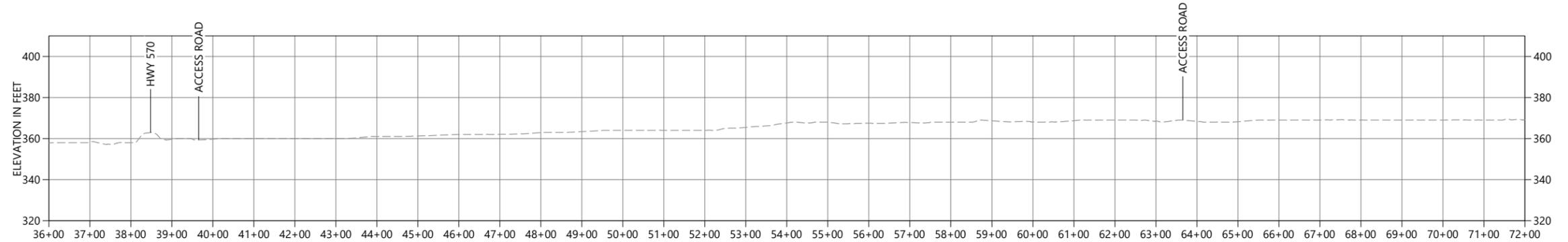
MUCK CREEK REACH 4 PRELIMINARY DESIGN
STREAM PROFILE (2 OF 2), 116+00 TO 225+00

C-06
 SHEET # **8** OF **12**

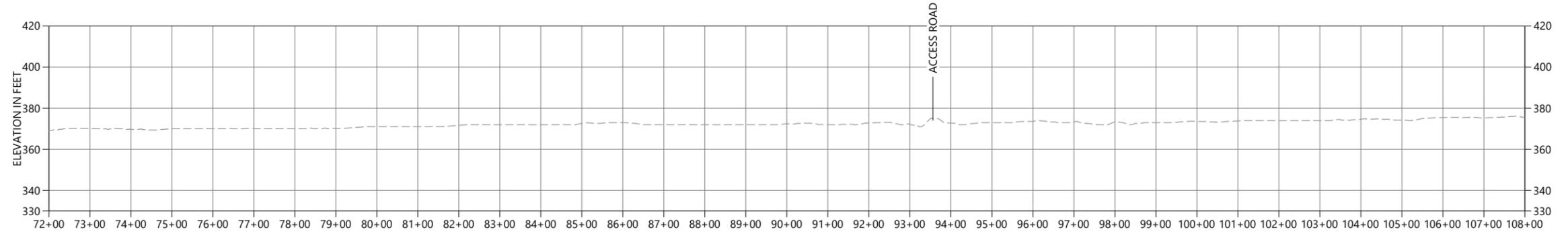
PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE" ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY



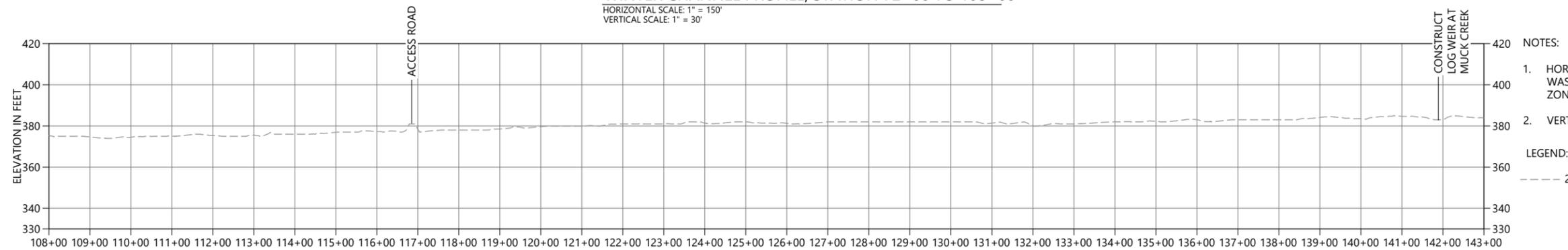
WINTER CHANNEL PROFILE, STATION 0+00 TO 36+00
 HORIZONTAL SCALE: 1" = 150'
 VERTICAL SCALE: 1" = 30'



WINTER CHANNEL PROFILE, STATION 36+00 TO 72+00
 HORIZONTAL SCALE: 1" = 150'
 VERTICAL SCALE: 1" = 30'



WINTER CHANNEL PROFILE, STATION 72+00 TO 108+00
 HORIZONTAL SCALE: 1" = 150'
 VERTICAL SCALE: 1" = 30'



WINTER CHANNEL PROFILE, STATION 108+00 TO 143+00
 HORIZONTAL SCALE: 1" = 150'
 VERTICAL SCALE: 1" = 30'

- NOTES:**
- HORIZONTAL DATUM:
WASHINGTON STATE PLANE SOUTH ZONE, HARN, U.S. SURVEY FEET
 - VERTICAL DATUM: NAVD88

LEGEND:
 --- 2005 LIDAR SURFACE

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE".

ONE INCH AT FULL SIZE. IF NOT ONE INCH SCALE ACCORDINGLY.

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

K:\Projects\2489-nisqually_river_foundation\muck_creek_streamflow_restoration\construction_plans\2489-P104-PROFILE.dwg C-07

Mar 12, 2024 3:40pm jsexton



NISQUALLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

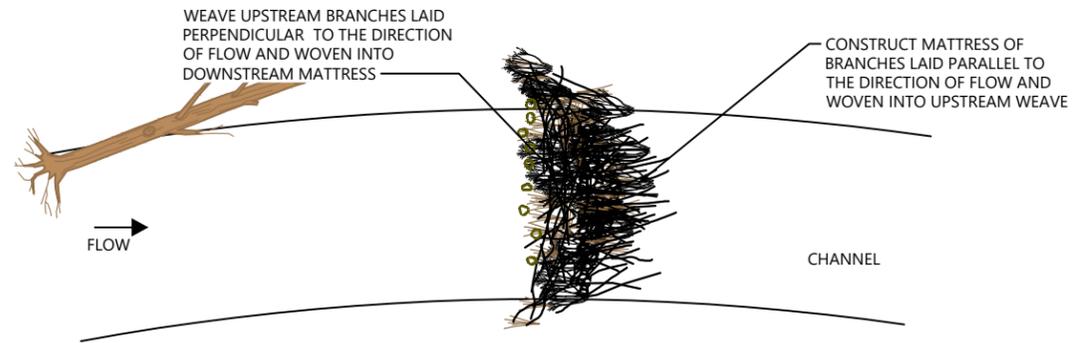
DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

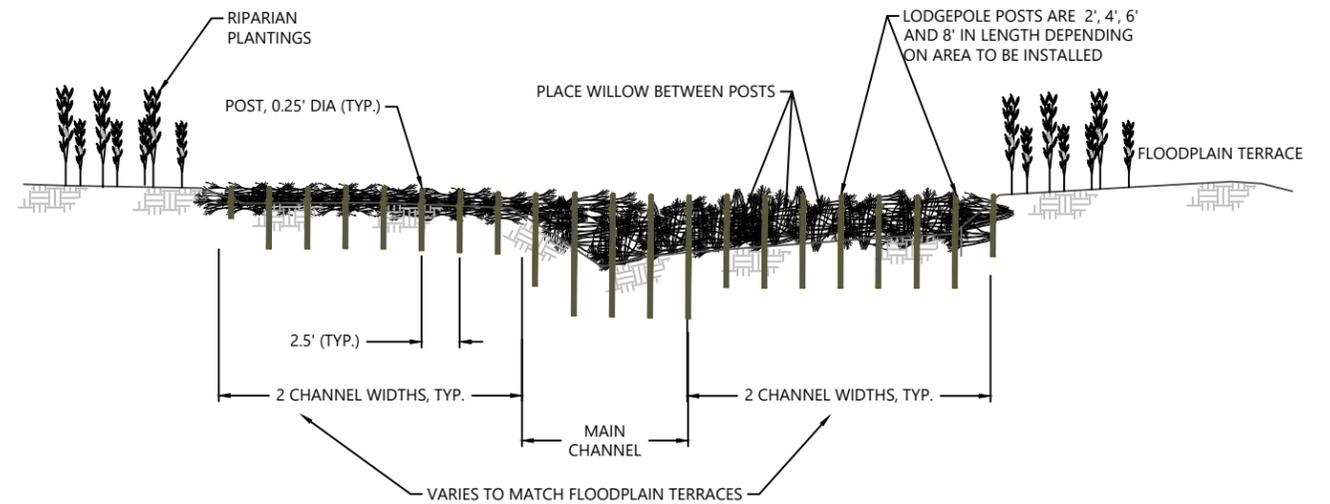
WINTER CHANNEL STREAM PROFILE

C-07

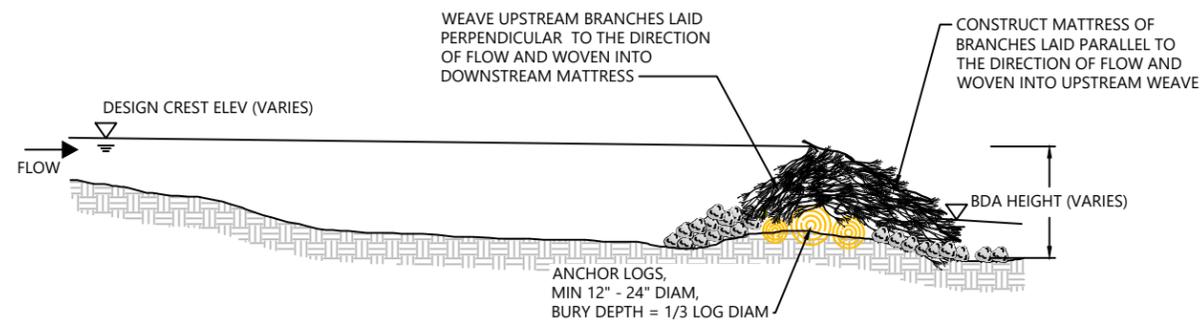
SHEET # **9** OF **12**



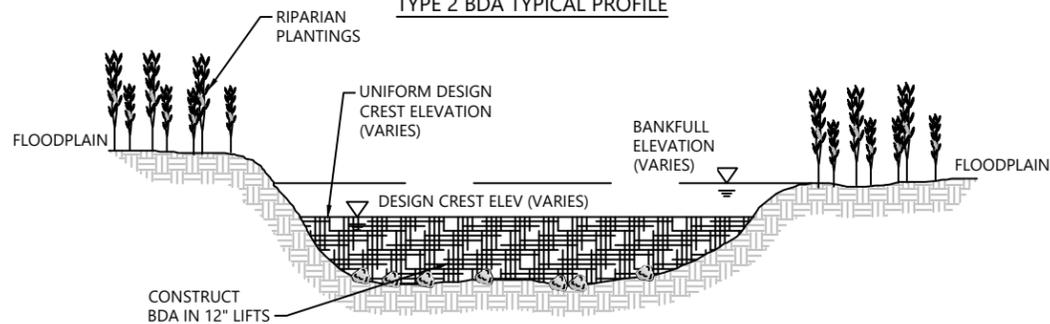
TYPE 2 BDA TYPICAL PLAN



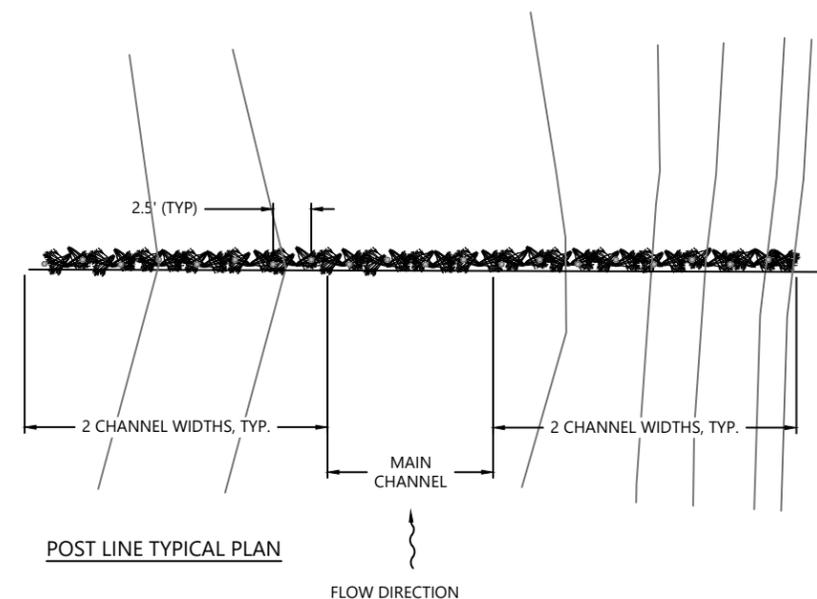
POST LINE TYPICAL PROFILE



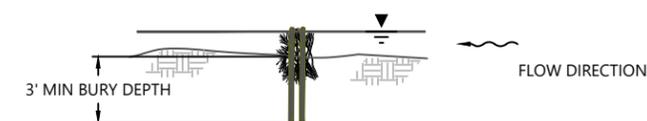
TYPE 2 BDA TYPICAL PROFILE



TYPE 2 BDA TYPICAL SECTION



POST LINE TYPICAL PLAN



POST LINE TYPICAL SECTION

2 TYPE 2 BDA DETAILS
C-02 SCALE: NTS

1 POST LINE BDA DETAILS
C-02 SCALE: NTS

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION



NISQAULLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

MUCK CREEK REACH 4 PRELIMINARY DESIGN

RESTORATION DETAILS - BDAS

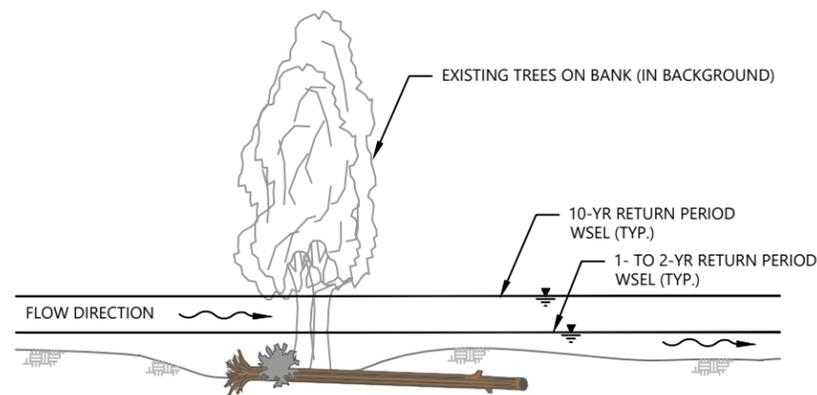
C-08

SHEET # 10 OF 12

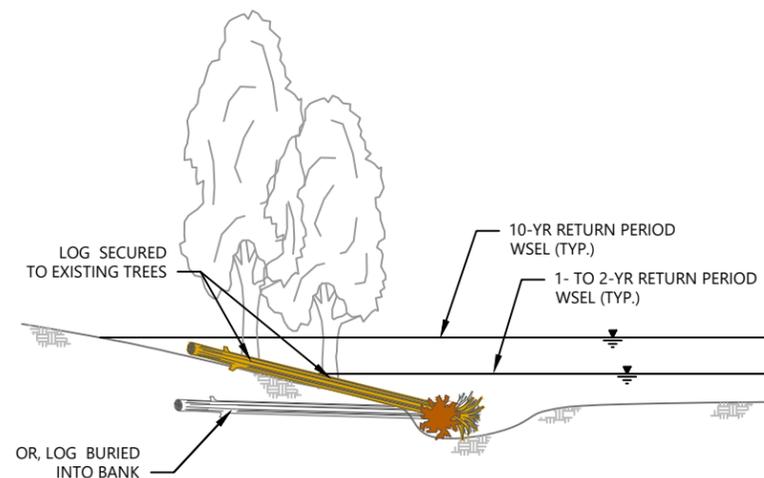
k:\Projects\2488-nisqually_river_foundation\muck_creek_streamflow_restoration\construction_plans\2488-PI05-BDA-DETAILS.dwg C-08 Mar 12, 2024 3:25pm jsexton

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE" ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY

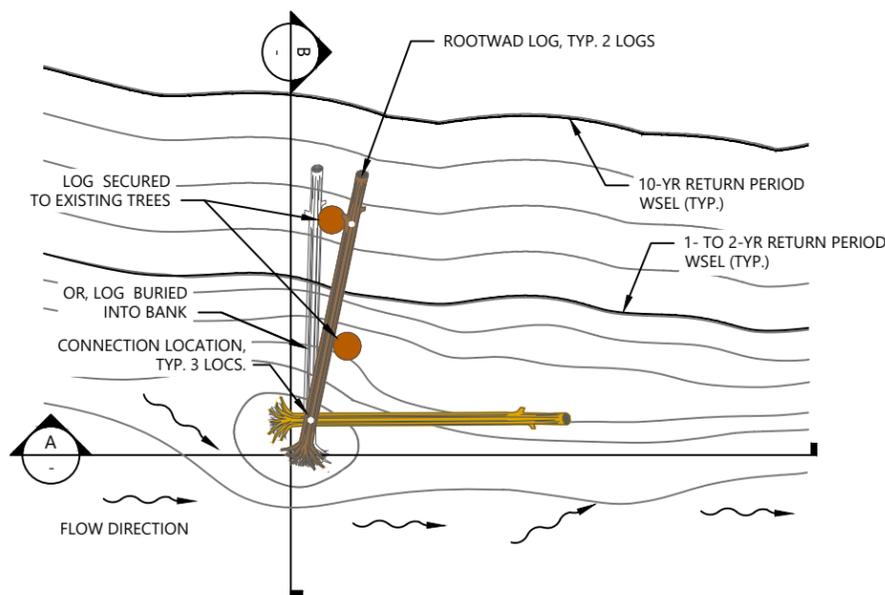
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Mar 12, 2024 3:25pm jsexton



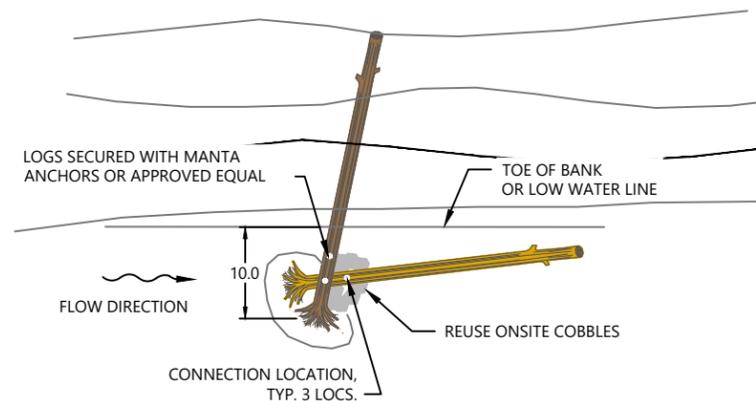
A LWD FEATURE TYPICAL PROFILE
SCALE: 1" = 10'



B LWD FEATURE TYPICAL SECTION
SCALE: 1" = 10'



A LWD FEATURE TYPICAL PLAN
SCALE: 1" = 10'



B LWD FEATURE TYPICAL PLAN
SCALE: 1" = 10'

CONSTRUCTION NOTES:

LWD WILL BE FIELD LOCATED AT TIME OF CONSTRUCTION BY THE ENGINEER.

FOR LWD BURIED INTO THE BANK

1. EXCAVATE TRENCH FOR LOG PERPENDICULAR TO FLOW AS APPROVED BY THE ENGINEER.
2. PLACE THE ROOTWAD LOG PARALLEL TO FLOW AT THE TOE OF THE BANK AS SHOWN.
3. PLACE THE ROOTWAD LOG PERPENDICULAR TO THE BANK INTO THE TRENCH AND POSITION UNDER THE PARALLEL TO FLOW ROOTWAD LOG AS SHOWN. ALTERNATIVELY A LOG POLE MAY BE USED AS APPROVED BY THE CONTRACTING OFFICER.
4. BACKFILL THE TRENCH OVER THE BOLE OF THE ROOTWAD LOG.

FOR LWD PLACED BETWEEN EXISTING TREES

5. PLACE THE ROOTWAD LOG PARALLEL TO FLOW AT THE TOE OF THE BANK AS SHOWN.
6. PLACE THE ROOTWAD LOG PERPENDICULAR TO THE BANK BETWEEN EXISTING TREES DISTANCE BETWEEN TREES MAY VARY BETWEEN 8 AND 15 FT. ALTERNATIVELY A LOG POLE MAY BE USED AS APPROVED BY THE CONTRACTING OFFICER
7. LASH THE ROOTWAD LOG TO THE EXISTING TREES USING 1/2" DIA. MANILA ROPE

RE-VEGETATION NOTE

8. CONTRACTOR SHALL COORDINATE WITH RE-VEGETATION CREWS FOR INSTALLATION OF PLANTS. PLANTS WILL BE INSTALLED BY OTHERS WITHIN AND AROUND THE STRUCTURE NEAR THE GROUNDWATER LEVEL. CARE SHALL BE TAKEN NOT TO DAMAGE PLANTINGS INSTALLED PRIOR TO COMPLETION OF THE STRUCTURE.



EXAMPLE LARGE WOOD CLUSTER

PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"
ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION



NISQUALLY RIVER FOUNDATION

REVISIONS				
REV	DATE	BY	APP'D	DESCRIPTION

DESIGNED BY: J. SEXTON
 DRAWN BY: J. SEXTON
 CHECKED BY: M. MARTZ
 APPROVED BY: R. MONTGOMERY
 SCALE: AS NOTED
 DATE: JANUARY 2024

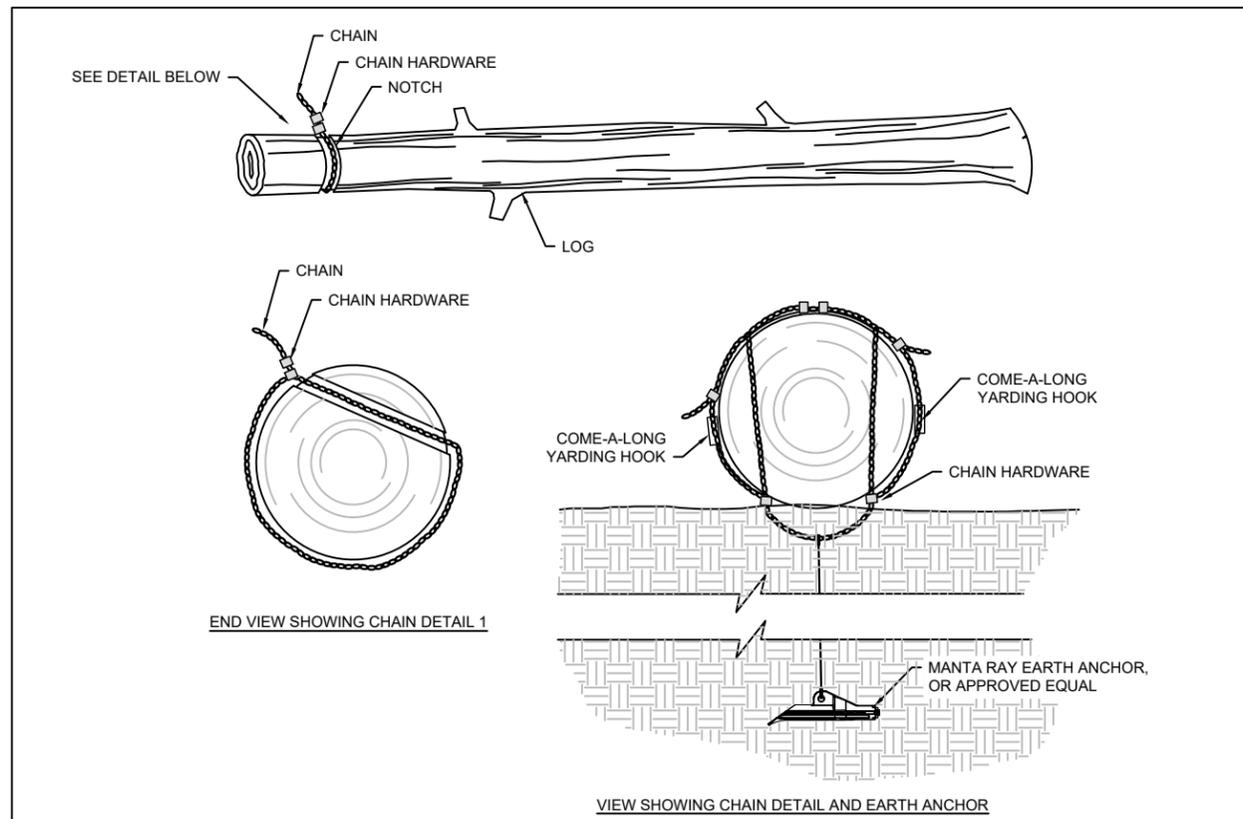
MUCK CREEK REACH 4 PRELIMINARY DESIGN

RESTORATION DETAILS - LWD

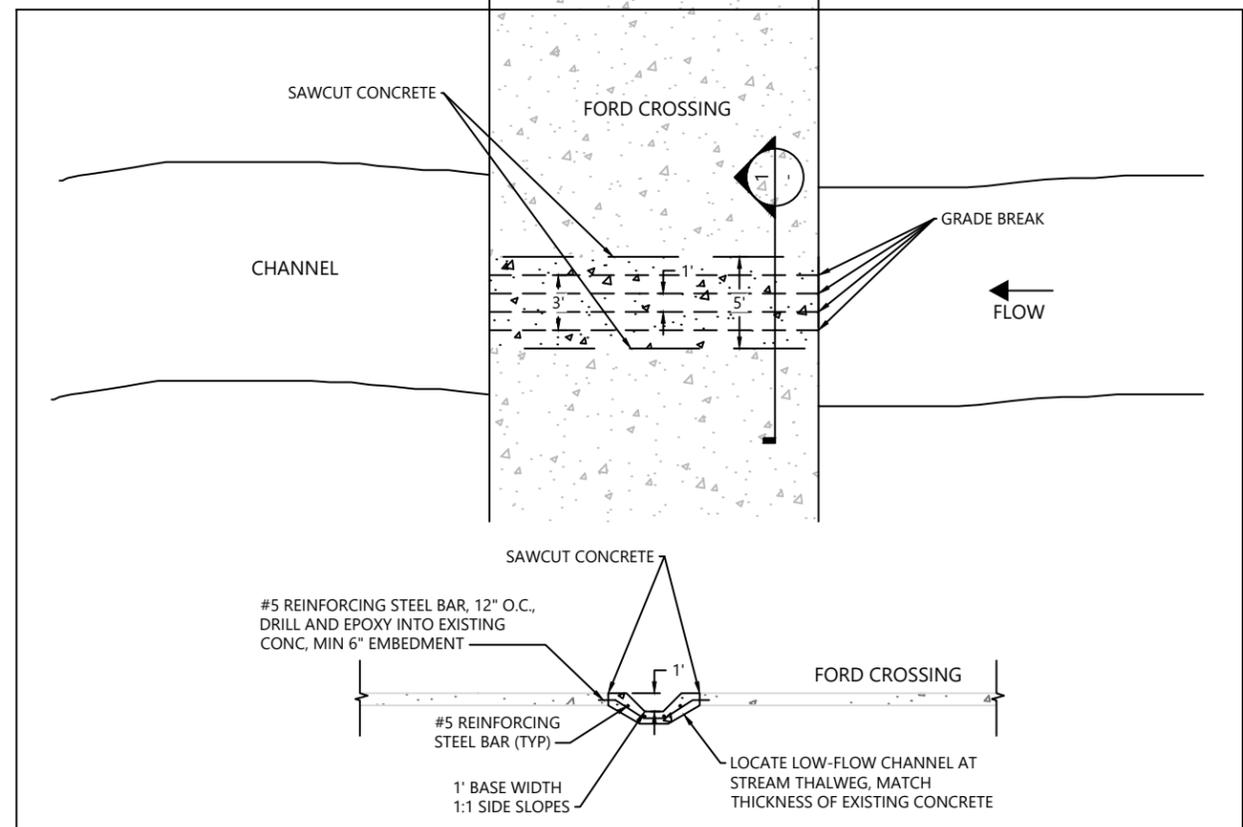
C-09

SHEET # **11** OF **12**

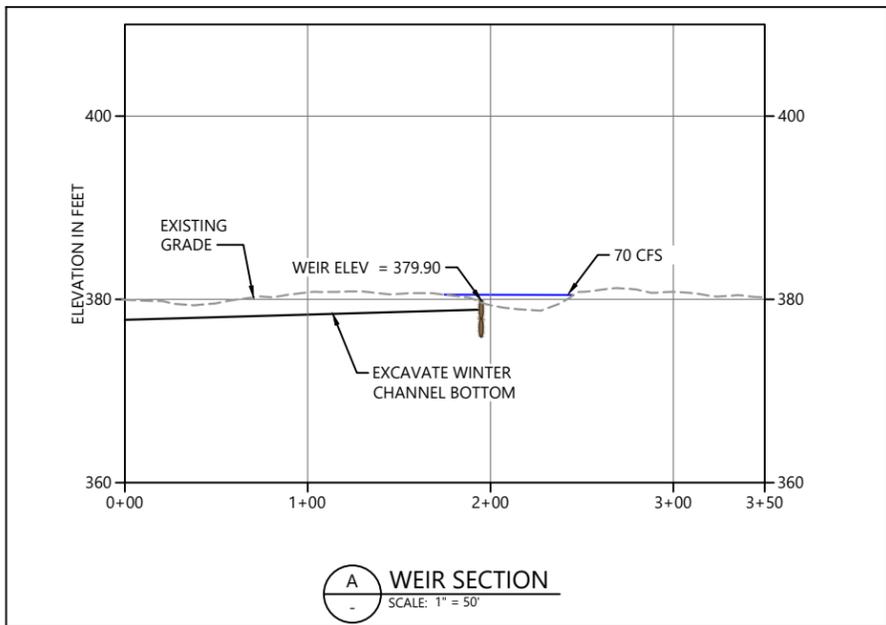
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Mar 12, 2024 3:25pm jsexton



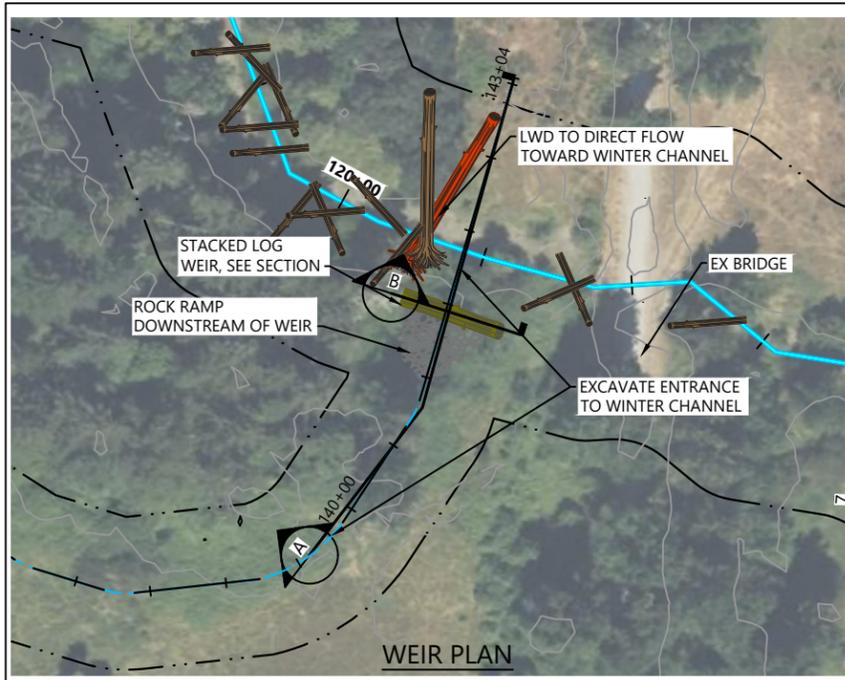
2 MANTA RAY ANCHOR INSTALLATION DETAIL
C-09 SCALE: 1" = 2'



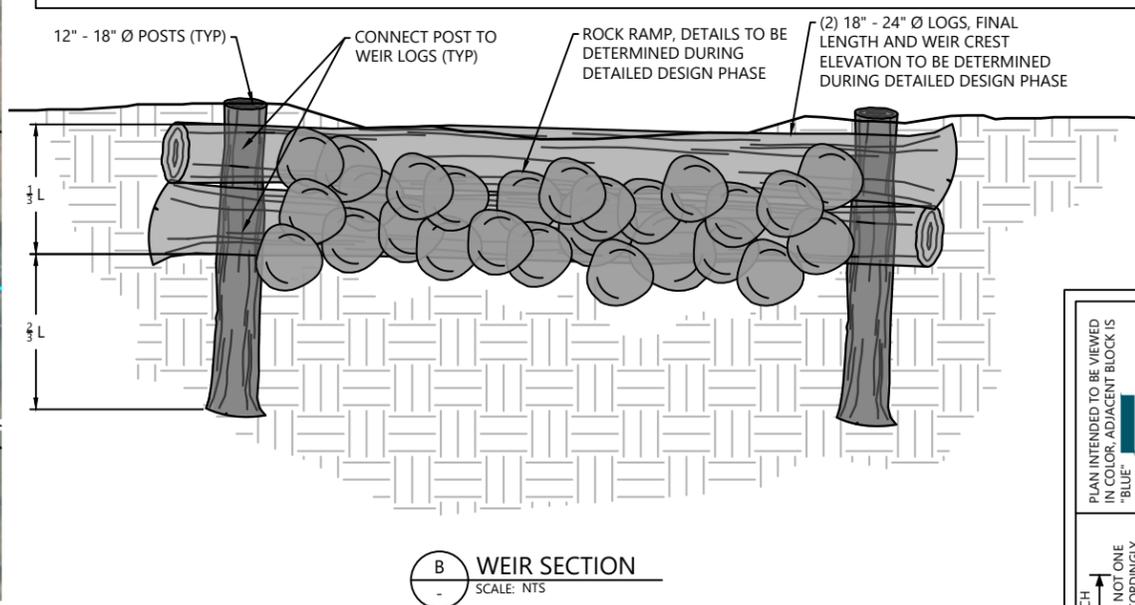
1 FORD CROSSING LOW-FLOW CHANNEL DETAIL
C-02 SCALE: 1" = 5'



A WEIR SECTION
SCALE: 1" = 50'



4 LATERAL LOG WEIR DETAILS
SCALE: NTS

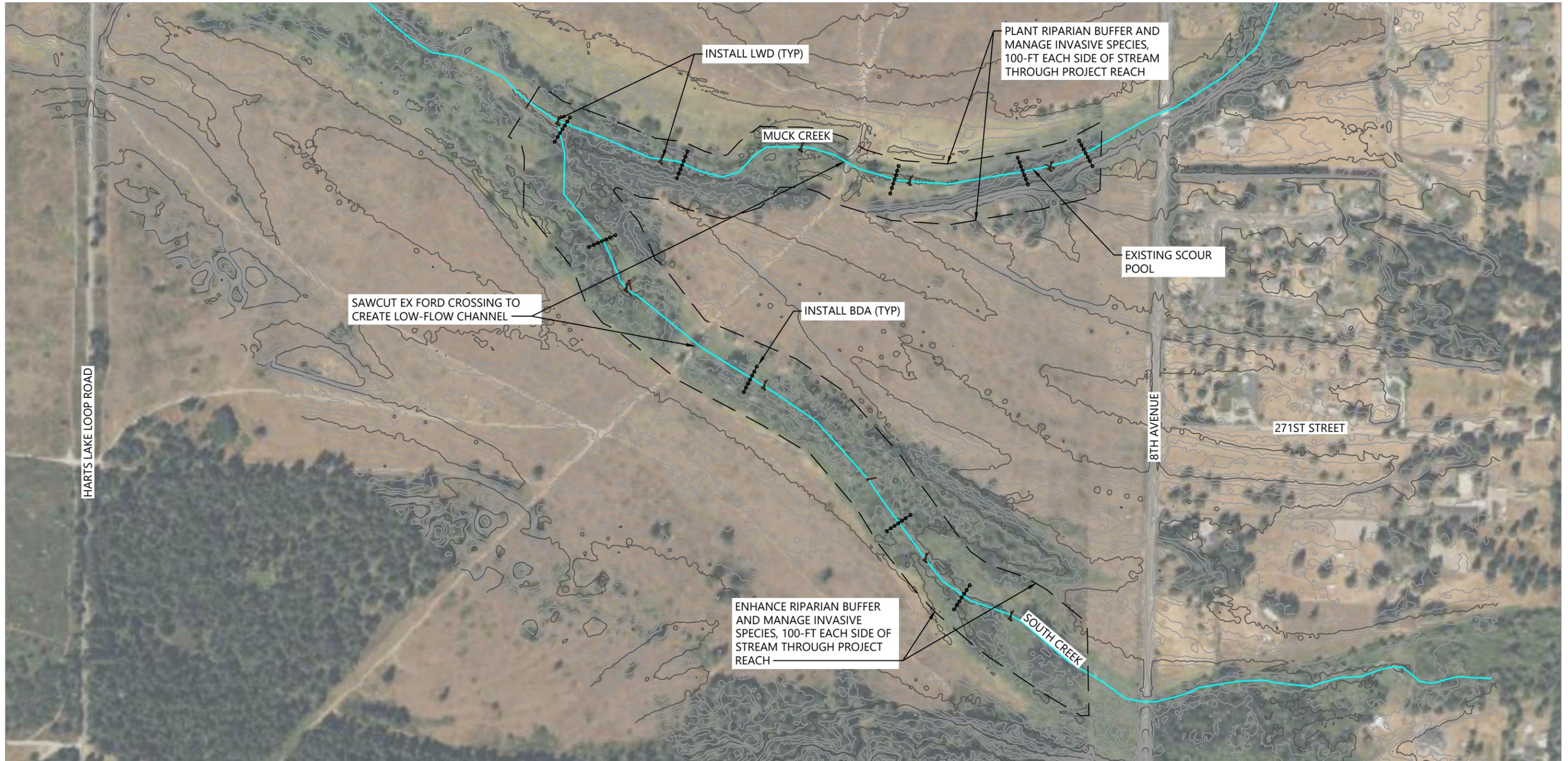


B WEIR SECTION
SCALE: NTS

ONE INCH AT FULL SIZE IF NOT ONE INCH SCALE ACCORDINGLY
PLAN INTENDED TO BE VIEWED IN COLOR. ADJACENT BLOCK IS "BLUE"

PRELIMINARY DESIGN: NOT FOR CONSTRUCTION

	NISQUALLY RIVER FOUNDATION	REVISIONS				DESIGNED BY: J. SEXTON DRAWN BY: J. SEXTON CHECKED BY: M. MARTZ APPROVED BY: R. MONTGOMERY SCALE: AS NOTED DATE: JANUARY 2024	MUCK CREEK REACH 4 PRELIMINARY DESIGN	C-10
								GENERAL DETAILS

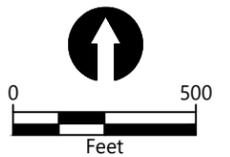


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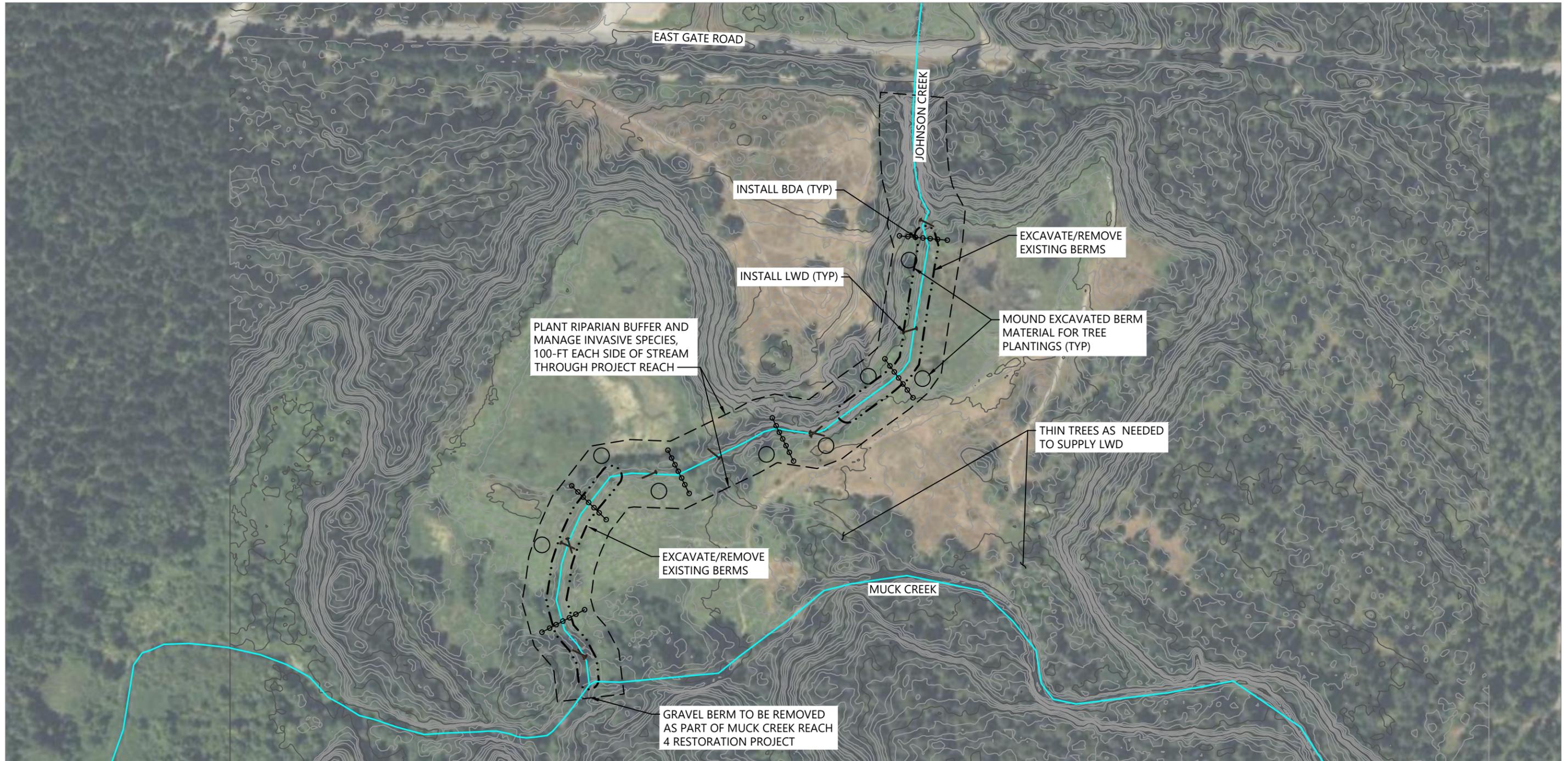
1. Horizontal Datum: Washington State Plane South Zone, NAD83, U.S. Survey Feet
2. Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
3. Topographic data obtained from DNR LiDAR database, 2005 Puget Lowlands dataset, collected February 2005.
4. Aerial photography - 2023 Bing maps
5. BDAs not shown to scale for clarity

LEGEND:

- | | | | |
|--|--------------------------|--|---------------|
| | 5' AND 1' LIDAR CONTOURS | | PLANTING AREA |
| | STREAM | | |
| | LARGE WOODY DEBRIS (LWD) | | |
| | BEAVER DAM ANALOG (BDA) | | |



Publish Date: 2024/03/29 9:20 AM | User: jsexton
 Filepath: K:\Projects\2489-Nisqually River Foundation\Muck Creek Streamflow Restoration\Conceptual_Designs\2489-CONCEPTUAL-PLAN-REACH-5.dwg Reaches 5 and 7 (R5-P1 and R7-P1) Conceptual Restoration Plan

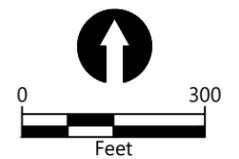


NOTES:

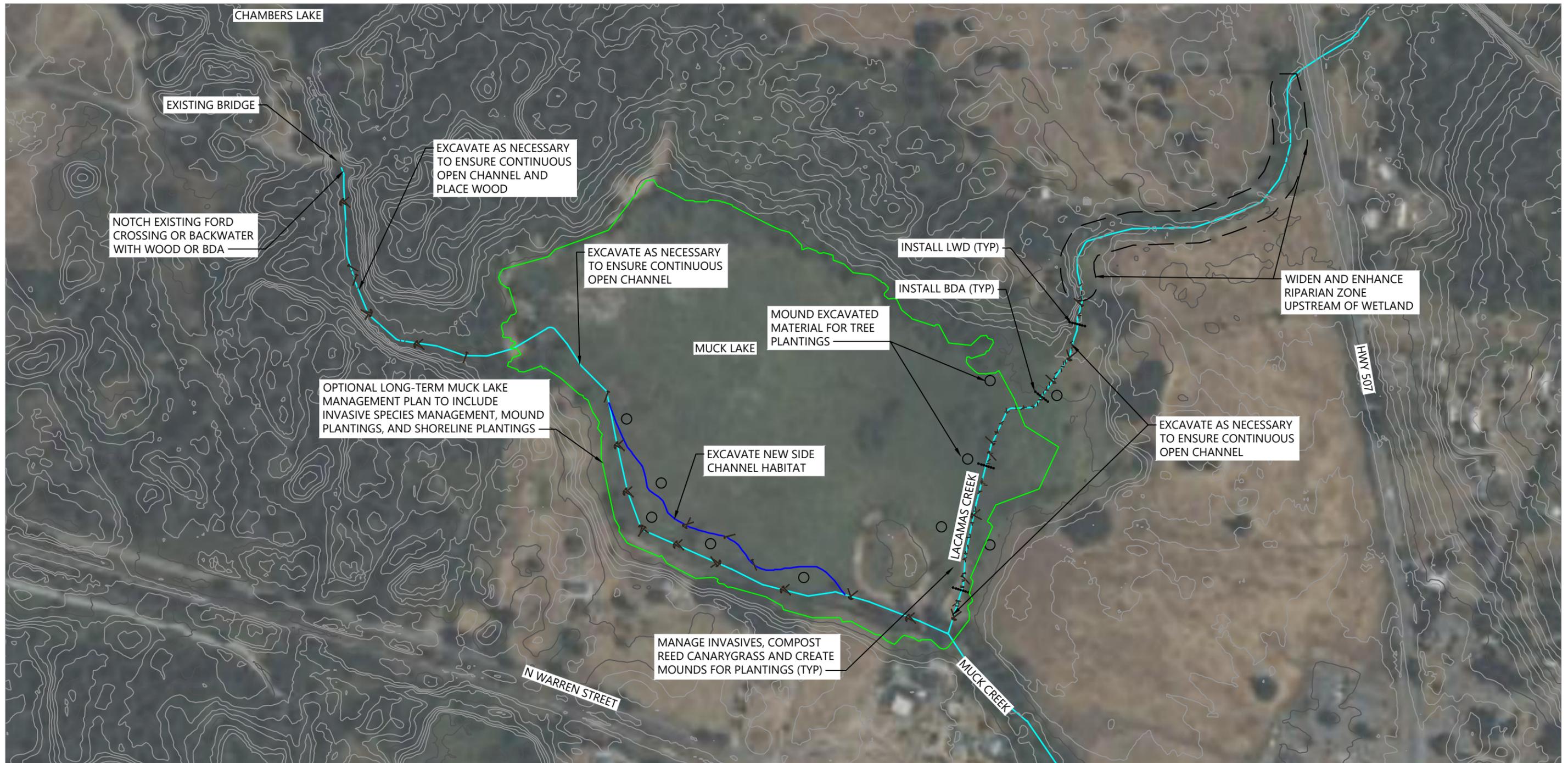
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2. Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
3. Topographic data obtained from DNR LiDAR database, 2005 Puget Lowlands dataset, collected February 2005.
4. Aerial photography - 2023 Bing maps
5. BDAs not shown to scale for clarity

LEGEND:

- 5' AND 1' LIDAR CONTOURS
- STREAM
- LARGE WOODY DEBRIS (LWD)
- BEAVER DAM ANALOG (BDA)
- BERM REMOVAL



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 Filepath: K:\Projects\2489-Nisqually River Foundation\Muck Creek Streamflow Restoration\Conceptual_Designs\2489-CONCEPTUAL-PLAN-JohnsonCreek.dwg Johnson Creek (R11-P1) Conceptual Restoration Plan

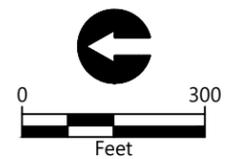


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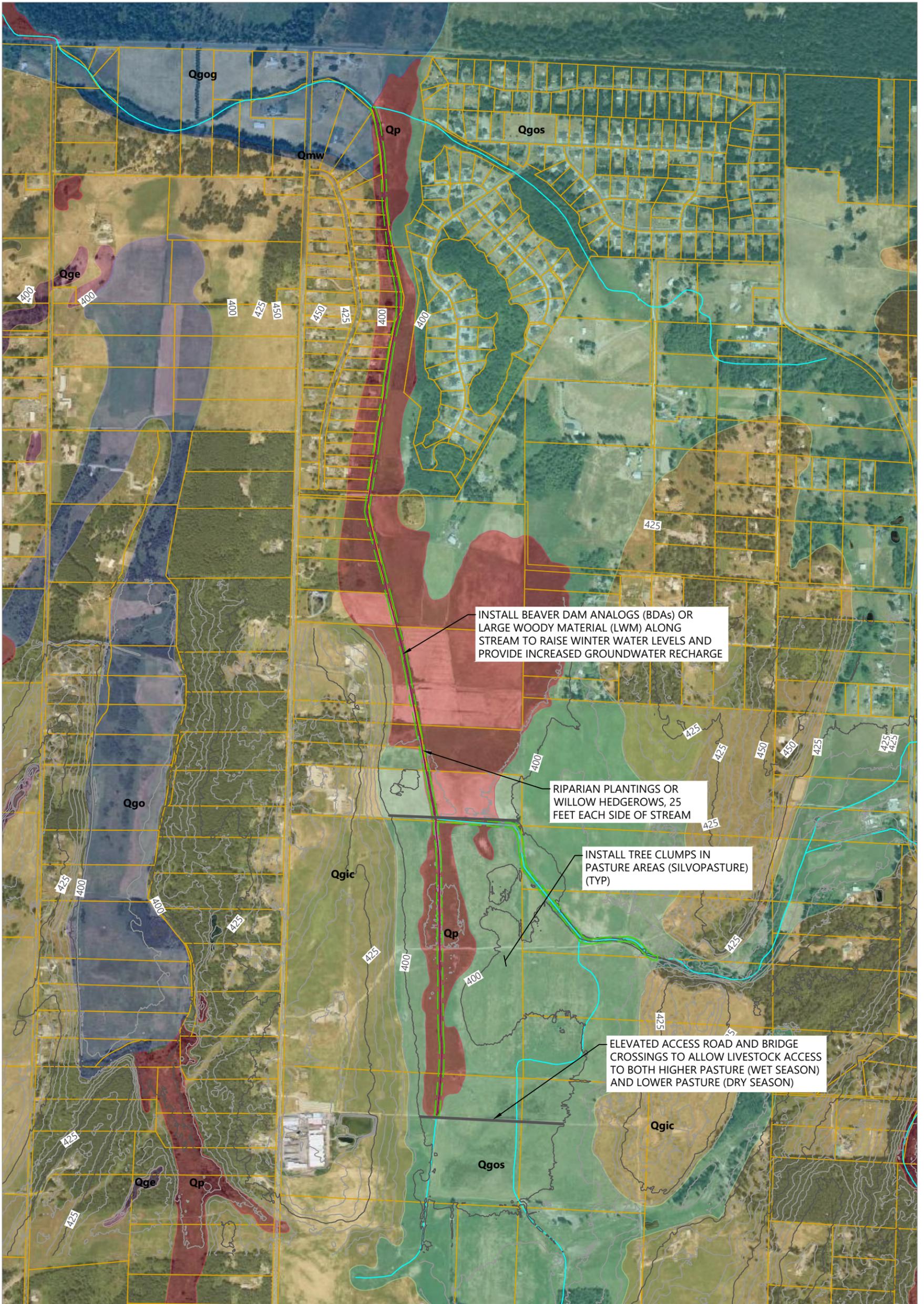
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2. Vertical Datum: North American Vertical Datum of 1988 (NAVD88)
3. Topographic data obtained from DNR LiDAR database, 2005 Puget Lowlands dataset, collected February 2005.
4. Aerial photography - 2023 Bing maps

LEGEND:

- | | | | |
|--|---------------------------|--|------------------------------------|
| | 10' AND 2' LIDAR CONTOURS | | LARGE WOODY DEBRIS (LWD) |
| | STREAM | | OPTIONAL LONG-TERM MANAGEMENT AREA |
| | NEW SIDE CHANNEL | | RIPARIAN PLANTING AREA |
| | BEAVER DAM ANALOG (BDA) | | |



Publish Date: 2024/03/29 9:20 AM | User: jsxton
 Filepath: K:\Projects\2489-Nisqually River Foundation\Muck Creek Streamflow Restoration\Conceptual_Designs\2489-CONCEPTUAL-PLAN-LacamasCreek.dwg Lacamas Creek (R12-P1 and R3-P4) Conceptual Restoration Plan



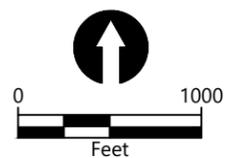
HORIZONTAL DATUM: Washington State Plane
South Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: North American Vertical Datum
of 1988 (NAVD88)

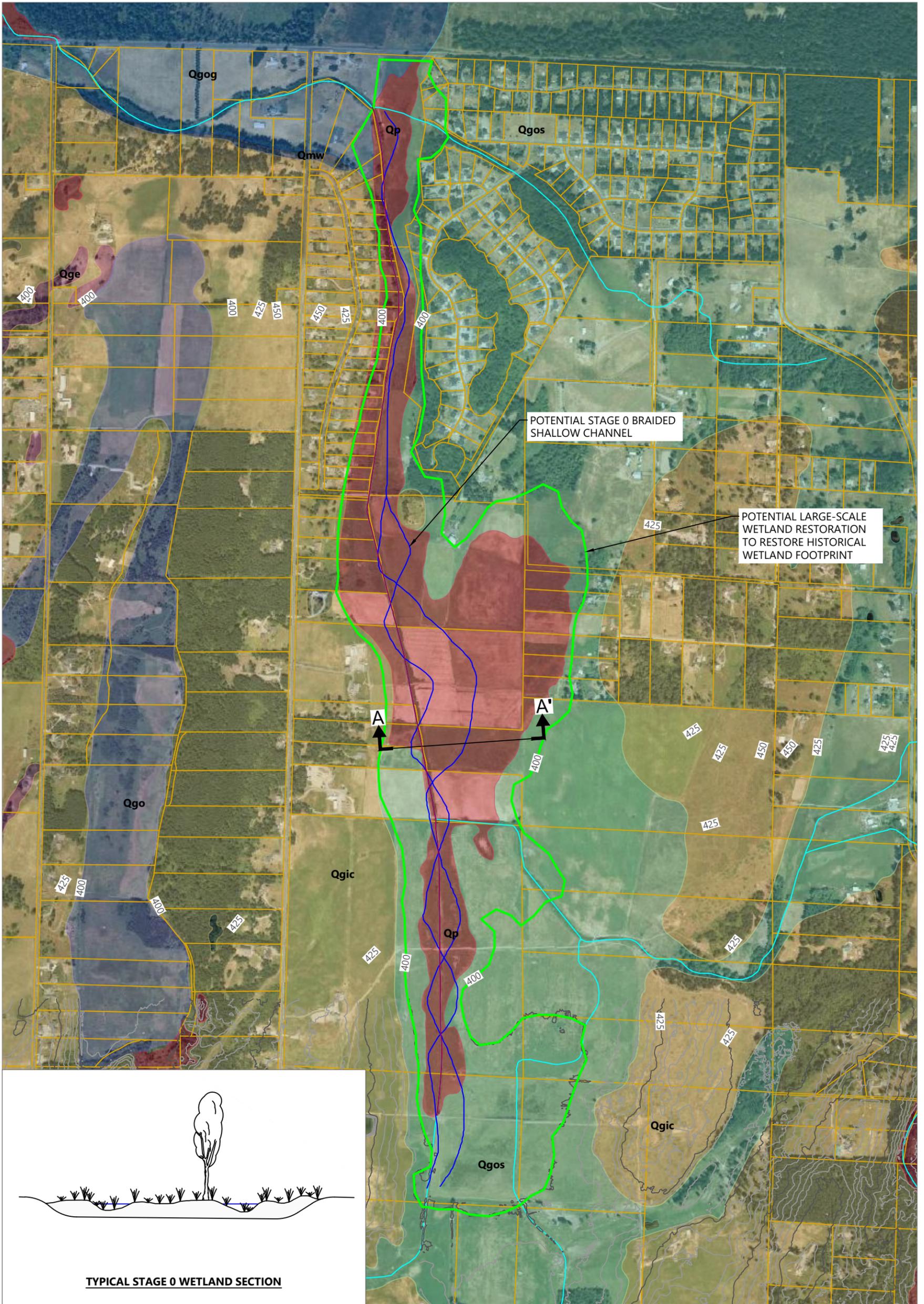
LEGEND:

- 400 — 5' and 25' Contours
- ▭ Parcel Boundary
- Stream
- ▬ Raised Road/Bridge
- ▭ Riparian Planting Area

GEOLOGY

- ▭ Qgic
- ▭ Qp
- ▭ Qgos
- ▭ Qgo
- ▭ Qmw
- ▭ Qge
- ▭ Qgog



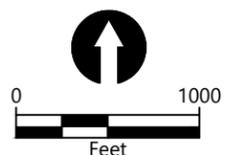


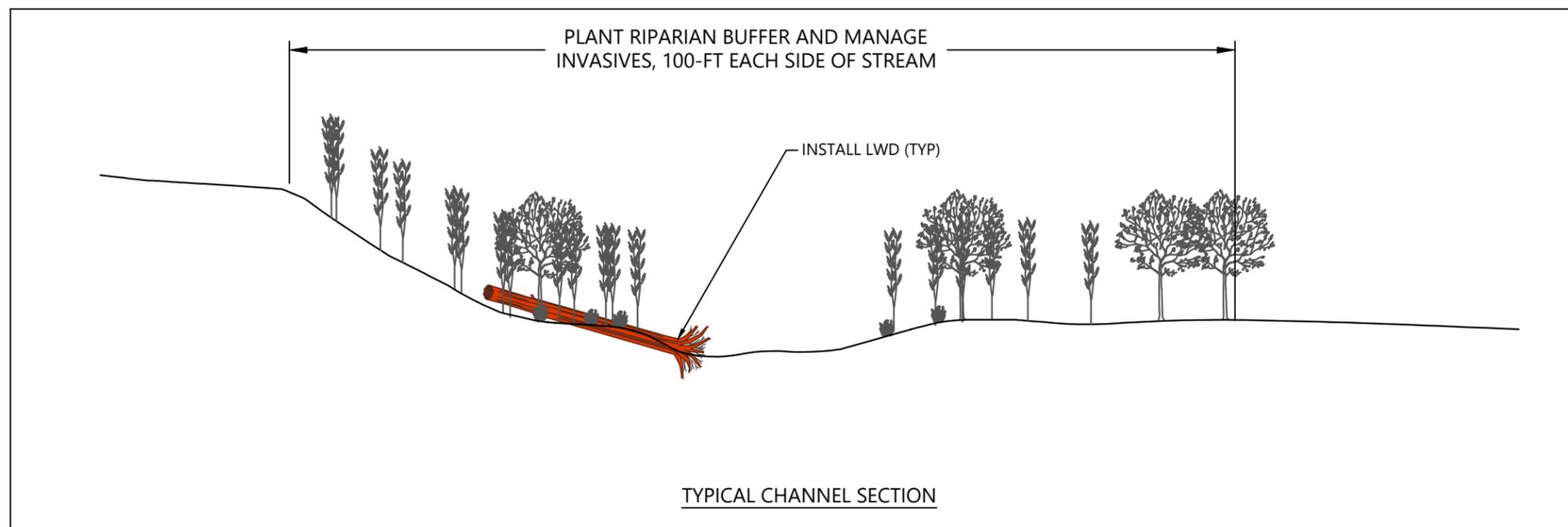
TYPICAL STAGE 0 WETLAND SECTION

HORIZONTAL DATUM: Washington State Plane South Zone, NAD83, U.S. Survey Feet
VERTICAL DATUM: North American Vertical Datum of 1988 (NAVD88)

LEGEND:

- | | | | | |
|-------|----------------------------|---------|------|------|
| — 400 | 5' and 25' Contours | Geology | Qgic | Qge |
| — | Parcel Boundary | Qp | Qgos | Qgog |
| — | Existing Stream | Qgo | Qmw | |
| — | Potential Restoration Area | | | |
| — | Potential Braided Channel | | | |

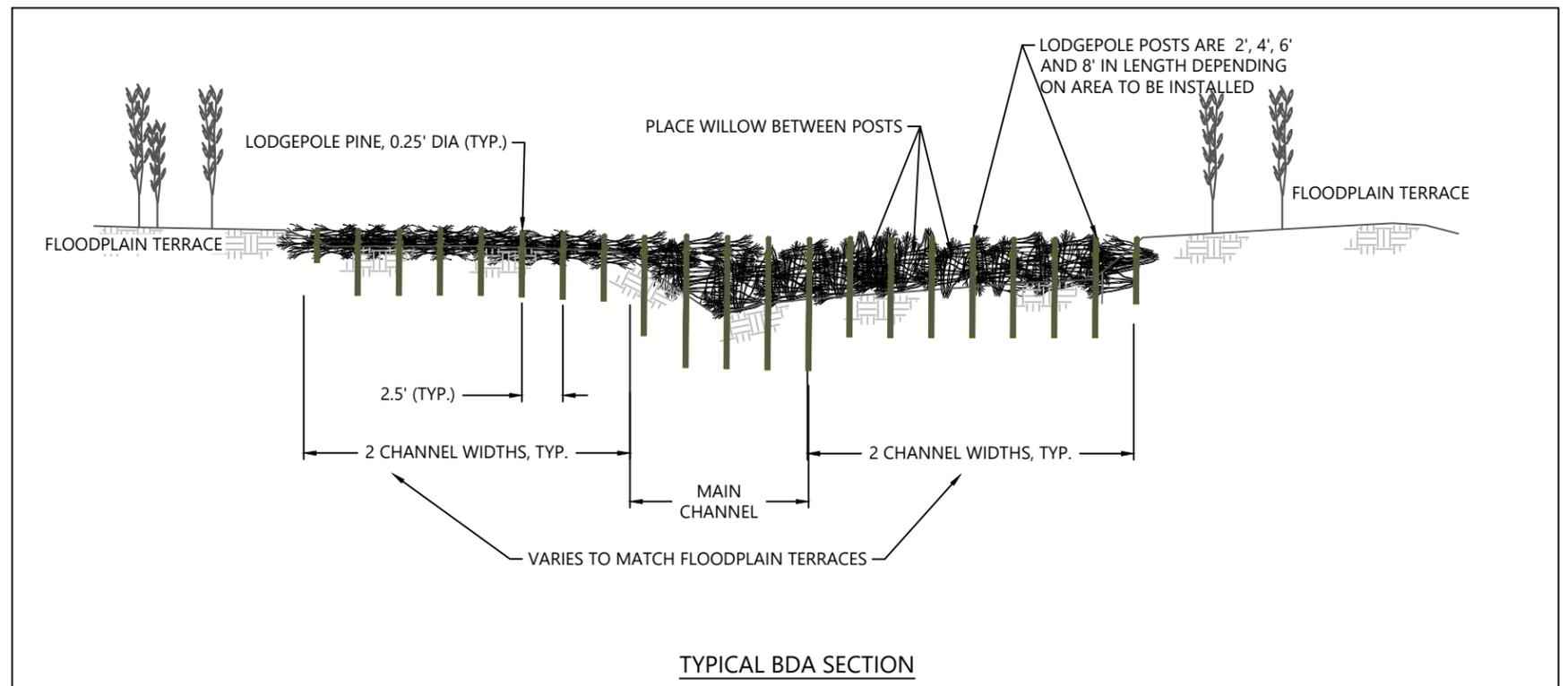




BDA EXAMPLES



LWD EXAMPLE



1 Conceptual Restoration Design Projects

After evaluating potential projects throughout the Muck Creek watershed, five areas were prioritized for restoration and enhancement and are described in the narrative below and shown on the attached figures.

1.1 Project 1 - Muck Creek Reach 4 (R4-P1)

The Muck Creek Reach 4 project site is located from the Johnson Creek confluence upstream to the confluence between Upper Muck Creek and South Creek. This project was taken to the preliminary design level. The key objective is to increase the duration of surface water in this reach that most inhibits access by salmonids to upper reaches. In addition, this reach is the primary “prairie reach” and the prairie habitats have been substantially reduced by encroaching forest habitat and the presence and spread of invasive plant species. The gravelly, well-drained glacial soils contribute to seasonal dry-bed conditions, exacerbated by upstream agriculture and human-influence that have channelized the creek, removed much of the wood and former beaver pond habitats throughout the basin that previously contributed to in-channel and floodplain wetland water storage. The following proposed restoration elements target the low baseflow/dry streambed conditions, loss of quantity and quality of prairie and native riparian habitat, and enhancement of stream habitat for salmonids.

Muck Creek Reach 4 encompasses approximately 4 miles of stream habitat. Proposed restoration elements include installation of approximately 32 BDAs, anchored and mobile LWD (total number to be determined during final design phase), modifying 9 ford crossings to include low-flow channels, excavation as needed to reconnect a side channel herein referred to as the winter channel and riparian buffer enhancement. Proposed riparian buffer improvements represent 130 acres of planting and invasive species management, which includes a 100-foot buffer on each side of Muck Creek and a 50-foot buffer along the winter channel. An additional 10-20 acres of forest may be thinned to reduce forest density on former prairie habitat and provide woody material for use in BDAs and as LWD.

1.1.1 Beaver Dam Analogs (BDAs)

Beaver dam analogs (BDAs) are constructed structures designed to mimic the form and function of a natural beaver dam and may also promote beaver colonization. In this reach, the conceptual design incorporates BDAs in locations to enhance water storage, improve floodplain and wetland connectivity, and increase baseflow by promoting groundwater recharge and slowing rainfall runoff. To provide diversity in habitat features, two styles of BDAs are proposed for use throughout the reach: the post-assisted BDA is the more robust style of BDA to provide larger ponded habitat and reduce water velocities during high flow events; and post-less BDAs that more closely mimic the form and function of beaver dams, potentially recruiting beavers to the area.

The post-assisted BDAs are proposed for upstream of ford crossings, bridges, and roads to focus ponding away from these structures and collect LWD and other debris that otherwise can deposit on the structures. Vertical posts, driven into the soil, would be spaced 1.5 to 2 feet apart and span the channel from bank to bank, extending up into the floodplain where there are shallow banks to maximize the amount of water storage and improve floodplain connectivity. Post-less BDAs are similar in function; however, instead of vertical posts installed at regular distances, the BDA is formed by placing channel-spanning logs and using smaller slash, branches, cobbles, and debris in the interstitial spaces to provide the water storage.

1.1.2 Large Woody Debris (LWD)

LWD is integral for the development of diverse in-channel habitat features, such as pools, undercut banks, and gravel bars. Humans have actively reduced the amount of wood in streams and rivers through direct removal during land management and by reducing the amount of potential recruitment material through forestry and land development practices. In Reach 4, Muck Creek historically was primarily in prairie habitat, and now flows through a mix of prairie and forested habitat but there is limited LWD within the channel to support habitat forming features and bed stability. The conceptual design proposes the placement of both anchored and loose (mobile) wood pieces.

Fox and Bolton (2007) assessed natural wood loading and recommended wood quantities (per 100 meters [330 feet]) in streams throughout Washington based on the bankfull width of the stream. The guidelines along Western Washington are specific for forested areas. Because much of the reach flows through prairie habitat, target volumes proposed are at the 25th percentile of the recommended amount. For 4 miles of restoration through Muck Creek (estimated 18-foot bankfull width), total LWD number is 26 pieces per 330 feet (total 1,673 pieces) for a total LWD volume of 918 cubic feet per 330 feet of channel (total 59,081 cubic feet). Of that total LWD, 1 LWD per 330 feet should be key pieces, for a total of 64 key pieces. The material used to create BDAs also counts towards the LWD count and volume. Of the 32 proposed BDAs, 16 will be post-assisted adding 427 LWD and 16 will be post-less adding 48 LWD, for a total of 475 LWD.

LWD is anchored through burying a portion of the log within the bank, anchoring to existing trees, or using soil anchors to lock the LWD in place along the bank. The anchored pieces are placed at strategic locations to reduce bank erosion, direct flows to side channels, and develop diverse instream features (e.g., undercut banks, pools, gravel retention, etc.). Mobile (unanchored) wood is proposed to be placed within the channel upstream of BDAs or anchored LWD so they may move through the system, settling naturally into position temporarily before shifting to new locations downstream during higher streamflow events.

1.1.3 Winter Channel Reconnection

The winter channel has lost its connectivity to the main channel due to probable placement of sediment along the bank from channelization, on-going channel incision and forest development. A comparison of LiDAR and aerial imagery showing the existing configuration of the main channel, and the location of nearby infrastructure were all considered when identifying the most appropriate location for the new winter channel inlet. To ensure the channel is only engaged during higher flows, a log will/weir will span the channel's inlet, and anchored LWD will be installed just downstream and across the Muck Creek channel in a manner to locally elevate and direct higher flows towards the side channel. By placing the LWD higher on the bank to be engaged (and direct flows) during higher flow levels and incorporating a weir at the side channel inlet, the existing flows within Muck Creek will not be reduced during lower flow periods and flow velocity will be decreased during high flow events due to the additional flow pathway of the winter channel.

1.1.4 Ford Crossing Low-Flow Channel

Reach 4 is within JBLM property and is within areas that are used for training exercises. There are numerous ford crossings and the raised profile of, and relatively flat concrete bottoms of the crossings may inhibit fish passage during low-flow conditions. The proposed low-flow channel includes a 5-foot-wide cut-out of the ford and replacement with a 1-foot deep concrete notch that allows continuous stream flow with sufficient depth for fish passage, even in baseflow conditions. The center of the channel cut-out features a 1-foot-wide base, 1:1 side slope, and a 1-foot-wide top to match the thickness of the existing concrete. The concrete base, sides, and top will all be reinforced with rebar to add strength to maintain vehicle crossings.

1.1.5 Forest Thinning

Forest encroachment is a leading cause for the loss of rare prairie habitat in this reach of Muck Creek; however, maintaining canopy cover and riparian vegetation adjacent to the stream is important for temperature control, organic input, and beaver forage material. To meet those conflicting needs, two forested areas adjacent to, but not within the riparian buffer of both the winter channel and Muck Creek mainstem were identified for thinning - removing trees from the edges, as well as some larger trees from the center. Trees thinned from forest habitat will be reused in the anchored or mobile LWD, log weirs, or in BDAs.

1.1.6 Riparian Planting

In the non-forested segments of Reach 4, where Muck Creek flows through prairie habitat, the riparian cover over the stream will be enhanced by planting willows immediately along the creek edge and an approximately 100-foot wide sparse riparian forest with understory shrub vegetation. The willow plantings will be concentrated in areas that are seasonally wetted and in areas with a

focus to provide rapid shading as part of the invasive species management, described further in Section 1.1.7.

1.1.7 Invasive Species Management

Several invasive plant species present in the project area, and both reduce available habitat for prairie and aquatic species and are potential fish passage barriers. Scot's broom (uplands) and reed canary grass (channel and wetlands) are prevalent across the project site and threatening to each ecosystem. Scot's broom replaces native vegetation, creating homogenous fields while not providing suitable forage material for sensitive butterfly or bird species. Reed canary grass similarly creates homogenous plant communities and reduces woody plant growth and encroaches on aquatic habitat creating fish barriers as it traps sediment in the center of the channel, reducing depth and open water during baseflow conditions.

Invasive species are being actively managed in several areas by JBLM through mowing, controlled burns, and herbicide treatments. Additional treatment through concentrated mowing, mulching, and riparian planting of native vegetation along the streambanks will reduce plant vigor, reduce seed production, and increase the amount of shade, reducing the production and spread of reed canary grass.

1.2 Project 2 – Muck Creek Reach 5/South Creek Reach 7 Confluence (R5-P1 and R7-P1)

The Muck Creek Reach 5/South Creek Reach 7 confluence conceptual design extends approximately 3,000 feet and 4,000 feet up the North Fork and South Creek channels, respectively (all on JBLM lands). Overall, the conceptual design for the project features 12 BDAs, LWD (total number to be determined during detailed design phase), 2 ford crossing low-flow channels, and approximately 45 acres of riparian supplemental planting and invasive species management.

1.2.1 Beaver Dam Analogs (BDAs)

Work on Muck Creek will include a mix of post-assisted and post-less BDAs for water storage and habitat diversity, similar to that described in Section 1.1.1. South Creek experiences more flashy flows, requiring stronger features to withstand higher flows. Therefore, the post-less BDAs may not be robust enough to withstand higher flows. Final BDA placement will take into consideration the existing wetlands and ponded areas, as well as existing upstream infrastructure to minimize risk of flooding and enhancing existing wetted areas. Near the confluence, a large post-assisted BDA that spans both channels would engage the floodplain and increase wetland habitat.

1.2.2 Large Woody Debris (LWD)

Similar to Muck Creek mainstem, LWD placement will be used to enhance the development of aquatic habitat features. Due to the flashiness that is experienced in South Creek, all LWD will be anchored using soil anchors to prevent mobilization. Some mobile pieces may be placed in the North Fork, but no mobile wood will be placed in areas immediately upstream of infrastructure (e.g., ford crossings, roads, bridges, culverts).

Based on the 25th percentile recommendations in Fox and Bolton (2007) and a 40-foot bankfull width, this project site should include approximately 254 total pieces of large wood and a total volume of 333 CY, with 10 key pieces. By incorporating 12 BDAs into the design, 10 of which are post-assisted and 2 that are post-less, the BDAs add approximately 273 pieces of wood.

1.2.3 Ford Crossing Low-Flow Channels

This project reach has two ford crossings and the smooth concrete bottom along the channel reduces passability for fish during low-flow conditions. The proposed conceptual low-flow channel is the same as described in Section 1.1.4.

1.2.4 Riparian Planting

The riparian zone in the project area is fairly well developed, so the focus will be on supplementing areas with narrow riparian or invasive species. Riparian vegetation plantings will consist of a mix of willow stakes and upland and wetland shrubs suitable in the prairie situation, installed along the banks.

1.2.5 Invasive Species Management

Invasive species presence in the project area is dominated by reed canary grass. Reed canary grass will be partially managed through mowing, herbicide treatment, and solarizing, then planting rapidly growing native woody species that may include willows and other shrubs to help reduce reed canary grass vigor and growth.

1.3 Project 3 - Johnson Creek/Watkins Springs (R11-P1)

Johnson Creek is fed by Watkins Springs above its confluence with Muck Creek. Currently, the stream is channelized with berms along both banks. The springs have formed a large wetland surrounded by forested vegetation. The conceptual design features removing the existing berms to reconnect the channel to floodplain and wetland habitat. Excavated material from the berms will be used to create hummock islands in the wetland areas for planting native vegetation to provide important temperature control, invasive species management, and creation of aquatic and terrestrial habitat for fish and wildlife. The design includes 6 BDAs, LWD (total amount to be determined during detailed design), and 9.9 acres of riparian planting along approximately 2,150 feet of channel.

1.3.1 Berm Breaches/Excavation

The berms extend approximately 500 feet along the left and right banks of the creek. The berms will be excavated to the natural bank elevation to allow for wetland and floodplain connectivity, and generating material that will be used for hummock island creation. The enhanced connectivity will allow seasonal fish access and water exchange with the approximately 20 acres of wetland, improving baseflow and providing rearing habitat.

1.3.2 Hummock Islands

The material excavated from the berms will be used to create hummock islands that are elevated above the surrounding surface in wetland and floodplain. The number and location of hummocks will be determined during detailed design. The hummocks will be planted with native woody vegetation. The diversity in topography will form complex habitat features and morphology.

1.3.3 Beaver Dam Analogs (BDAs)

Although the removal of the berms will allow for wetland and floodplain connectivity, the stream has become channelized after being forced into one alignment by the berm's presence. Installation of BDAs will further reconnect the channel with wetlands and floodplain, as well as adding LWD to the ecosystem. These would be similar to the description in Section 1.1.1.

1.3.4 Large Woody Debris (LWD)

LWD will be placed between BDAs as single logs or small clusters to engage flows and create complex habitat features. The conceptual design proposes the placement of both anchored and loose (mobile) wood pieces for placement. Using the 25th percentile in the guidance from Fox and Bolton (2007), the 2,150 feet of channel with an estimated bankfull width of 35 feet should incorporate 170 pieces of LWD, of which 7 should be key pieces, with a total wood volume of 222 CY. The installation of 3 post-assisted and 3 post-less BDAs will add approximately 79 pieces of large wood.

1.3.5 Forest Thinning

To reduce evapotranspiration and provide wood for restoration, the area south of the channel will be thinned by removing mature trees along the edges or fringe of the forest.

1.3.6 Riparian Planting

Areas along the banks and in the hummocks will be planted with appropriate native riparian and wetland species for the prairie context.

1.3.7 *Invasive Species Management*

Invasive species presence in the project area is dominated by reed canary grass. Reed canary grass will be partially managed through mowing, herbicide treatment, and solarizing, then planting rapidly growing native woody species that may include willows and other shrubs to help reduce reed canary grass vigor and growth.

1.4 Project 4 - Lacamas Creek/Muck Lake (R12-P1 and R3-P4)

A previous project excavated a channel along the south side of Muck Lake to provide fish passage; however, reed canary grass continues to dominate the area, including the channel of Lacamas Creek, creating low flow barriers to fish passage. To supplement and enhance previous efforts, the conceptual design includes excavating the existing channel (as needed) and creating a secondary channel through Muck Lake, as well as excavating as needed for the Lacamas Creek channel. Excavated material will be used to create hummock islands, and LWD (total number to be determined during detailed design) will be added to the reach to increase habitat diversity along with constructing 4 BDAs and installing native vegetation along 6 acres of stream banks and hummocks. It is also recommended that a long-term management plan be developed for Muck Lake that would include invasive species management and plantings over the long-term to enhance fish and wildlife habitat.

1.4.1 *Channel Width and Side Channel Excavation*

Approximately 1,000 feet of the Lacamas Creek channel will be excavated to increase the width through the wetland. Additionally, a side channel approximately 1,000 feet long will be excavated through Muck Lake to enhance flows and access. The excavation of the main Lacamas channel and Muck Creek channel will create material that will be used to create the hummock islands, described in Section 1.4.2.

1.4.2 *Hummock Islands*

The excavated material will be used to create hummock islands that are elevated above the surrounding surface in the wetland and floodplain. The total number and placement of the hummocks will be determined during detailed design. The hummocks will be planted with native woody wetland and riparian vegetation.

1.4.3 *Beaver Dam Analogs (BDAs)*

Installation of BDAs in Lacamas Creek upstream of the confluence with Muck Creek and in a couple places through Muck Lake will maintain open water and provide habitat diversity. Both post-assisted BDA and post-less BDAs will be used to mimic the form and function of beaver dams as described in Section 1.1.1.

1.4.4 Large Woody Debris (LWD)

The conceptual design proposes the placement of both anchored and loose (mobile) wood pieces. Using the same 25th percentile guidance from Fox and Bolton (2007) as described above, the amount of wood in Lacamas is estimated based on an approximately 30 foot wide channel. Along the 2,150-foot of restored channel, the design should incorporate 170 pieces of LWD, of which 7 are key pieces, for a total wood volume of 222 CY. The installation of 2 post-assisted and 2 post-less BDAs would add 46 pieces of large wood.

1.4.5 Riparian Planting

The banks of Lacamas Creek, Muck Lake and the hummocks will be planted with a mix of willow stakes and riparian and upland tree and shrub species.

1.4.6 Invasive Species Management

Invasive species presence in the project area is dominated by reed canary grass. Reed canary grass will be partially managed through mowing, herbicide treatment, and solarizing, then planting rapidly growing native woody species that may include willows and other shrubs to help reduce reed canary grass vigor and growth.

1.5 Project 5 – Reach 13 Lacamas Wetland Restoration (R13-P1)

A large wetland was historically mapped in Reach 13 of Lacamas Creek, and peat/hydric soils are still present. The creek has been deepened and channelized through the wetland that is now used for pasture and hay. The channelized creek serves to drain water from the remnant wetland and also speeds runoff downstream during high flows. Historically, this large wetland would have stored water likely for many months of the year and contributed to downstream flows throughout the year.

A wide range of actions could be undertaken at this site from a Stage 0 restoration that would fill the existing channel and ditches and excavate shallow braided channels to restore a highly complex wetland system to a design that could maintain existing land uses but promote a seasonal wetland and riparian zone adjacent to the creek to allow seasonal flooding of portions of the wetland. The conceptual design shows two options to return the entire floodplain back to wetland or to include BDAs, a narrower riparian planting zone, and stream crossings to allow cattle to cross and use upland pasture during winter.

2 References

Fox, M., and S. Bolton, 2007. "A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State." *North American Journal of Fisheries Management* 27(1)342–359.

**Nisqually River Foundation - Muck Creek Reach 4 Preliminary Design
Opinion of Probable Costs**

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 321,400
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 311,400	\$ 311,400
1.02	Construction Surveys	LS	1	\$ 10,000	\$ 10,000
2.00	Site Preparation and TESC Measures				\$ 40,000
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 7,500	\$ 15,000
2.02	TESC and Site Security Measures	LS	1	\$ 25,000	\$ 25,000
3.00	LWM (Assumes On-site Generation from Thinning)				\$ 348,600
3.01	Rootwad Log, 2' dia. 30' L Log, 6' dia. 4' L RW	EA	64	\$ 600	\$ 38,400
3.02	Rootwad Log, 2' dia. 20' L Log, 6' dia. 4' L RW	EA	100	\$ 600	\$ 60,000
3.03	Log Pole, 1.5' dia., 15' L	EA	400	\$ 220	\$ 88,000
3.04	Log Pole, 1.5' dia., 10' L	EA	650	\$ 220	\$ 143,000
3.05	LWD Anchoring (Chain/Cable, Staples, Soil Anchors)	EA	64	\$ 300	\$ 19,200
4.00	Beaver Dam Analogs				\$ 91,620
4.01	Post, 3-inch Diameter	EA	450	\$ 130	\$ 58,500
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	960	\$ 12	\$ 11,520
4.03	Slash and small woody debris (per postless BDA)	CY	160	\$ 60	\$ 9,600
4.04	Stream Cobbles/Boulders	TON	120	\$ 100	\$ 12,000
5.00	Riparian Buffer Management				\$ 2,500,000
5.01	Riparian Plantings	AC	100	\$ 10,000	\$ 1,000,000
5.02	Invasive Species Management (3 years)	AC	100	\$ 15,000	\$ 1,500,000
6.00	Ford Crossing Low Flow Channels				\$ 18,000
6.01	Saw Cut and Dispose Concrete, Reinforced Concrete Low-Flow Channel	EA	9	\$ 2,000	\$ 18,000
7.00	Winter Channel Reconnection				\$ 100,900
7.01	Earthwork, excavation, bulk	CY	3600	\$ 25	\$ 90,000
7.02	Lateral Log Weir	LS	1	\$ 7,500	\$ 7,500
7.02	Rock Ramp (Streambed Sediment)	TON	20	\$ 70	\$ 1,400
7.03	Rock Ramp (Stream Cobbles/Boulders)	TON	20	\$ 100	\$ 2,000
8.00	Water Control and Fish Exclusion				\$ 10,000
8.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 10,000	\$ 10,000
9.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 5,000
9.01	Site Restoration and Revegetation	AC	1	\$ 5,000	\$ 5,000
Construction Subtotal					\$ 3,435,520
Contingency (30%)					\$ 1,030,656
Construction Subtotal w/ Contingency					\$ 4,466,176
Pierce County Sales Tax (8.1%)					\$ 361,760
Total Construction Cost					\$ 4,828,000
Engineering, Permitting, and Administration (15%)					\$ 724,200
Total Project Cost					\$ 5,552,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

**Nisqually River Foundation - Muck Creek Reach 5/South Creek Reach 7 Conceptual Design
Opinion of Probable Costs**

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 163,900
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 160,900	\$ 160,900
1.02	Construction Surveys	LS	1	\$ 3,000	\$ 3,000
2.00	Site Preparation and TESC Measures				\$ 9,000
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 2,000	\$ 4,000
2.02	TESC and Site Security Measures	LS	1	\$ 5,000	\$ 5,000
3.00	LWM (Assumes On-site Generation from Thinning)				\$ 32,000
3.01	Rootwad Log, 2' dia. 30' L Log, 6' dia. 4' L RW	EA	20	\$ 600	\$ 12,000
3.02	Rootwad Log, 2' dia. 20' L Log, 6' dia. 4' L RW	EA	5	\$ 600	\$ 3,000
3.03	Log Pole, 1.5' dia., 15' L	EA	20	\$ 220	\$ 4,400
3.04	Log Pole, 1.5' dia., 10' L	EA	30	\$ 220	\$ 6,600
3.05	LWD Anchoring (Chain/Cable, Staples, Soil Anchors)	EA	20	\$ 300	\$ 6,000
4.00	Beaver Dam Analogs				\$ 56,460
4.01	Post, 3-inch Diameter	EA	270	\$ 130	\$ 35,100
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	580	\$ 12	\$ 6,960
4.03	Slash and small woody debris (per postless BDA)	CY	95	\$ 100	\$ 9,500
4.04	Stream Cobbles/Boulders	TON	70	\$ 70	\$ 4,900
5.00	Riparian Buffer Management				\$ 1,500,000
5.01	Riparian Plantings	AC	60	\$ 10,000	\$ 600,000
5.02	Invasive Species Management	AC	60	\$ 15,000	\$ 900,000
6.00	Ford Crossing Low Flow Channels				\$ 4,000
6.01	Saw Cut and Dispose Concrete, Reinforced Concrete Low-Flow Channel	EA	2	\$ 2,000	\$ 4,000
8.00	Water Control and Fish Exclusion				\$ 5,000
8.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 5,000	\$ 5,000
9.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 2,500
9.01	Site Restoration and Revegetation	AC	0.5	\$ 5,000	\$ 2,500
	Construction Subtotal				\$ 1,772,860
	Contingency (30%)				\$ 531,858
	Construction Subtotal w/ Contingency				\$ 2,304,718
	Pierce County Sales Tax (8.1%)				\$ 186,682
	Total Construction Cost				\$ 2,491,000
	Engineering, Permitting, and Administration (15%)				\$ 373,650
	Total Project Cost				\$ 2,865,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

Nisqually River Foundation - Johnson Creek Conceptual Design Opinion of Probable Costs

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 39,900
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 37,900	\$ 37,900
1.02	Construction Surveys	LS	1	\$ 2,000	\$ 2,000
2.00	Site Preparation and TESC Measures				\$ 4,500
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 1,000	\$ 2,000
2.02	TESC and Site Security Measures	LS	1	\$ 2,500	\$ 2,500
3.00	LWM (Assumes On-site Generation from Thinning)				\$ 25,700
3.01	Rootwad Log, 2' dia. 30' L Log, 6' dia. 4' L RW	EA	7	\$ 600	\$ 4,200
3.02	Rootwad Log, 2' dia. 20' L Log, 6' dia. 4' L RW	EA	3	\$ 600	\$ 1,800
3.03	Log Pole, 1.5' dia., 15' L	EA	30	\$ 220	\$ 6,600
3.04	Log Pole, 1.5' dia., 10' L	EA	50	\$ 220	\$ 11,000
3.05	LWD Anchoring (Chain/Cable, Staples, Soil Anchors)	EA	7	\$ 300	\$ 2,100
4.00	Beaver Dam Analogs				\$ 16,240
4.01	Post, 3-inch Diameter	EA	80	\$ 130	\$ 10,400
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	170	\$ 12	\$ 2,040
4.03	Slash and small woody debris (per postless BDA)	CY	30	\$ 60	\$ 1,800
4.04	Stream Cobbles/Boulders	TON	20	\$ 100	\$ 2,000
5.00	Channel Excavation				\$ 63,000
5.01	Excavate to Remove Existing Berms Along Channel	CY	1,800	\$ 25	\$ 45,000
6.03	Hummock Islands	CY	1,800	\$ 10	\$ 18,000
6.00	Riparian Buffer Management				\$ 300,000
6.01	Riparian Plantings	AC	12	\$ 10,000	\$ 120,000
6.02	Invasive Species Management	AC	12	\$ 15,000	\$ 180,000
7.00	Water Control and Fish Exclusion				\$ 30,000
7.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 30,000	\$ 30,000
8.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 2,500
8.01	Site Restoration and Revegetation	AC	0.5	\$ 5,000	\$ 2,500
Construction Subtotal					\$ 418,840
Contingency (30%)					\$ 125,652
Construction Subtotal w/ Contingency					\$ 544,492
Pierce County Sales Tax (8.1%)					\$ 44,104
Total Construction Cost					\$ 589,000
Engineering, Permitting, and Administration (15%)					\$ 88,350
Total Project Cost					\$ 677,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

Nisqually River Foundation - Lacamas Creek Conceptual Design Opinion of Probable Costs

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 25,000
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 23,000	\$ 23,000
1.02	Construction Surveys	LS	1	\$ 2,000	\$ 2,000
2.00	Site Preparation and TESC Measures				\$ 4,500
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 1,000	\$ 2,000
2.02	TESC and Site Security Measures	LS	1	\$ 2,500	\$ 2,500
3.00	LWM (Assumes On-site Generation from Thinning)				\$ 31,700
3.01	Rootwad Log, 1.5' dia. 30' L Log, 4.5' dia. 3' L RW	EA	7	\$ 600	\$ 4,200
3.02	Rootwad Log, 1.5' dia. 15' L Log, 4.5' dia. 3' L RW	EA	2	\$ 600	\$ 1,200
3.03	Log Pole, 1.5' dia., 15' L	EA	40	\$ 220	\$ 8,800
3.04	Log Pole, 1.5' dia., 10' L	EA	70	\$ 220	\$ 15,400
3.05	LWD Anchoring (Chain/Cable, Staples, Manta Ray Anchors)	EA	7	\$ 300	\$ 2,100
4.00	Beaver Dam Analogs				\$ 10,520
4.01	Post, 3-inch Diameter	EA	50	\$ 130	\$ 6,500
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	110	\$ 12	\$ 1,320
4.03	Slash and small woody debris (per postless BDA)	CY	20	\$ 60	\$ 1,200
4.04	Stream Cobbles/Boulders	TON	15	\$ 100	\$ 1,500
5.00	Channel Excavation				\$ 51,075
5.01	Excavate to Widen Existing Channel	CY	300	\$ 35	\$ 10,500
5.02	Excavate New Side Channel Habitat	CY	450	\$ 35	\$ 15,750
6.03	Hummock Islands	CY	750	\$ 10	\$ 7,500
5.03	Install and Remove Temporary Gravel Access Pads	TON	385	\$ 45	\$ 17,325
6.00	Riparian Buffer Management				\$ 150,000
6.01	Riparian Plantings	AC	6	\$ 10,000	\$ 60,000
6.02	Invasive Species Management	AC	6	\$ 15,000	\$ 90,000
8.00	Water Control and Fish Exclusion				\$ 30,000
8.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 30,000	\$ 30,000
9.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 2,500
9.01	Site Restoration and Revegetation	AC	0.5	\$ 5,000	\$ 2,500
Construction Subtotal					\$ 254,220
Contingency (30%)					\$ 76,266
Construction Subtotal w/ Contingency					\$ 330,486
Pierce County Sales Tax (8.1%)					\$ 26,769
Total Construction Cost					\$ 357,000
Engineering, Permitting, and Administration (15%)					\$ 53,550
Total Project Cost					\$ 411,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

**Nisqually River Foundation - Muck Lake/Muck Creek Upstream
Opinion of Probable Costs**

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 37,200
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 35,200	\$ 35,200
1.02	Construction Surveys	LS	1	\$ 2,000	\$ 2,000
2.00	Site Preparation and TESC Measures				\$ 5,500
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 1,000	\$ 2,000
2.02	TESC and Site Security Measures	LS	1	\$ 3,500	\$ 3,500
3.00	LWM (Assumes On-site Generation from Thinning)				\$ 48,400
3.01	Rootwad Log, 1.5' dia. 30' L Log, 4.5' dia. 3' L RW	EA	12	\$ 600	\$ 7,200
3.02	Rootwad Log, 1.5' dia. 15' L Log, 4.5' dia. 3' L RW	EA	4	\$ 600	\$ 2,400
3.03	Log Pole, 1.5' dia., 15' L	EA	60	\$ 220	\$ 13,200
3.04	Log Pole, 1.5' dia., 10' L	EA	100	\$ 220	\$ 22,000
3.05	LWD Anchoring (Chain/Cable, Staples, Manta Ray Anchors)	EA	12	\$ 300	\$ 3,600
4.00	Beaver Dam Analogs				\$ 10,520
4.01	Post, 3-inch Diameter	EA	50	\$ 130	\$ 6,500
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	110	\$ 12	\$ 1,320
4.03	Slash and small woody debris (per postless BDA)	CY	20	\$ 60	\$ 1,200
4.04	Stream Cobbles/Boulders	TON	15	\$ 100	\$ 1,500
5.00	Channel Excavation				\$ 51,075
5.01	Excavate to Widen Existing Channel	CY	300	\$ 35	\$ 10,500
5.02	Excavate New Side Channel Habitat	CY	450	\$ 35	\$ 15,750
6.03	Hummock Islands	CY	750	\$ 10	\$ 7,500
5.03	Install and Remove Temporary Gravel Access Pads	TON	385	\$ 45	\$ 17,325
6.00	Riparian Buffer Management				\$ 250,000
6.01	Riparian Plantings	AC	10	\$ 10,000	\$ 100,000
6.02	Invasive Species Management	AC	10	\$ 15,000	\$ 150,000
8.00	Water Control and Fish Exclusion				\$ 35,000
8.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 35,000	\$ 35,000
9.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 2,500
9.01	Site Restoration and Revegetation	AC	0.5	\$ 5,000	\$ 2,500
Construction Subtotal					\$ 389,120
Contingency (30%)					\$ 116,736
Construction Subtotal w/ Contingency					\$ 505,856
Pierce County Sales Tax (8.1%)					\$ 40,974
Total Construction Cost					\$ 547,000
Engineering, Permitting, and Administration (15%)					\$ 82,050
Total Project Cost					\$ 629,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

Nisqually River Foundation - Lacamas Creek Stream and Riparian Conceptual Design
Opinion of Probable Costs

J. Sexton
 29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 86,300
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 86,300	\$ 86,300
1.02	Construction Surveys	LS	1	\$ 5,000	\$ 5,000
2.00	Site Preparation and TESC Measures				\$ 25,000
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 5,000	\$ 10,000
2.02	TESC and Site Security Measures	LS	1	\$ 15,000	\$ 15,000
3.00	LWM				\$ 41,000
3.01	Rootwad Log, 1.5' dia. 30' L Log, 4.5' dia. 3' L RW	EA	25	\$ 600	\$ 15,000
3.02	Rootwad Log, 1.5' dia. 15' L Log, 4.5' dia. 3' L RW	EA	7	\$ 600	\$ 4,200
3.03	Log Pole, 1.5' dia., 15' L	EA	25	\$ 220	\$ 5,500
3.04	Log Pole, 1.5' dia., 10' L	EA	40	\$ 220	\$ 8,800
3.05	LWD Anchoring (Chain/Cable, Staples, Manta Ray Anchors)	EA	25	\$ 300	\$ 7,500
4.00	Beaver Dam Analogs				\$ 66,700
4.01	Post, 3-inch Diameter	EA	330	\$ 130	\$ 42,900
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	700	\$ 12	\$ 8,400
4.03	Slash and small woody debris (per postless BDA)	CY	115	\$ 60	\$ 6,900
4.04	Stream Cobbles/Boulders	TON	85	\$ 100	\$ 8,500
5.00	Riparian and Wetland Plantings				\$ 675,000
5.01	Riparian Plantings	AC	15	\$ 10,000	\$ 150,000
5.02	Silvopasture Plantings	AC	300	\$ 1,000	\$ 300,000
5.02	Invasive Species Management	AC	15	\$ 15,000	\$ 225,000
6.00	Elevated Access Roads				\$ 517,000
6.01	Earthwork - Elevated Access Roads	CY	11,000	\$ 35	\$ 385,000
6.02	Bridge Crossings	EA	2	\$ 50,000	\$ 100,000
6.03	Culverts for Hydraulic Connectivity	EA	4	\$ 8,000	\$ 32,000
8.00	Water Control and Fish Exclusion				\$ 50,000
8.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 50,000	\$ 50,000
9.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 5,000
9.01	Site Restoration and Revegetation	AC	1	\$ 5,000	\$ 5,000
	Construction Subtotal				\$ 1,466,000
	Contingency (30%)				\$ 439,800
	Construction Subtotal w/ Contingency				\$ 1,905,800
	Pierce County Sales Tax (8.1%)				\$ 154,370
	Total Construction Cost				\$ 2,060,000
	Engineering, Permitting, and Administration (15%)				\$ 309,000
	Total Project Cost				\$ 2,369,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad

**Nisqually River Foundation - Lacamas Creek Historical Wetland Restoration
Opinion of Probable Costs**

J. Sexton
29-Mar-24

#.	Work Item	Unit	Quantity	Unit Cost	Line Cost
1.00	General Requirements				\$ 266,900
1.01	Mobilization, Demobilization, and Restoration (10%)	LS	1	\$ 266,900	\$ 266,900
1.02	Construction Surveys	LS	1	\$ 5,000	\$ 5,000
2.00	Site Preparation and TESC Measures				\$ 25,000
2.01	Clearing and Disposal of Cleared Materials	AC	2	\$ 5,000	\$ 10,000
2.02	TESC and Site Security Measures	LS	1	\$ 15,000	\$ 15,000
3.00	LWM				\$ 58,400
3.01	Rootwad Log, 1.5' dia. 30' L Log, 4.5' dia. 3' L RW	EA	35	\$ 600	\$ 21,000
3.02	Rootwad Log, 1.5' dia. 15' L Log, 4.5' dia. 3' L RW	EA	10	\$ 600	\$ 6,000
3.03	Log Pole, 1.5' dia., 15' L	EA	35	\$ 220	\$ 7,700
3.04	Log Pole, 1.5' dia., 10' L	EA	60	\$ 220	\$ 13,200
3.05	LWD Anchoring (Chain/Cable, Staples, Manta Ray Anchors)	EA	35	\$ 300	\$ 10,500
4.00	Beaver Dam Analogs				\$ 100,200
4.01	Post, 3-inch Diameter	EA	500	\$ 130	\$ 65,000
4.02	Willow Cuttings, 1.5" dia., 15' L (For weaving, per BDA)	EA	1,000	\$ 12	\$ 12,000
4.03	Slash and small woody debris (per postless BDA)	CY	170	\$ 60	\$ 10,200
4.04	Stream Cobbles/Boulders	TON	130	\$ 100	\$ 13,000
5.00	Channel Excavation				\$ 360,000
5.01	Excavate Shallow Channels	CY	15,000	\$ 12	\$ 180,000
5.02	Fill Existing Channel	CY	15,000	\$ 12	\$ 180,000
6.00	Riparian and Wetland Plantings				\$ 2,050,000
6.01	Riparian and Wetland Plantings	AC	15	\$ 10,000	\$ 150,000
6.02	Wetland Planting	AC	335	\$ 5,000	\$ 1,675,000
6.03	Invasive Species Management	AC	15	\$ 15,000	\$ 225,000
7.00	Water Control and Fish Exclusion				\$ 50,000
7.01	Water Control and Fish Exclusion (labor & equipment)	LS	1	\$ 50,000	\$ 50,000
8.00	Site Restoration and Revegetation (Access and Staging Areas)				\$ 25,000
8.01	Site Restoration	AC	5	\$ 5,000	\$ 25,000
	Construction Subtotal				\$ 2,575,500
	Contingency (30%)				\$ 772,650
	Construction Subtotal w/ Contingency				\$ 3,348,150
	Pierce County Sales Tax (8.1%)				\$ 271,200
	Total Construction Cost				\$ 3,619,000
	Engineering, Permitting, and Administration (15%)				\$ 542,850
	Total Project Cost				\$ 4,162,000

General Notes and abbreviations:

Totals are rounded to the nearest \$1,000

Mobilization is assumed to be 10% of the construction subtotal.

The extent of site preparation and TESC Measures along with requirements for care of water work will be defined by the permits.

Costs are in 2024 dollars.

AC - Acre, CY - Cubic Yard, Dia. - Diameter, EA - Each, LS - Lump Sum

LWM - Large Woody Material, Cap. - Capacity, RW - Rootwad