Wolf Creek Reach Assessment & Restoration Strategy
Final Report

DECEMBER 2020

Wolf Creek at Reach 4, Winthrop, WA (October, 2019)

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1. Introduction

1.1 PROJECT OVERVIEW

The Wolf Creek Reach Assessment and Restoration Strategy evaluates existing aquatic habitat and watershed process conditions along the lower 4.53 river miles of Wolf Creek. Wolf Creek is a tributary of the Methow River, located within the eastern foothills of the Cascade Mountains in central Washington along the western border of the Columbia Plateau (Figure 1). Wolf Creek flows east-southeast through the foothills and joins the Methow River approximately 54.2 river miles (RM) upstream of where the Methow meets the Columbia River near the town of Pateros, Washington.

This reach assessment provides a technical foundation for understanding existing conditions of lower Wolf Creek and for identifying appropriate restoration strategies to improve aquatic habitat conditions. Conditions are assessed at both the assessment area scale and reach scale. The aim of this assessment is to identify restoration actions that address factors limiting the productivity of native salmonids, and to ensure that the identified actions fit within the appropriate geomorphic context of the river system. An emphasis is placed on understanding the underlying biological and physical processes at work and how human impacts have affected these processes and the habitat they support. Restoration measures focus on recovering, to the extent possible, these impaired processes. Additionally, areas of minimal human impact are identified to promote conservation of healthy fluvial process. Although the proposed restoration and conservation measures are expected to benefit a large suite of native aquatic and terrestrial species, there is a particular emphasis on recovery of Endangered Species Act (ESA) listed Upper-Columbia Summer Steelhead (*Oncorhynchus mykiss*), Upper-Columbia Spring Chinook (*Oncorhynchus tshawytscha*), and Columbia River bull trout (*Salvelinus confluentus*).

The report includes the following components:

- Study area characterization: Summary evaluation of valley and basin-scale factors influencing aquatic habitat and stream geomorphic processes.
- Reach-scale characterization: Inventory and analysis of habitat and geomorphic conditions at the reach and sub-reach scales.
- Restoration strategy: A comparison of “existing” conditions to “target” conditions at the reach-scale and identification of recommended restoration treatments that address habitat and ecological process limitations within the geomorphic context of the reach.
- Stream habitat assessment: Aquatic habitat inventory at the reach-scale.
- Reach-Based Ecosystem Indicators (REI) analysis – Comparison of habitat conditions to established functional thresholds.
- Specific project opportunities: A list and maps of specific potential project opportunities that would help to achieve the reach-scale restoration strategies.
- Hydraulic analysis: Stream power comparison across the study area reaches and preliminary 2-D hydraulic model results for Reach 1.

This framework allows for the identification of restoration activities at discrete locations while considering broader scale physical, ecological, and anthropologic factors that influence the assessment study area.

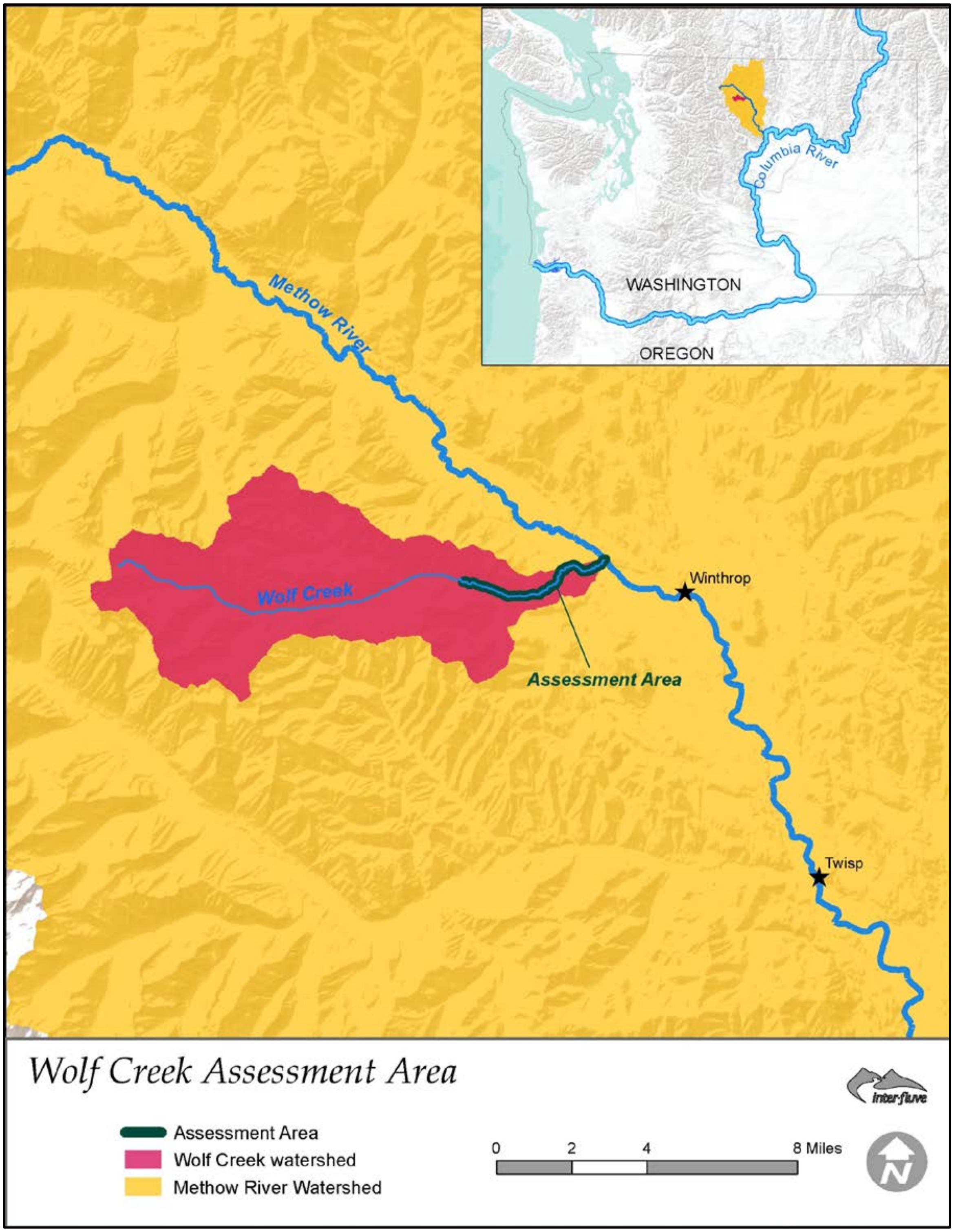


Figure 1. Wolf Creek assessment area locator maps. Basemaps: ESRI world terrain map.

1.2 BACKGROUND

This project was completed on behalf of the Yakama Nation as part of their efforts to improve native aquatic fisheries within the Columbia River Basin through their Upper Columbia Habitat Restoration Project (UCHRP). The UCHRP works to achieve the objectives of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (USFWS, 2007), and the associated updated Biological Strategy (UCRTT 2017).

Conducting the assessment involved collecting field data of the area and combining it with existing available information on Wolf Creek and the Methow River watershed. Existing available information utilized in this assessment includes, but is not limited to, 2005 habitat assessment (USFS 2005), Yakama Nation fish use report on Wolf Creek Ponds (Eckmann, 2018), Wolf Creek Ponds Restoration Conceptual Designs Report (Aspect Consulting, 2018), Hydrogeology of the Unconsolidated Sediments (Konrad et al., 2005), Biological Strategy for the Upper Columbia Region (UCRTT 2017), Methow Subbasin Geomorphic Assessments (USBR 2008; 2011), available digital and paper geologic and soil maps, and County property tax lot data. This report does not attempt to re-create the work accomplished in existing documents, but summarizes that material and adds detail where appropriate. New data collection and analysis performed as part of this effort include a geomorphic assessment of the lower 4.53 miles of the mainstem channel, side channels, and floodplain surfaces, as well as an aquatic habitat inventory, characterization of landforms and human impacts, and identification of habitat restoration opportunities.

1.3 PURPOSE

The purpose of this assessment is to document and evaluate hydrologic processes, geomorphic processes, and aquatic habitat conditions in lower Wolf Creek (RM 0 - 4.53), and to present a comprehensive reach-based restoration strategy to address limiting factors to aquatic habitat. Evaluations used in this assessment include historical characterization, geomorphic assessment, preliminary hydraulic assessment, and an aquatic habitat inventory.

Assessment goals:

- Provide a comprehensive inventory and assessment of geomorphic and aquatic habitat conditions and trends to provide the technical foundation for development of an effective stream habitat restoration strategy.
- Develop a restoration strategy that identifies and prioritizes restoration actions that protect and improve aquatic habitat and supports ecological processes, with an emphasis on culturally significant riverine species.
- Provide a resource for coordinating efforts with local landowners, resource managers, and other stakeholders in order to establish collaborative efforts that contribute to the success of restoration strategies.

1.4 SALMONID USE AND STATUS

Wolf Creek currently supports anadromous runs of Upper Columbia River (UCR) summer steelhead trout, UCR spring Chinook salmon, and resident and fluvial UCR bull trout (NPCC, 2004; NPCC, 2002; UCRTT, 2017; USFS, 2005). UCR spring Chinook are classified as endangered (listed in 1999); UCR summer steelhead are classified as threatened (most recently classified in 2009); and UCR bull trout are classified as threatened (listed in 1999). Coho salmon were once present in the watershed but the wild populations have since been extirpated (Nehlsen et al., 1991). Reintroduction efforts by the Yakama Nation Fisheries program are attempting to increase the population in the watershed.

Within the assessment area of Wolf Creek (RM 0-4.53), the primary focal species for restoration efforts for Yakama Nation include spring Chinook and Coho salmon, steelhead trout, and bull trout. Wolf Creek supports spawning and rearing habitat for Chinook and steelhead (Figure 2). Wolf Creek is considered a stronghold for bull trout within the greater Methow Basin, with foraging, migration, and overwintering (FMO) and rearing habitats within the study reach. Spawning and rearing habitats are also present upstream of the study area. Other resident species in the sub-basin include salmonids such as west-slope cutthroat, rainbow trout, and mountain whitefish. Pacific lamprey is present in the Methow River and therefore may be present at the mouth of Wolf Creek. However, there are limited data to confirm the use of Wolf Creek by adult or juvenile lamprey. A diagram that provides the life stage and usage timing for the focal species is provided in Figure 2.

The revised Biological Strategy for the Upper Columbia Region (UCRTT, 2017) describes habitat conditions and primary ecological concerns within the Upper Columbia Basin, including Wolf Creek and the Middle Methow River. Of primary concern in Wolf Creek, according to the 2017 revised strategy, are:

- Injury or Mortality (Mechanical Injury),
- Riparian Condition (Riparian Condition and LW Recruitment),
- Peripheral and Transitional Habitat (Side Channel and Wetland Connection),
- Channel Structure and Form (Instream Structural Complexity), and
- Water Quantity (Decreased Water Quantity).

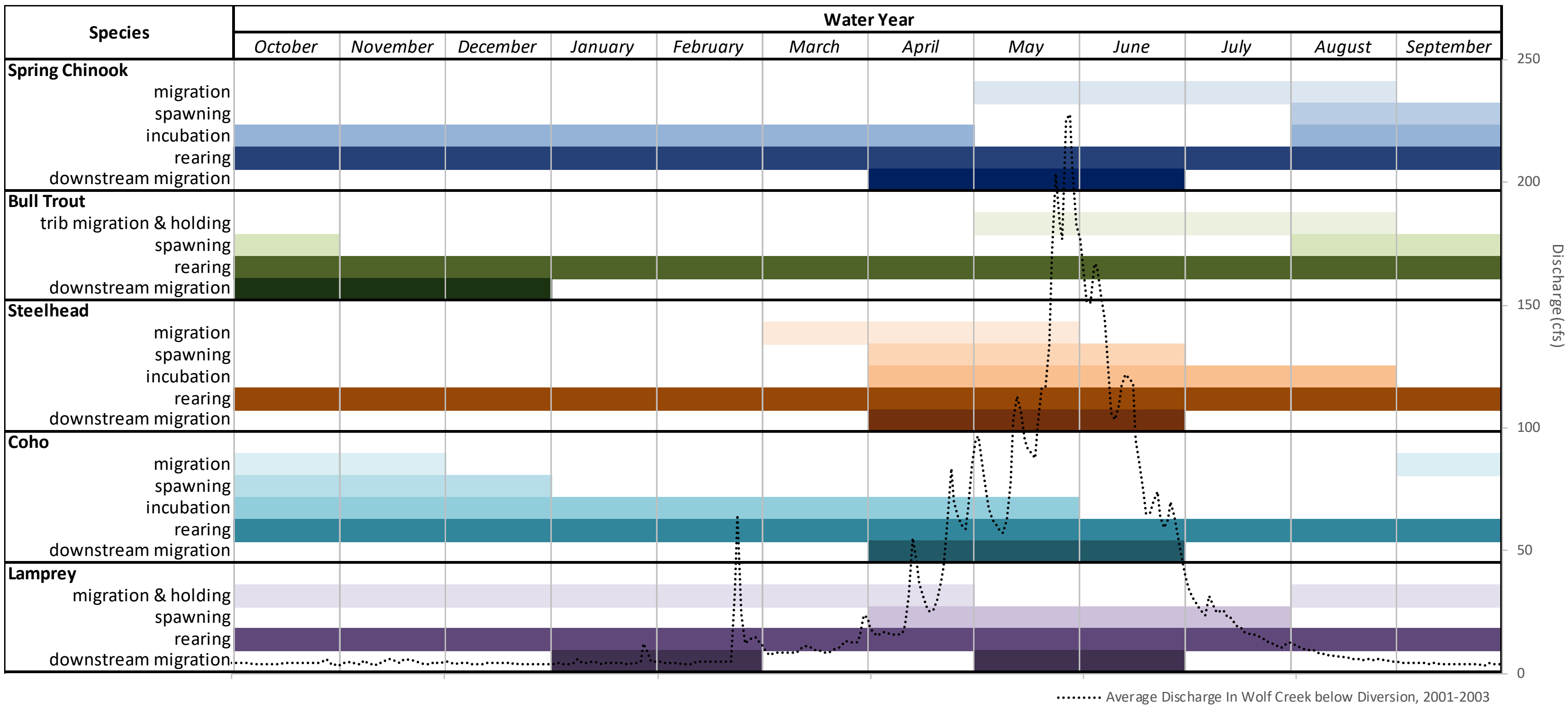


Figure 2. Summary of life history timing of steelhead, bull trout, Chinook, and Pacific lamprey in the Methow River and Wolf Creek, overlaid on an annual hydrograph depicting mean daily discharge from the period 2001 – 2003 in Wolf Creek near the mouth. (Life history references cited in species description sections 1.4.1 – 1.4.5)

In the downstream reach of the assessment area (Reach 1), habitat complexity in the channel is limited, in part due to the historical riparian zone clearing, human modifications that straightened, confined, and simplified the channel, and removal of large woody material from the river. In the upstream reaches of the study area the channel is relatively confined between hillslopes and the channel has higher stream gradients. A series of two private ponds, the Wolf Creek Ponds, are located on river left in Reach 1 near RM 1. The ponds are fed by a water diversion and connected via a culvert. A short, small outlet reconnects the ponds to the Creek. Juvenile chinook and steelhead have been documented in these ponds, but access to the ponds is limited and may present a stranding risk. These ponds have been used by Yakama Nation Fisheries as acclimation ponds for juvenile Coho and spring Chinook salmon rearing as a part of the mid-Columbia Coho reintroduction program (YNFRM 2017).

1.4.1 Steelhead

Summer steelhead (*Oncorhynchus mykiss*) enter fresh water from the Pacific Ocean May through October, and overwinter in the mainstem Columbia River or deep pools and glides in the lower Methow before returning to the upstream portions of the Methow basin in the late winter to spring prior to spawning (UCRTT, 2017). Spawning primarily occurs between March and June (Andonaegui, 2000) in the Methow and its tributaries (Figure 2), peaking in April and May in Wolf Creek (J. Crandall, pers. comm. 2020). In other Upper Columbia River subbasins, egg survival has been shown to be highly sensitive to intra-gravel flow and temperature (Peven et al., 2004) and particularly sensitive to siltation earlier in the incubation period. Fry emerge from the gravels between July and early October, typically between six to ten weeks after spawning (Andonaegui, 2000; UCRTT, 2017).

Age-0 juveniles spend their first year primarily in shallow riffle habitats, feeding on invertebrates and utilizing overhanging riparian vegetation and undercut banks for cover (Moyle, 2002). Age-0 steelhead use slower, shallower water than Chinook salmon, preferring small boulder and large cobble substrate (Hillman & Miller, 1989). Older juveniles prefer faster moving water including deep pools and runs over cobble and boulder substrate. Juveniles typically out-migrate between ages one and three, though the Methow basin produces some of the oldest steelhead smolts. Seven-year-old smolts have been reported (Mullan, et al., 1992) while some may also hold over and display a resident life history form. The majority of smolts migrate downstream from natal areas in May (UCRTT 2017; Andonaegui 2000; USFWS 2007; NMFS 1997) (Figure 2).

Steelhead are present in lower Wolf Creek (Figure 3). Snorkel surveys by the USFS in the lower six miles of Wolf Creek, encompassing the assessment area, found that a majority of the fish sampled (approximately 93%) were rainbow trout/steelhead. High-quality spawning habitat for steelhead has been documented in the lower 4 miles of Wolf Creek, but the stream has not been consistently surveyed for steelhead redds (UCRTT, 2017; USFS, 2005). During the period 2005 to 2017, only three steelhead redds have been recorded in Reach 1 of Wolf Creek, equating to approximately 2.2 redds/mile. No steelhead redds have been recorded in the other reaches of the study area (Figure 4).

1.4.2 Spring Chinook

Spring Chinook (*O. tshawytscha*) are present in Wolf Creek (Figure 3) and use lower Wolf Creek for spawning (USFS, 2005; UCSRB, 2018). Adult spring Chinook enter the Methow basin from mid-May through July, holding in deep pools under overhead cover until spawning occurs from very late July through September (Andonaegui, 2000). Spawning typically begins when temperatures drop below 16°C (Healy 1991). Fry emerge in the late winter and spring, which coincides with the rising hydrograph (Figure 2). During higher flows, juveniles seek backwater or margin areas with lower velocities, dense cover, and abundant food (Quinn, 2005). Fry are vulnerable in these systems when they emerge, because their swimming ability is poor and flows are high. Near-shore areas with eddies, large woody debris, undercut tree roots, and other cover are very important for post-emergent fry (Healy, 1991b; Hillman & Miller, 1989). Older juveniles utilize deeper pools with resting cover in mainstem habitats more than post-emergent individuals. Spring Chinook typically rear for one year in their natal freshwater habitats before out-migrating to the estuary and ocean as yearlings. Out-migration typically peaks between mid-April and mid-May (Andonaegui, 2000) (Figure 2).

Juvenile Chinook have been found rearing in the mainstem Methow River close to most of the identified Chinook spawning areas, mainstem margins and side channels associated with the rivers, as well as in some of the mouths of smaller tributaries (UCRTT 2017). Small numbers of spring Chinook spawn and rear in lower Wolf Creek. During the period 2003 to 2017, spring Chinook had the highest number of redds per mile in Reach 1, with 20.9 redds/mile. Reaches 2 and 3 had 18.6 and 17.7 redds/mile, respectively during that same period (Figure 4). No redds have been recorded in Reaches 4 or 5. Small numbers of spring Chinook redds (< 5 per year) were observed in lower Wolf Creek during redd surveys conducted by Yakama Nation before 2003 (Yakama Indian Nation Redd Survey Reports, 1987-2002 as reported in USFS, 2005). Spring Chinook salmon juveniles were observed in the lower 2.4 miles of Wolf Creek during snorkel surveys conducted by the USFS in 2005 (UCSRB, 2018; USFS, 2005).

1.4.3 Coho Salmon

Historically, it is likely that the Methow supported considerable runs of wild Coho salmon (*O. kisutch*). However, the indigenous population of Coho salmon were extirpated from the Methow and Upper Columbia basins in the early 1900s (YNFRM, 2017). A Coho reintroduction program has been established by the Yakama Nation in the Mid and Upper Columbia watersheds and a small population of Coho salmon now return to the Methow subbasin. Because the indigenous stock of Coho salmon was extirpated in the upper Columbia River system, Coho returning to the Methow subbasin are not included under the ESA (YNFRM, 2017).

Adult Coho migrate back into the Methow River in early September through late November. Adults spawn in the tributaries between mid-October and late December (YNFRM, 2017). Eggs incubate over the winter and fry typically emerge from the gravels in April and May. As with other salmonid species, Coho egg survival is highly sensitive to intra-gravel flow, siltation, high-flow scour, and dewatering or freezing (Peven, 2003; YNFRM, 2017). Compared to steelhead and Chinook, juvenile

Coho tend to seek off-channel habitats and tributaries with lower velocities and overhanging cover. Most juvenile Coho salmon rear in their natal tributaries for approximately a year before migrating downstream, though a portion may migrate downstream in the fall of their first year, likely seeking overwintering habitat in the larger riverine systems (YNFRM, 2017).

Coho spawn in tributaries to the Methow as well as the Mainstem Methow, Chewuch and Twisp Rivers (YNFRM, 2017). Since 2013, juvenile Coho have been acclimated in the Wolf Creek Ponds in Reach 1 before downstream migration to the ocean (Alford et al., 2017). A small number of adult Coho, and only a single redd, have been observed in Wolf Creek since 1999 during fall surveys (Alford et al., 2017). Additionally, an analysis of Methow basin adult Coho productivity values predicted by EDT indicated a low likelihood of a naturally reproducing population establishing in the Wolf Creek drainage. The primary limiting factors to productivity in the Wolf Creek basin were identified by EDT as habitat diversity, sediment load, and habitat quantity (YNFRM, 2017).

1.4.4 Bull Trout

Bull trout (*Salvelinus confluentus*) exhibit both resident and migratory life-history strategies (Rieman & Mclntyre, 1993). Resident bull trout complete their life cycles in the tributary streams, such as Wolf Creek, in which they spawn and rear. Compared to other salmonids, bull trout have more specific habitat requirements that appear to influence their distribution and abundance. Critical parameters include water temperature, cover, channel form and stability, valley form, spawning and rearing substrates, and migratory corridors (*Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Bull Trout in the Coterminous United States*, 1999).

Bull trout normally reach sexual maturity in 4 to 7 years and can live 12 or more years. Adult Methow bull trout migrate from the Columbia River and mainstem Methow back to the headwaters and tributaries of the Methow in May through June (UCRTT 2017). Spawning begins in headwater streams in late August and continues through mid-October (Goetz 1989; Brown 1994). Most bull trout remain within the tributaries until October-November, when they migrate back to the mainstem Columbia and Methow Rivers (UCRTT 2017) (Figure 2). Preferred spawning habitats are generally low gradient stream reaches, or in areas of loose, clean gravel in higher gradient streams (Fraley & Shepard, 1989), and where water temperatures are between 5 to 9° C (41 to 48° F) in late summer to early fall (Goetz, 1989). Spawning areas are often associated with cold-water springs, groundwater infiltration, and are typically the coldest systems in a given watershed (*Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Bull Trout in the Coterminous United States*, 1999).

Depending on water temperature, egg incubation can last between 100–200 days, and juveniles remain in the substrate after hatching. Fry normally emerge from early April through May, depending upon water temperatures and increasing stream flows (*Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Bull Trout in the Coterminous United States*, 1999). The long over-winter phase for incubation and development leaves bull trout vulnerable particularly to increases in fine sediment or scour, especially during snow-melt events, and degradation of water quality (Fraley & Shepard, 1989). Good hiding cover is also important to all life stages of all forms of bull trout. Juvenile bull trout, particularly young-of-the-year (YOY), have very specific habitat requirements. Bull trout fry less than 4 inches (100 mm) long are primarily bottom-dwellers, often found on margins over fine depositions of detritus (Andonaegui, 2000). They occupy positions just above, in contact with, or even within the substrate. Fry and juveniles can be found in pools or runs in close proximity with cover provided by boulders, cobble, or large woody debris. Age 1+ and older juveniles utilize deeper, faster water than YOY, often in pools with shelter-providing large organic debris or clean cobble substrate. In large rivers, the highest abundance of juveniles can be found near rocks, along the stream margin, or in side channels (Andonaegui, 2000).

Wolf Creek is identified by the USFS as containing important spawning and rearing habitat for the Methow River bull trout population (USFS, 2005) and as a core area supporting a genetically distinct local population (UCRTT 2017; J. Crandall, pers. comm. 2020) with a small number of individuals that is stable or decreasing (US Fish and Wildlife Service, 2015). Bull trout are present throughout Wolf Creek (Figure 3), though spawning and rearing likely primarily occurs in the middle and upper portions of the watershed, upstream of the assessment area. Bull trout have been observed between RM 1.7 and RM 8.2 during snorkel surveys in Wolf Creek conducted by the USFS in 2005. Redd surveys between 1998 and 2005 have documented bull trout spawning in a three-mile reach starting at approximately RM 3 and ending just above the confluence with the North Fork of Wolf Creek at RM 6 (UCRTT 2017). However these surveys are not included in the bull trout redd counts shapefile from UCSRB (2018) where data is compiled from various fisheries organizations active in the Upper Columbia basin and thus are not included in the data shown on Figure 4. Resident bull trout are likely present upstream of the anadromous barrier at RM 6 (J. Crandall, pers. comm. 2020).

1.4.5 Pacific Lamprey

Adult upstream migration of Pacific lamprey occurs from the late spring through fall in the Columbia River Basin, with peak passage occurring in the Upper Columbia at Rock Island Dam in late August (McIlraith et al., 2017). In the nearby Entiat basin, spawning generally occurs from March through July at temperatures between 10-15°C (50-59°F) (USBR, 2017a). Preferred spawning habitat is in low gradient runs and pool tail-outs. Hatching date varies according to water temperature and is typically around 15 days after spawning. Ammocetes, the larval stage of the lamprey, spend a short period of time (~15 days) in the redd after hatching before drifting downstream to suitable rearing habitats. Rearing habitat typically consists of low gradient areas with low water velocity, soft substrate, and organic material. Ammocetes can rear in freshwater for up to 7 years as they grow, during which time they filter feed on diatoms and suspended organic material. Juvenile downstream migration occurs between July and October and includes metamorphosis into macropthalmia (adult stage), similar to smoltification in salmonids. Macropthalmia then migrate to the ocean during high flows in late winter or early spring (USBR, 2017b).

The known distribution of Pacific lamprey in the greater Methow Basin includes the lower 0.06 miles of Wolf Creek (Lumley et al., 2020). Electrofishing surveys for larval lampreys started in 2008 and is ongoing by the Yakama Nation Pacific Lamprey Project. Additional years of monitoring will continue to assess Pacific lamprey distribution in Wolf Creek and the rest of the Methow subbasin.

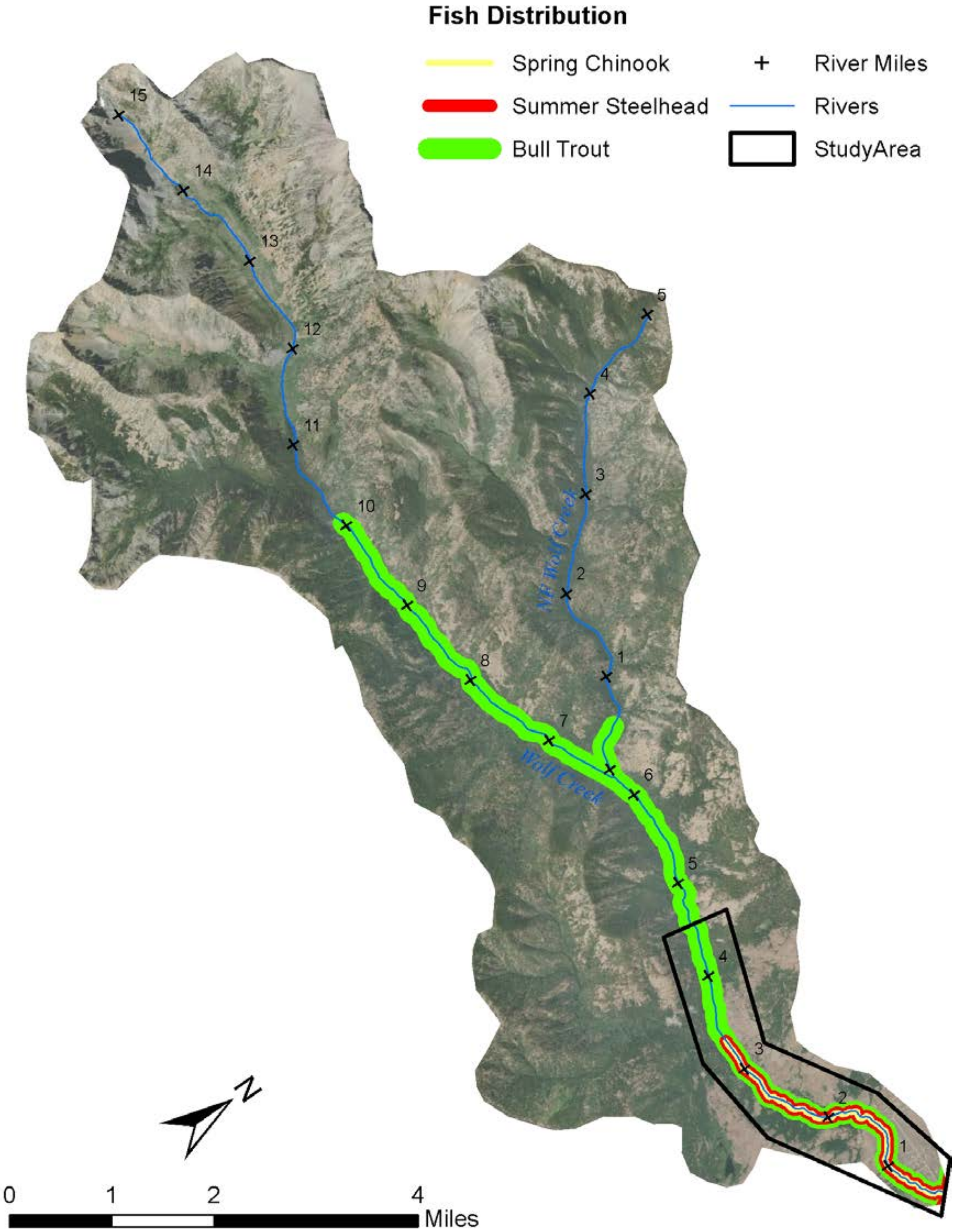


Figure 3. Reported distribution of Spring Chinook, Summer steelhead, and bull trout in the Wolf Creek sub-basin (Streamnet.org GIS data portal, accessed 04/2020). Coho salmon are being reintroduced to the Methow by the Yakama Nation, but full basin-wide distribution and Coho presence within Wolf Creek has not been fully documented and likely continues to shift as more Coho are returning to the basin.

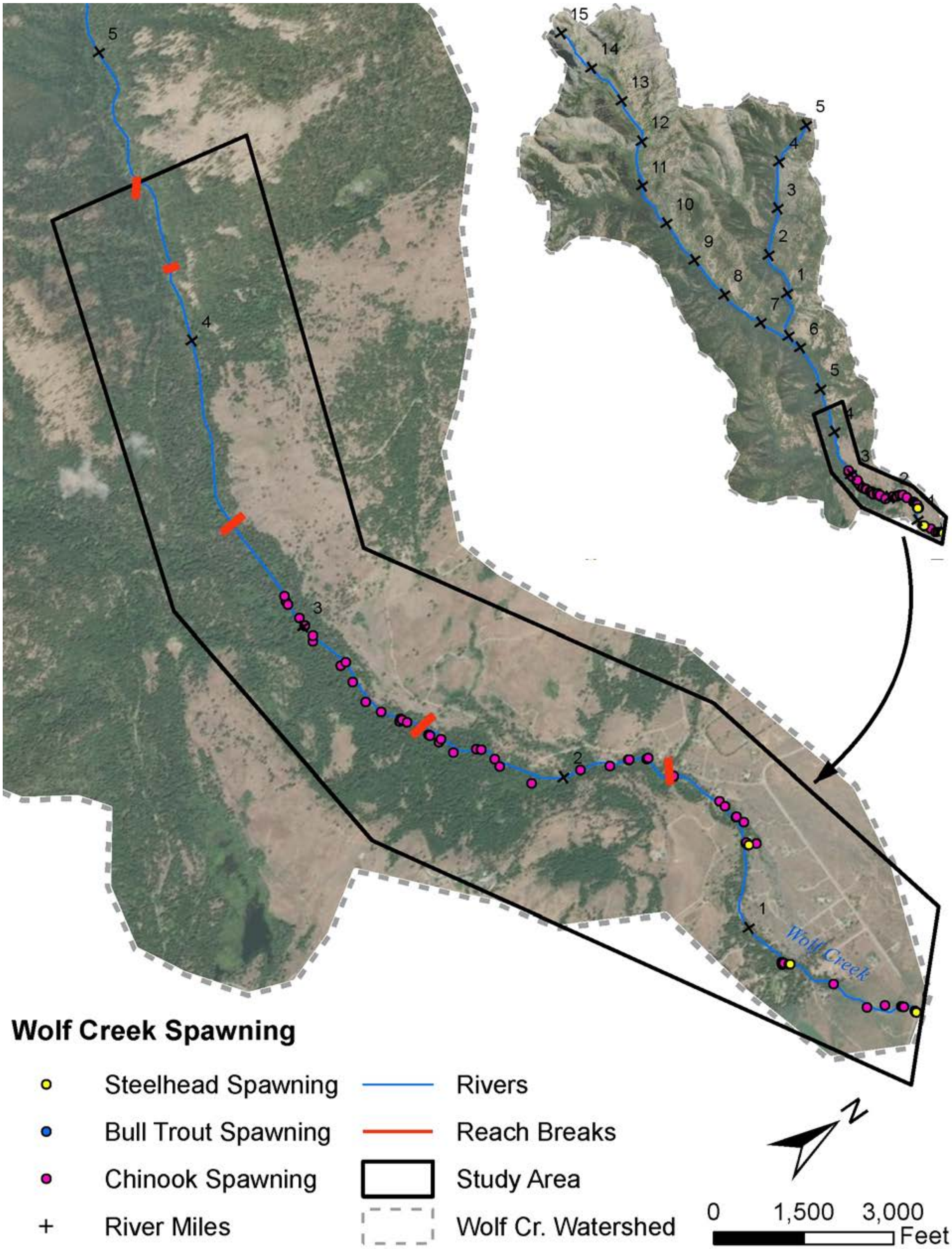


Figure 4. Steelhead trout and spring Chinook salmon redd locations collected in Wolf Creek between 2010 – 2017 (UCSRB, 2018). Note: the dataset does not include USFWS surveys conducted in Wolf Creek which reported bull trout spawning and rearing.

2. Assessment Area Characterization

2.1 SETTING

Wolf Creek is a tributary to the Methow River, which is a contributing river within the greater Upper Columbia River Basin. Wolf Creek is approximately 14.5 river miles (RM) long from its headwaters to its confluence with the Methow. Flowing eastward into the Methow Valley, it joins the Methow River approximately 54.2 RM upstream of where the Methow meets the Columbia River and just 2.5 miles upstream from the town of Winthrop, WA. The Yakama Nation has identified the lower 4.53 river miles of Wolf Creek for assessment and potential restoration efforts for native salmonid and bull trout populations. Little Wolf Creek is the largest contributing tributary within the assessment area and it joins Wolf Creek at approximately RM 3.25. The other tributaries within the assessment area are relatively small and ephemeral. Flow is diverted seasonally from the mainstem at the upstream boundary of the assessment area into the Wolf Creek irrigation ditch. During low-flow summer months the Wolf Creek ditch/aqueduct diverts all available surface flow from Little Wolf Creek.

The assessment area was divided into five distinct geomorphic reaches to facilitate description and discussion of local channel characteristics and restoration needs. Reaches were delineated at major physical transitions in channel form, gradient, degree of sinuosity, confinement, bedload, and floodplain connectivity. Reaches are numbered from downstream to upstream within the assessment area. A map of the assessment area with reach breaks is provided below in Figure 5.

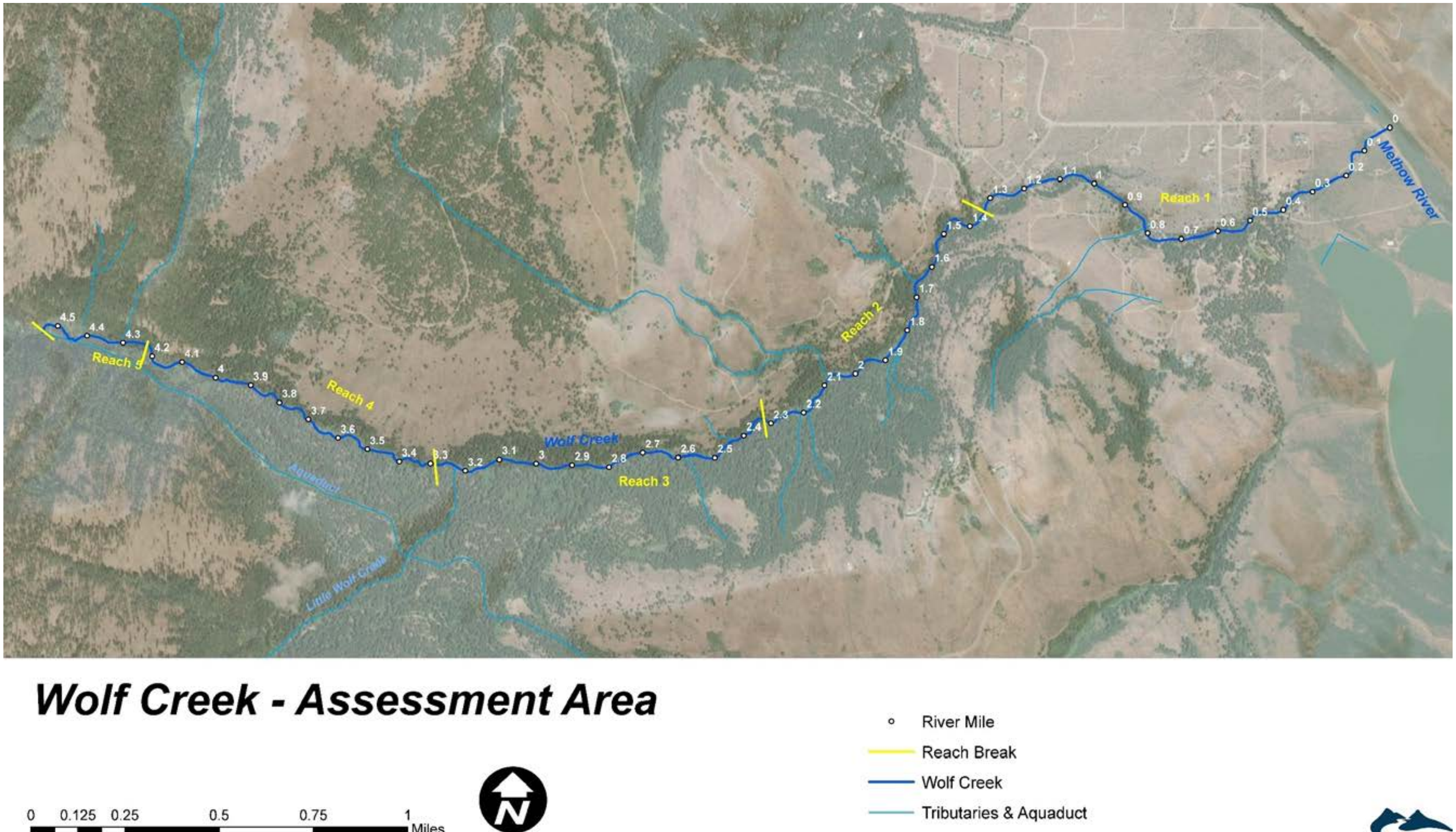


Figure 5. Wolf Creek assessment area with reach breaks and river miles.

Most of the Wolf Creek watershed is within the Okanogan National Forest and managed by the US Forest Service. Private land ownership is limited to the downstream reaches. Private property adajecent to the channel is located in Reach 1 and parts of Reach 2 (Figure 6).

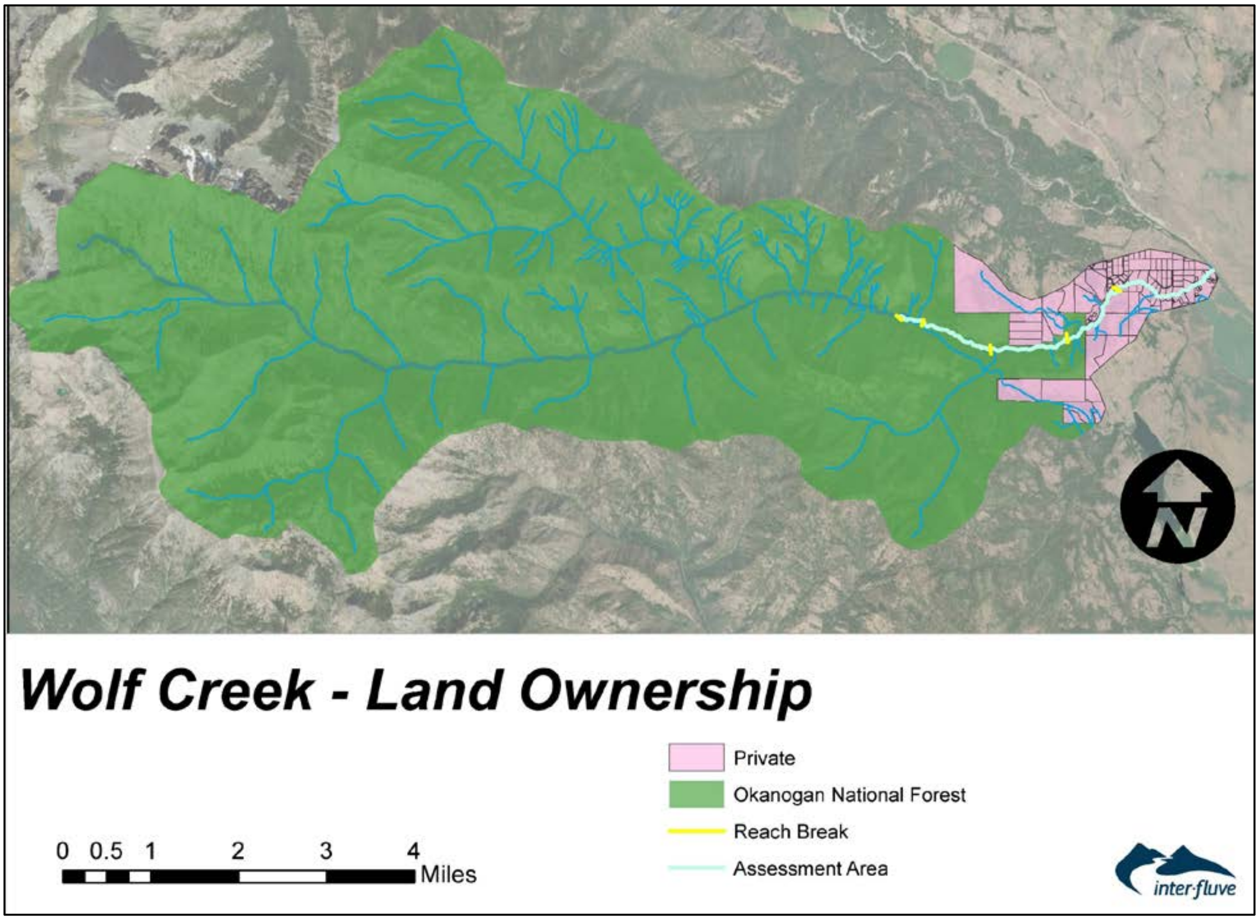


Figure 6. Wolf Creek land ownership map. (Property ownership GIS source: Okanogan County)

2.2 GEOLOGY

The geology and landscape history of the assessment area and its watershed are important components of ongoing local geomorphic processes. The Wolf Creek watershed is located within the eastern portion of the North Cascades Geologic Province, a complex assemblage of lithologic types shaped by millions of years of geologic development dominated by tectonic activity. The formation of the province was and is powered by subduction along the evolving western margin of the North American Plate, resulting in sequences of deposition, accretion, and volcanic processes that are still underway throughout the Cascades. The Province is divided into three general fault-bound terrains with unique stratigraphic and structural histories. Wolf Creek resides within the eastern-most fault bound terrain named the Methow Basin Domain. The Methow Basin geologic domain originated as

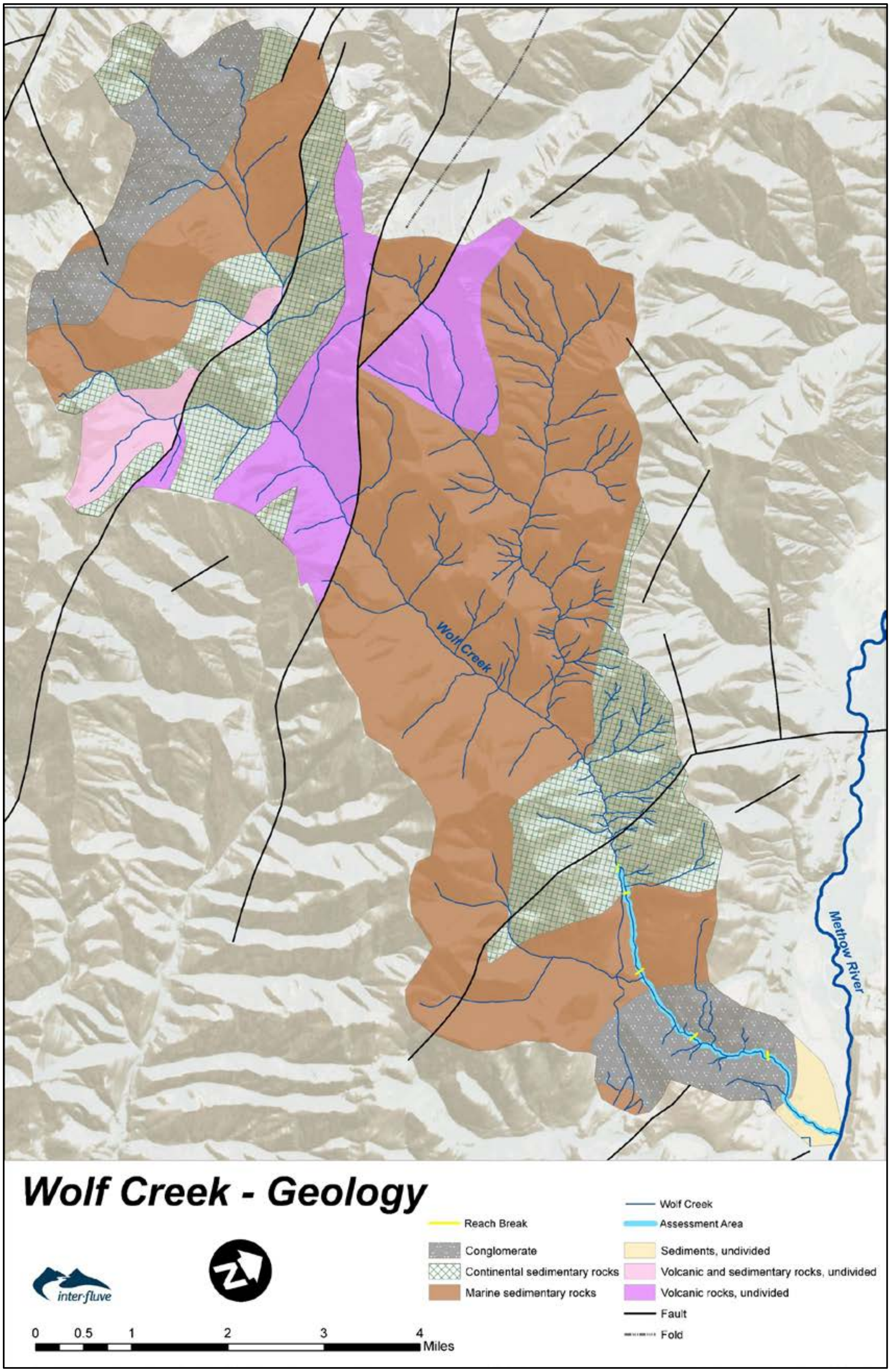


Figure 7. Surficial geology of the Wolf Creek watershed (Geology unit map source: WDNR, 2010).

continental shoreline and ocean floor deposits (Methow Ocean) of sediment eroded from the adjacent continent combined with volcanic contributions of basalt and granitic intrusions. The sediments and basalt were then later metamorphosed via processes of tectonic uplift, faulting, and folding (WDNR, 2010). The formative tectonic uplift and compression produced northwest-southeast faults and folds that define the pathway of the Methow River within the Methow Basin Domain. Wolf Creek's drainage path cuts almost perpendicular to the general direction of the faults within its watershed. Erosivity of the varied surficial geologies subtly influences channel gradient and valley confinement, in the assessment area (Figure 7). See Section 3 for reach-based gradients.

Today's surficial geology of the Wolf Creek watershed is dominated by (1) Cretaceous metamorphic and volcanic rocks, and (2) Quaternary glacial and alluvial deposits. The protoliths (original lithology types) of today's bedrock are marine/near-shore sedimentary deposits and volcanics. The sedimentary rocks were metamorphosed via tectonic processes into a variety of conglomerates with a mix of sedimentary and meta-volcanic clasts, sandstones, mudstones, shale, and cherts. The volcanic lithologies expressed today include andesite and dacite flows as well as breccia and tuffs. The Wolf Creek alluvial fan is a mix of Quaternary-aged glacial outwash and alluvial deposits sourced from Wolf Creek and the Methow River (Haugerud and Tabor 2009; DNR 2020). The hillslope confined valley floor of Wolf Creek is a mix of glacio-alluvial, alluvial, and hillslope sediment accumulations. Remnants of the accumulated glacio-alluvial and alluvium now form terrace strips and narrow pockets that border the valley floor, where space allows.

2.2.1 Pleistocene Glaciation

Pleistocene glaciation contributed to surficial deposits and the modern topography of the Methow Basin, including the Wolf Creek watershed. The last glacial maximum (LGM) in the Methow Valley and its tributaries combined alpine and continental glacial processes. Alpine glaciers developed initially in the mountains at higher elevation but these glaciers did not extend down slope into the Methow Valley. Then, the Okanogan Lobe of the Cordilleran Ice Sheet (CIS) extended southward from Canada to its maximum extent of glaciation just south of Lake Chelan. At its maximum, glacial ice of the CIS filled the Methow Valley, leaving only the highest peaks exposed. In the proximity of Wolf Creek, CIS thickness is reported as reaching approximately 2,000 feet, leaving only Wolf Creek headwater peaks such as Gardner Mountain, Story Peak, and Abernathy Peak exposed. At the end of the LGM, relatively rapid glacial recession in the area produced copious amounts of water and sediment

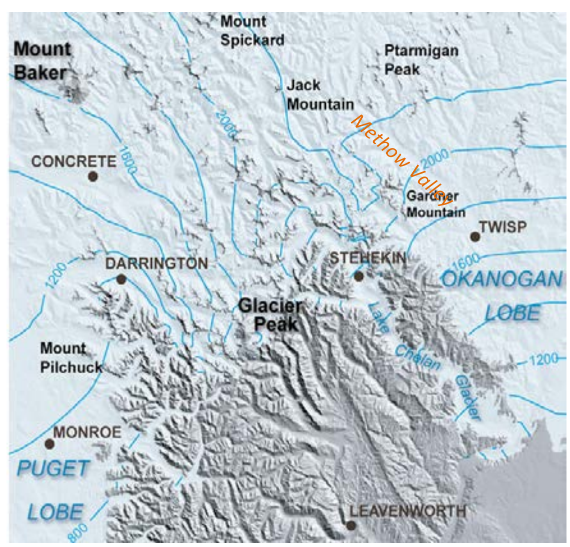


Figure 8. Cordilleran Ice Sheet extent at the Okanogan Lobe. From https://www.dnr.wa.gov/

that, combined with proglacial and ice-marginal lakes in the Methow Valley, created prominent kame terraces and draped valley-margin hillslopes with glacial till. The recessional moraine (last glacial stand during recession) in the Methow is the Winthrop Moraine, located just a couple of river miles downstream from the mouth of Wolf Creek near the town of Winthrop, WA. Cirques, aretes, subtle hanging troughs, and U-shaped headwater valleys of upper Wolf Creek and neighboring tributaries are remnants of the high peak alpine glaciers. These alpine glaciers only extended partially into the drainage. Thus, the downstream hillslope confined portion of modern Wolf Creek is a V-shaped valley, cut by eroding fluvial processes instead of an ice-carved U-shaped. Where Wolf Creek enters the Methow Valley it formed a broad alluvial fan composed of the sediments sourced from the glacial-till draped hillslopes as well as the glacial and fluvially carved bedrock upstream (DNR 2020; Booth et al. 2003; Barksdale 1975; Konrad, Drost, and Wagner 2005; Riedel 2017; Haugerud and Tabor 2009).

2.2.2 Soils

Soils on the adjacent hillslopes and valley floor of Wolf Creek are derived from the underlying bedrock, draped glacial till, glacial-fluvial deposits, and aerial inputs of volcanic ash material from Holocene eruptions of the Cascades. A map of the soils in the assessment area is provided in Figure 9. Soil composition ranges from ashy fine to stoney loams. Several of the soils on the hillslopes are draped glacial till or glacial fluvial deposits. Soils are relatively thick and all the soil types present are considered well-drained (USDA & NRCS, 2008, 2010).

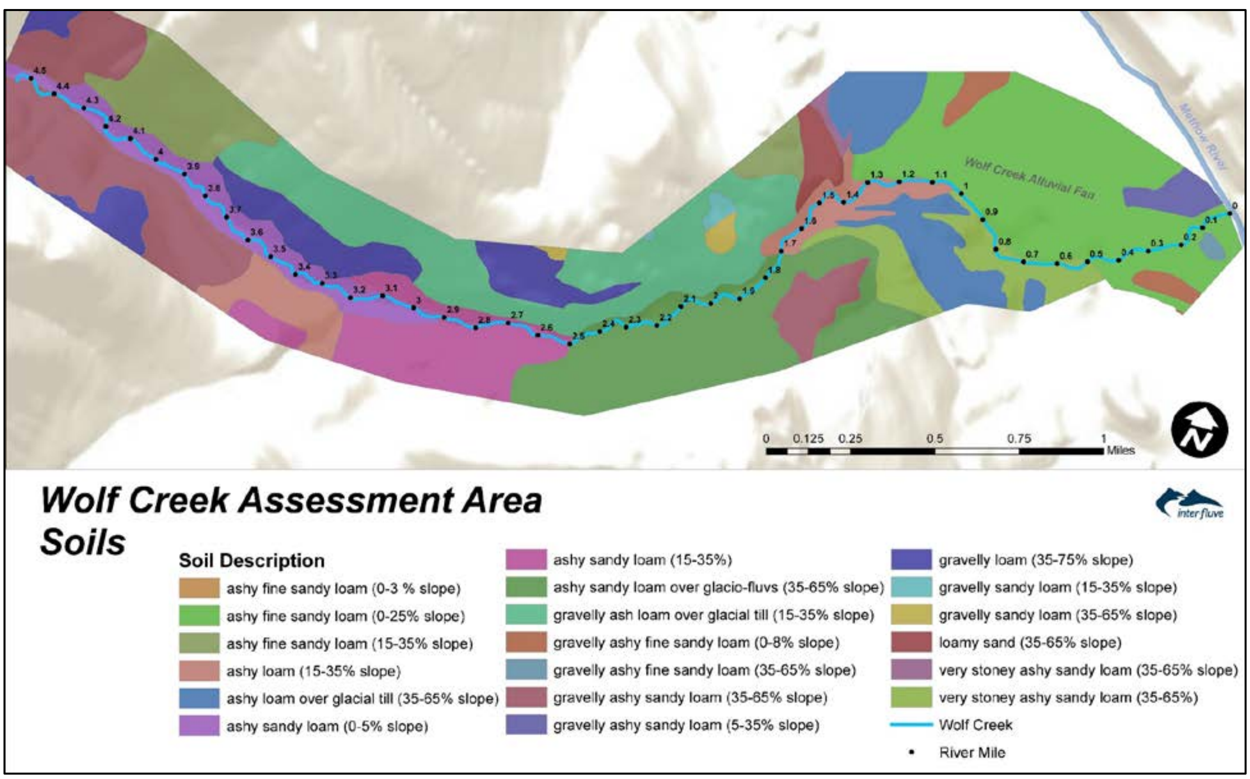


Figure 9. Soil types within the Wolf Creek Assessment Area. GIS soil layer source: (USDA & NRCS, 2008, 2010)

2.3 HISTORICAL FORMS AND PROCESSES

Historical conditions are considered as those that would have existed previous to Euro-American settlement. Historical conditions represent those to which native species such as salmonids were presumably best adapted, prior to the population crashes that ensued as human disturbances increased on the landscape in the last two hundred years. In many cases, restoration to historical conditions is not possible or appropriate considering modern infrastructure and existing hydro-geomorphic regimes. However, historical conditions nevertheless provide a reference point to help determine how habitats and processes evolve in this system and help inform the identification of restoration objectives. This section provides a brief summary of presumed historical conditions of Wolf Creek.

Although there is little available written information about conditions of Wolf Creek before the early twentieth century, field observations combined with USGS records and maps, modern landforms, underlying geology, and glacial cycles can provide some theories on historical channel process. Overall, the watershed was likely forested with mature conifers of mixed composition and diverse riparian vegetation along the channel(s) prior to Euro-settlement in the 1800's. In the hillslope confined sections of the assessment area, regional fire suppression has likely reduced diversity of modern forest composition, health, and large wood contributions (USBR, 2011). Channel form in the hillslope confined section of the assessment area is assumed to be relatively similar to conditions today (single thread channel), but with more large wood influenced channel and floodplain complexity (split-flow and inundation). Historical channel form is based on modern floodplain elevations, composition, and scars combined with channel scars on terraces and small analog sites with localized wood loading. Forest density hides channel form in historical aerial imagery.

Historical channel form and process across the alluvial fan have been drastically altered by confining features such as levees, bridges, outtake structures, and ditches. Topographic flow scars and fan shape indicate that Wolf Creek had an historically active alluvial fan. The channel's primary flow path would have shifted locations as part of natural fan development and was likely multi-threaded at times. Flood flows probably activated large portions of the fan's surface and supported a diverse mosaic forest and a habitat-rich confluence(s) with the Methow River. Today, the channel is confined to a singular flow path and the remainder of the fan has been abandoned. In addition to channel confinement across the fan, Wolf Creek is expected to continue to slowly adjust (incise) its downstream baselevel elevation to that of the anthropogenically impacted Methow River.

Fire suppression has reduced the overall health of the forests in the region (USBR, 2011). Vegetation removal and channel clearing of large wood near infrastructure such as bridges and homes has further reduced potential forest contributions and channel complexity, most notably across Wolf Creek's alluvial fan. Due to steep slopes and difficult access, USFS records indicate minimal timber sales adjacent to the channel upstream of the Wolf Creek alluvial fan. Evidence of tree harvest was observed as stumps and second growth conifers on the private lands upstream of the alluvial fan. Lack of sufficient large wood recruitment and removal of large wood and reduced riparian cover in the downstream reaches inevitably reduced and continues to reduce channel complexity compared to historical conditions. Non-adjacent timber harvest and roads likely altered sediment and hydrology runoff patterns from hillslopes and tributaries, such as in Little Wolf Creek. Seasonal surface water withdrawals and the hard structures associated with them locally confine lateral channel process and reduce flow dynamics. For example, the Wolf Creek ditch/aqueduct irrigation withdrawal outtake at the upstream end of the assessment area includes a cement and riprapped on the river right side of the channel and steel plate weirs that hold the channel in place, limiting local processes and altering seasonal flow regimes downstream.

2.4 HISTORICAL HUMAN DISTURBANCE

Human disturbance in the Wolf Creek basin is primarily located in the lower 1.5 miles of channel and floodplain on the alluvial fan, within the Little Wolf Creek subbasin, and at the Wolf Creek ditch/aqueduct outtake at the upstream end of the project area (RM 4.53). Eighty percent of the Wolf Creek watershed lies within the Chelan-Sawtooth Wilderness inside the Okanogan National Forest managed by the US Forest Service (USFWS). The assessment area is downstream of the wilderness boundary. In addition to Wilderness protection, the remainder of the channel and contributing hillslopes within the National Forest are relatively inaccessible for timber harvest or other development due to steep topography (USFS 2005). Thus, impacts in the Okanogan National Forest from timber harvest and road building are isolated primarily to the Little Wolf Creek drainage (NPCC (Northwest Power and Conservation Council), 2004). Over 100 years of fire suppression impacted forest succession and fuel-loading to some degree in the region, included the entire Wolf Creek watershed (USBR, 2011). Historical public lands grazing of sheep and cattle are expected to have impacted, to some degree, channel and bank stability at animal crossings, understory density and, to hillslope erosion processes – though minimal grazing occurs in the assessment area today.

The lower 1.5 river miles of Wolf Creek have experienced ongoing anthropogenic impacts for over 100 years. The historical General Land Office (GLO) maps and a set of aerial images capture some of the anthropogenic disturbances in the lower 1.5 miles of the channel (Figure 10). The GLO survey plat map from 1895 shows the Wolf Creek main channel flowing north of its current position on its vegetated alluvial fan surface. The earliest available aerial image from 1947 shows the main channel several thousand feet to the south. The main channel is located in approximately its present-day alignment but also has a road with crossings over the historical alignment and an irrigation ditch. The 1947 alignment may have been a natural process in response to high-flow events, but more likely the channel was moved by humans to accommodate roads, crossings, and land-use maximization. Major flooding in the Methow basin occurred in 1948; the 1953 aerial image shows evidence of overland flow across the alluvial fan north of the main channel. In response to flooding, the main channel was channelized and leveed in the 1960s and 70s (USBR 2008) to attenuate flood risks. By 1990, the historical flow path is filled with a road prism and any evidence of high flows on the fan surface is eliminated. The 2017 image shows a relatively static channel planform and a steady increase in residential development on the alluvial fan, including areas historically activated by flood events.

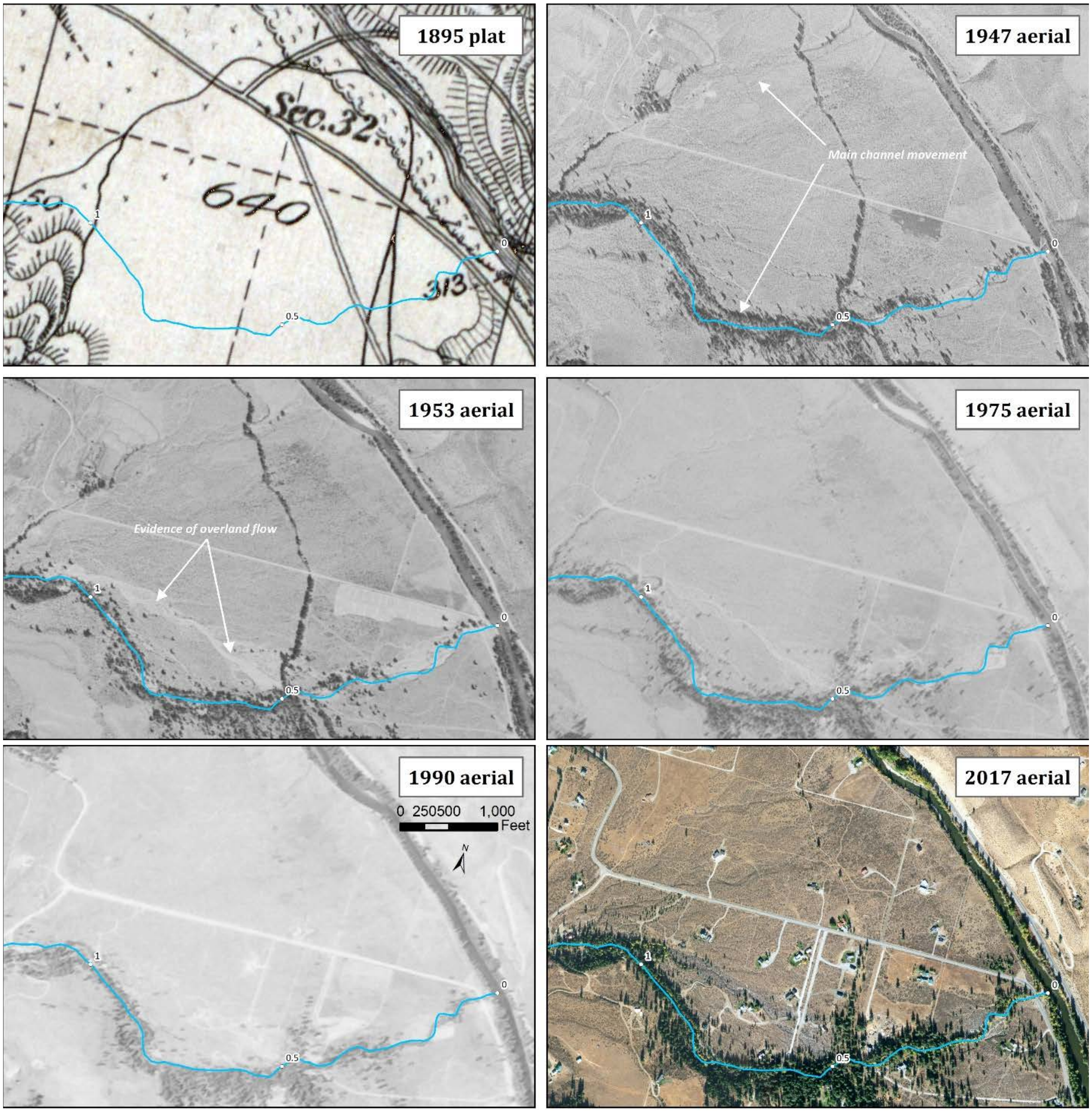


Figure 10. Aerial imagery and survey plat maps of the Wolf Creek alluvial fan from 1895 to 2017 with the modern location of the channel depicted with the blue line. (1895 sourced from BLM GLO and aerials sourced from USGS – Earth Explorer)

In 1969 a water right permit (app # 21560) was granted by the state of Washington to a resident of the area to continuously divert water from Wolf Creek near modern day river mile 1. The diversion feeds a set of constructed ponds connected to the channel at the up and downstream end via a culvert and ditches. The ponds are used for domestic aesthetic use, fish propagation, and wildlife refuge development on the disconnected river left floodplain. After construction, the ponds have proven to be low-quality off-channel habitat used by rearing salmonids and the return ditch a location where redds were occasionally surveyed. Yakama Nation has collaboratively utilized the lower pond and return ditch to acclimate reintroduced Coho and spring Chinook to the system. Observations of degrading habitat quality within the site prompted the investigation of potential treatments that could improve off-channel habitat conditions in this area. Details about the investigation and site conditions can be found in the Wolf Creek Ponds Conceptual Design Report (Aspect Consulting, 2018). On the river left side of the mainstem channel at the pond site, a cement wall approximately 50 feet long and connected to levees at the up and downstream end force channel confinement between itself and the toe of the opposite hillslope. This is the narrowest section of the channel within the assessment area.

2.5 EXISTING ANTHROPOGENIC FEATURES

Human-built features have the potential to influence or inhibit geomorphic and ecologic processes depending on their proximity to a channel and its floodplain. Human-built features include constructed components on the modern landscape such as levees, roads, bridges, culverts, irrigation structures or piping, buildings, riprap and other bank protection, and utility crossings. Figure 12 displays the mapped built anthropogenic features within the assessment area. Reach-scale maps of these features are provided in Section 3.

Wolf Creek is considered a rural watershed with relatively low population density. However, human-built features dominate and influence natural processes between river miles 0-1.47. Upstream of RM 1.47, limited built features impede the modern channel and its active floodplain until the upstream boundary of the assessment area at RM 4.53, where the Wolf Creek ditch/aqueduct irrigation diversion and weirs are located.

The Wolf Creek Reclamation District operates surface water irrigation diversion facilities on Wolf Creek and Little Wolf Creek. The Wolf Creek diversion, grade control weirs, fish screen, and ditch/aqueduct initiate at the upstream boundary of the assessment area (RM 4.53) – see Figure 11. The existing water right authorizes a maximum instantons diversion rate (Qi) of 30cfs from October 1st to July 1st. Between April 1st and September 30th, the diversion is allowed to divert up to 12.5-13 cfs from Wolf Creek as well as the entire flow of Little Wolf Creek, to ditch capacity. When discharge at the mouth of Wolf Creek lowers to 9cfs or a depth less than 8 inches, diversion at the Wolf Creek ditch/aqueduct is shut off to meet Endangered Species Act requirements (8cfs) and a Trout Unlimited agreement (additional 1cfs) (Haller, 2003; Schull, 2019; USDA Forest Service, 2005). The Wolf Creek diversion and fish screen were improved in 2017 through a joint effort between Cascade Fisheries Enhancement Group, the USFS, and WA Department of Fish and Wildlife to mitigate for loss (take) of juvenile steelhead and bull trout (WA RCO 2011). Little Wolf Creek is the largest contributing drainage within the assessment area. Diverting all of the tributary’s surface flow during irrigation season removes its discharge and nutrient contributions to the mainstem channel and removes any seasonal viable habitat it once supported.

Figure 11. Wolf Creek diversion withdrawal gate, ditch, and overflow return gate (foreground). (Photo: 10/5/2019)

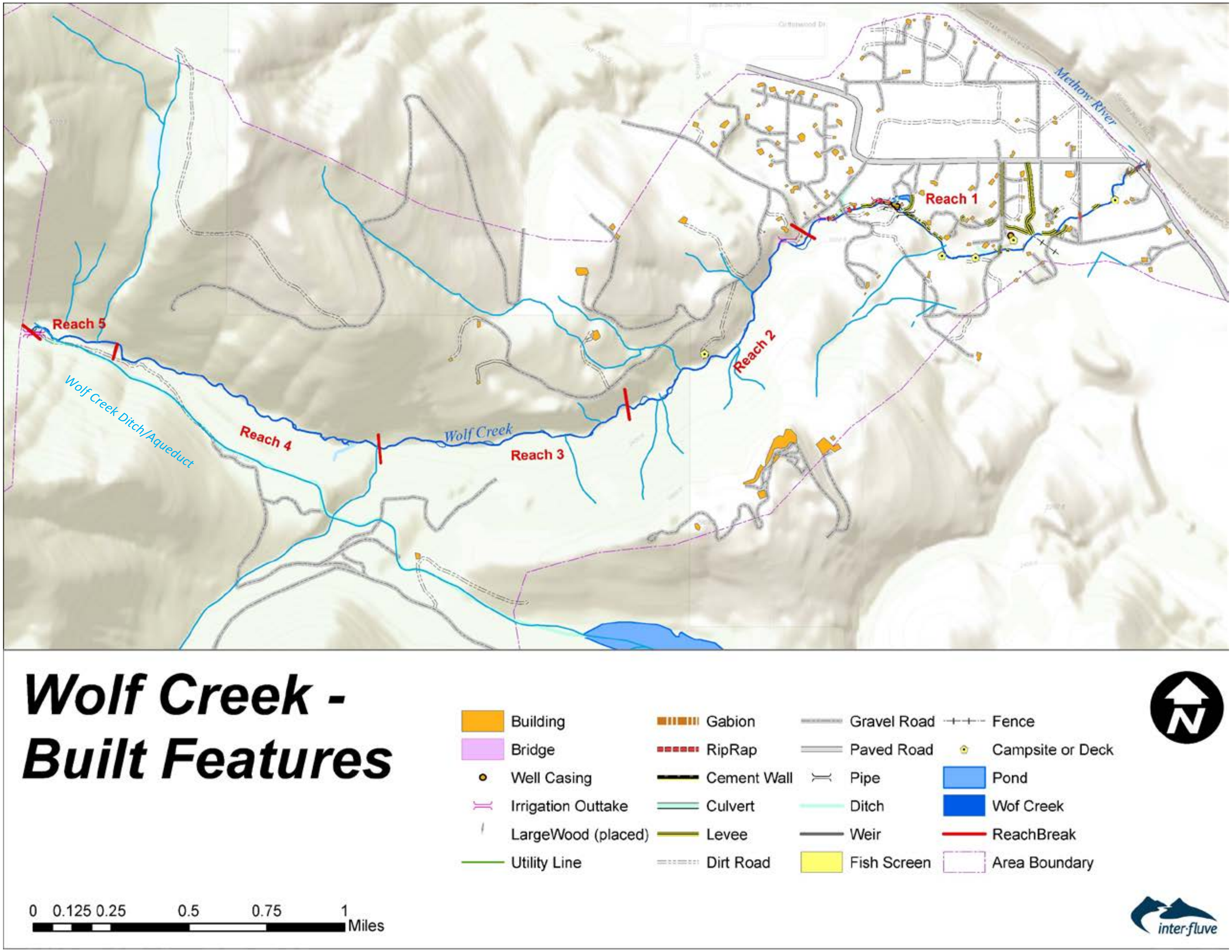


Figure 12. Human-built features within the Wolf Creek assessment area (RM 0-4.53). Note: reach-scale maps are provided in Section 3.

2.6 CLIMATE

The climate of the Wolf Creek basin generally consists of dry, warm summers and cold, relatively wet winters. The majority of the precipitation throughout the basin falls as rain and snow in the winter and spring. However, the annual precipitation received varies across the basin from headwater to the mouth (Figure 13). The headwaters to the west receive over 57 inches of precipitation on average annually, while the eastern portion of the basin, near the confluence with the Methow River, receives only about 15 inches annually (PRISM Climate Group, Oregon State University, 2017).

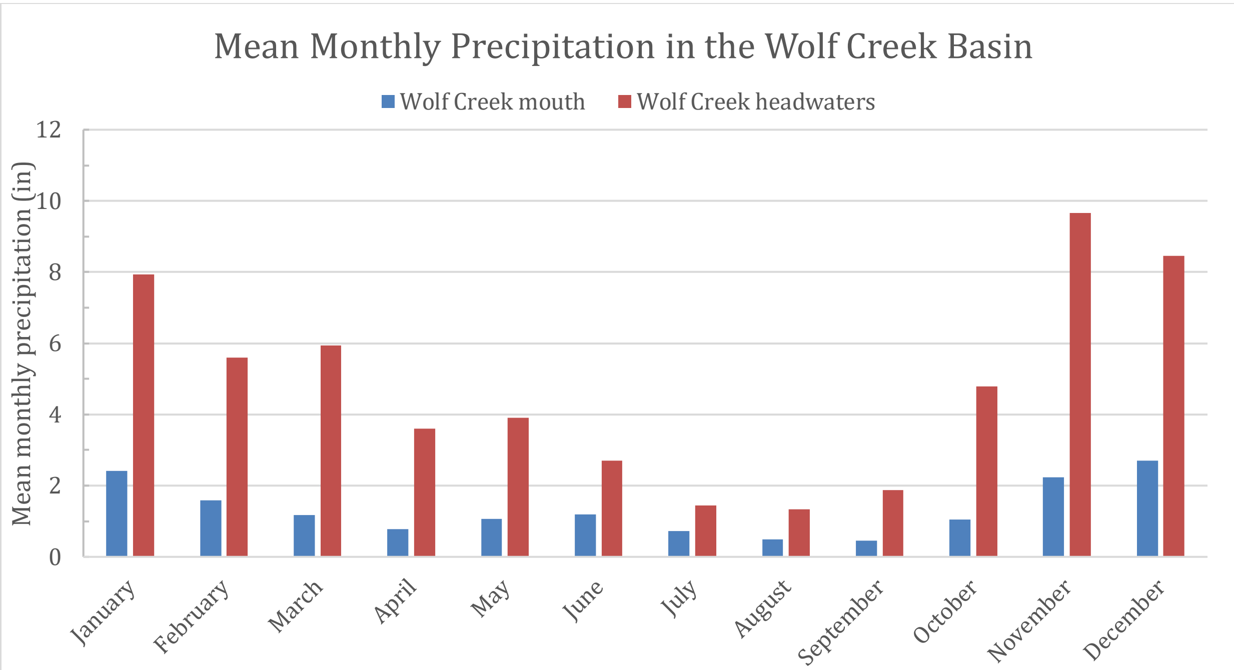


Figure 13. Monthly average precipitation in the Wolf Creek basin at the headwaters and near the confluence with the Methow River.

Near the mouth of Wolf Creek, winters are cold while summers are moderately warm (Figure 14). Mean air temperatures throughout the winter are 20-30°F, while mean air temperatures in the summer months (June–August) typically fluctuate between 60-70°F (PRSIM Climate Group, Oregon State University, 2017). Average air temperatures in the winter months decrease upstream as elevation increases towards the headwaters. As a result, the headwater areas that receive notably more precipitation in the winter receive more of it as snow. The snow accumulations in the upper watershed provide a source of water to the channel throughout the spring and summer months.

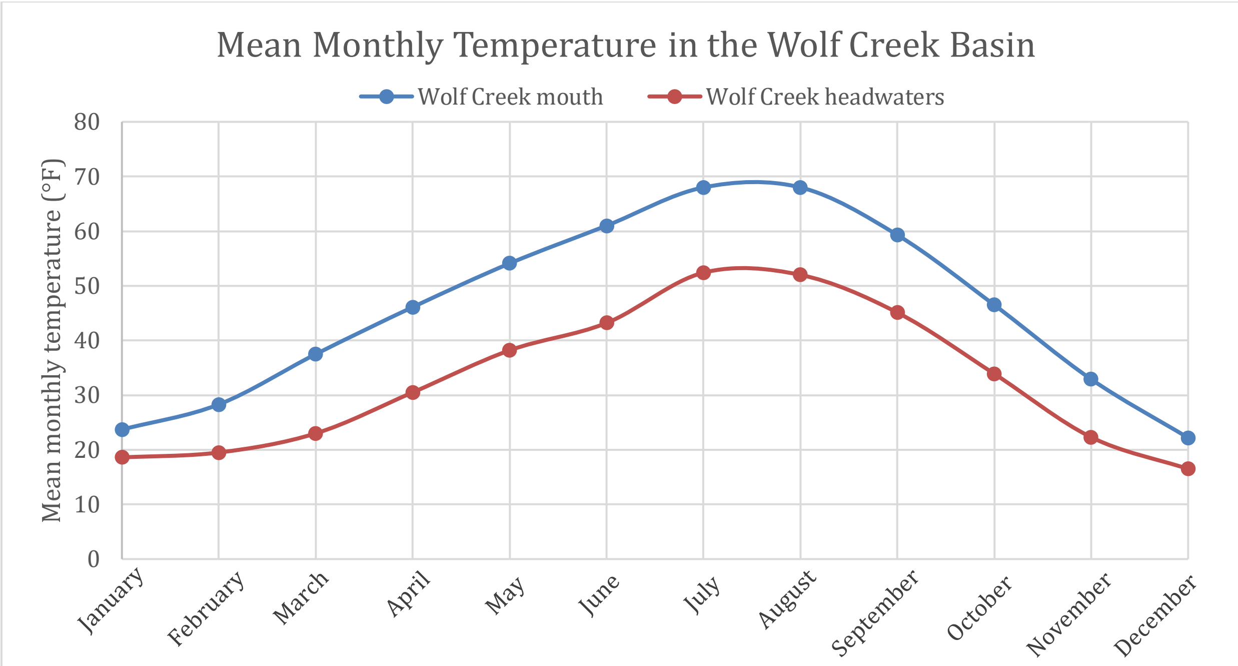


Figure 14. Average monthly temperatures near mouth of Wolf Creek and in the headwaters (PRISM 2017).

2.6.1 Climate Change

Global climate models used to capture the 1.4°F warming measured in the Pacific Northwest over the 20th century created by others (Srinivasan et al., 2007) predict an average increase in annual temperature in the region of 2.0° F by the 2020s, 3.2° F by the 2040s, and 5.3°F by 2080 (Mote & Salathé, 2010). Climate simulations indicate precipitation and streamflow in the Pacific Northwest will respond to a changing climate through increased intensity of winter storm events resulting in higher streamflow, and decreased summer precipitation resulting in longer periods of and decreased baseflow discharge (Mantua et al, 2009). These changes are predicted to have the most substantial implications for transient and snowmelt driven watersheds such as Wolf Creek, that are influenced by both autumn rains and spring snowmelt.

The US Geological Survey (USGS) examined the potential impacts of predicted climate change scenarios in the Methow Basin specifically – all of which predict increases in winter temperature. Warmer winters result in more precipitation falling as rain instead of snow. This is expected to decrease streamflow during spring and summer because of reduced snowpack, but to increase flow during fall and winter. Voss and Mastin (2012) provide a web-based tool to plot modeled flows based on climate change scenarios. Figure 15 shows the modeled data for USGS gage #12447387 (Wolf Creek below diversion), which is at the upstream boundary of the study area. These results suggest that overall snowmelt peaks will be less than existing conditions, and fall and winter peaks will be greater than existing conditions. Overall, annual peak flows would be expected to decrease in size. Baseflow is expected to decrease in magnitude slightly, in response to lower snowpack.

The effects of these potential changes on Wolf Creek and aquatic habitat depend on many factors such as timing of the events, sediment supply, and icing. Prediction of larger and flashier fall and winter discharge events (rain fall induced) would be expected to result in more seasonal channel response (i.e., sediment mobilization and bank activation) than occurs during these months when precipitation is received and stored as snow. Decreased snow pack is expected to reduce duration of snow-melt influence on spring events however, peak flood discharge value changes and timing cannot be predicted without additional analysis. Decreased base flow and increased ambient temperature predictions increase the risk of summer time water temperature exceedances for bull trout and salmonids. Such channel response mechanisms are important to consider with the inevitable influence that present and future climate change will have on the river and the habitat it provides.

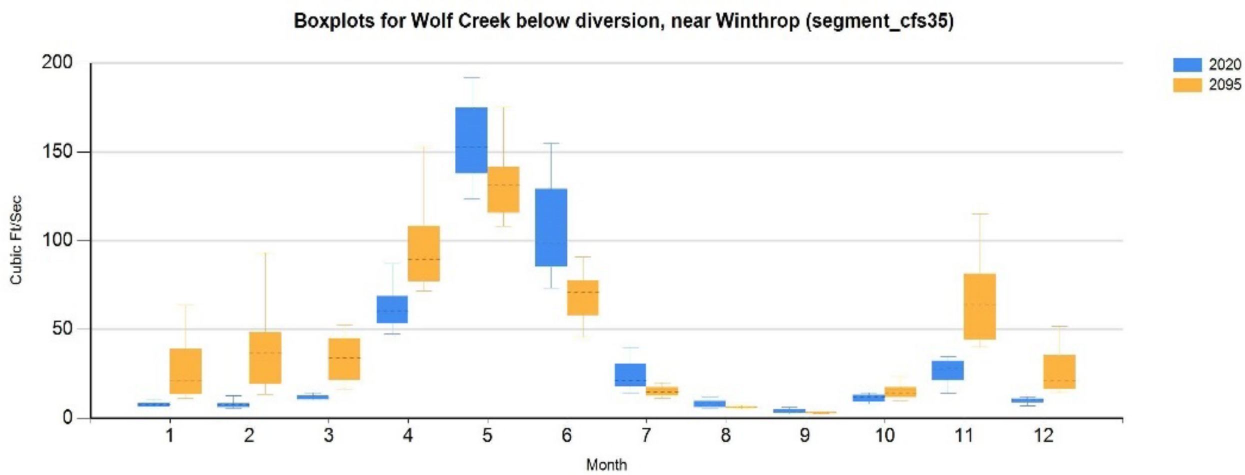


Figure 15. PRMS-simulated daily values of Wolf Creek below diversion, near Winthrop by month for all GCMs and scenarios over 11-year centered around 2020 and 2095.

2.7 HYDROLOGY

2.7.1 Basin Characteristics

Wolf Creek flows approximately 14.5 river miles east from its headwater peaks in the Lake Chelan – Sawtooth Wilderness (max elevation 8,840 feet) to its confluence with the Methow River (elevation 1,790 feet), northwest of Winthrop. The drainage area of the Wolf Creek watershed is approximately 40 square miles, with a mean basin elevation of 5,090 feet above sea level (USGS, 2020). Wolf Creek initiates at its headwaters in the vicinity of Gardner Meadows, then flows through a hillslope confined valley until it reaches the Methow Valley, where it flows across its own historical alluvial fan to reach its terminus at the confluence with the Methow River.

2.7.1 Assessment Area Hydrology

The assessment area (RM 0–4.53) receives hydrologic watershed inputs from upstream as well as from within the assessment area. Figure 16 provides a map of the Wolf Creek watershed and its contributing tributaries. The primary tributaries within the larger watershed include North Fork

Wolf Creek, South Fork, Hubbard Creek, and Little Wolf Creek. Within the assessment area, Little Wolf Creek provides surface water inputs at RM 3.25. All of Little Wolf Creek's dry season contributions are captured and diverted by the Wolf Creek ditch/aqueduct. The other tributaries in the assessment area are naturally ephemeral.

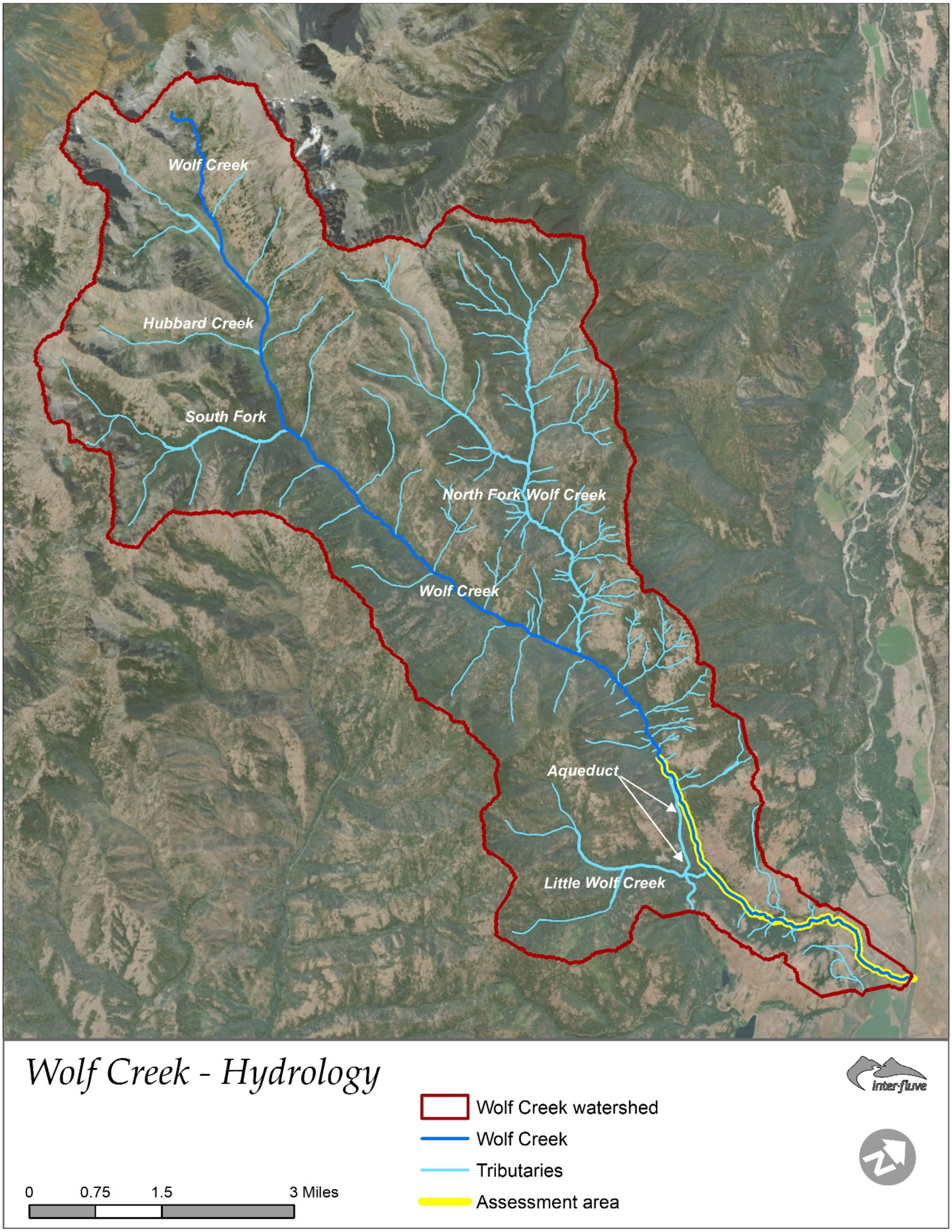


Figure 16. Wolf Creek watershed and tributaries hydrology network.

2.7.2 Surface Water

The average annual discharge of the Wolf Creek watershed follows a spring-time snowmelt runoff pattern typical of east-slope Cascade Mountain streams with smaller precipitation-driven flow increases in late fall. A USGS gage located on Wolf Creek just below the diversion (USGS #12447387) provides surface water discharge data from 2000–2003 (Figure 17). Although the period of recorded data is short, it depicts an annual hydrograph with high flows in the spring during peak snow melt. For basin comparison, water years 2000-2003 produced near and below average annual discharge in the Methow River at Winthrop (USGS gage 12448500). The data for Wolf Creek shows a relatively constant baseflow from August through February with short-lived discharge increases in the fall. Autumn and winter rain events produce the small peaks prior to snow accumulation and prior to the snowpack melting in spring. The hydrograph should be reviewed with the understanding that the water right for the diversion immediately upstream of the gage authorizes a maximum instantaneous diversion rate (Qi) of 30 cfs from October 1 through July 1, and 13 cfs from July 1 through September 30, with an annual maximum withdrawal quantity (Qa) of 3,065.6 ac-ft for irrigation of 790.18 acres.

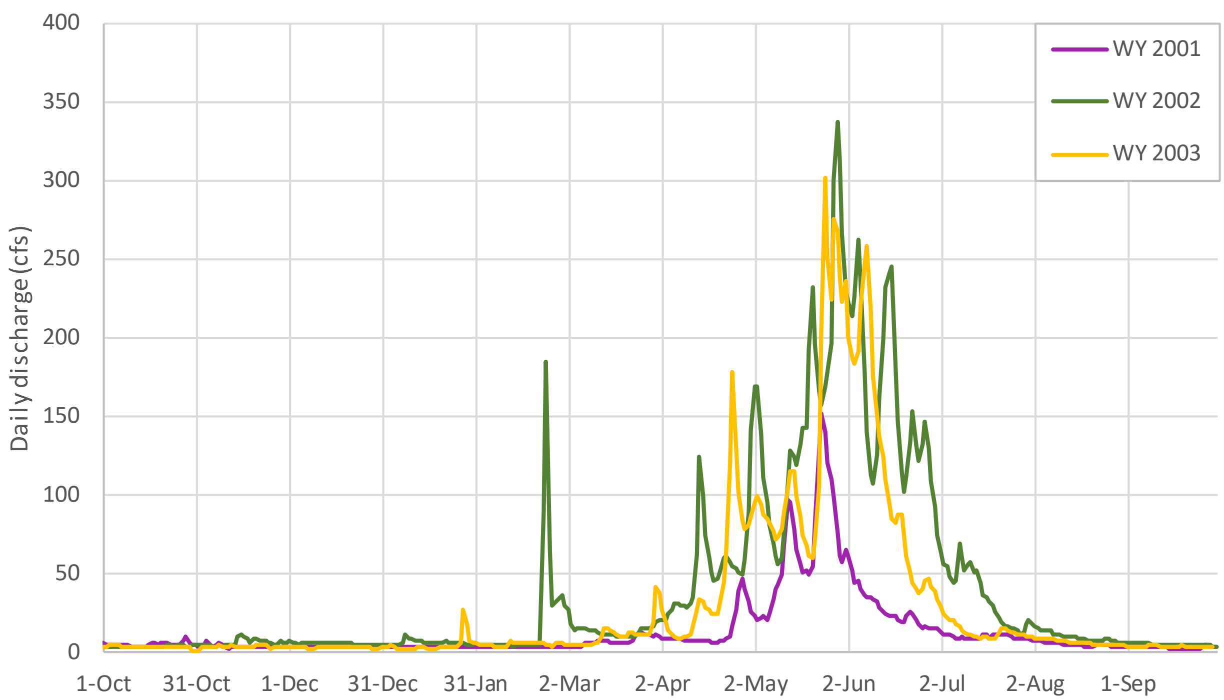


Figure 17. Daily average discharge at Wolf Creek below the diversion for water years 2001 through 2003 (USGS gage 12447387 Wolf Creek).

2.7.3 Peak Flows

Because the period of gaged discharge data spans only three years, flood frequency discharges are estimated using StreamStats (USGS, 2020) at the mouth of the channel (RM 0). StreamStats uses regional regression equations developed by the USGS (Mastin et al., 2016). The standard error reported for these estimates range between 69% for the 5-year return period event to 97% for the

100-year return period event. Given the large standard error of the peak flow estimates, these results should be considered with caution. The estimated peak discharge value results are provided in Table 1.

Table 1. Wolf Creek estimated discharge for peak flood events (USGS, 2020).

Flood Return Interval	Estimated Peak Discharge (cfs)	Standard Error of Prediction (%)
2 Year	263	77.2
5 Year	467	69.1
10 Year	638	72.2
25 Year	886	81.2
50 Year	1110	89.2
100 Year	1340	96.9

2.8 HYDRAULIC ANALYSIS

The hydraulic analysis for this assessment includes a reach-based stream power analysis for Reaches 1-5, as well as a preliminary-level 2-dimensional (2-D) hydraulic model (HEC-RAS) of estimated peak flood events for Reach 1, where LiDAR was available at the time of the analysis.

2.8.1 Stream Power

Stream power is the amount or rate of energy exerted on the banks and bed of a channel from the water flowing over it. This widely used hydraulic analysis technique (Fonstad 2003; Knighton 1999; Burke et al. 2009; Julian et al. 2012; Bureau of Reclamation 2006; Bizzi and Lerner 2015) was selected because it is appropriate where the channel is primarily single-thread, reach-scale assessment is being performed, and detailed topographic data and cross sections of the channel and floodplain are not available for the entire study area. As a measure of the hydraulic energy produced by a river, stream power is commonly used to estimate hydraulic forces acting on the channel bed and banks and to quantify a river's capacity to perform geomorphic work (i.e., erosion, deposition, sediment transport). This analysis examines the total cross sectional stream power (Watts/m (Ω)) and unit stream power (Watts/m^2 (ω)) as defined by Rhoads (1987) for a set of selected discharges at the downstream boundary of each reach in the assessment area.

Controlled by slope and discharge, stream power quantifies the kinetic energy of water that a flow event has to perform work (sediment transport or erosion) on the channel bed it moves over (Knighton, 1998). Stream power, a function of discharge, slope, and channel geometry, is calculated for the reach-averaged slope and channel width to aid in characterizing the dominant hydraulic and/or geomorphic variables responsible for downstream patterns of sediment transport.

Total cross-sectional stream power is calculated for a set of estimated peak flood discharges (Q). The set of peak flood events (2, 5, 10, 25, 50, and 100-year) were estimated at the downstream boundary of each reach using StreamStats (USGS, 2020). The estimated flood events are provided in Table 2.

Table 2. Peak flood discharge estimates– derived using StreamStats generated flood event estimates calculated for the downstream boundary of each reach (USGS, 2020)**.**

Flood Event	Estimated Discharge (cfs) Reach 1	Estimated Discharge (cfs) Reach 2	Estimated Discharge (cfs) Reach 3	Estimated Discharge (cfs) Reach 4	Estimated Discharge (cfs) Reach 5
2-year	263	263	263	258	258
5-year	470	467	466	459	458
10-year	644	637	635	627	626
25-year	899	886	880	872	870
50-year	1130	1110	1100	1090	1090
100-year	1370	1340	1330	1320	1320

Stream power is then calculated using: $\Omega = pgQS$
where p is the density of water, g is acceleration due to gravity, Q is discharge, and S is reach slope. Reach slope is determined by taking total elevation gain within the reach divided by channel length (see Table 6).

Table 3 below provides the calculated reach-scale stream power results.

Table 3. Stream power (Watts/m) for each estimated flood event discharge. Discharge estimates in Table 3 converted from cfs to si units for stream power calculations.

Stream Power (Watts/m)

Flood Event	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
2-year	1032	2850	3456	2885	5085
5-year	1843	5061	6123	5133	9027
10-year	2526	6903	8344	7011	12338
25-year	3526	9601	11563	9751	17147
50-year	4432	12029	14453	12189	21483
100-year	5373	14521	17475	14761	26016

As assumed, stream power increases with increasing discharge. However, higher channel slopes in Reach 3 compared to Reaches 1, 2, and 4 result in higher stream powers in the middle section of the assessment area. Reach 5 has the smallest upstream drainage area and thus the smallest estimated discharge for each flood event, but its increased gradient produces the highest stream powers in the assessment area.

2.8.2 Specific Stream Power

Estimations of specific stream power is used to quantify a river's capacity to transport sediment, investigate hydraulic thresholds of flood-related geomorphic response (Costa & O'Connor, 2013;

Fonstad, 2003; Magilligan, 1992), and to classify and define channel-floodplain types and floodplain genesis (Nanson & Croke, 1992). Specific stream power takes the value calculated above for total stream power for the 2-year flow event (effective flow event) and normalizes it based on channel width. In this case, we use reach-averaged bankfull widths as measured in the field for the Habitat Survey (see Appendix A and Table 5) as the representative bankfull channel width for each reach.

Specific stream power is calculated using: $\omega = \Omega / w$
where w is reach-averaged bankfull width.

Specific Stream Power (Watts/m^2)

Flood Event	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
2-year	88	285	275	283	498
5-year	158	506	486	503	884

Based on Nanson and Croke's (1992) classification, Reaches 1–4 are considered medium-energy systems at the reach-averaged bankfull width for the 2-year estimated flood discharge (shaded green) and Reach 5 is considered high-energy (shaded purple). Medium-energy systems (ω = 10-300 W/m^2) are described by Nanson and Croke as having non-cohesive floodplains, meandering to braided form, and point bar or braid/multi-channel accretion processes that form floodplains. High-energy systems (ω > 300 W/m^2) have non-cohesive floodplains, confinement where lateral processes are inhibited, and vertical accumulations of coarse gravels and sands to form floodplains. Since estimated average bankfull width is used in this analysis, it is understood that stations within each reach that have a narrower bankfull width would have higher specific stream power for the same discharge (Q), and wider areas would have slightly lower specific stream power. Note that the specific stream power for reaches 2–4 at the 2-year estimated flood event is near the upper range of what is considered medium energy.

Within the study area, the floodplains are composed primarily of non-cohesive sands, gravels, and cobbles. Channel form is primarily hillslope confined meandering with anthropogenically-forced confinement in Reach 1. Point bar and floodplain pocket development of non-cohesive materials does occur where reduced confinement allows. It is expected that Reach 1 would express multi-threading and braiding common on alluvial fans if not confined/entrenched in its modern channelized form, especially considering potential for delivery of sediment from the upstream reaches.

Based on this analysis, Reaches 2–5 are expected to be capable of transporting larger sized bedload material than Reach 1 (on average). The channel and floodplain characteristics observed and surveyed as part of this assessment (see Reach-Scale Conditions in Section 3) confer that modern geomorphology in Reach 1 is currently medium energy but with medium-high energy formation in the levee confined upstream sections, Reaches 2–4 are medium-high energy formed and Reach 5 is high energy formed. This confers that Reaches 1, with a lower gradient and wider average channel width at the downstream end and where inset floodplain pockets exist, has more capacity to store sediment compared to the upstream reaches, if space was available. Likewise, Reach 5 has the least capacity to store less coarse sediment, comparatively.

2.8.3 2-D Hydraulic Modeling – Reach 1 (RM 0-1.34)

A preliminary-level 2-dimensional (2-D) hydraulic model was undertaken for existing conditions in Reach 1 (RM 0-1.34) using the StreamStats generated estimated flood discharges. The model was developed to evaluate flood flow hydraulics (velocity) and inundation patterns. Only Reach 1 was modeled because it is the only reach in the assessment area with substantial human infrastructure and was the only reach with available LiDAR (2016) at the time of analysis - which was necessary to complete the 2D modeling effort. The 2-D hydraulic model was developed in the U.S. Army Corps of Engineers HEC-RAS 5.0.7 software (USACE 2019). Information on the preliminary hydraulic model and flow velocity model results for the estimated peak flow events of the 2, 5, 10, 25, 50, 100, 200, and 500-year flood events are provided in Appendix D.

A sample of the preliminary hydraulic model results that reveal inundation and flow velocity of existing conditions (LiDAR 2016) for the 2, 10, 50, and 100-year estimated flood events are provided below (Figures 18-22).

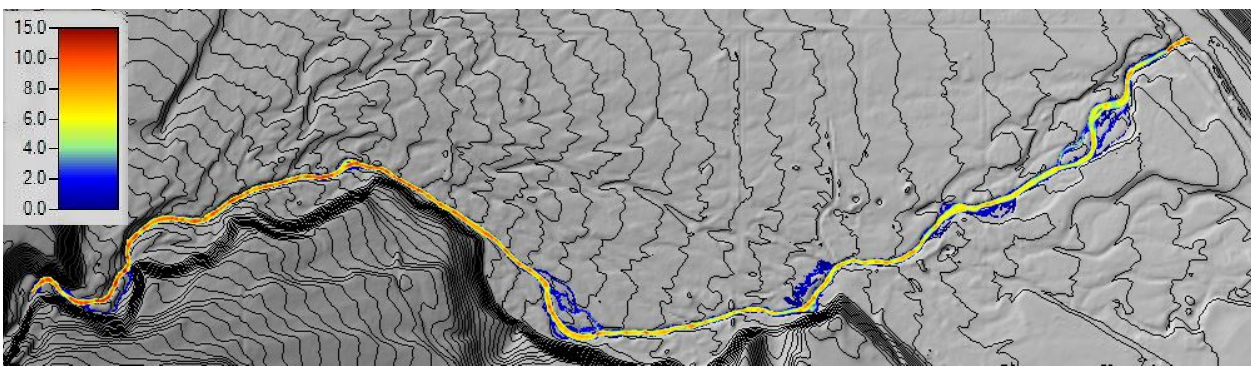


Figure 18. Modeled velocities under existing conditions at the 2-year flow event (263 cfs).

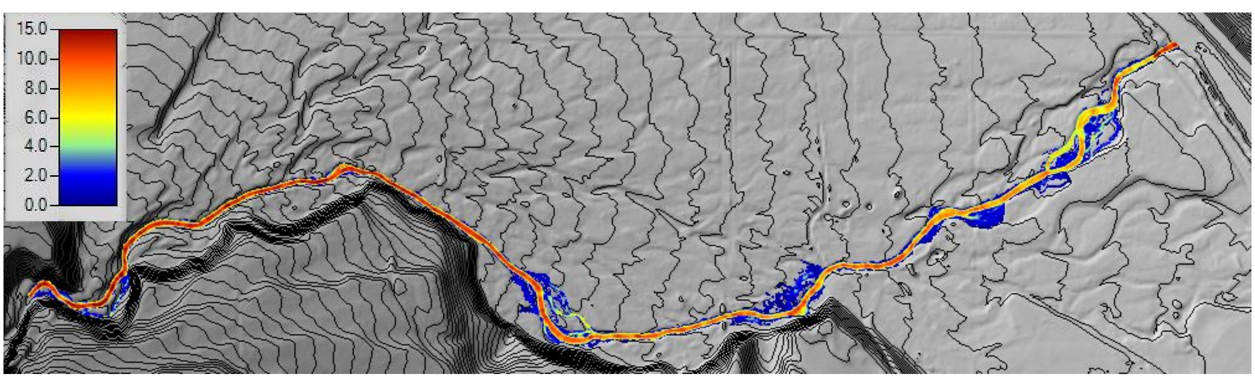


Figure 19. Modeled velocities under existing conditions at the 10-year flow event (637 cfs).

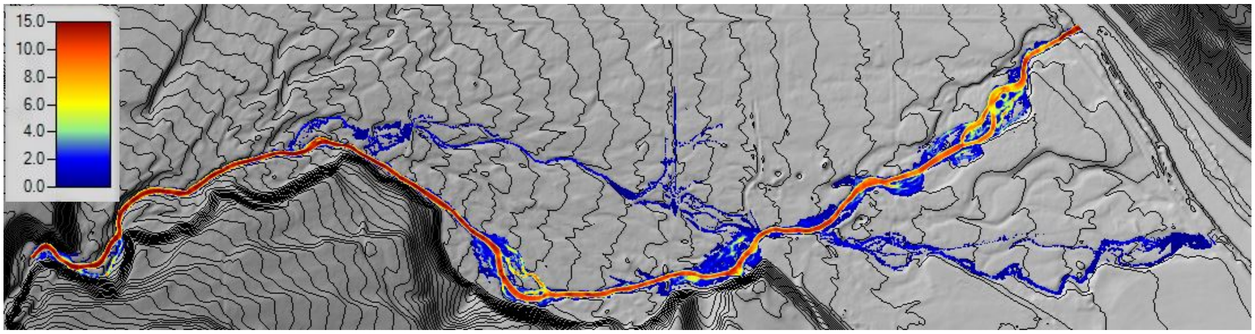


Figure 20. Modeled velocities under existing conditions at the 50-year flow event (1,110 cfs).

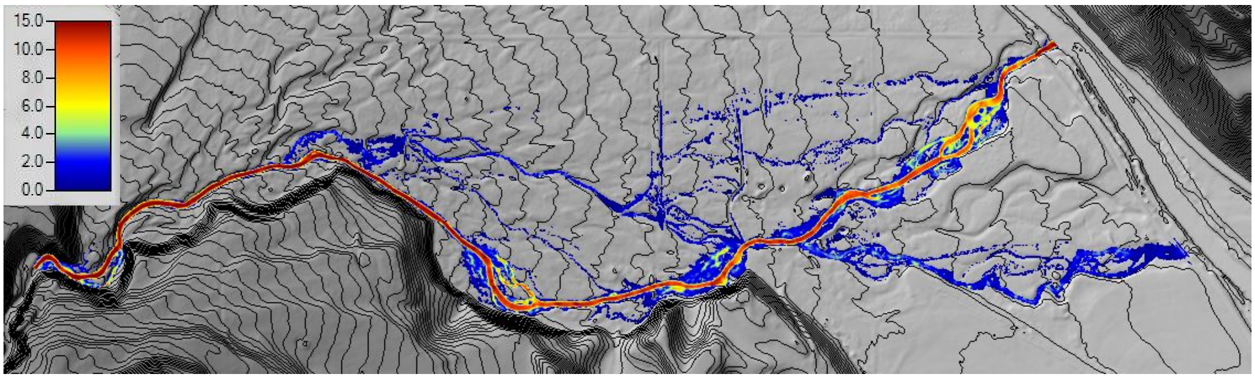


Figure 21. Modeled velocities under existing conditions at the 100-year flow event (1,340 cfs).

Preliminary model results of flow velocity and inundation confirm field observations that, at existing conditions with anthropogenic confinement and channel entrenchment throughout much of Reach 1, flood flows remain within the entrenched/leveed channel until between the estimated 25- and 50-year flood discharges. This also confirms the degree at which the channel is disconnected from its historical alluvial fan/abandoned floodplain surface. Even at the 100-year estimated discharge, the mouth of the channel is confined and unable to develop river-delta habitat conditions. By the 50-year modeled discharge, surface flows at levee breaches finally begin to wet the alluvial fan. Secondary perpendicular levees and ditches constructed on the alluvial fan for additional property protection are activated at the higher discharges.

Where inset floodplain features exist, high-flow side channels show as activated at the 2-year modeled discharge. Confinement in large sections of Reach 1 produces relatively high flow velocities in the channel, even at the 2-year flood discharge. As expected, velocities are higher in the more confined sections of the reach. This correlates to the increase in bedload grain size from downstream to upstream, as observed during the field survey. The modeled velocities also correlate to the stream power analysis described above.

2.9 GEOMORPHOLOGY

Developing a successful habitat restoration strategy requires an understanding of the geomorphic processes and trends of the modern channel, floodplain, and contributing hillslopes. This section provides an overview of the geomorphology of the watershed as well as a summary discussion on the primary geomorphic features of Wolf Creek from RM 0–4.53. The information presented here is based on field-based survey observations (October 1 – 5, 2019 and July 7 & 8, 2020) combined with available digital and printed data and reports (as referenced). Detailed discussions of geomorphic conditions and trends at the reach-scale are provided in Section 3.

The Wolf Creek watershed is a relatively steep montane system that initiates off the mountain tops and high meadows of glacially carved peaks and ridges such as Gardner Mountain, Story Peak, and Abernathy Peak, located in the eastern foothills of the North Cascades. Small glacially carved headwater meadowed valleys define the upper drainages of the streams. Downstream, the channel and its tributaries into v-shaped hillslope confined valleys eroded by fluvial processes. The channel is primarily single-thread at base-flow with a planform defined by the pathway the river cut into the underlying geology and the resulting hillslope and tributary contributions. Bedrock exposures and head scarp scars on hillslopes indicate that mass wasting processes such as landslides and debris flows supply periodic contributions of sediment and likely large wood to the system. It is probable that such contributions have temporarily blocked or confined sections of the channel in the past.

Within the hillslope-confined portion of the study area (RM 1.34–4.53), the valley bottom varies in widths with alternating bedrock bank exposures that maintain channel form. When Wolf Creek exits the mountains at RM 1.34, it then flows across its historical alluvial fan before it terminates at its confluence with the Methow River at RM 0. Remnants of the channel’s paleo fan surfaces exist as terraces at the top of the alluvial fan. Brief descriptions of the primary geomorphic features (see Figure 22) in the assessment area are provided below (hillslopes, valley, floodplains, terraces, fans, tributaries, and channel). Reach-scale maps of geomorphic surfaces are provided in Section 3.

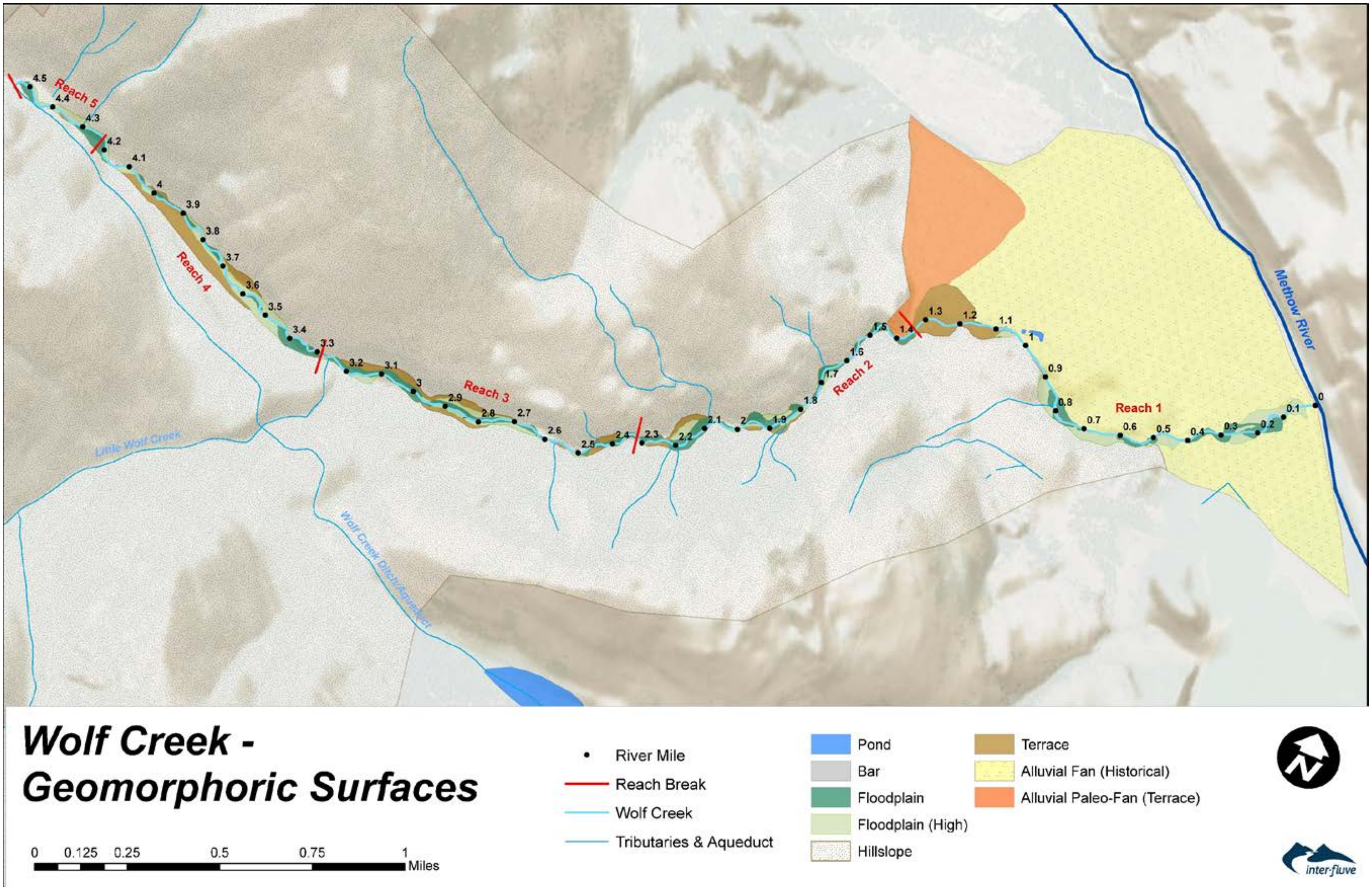


Figure 22. Geomorphic surfaces of the Wolf Creek assessment area (RM 0-4.53).

2.9.1 Hillslopes and Valley

The hillslopes that contribute sediment to and host tributaries of the Wolf Creek assessment area are relatively steep and vegetated with sparse conifer forests. Their geologic composition is a mix of conglomerate, marine sedimentary and continental sedimentary rock (see Geology, Section 2.2). These bedrocks are moderately erosive and thus form relatively open v-shaped walls. The hillslopes and valley of Wolf Creek were created by the gradual process of downcutting over millennia via fluvial erosion and mass wasting. Alpine glaciers did not extend into the assessment area during the last glacial period but the Cordilleran Ice Sheet covered it and draped the hillslopes with glacial till during their recession. Hillslope soil composition and slope is provided in Figure 9 (see Section 2.2.2). The hillslope-valley form is generally "V" shaped and thus there is a high degree of natural hillslope toe to channel coupling that influences channel form, shape, confinement, and sediment supply. Bedrock bank exposure often occur in the confined section where the channel contacts hillslope toes on alternate sides of the valley. Hillslope and tributary contributions in the form of landslides and debris flows have and will continue to influence river morphology through sediment contribution and wood routing to the channel. Future land use planning and management in the area should consider the potential for an increase in triggered sediment and wood inputs from the hillslopes from activities such as logging and road building, or increased risk of wildfires, as has been described in similar montane systems (Beschta et al., 2004; Silins et al., 2009).

Figure 23. Hillslopes of the Wolf Creek assessment area. Looking up-valley from Reach 2 with the headwater source ridges in the background. (Photo: 7/8/2020)

The valley floor upstream of RM 1.34 is confined by hillslopes throughout the assessment area. The width of the modern valley floor ranges from approximately 250 feet to 25 feet. Downstream of RM 1.34 the channel remains anthropogenically confined across the wide historical Wolf Creek alluvial fan. The valley floor of Wolf Creek is composed of both alluvial (river reworked and deposited) and colluvial (hillslope contributed) materials. Valley width and gradient is influenced by valley down-cutting, bedrock grade controls, and hillslope sediment contributions. Floodplains and paleo-floodplain terraces exist where valley width allows.

2.9.2 Terraces, Floodplains, and Fans

Terraces in the Wolf Creek assessment area are alluvially created or re-worked depositional surfaces that are no longer connected to or inundated by the channel during flood flows. Terraces, if adjacent to the channel, can contribute sediment, large wood, and nutrients, especially when lateral channel processes result in bank toe erosion or via mass wasting processes such as slope failure landslides. The terraces are composed primarily of alluvially reworked glacial till previously draped on the landscape combined with additional sediment contributions (upstream, hillslopes, tributaries) formed during regional glacial recessions when larger discharge and sediment regimes occurred (see Section 2.2.1). Since the last glacial recession, discharge and sediment regimes (flow capacity and quantity of available sediment) of Wolf Creek and the Methow River have decreased. The rivers adjusted to these changes by incising into the historical floodplain surfaces and converting them to terraces. The terraces in Reach 4 on river right are stair stepped with evidence of paleo-channel scars, revealing periods of relative equilibrium where inset floodplains formed in sequences, converting abandoned floodplains to terraces (Figure 24).

Figure 24. Horizontal terrace surface in Reach 4 (river right) with paleo-channel scar topography (vegetated). (Photo: 10/5/2019)

The paleo alluvial fan terrace located at the apex (upstream end) of the modern Wolf Creek alluvial fan is another remnant of the historical discharge and sediment regimes. It is assumed that the paleo-fan surface correlates to upstream high terrace surfaces. However, it is not possible to determine which terraces are correlated without further research beyond the scope of this assessment. Inset below the paleo-fan terrace is a modern fan terrace maintained by leveeing and subsequence channel entrenchment. The floodplain surfaces of Wolf Creek range in size and distribution, depending on anthropogenic and/or hillslope confinement. Across the alluvial fan (Reach 1) modern floodplain surfaces are limited to pockets and strips along the entrenched channel. Based on modern vegetation, surface elevations, observed high-water indicators, and channel form the low floodplain surfaces are expected to get inundated during high flow events at least every 1-5 years. The high floodplain surfaces are expected to be inundated every approximately 5-25 years.

Floodplain surfaces throughout the project area are vegetated, but the maturity and composition of the vegetation varies depending on land-use history. The floodplain surfaces are composed primarily of alluvial deposits. However, in the hillslope confined reaches (2-5) hillslope colluvium also contributes materials to the construction of floodplain surfaces. Floodplain materials generally include a boulder and cobble base strata that is topped with gravels and sand. The upper soil layer is generally gravelly ashy sandy loam. The mixed coarse-grained composition of the floodplain and active bar material indicates that hyporheic flow exchange is expected. Some loss of surface water via infiltration is also expected across the alluvial fan during seasonal low-flow periods. No reports or data were found that indicate the rate of infiltration or discharge loss and no records indicate modern channel drying due to infiltration. Currently, in-water discharge requirements at the mouth of the channel regulate upstream irrigation withdrawals so that the mainstem channel maintains perennial surface water flow (see Section 2.5).

Alluvial fans or debris fans form where the slope of a contributing flow-path is reduced and available lateral area increases – allowing for sediment to be deposited and accumulate. Alluvial fans are usually developed over time from a sequence of depositional events that shift the location of the primary flow-path(s) across the apron of the fan. In montane environments, fans usually form at the edge of a valley along the toe of hillslopes or at the mouth of a tributary which has a greater slope than the channel and valley it is contributing to. Unlike a floodplain surface that generally has a horizontal down-valley slope to its surface, an alluvial fan often has a subtle convex apron shape with an axis that slopes towards the valley it is developing in. Fans can be reworked into floodplain features or truncated by the channel in which it is contributing. The paleo-alluvial fan surface of Wolf Creek, located at the top of the modern fan, has been truncated on the north side by the Methow River and on the southeast side by Wolf Creek. Incision and anthropogenic infrastructure exaggerate abandonment of Wolf Creek's alluvial fan (historical and modern) such that most of the fan now functions as a disconnected terrace surface.

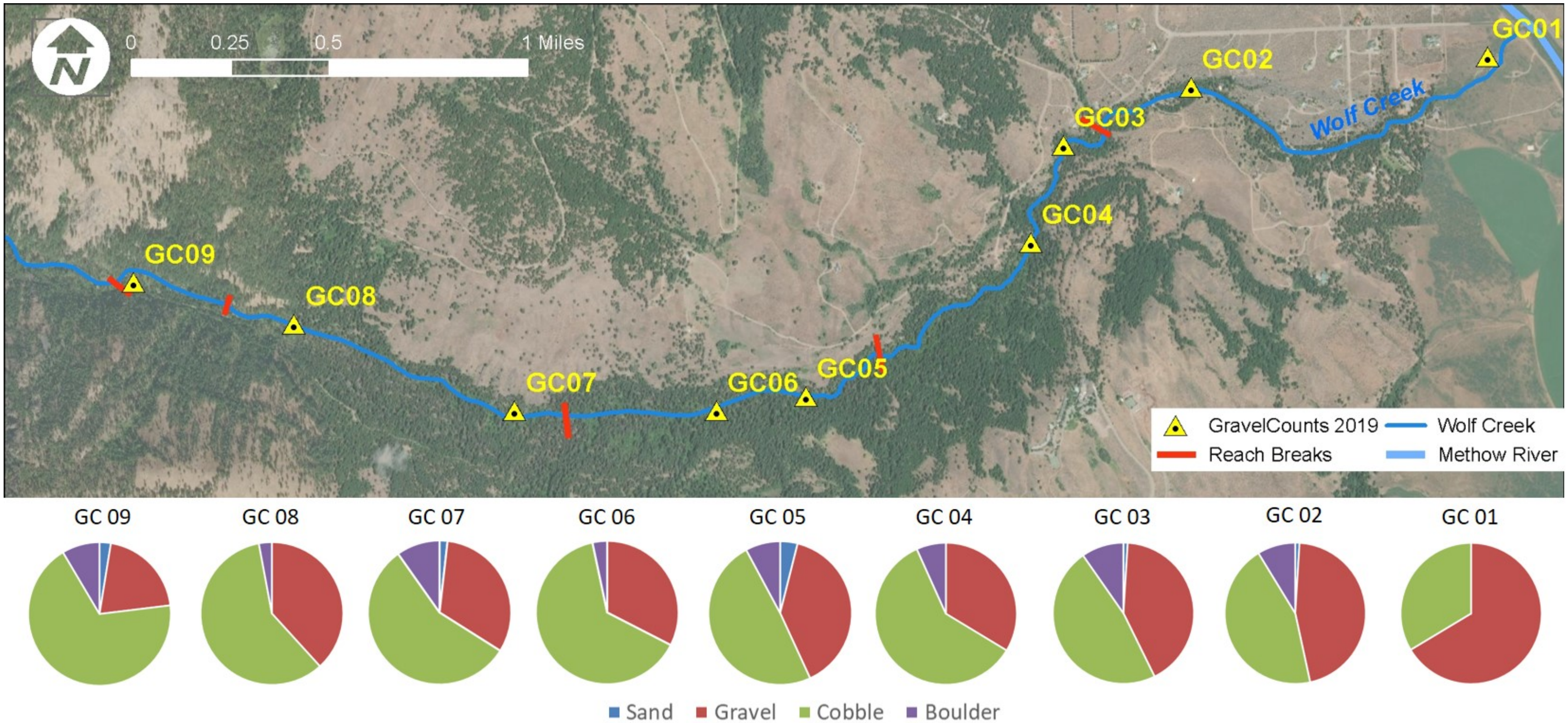
2.9.3 Tributaries and Channel

Wolf Creek is a montane river system that alternates between confined and partially confined. Channel form is straight to moderately sinuous. Substrate is primarily gravel-cobble-boulder alluvium and size distribution varies depending on gradient, proximity to active sediment sources, and geomorphic complexity. For example, an extended riffle in a low gradient, entrenched section (Reach 1) has a cobble-boulder substrate composition (i.e., lack finer sediments and gravels), while a boulder or log-step in a higher gradient section creates localized reduction in stream energy where accumulations of gravels occur at tail outs or in back-eddies associated with boulders and large wood. This reflects a mixed-size bedload transport capacity (i.e., coarse sand to small boulder) that is driven both by stream power and local sediment supply and/or lack thereof. Bedrock bank and bed contacts occur periodically on alternating sides of the channel in Reaches 2-4 and immediately upstream of the assessment boundary (river right side). Large boulder colluvium and boulder steps act as mainstem grade control elements where they occur in the channel and add geomorphic complexity in the hillslope confined Reaches 2-5.

The tributaries of Wolf Creek within the assessment area are primarily ephemeral–except Little Wolf Creek. However, the Wolf Creek irrigation ditch/aqueduct captures all the flow from Little Wolf Creek between April to September so its contributions to Wolf Creek are currently considered seasonal ephemeral instead of perennial. The several unnamed ephemeral streams that contribute seasonal inputs in the assessment area are steep and relatively small in upstream acreage. Except for Little Wolf Creek, the ephemeral tributaries provide minimal annual discharge to the channel. However, it is likely that many of them do or have served as contribution routes of sediment to the mainstem or supplied debris flows or landslide material to the valley floor, and may serve this purpose again in the future. A small alluvial fan composed of cobbles and gravels at the mouth of Little Wolf Creek confirms that it seasonally provides discharge and sediment inputs to Wolf Creek. Multiple spring seeps sourced at the boundary of a terrace surface on river right enter the mainstem channel at RM 2.77, 2.84, 2.86, and 2.94. The seeps were wetted during both surveys (Oct 2019 and July 2020), and vegetation around the springs is well established, suggesting they are perennial discharge sources to the mainstem.

The mainstem channel is primarily single thread in channel form. Split-flow conditions and high-flow side channels occur where available floodplain width provides. Split-flow conditions in the assessment area correlate to large wood accumulations and/or large boulders that instigate and/or maintain hydraulic complexity. These areas provide the highest quality habitat zones in the assessment area.

Nine bedload sediment surveys (gravel counts) were performed during the October 2019 field surveys following the Wolman Pebble Count method (1954). This method includes sampling and measuring a minimum of 100 separate pieces of sediment from a representative bed feature. The substrate of Wolf Creek within the assessment area is composed primarily of cobble and gravel with sparse boulders and minimal sands. Figure 25 provides the locations of the gravel count surveys and the distribution of grain sizes at each count.



Material	GC 09 Percent Composition	GC 08 Percent Composition	GC 07 Percent Composition	GC 06 Percent Composition	GC 05 Percent Composition	GC 04 Percent Composition	GC 03 Percent Composition	GC 02 Percent Composition	GC 01 Percent Composition
Sand	3%	0%	2%	0%	4%	0%	1%	1%	0%
Gravel	21%	38%	32%	33%	39%	34%	42%	46%	66%
Cobble	68%	59%	56%	64%	49%	60%	48%	45%	34%
Boulder	9%	3%	10%	3%	8%	7%	10%	9%	0%
Size Class	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**	**Size percent finer than (mm)**
D16	48	35	45	51	33	19	28	22	16
D50	112	78	93	87	72	118	77	72	40
D84	193	143	211	140	147	181	187	216	87

Figure 25. Gravel Count locations and grain size distribution results (Inter-Fluve: Oct 2019)

2.10 LARGE WOOD MATERIAL (LWM)

Pieces of large wood (≥ 6 inches diameter) in a channel contribute nutrients, shade, cover, and promote habitat complexity suitable for many riverine species (Langford et al., 2012). Quality large woody material (QLW) (≥12-in dbh and at least 35 feet long) in a channel is expected to influence local geomorphic processes and increase channel complexity by promoting scour and erosion related to the induced flow hydraulics associated with them and by redirecting or splitting flow pathways (Grabowski & Gurnell, 2016; Langford et al., 2012; Montgomery & Piégay, 2003). The quantity of quality LWM within a riverine system depends on the presence of mature or maturing forests, as well as the processes of recruitment such as infall from banks, debris flows or landslides off hillslopes, in-channel transport, etc. Tree size (length and diameter) compared to active channel width, channel form, and flow regimes control retention and accumulation patterns of the LWM in the channel.

Within the project area of Wolf Creek, LWM currently plays an important role in the modern geomorphology. Where LWM occurs, it is associated with habitat complexity. A total of 210 pieces of channel-influencing QLW (sized medium and large) LWM were counted during field surveys (Oct 1 to 5, 2019) within the 4.53 river miles included in the assessment area (see Section 3.4 in Appendix A). Of the quality LWM identified in the 2019 survey, Reach 1 (RM 0-1.34) contains 4.5% (10 pieces), Reach 2 (RM 1.34-2.31) contains 31% (65 pieces), Reach 3 (RM 2.31-3.27) contains 26% (55 pieces), Reach 4 (RM 3.27-4.21) contains 30% (63 pieces), and Reach 5 (RM 4.21-4.53) contains 8% (17 pieces). Reaches 1 and 2 do not meet minimal quality LWM metrics for habitat function. Thirteen large wood jams (>10 pieces of LWM) were recorded in the assessment area during the 2019 habitat survey. Of the thirteen, six of the jams are located in Reach 4, three are in Reach 2 and Reach 3, and one is in Reach 5. No LW jams were recorded in Reach 1. Homes and structures, levees, roads, and vegetation clearing in Reach 1, and historical logging in a small section of Reach 2, has reduced local available mature forest contributions. Adding large wood would improve both geomorphic and habitat complexity throughout the assessment area.

Land use practices on the Wolf Creek alluvial fan (Reach 1) impact both channel and floodplain processes. For example, surface grading and vegetation clearing near homes altered floodplain contributions (large wood and nutrients) and thus further reduced habitat complexity. Levee construction and channel dredging impede potential floodplain connectivity and natural lateral channel processes across the historical alluvial fan. Maintenance and safety requirements associated with human-built infrastructure such as irrigation outtakes, bridges, utility crossings, etc. have likely resulted in periodic “cleaning” of wood from the channel, further reducing natural retention of LWM contributions from the existing riparian area in Reach 1. These activities have simplified aquatic habitat in Reach 1. To partially mitigate for these impacts, seven pieces of partially buried large wood and boulder weirs were installed in the lower section of Reach 1 in 2000 by the Wolf Creek Reclamation District and several private landowners (Figure 26), accounting for most of the pieces of LW counted in the 2019 survey.

Figure 26. Partially buried LW at RM 0.05 on river right in Reach 1. (Photo: 10/1/19)

2.11 VEGETATION

Riparian vegetation in the Wolf Creek assessment area generally consists of a mid- to late-seral stage coniferous overstory with a dense shrub/sapling understory. The primary overstory species included Douglas fir (*Pseudotsuga menziesii*), western red Cedar (*Thuja plicata*), black Cottonwood (*Populus trichocarpa*), Ponderosa pine (*Pinus ponderosa*) and mountain Alder (*Alnus icana*). Douglas fir is more prominent in the downstream reaches and less prominent in the upstream reaches. Generally, tree age and size increase upstream through the project area with the largest overstory tree canopy, "mature tree", occurring in Reaches 3-5. Understory species in Reach 2-5 are dominated by red osier dogwood (*Cornus sericea*), Vine maple (*Acer circinatum*); Snowberry (*Symphoricarpos occidentalis*); and Cedar (*Thuja plicata*). Understory species also increase in diversity and density upstream of Reach 1. Understory vegetation in Reach 1 was primarily grasses and Alder as a result of the increased density of human land use and vegetation clearing within the riparian area. Hillslope vegetation is primarily coniferous forests dominated by pine with an understory composed of transitional or upland grasses and shrubs. Forest density on hillslopes correlates to soil depth, proximity to water, and aspect (subtly).

2.12 AQUATIC HABITAT CONDITIONS

Water temperatures were monitored in Wolf Creek between 2016 and 2019 near the mouth (RM 0.1) and near the Wolf Creek irrigation withdrawal at RM 4.53 (at the upstream extent of the assessment area) by the Methow Salmon Recovery Foundation (MSRF, 2019). Seasonal temperature data ranges from 0^{o}C on colder winter days, to 20.7^{o}C on July 30, 2018 (Figure 27). The raw data indicate that over the period of record, mean and maximum daily water temperatures are often higher at the mouth of the channel compared to upstream, on the same day, from early summer through autumn by up to three degrees Celsius.

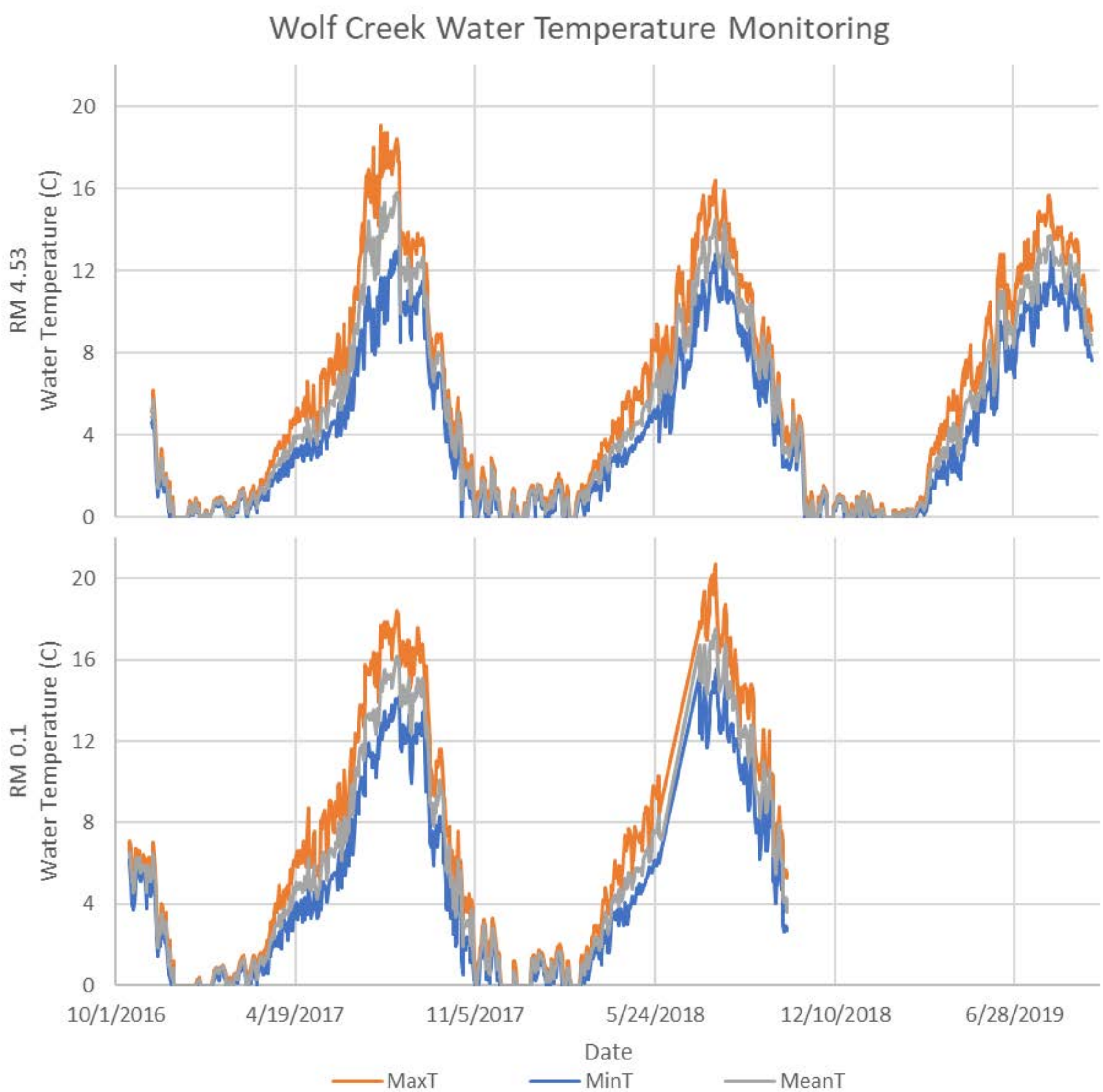


Figure 27. Water temperatures recorded in Wolf Creek near the mouth (RM 0.1) and near the diversion (RM 4.53) which is the upstream extent of the study area.

The 7-day average daily maximum water temperatures (7DADMax) were calculated from these data and is shown in Figure 28. The 7DADMax at the mouth of Wolf Creek exceeded the thermal criteria of 17.5°C set by the state of Washington for salmonid spawning, rearing and migration for only three days in 2017 and for a total of 22 days in 2018, between mid-July and mid-August. Water temperatures recorded upstream near the irrigation diversion exceeded the 17.5°C thermal criteria in 2017 for a total of 10 days between late July and mid-August. Temperatures at the diversion did not exceed the criteria in 2018 or 2019.

Thermal criteria for core salmonid summer habitat thermal criteria is 16°C in the State of Washington. Based on the 7DADMax, thermal criteria for salmonid summer habitat was exceeded at the mouth in both 2017 and 2018. In 2017, the 7DADMax exceeded 16°C for a total of 41 days, between July 23 and August 22, 2017, and then again between August 29 and September 7. In 2018, the 7DADMax exceeded 16°C for a total of 36 days between July 14 and August 18. Water temperatures recorded upstream near the irrigation diversion exceeded the 16°C thermal criteria in 2017 for a total of 28 days between July 9 and 13 and then again between July 21 and August 12. Temperatures at the diversion did not exceed the 16°C criteria in 2018 or 2019.

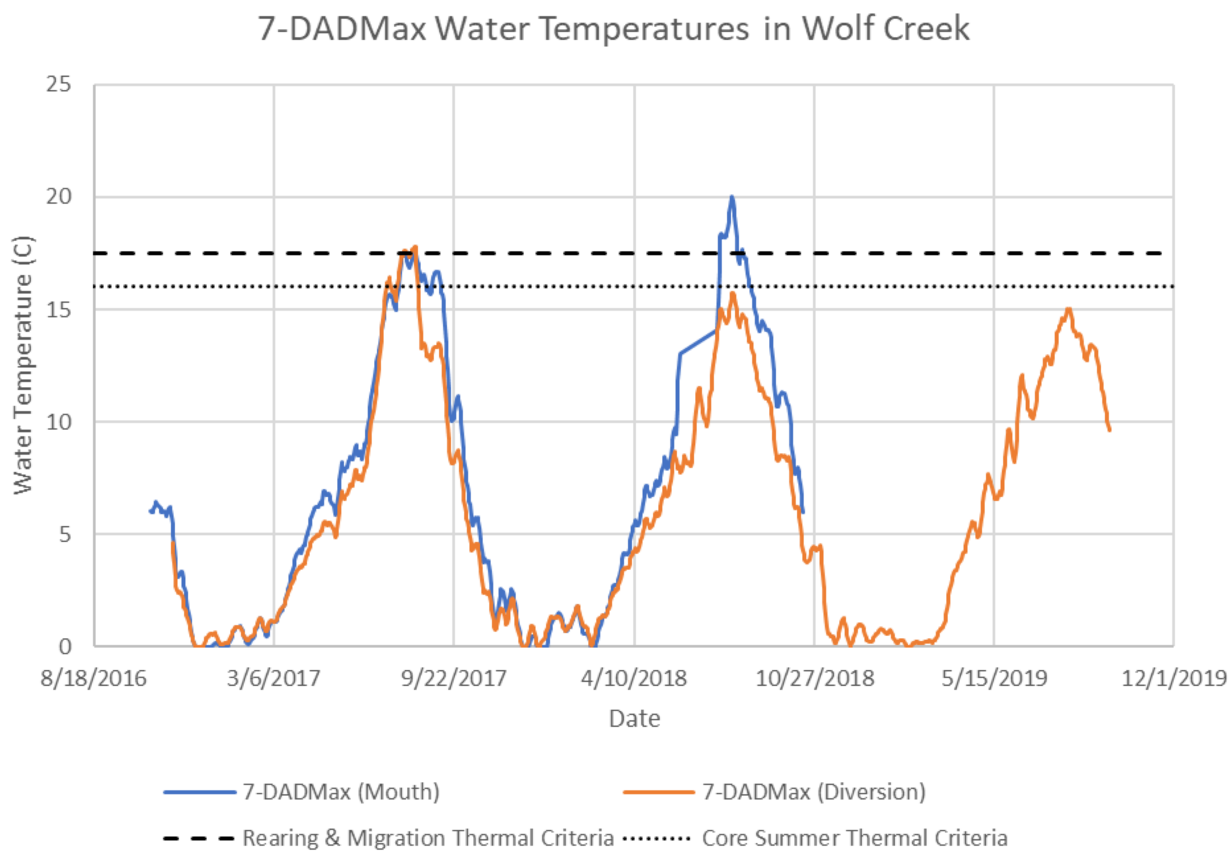


Figure 28. Wolf Creek water temperature monitoring near the mouth (RM 0.1) and upstream of the Wolf Creek irrigation withdrawal at RM 4.53 (which is the upstream extent of the study area) between fall 2016 and 2019. Thermal criteria set by the State of Washington for salmonid spawning, rearing, and migration (17.5°C) is shown with the black dashed line and core summer salmonid habitat (16°C) is shown with the black dotted line. (source: J. Crandall – 2020)

Monitoring by the USFS in 2005 also found water temperatures in the lower 4.4 miles of Wolf Creek exceeded USFWS standards for bull trout rearing and migration, and exceeded NOAA Fisheries standards for anadromous fish habitat. During the summer of 2005, water temperatures were approximately 1-2°C warmer in Wolf Creek than the Methow River at their confluence, while water temperature sampling in August 2009 recorded temperatures of 17.4°C in Wolf Creek and 15.7°C in the Methow near their confluence (USFS, 2005; Watershed Sciences, 2009). Water temperatures in the off-channel ponds in Reach 1 at RM 1 on river left were recorded in 2017-2018. According to the reported temperature logger data, pond temperatures approached 20°C in the summer months (Eckmann, 2018).

The Wolf Creek Stream Habitat Assessment (Appendix A) provides an inventory of the habitat conditions in the Wolf Creek Assessment area. Reach 1 (RM 0-1.34) has limited deep pools and a large proportion of higher velocity riffles. Based on field survey (2019), spawning areas and refugia in Reach 1 have been reduced as a result of channel simplification and confinement. The upstream reaches (2-5) are naturally confined or partially confined and have relatively steeper gradients with larger substrates. Spawning gravels are limited to marginal eddies or at large wood accumulation zones. Rearing habitats are limited. Spawning habitat is found mainly at the pool crests, along the channel margins, and behind accumulations of large wood. According to past surveys, spawning gravels are most abundant above the South Fork of Wolf Creek (upstream of the assessment area), where only cutthroat trout are found, and in the two lower gradient reaches (Reaches 1 and 4) in the assessment area compared to elsewhere in the basin (USFS, 2005). Key pieces of large wood are lacking in the lower reaches (Reaches 1 and 2). The proportion of surface fines in the channel meet conditions suitable for salmonid habitats throughout the study area. A summary of key habitat metrics is provided in Table 4.

Table 4. Summary of key habitat metrics recorded during habitat survey in 2019. *S.Ch = Side Channel; LWM = Large Woody Material; ST = Small Tree; S/P = Sapling/Pole; S/S = Shrub/Sapling*

Habitat Metric	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Habitat Areas (%)	Pool: 18% Glide: 3% Riffle: 79% S.Ch: 0%	Pool: 11% Glide: 0% Riffle: 85% S.Ch: 4%	Pool: 15% Glide: 1% Riffle: 81% S.Ch: 3%	Pool: 13% Glide: 0% Riffle: 83% S.Ch: 4%	Pool: 20% Glide: 0% Riffle: 80% S.Ch: 0%
Substrate (% gravel)	56%	38%	36%	35%	21%
Quality LWM / mile	7.5	67	50	74	53
Pools / mile	17.9	21.6	16.7	19	34
No. pools w/ residual depths >3 ft	1	0	0	2	2
No. side channels	0	7	3	6	0
Riparian conditions	44% ST 33% S/P 22% S/S	86% ST 14% S/P	100% ST	80% ST 20% S/P	100% ST

The private off-channel ponds in Reach 1 near RM 1 are connected to the mainstem via an irrigation outtake supported by a grade control constructed of large boulders in the mainstem channel. Water retrieved at the outtake flows through a sequence of ditches and culverts to the ponds and then through more ditches back to the mainstem channel. Because they do maintain downstream connectivity, the ponds offer off channel habitat. However, fish stranding risk is of concern due to the small size of the culverts, limited upstream passage due to culvert placement and water drop, overwintering conditions, and periods of limited passage due to debris or other blockages. Both adult (spawning) and juvenile (rearing) fish use have been documented in the ponds and downstream return-flow ditch, including rearing juvenile Spring Chinook and steelhead (Eckmann, 2018). The proximity of the ponds to the confluence of Wolf Creek and the Methow River (1 river mile) suggests that juveniles may originate from the Methow and utilize the ponds as off channel rearing habitats. Hatchery release of juvenile Coho have utilized the return-flow ditch for climatization to the system. It is also possible that the juveniles have been naturally spawned in the outlet channel of the pond system where spawning has been documented in redd surveys between 2009 and 2012 (pers. Comm. Charles Frady, WDFW via YNF).

In summary, habitat conditions in the Wolf Creek assessment area include a large proportion of higher velocity riffles and a minimal number of pools with even fewer glides and side channel habitat units. Based on field observations, aquatic habitat conditions for salmonids are limited in Reach 1, 2, and partially 3. The presence of large wood and relatively mature forests within the riparian borders of Reaches 3-5 provide comparatively more complex habitat. Channel-spanning and complex log jams produce local reductions in channel gradient and maintenance of covered scour pools. LW jams without QLW pieces are considered transitory in the higher energy, confined sections of the channel. Micro-pools located behind large boulders and at step-pools provide some velocity refuge for salmonids and bull trout migrating upstream or holding in the system, depending on the flows. There is concern that temperature may, or has already, become impaired in Reach 1 with increased development, vegetation removal and climate change impacts (see Section 2.6.1). For more information on habitat conditions in the assessment area and for each reach, please see Appendix A.

2.13 REACH-BASED ECOSYSTEM INDICATORS (REI)

The complete REI assessment is available as Appendix B to this report. This section provides a summary of the REI results.

Watershed-scale ratings for Wolf Creek were varied, ranging from **Adequate** to **Unacceptable**. Both the Drainage Network and Disturbance Regime indicators were rated **Adequate** for the study area, while the Streamflow indicator received an At Risk rating. Water temperature monitoring in the study area indicates temperatures often exceed thermal criteria for salmonids, therefore, the Temperature indicator was rated **Unacceptable**.

In the reach-scale metrics, Reach 1 is the most impacted reach with eight **Unacceptable** ratings, the most of all the reaches, and one **At Risk**. Reach 2 had only one **Unacceptable** rating and three **At Risk** ratings. The legacy of historical and ongoing human disturbances – including timber harvests, development for residential and lack of instream large wood – have contributed to the ecosystem impacts in Reaches 1-2. Reaches 3 through 5 were the least impacted to varying degrees; Reach 3 had the most **Adequate** ratings (10) with one **Unacceptable** rating, while Reach 4 has the most **Adequate** ratings with just one At Risk rating and Reach 5 has three **At Risk** ratings while all other metrics are **Adequate**.

All reaches received **Adequate** ratings for the Habitat Access Pathway- Main Channel Barriers and Dominant Substrate/Fine Sediment indicators since there were no barriers within the main channel that completely excluded fish passage and there is a lack of sands and small gravels that can be detrimental to egg incubation.

LWM ratings increased from **Unacceptable** in Reach 1 and **At Risk** in Reach 2 to **Adequate** in Reaches 3–5. The lower reaches had low numbers of large wood pieces, especially quality pieces of large wood and lacked potential large wood recruitment. Pool frequency was rated **Unacceptable** in Reaches 1–3 and **At Risk** in Reaches 4–5 due to low pool frequency and low quality of the pools (low residual depths and minimal/no large wood cover or habitat). The Off-channel Habitat indicator was rated as **Unacceptable** for Reach 1 and **At Risk** for Reaches 3 and 5 due to either the complete lack or very infrequent occurrence of connected alcoves and side channels.

Riparian vegetation condition indicators, Structure and Canopy Cover, were both rated **Unacceptable** for Reach 1 and **At Risk** for Reach 2. Though the observed seral stage of the riparian vegetation in Reaches 3–5 was classified as primarily small trees, these reaches were rated **Acceptable** in both Structure and Canopy Cover indicators because there is no modern history of human disturbances in these reaches and mature forests are established on the floodplains– suggesting this is the natural condition of the riparian buffer. Reaches 1 and 5 received **At Risk** ratings in the Human Disturbance indicator due to the number of residences, confinements, and developed areas within the riparian zone of Reach 1 and the irrigation withdrawal infrastructure and access road on the hillside that periodically is adjacent to the river in Reach 5. Reaches 2–4 received ratings of **Adequate** for this indicator due to minimal roads and development located within the riparian zone of these reaches.

Channel dynamics for Reach 1 is unsatisfactory. Reach 1 received **Unacceptable** ratings in all three indicators: Floodplain Connectivity, Bank Stability/Channel Migration, and Vertical Channel Stability due to anthropogenic channel entrenchment/confinement. Reaches 2–5 were rated **Adequate** for all three Channel Dynamics indicators.

For the study area as a whole, **Adequate** was the most common rating (36), followed by **At Risk** (9) and **Unacceptable** ratings (10 each). A summary of the ratings is presented in Table 4.

Table 5. Summary table of the Wolf Creek Reach-based Ecosystem Indicators (REI) analysis results. (See Appendix B for details)

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Habitat Access	Physical Barriers	Main Channel Barriers	Adequate	Adequate	Adequate	Adequate	Adequate
Habitat Quality	Substrate	Dominant Substrate / Fine Sediment	Adequate	Adequate	Adequate	Adequate	Adequate
	LWM	Pieces per Mile at Bankfull	Unacceptable	At Risk	Adequate	Adequate	Adequate
	Pools	Pool Frequency and Quality; Presence of Large Pools	Unacceptable	Unacceptable	Unacceptable	At Risk	At Risk
	Off-Channel Habitat	Connecivity with Main Channel	Unacceptable	Adequate	At Risk	Adequate	At Risk
Riparian Vegetation	Condition	Structure	Unacceptable	At Risk	Adequate	Adequate	Adequate
		Disturbance (Human)	At Risk	Adequate	Adequate	Adequate	At Risk
		Canopy Cover	Unacceptable	At Risk	Adequate	Adequate	Adequate
Channel	Dynamics	Floodplain Connecivity	Unacceptable	Adequate	Adequate	Adequate	Adequate
		Bank Stability / Channel Migration	Unacceptable	Adequate	Adequate	Adequate	Adequate
		Vertical Channel Stability	Unacceptable	Adequate	Adequate	Adequate	Adequate

3. Reach-Scale Conditions

The Wolf Creek (RM 0-4.53) assessment area was divided into five distinct geomorphic reaches to facilitate description and discussion of local channel characteristics and restoration needs (Figure 29). Reaches were delineated at major tributary confluence and by physical transitions in channel form, gradient, degree of sinuosity, bedload, and floodplain connectivity. Reaches are numbered from downstream to upstream within the assessment area. Geomorphologists walked each reach in the assessment area to characterize physical conditions and channel processes as well as identify restoration treatment opportunities. Specifically, we focused on: 1) channel incision and channel evolution trends, 2) substrate type, distribution, and sediment availability, 3) surface and subsurface flow interactions, 4) channel bank composition and migration patterns, 5) floodplain and habitat connectivity, 6) occurrence and influence of large woody material, and 7) influence of past and current human structures and activities. Information from the reach-scale geomorphic assessment is used to inform the REI analysis. Table 5 includes a set of metrics used to help characterize each reach. In addition to the channel and floodplain information in the metrics table, discussion about reach-scale vegetation condition, large wood, the location and influence of human-built features, and treatment recommendations are provided below.

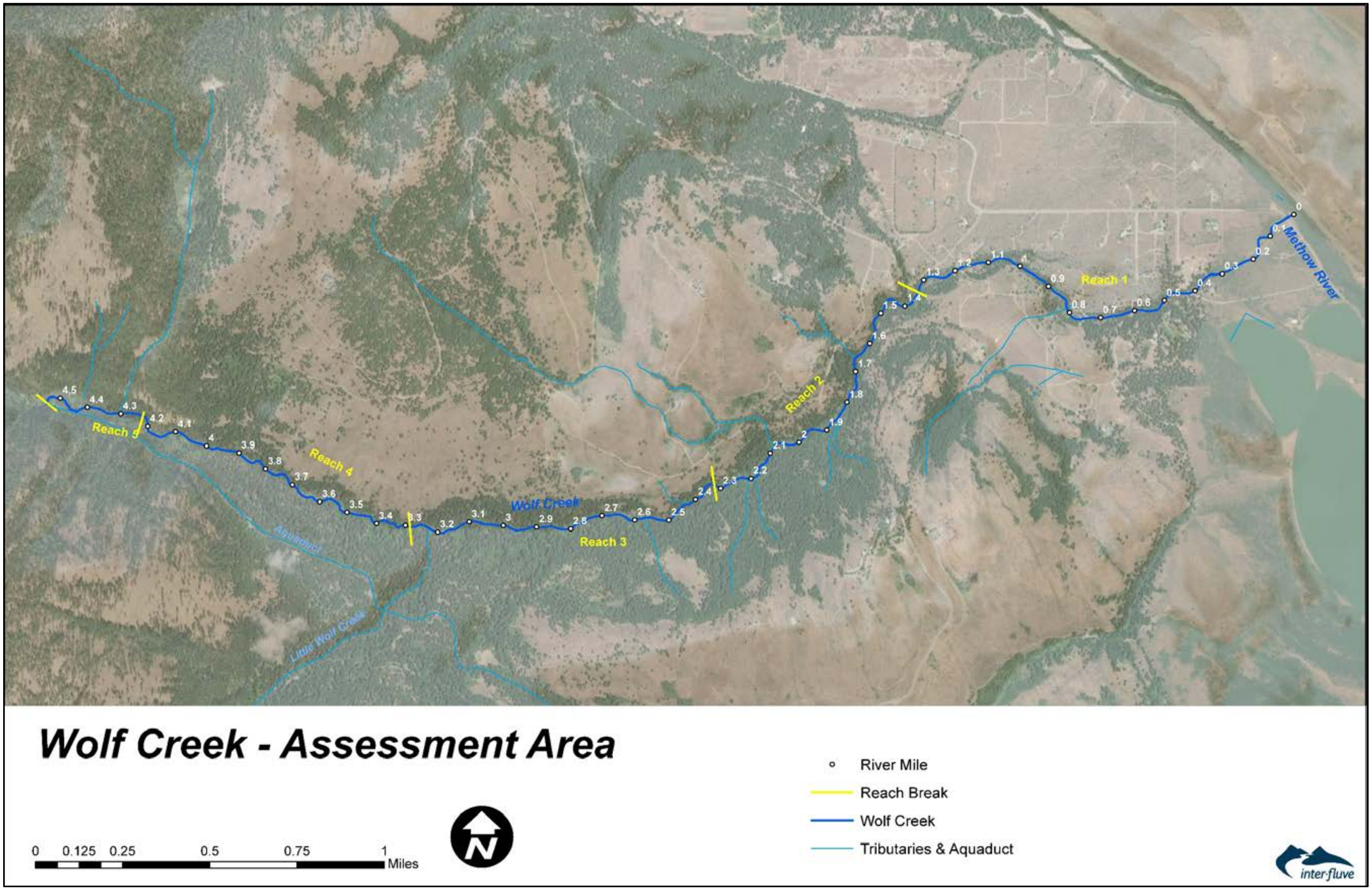


Figure 29. Wolf Creek assessment area with reach boundaries and river miles. Basemap: ESRI Topography & Aerial Imagery

Table 6. Reach-scale metrics for Wolf Creek – RM 0 to 4.53.

	METRIC	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Channel and Floodplain	Length (miles)	1.34	0.97	0.96	0.94	0.32
	River Mile	0 - 1.34	1.34-2.31	2.31-3.27	3.27-4.21	4.21-4.53
	Stream Gradient (%)	1.41%	3.91%	4.73%	4.03%	7.10%
	Sinuosity	1.08	1.06	1.04	1.12	1.08
	Dominant Channel Habitat Unit Type	Riffle	Riffle	Riffle	Riffle	Riffle
	Average Bankful Width (ft)	38.4	32.8	42.3	34.7	33.5
	Average Floodprone Width (ft)	249.7	103.0	130.0	126.7	110.5
	Dominant Substrate	Gravel	Cobble	Cobble	Cobble	Cobble
Channel Habitat Area (%)	Pool	18%	11%	15%	13%	20%
	Riffle	79%	85%	81%	83%	80%
	Glide	3%	0%	1%	0%	0%
	Side Channel	0%	4%	3%	4%	0%

NOTES: Average Bankfull Width and Channel Habitat Unit Types surveyed in the field per USFS Stream Inventory Guidelines (2015). See Habitat Assessment for analysis and results (Appendix A).

Degree of sinuosity and channel form is based on Brierley and Fryirs (2005) classifications.

3.1 REACH 1 (RM 0–1.34)

3.1.1 Overview

Reach 1 is 1.34 river miles long and extends from the mouth of Wolf Creek at its confluence with the Methow River to the top (apex) of Wolf Creek's historical alluvial fan, where the channel exits the mountains to meet the Methow Valley. Throughout Reach 1, the river is a single-thread channel with a low sinuosity of 1.08 and a reach gradient of 1.41%. Average bank-full width measured during the Habitat Assessment (Appendix A) of the channel is 38.4 feet. The channel is entrenched and leveed in the upper portion of the reach and entrenched and confined via channel bridge crossings with marginal inset floodplain development in the lower portion of the reach. Even though this reach is located on a wide alluvial fan, the floodplain surfaces (inundated ~1-5 years) and high floodplain surface (inundated ~5–25 years) exist as discontinuous strips and pockets (Figure 31). Riparian vegetation, dominated by small trees and shrubs, sparsely populate the floodplain surfaces and channel banks. Wolf Creek's historical alluvial fan is now an abandoned surface that is only inundated during very large flood events due to anthropogenic leveeing, channelization, and confinement. Thus, the fan surface functions mostly as a terrace that has been cleared and altered for home development and road construction. Direct hillslope coupling with the channel occurs on river right from RM 0.91 to 1.05 where modern levees hold the channel in place. Vegetation clearing for homes and roads along with disconnection of the surface via levees and channel entrenchment has converted the vegetation across the historical fan surface to primarily upland grasses and sparse shrubs. Today, the channel in this reach is lacking in large wood recruitment potential and retention.

Figure 30. Wolf Creek at RM 0.15 looking upstream. (10/1/2019)

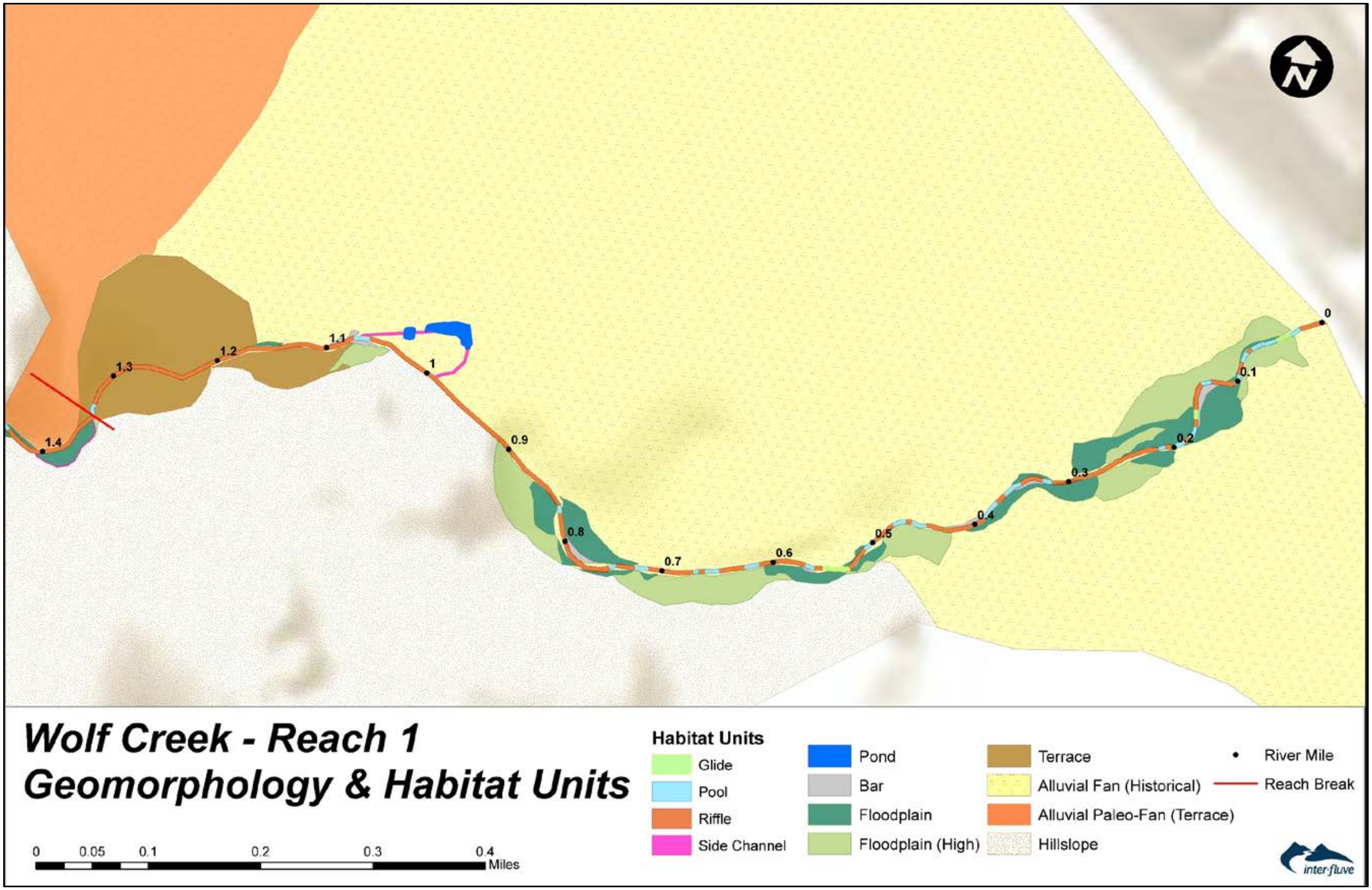


Figure 31. Reach 1: Geomorphic surfaces and channel units. Basemap: ESRI Topography

3.1.2 Channel and Floodplain Geomorphology

Wolf Creek in Reach 1 has a moderate gradient with a planform that alternates between straight and low sinuosity (Figure 31). The channel is entrenched below its historical floodplain (alluvial fan) throughout the reach. The levees along the channel appear to be constructed of material excavated from the bed of the channel, exaggerating entrenchment and facilitating disconnection of the historical alluvial fan. Channel banks are composed of coarse alluvium (gravel to boulder) that is mixed and topped with gravel and sand. Soils of the modern floodplain and banks along the channel are composed of ashy sandy loam (0-25% gradient) across the lower alluvial fan, very stoney ashy sandy loam (35-65%) in the middle section along the toe of the hillslope, and ashy loam (15-35%) in the upper portion of the reach (USDA & NRCS, 2017). Inset floodplain surfaces in the downstream portion of the reach range from 1-foot to approximately 4-6 feet above the elevation of the channel bed (Figure 32).

Figure 32. Looking upstream at Wolf Creek RM 0.18. The subtle meandering (low sinuosity) channel maintains inset floodplains and sparse vegetation. (Photo: 10/1/2019)

Terrace surfaces and leveed banks range from 6-15 feet above the elevation of the channel bed, increasing in height upstream. Historical aerial photos from 1947 confirm that the mainstem channel has been confined in basically the same location for at least 70 years. A lack of lateral processes in the upstream portion of the reach due to channel leveeing, bridge confinement, and bank hardening (i.e., rip rap, cement walls) has resulted in channel entrenchment and minimal local sediment sourcing for bar or spawning habitat development. Subtle lateral processes occurring in the downstream portion of the reach between confining bridges has developed pockets of inset floodplain surfaces. Where established, tree roots and riparian vegetation contribute additional stability to the banks (Figure 33).

Figure 33. Looking upstream at Wolf Creek RM 0.95. River left (right side of photo) is leveed bank. River right is confining hillslope. Tree roots add additional bank stability. (Photo: 10/1/2019).

Channel complexity in Reach 1 is impaired by anthropogenic confinements and the continued periodic removal of large wood. The 2020 Habitat Assessment (see Appendix A) measured 79% of the channel as extended riffles, while only 18% is pool habitat, and the remaining 3% is glides. The glides and several of the riffles are plane-bed. The pools occur where large boulders and/or built features, such as constructed bank-attached large wood pieces, or a large boulder weir, foster scour hydraulics. The bed of the channel is dominated by coarse alluvium, gravel-cobble, in the downstream portion of the reach, and cobble-boulder in the upstream. Narrow gravel-cobble bars have formed at the inside bends of the subtle meanders at RM 0.15, 0.35, 0.4, 0.55, 0.79, and 1.09, as well as at the mouth of the channel. Gravel and cobble accumulations were observed at a wide bridge crossing at RM 0.3 (Figure 34) where pilings create downstream hydraulics conducive to deposition.

Figure 34. Private bridge crossing at RM 0.3. Photo at downstream side of bridge on river right looking across active channel where sediment is accumulating. Low-flow channel in background next to boulder gabion and riprap. (Photo: 10/1/2019)

The private rail-car bridge crossing at RM 0.61 with a freeboard of approximately 8 feet has fines and gravels caught in the steel girders on its underside, indicating that sediment-laden high-flow events interact with the bridge. The presence of gravels and limited active lateral processes in the upstream portion confirm that gravels are mobilized through the confined sections of the reach. Where reduced confinement exists, some sediments are retained. Based on bed and bank material, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces.

Wolf Creek has only a small cobble delta at its confluence with the Methow River. The stable location of the Methow River at the confluence also produces simplified processes that maintain its own channel entrenchment, which inevitably influences the base elevation of Wolf Creek. The terminus of Wolf Creek at the Methow River is located only 115 feet downstream of the confining Wolf Creek Road bridge crossing (Figure 35). This provides little room for delta or confluence habitat development in a location that should be naturally complex aquatic habitat.

Figure 35. Confluence of Wolf Creek with the Methow River. Wolf Creek Road bridge crossing in the background. (Photo: 10/1/2019)

3.1.3 Vegetation and Large Woody Material

Riparian vegetation in Reach 1 is a discontinuous strip of trees and shrubs with open patches composed of grasses and forbes. The riparian strip is primarily a sparse overstory of cottonwood and Ponderosa pine with an understory of alder, dogwood, and willow (Figure 36A). The native vegetation beyond the existing riparian strip has been cleared or partially cleared for homesite development and roads. The cleared areas are now vegetated primarily with grasses, forbes, and sparse dryland shrubs. The overstory riparian trees are mostly classified as small (9.0–20.9-inch diameter at breast height) and are primarily composed of Douglas fir, Cottonwood, and Ponderosa

Pine. Alder is the dominant riparian shrub/small tree. Tree roots provide additional bank stability in areas where lateral migration has been limited (Figure 36B). The inset floodplain surfaces support zones of increased riparian vegetation buffer widths. Existing vegetation is expected to provide a partial shade canopy for the channel during the summer. It is probable that all riparian vegetation in Reach 1 was removed at some point in the last 100 years, including when levees were being constructed. The riparian strip that exists today is in the process of maturing but at risk with continued home development.

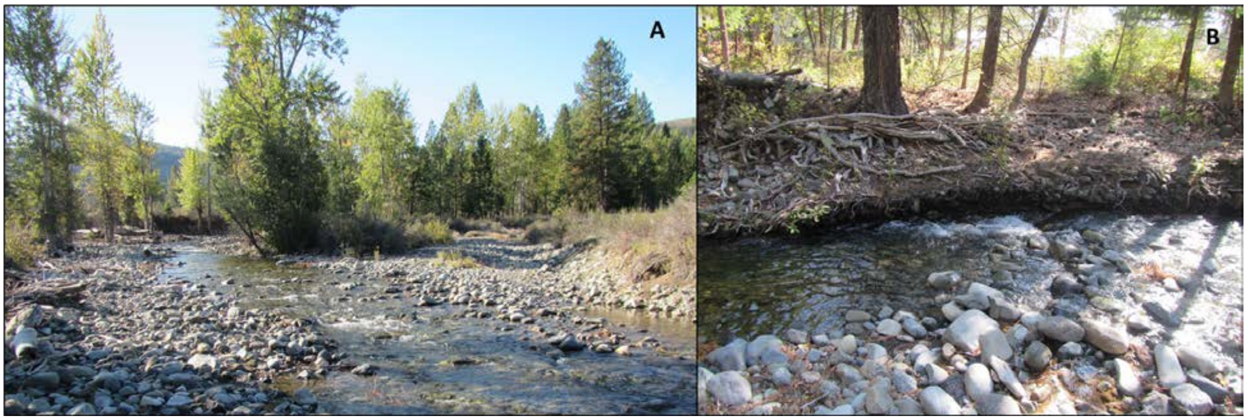


Figure 36. A) Riparian vegetation at RM 0.15 with inset floodplain. B) Example of root-stabilized bank (RM 0.53). (Photos: 10/1/2019)

The lack of mature or large trees (21-32-inch dbh), the narrowness of the vegetated riparian zone, and channel confinement limit local source and recruitment potential of large woody materials (LWM) in Reach 1. A total of 52 pieces of LWM and no log jams were observed in the channel during the survey (10/1/2019). Eighty percent of the surveyed pieces are classified as small size class. A total of 10 pieces of quality large wood (QLW: medium or large size class: >12-inch dbh and at least 35-feet long) were recorded. Figure 37 shows the distribution of quality LWM surveyed in Reach 1 in 2019 and its relationship to mapped habitat units. Only two pieces of quality LWM occurred from RM 0.82 to the upstream boundary at RM 1.34 where levees and entrenchment confine the channel and long extended riffles dominate the habitat units. Seven of the LWM pieces are in constructed (partially bank buried or cabled) 1-log features between RM 0-0.07 and at RM 0.14. One piece of quality LW at RM 0.15 had recently been recruited by lateral channel processes and was influencing bed complexity at the time of the survey. Where it occurs, LWM does play a role in providing the minor amount of aquatic habitat and geomorphic complexity that currently exists in Reach 1. The lack of LWM in Reach 1 is the result of past riparian vegetation removal, lack of mature trees in the riparian corridor, lack of channel migration capacity, and probably continued periodic "cleaning" of wood from the channel. Clearing large wood from the channel is a common practice in places were infrastructure such as small bridges, irrigation intakes, and homes exist.

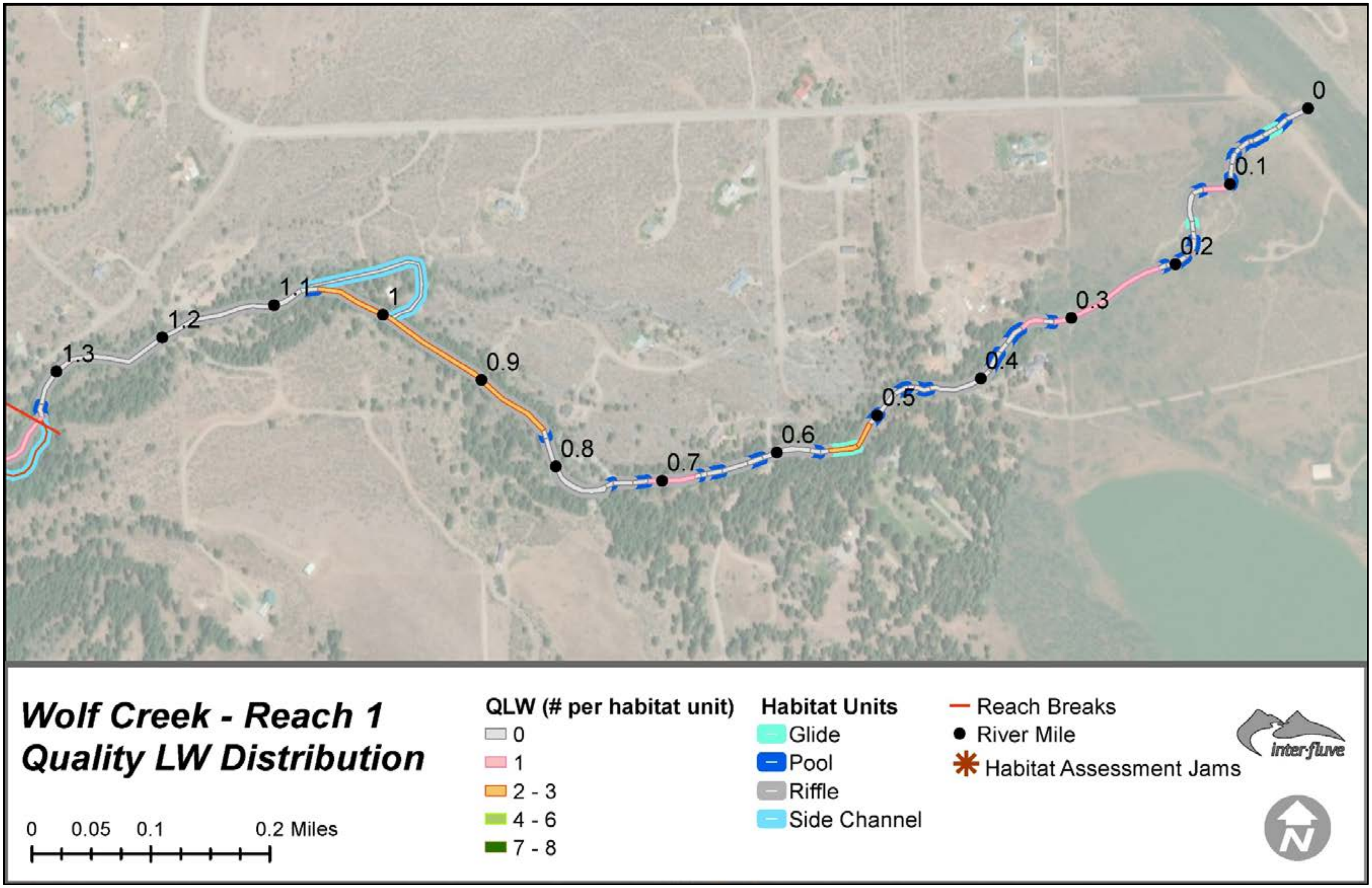


Figure 37. Reach 1 – Quality Large Woody (QLW) Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat (2019 Habitat Survey) and the location of LW jams (>10 pieces of LWM accumulated).

3.1.4 Human Alterations

Reach 1 contains the most anthropogenic built-features in the assessment area. In addition to altering flow pathways across the alluvial fan and clearing riparian vegetation, anthropogenic features in Reach 1 include buildings/homes, roads, bridges, levees, riprap, gabions, cement walls, boulder weirs, constructed LW installations, irrigation intakes, ditching, and utility crossings (Figure 39). Levees up to 3 feet higher than the historical floodplain surface and constructed of material excavated locally from the channel or floodplain exist both along the channel and across the historical alluvial fan. An almost continuous levee exists along river left from RM 0.84 to 1.14, including a cement wall (home foundation) and added boulder riprap at RM 1.04. Constructed levees also exist throughout the reach on river left at RM 1.26, 0.4–0.45, and 0.24–0.26 as well as on river right at RM 0.6, 0.37–0.42, and 0.03–0.07. Additional levees of up to 1,275 feet long exist across the historical alluvial fan associated with ponds, ditches (irrigation and drainage), and historical flood pathways to divert flow away from infrastructure and private property. Three bridges cross and confine the channel in Reach 1 at RM 0.03, 0.3, and 0.6. The Wolf Creek Road bridge (RM 0.03) has confining cement wing walls protected with riprap and large boulder weirs at and upstream side (Figure 38A). The two other bridges are private and constructed of railroad cars with cement, boulder riprap, and boulder gabion footings as well as raised access road prisms. The bridge at RM 0.3 is ~145 feet long and thus requires three rail cars and two sets of mid-channel footings (cement and boulder gabions) (see Figure 34).

Figure 38. A) Wolf Creek Road (RM 0.03) crossing and related large boulder weirs at and upstream. B) Railroad car bridge with cement footings and large boulder riprap and raised access road prism. (Photos: 10/1/2019)

Cement and riprap bank armoring are present at two irrigation intake points and in a few locations associated with private property protection in Reach 1. The cement wall (home foundation) on river left at RM 1.03 covers approximately 80 feet of bank on river left and protrudes from the bank. The opposite bank is a confining hillslope, making this point the most confined section of the channel (~25 ft wide). The irrigation intake on river left at RM 1.26 is associated with a leveed ditch (Figure 40A).

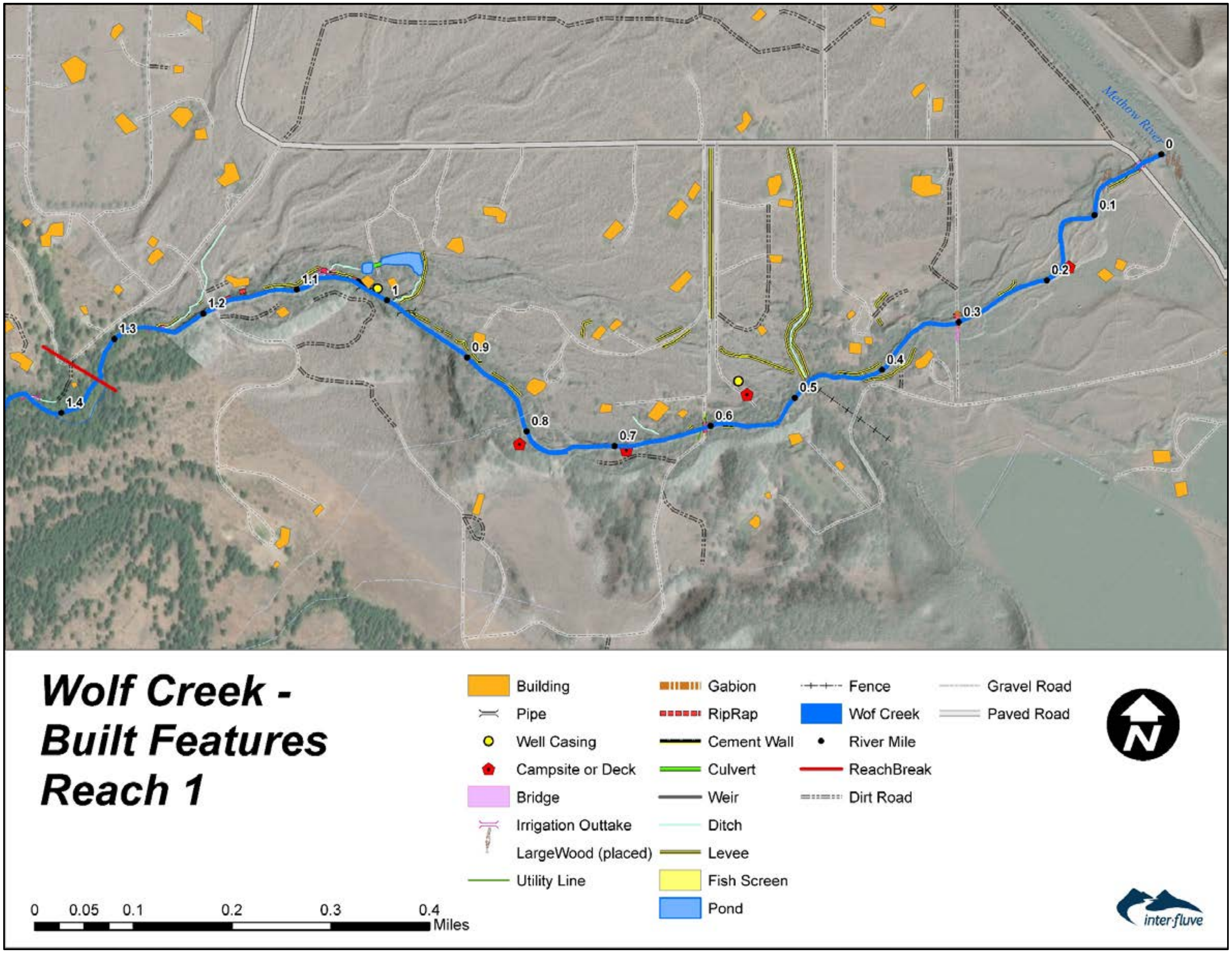


Figure 39. Reach 1: Anthropogenic built features. Basemap: ESRI World Imagery.

Figure 40. A) Boulder and cement irrigation outtake at RM 1.26 with leveed ditch in the background. B) irrigation-fed set of ponds on historical alluvial fan at RM 1 connected via ditches and culverts to the mainstem channel. (Photos: 10/1/2019)

The irrigation intake at RM 1.07 feeds a set of private ponds with levees that are located on the historical alluvial fan and connected to the mainstem channel via ditches and culverts (Figure 40B). Riprap is also present on river left at RM 1.02, RM 1.04, and RM 1.17-1.19. Other anthropogenic features that interact directly with the channel are large boulder weirs at RM 0.02, 0.03, 0.06, and 1.07. The electric fish-tag counting system with in-channel piping and a data collection box at RM 0.03 imposes minimal impacts to modern channel processes.

3.1.5 Recommended Actions

Recommended actions for Reach 1 are focused on improving riparian vegetation, upgrading existing anthropogenic features such that they pose less of an impact on processes and habitat, increasing channel complexity, and enhancing aquatic habitat. Opportunities for enhanced complexity and improved habitat are present throughout the reach but the greatest potential is located in the downstream portion where existing constructed confinements and home development is less. The recommended treatments consider private land ownership and density of development on both sides of the channel through Reach 1. The recommended actions in Reach 1 will require landowner engagement and approval. In this area, recommended actions include installation of large wood (LW) jams, development of inset floodplains, native riparian vegetation restoration, improved bridge crossings, culvert replacement, development of off-channel or side-margin refugia habitat, and the removal of anthropogenic features. The irrigation intake structure at RM 1.26 should be evaluated and improved or removed because of fish stranding potential. Upgrading the existing bridge crossings at RM 0.03 and 0.6 by improving footings and associated bank armoring as well as widening the bridge span to reduce channel confinement and continued entrenchment is recommended. Due to the close proximity of private property to the channel and the role of property protection that many of the levees and bank armoring treatments currently play, recommendations for actions in Reach 1 are limited and should be carefully considered and modeled. Maps and detailed descriptions of recommended treatments are provided in Section 4 (Restoration Strategy Framework) and Appendix C (Project Opportunities and Prioritization).

3.2 REACH 2 (RM 1.34–2.31)

3.2.1 Overview

Reach 2 is 0.97 river miles long and occupies a river valley that alternates between confined and un-confined. The reach extends from the top (apex) of the Wolf Creek alluvial fan at RM 1.34 to RM 2.31, where valley confinement and gradient increases (Figure 42). Channel form is primarily single thread except where side-channels occur from RM 1.34 to 1.41, at RM 1.8, and between RM 2.1–2.6. Channel sinuosity (1.06) is similar but reach gradient (3.91%) is notably increased compared to Reach 1. Average bank-full width of the channel is 32.8 feet – slightly narrower than Reach 1. Hillslope and bedrock confined sections alternate with relatively broad floodplain segments. The existing floodplain and terrace surfaces are well vegetated with riparian trees and shrubs. Evidence of some historical logging (stumps and smaller tree diameters) indicated that the floodplains in this reach have had some vegetation clearing in the past. Terrace surfaces occur in Reach 2 and occasionally border the channel with high alluvial banks on river left at RM 1.34–1.44 and RM 2.2 and on river right at RM 1.9, 1.92, 19.7, and RM 2.25–2.29. The channel is bordered by private property from RM 1.23–2 and the remainder (RM 2–2.31) is within the Okanogan National Forest. Large wood recruitment and retention in Reach 2 is partially limited and habitat complexity could be improved.

Figure 41. Wolf Creek at RM 1.46, looking downstream. (Photo: 10/3/2019)

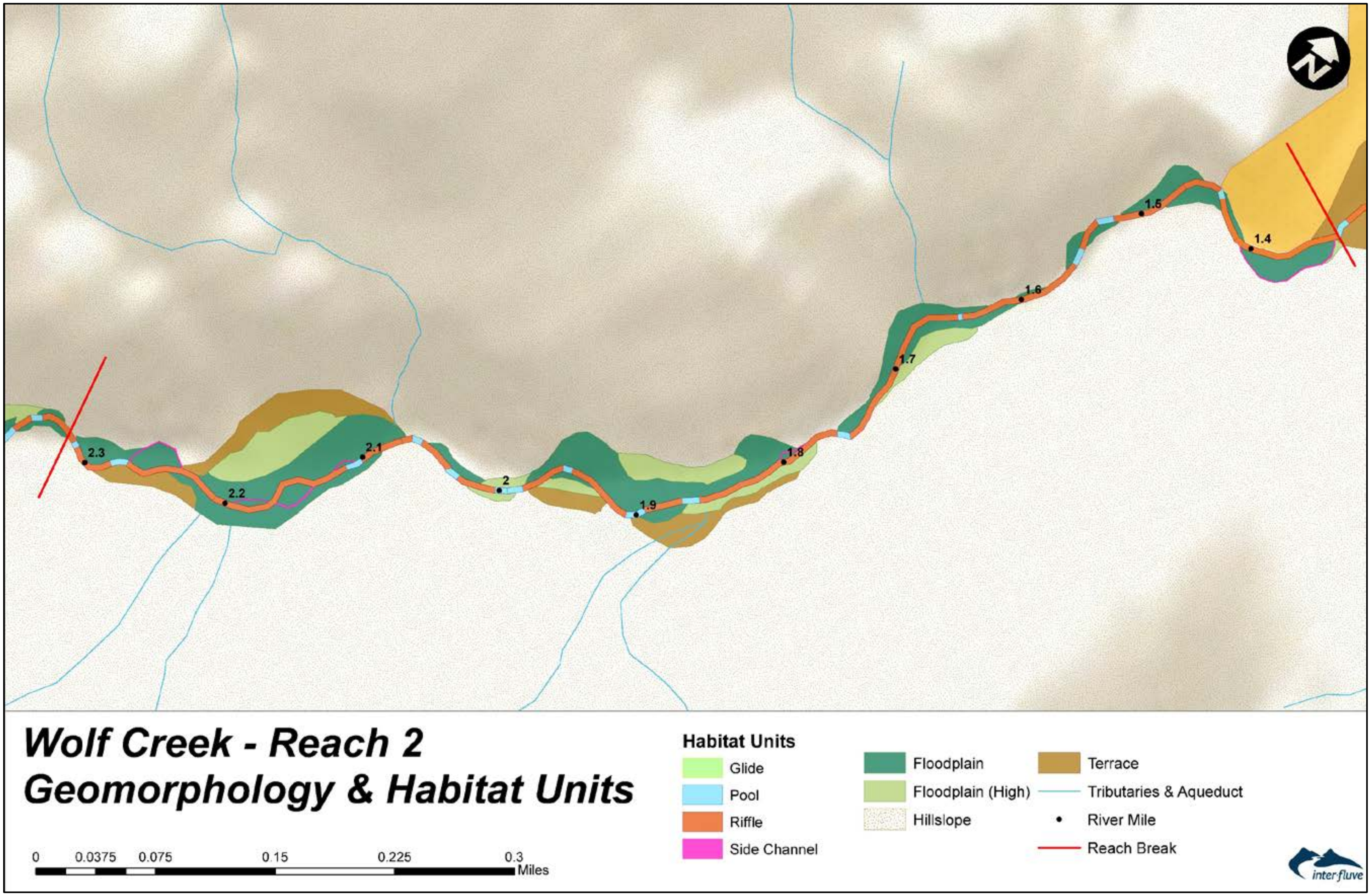


Figure 42. Reach 2: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.2.2 Channel and Floodplain Geomorphology

Wolf Creek in Reach 2 has a relatively high average gradient (3.91%) with extended boulder riffles and step pool sequencing (Figure 43). Planform is low in sinuosity with subtle meandering that is partially controlled by gradient as well as periodic bedrock bank and hillslope toe contacts. Side channels provide additional habitat and floodplain activation where they occur. Hillslopes and bedrock exposures contribute colluvium and boulders that add localized geomorphic complexity, including scour pools at bedrock contacts. Channel substrate is composed of cobble and boulders with sparse gravels. Gravels were observed in backwater eddies at boulders, marginal lateral bars, near large wood accumulations, and in some of the side channels. Based on bed and bank material, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces. Pool frequency and depth are rated as Unacceptable and large wood material quantities per mile are rated as At Risk for quality salmonid habitat conditions in Reach 2 (see Section 2.13).

Figure 43. Reach 2 at RM 1.6 (looking upstream): Extended boulder riffle, confining hillslope on river left, and vegetated floodplain on river right. (Photo: 7/7/2020)

Bedrock bank exposures and hillslope toes alternately confine sections of the channel. Almost all bedrock bank exposures are corelated with shallow scour holes. However, bedrock was only exposed in the bed of the channel at RM 1.53, 1.99, 2.03, and 2.08. Otherwise, the channel bed is composed of alluvial boulders, cobbles, and gravels mixed with hillslope sourced boulders. Boulders are organized as steps in the higher gradient sections and create hydraulic complexity including lower gradient sections where gravels accumulate. The Habitat Assessment (see Appendix A) measured 85% of the channel as extended riffles and 12% as pool habitat. Pool habitat is rated as unacceptable based on frequency and quality (depth and cover). The pools that do exist are maintained at boulder steps, bedrock exposures, and in association with scour hydraulics at large wood jams. Side channels represent only 4% of the available habitat in the reach.

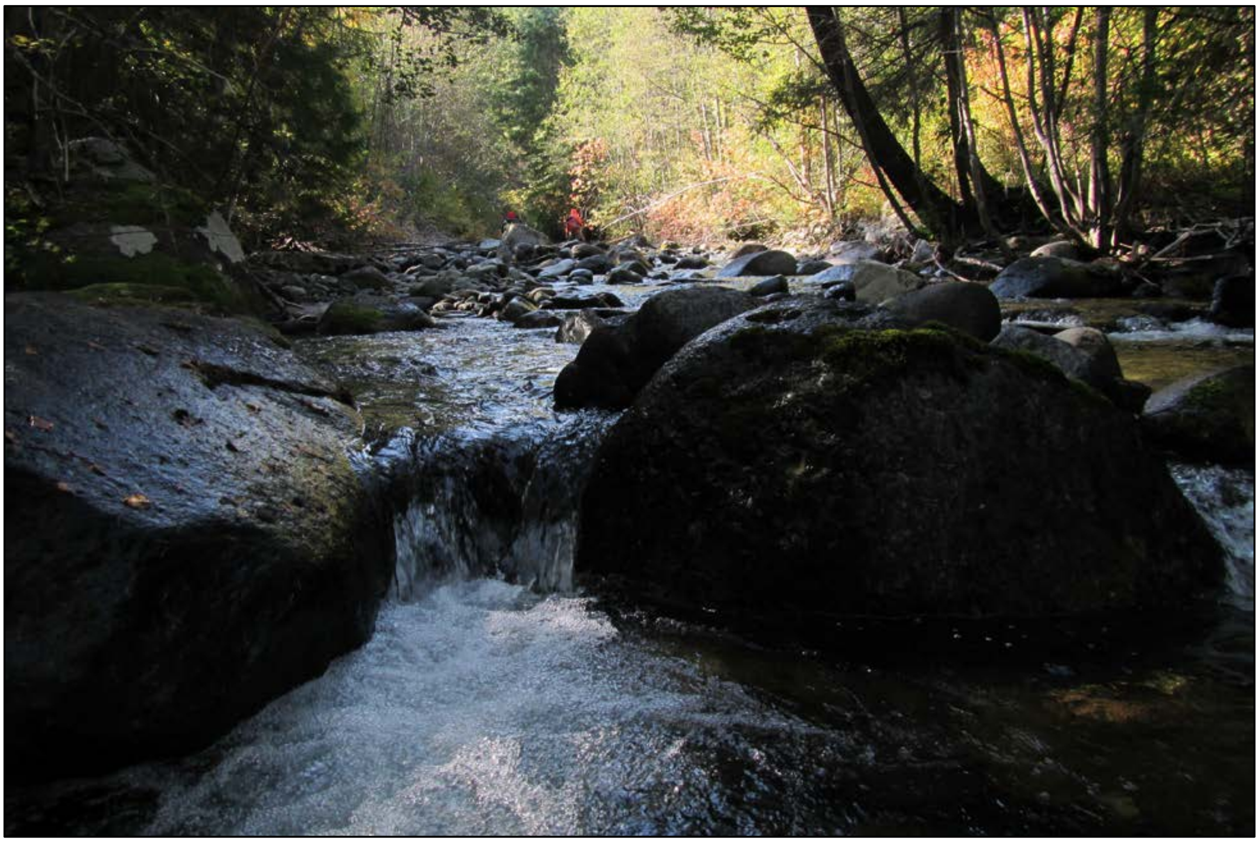


Figure 44. Reach 2 at RM 1.87: Boulder step with a scour pool. Looking upstream. (Photo: 10/3/2019)

The floodplains are well vegetated with a mix of riparian vegetation. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with gravels that fine-upward to coarse sands. Floodplain, terrace, and adjacent hillslope soils in Reach 2 are described as ashy loam in the downstream portion (RM 1.34–1.7) and ashy sandy loam over glacio-fluvs in the upstream portion (USDA & NRCS, 2017). Where low floodplains exist, they range from 1 to approximately 4 feet above the bed of the channel. The low floodplains are expected to be inundated every 1-5 years and the high floodplain surfaces are expected to be inundated every 5-25 years, based on current configurations. The paleo-alluvial terrace surfaces that formed during glacial recession and deposition occur discontinuously in Reach 2. The terraces range from 8-20 feet higher than the floodplain surfaces.

3.2.3 Vegetation and Large Woody Material

Vegetation in Reach 2 is well established. A natural vegetation condition of mature conifer forest with a thick understory of native riparian vegetation are present throughout Reach 2, except where bedrock bank/hillslope exposures occur. The riparian vegetation has an overstory of fir, cottonwood, and cedar with a thick understory of alder, dogwood, snowberry, and maple. The adjacent riparian vegetation is often dominated with small trees and brush that establish along the channel margins (Figure 45A), especially in the downstream portion of the reach within the privately owned section. In the upstream section, the riparian forest has more mature old-growth trees that border and contribute directly to the channel (Figure 45B). Throughout Reach 2, the riparian vegetation provides a shade canopy for most of the channel during summer months. The adjoining hillslope vegetation is far less dense and dominated with conifers (fir and pine) and a grass and shrub understory. Periodic wildfires are assumed to be part of the historical landscape and vegetation.

Figure 45. A) Example of understory riparian vegetation (RM 1.45); B) Old-growth riparian forest at RM 2.61. (Photos: 10/3/2019)

A total of 198 pieces of woody material and three log jams (accumulation of ≥ 10 LWM) were observed in the channel during the survey (10/3/2019). Of the 198 pieces, 65 were classified as quality large wood (QLW); 32 classified as large size class (≥20-inches dbh and >35-feet long); and 33 as medium size class (12 to 20-inch dbh and at least 35-feet long). The LW jams are located at RM 1.69, 2.17, and 2.28. An additional LW accumulation that does not meet the "jam" classification (> 10 LWM pieces) is located at RM 1.41 at the top of the split-flow side channel. Where they occur, the LW jams and accumulations support geomorphic complexity and habitat function. Figure 46 shows the location of the LW jams and the distribution of the other QLW material (>12-in dbh and at least 35-feet long) per mapped habitat unit (2019) throughout the reach and the location of the LW jams.

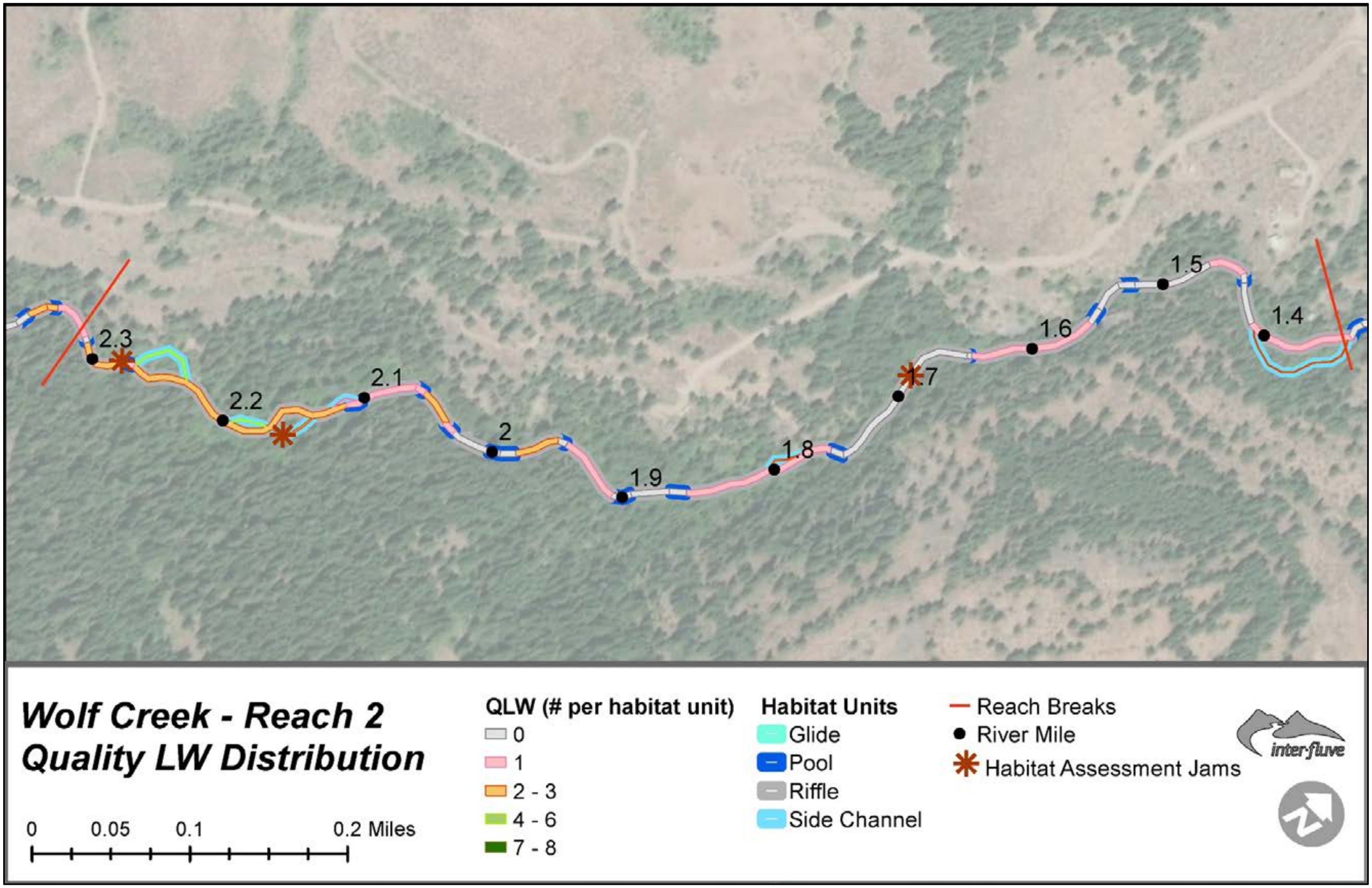


Figure 46. Reach 2 – Quality Large Woody (QLW) Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat (2019 Habitat Survey) and the location of LW jams (>10 pieces of LWM accumulated).

Reach 2 has less quality LW (QLW) per mile than recommended for quality aquatic habitat conditions. Where LWM and jams occur, they influence geomorphic processes such as channel avulsion, pool scour, sediment accumulations, improved floodplain connectivity, and split flow conditions (Figure 47). The LWM jams are effective at increasing localized geomorphic and aquatic habitat complexity in Reach 2 because it is a relatively high gradient reach with moderate-high specific stream power. Larger masses of QLW are necessary in Reach 2 to effect hydraulics and sustain function. The limited LWM in Reach 2 today is likely the result of past riparian vegetation clearing and logging in the downstream privately owned section that reduced the number of quality (large or medium) sized trees in the riparian area and available floodplain.

Figure 47. Large wood jam at RM 2.28 in Reach 2 – at downstream side of jam. (Photo: 10/3/2019)

3.2.4 Human Alterations

Although the downstream section of the reach is privately owned, anthropogenic features that interact with the channel are relatively minor in Reach 2 (Figure 48). The few home sites located on the hillslopes above the valley floor currently impose no impact to the channel and its floodplain. An access road to the floodplain with a cleared parking area, thinned floodplain vegetation, trail, and a

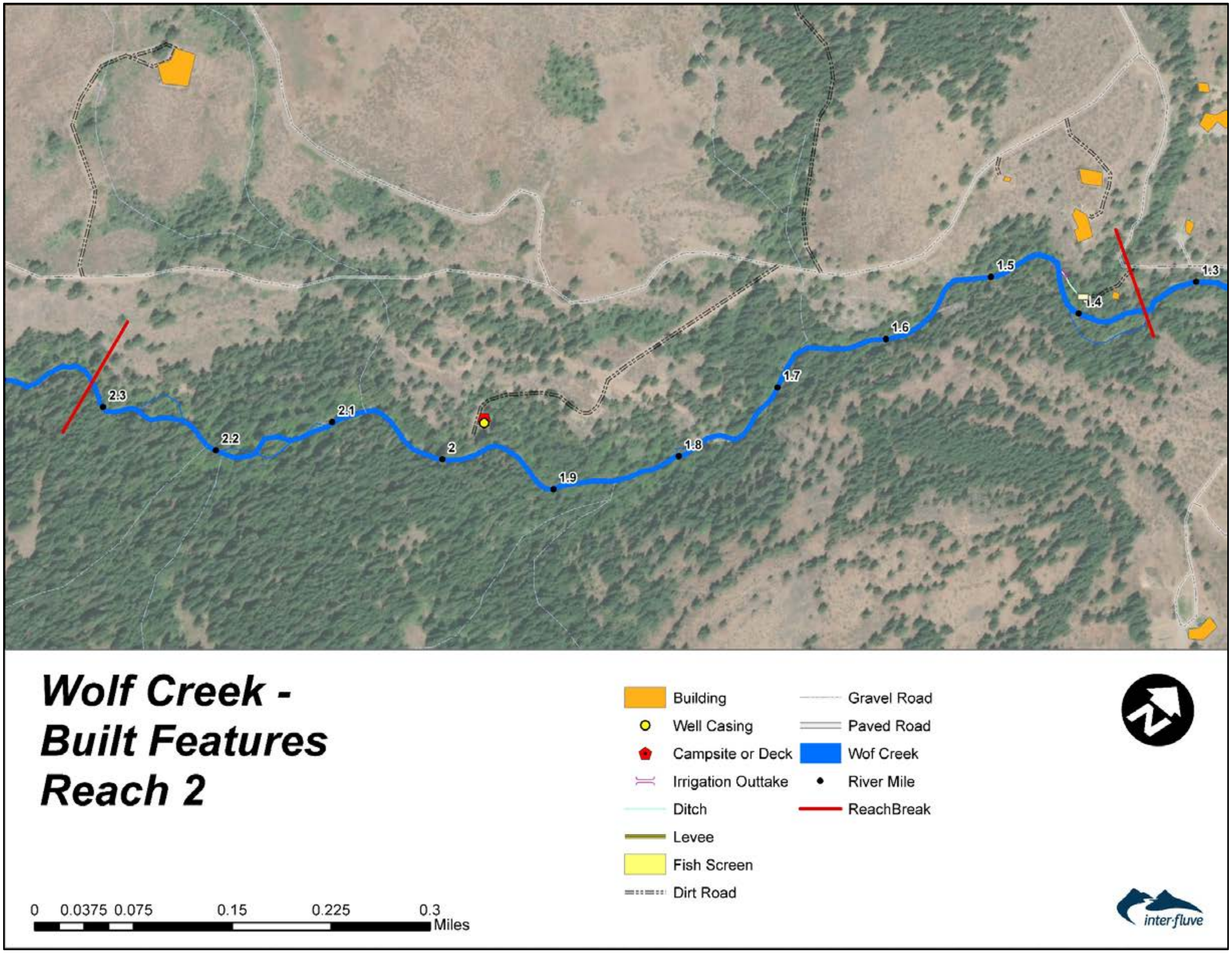


Figure 48. Reach 2: Anthropogenic built features. Basemap: ESRI World Imagery

well do exist on river left at RM 1.98. The other notable anthropogenic features in Reach 2 include an irrigation intake on river left at RM 1.44 (Figure 49). The intake appears to function seasonally and is constructed of cement, boulders, and steel and is designed to have the quantity of inflow managed by removing or inserting wooden or metal slats. A ditch runs from the intake structure point to a modern fish screen, and then into another ditch to a buried pipe. Evaluation of potential impacts of the intake, ditch, and fish screen and the seasonal management plan of it to fish species of concern are recommended. A pump house and cistern managed and operated by the Wolf Creek Property Owners Association (WCPOA) is located near the fish screen. CWPOA operates the water system for the local community on the Wolf Creek Fan and the community trail at RM 1.35.

Figure 49. A) irrigation outtake at RM 1.44; B) fish screen associated with irrigation outftake and ditch.

3.2.5 Recommended Actions

Recommended actions for Reach 2 are focused on increasing channel complexity, enhancing aquatic habitat, and evaluating the potential to remove or improve an irrigation intake structure. The recommended treatments are helicopter placement of LW jams and LW channel loading. All actions downstream of RM 2 are within private property and thus will require owner cooperation. Helicopter placement of large wood in the mainstem channel is recommended at appropriate locations that take advantage of existing features (boulders, bedrock, channel form, and available floodplain) to instigate geomorphic function (i.e., pool development, side channel activation, floodplain activation, LW recruitment and retention, spawning gravel recruitment and retention) that will increase channel complexity and habitat quality. Evaluation of the existing irrigation intake, ditch, fish screen and the related seasonal management plan for their potential impact(s) to ESA fish is recommended. If needed, the intake may need to be upgraded, decommissioned, or removed. Consider off-channel water sources (wells) to replace water user needs. Maps and detailed descriptions of recommended treatments are provided in Section 4 (Restoration Strategy Framework) of this report and Appendix C (Project Opportunities and Prioritization).

3.3 REACH 3 (RM 2.31–3.27)

3.3.1 Overview

Reach 3 is 0.96 river miles long and occupies confined and semi-confined sections of the Wolf Creek river valley. Hillslopes and terraces occupy portions of the valley and act as channel confining features. Where valley width allows, sections of the channel are bordered by elongate swaths of floodplain. Reach 3 extends from RM 2.31 to the confluence with Little Wolf Creek at RM 3.27. The channel is primarily single thread throughout Reach 3, with the exception of four side channels at RM 2.48, 2.65, 2.84, and 3.0. Reach sinuosity (1.04) is lower than Reach 2 and gradient (4.73%) is higher. Average bankfull width of the channel in Reach 3 is 42.3 feet, which is the widest average bankfull width among the reaches in the assessment area. Low floodplain surfaces (inundated ~1-5 years) exist as elongate swaths in the semi-confined segments and as discontinuous pockets or non-existent in the short, confined segments (Figure 51). The existing floodplain surfaces are well-vegetated with mature conifer forests, riparian trees and a thick understory of shrubs. Little Wolf Creek's alluvial fan is small and its sediment contributions are currently truncated by Wolf Creek, but the confluence does occupy the river right side of the upstream border of the reach. Recruitment and retention of LWM is occurring in patches, and where it does occur, geomorphic complexity is increased. The entirety of the reach is within the Okanogan National Forest.

Figure 50. Wolf Creek at RM 2.62, looking upstream. (Photo: 10/4/2019)

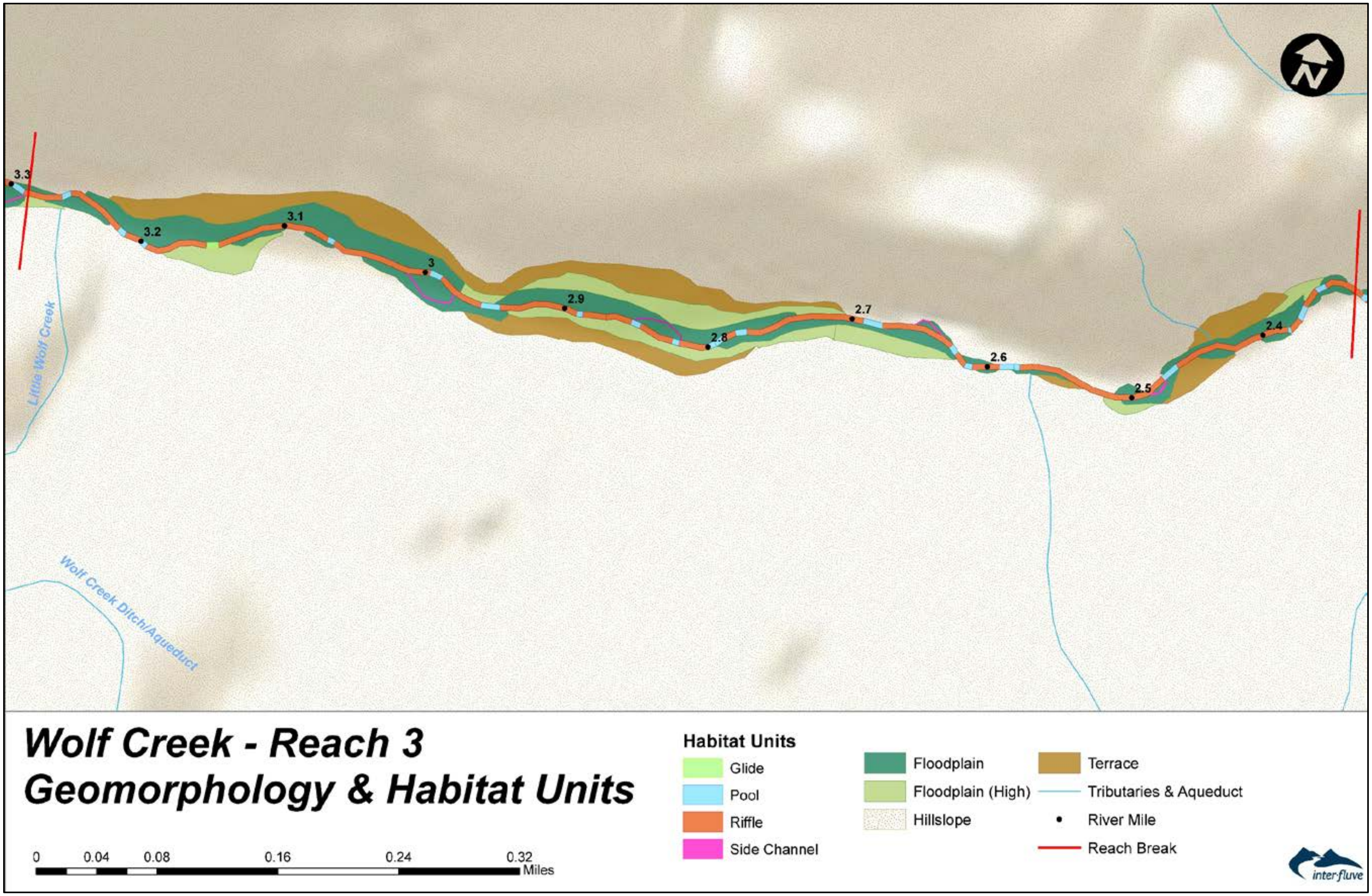


Figure 51. Reach 3: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.3.2 Channel and Floodplain Geomorphology

Wolf Creek in Reach 3 is considered a high gradient channel (reach average gradient is 4.75%) with a low sinuosity planform that alternates between meandering and straight. Planform is partially a product of the pathway the channel has eroded into the underlying bedrock, over timeas well as how it has historically and currently situated itself in the valley in relationship to paleo and modern alluvial surfaces (floodplains and terraces). Active side channels exist in locations where available floodplain occurs and boulder or LWM accumulations promote split flow. The side channels provide quality habitat and increased floodplain connectivity. The hillslopes and bedrock bank exposures contribute colluvium, such as boulders and LWM, that add complexity to the channel's geomorphology. Pool frequency and depth are rated as unacceptable for quality salmonid habitat conditions in Reach 3.

Bedrock occurs as a grade control in the channel bed in the more confined section of the reach at RM 2.42, 2.56, 2.58, and 2.59. Otherwise, channel substrate in Reach 3 is composed of cobble and boulders with sparse gravels (Figure 52). Gravels were observed in backwater eddies at boulders, at the riparian margin, near large wood accumulations, at step-pool tail-outs and in some of the side channels. Large boulder colluvium sourced from adjacent hillslopes provide additional complexity to the channel. Based on bed and bank material, as well as side-channel wetting, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces.

Figure 52. Wolf Creek at RM 2.86, looking upstream. (Photo: 10/4/2019)

The channel is primarily a cascading riffle reach with periodic step pools. The Habitat Assessment (see Appendix A) recorded 81% of the channel area as extended riffles, 15% as pool habitat, and just 1% as glide. Pool habitat is rated as unacceptable based on lack of frequency and quality (depth and cover), otherwise all other ecosystem indicators are ranked as adequate–see REI summary in Section 2.13. The pools that do exist are maintained at boulder steps, bedrock exposures, and in association with scour hydraulics at LWM jams. Side channels represent just 3% of the available habitat in the reach even though there is floodplain area available to occupy.

Little Wolf Creek enters the mainstem channel near the upstream boundary of Reach 3 (RM 3.27). However, irrigation withdrawals by the Wolf Creek ditch/aqueduct captures all of Little Wolf Creek's discharge during low-flow months–making it a seasonal or ephemeral supply of surface water to Wolf Creek. Little Wolf Creek has a small cobble delta at its confluence with Wolf Creek. During the October 2019 survey, the Little Wolf Creek delta was wetted (post-irrigation diversion period) and loaded with small debris, see Figure 53. During the July 2020 geomorphology survey, no surface water was observed at the confluence because all of its flow was being diverted by the irrigation ditch. Two other small ephemeral tributaries seasonally contribute minor inputs at RM 2.45 (river right) and RM 2.57 (river left).

Figure 53. Little Wolf Creek confluence. (Photo: Oct 4, 2019)

Multiple spring seeps sourced from the toe of the floodplain terrace exist in Reach 3. The spring seeps produce sufficient discharge to create surface flow across the floodplain and support well established vegetation (observed Oct 2019 and July 2020), suggesting they are perennial sources of water to the floodplain and channel (Figure 54). The spring-fed tributaries meet Wolf Creek on river right at RM 2.77, 2.84. 2.86, and 2.94.

Figure 54. Spring seep floodplain tributaries, A) spring seep on terrace at RM 2.77; B) spring seep surface flow on floodplain entering Wolf Creek at RM 2.94. (Photos: 10/4/2019)

The floodplains are well vegetated with a mix of mature forests and dense riparian vegetation. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with coarse gravels and sands. Floodplain and adjacent hillslope soils in Reach 3 are described as ashy sandy loam over glacio-fluvs (35-65% slope) from RM 2.31 to 2.5 and ashy sandy loam (15-35% slope) from RM 2.5 to 3.27 (USDA & NRCS, 2017). Where floodplains exist, channel banks range from 1 to approximately 5 feet above the bed of the channel. The low floodplains are expected to be inundated every 1-5 years and the high floodplain surfaces are expected to be inundated every 5-25 years, based on current configurations. The terrace surfaces occur as alternating confining features at RM 2.36-2.48 and at 2.55. In the upstream portion of the reach the terraces are elongate features that extend along the valley wall from RM 2.7-3.25 on river left and from RM 2.77-2.96 on the river right side. The terraces range from ~9-20 feet higher than the floodplain surfaces.

3.3.3 Vegetation and Large Woody Material

Riparian and floodplain vegetation in Reach 3 is well established. A natural vegetation condition of mature old-growth conifer forest exists with a thick understory of native riparian vegetation bordering much of the channel, except where bedrock bank/hillslope exposures occur. The overstory trees on the floodplain surfaces are primarily fir and cedar. The riparian border understory is dominated by dogwood, alder, cedar, snowberry, and maple. The adjacent riparian border is often a mix of small trees and brush established along the channel margins, especially where bank disturbance (high flow event), or developing floodplains exist (Figure 55). The forest and other riparian vegetation provide a shade canopy for the channel throughout Reach 3. The adjoining hillslope vegetation is far less dense and composed of conifers (fir and pine) with an understory of shrubs and grasses. Periodic wildfires are assumed to have been part of the historical landscape and vegetation evolution here, especially on the hillslopes.

Figure 55. Example of well-established mixed vegetation on floodplain surfaces in Reach 3, RM 2.75. (Photo: 10/4/2019)

A total of 121 pieces of large woody material (LWM) and two log jams (accumulation of ≥ 10 LWM) were observed in the channel during the survey (10/4/2019). Of the 121 pieces, 48 are considered QLW; 24 classified as large size class (≥20-inches dbh and >35-feet long); and 24 as medium size class (12 to 20-inch dbh and at least 35-feet long). The LW jams, located at RM 2.88 and 3.02 have multiple pieces of QLW and thus are effective channel influencing and habitat forming structures. See Figure 56 for the LW jam locations and the distribution of the other QLW (>12-in dbh and at least 35 feet long), per mapped habitat unit in Reach 3. Where LWM exists, it plays an important role in aquatic habitat and geomorphic channel complexity such as pool development/maintenance, gravel accumulations, hydraulic diversity, floodplain activation/development, side channel activation/maintenance, and lateral processes.

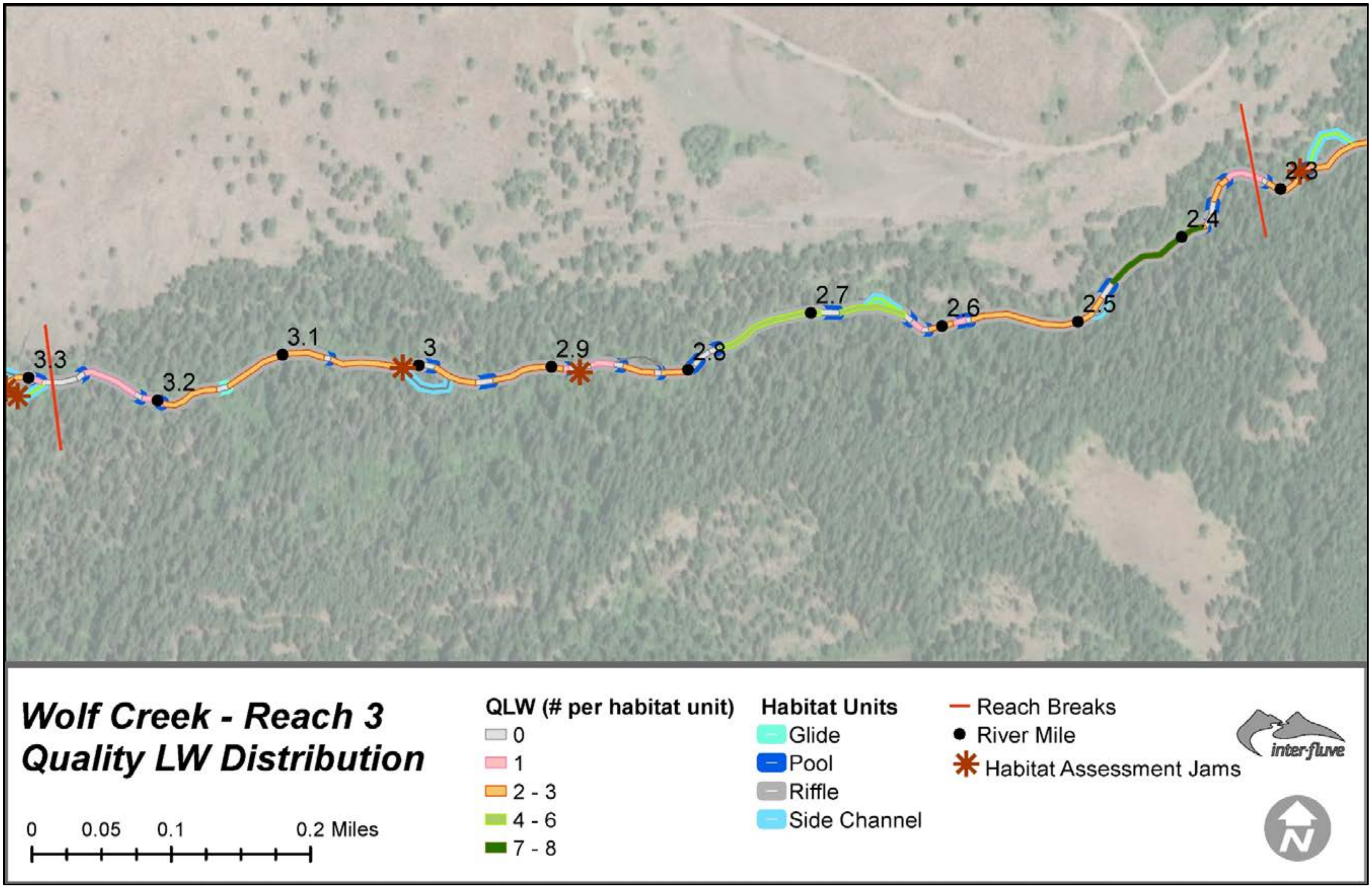


Figure 56. Reach 3 - Quality Large Woody (QLW) Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat (2019 Habitat Survey) and the location of LW jams (>10 pieces of LWM accumulated).

Large Wood jams and geomorphically-effective QLW pieces occur where large boulders or adjacent floodplain trees provide ballasting and where channel planform produces catchment areas (meander bends, side channel apex, etc.). Geomorphic complexity, and thus habitat complexity, are greatest where QLW interacts with the channel, and where available floodplain bordering the channel allows for channel response. The size (quality) of the standing LW in the mature forest that borders the channel in Reach 3 is large enough to produce geomorphic complexity as single logs if recruited into the channel. For example, one or just a few channel-spanning naturally-ballasted QLW can produce steps or a mid-channel obstacle that directly influences flow hydraulics to produce features such as scour pools, sediment accumulation, and locally reduced channel gradient (Figure 57).

Figure 57. Example of hydraulic step created by 3 pieces of channel-spanning QLW with accumulated sediment upstream at RM 3.0. (Photo: 7/8/2020)

3.3.4 Human Alterations

Anthropogenic features that interact with the channel are relatively minor in Reach 3 (Figure 58). A few gravel or dirt roads and homes located on the hillslopes above the valley floor and terrace surfaces do not directly impact the channel or aquatic habitat. The one notable human alteration in Reach 3 is the seasonal irrigation withdrawal by the Wolf Creek ditch/aqueduct that alters the quantity and timing of surface water discharge input from Little Wolf Creek to Wolf Creek at the upstream border of Reach 3. Irrigation withdrawals are reported to capture all of Little Wolf Creek during low-flow summer months when perennial contributions to the mainstem could be beneficial. This also removes lower Little Wolf Creek as potential rearing habitat during these months. Seasonal drying or flow reductions from irrigation withdrawals may also pose stranding issues to fish that choose to utilize it as off channel refugia during high-flow events or for spawning when it is connected. Further investigation is warranted to evaluate the potential impacts of irrigation withdrawal from Little Wolf Creek and the loss of potential habitat it represents to Wolf Creek.

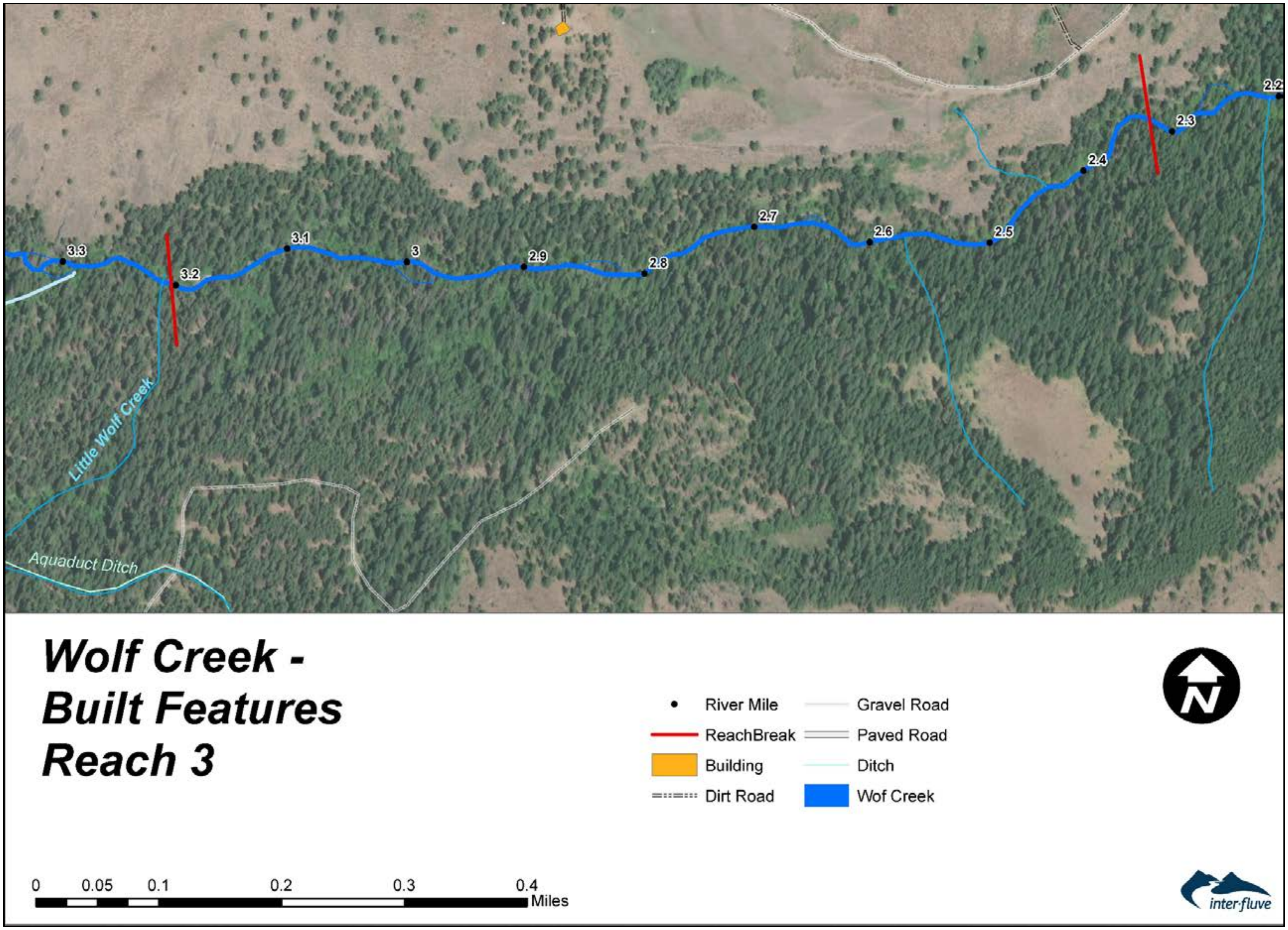


Figure 58. Anthropogenic features in Reach 3. Basemap: ESRI World Imagery

3.3.5 Recommended Actions

Recommended actions for Reach 3 are focused on increasing channel complexity and improving the quality and quantity of available aquatic habitat. All recommended actions are within the Okanogan National Forest. The recommended treatment is helicopter placement of large wood (LW) jams and mainstem LW channel loading in appropriate locations. The placements should take advantage of existing features (boulders, bedrock, channel form, and available floodplain) to instigate geomorphic function (i.e., pool development, side channel activation, floodplain activation, LW recruitment and retention, spawning gravel recruitment and retention) that increase channel complexity and habitat quality. We recommend a formal evaluation of the irrigation withdrawals from Little Wolf Creek via the current management of the Wolf Creek ditch/aqueduct and the potential impact these actions pose to ESA fish in Wolf Creek. This evaluation should consider potential habitat uses downstream of the withdrawal in lower Little Wolf Creek, as well as the habitat benefits perennial connection and discharge from Little Wolf Creek could provide to Wolf Creek. Maps and more detailed descriptions of recommended treatments are provided in Section 4 (Restoration Strategy Framework) of this report and Appendix C (Project Opportunities and Prioritization).

3.4 REACH 4 (RM 3.27–4.21)

3.4.1 Overview

Reach 4 is 0.94 river miles long and extends from the confluence with Little Wolf Creek (RM 3.27) to RM 4.21. The reach is unconfined from RM 3.27–3.85, as well as RM 4.1–4.21, and then confined to semi-confined from RM 3.85–4.1. Hillslopes and terraces border the floor of the valley and contact the channel in locations of confinement or where lateral processes have placed the channel along their toes. The channel is primarily single thread throughout Reach 4, with the exception of five side channels in the unconfined sections at RM 3.3, 3.33, 3.4, and 3.52, as well at RM 4.18 (Figure 60). Reach average sinuosity (1.12) is low, and gradient (4.03%), is slightly lower than Reach 3, and notably lower than Reach 5. Average bankfull width of the channel in Reach 4 is 34.7 feet, which is narrower than average bankfull width in Reach 3, but similar to that of upstream Reach 5. Low floodplain surfaces (inundated ~1-5 years), and high floodplain surfaces (inundated ~5-25 years), vary in width and occurrence depending on hillslope and terrace confinement. Channel and habitat complexity are greatest where low floodplain surfaces (inundation ~1-2 years) border the channel. The existing floodplain surfaces are well-vegetated with mature conifer forests, riparian trees, and a thick understory of shrubs. Recruitment and retention of large woody material (LWM) is occurring, and where it does occur, geomorphic complexity is increased. The entirety of the reach is within the Okanogan National Forest.

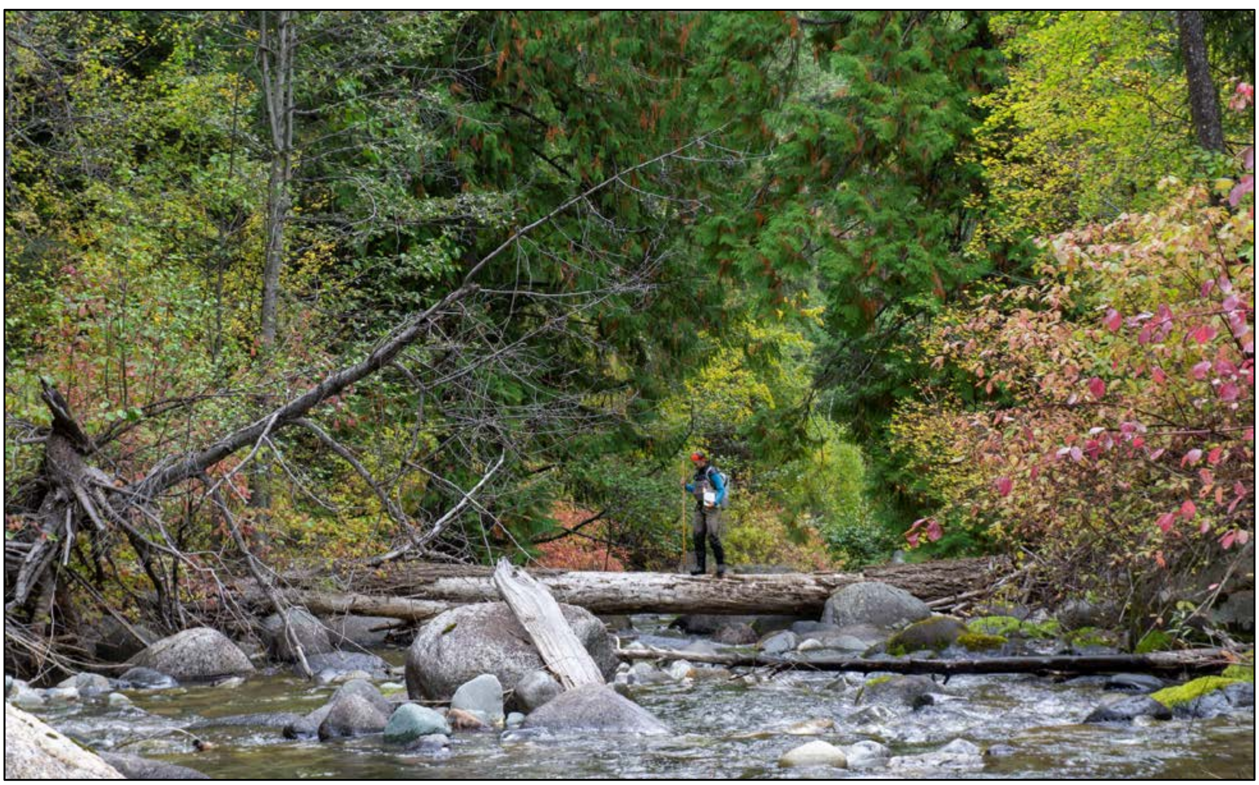


Figure 59. Wolf Creek at RM3.72. (Photo: 10/4/2019)

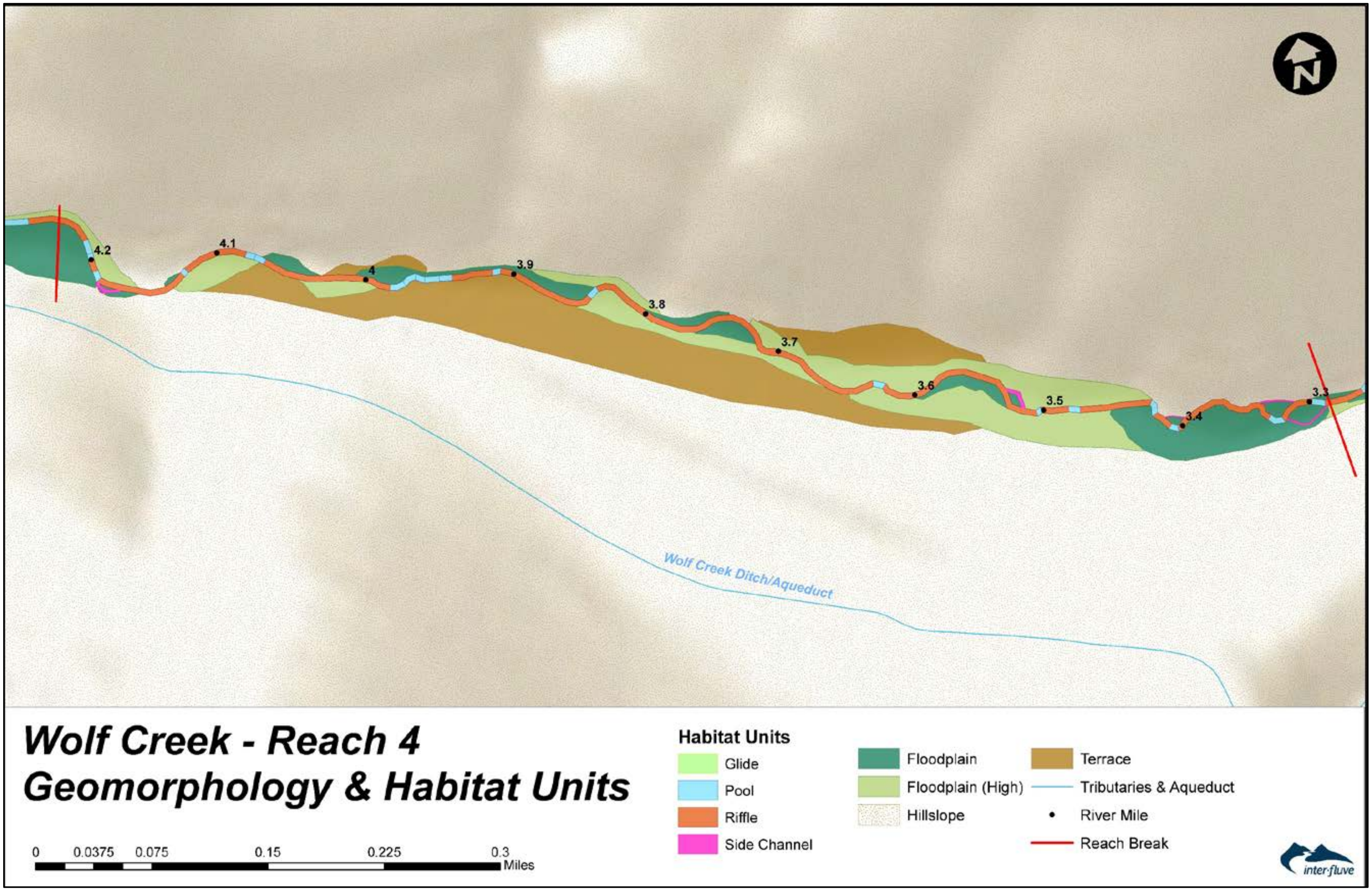


Figure 60. Reach 4: Geomorphic surfaces and channel units. Basemap: ESRI World Imagery

3.4.1 Channel and Floodplain Geomorphology

Wolf Creek in Reach 4 is considered a high gradient channel (reach average gradient is 4.03%) with a partial meandering planform. Planform is both a product of the pathway the channel has eroded into the underlying bedrock over time as well as how the channel has situated itself in the valley floor in relationship to paleo and modern alluvial surfaces (terraces and floodplains). Active side channels exist in locations where available floodplain occurs and often where LWM accumulations promote split flow. The LWM and side channels provide quality habitat and increased floodplain connectivity. The hillslopes, terraces, and bedrock bank exposures periodically contribute colluvium and landslide debris such as boulders, sediment, and LWM that add complexity to the channel's geomorphology. One notable bedrock contact at RM 3.44 produces a hard-bank meander point for the modern channel. Pool frequency and depth and off-channel habitat connectivity to the mainstem are rated as At Risk for quality salmonid habitat conditions in Reach 4 (See Section 2.13). Otherwise, ecosystem indicators are ranked as adequate.

Figure 61. Wolf Creek at RM 3.77, looking upstream. (Photo: 10/5/2019)

Channel substrate in Reach 4 is composed of cobble and boulders with sparse gravels (Figure 61). Gravels were observed in backwater eddies at boulders, at the riparian margin or small bars, near large wood accumulations, at step-pool tail-outs, and in side channels. Large boulder colluvium sourced from adjacent hillslopes provide additional complexity to the channel. Based on bed and bank material, and side channel wetting, hyporheic flow is expected to occur between the channel bed, bars, and floodplain surfaces.

The channel is primarily a cascading riffle reach with periodic step pools. The Habitat Assessment (see Appendix A) recorded 83% of the channel area as extended riffles, and 13% as pool habitat. Pool habitat is rated as At Risk based on a lack of frequency and quality (depth). The pools that do exist are maintained at boulder steps, bedrock exposures, and in association with scour hydraulics at LWM jams. Side channels represent just 4% of the available habitat in the reach even though there is floodplain area available to occupy. Off channel habitat is rated as At Risk in Reach 4 for quantity connected to the mainstem channel.

The floodplains are well vegetated with a mix of mature forests and dense riparian vegetation. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with coarse gravels and sands. Floodplain and terrace soils in Reach 4 are described as ashy sandy loam (0-5% slope) and the adjacent hillslopes are a mix of gravelly loam, ashy or fine loam, and gravelly ashy sandy loam with slopes ranging from 15-75% grade (USDA & NRCS, 2017). Floodplain surfaces range from 1 to approximately 5 feet above the bed of the channel. The low floodplains are expected to be inundated every 1-5 years and the high floodplain surfaces are expected to be inundated every 5-25 years, based on current configurations. The terrace surfaces occur as discontinuous features on river left at RM 3.55-3.73 (Figure 62) and at 3.96-4.04. On river right (south side) of the valley the terraces are elongate stair steps with paleo-alluvial scars that extend from RM 3.55-4.12. The terraces range from ~9-60 feet higher than the floodplain surfaces.

Figure 62. Horizontal high terrace surface at hillslope toe contact on river left (north) side of the valley – RM 3.64 (Photo 10/5/2019)

3.4.2 Vegetation and Large Woody Material

Vegetation in Reach 4 is well established. A natural vegetation condition of mature old growth conifer forest exists on the floodplain with a thick understory of native riparian vegetation bordering much of the channel. The overstory mature forest trees on the floodplains are primarily fir and cedar. The riparian border understory vegetation is dominated by dogwood and maple (Figure 63). The riparian border vegetation is often a mix of small trees and shrubs that occur where bank disturbance (high flow events) or developing floodplains occur. The forest and riparian vegetation provide a shade canopy for the channel throughout Reach 4. The adjoining hillslope and terrace vegetation are far less dense and composed of conifers (fir and pine) with an understory of low shrubs and grasses. Periodic wildfires are assumed to have been part of the historical landscape and vegetation evolution here, especially on the hillslopes.

Figure 63. Example of well-established mixed vegetation on floodplain surfaces in Reach 4 – RM 3.82. (Photo: 10/5/2019)

A total of 209 pieces of large wood material (LWM) and seven log jams (accumulation of ≥ 10 LWM) were observed in the channel during the habitat survey (10/4/2019). Of the 225 pieces, 70 are considered QLW: 48 classified as large size class (≥20-inches dbh and >35-feet long), and 22 as medium size class (12 to 20-inch dbh and at least 35-feet long). Jams located at RM 3.31, 3.32, 3.35, 3.41, 3.42, 3.53, and 3.6, each had additional multiple pieces of QLW in them. All but the jam at RM 3.6 correlate to split-flow channel complexity in Reach 4. See Figure 64 for the LW jam locations and the distribution of the other QLW material (>12-in dbh and at least 35 feet long) per mapped habitat unit in Reach 4. Where LWM exists, it plays an important role in aquatic habitat and geomorphic channel complexity such as pool development/maintenance, gravel accumulations, hydraulic diversity, floodplain activation/development, side channel activation/maintenance, and lateral processes.

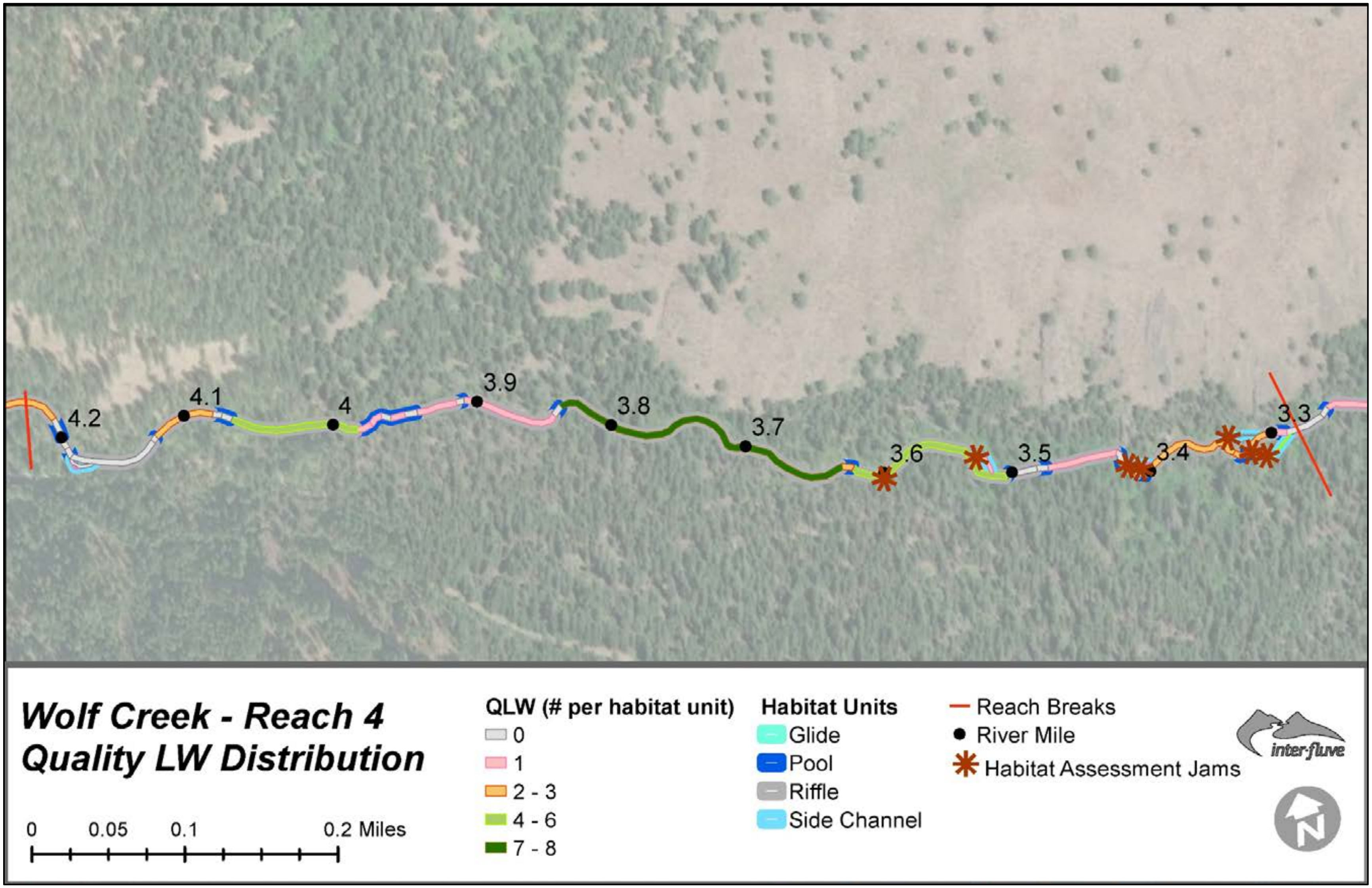


Figure 64. Reach 4 - Quality Large Woody (QLW) Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat (2019 Habitat Survey) and the location of LW jams (>10 pieces of LWM accumulated).

Large Wood jams and geomorphically-effective QLW pieces occur where large boulders or adjacent floodplain trees provide ballasting and where channel planform produces catchment areas (meander bends, side channel apex, etc.). Geomorphic complexity and thus habitat complexity are greatest where QLW interacts with the channel and where available floodplain bordering the channel allows for channel response. The size (quality) of the LW of the mature forests that border Reach 4 are capable of producing geomorphic complexity as single or small accumulations, as well as LW jams where pieces accumulate. Reach 4 has the largest and greatest number of LWM jams in the assessment area. The jams provide good analogues for large wood loading that produces diverse channel complexity (Figure 65). A recently accumulated/ing LWM jam at RM 3.32 has avulsed the mainstem to river left so that the channel is currently multi-threaded with some of the most diverse quality habitat in the assessment area (Figure 66).

Figure 65. Bedrock wall on river left at RM 3.44 and downstream channel-spanning log jam with bar accumulation upstream. (Photo: 10/4/2019)

Figure 66. LWM jam at RM 3.32 and resultant multi-threaded flow path avulsion across the floodplain. (Photo: 10/4/2019)

3.4.3 Human Alterations

Anthropogenic features that interact with the channel are relatively minor in Reach 4 (Figure 67). A gravel road and the Wolf Creek irrigation ditch/aqueduct are located on the southern hillslopes above the valley floor and terrace surfaces. The road (Little Wolf D, NF-Trail 527) is the access road for the Wolf Creek ditch/aqueduct and irrigation withdrawal. It is closed (locked gate) to the public and managed by the US Forest Service (USFS). At RM 4.15 the road cut is just 15 feet above the channel on the adjacent hillslope along river right. Otherwise, neither the road or the irrigation ditch/aqueduct interacts directly with the channel or its modern floodplain in Reach 4. The modern Wolf Creek Trail (NF 527) traverses the hillslopes on the north (river left) side of the channel and drops into the valley at the upstream end of the reach. No record of logging was found in the USFS databases in this reach. However, it is possible that previous to being part of the Okanogan National Forest, timber resources were extracted and livestock grazing occurred.

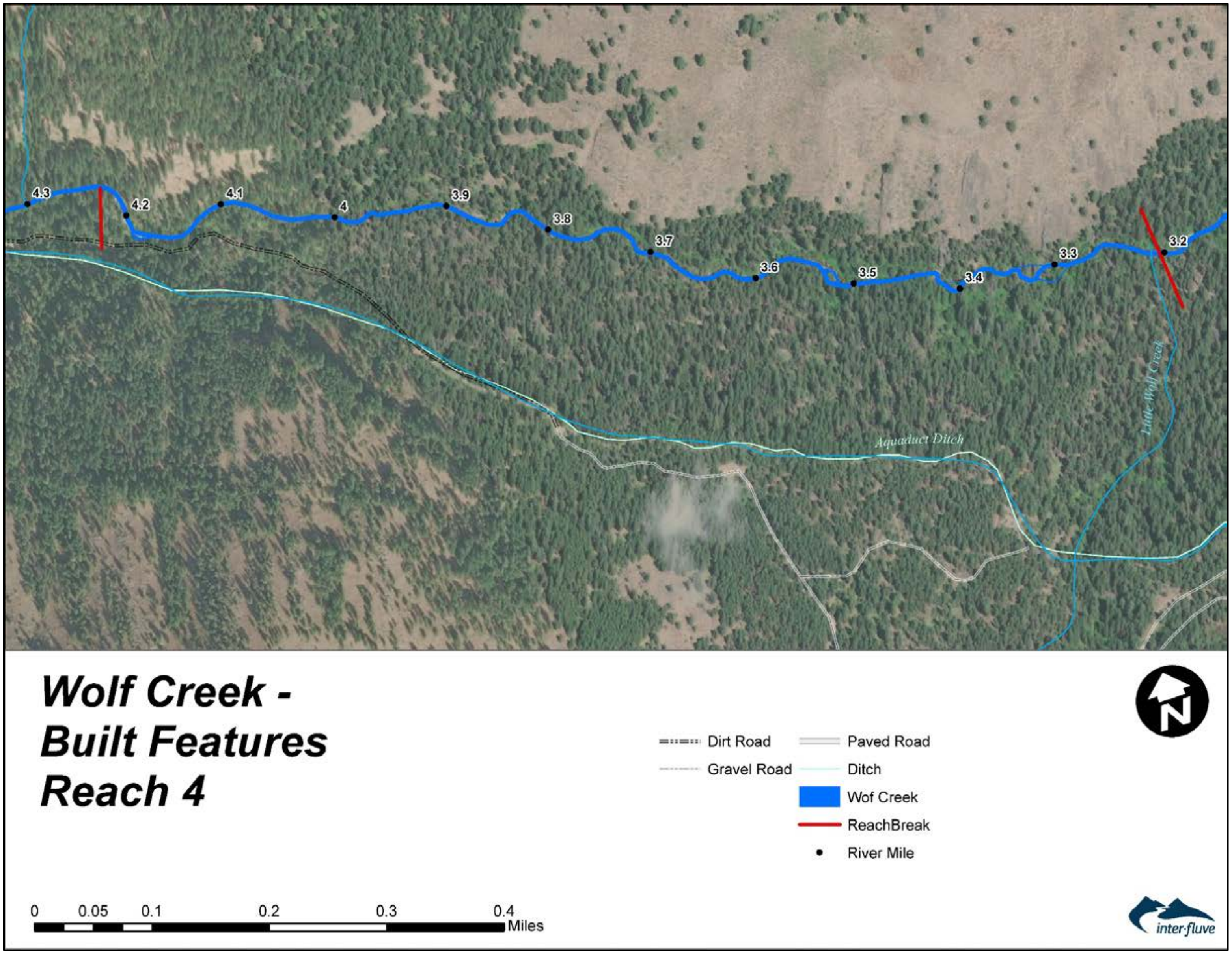


Figure 67. Anthropogenic features in Reach 4. Basemap: ESRI World Imagery

3.4.4 Recommended Actions

Recommended actions for Reach 4 are focused on increasing channel complexity and improving the quality and quantity of available aquatic habitat. All recommended actions are within the Okanogan National Forest. The recommended treatment is helicopter placement of LW jams and mainstem LW channel loading in appropriate locations. The LW should take advantage of existing features (boulders, bedrock, channel form, and available floodplain) to instigate geomorphic function (i.e., pool development, side channel activation, floodplain activation, LW recruitment and retention, spawning gravel recruitment and retention) that increases channel complexity and habitat quality. Maps and more detailed descriptions of recommended treatments are provided in Section 4 (Restoration Strategy Framework) of this report and Appendix C (Project Opportunities and Prioritization).

3.5 REACH 5 (RM 4.21–4.53+)

3.5.1 Overview

The section of Reach 5 included in the assessment area is 0.32 river miles long and extends from RM 4.21 to the Wolf Creek Ditch irrigation withdrawal immediately downstream of the Lake Chelan – Sawtooth Wilderness boundary. Although a relatively short reach, the channel varies from unconfined to semi-confined between RM 4.21-4.52 and then is confined at the upstream end (RM 4.52-4.53) at the constructed weirs and cement withdrawal gate associated with the Wolf Creek irrigation ditch intake infrastructure. Hillslopes and a small terrace contact the channel in locations of confinement or where lateral processes have placed the channel along hillslope toes. The channel is single thread throughout Reach 5, with no established side channels (Figure 69). In this section of the reach, average sinuosity (1.08) is low and gradient (7.1%) is notably higher than the other reaches in the assessment area. Average bankfull width of the channel is 33.5 feet, similar to that of Reach 4. Floodplain surfaces (inundated ~1-25 years) vary in width and occurrence depending on valley confinement. Channel and habitat complexity are greatest where low floodplain surfaces (inundation ~1-5 years) border the channel. Except for the access road and the cleared area associated with the Wolf Creek irrigation withdrawal and fish-ladder infrastructure, the floodplain surfaces are well vegetated with mature conifer forests, riparian trees, and a thick understory of shrubs. Recruitment and retention of LWM is minimal, but where it does occur, geomorphic complexity is increased. The entirety of the reach is within the Okanogan National Forest.

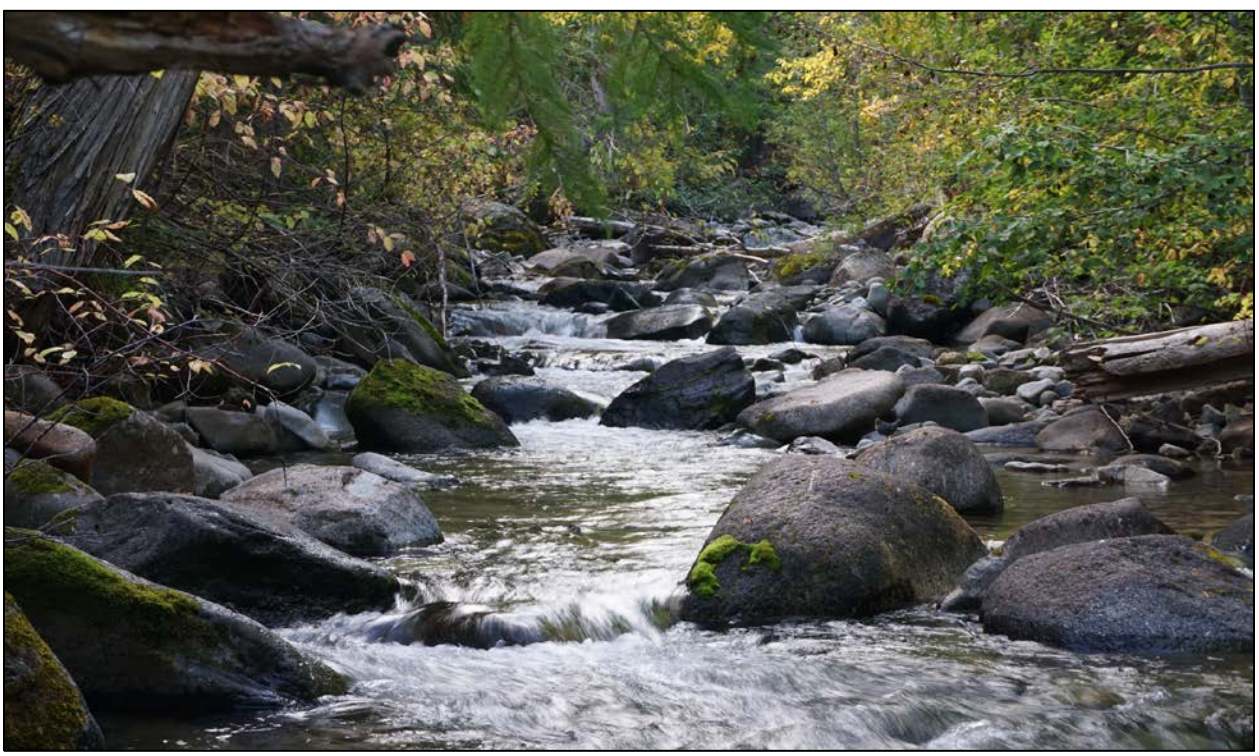


Figure 68. Wolf Creek at RM 4.45. (Photo: 10/5/2019)

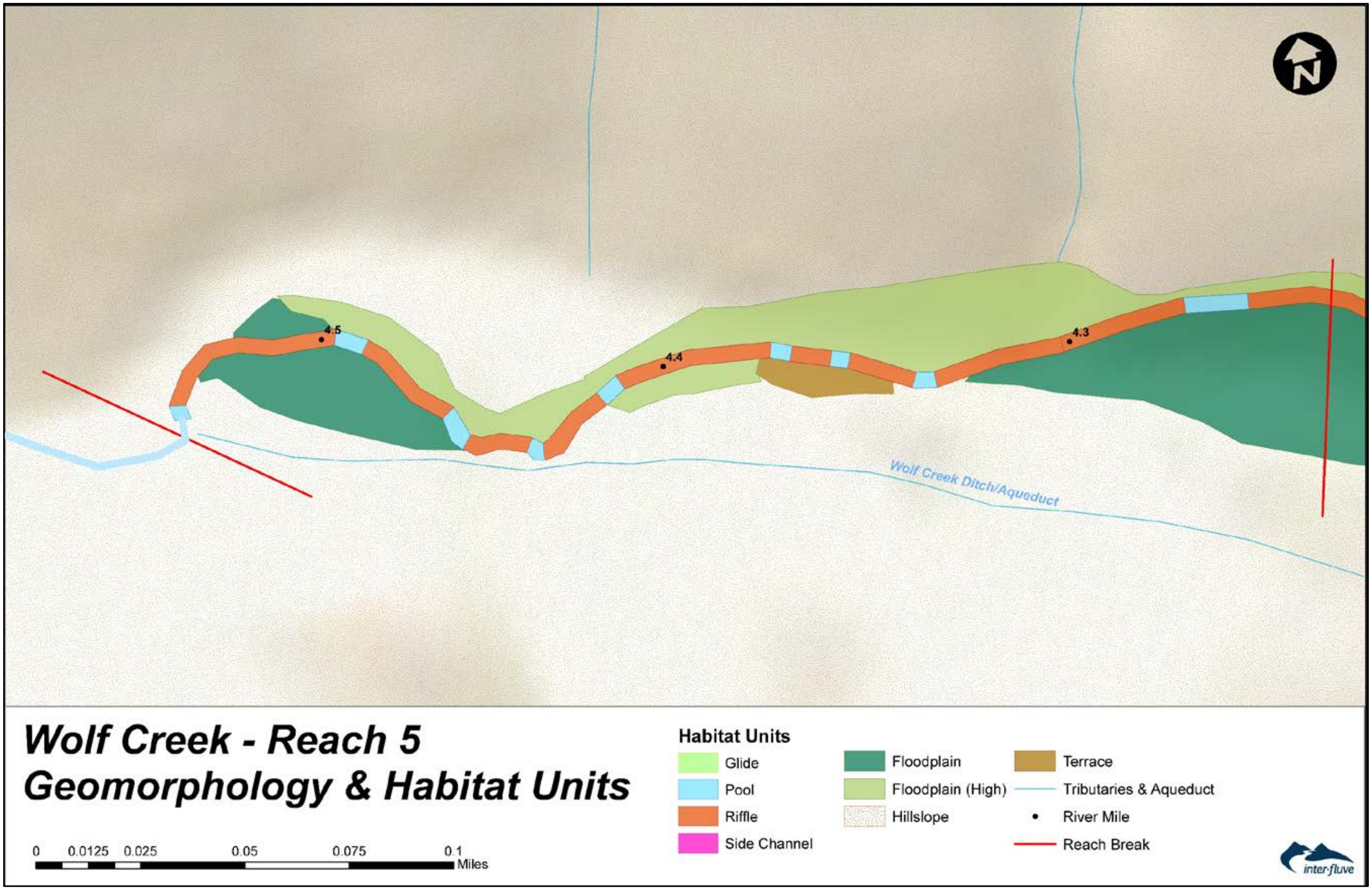


Figure 69. Reach 5: Geomorphic surfaces and channel units.

3.5.2 Channel and Floodplain Geomorphology

Wolf Creek in this portion of Reach 5 is considered a high gradient channel (reach average gradient is 7.1 %) with a subtle meandering planform. Planform is both a product of the pathway the channel has eroded into the underlying bedrock over time as well as how it has historically and currently situated itself in the valley floor in relationship to paleo and modern alluvial surfaces (terraces and floodplains). The hillslopes, terraces, and the bedrock bank exposures (RM 4.53 and 4.43 on river right) contribute colluvium and debris such as boulders and sediment that add complexity to the channel's geomorphology. The presence of very large boulders in the channel, banks, and across the floodplain influence channel form, localized hydraulics (scour and deposition), LWM retention, and bank and bed roughness and stability. Pool frequency and depth and off channel habitat connectivity to the mainstem are rated as At Risk for quality salmonid habitat conditions in Reach 5 (See REI summary in Section 2.13).

Figure 70. Wolf Creek at RM 4.36, looking upstream. (Photo: 10/5/2019)

Channel substrate in Reach 5 is composed of boulders and cobble with sparse gravels. Gravels were observed in backwater eddies at boulders and near large wood accumulations. Large boulder colluvium sourced from adjacent hillslopes provide additional complexity to the channel. Based on bed and bank material, hyporheic flow is expected to occur between the channel bed and floodplain surfaces.

Figure 71. Wolf Creek at RM 4.5 (Reach 5). (Photo: 10/45/2019)

The channel is primarily a cascading boulder riffle reach with periodic step pools. The Habitat Assessment (see Appendix A) recorded 80% of the channel area as extended riffles, and 20% as pool habitat. Pool habitat is rated as At Risk based on lack of frequency and quality (depth). The pools occur at boulder steps. No side channels were recorded in the October 2019 habitat survey and off channel habitat is rated as At Risk in Reach 5 for lack of connection to the mainstem channel.

Downstream of the disturbed banks associated with the Wolf Creek irrigation ditch withdrawal and fish screen infrastructure (RM 4.51-4.53), the floodplains are well vegetated with a mix of mature forests and dense riparian vegetation. Based on exposed banks, the floodplains are composed of a cobble-boulder base topped with coarse gravels and sands. Floodplain soils in Reach 5 are described as ashy sandy loam (0-5% slope) and the adjacent hillslopes are ashy fine sandy loam (15-35% slope) and gravelly ashy sandy loam (35-65% slope) (USDA & NRCS, 2017). Floodplain surfaces range from 1 to approximately 4 feet above the bed of the channel. The low floodplains are expected to be inundated every 1-5 years and the high floodplain surfaces are expected to be inundated every 5-25 years, based on current configurations. The only terrace surface in the reach is located on river right, adjacent to the channel, at RM 4.35-4.37. The terrace provides boulders and sediment to the channel though it is vegetated with shrubs and small trees.

3.5.3 Vegetation and Large Woody Material

Vegetation in Reach 5 is well established downstream of RM 4.52. A natural vegetation condition of mature old growth conifer forest exists on the floodplain with a section of the reach also having a thick understory of native riparian vegetation bordering much of the channel. The overstory mature forest trees on the floodplains are primarily fir and cedar. The riparian border understory vegetation is dominated by dogwood with some alder and maple. The riparian border vegetation is often a mix of small trees and shrubs. The forest and riparian vegetation provide a shade canopy for the channel except at the upstream end where it's been cleared and thinned adjacent to the irrigation withdrawal and other infrastructure related to the Wolf Creek Ditch and fish screen. The adjoining hillslope and terrace vegetation are less dense and composed of conifers (fir and pine) with an understory of low shrubs and grasses. Periodic wildfires are assumed to be part of the historical landscape and vegetation evolution here, especially on the hillslopes.

Figure 72. Example of well-established mixed vegetation on floodplain surfaces in Reach 4, RM 4.38. (Photo: 10/5/2019)

A total of 62 pieces of LWM and one log jam (accumulation of ≥ 10 LWM) were observed in the channel during the survey (10/5/2019). Of the 62 pieces, 17 are considered QLW: 3 classified as large size class (≥20-inches dbh and >35-feet long), and 14 as medium size class (12 to 20-inch dbh and at least 35-feet long). The LW jam, located at RM 4.42, contained multiple pieces of QLW. See Figure 73 for the LW jam locations and the distribution of the other QLW material (>12-in dbh and at least 35 feet long) per mapped habitat unit in Reach 5.

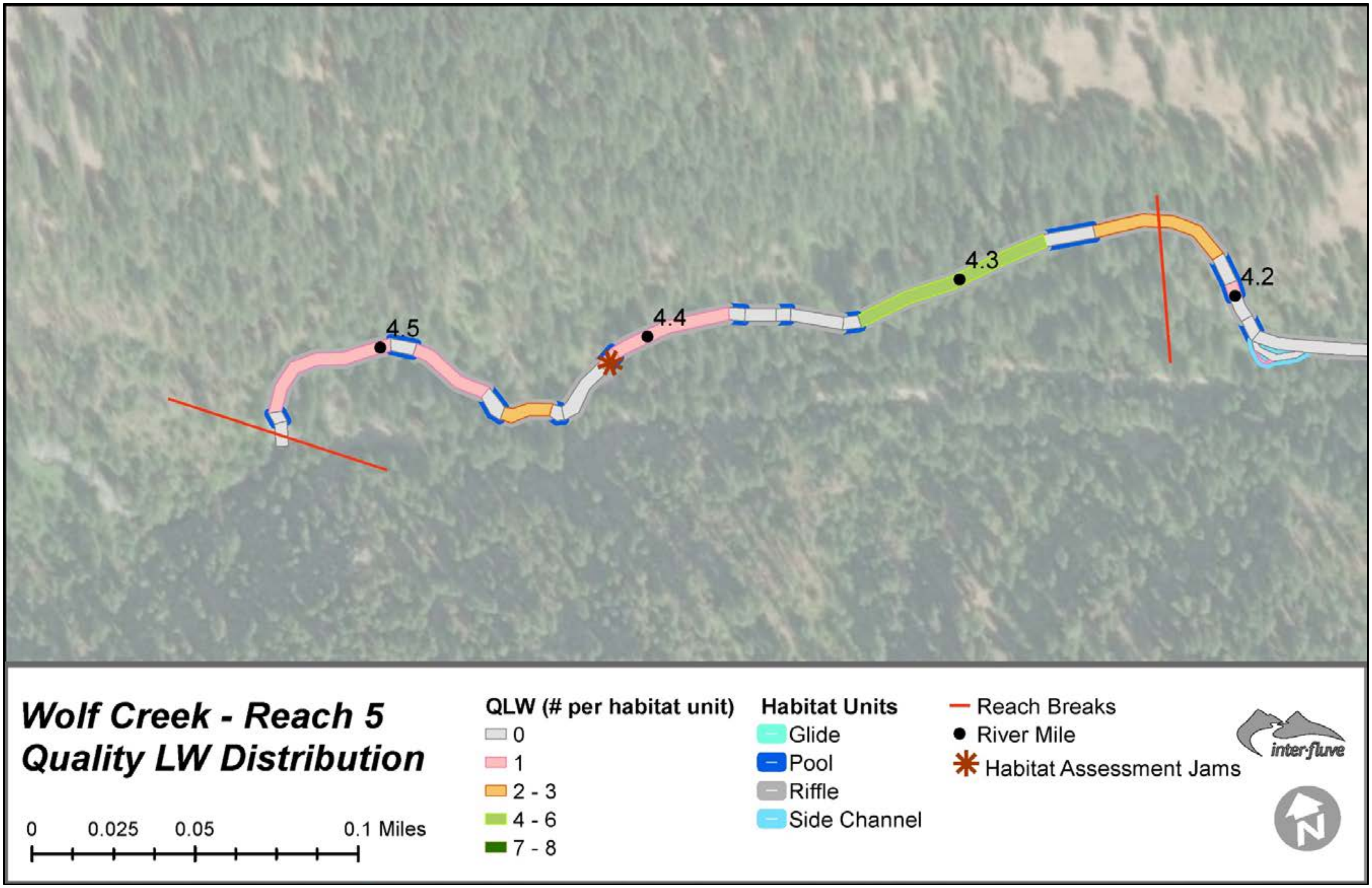


Figure 73. Reach 5 - Quality Large Woody (QLW) Material (>12-inch dbh and at least 35 feet long) distribution by number of pieces per mapped habitat (2019 Habitat Survey) and the location of LW jams (>10 pieces of LWM accumulated).

Where LWM exists, it plays an important role in aquatic habitat and geomorphic channel complexity such as pool development/maintenance, gravel accumulations, hydraulic diversity, and floodplain activation/development. There are three likely reasons for a lack of LWM in the upstream portion of Reach 5: the irrigation withdrawal gate and weirs at the upstream end of the reach are maintained and likely regularly cleared of LWM; floodplain vegetation removal and thinning near the infrastructure; . However, LW jams and geomorphically-effective QLW pieces are retained downstream of the structure where large boulders or adjacent floodplain trees provide ballasting and where channel planform produces catchment areas (bedrock meander bend). Geomorphic complexity and thus habitat complexity are greatest where QLW interacts with the channel and available floodplain. The size (quality) of the mature forests that border Reach 5 are capable of producing geomorphic complexity, especially as LW jams. The LW jam at RM 4.42 provides a good analogue example for effective jams for the assessment (Figure 74).

Figure 74. Channel-spanning LWM jam at RM 4.42. (Photo: 10/5/2019)

3.5.4 Human Alterations

Anthropogenic features that interact with the channel in Reach 5 (Figure 76) are associated with the irrigation withdrawal infrastructure of the Wolf Creek Ditch (Figure 75). The withdrawal outtake gate (RM 4.53) is located on river right downstream from a bedrock bank outcrop and immediately upstream of a set of 5 steel plate weirs constructed to hold bed elevation for the withdrawal (Figure 77). The weirs are reinforced with boulders and notched in the middle to direct flow down the center of the channel (Figure 77). The weirs are currently fish passable for up-migrating adults but may pose a minor passage issue for juveniles at low flows until sufficient bedload accumulates behind the plates. The river right side of the channel is riprapped with large boulders and cement.

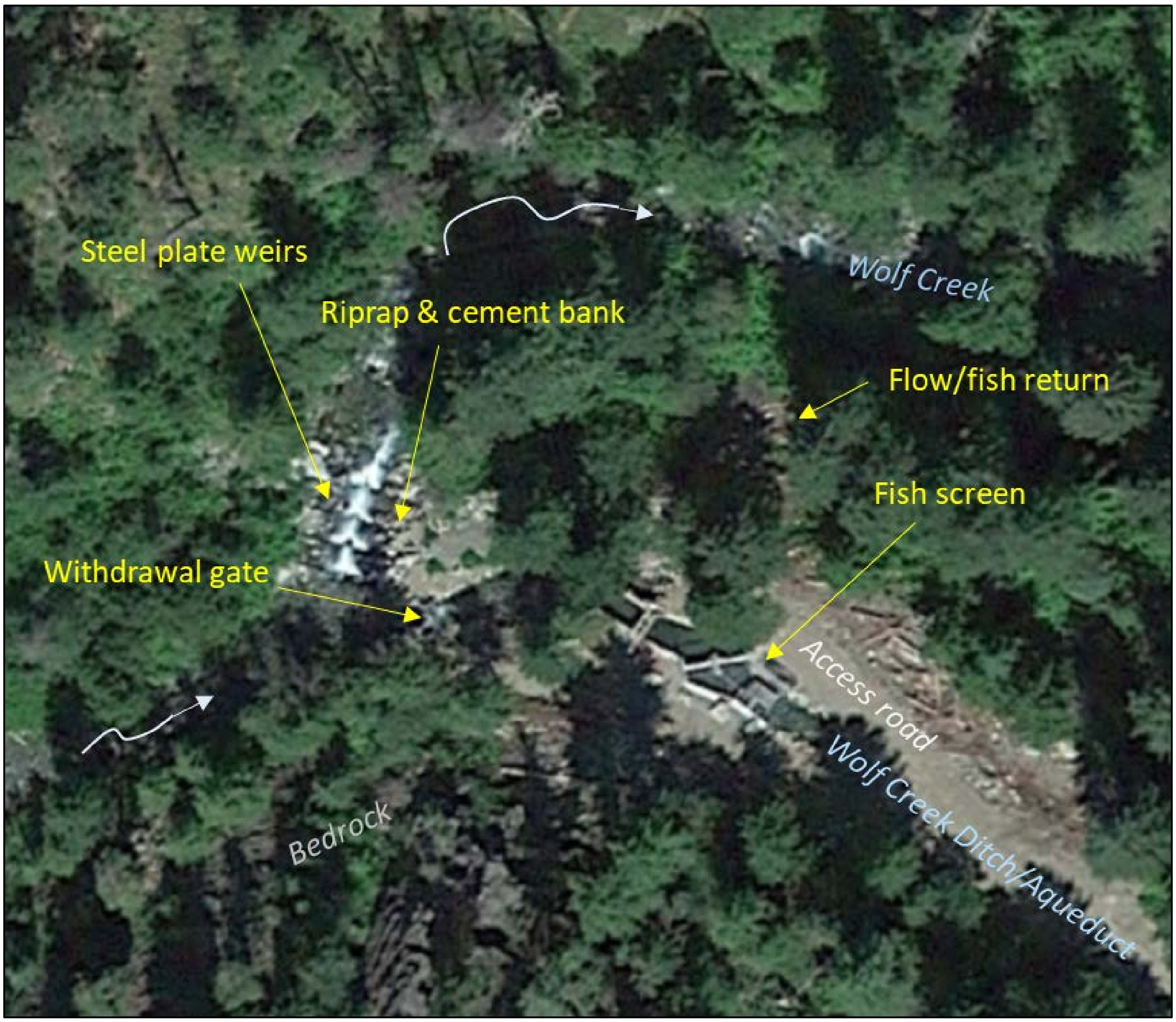


Figure 75. Overview of the Wolf Creek irrigation diversion at RM 4.53. (GoogleImage)

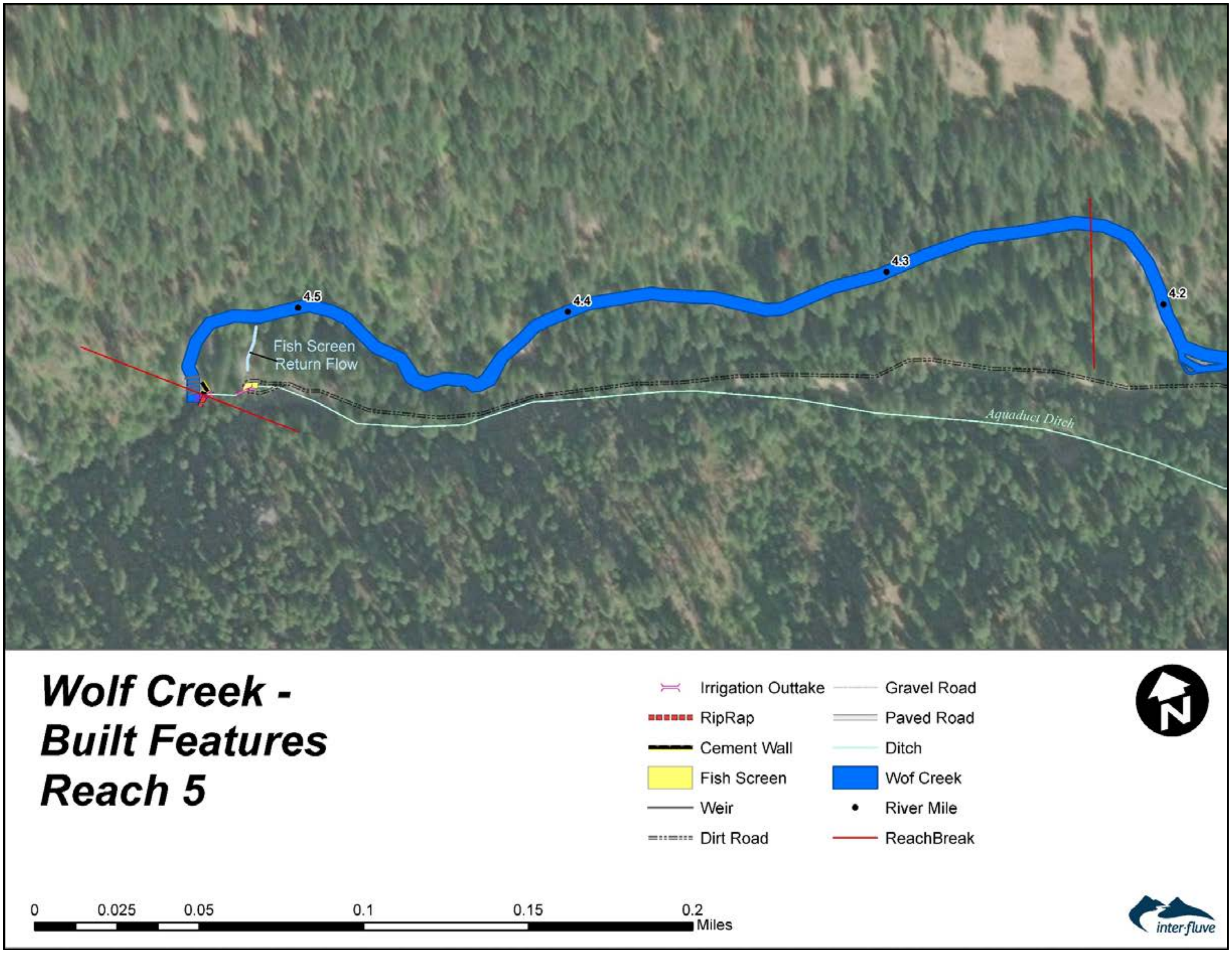


Figure 76. Anthropogenic features in Reach 5. Basemap: ESRI World Imagery

Figure 77. Wolf Creek diversion gate and downstream constructed steel plate weirs at RM 4.53. (Photo: 7/8/2020)

After the diverted irrigation water passes through a fish screen, it enters the Wolf Creek irrigation ditch/aqueduct which starts as a buried culvert under the USFS managed gravel access road (Little Wolf D, NF-Trail 527). Water in the ditch/aqueduct flows through a sequence of buried culverts and an open ditch to reach the private storage pond it supplies water to approximately 2.5 miles down valley.

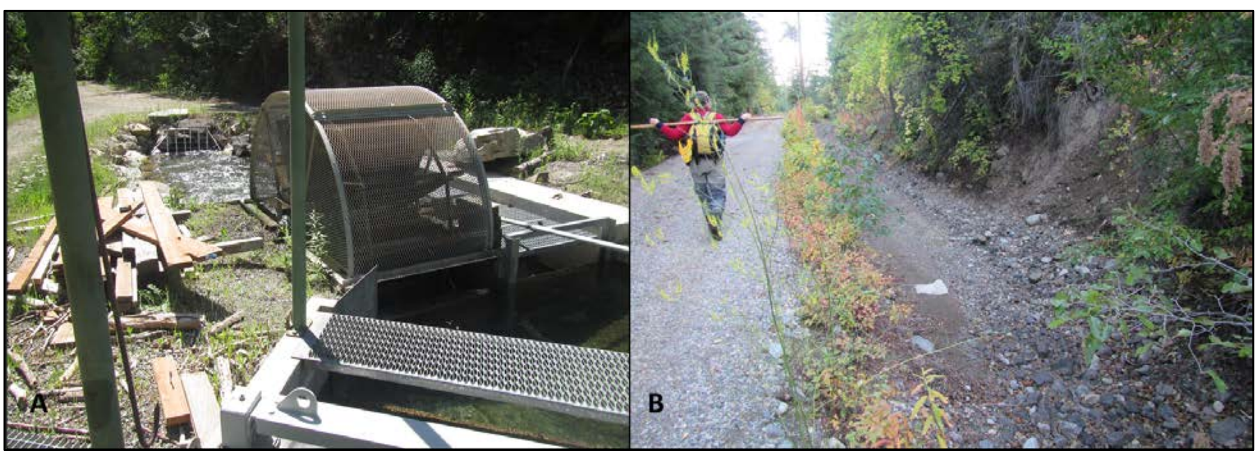


Figure 78. A) Fish screen that leads into Wolf Creek irrigation ditch buried under access road (Photo: 7/8/2020) B) Wolf Creek irrigation open ditch down valley along access road (Photo: 10/5/2019)

3.5.5 Recommended Actions

Recommended actions for Reach 5 are focused on increasing channel complexity and improving the quality and quantity of available aquatic habitat. Upgrading fish passage at the constructed weirs associated with the Wolf Creek irrigation withdrawal is also recommended. All recommended actions are within the Okanogan National Forest. The recommended channel treatment is helicopter installation of large wood (LW) jams and mainstem LW channel loading in appropriate locations that take advantage of existing features (boulders, bedrock, channel form, and available floodplain) to uplift geomorphic function (i.e., pool development, side channel activation, floodplain activation, LW recruitment and retention, spawning gravel recruitment and retention) and increase habitat quantity and quality.

Assuming that the Wolf Creek irrigation diversion must remain in place and in functioning order, improvements to the existing grade control weirs would improve fish passage conditions and structure longevity. Constructing a set of boulder steps that have multiple flow pathways at high flow and concentrated but offset flow paths at low flow would provide more natural and easier fish passage instead of a sequence of middle-notched weirs that focus flow energy. Burial of the large boulders could extend into the banks to both maintain flow direction towards the withdrawal gate and provide valley-wide grade control. This design would also minimize ongoing maintenance of the existing weir and outtake point structure.

Maps and more detailed descriptions of recommended treatments are provided in Section 4 (Restoration Strategy Framework) of this report and Appendix C (Project Opportunities and Prioritization).

Restoration Strategy Framework

3.6 INTRODUCTION

The Restoration Strategy uses the field surveys, inventories, and analyses performed in the Reach Assessment (Sections 1-3 and Appendices A) as the technical basis for identifying and prioritizing restoration actions. The intent is to provide a direct linkage between the technical analyses, identified limiting factors, and the actions that are moved forward towards implementation. At the core of the Restoration Strategy is the ‘Gap Analysis,’ which compares existing and target conditions in order to identify and evaluate project opportunities. The existing and target conditions are obtained from the findings of the Reach Assessment and rely heavily on the REI ratings, although other factors are also considered. For each project area, existing and target conditions are compared, which helps to identify the types of actions that need to be performed and is also used as a factor in project ranking–i.e., the larger the ‘gap’ between existing and target conditions that can be addressed through restoration, the higher the project is ranked. Other factors are also considered, including the potential for the site to support the focal species and whether or not it is possible to address the root causes of impairments.

The Restoration Strategy describes the restoration opportunities identified in nine distinct project areas to address the identified limiting factors. Planform concept maps are included for each project area below the descriptions. The project area ranking and prioritization is included after the concept maps.

3.7 RESTORATION STRATEGY FRAMEWORK

An overview of the restoration strategy for Wolf Creek is presented in Section 4.3. Following this, in Section 4.4, are the individual reach-scale restoration strategies. The information included in the reach-scale strategies is described in the subsections below.

3.7.1 Summaries of Reach Assessment Findings

For each reach, the summary of reach assessment findings distills the large amount of information contained in the Reach Assessment (Sections 1–3) into a “snapshot” summary for each reach. It includes a designation of good, moderate, or high for overall ecological function. The rationale for the designation is provided in the table. The summary also includes a description of the trajectory of the system if no action is taken. This is based primarily on the geomorphic analysis including current trends and the effects of land use. A rating of high, medium, or low is also provided for the recovery potential of the reach. This designation is based on the likelihood of being able to effectively address degraded processes and habitat based on the realities of current and anticipated land use, infrastructure, and ownership.

3.7.2 Restoration Objectives

Restoration objectives were developed for multiple ecological attributes, including habitat, geomorphic, and riparian. These objectives are presented as restoration targets. They are made to be as quantifiable as possible at this stage of analysis. These target conditions are compared to existing conditions from the Reach Assessment. This highlights habitat deficiencies and the "gap" that needs to be filled to recover habitat.

Target conditions were developed using the Reach-based Ecosystem Indicators (REI) targets (Appendix B) as well as reference to site conditions and inference from regional studies. The REI analysis is based on previous REI analyses conducted by the USBR and Yakama Nation in other Upper Columbia tributaries, with some modifications. See Section 2.13 of this report and Appendix B for more information on the REI analysis.

3.7.3 Restoration Action Types

Four restoration action types appropriate for the aquatic species and geomorphic processes of the Wolf Creek assessment area were developed for application in individual project areas within each reach. Action types are developed at a broad scale and are often achieved through the use of numerous project elements. For example, the action type "improve habitat and channel complexity" can be achieved in various ways ranging from excavating an inset floodplain along an entrenched segment of channel or helicopter installation of large wood in the upstream roadless sections. The specific project opportunities, on the other hand, are more site-specific and have unique characteristics (i.e., general size or type of LW jam), depending on the particular habitat conditions, land uses, geomorphic context of the site, and existing infrastructure limitations.

We use the term 'restoration' as a broad catch-all when we refer to recommended actions; however, we acknowledge that many of the actions are not restoration in the true sense of the word, and would be more appropriately labeled as "enhancement," "improvement," or "creation." We consider true restoration actions to be those that address root causes of impairments and that aim to return the system close to its naturally functioning state. This is often not achievable due to past changes to the underlying processes or to process impairments that are unlikely to change due to infrastructure. An example of a true restoration project would be one that fully removes a levee, returns the channel to its historical form, and replants the valley floor to restore natural floodplain inundation patterns. Enhancement measures are those that improve or rehabilitate habitat to the extent possible given existing impaired processes and anthropogenic constraints. Installation of a bank buried LW jam at an existing pool to provide cover is an example of habitat enhancement. Installation of a large wood apex jam to encourage split flow conditions is an example of complexity enhancement. Creation projects are those that create new habitat that is currently lacking or that will not be created on its own in a reasonable timeframe given existing trends and process impairments. Excavating an inset floodplain along an otherwise entrenched channel is an example of a creation project.

The four action types recommended for the Wolf Creek assessment area are described below.

1. Riparian Vegetation

Riparian restoration projects are located in areas where native riparian vegetation communities have been impacted such that riparian function and connection with the stream are compromised. In the Wolf Creek assessment area, riparian vegetation has been cleared for homes, domestic uses, and access (roads and bridges). Restoration actions are focused on restoring native riparian buffer vegetation communities in order to reestablish natural stream stability, stream shading, nutrient exchange, and large wood recruitment. Even though it is not always explicitly stated in the other actions, riparian restoration is also a recommended component of actions that result in ground disturbance.

Examples:

- Replanting a riparian buffer area with native vegetation.
- Planting native vegetation in areas disturbed by decommissioning, removing, or upgrading existing human infrastructure.
- Fencing out grazing animals along a riparian area that is being restored to minimize impacts on naturally regenerated and/or planted vegetation.

2. Upgrade or Remove Anthropogenic Features

This action includes identifying the human placed items currently impeding natural channel processes and/or habitat complexity and determining how best to address those impacts. For example, large sections of Wolf Creek in Reach 1 are entrenched and confined but preliminary assessment has determined that removing the levees or lifting the channel will increase flood risk to existing infrastructure. However, upgrading bridge crossings or removing/decommissioning outdated irrigation withdrawals can improve localized habitat and geomorphic function without increasing risk to infrastructure in some locations. Selection and removal of such elements need to be evaluated for potential disturbance and remediation as well as resultant changes to channel stability and flow hydraulics.

Examples:

- Upgrade and widen bridge crossing to reduce local channel confinement.
- Decommission and/or remove irrigation withdrawal and replace with off-channel well(s).
- Upgrade in-channel grade control structures to improve longevity and fish passage.

3. Enhance Aquatic Habitat

This strategy includes placement of habitat structures such as large wood and log jams in order to improve existing local habitat features. Sections of the Wolf Creek assessment area are lacking in quality mainstem large wood, pool, and off channel habitat. Aquatic habitat improvement projects are scaled and designed to meet flow hydraulics and minimize risk to existing infrastructure. For instance, stream energy and density/proximity of homes and bridges in Reach 1 suggest that large wood installations need to be bank buried and scaled in size depending on available inset floodplain. In contrast, aquatic habitat enhancement large wood treatments in sections of the assessment area within the Okanogan National Forest will not require bank burial. In either scenario, the structural elements included in these actions are placed in areas where they would naturally accumulate and be maintained by existing stream hydrology and geomorphology. These projects are generally considered enhancement measures, as they do not fully restore the root cause of the problem (e.g., channel entrenchment due to leveeing, bank hardening, and bridges).

Examples:

- Installation of a large wood bank buried log jam to maintain pool scour, provide cover, and to increase quantity of available high velocity refugia for rearing.
- Installation of large wood bank buried apex jam to instigate and maintain floodplain connectivity and side channels.
- Installation of large wood mid-channel jam to increase habitat complexity.
- Placement of large boulders to increase habitat complexity and ballast/catch LW.

4. Increase Complexity

Habitat and channel complexity improvement actions are aimed at increasing geomorphic complexity such that habitat conditions are improved locally and overall, in a reach. This type of action is designed in areas where they will naturally be maintained and organized by stream hydrology and geomorphology. For the Wolf Creek assessment area, this action type includes a range of various sized large wood channel loading and jam installations by helicopter where appropriate, in Reaches 2-5. These actions identify and take advantage of existing conditions such as locations of large boulders, channel planform and geometry, gradient and stream energy, available valley width and maturity of vegetation.

Project examples:

- Excavate inset floodplain along entrenched channel to improve system function to support aquatic habit diversity.
- Helicopter installation of LWM jam in a location that will promote split-flow or floodplain activation, sediment accumulation, and pool scour such that habitat complexity and system connectivity is improved.
- Helicopter installation of LWM loading along a section of channel to increase complexity of flow hydraulics. The expectation is that the channel will respond to (i.e., pool scour, sediment accumulations) and organize (i.e. jam accumulations or steps) the added material into highly functional habitat units.

3.7.4 Projects and Prioritization

Projects were identified through field surveys and analysis performed in the Reach Assessment. Project elements were identified that are believed to best achieve target conditions and to address key factors limiting ESA listed steelhead, Chinook, and bull trout populations and improve their habitat conditions in lower Wolf Creek. These projects represent an initial first step in this process; it is expected that projects will be modified as appropriate once project-specific surveys, analysis, and stakeholder coordination are performed as part of design. Project descriptions and maps are provided below.

Project prioritization was performed to rank the projects into three priority tiers. Prioritization occurred by subjecting the projects to a set of scoring criteria. These criteria are based on several factors, including how well projects address the "gap" between existing and target conditions, species use/potential use of the area, and whether or not projects address root causes of impairments. Projects are also given a cost score and feasibility designation in order to provide a relative cost perspective in project selection and planning.

3.8 RESTORATION STRATEGY OVERVIEW

An overview of the reach-scale conditions, recovery potential, identified projects within each reach, and recommended restoration action types are provided in Table 7. The ecological function (Low, Moderate, and High) of each reach is characterized by the ratings that resulted from the REI (see Appendix B). The trajectory (decline, same, improve) is determined by evaluation of the modern geomorphic trends, related existing habitat conditions, and continued limitations such as infrastructure and land use (see this Reach Assessments in Section 3). The recovery potential (Low, Moderate, and High) is based on the potential for the site to recover functioning habitat and processes with restoration actions. To do so, the potential for the REI indicator ratings to improve via restoration actions is considered. The recovery potential rating considers known limitations to recovery that are unlikely to be eliminated as part of implementation of this restoration strategy, such as the presence of residential infrastructure or required irrigation diversions. Below, the project prioritization and recommended restoration action types for each project area are presented.

Table 7. Overview of restoration strategy for Wolf Creek RM 0 - 4.53 (Reaches 1-5).

Reach	Ecological Function	Trajectory	Recovery Potential	Prioritization (Tier 1-3)	Project Area	Restoration Action Type
1	Low	same - decline	Moderate - High	1	Lobos	1, 2, 3, 4
				3	Wolf Den	2, 3
				2	Ponds	2, 3
				2	Wildflower	2, 3, 4
2	Moderate	same - improve	High	1	R2a HeliLW	2, 3, 4
				1	R2b HeliLW	3, 4
3	Moderate-High	same	High	1	R3 HeliLW	3, 4
4	High-Moderate	same	High	1	R4 HeliLW	3, 4
5	Moderate	same	High	1	R5 HeliLW	3, 4
				2	Wolf Weir	2

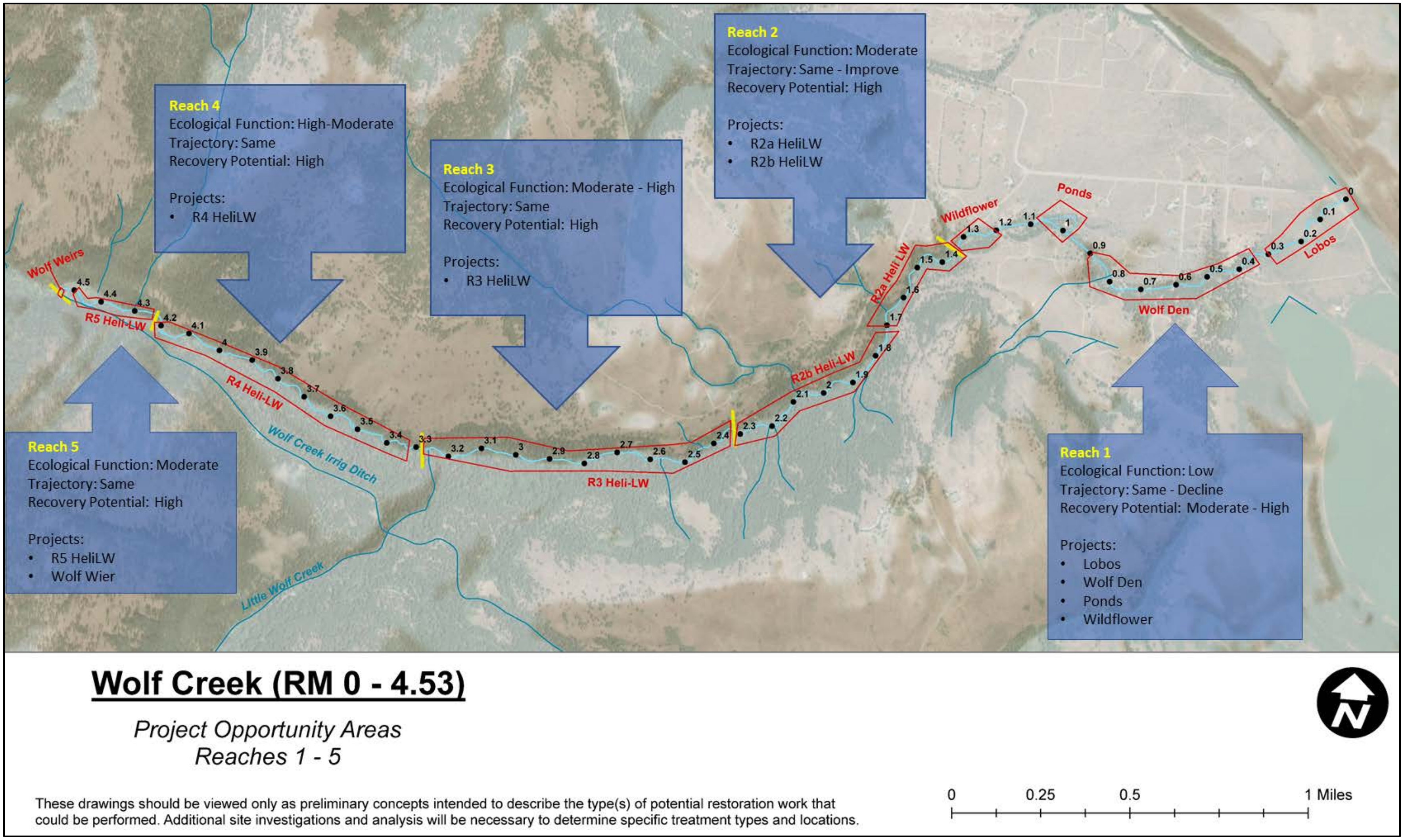


Figure 79. Wolf Creek RM 0-4.53 reach-based restoration strategy overview – Project Areas. Basemap: ESRI

3.9 REACH-SCALE STRATEGIES

3.9.1 Reach 1 Restoration Strategy

Overall ecological function	**Low**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. Eight of the 11 REI metrics are at unacceptable condition and one is at risk. Significant impairment of channel and floodplain function due to channel entrenchment, constructed levees, riprap and cemented banks, confining bridge crossings, home development, riparian vegetation clearing, few pools and only one ≥ 3-ft deep, minimal habitat complexity, lack of large wood in the channel, and lack off channel habitat.
Trajectory if no action taken	**Same – Decline**
	Same and continued degradation due to persistent anthropogenic impacts to floodplain, channel migration and entrenchment, riparian, and large wood processes. Limited lateral processes and inset floodplain development in less confined segment and minor passive recovery of riparian shade function due to vegetation establishment at channel margins.
Recovery potential	**Moderate – High**
	Downstream and upstream project areas have no homes = potential to increase channel, floodplain, and delta function. Enhanced habitat complexity potential via increased scour pools and added large wood. Of - channel habitat development potential at existing ditch. Home development limits capacity to remove most of the levees or reactivate historical fan.
Restoration objectives	**Target conditions in Table 8**
	Bring existing conditions to target conditions (multiple habitat and geomorphic attributes), where possible, for the metrics identified in Table 8 below. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Riparian Restoration** **Upgrade or Remove Anthropogenic Features** **Enhance Aquatic Habitat** **Increase Complexity**
	Actions include improvement of channel complexity and enhancement of aquatic habitat as well as upgrading anthropogenic features from to restore function. Full restoration is limited by existing private land ownership and risk to existing infrastructure.
Project Areas & Prioritization	**Lobos (Tier 1)** **Wolf Den (Tier 3)** **Ponds (Tier 2)** **Wildflower (Tier 2)**
	The potential to improve the quantity and quality of available habitat in Reach 1 is moderate to high. The Lobos and Ponds project areas have moderate potential, Wolf Den is high, and Wildflower is low. Several Homes are dependent on constructed levees and ditches for flood protection, limiting recovery potential. All Reach 1 project areas are complimentary to each other but would provide habitat and function benefits if completed independently.

Table 8. Reach 1 Restoration Objectives, Action Types, and Projects.

Attribute	**Existing Condition (from assessment)**	**Target Condition [REI – Adequate Rating]**	**Action Type**	**Project**
Habitat Access	There are no anthropogenic barriers in the main channel that inhibit fish passage.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow. Connector culvert at constructed ponds are potential seasonal barriers (YNF).	Upgrade Anthropogenic Features	Ponds
Habitat Quality	Gravel-cobble dominated substrate; gravels on bars. 7.5 pieces of installed LW per mile. 17.9 pools per mile with 1 pool > 1m (3ft) and low pool shade/cover. No side channel or off channel refugia.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off-channel refugia.	Upgrade Anthropogenic Features Enhance Aquatic Habitat Increase Complexity	Lobos Wildflower Ponds Wolf Den
Riparian Condition	Forested riparian buffer (200ft): 0% large trees; 3.9% disturbed; >50% canopy cover for thermal shading; and 11 mile/miles^2 road density	At least a 200-ft riparian buffer with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	Riparian Restoration Increase Complexity	Lobos
Channel Dynamics	Channel entrenchment & floodplain disconnection throughout exaggerated by levees, roads, riprap, and bridges. Large section of the channel with no lateral migration occurring due to human built features and probable bed excavation to build levees. Continued incision is possible but will not be rapid.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Upgrade Anthropogenic Features Enhance Channel Complexity Increase Complexity	Lobos Wildflower

3.9.2 Reach 2 Restoration Strategy

Overall ecological function	**Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. Three of the 11 REI metrics are at risk and one is unacceptable. Impairments due to no pools ≥ 3-ft deep, lack of large wood, and riparian vegetation structure and cover.
Trajectory if no action taken	**Same - Improve**
	The riparian forest in the downstream half of the reach is in the process of passively maturing. Over time, quantity and quality of available LW will increase and shade cover will increase. If clearing or thinning occurs or LW is cleared from the channel in the area bordered by private property, conditions could remain the same or decline. Channel gradient (stream power) requires quality (med to large sized LW) to effectively alter trajectory.
Recovery potential	**High**
	If complexity added (large wood jams and loading) where appropriate and riparian vegetation permitted to mature, then high potential for improved quantity and quality of habitat, increased floodplain connectivity, and side channel development/maintenance.
Restoration objectives	**Target conditions in Table 9**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 9 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Remove / upgrade anthropogenic infrastructure** **Enhance Aquatic Habitat** **Increase Complexity**
	Actions include enhance aquatic habitat and increase channel complexity via helicopter installation of LW jams and mainstem LW channel loading. Evaluate potential need to remove or upgrade existing surface water withdrawal.
Projects & Prioritization	**R2a HeliLW (Tier 1)** **R2b HeliLW (Tier 1)**
	Helicopter installation of LW jams and mainstem channel LW loading at locations with available floodplain, appropriate channel form, and large boulders for natural ballasting. LW pieces in loaded areas will be reorganized by high flow events and expected to create accumulations (jams). Treatment expected to instigate some side channel and floodplain activation. R2a HeliLW includes WCPOA water withdrawal to be evaluated and limited number of areas appropriate for LW jam and no areas appropriate for loading. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently.

Table 9. Reach 2 Restoration Objectives, Action Types, and Projects.

Reach 2 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	There are no anthropogenic barriers in the main channel that inhibit fish passage.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	No action needed	
Habitat Quality	Cobble dominated substrate; gravels retention associated with large boulders and LW. 67 med/large pieces of LW per mile. 21.6 pools per mile with 0 pools > 1m (3ft) and marginal pool shade/cover. Seven existing side channel with moderate cover.	At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off channel refugia.	Decommission or Upgrade Anthropogenic Feature Enhance Aquatic Habitat Increase Complexity	R2a HeliLW R2b HeliLW
Riparian Condition	Riparian buffer composition: 88% small trees; 0.6% disturbance; 50-80% canopy cover for thermal shading; and 1.6 mile/miles^2 road density within 200-ft riparian buffer	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	(passive forest recovery) Increase Complexity	R2a HeliLW R2b HeliLW
Channel Dynamics	Where valley width allows, vegetated floodplains occur. Lateral processes (usually instigated by LW accumulations) periodically occur but are limited in the section border by private property. Sufficient quantity and substrate size limits modern incision.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Increase Complexity	R2a HeliLW R2b HeliLW

3.9.3 Reach 3 Restoration Strategy

Overall ecological function	**Moderate - High**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. One of the 11 REI metrics are unacceptable and one is at risk. Impairments are associated with few pools of inadequate size and 0 ≥ 3-ft deep and limited off channel habitat.
Trajectory if no action taken	**Same**
	Ecologic function is expected to remain relatively the same under existing conditions–unless wildfire and/or landslide provides increased quantity of LW and sediment to the channel.
Recovery potential	**High**
	The reach is entirely within a roadless section of the Okanogan National Forest. LW loading is expected to instigate trajectory (channel response) that will restore channel and floodplain function.
Restoration objectives	**Target conditions in Table 10**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 9 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Enhance Aquatic Habitat** **Increase Complexity**
	Actions include enhance aquatic habitat and increase channel complexity via helicopter installation of LW jams and mainstem LW channel loading.
Projects & Prioritization	**R3 HeliLW (Tier 1)**
	Helicopter installation of LW jams and mainstem channel loading at locations with available floodplain, appropriate channel form, and large boulders for natural ballasting. LW pieces in loaded areas will be organized by high flow events and create accumulations. Treatment expected to instigate side channel and floodplain activation. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently.

Table 10. Reach 3 Restoration Objectives, Action Types, and Projects.

Reach 3 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	There are no anthropogenic barriers in the main channel.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	No action needed	
Habitat Quality	Cobble dominated substrate with gravels and boulders; gravels retention associated with large boulders and LW. 50 med/large pieces of LW per mile. 16.7 pools per mile with 0 pools > 1m (3ft) and marginal pool shade/cover. 3 existing side channel with moderate cover.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off channel refugia.	Enhance Aquatic Habitat Increase Complexity	R3 HeliLW
Riparian condition	Riparian buffer composition: 100% small trees riparian border (natural functioning condition with mature forest on floodplain); 0% disturbed; >80% canopy cover for thermal shading; and no roads within 200-ft riparian buffer	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	No action needed	
Channel Dynamics	Where valley width allows, vegetated floodplains occur. Lateral processes (usually instigated by LW accumulations) occur. Sufficient quantity and substrate size limits modern incision.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Increase Complexity	R3 HeliLW

3.9.4 Reach 4 Restoration Strategy

Overall ecological function	**High-Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. Only one of the 11 REI metrics are at risk. Impairment is associated with too few pools of adequate size, only 2 ≥ 3-ft deep.
Trajectory if no action taken	**Same**
	Ecologic function is expected to remain relatively the same under existing conditions–unless wildfire and/or landslide provides increased quantity of LW and sediment to the channel.
Recovery potential	**High**
	The reach is entirely within a roadless section of the Okanogan National Forest. LW loading is expected to instigate trajectory (channel response) that will restore channel and floodplain function.
Restoration objectives	**Target conditions in Table 10**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 10 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Enhance Aquatic Habitat** **Increase Complexity**
	Actions include enhance aquatic habitat and increase channel complexity via helicopter installation of LW jams and mainstem channel LW loading.
Projects & Prioritization	**R4 HeliLW (Tier 2)**
	Helicopter installation of LW jams and mainstem channel LW loading at locations with available floodplain, appropriate channel form, and large boulders for natural ballasting. LW pieces in loaded areas will be reorganized by high flow events and expected to create accumulations (jams). Treatment expected to instigate some side channel and floodplain activation. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently.

Table 11. Reach 4 Restoration Objectives, Action Types, and Projects.

Reach 4 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	There are no anthropogenic barriers in the main channel.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	No action needed	
Habitat Quality	Cobble dominated substrate with gravels and boulders; gravels retention associated with large boulders and LW. 74 med/large pieces of LW per mile. 19 pools per mile with 2 pools > 1m (3ft) and marginal pool shade/cover. 6 existing side channel with adequate cover.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off channel refugia.	Enhance Aquatic Habitat Increase Complexity	R4 HeliLW
Riparian condition	Riparian buffer composition: 80% small trees riparian border (natural functioning condition with mature forest on floodplain); 0.5% disturbed; >80% canopy cover for thermal shading; and 2.3 miles/miles^2 within 200-ft riparian buffer.	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	No action needed	
Channel Dynamics	Where valley width allows, vegetated floodplains occur. Lateral processes (usually instigated by LW accumulations) occur. Sufficient quantity and substrate size limits modern incision.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Increase Complexity	R4 HeliLW

3.9.5 Reach 5 Restoration Strategy

Overall ecological function	**Moderate**
	Rating is based on the Reach Assessment evaluations of habitat, geomorphology, hydrology, hydraulics, and vegetation. Three of 11 REI metrics at risk. Impairments are associated with few pools of adequate size only 2 ≥ 3-ft deep; limited side channel or off channel refugia; and riparian canopy disturbance.
Trajectory if no action taken	**Same**
	Ecologic function is expected to remain relatively the same under existing conditions–unless wildfire and/or landslide provides increased quantity of LW and sediment to the channel.
Recovery potential	**High - Moderate**
	The reach is entirely within the Okanogan National Forest. LW loading is expected to instigate trajectory (channel response) that will restore channel and floodplain function. The Wolf Creek irrigation withdrawal and associated weirs limit full recovery at the upstream end of the reach.
Restoration objectives	**Target conditions in Table 11**
	Bring existing conditions to target conditions for the habitat and geomorphic metrics identified in Table 11 below. These targets apply to multiple habitat and geomorphic attributes. To the extent possible at this stage of planning, the targets are presented as measurable quantities.
Action Types	**Upgrade Anthropogenic Features** **Enhance Aquatic Habitat** **Increase Complexity**
	Actions include enhance aquatic habitat and increase channel complexity via helicopter installation of LW jams and mainstem channel LW loading. Fish passage improvements and structure longevity at the weirs (replace steal weirs with large boulder step pool) at the upstream end of the reach.
Projects & Prioritization	**R5 HeliLW (Tier 1)** **Wolf Weir (Tier 2)**
	R5 HeliLW: Helicopter installation of LW jams and mainstem channel loading at locations with available floodplain, appropriate channel form, and large boulders for natural ballasting. LW pieces in loaded areas will be reorganized by high flow events and expected to create accumulations (jams). Treatment expected to instigate some side channel and floodplain activation. *Wolf Weir: Upgrading the existing steel plate weirs at the upstream boundary with set of fish passage large boulder steps and pools will improve fish passage and the longevity of the structure. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently.*

Table 12. Reach 5 Restoration Objectives, Action Types, and Projects.

Reach 5 Attribute	Existing Condition (from assessment)	Target Condition [source]	Action Type	Potential Projects
Habitat Access	The steel plate weirs at the upstream boundary are not considered a barrier to fish passage – though they could be improved.	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	Upgrade/Improve Anthropogenic Feature	Wolf Weir
Habitat Quality	Cobble dominated substrate with large boulders and gravels; gravels retention associated with large boulders and LW. 53 med/large pieces of LW per mile. 34 pools per mile with 2 pools > 1m (3ft) and marginal pool shade/cover. No existing side channels or off channel refugia.	Gravels or small cobbles make up >50% of the bed materials in spawning areas and ≤12%fines/sand (<2 mm) in spawning gravel. At least 32 pieces/mile of large wood and sources for LW recruitment. Pool frequency of 23/mile with ≥50% of pools ≥1m (3ft) deep and good fish cover and cool water. Contains side or off channel refugia.	Enhance Aquatic Habitat Increase Complexity	R5 HeliLW
Riparian condition	Riparian buffer composition: 100% small trees riparian border (natural functioning condition with mature forest on floodplain); 2.4% disturbed; >80% canopy cover for thermal shading; and 8.8 miles/miles^2 road density within 200-ft riparian buffer.	At least a 200-ft riparian buffer where road does not exist with: > 80% mature trees, or consistent with potential native community < 20% riparian disturbance (human) > 80% canopy thermal coverage; and <1 mile/miles^2 road density	No action needed	
Channel Dynamics	Where valley width allows, vegetated floodplains occur. Lateral processes (usually instigated by LW accumulations) occur. Sufficient quantity and substrate size limits modern incision. Placed boulders at upstream weirs inhibit incision at Wolf Creek irrigation withdrawal.	Floodplain areas are hydrologically linked to main channel within the context of the local process domain. Channel is migrating at or near natural rates within the geomorphic construct of the reach. No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach	Increase Complexity (improve adequate condition)	R5 HeliLW

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Appendix A

Stream Habitat Assessment

Wolf Creek Reach Assessment

December 2020

Habitat Inventory: Confluence with Methow River (RM 0) to (RM 4.53)

Survey: October 1 – October 5, 2019

Table of Contents

1 Introduction & Background

Wolf Creek is located within the eastern foothills of the North Cascade Mountains in northern Washington. It is approximately 14.5 river miles long from its headwaters to its confluence with the Methow River. Flowing eastward into the Methow Valley, it joins the Methow River approximately 54.2 river miles (RM) upstream of where the Methow meets the upper Columbia River. The Wolf Creek Reach Assessment and Restoration Strategy evaluates existing aquatic habitat and watershed process conditions along the lower 4.53 miles of Wolf Creek and was completed on behalf of the Yakama Nation as part of their efforts to assess and improve Threatened and Endangered salmon and trout habitat within the Columbia River Basin. As part of the assessment process, Inter-Fluve conducted this salmonid habitat survey of Wolf Creek between October 1st and 5th, 2019 from RM 0 (confluence with the Methow River) to RM 4.53 (Wolf Creek Ditch irrigation diversion, near the northeastern boundary of the Lake Chelan-Sawtooth Wilderness). A flow rate of 6.4 cfs was measured in the field on October 1st immediately upstream from the Wolf Creek Bridge crossing – approximately 175 feet upstream from the confluence with the Methow River. A flow rate of 7.2 cfs was measured at the same location on October 5th. Insignificant precipitation was received over the survey period. Stream flow was not otherwise measured as part of this survey.

The objective of the Habitat Assessment is to characterize the habitat quantity and quality for salmonid species native to Wolf Creek by quantifying in-channel morphologic features, characterizing riparian conditions, and identifying anthropogenic features influencing aquatic habitat. This information is used to inform potential restoration and conservation actions and will provide a baseline for evaluating future habitat trends and measuring the effectiveness of restoration efforts to improve the quantity and quality of available habitat within the study area.

1.1 COMPARISON TO PREVIOUS SALMON HABITAT ASSESSMENTS

Stream surveys in Wolf Creek have been completed by the Okanogan-Wenatchee National Forest - USFS in 2005 and 1994 (USFS 2005). The stream survey report from the 2005 effort was reviewed and is summarized on the following page; no data or report for the 1994 field work was available except as referenced in the 2005 report. A modified Hankin-Reeves approach (Region 6 USFS standard stream survey protocol) has been used for stream surveys since the 1990s, therefore facilitating the capacity for a relatively direct comparison of recent historical data to the present stream habitat survey. The 1994 survey had slightly different large wood (LWD) and pool habitat assessment methods, described and compared to the 2005 methods in the 2005 Stream Survey report. The reach breaks used in the 2005 survey were different than the geomorphic reach breaks defined in this survey – see Table 1.

Table 1. Reach break river miles for the 2005 USFS survey compared to this 2019 survey by Inter-Fluve.

	Reach 1 (RM)	Reach 2 (RM)			Reach 3 (RM)
2005 Survey (USFS)	0-1.4	1.4-4.2			4.2-5.4
	Reach 1 (RM)	**Reach 2 (RM)**	**Reach 3 (RM)**	**Reach 4 (RM)**	**Reach 5 (RM)**
2019 Survey (IFI)	0-1.34	1.34-2.31	2.31-3.27	3.27-4.21	4.21-4.53

1.1.1 2005 Okanogan-Wenatchee National Forest Stream Inventory – Results Summary

The summer of 2005 had unusually low flow, reported as a result of a lack of snowfall during the winter of 2004-2005, reportedly resulting in lower than normal stream flow in Wolf Creek and the entire Methow Basin. Discharge recorded at the mouth of Wolf Creek was 1.5 cfs on September 2, 2005, which is likely base flow at the mouth. The measured discharge at the top of the alluvial fan (RM 1.4) was 5 cfs on the same date.

In 2005, the number of large wood debris (LWD) pieces with a length greater than 35 feet long and a diameter of at least 12 inches exceeded NOAA Fisheries and USFWS standards (20 pieces/mi) in every stream reach surveyed in Wolf Creek except for Reach 1, where only 11 pieces of large wood per mile were recorded and nearly all of these pieces were standing trees within the stream's bankfull width. Most of the large wood in Reach 1 had been reported as removed from the creek and the recruitment potential for large wood was considered poor to fair. Throughout the upper reaches of Wolf Creek, it was noted in 2005 that much of the large wood was in log jams, due largely to the wood accumulations at constrained points of the channel. Pieces of large wood (especially in log jams) were reportedly capturing gravels and creating much of the available fish spawning habitat in Wolf Creek. No dramatic changes were reported in the amount of large wood in Wolf Creek between 1994 and 2005.

Wolf Creek was above USFWS standards for numbers of pools per mile (39 pools per mile) for properly functioning bull trout habitat in every reach except Reach 1, according to the 2005 survey. In Reach 1, only 21 pools per mile were recorded. None of the reaches within the anadromous zone contained enough pools per mile to meet NOAA Fisheries standards for properly functioning anadromous fish habitat. According to the 2005 report, pool habitat was likely below naturally occurring levels in Reach 1 due to the anthropogenic removal of large wood. Upstream of Reach 1, pool habitat was likely close to naturally occurring levels due to the lack of past management activities along the stream. It was also noted as "unlikely" that pool habitat changed much in Wolf Creek between 1994 and 2005 due to the highly stable banks, high gradient, and channel confinement. Riffle habitat was the dominant habitat type recorded in all reaches in 2005 (77.6%-87.8% in Reaches 1-3). The average wetted width in 2005 was 22.1 ft, while the average bankfull width was 31.2 ft.

Off-channel habitat was reported as scarce (USFS 2005) in Wolf Creek and associated mainly with the high gradient and naturally confined stream channel above the top of the alluvial fan (RM 1.4). Less than 3% of the total habitat area consisted of side channel habitat. In Reach 1, the stream had been channelized, which presumably resulted in the loss of off-channel habitat within the reach. The amount of side channel habitat measured in 2005 was nearly identical to side channel habitat reported as measured in 1994.

In 2005, riparian vegetation within the 25' riparian buffer zone consisted of deciduous overstory trees dominated by alder and cottonwood, with subdominant coniferous trees such as cedar and Douglas fir. The outer riparian zone consisted largely of Douglas fir and ponderosa pine.

The dominant streambed substrate was reported as cobble with gravel and boulders as subdominant substrate. Higher gradient reaches had higher proportions of boulder substrate. Surface fines were generally low, ranging between 7% in Reach 2 and 14% in Reach 3 (and 12% in Reach 1). Very few eroding banks were observed, with the highest percentage in Reach 1 (2.5% of the banks). The channel gradient was the lowest in Reach 1 (2.4%) and highest in Reaches 3 and 2 (4.7%and 4.6%, respectively).

In the 2005 survey, stream shade varied among reaches. Reach 1, the most highly modified portion of the study area, was rated as “Fair” for stream shading with 30-60% shade. Reaches 2-3 were rated as “Good” with over 60% stream shade. The greatest impacts noted in the survey include water diversions and channel confinement due to roads and residential uses in Reach 1.

Snorkel surveys were conducted throughout Wolf Creek during the summer of 2005. Rainbow or steelhead trout were the dominant fish species observed in the lower 6 miles of Wolf Creek (from the mouth to the confluence with North Fork Wolf Creek): about 93% of the fish sampled were rainbow or steelhead. Cutthroat trout were only observed above RM 2.7, with small numbers of cutthroat and rainbow/cutthroat hybrids observed between RM 2.7 and RM 6.0. A small number of bull trout were observed between RM 1.7 and RM 2.9. Spring Chinook salmon juveniles were observed in Wolf Creek from the mouth up to RM 2.4, though the majority of these were located downstream of RM 1.7 (only one spring Chinook juvenile was observed above RM 1.7). No brook trout were observed in Wolf Creek during the 2005 snorkel surveys, though brook trout had been observed in the lower mile of Wolf Creek during other snorkel surveys conducted by the USFS in the late 1990s and early 2000s.

2 Methods

In this habitat assessment, the study area (RM 0-4.53) was subdivided into five distinct geomorphic reaches. The same reach delineations were used for both this habitat assessment as well as the geomorphic reach assessment and restoration strategy (See main report).

This survey employed the methods outlined in the US Forest Service Region 6 Level I & II Stream Inventory Handbook, Version 2.15 (USFS, 2015) and the “Eastside Forest Option” protocol was used. All protocols were followed when safe and most of the suggested forest inventory options were applied in the survey. Discharge values were measured on October 1, 2019 upstream of the confluence of Wolf Creek with the Methow River immediately upstream from the Wolf Creek Road bridge and again on October 5 in the same location. Between these two dates, there was negligible precipitation and temperatures were seasonal.

Adaptions to the USFS Eastside protocol were made for this survey. Those adaptations include:

- All reach and habitat unit lengths were measured in GIS from field recorded GPS data collected with a high-accuracy Trimble GeoExplorer GPS unit instead of measuring the distance between unit breaks with a tape in the field.
- Floodplain width was measured in-house using GIS and LiDAR instead of using in-the-field measurements.

The n^{th} channel unit (riffle, pool, glide) measurement frequency applied in the field for data collection was 20%, or every 5^{th} unit, for all channel units. At n^{th} units, the surveyors performed an ocular estimate of the wetted channel width and flood-prone width, and also recorded the wetted channel width with a 100-foot tape. At every channel unit measured, the length of human influenced unstable bank was observed for both the left and right channel banks. No unstable banks were recorded throughout the entire project area. Depth of pools, riffles, and glides was measured using a graduated stadia rod carried by the observer.

For the riparian vegetation measurements, the riparian corridor can be defined as either a single 100-ft wide zone or two adjacent riparian zones (inner and outer zones) totaling 100 feet in width (USFS, 2015). For this assessment, one single 100-ft wide riparian zone was designated for the Wolf Creek study area. Survey methods dictate defining a dominant size class of vegetation type within the riparian corridor (e.g. small trees, shrubs), then defining the dominate species observed in the overstory and understory. Survey protocol differed from USFS protocol by collecting a dominant overstory size class and species, and a dominant understory species within the 100-foot wide riparian zone in addition to species.

Two gravel counts were completed by the survey team in each of the Reaches 1-4 and one in Reach 5 to characterize the size distribution of bedload sediment. In total, nine gravel counts were completed. Criteria for gravel count locations state that they be representative of the general character of the individual reach and completed at a representative glide to riffle transition point. Due to bed armoring, the presence of bedrock, and lack of representative riffle crests, three of the seven gravel counts done in the higher gradient reaches (2-5) were completed on exposed bed wash bars. This protocol modification provides data that represents the bedload wash at accumulation zones within the mainstem channel.

For this habitat survey, we considered “side-channels” as naturally wetted flow paths connected to the mainstem channel at their upstream and downstream ends at average annual flow. Side channel units were identified when the main channel split to form a stable island with soil or fine sediment accumulations and with established vegetation older than 2 to 3 years. Each side channel was determined to be fast or slow, and its average width and length measured. Total lengths were recorded using GPS. If the entire side channel was not wet at the time of survey, the length of the wetted portion of the side channel was also estimated. This report provides data based on total side channel lengths, unless otherwise noted.

A Plunge Pool is identified as spanning the width of the wetted channel, but need not be longer than its width. One Plunge Pool (SSPL) was identified in Reach 1. Throughout the remainder of the survey area, features with similar characteristics were categorized as “pool” because they represented the pool units in these higher gradient reaches.

Large woody material (LWM) was counted in the mainstem and side channels following the size class characterizations for “Eastside” forests. The forest option to count large wood pieces in the small size category was used. Tallies of Small (> 6 in. diameter, >20 ft long), Medium (>12 in. diameter, > 35 ft long) and Large (>20 in. diameter, >35 ft long) pieces of Large Wood were completed for each reach. For this report, Medium and Large pieces of LWM will be collectively referred to as “Quality Large Wood.” A total of 13 log jams were identified within the study area.

3 Summary of Results

This section summarizes the results of the five channel reaches surveyed between October 1st and 5th, 2019 from RM 0 to 4.53 on Wolf Creek. Detailed descriptions of the survey results from the individual reaches are included in Section 4 of this report.

3.1 CHANNEL MORPHOLOGY

Channel morphology within the Wolf Creek study area (RM 0-4.53) is dominated by extended riffle and riffle-cascade morphology with infrequent pools. Channel form is primarily single thread with split flow conditions occurring only occasionally. Most of Reach 1 (RM 0-1.34) is entrenched and leveed into a single channel where historically it would have had access to the entirety of the Wolf Creek alluvial fan. Reaches 2–5 (RM 1.34-4.53) are higher gradient and naturally confined by steep hillslopes and bedrock outcroppings that alternate with strips of floodplain and historical terraces. Split flow channel conditions in these reaches where floodplain is available to accommodate flows is usually correlated with large wood accumulations and/or hillslope sediment contributions.

Channel geometry varied within the study area. Maximum bankfull and floodprone widths are comparatively high in Reach 1 at 67 ft and 391 ft, respectfully. However, mean values of bankfull width are highest in Reach 3 at 42.3 ft, while mean Floodprone width of Reach 1 at 249.7 ft is the widest. This reflects the anthropogenic confinement of Reach 1. Mean bankfull depths are highest in Reach 1 at 4.2 feet and progressively decrease upstream to 2.6 feet in Reach 5 (Table 2).

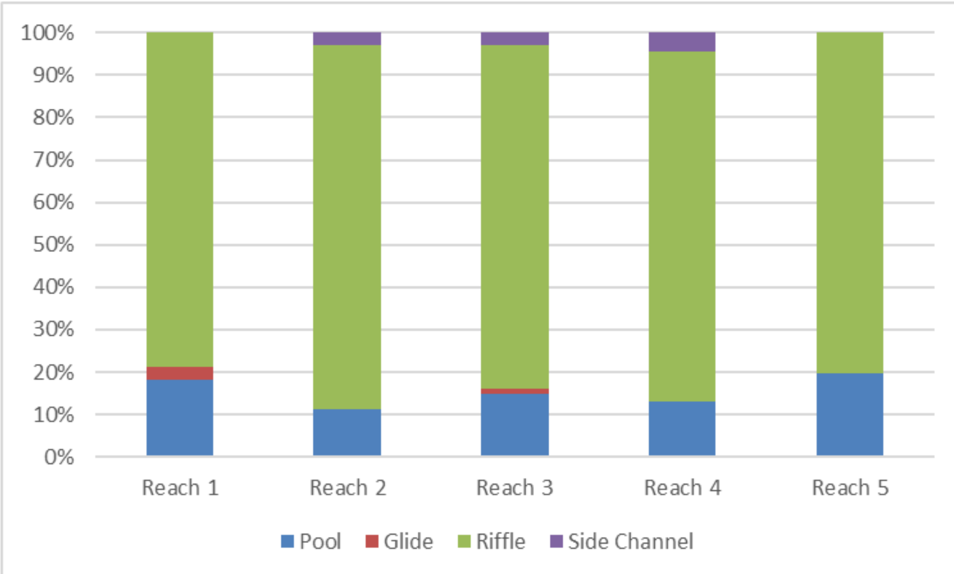
Table 2. Wolf Creek bankfull width results from habitat assessment.

Bankfull Widths (feet)					
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
Max	67.0	37.0	46.0	38.0	37.0
Min	14.0	25.0	30.0	30.0	30.0
Mean	38.4	32.8	42.3	34.7	33.5
St Dev	19.9	5.3	3.2	4.2	4.9
Floodprone Widths					
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
Max	391.0	143.0	162.0	239.0	171.0
Min	107.3	46.0	98.0	50.0	50.0
Mean	249.7	103.0	130.0	126.7	110.5
St Dev	115.7	42.3	32.0	98.2	85.6
Bankfull Depths (feet)					
	Reach 1	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
Max	4.2	3.8	3.2	2.9	2.6
Min	3.2	2.8	2.4	1.9	1.9
Mean	3.7	3.3	2.7	2.6	2.3
St Dev	1.0	0.4	0.5	0.3	0.5

3.2 HABITAT UNIT COMPOSITION

Within the surveyed area, riffles are the dominant habitat type, comprising 82% of the total area of the channel. Glides comprise 1% of the area, and pools 14%. Side channels comprise 3% of the channel area (Figure 1). Reach 5 maintains the highest percentage of pool habitat at nearly 20%, while Reach 2 is the lowest at 11%. Side channel habitat area is low overall across the study area with no side channel habitat in Reach 5; Reaches 2, 3 and 4 have similar percentages of side channel habitat with 4%, 3.1% and 4%, respectively. Reach 1 has a set of ponds located in what appears to be an historical channel scar. The ponds are connected perennially to the mainstem at the up and downstream ends via an irrigation out-take, ditches, and culverts – within an otherwise leveed and confined segment of the channel. The up and downstream connectivity partially renders it as a side channel; however, it currently does not function as a natural side channel and thus is not classified as side channel habitat in this assessment.

The mean residual pool depth for the entire study area is relatively consistent, ranging from 1.6 feet (lowest) in Reach 1, to 1.9 feet in Reaches 4 and 5 (highest). Overall, the mean residual pool depth across all reaches is 1.7 feet. The residual pool depth of individual pools ranges from a minimum of 0.6 feet in Reach 1, to a maximum of 4 feet in Reach 5 (Figure 2). Pool frequency is highest in Reach 1 where a total of 24 pools were identified, and lowest in Reach 5 where a total of 11 pools were identified. While Reach 5 has the lowest number of pools, they were the deepest. Reach 5 is equal to Reach 4 with the highest number of pools equal to or greater than three feet and Reach 5 has the highest percentage of pools greater than or equal to three feet (18%). Overall, the pools in the lower half of the project area are the shallowest; of the 60 pools identified in Reach 1, 2 and 3, only one of them measured equal to or greater than three feet deep. Average pool spacing throughout the study area is 7.4 channel widths per pool, and was relatively consistent for Reaches 1-4 (ranging between 7.4 and 8.4). Reach 5 maintains a markedly lower average pool spacing than the other reaches, with 4.6 channel widths per pool and Reach 4 maintains the highest pool spacing with an average of 8.4 channel widths per pool. The mean estimated wetted width of the main channel is 18.8 feet with a standard deviation of 3.8 feet. Mean riffle depths are lowest in Reach 1 (1.1 feet) and highest in Reach 5 (1.9 feet). In total, 87 fast water units (riffles and glides) were measured. Of the 87 fast water units, only 4 are glides. Three glides were observed in Reach 1, one glide was observed in Reach 3, and no glides were observed in Reaches 2, 4 and 5. A summary of all data recorded is provided in Table 16 in Section 4.6 Summary Data.



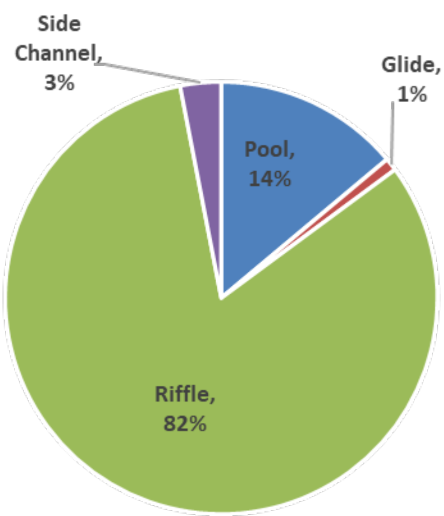


Figure 1. The top figure illustrates distribution of habitat unit composition of reaches 1-5; riffle habitat composed a large majority of the habitat area. The bottom figure displays habitat unit composition in the study area as a whole.

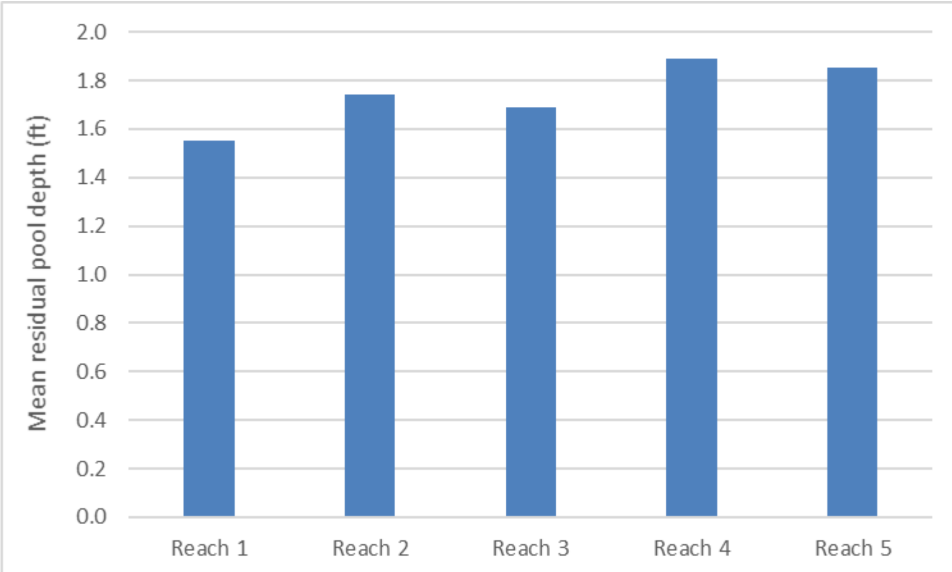


Figure 2. Mean residual pool depth by reach.

3.3 SIDE CHANNEL HABITAT

Overall side channel habitat area throughout the surveyed area is relatively low, accounting for just over 3% of the surface habitat area. In total, 16 side channel units exist, averaging 3.5 side channels per mile of stream. The side channels average 150 feet in length (total length of side channel) and 6.7 feet in width (wet width). The total side channel length throughout all reaches is 0.46 miles. The side channels contain a total of 97 pieces of small, medium and large wood. Thirty-three pieces of the large wood are medium and large wood, for an average of 75 pieces of medium and large wood (quality wood) per mile of side channel.

Figure 3. 125-foot long side channel in Reach 3 that had 9 pieces of large wood. (10/4/2019)

3.4 LARGE WOODY MATERIAL (LWM)

A total of 658 pieces of LWM were counted in the study area averaging 160 pieces per mile; 68% are Small pieces with diameters between 6 and 12 inches and lengths greater than 20 feet, 19% are Medium pieces with diameters between 12 and 20 inches and lengths over 20 feet, and 13% are Large pieces with diameters over 20 inches and lengths over 20 feet (Figure 4). Reach 4 maintains the most LWM in both number of quality pieces (medium and large) per mile (n = 76) and number of total pieces (n = 239). Reach 1 maintains the least LWM with only 39 pieces, of which 31 are categorized as Small. A total of 13 log jams were recorded (to classify as a jam, at least 10 pieces of qualifying large wood is required). A total of 95 pieces of large wood are in the jams.

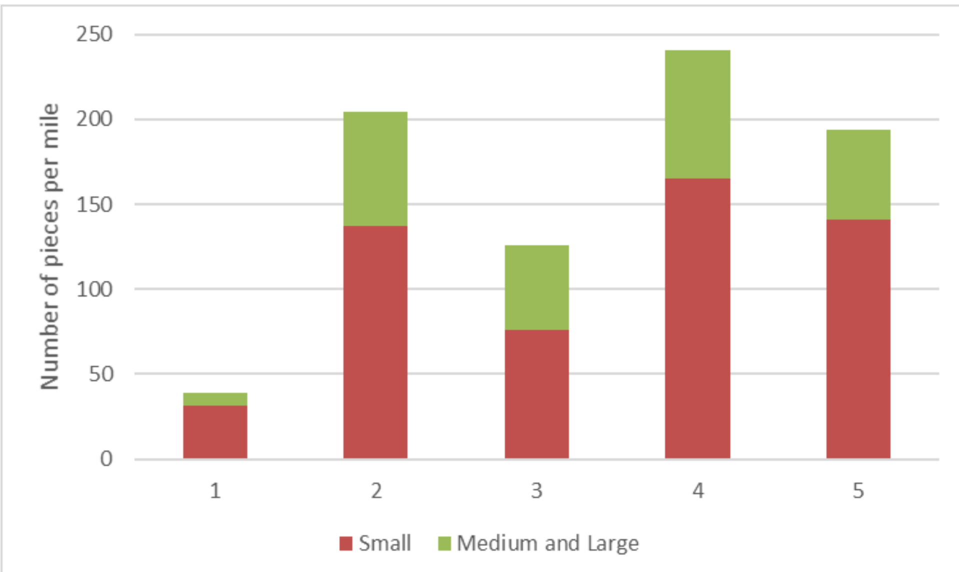


Figure 4. Pieces of large wood per river mile for Wolf Creek River reaches 1 – 5.

Based on thresholds established by Fox and Bolton (2007) for Eastside forests, the "adequate" threshold for LWM is >32 pieces per mile of quality medium and large size class wood, with additional woody debris available for short and long-term recruitment. There are 50.4 pieces of quality large wood per mile averaged across the whole study area. Reaches 2, 3, 4 and 5 maintain an "adequate" quantity of quality large wood, averaging 67, 50, 76 and 53 pieces of quality wood per mile–well above the benchmark "adequate" level of 32 pieces per mile. However, Reach 1, at 7.5 pieces of quality wood per mile, is in the "unacceptable risk" category for LWM present and LWM recruitment potential.

Figure 5. Channel-spanning logjam in Reach 5. (10/5/2019)

3.5 SUBSTRATE & FINE SEDIMENT

Bedload wash characterization is based on nine gravel counts completed in Reaches 1-5. Gravel count surveys were done at representative glide-to-riffle-transition crests or at representative bars. Overall, the gravel count survey results show an increase in cobble and boulder and decrease in gravel composition going upriver. However, boulders and gravels were present in all reaches (Figure 6 and Figure 7). Based on the two gravel counts per reach combined, average dominate surface substrate in Reach 1 is gravel (56%) while cobbles dominate in Reaches 2-5 (54%-68%). Although bedrock contacts periodically occur as confining banks throughout Reaches 2-5, it did not occur in the gravel count survey locations. Percent sand (<2mm) and small material (<6mm) content is low (0-4%, with a study area average of 2% for small substrates <6mm), indicating that fine sediments, which can be harmful to salmonid survival in high concentrations at spawning grounds, are likely readily transported out of the system and thus pose minimal risk to aquatic habitat quality in the surveyed area. Sand was observed accumulating on low floodplain surfaces or in small quantities in localized hydraulic eddies such as behind large boulders in shallow channel margin areas. Sediment type is classified by the B-axis diameter of the clasts sampled (sand = < 2mm, gravel = 2.1-64 mm, cobble = 64.1-256 mm, boulder = >256.1mm). Similar to the gravel count survey results, ocular observations of channel bed substrate throughout the study area recorded cobbles as the dominant size class with boulders prevalent in Reaches 2-5 and increasing upstream relative to reach gradient.

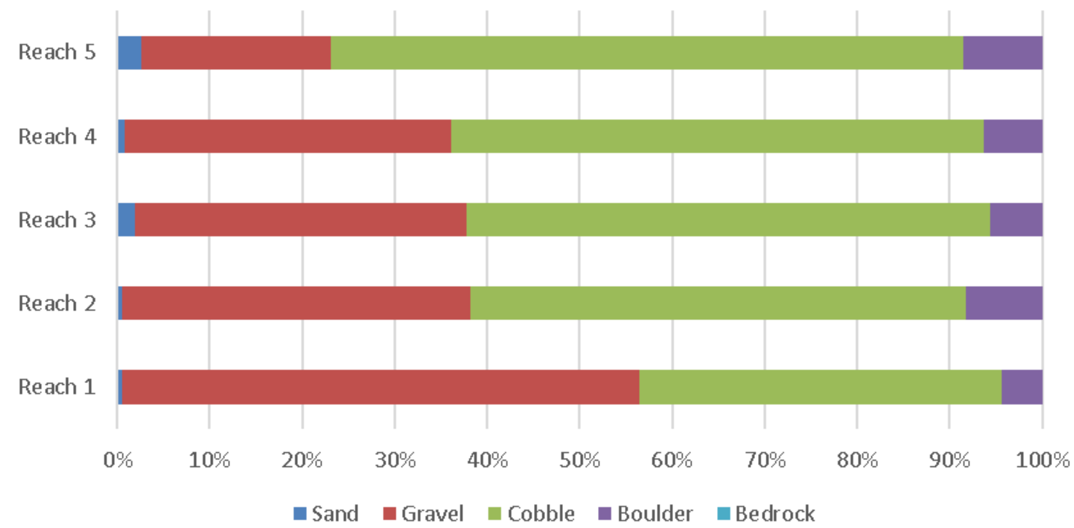


Figure 6. Gravel count classification of bar deposits by reach for Reaches 1-4. For each reach, two gravel counts were performed and then averaged. Only one was conducted in reach 5.

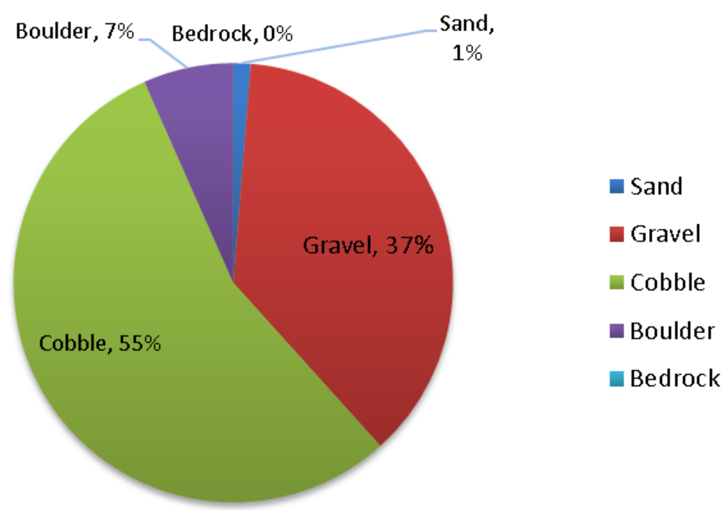


Figure 7. Gravel count of bar deposits clast size classification averaged for Reaches 1-5. Cobble is the dominant classification that was observed.

3.6 BANK INSTABILITY

Reach 1 had the most human imposed impacts including levees, home development, roads, bridges, armored banks, water out-takes, and human constructed ponds–all of which have resulted in channel entrenchment, geomorphic simplification, and riparian/floodplain vegetation clearing and alterations. Reach 1 remains the most confined reach within the study area. The channel and floodplain in Reaches 2, 3, 4 and 5 are partially confined within hillslopes that include periodic bedrock walls that contact and influence the channel pathway.

The habitat team estimated the extent of human caused, anthropogenic, bank erosion (instability) on both the left and right banks at each channel unit. While there is some bank erosion process occurring throughout the project area in all reaches, the habitat team did not identify any of it as directly human-caused.

Unstable banks indicate lateral and sometimes vertical processes and serve as sediment sources to the channel. Generally, bank erosion was found to be relatively low throughout the project area. Riprap and other bank armoring do exist in Reach 1 in conjunction with homes, bridges and roads.

Figure 8. Cement bank armoring and upstream levee on river left near a home in Reach 1 with undercut erosion occurring. (Photo: 10/1/2019)

3.7 FISH PASSAGE BARRIERS

No anthropogenic fish passage barriers were observed in the mainstem channel during the habitat assessment. However, there is a natural channel-spanning jam of wood and sediment (hillslope debris contribution) in Reach 3 that creates a 4-foot falls drop (Figure 9). The other 13 logjams identified in the study area were not identified as barriers for fish migration.

Figure 9. Channel spanning debris jam that creates 4-foot drop in Reach 3.

3.8 RIPARIAN CORRIDOR

Of the 17 n^{th} units measured in Reaches 1-5, the dominant (77%) overstory riparian vegetation size is classified as Small Tree (9.0 – 20.9-inch diameter at breast height (dbh). Sapling/Pole (5 – 8.9-inch dbh) is the second most dominant class (16%) and Shrub/Seedling (1.0-4.9 in. dbh) is the third most dominant size class (6%). In general, the dominant overstory riparian vegetation size class is smaller in the downstream reaches and increases in size going up river (Figure 10). The dominant overstory species is Douglas fir (69%), followed by Cedar (17%), Cottonwood (7%), Ponderosa (4%), and Alder (3%). In general, Douglas fir is more prominent in the lower reaches and less prominent in the upper reaches (Figure 11). Overall, the dominant riparian understory species is Dogwood (57%); Grassland Forbes (21%); Alder (11%); Vine maple (4%); Snowberry (3%); and Cedar (3%) (Figure 12). Reaches 3-5 have established mature old growth forest on their floodplain surfaces and mature or maturing second-growth forests (private land) on the floodplain surfaces in Reach 2.

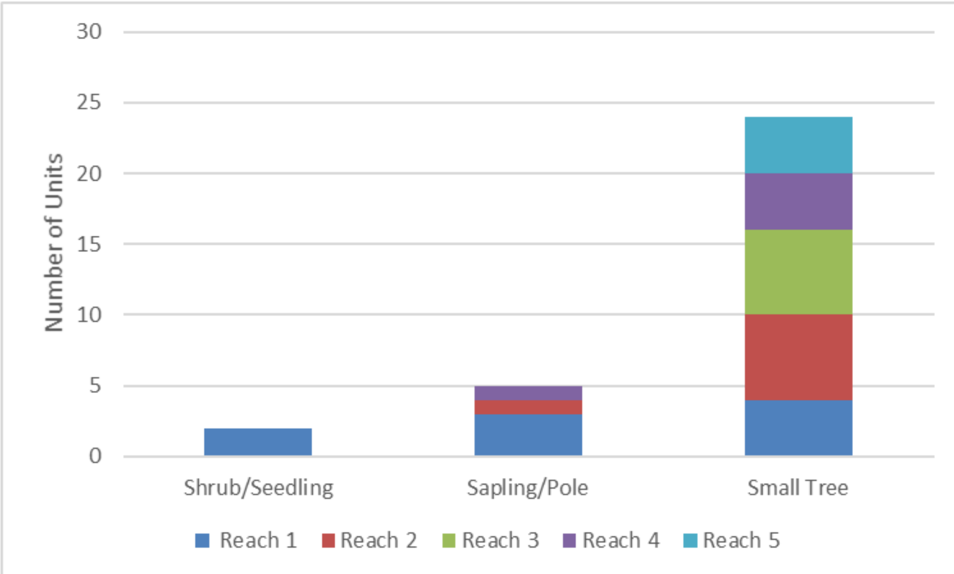


Figure 10. Distribution of dominant overstory size class category for the riparian zone, all reaches combined. Based on n^{th} unit measurements from Reaches 1-5. Shrub/Seedling = 1.0-4.9 in. dbh; Sapling/Pole = 5.0-8.9 in. dbh; and Small Tree = 9.0-20.9 in. dbh.

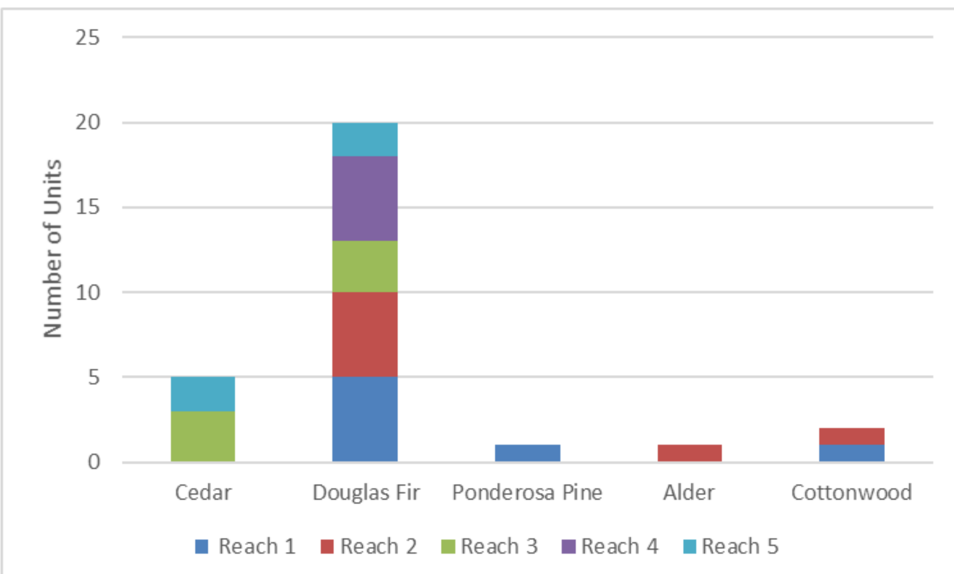


Figure 11. Dominant overstory species in the riparian zone, by species. Based on n^{th} unit measurements from Reaches 1-5.

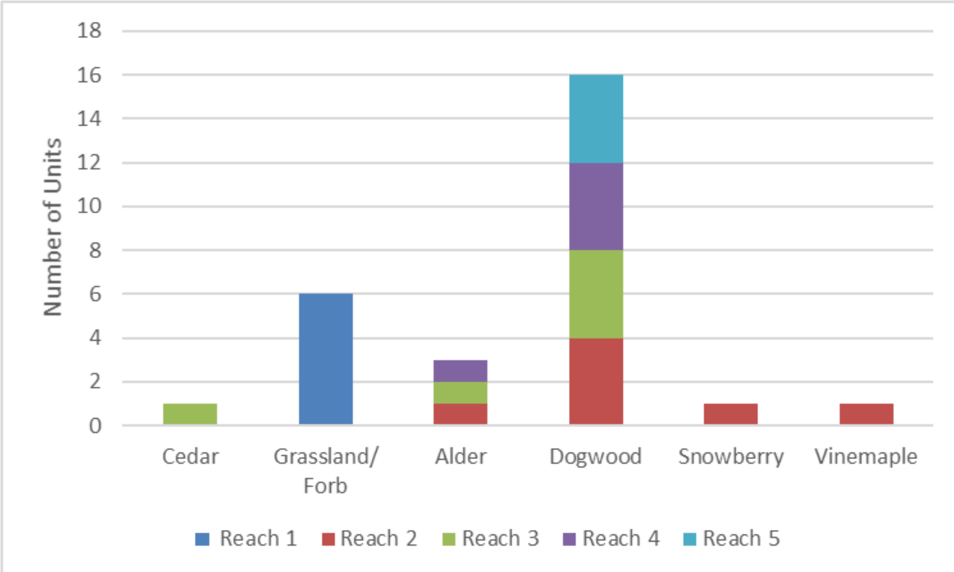


Figure 12. Dominant understory species in the riparian zone, by species. Based on nth unit measurements from Reaches 1-5.

4 Stream Habitat Reach Reports

4.1 REACH 1

Location: River mile 0 – 1.34
Total length: 1.34 miles
Survey date: October 1, 2019

Figure 13. Representative view of Reach 1. Habitat units are dominated by extended riffles. Human-induced channel confinement and riparian impacts are most frequent in this reach. (10/01/2020)

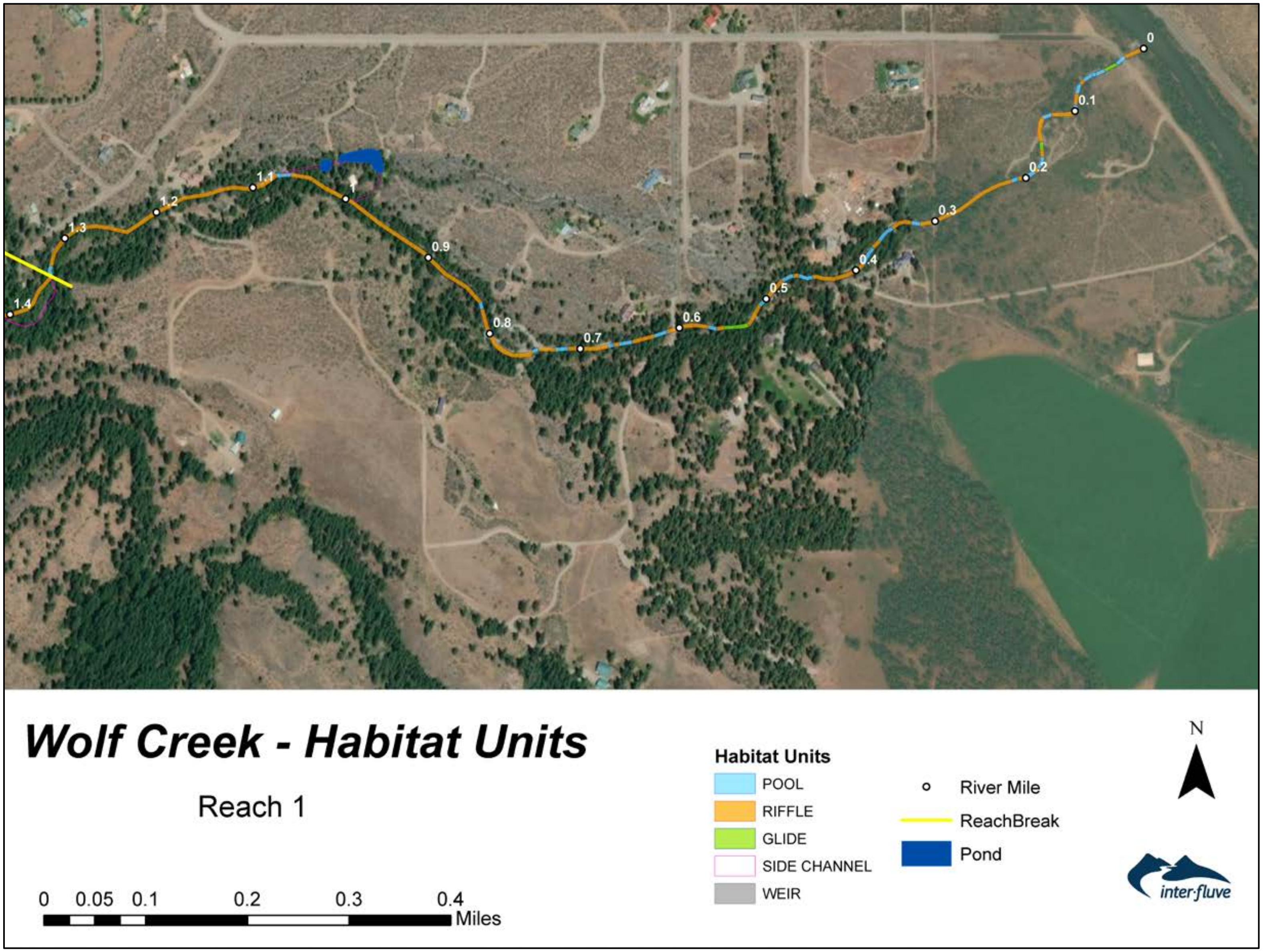


Figure 14. Wolf Creek, Reach 1–channel unit distribution (RM 0-RM 1.34), 2019. Basemap: ESRI Bing imagery

4.1.1 Habitat Unit Composition

Reach 1 is the longest reach delineated in the study area at 1.34 miles (Figure 14). Similar to all reaches in the project area, a large majority of the habitat area (79%) was riffle; the remaining habitat area was pool (18%); and glide (3%) (Figure 15). No side channels were present in Reach 1. The channel is confined by residential land use, levees,and bridges. Reach 1 maintains the lowest stream gradient of all five reaches at 1.41%.

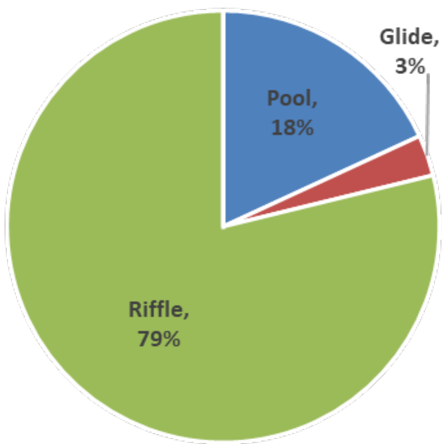


Figure 15. Stream habitat unit area composition of Reach 1.

4.1.2 Pools

Pool was the second most common habitat type recorded in Reach 1 with 18% of the habitat unit surface area identified as pools (Figure 15). A total of 24 pools were counted–the highest number of pools in the study area. However, the pools were in general short and shallow with 96% of the pools measuring less than 3 feet of residual depth (the entire project area averages 93% less than 3 feet of residual depth). The average residual depth of pools in Reach 1 is 1.6 feet, compared to the study area average of 1.7 feet. Reach 1 averaged 17.9 pools per mile. Mean pool spacing in Reach 1 was 7.7 channel widths per pool, compared to an average of 7.4 channel widths per pool for the surveyed area.

Figure 16. A total of 24 pools were identified in Reach 1. All but one had residual depths of less than 3 feet. (Photo: 10/01/19)

4.1.3 Side Channel Habitat

No naturally functioning side channels were observed in Reach 1. An irrigation out-take, ditches, and a culvert connect a set of ponds on the floodplain near RM 1.0 at both the up and downstream ends to the mainstem channel.

4.1.4 Large Woody Material

LWM quantities in Reach 1 were the lowest of all five reaches with a total of 52 pieces of LWM identified – equating to 39 pieces of wood per mile. About 80% of the pieces observed were in the "small" size class. A total of ten pieces of quality large wood (medium or large size class) was observed in Reach 1 and almost all of those pieces were installed features. No log jams were observed in Reach 1 (Table 3).

Table 3. Large woody material quantities in Reach 1.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	42	8	2	52
Number of pieces per mile	31	7.5		39
Number of jams	0			0
Number of jams per mile	0			0

4.1.5 Substrate & Fine Sediment

A total of two gravel counts were conducted in Reach 1 (GC 1.1 and GC 1.2). The composition of material from the gravel counts combined is primarily gravel (56%) with 39% cobble, 4% boulder, and ~1% sand. This distribution displays a higher gravel and lower cobble composition than the project area averaged grain composition of 37% gravel, 55% cobble, 7% boulder, and 1% sand. At GC1.1, only 2% of the sampled grains were sized at 1mm-5.8mm (sand-small gravels) and at GC 1.2, only 0%. The cumulative distribution curves and grain size class of the gravel counts completed in Reach 1 are provided below in Figure 17 and Table 4.

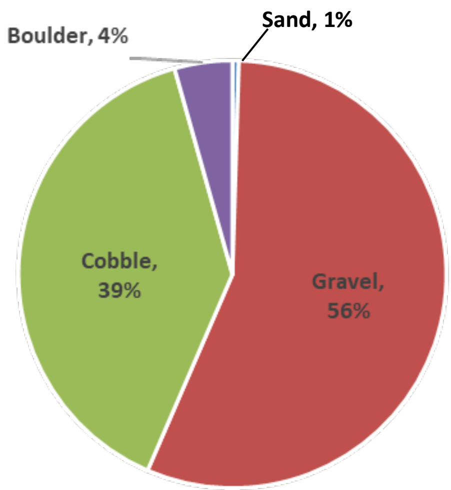
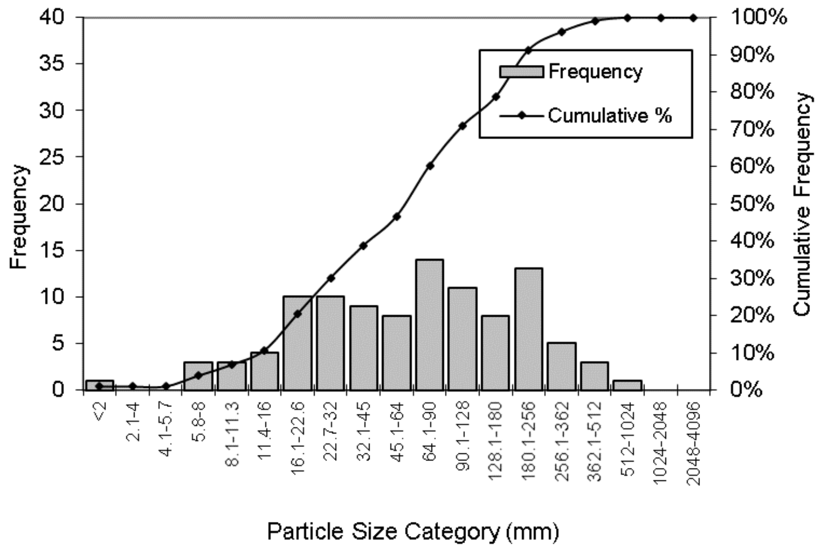


Figure 17. Combined percent composition sediment size type from two gravel counts on exposed bars in Reach 1.

Gravel count 1.1



Gravel count 1.2

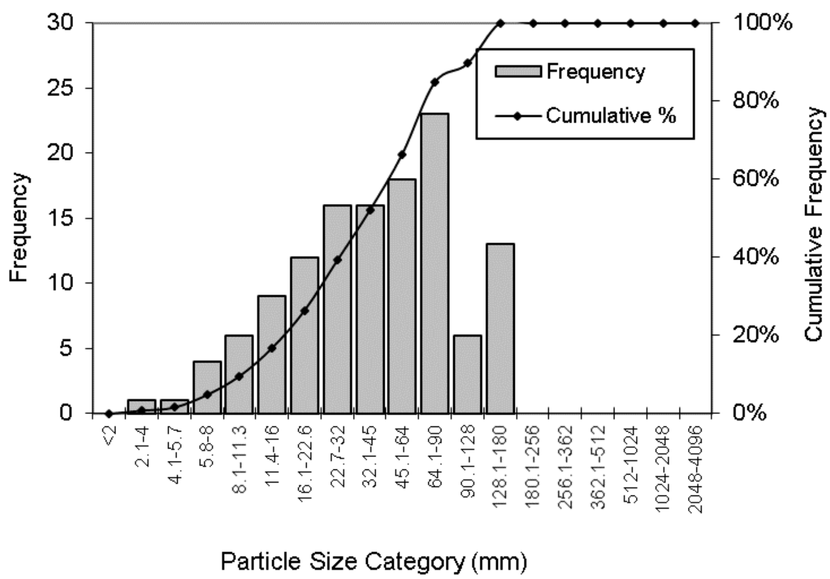


Figure 18. Cumulative grain size distribution for Gravel Count 1.1 and 1.2 (Reach 1).

Table 4. Grain size class for gravel counts 1.1 and 1.2 (assumed linear interpolation)

	1.1	**1.2**
Size Class	**Size percent finer than (mm)**	**Size percent finer than (mm)**
D5	13	9
D16	16	22
D50	40	72
D84	87	216
D95	104	279

4.1.6 Riparian Corridor

Reach 1 included nine riparian vegetation unit evaluations. Overall, the dominant riparian vegetation class is small tree (44%), followed by sapling/pole (33%) and shrub/seedling (22%). Overstory species are primarily Douglas fir (71%), Cottonwood (14%), and Ponderosa pine (14%) (Figure 19). The dominant, and only understory species class, is Grassland/Forb (Figure 20).

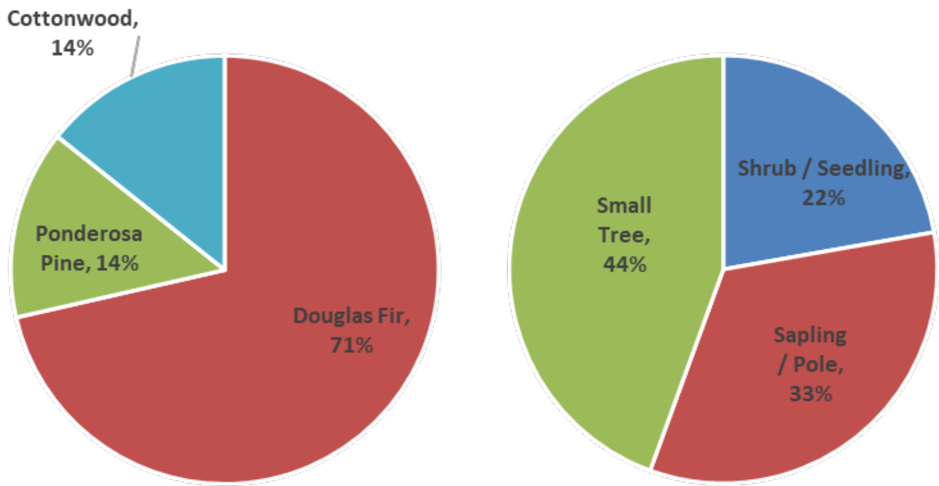


Figure 19. Dominant overstory riparian vegetation class and species within 100 feet of Wolf Creek by ocular estimate.

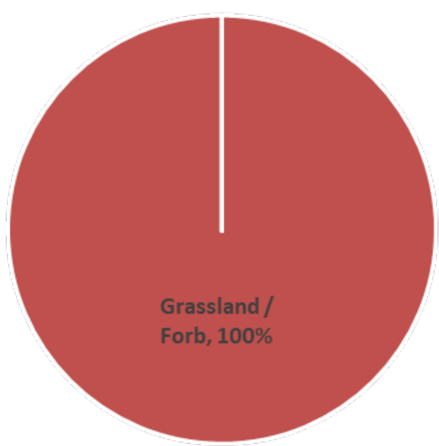


Figure 20. Dominant understory riparian vegetation class and species within 100 feet of Wolf Creek by ocular estimate.

4.2 REACH 2

Location: River mile 1.34 – 2.31
Total length: 0.97 miles
Survey Date: October 3, 2019

Figure 21. Representative view of Reach 2. Dominant habit unit is extended cascading riffles with large boulders. (Photo: 10/03/2019)

4.2.1 Habitat Unit Composition

Reach 2 has the highest proportion of riffle habitat area of all the reaches (85%), compared to a project area average of 82%. The remainder of the habitat area is comprised of pools (11%), and side channel (4%) (Figure 22 and Figure 23). The stream gradient of Reach 2 is 3.91%, more than double that of Reach 1.

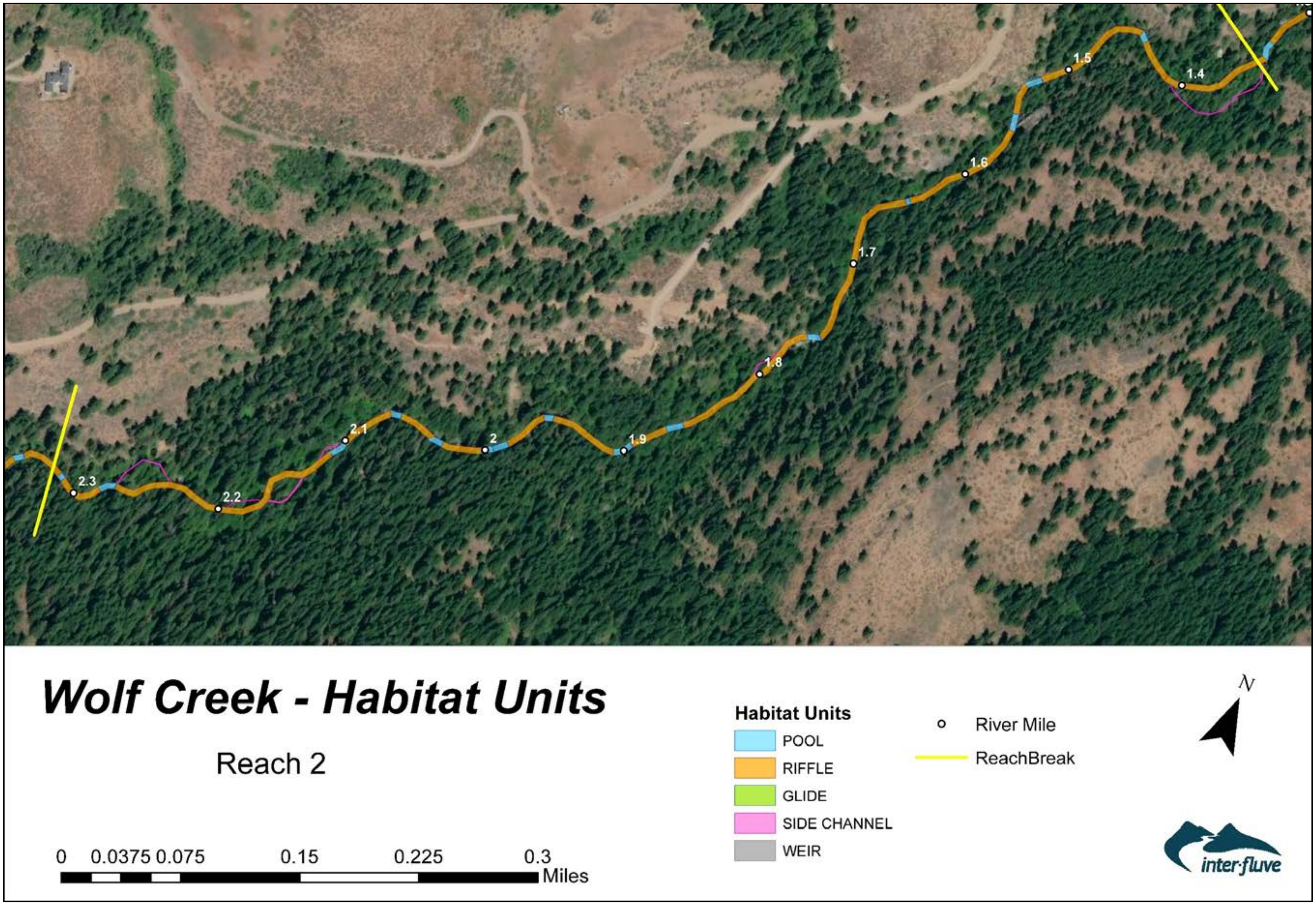


Figure 22. Wolf Creek, Reach 2–channel unit distribution: RM 1.34-2.31. Basemap: ESRI Bing imagery

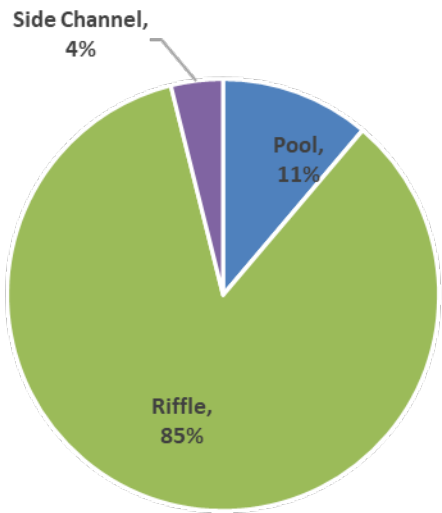


Figure 23. Stream habitat unit composition for Reach 2.

4.2.2 Pools

A total of 21 pools were identified in Reach 2, averaging 21.6 pools per mile. Residual depths of pools range from 1.1 feet (minimum) to 2.6 feet (maximum) with an average of 1.7 feet. Of the 21 pools counted, 100% have residual depths less than 3 feet. Reach 2 has the most pools over 4 feet deep (n = 4), comprising 19% of all pools in the reach. Mean pool spacing is 7.4 channel widths per pool, the second lowest of all the reaches and equivalent to the overall project area average.

4.2.3 Side Channel Habitat

A total of seven side channels are present in Reach 2 averaging 181 feet in length. All are slow-moving side channels at the time of survey. A total of 61 pieces of large wood were observed in the seven side channels (Table 5).

Table 5. Side channel observed in Reach 2.

Location	Length (ft)	Dominant unit type	Wood count
SIDE1S	450	Slow water	20
SIDE2S	10	Slow water	6
SIDE3S	90	Slow water	2
SIDE4S	160	Slow water	3
SIDE5S	120	Slow water	20
SIDE62	250	Slow water	7
SIDE7S	80	Slow water	3
Total	1,270		61

4.2.4 Large Woody Material

LWM quantities in Reach 2 are the second lowest of all four reaches with a total of 49 pieces of LWM identified, equating to 45.7 pieces of wood per mile (Table 6). Of these 49 pieces, 19 are classified as Medium (measuring more than 12 inches diameter and 35 feet in length) and only three pieces are in the Large category (greater than 20 inches diameter and at least 35 feet long). This equates to an average of 20.5 pieces of quality LWM per mile. One log jam was observed, consisting primarily of Small pieces (9) and a single Large piece of wood.

Table 6. Large woody material quantities in Reach 2.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	133	33	32	198
Number of pieces per mile	137	67		204
Number of jams	3			
Number of jams per mile	3			

4.2.5 Substrate & Fine Sediment

Two gravel counts were conducted in Reach 2–one at a glide-riffle crest (GC 2.1) and one on a longitudinal side bar (GC 2.2). The composition of material from the combined and averaged gravel counts indicates dominant substrate of cobble (54%) and gravel (38%) with 8% boulder and no sand (Figure 24). At GC 2.1, only 2% of the sampled grains were sized at 1mm-5.8mm (sand-small gravels) and at GC 2.2, only 1%. The cumulative distribution curves and grain size class of the gravel counts completed in Reach 2 are provided below in Figure 25 and Table 7.

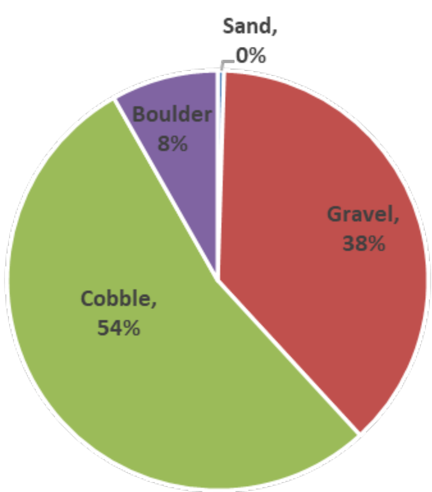
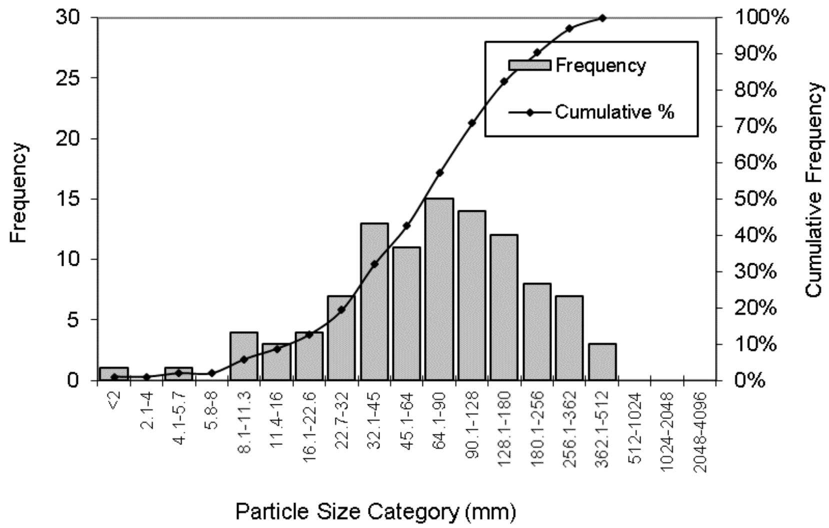


Figure 24. Combined percent composition sediment size type from two gravel counts in Reach 1.

GC 2.1



GC2.2

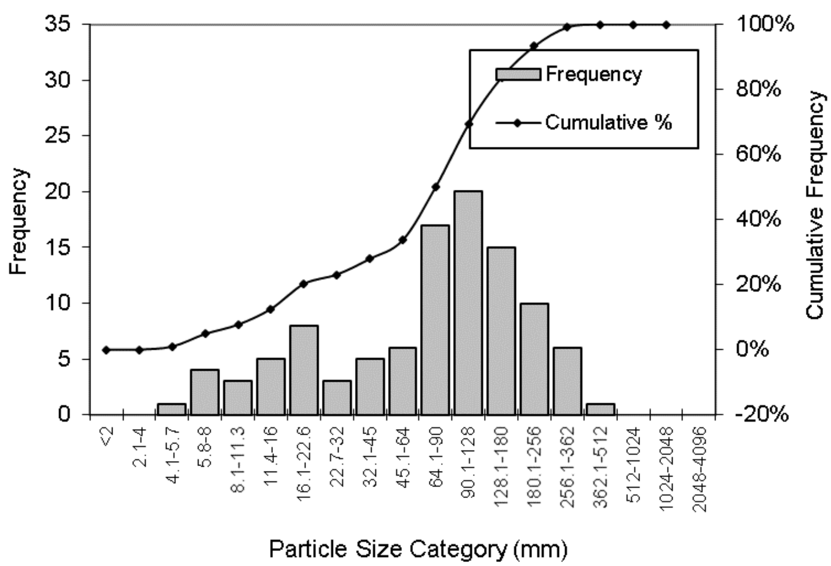


Figure 25. Cumulative grain size distribution for Gravel Count 2.1 and Gravel Count 2.2.

Table 7. Grain size class for Gravel Count 2.1 and 2.2. (assumed linear interpolation)

	2.1	**2.2**
Size Class	**Size percent finer than (mm)**	**Size percent finer than (mm)**
D5	11	8
D16	28	19
D50	77	118
D84	187	181
D95	302	270

4.2.6 Riparian Corridor

A total of seven n^{th} unit measurements were performed in Reach 2. The majority of the riparian vegetation within 100 feet of the river is classified as Small Trees (86%). The remaining 14% of vegetation is Sapling/Pole. The overstory species are primarily Douglas fir (72%) followed by Cottonwood and Alder (both 14%) (Figure 26). The riparian understory was composed primarily of Dogwood (57%) with equal parts Snowberry, Vinemaple and Alder (14%) (Figure 27). A natural vegetation condition of mature conifer forest on floodplains with a thick riparian buffer understory of native vegetation are present throughout Reach 2, except where bedrock bank/hillslope exposures occur.

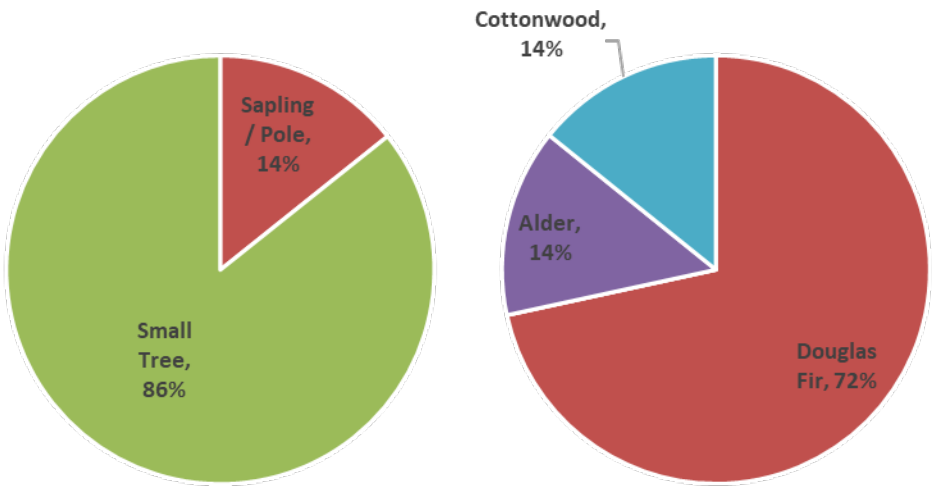


Figure 26. Dominant overstory riparian vegetation size (left0 and species (right) within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

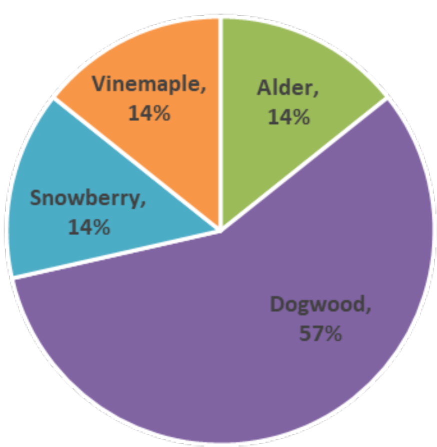


Figure 27. Dominant understory riparian vegetation species within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

4.3 REACH 3

Location: River mile 2.31 – 3.27
Total length: 0.96 miles
Survey Date: October 3-4, 2019

Figure 28. Representative view of Reach 3. Dominant habitat unit is extended riffles with boulders. (Photo: 10/04/19)

4.3.1 Habitat Unit Composition

Reach 3 is 0.96 miles long and has the greatest variety of habitat area with 81% of the habitat surface identified as riffle; 15% pool; 3% side channel and 1% glide (Figure 29 and Figure 30). Reach 1 is the only other reach where glide habitat is observed. Stream gradient in Reach 3 is the second highest in the study area at 4.73%.

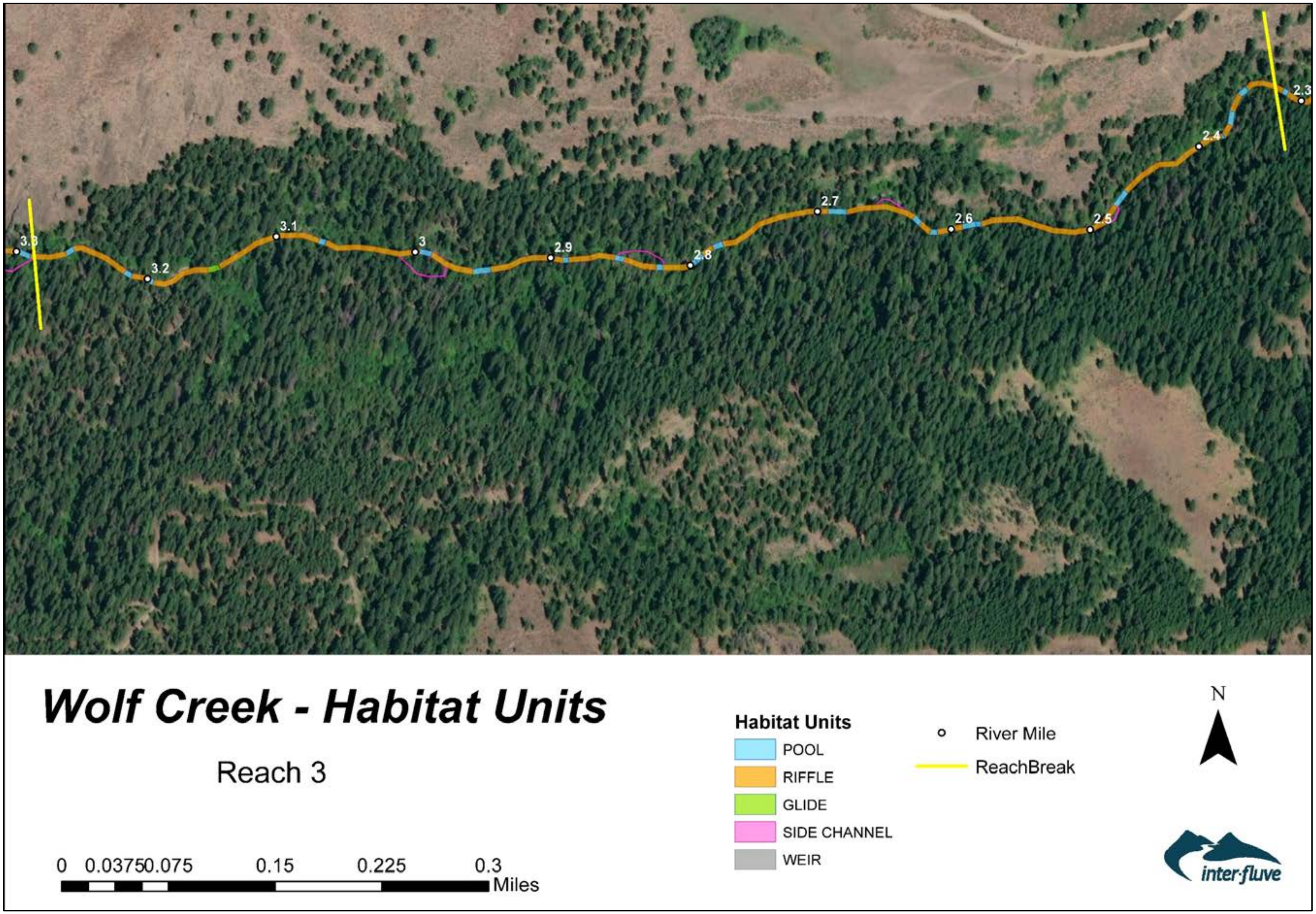


Figure 29. Wolf Creek, Reach 3–channel unit distribution: RM 2.31-3.27. Basemap: ESRI Bing imagery

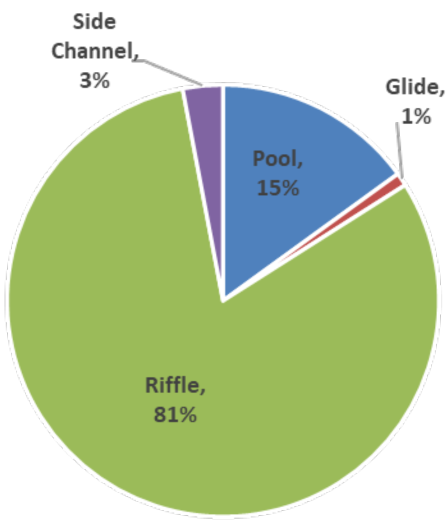


Figure 30. Stream habitat unit composition for Reach 3.

4.3.2 Pools

Reach 3 has a total of 16 pools and a pool frequency of 17 pools per mile, compared to an average of 20 pools per mile throughout the study area. Mean pool spacing for the reach is 7.7 channel widths per pool, which is slightly over the average for the entire project area at 7.4 channel widths per pool. No pools in this reach maintained residual depths of greater than three feet and the average residual pool depth is 1.7 feet.

4.3.3 Side Channel Habitat

Side channel habitat in Reach 3 accounts for 3% of the habitat area (Figure 30). A total of three side channels are present, totaling 555 feet in length and averaging 185 feet (Table 8). All three side channels are classified as slow water types. A total of 21 pieces of wood were recorded in the side channels; seven of those pieces are quality large wood.

Table 8. Secondary channel habitat in Reach 3.

Location	Length (ft)	Dominant unit type	Wood count
SIDE8S	125	Slow water	9
SIDE9S	200	Slow water	10
SIDE10S	230	Slow water	2
Total	555		21

4.3.4 Large Woody Material

LWM quantities in Reach 3 total 121 pieces, equating to 126 total pieces of wood per mile (Table 9). Of these 121 pieces, 24 are classified as Medium (measuring more than 12 inches diameter and 35 feet in length) and 24 pieces are in the Large category (greater than 20 inches diameter and at least 35 feet long). This equates to an average of 50 pieces of quality large woody material per mile. Two log jams were observed in Reach 3.

Table 9. Large woody material quantities in Reach 3.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	73	24	24	121
Number of pieces per mile	76	50		126
Number of jams	2			
Number of jams per mile	2			

4.3.5 Substrate & Fine Sediment

Two gravel counts were performed in Reach 3–one at a glide-riffle crest (GC 3.1) and one on a longitudinal side bar (GC 3.2). Cobble is the combined dominant substrate (57%) with 36% gravel, 2% sand and 6% boulder (Figure 31). At GC 3.1, only 4% of the surface sampled grains were sized at 1mm-5.8mm (sand-small gravels) and at GC 3.2, only 1%. The cumulative distribution curves and grain size class of the gravel counts completed in Reach 3 are provided below in Figure 32 and Table 10.

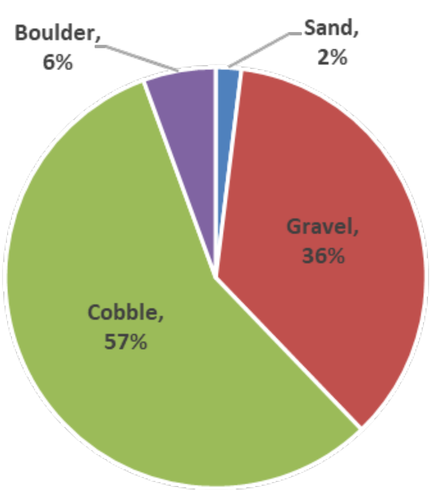
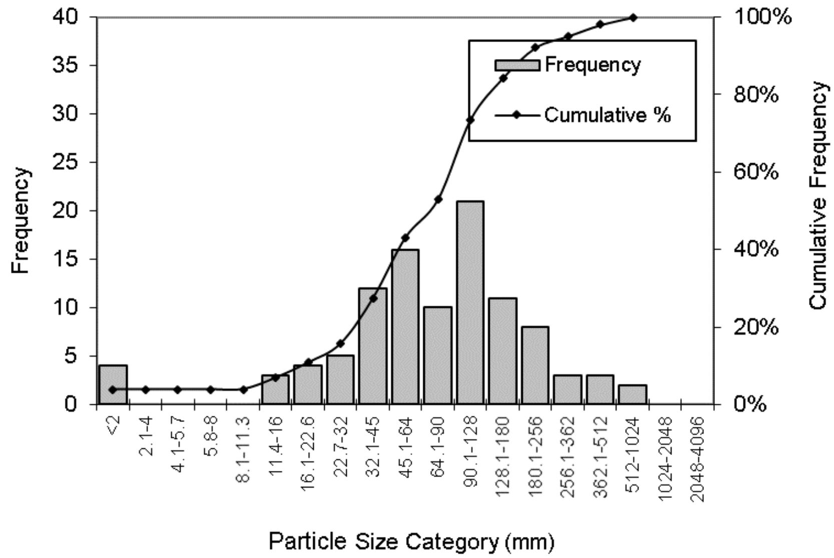


Figure 31. Combined percent composition sediment size type from two gravel counts in Reach 3.

GC 3.1



GC 3.2

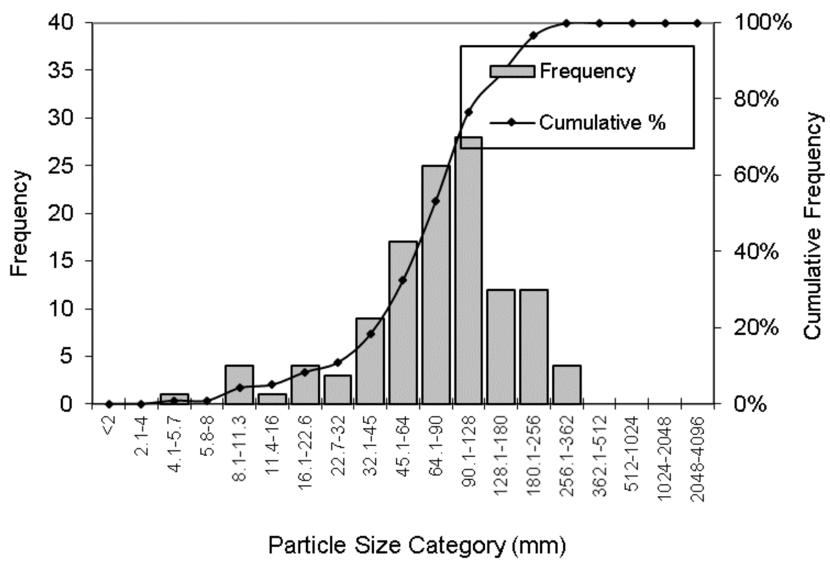


Figure 32. Cumulative grain size distribution for Gravel Count 3.1 and Gravel Count 3.2.

Table 10. Grain size class for Gravel Count 3.1 and 3.2. (assumed linear interpolation)

	3.1	**3.2**
Size Class	**Size percent finer than (mm)**	**Size percent finer than (mm)**
D5	12	12
D16	33	51
D50	72	87
D84	147	140
D95	284	223

4.3.6 Riparian Corridor

Based on six n^{th} unit measurements, 100% of the dominant overstory riparian vegetation identified within 100 feet of the creek is in the small tree size class (9.0 – 20.9 in. diameter). Douglas fir and cedar are the primary overstory species (50% each) (Figure 33). The understory is primarily Dogwood (66%), as well as Alder (17%), and Cedar (17%) (Figure 34). A natural vegetation condition of mature conifer forest on the floodplain surfaces with a thick riparian buffer understory of native vegetation are present throughout Reach 3, except where bedrock bank/hillslope exposures occur.

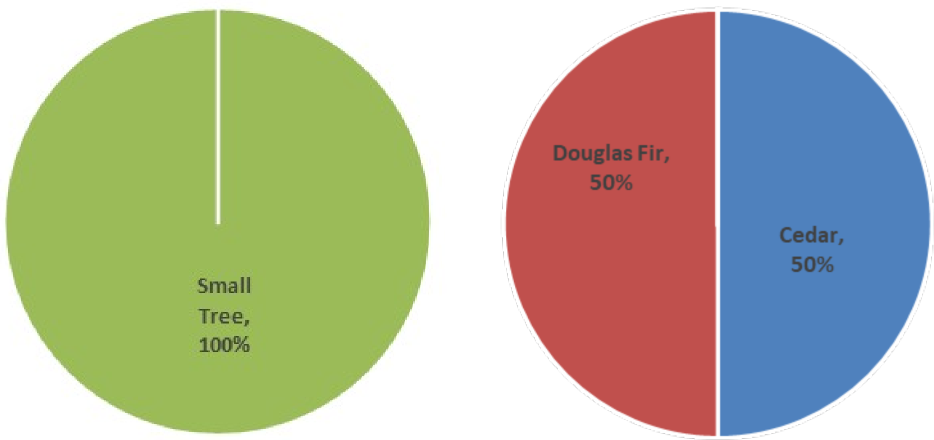


Figure 33. Dominant overstory riparian vegetation size and species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

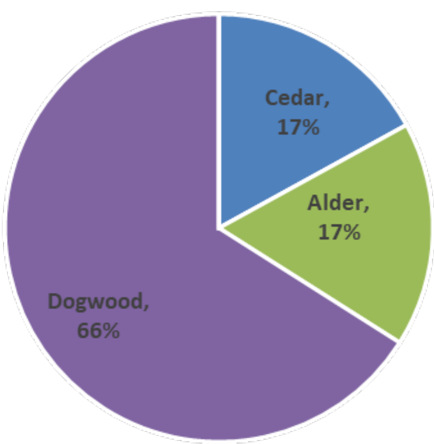


Figure 34. Dominant understory riparian vegetation species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

4.4 REACH 4

Location: River mile 3.27 – 4.21
Total length: 0.94 miles
Survey date: October 4, 2019

Figure 35. Representative view of Reach 4. Habitat units dominated by extended cascading riffles with boulders. (Photo: 10/04/2019)

4.4.1 Habitat Unit Composition

Reach 4 is 0.94 miles long (Figure 36). This reach is riffle-dominated, composed of 83% riffle, 13% pool, and 4% side channel (Figure 37). No glide habitat was observed in the reach. Reach 4 has a stream gradient of 4.03%.

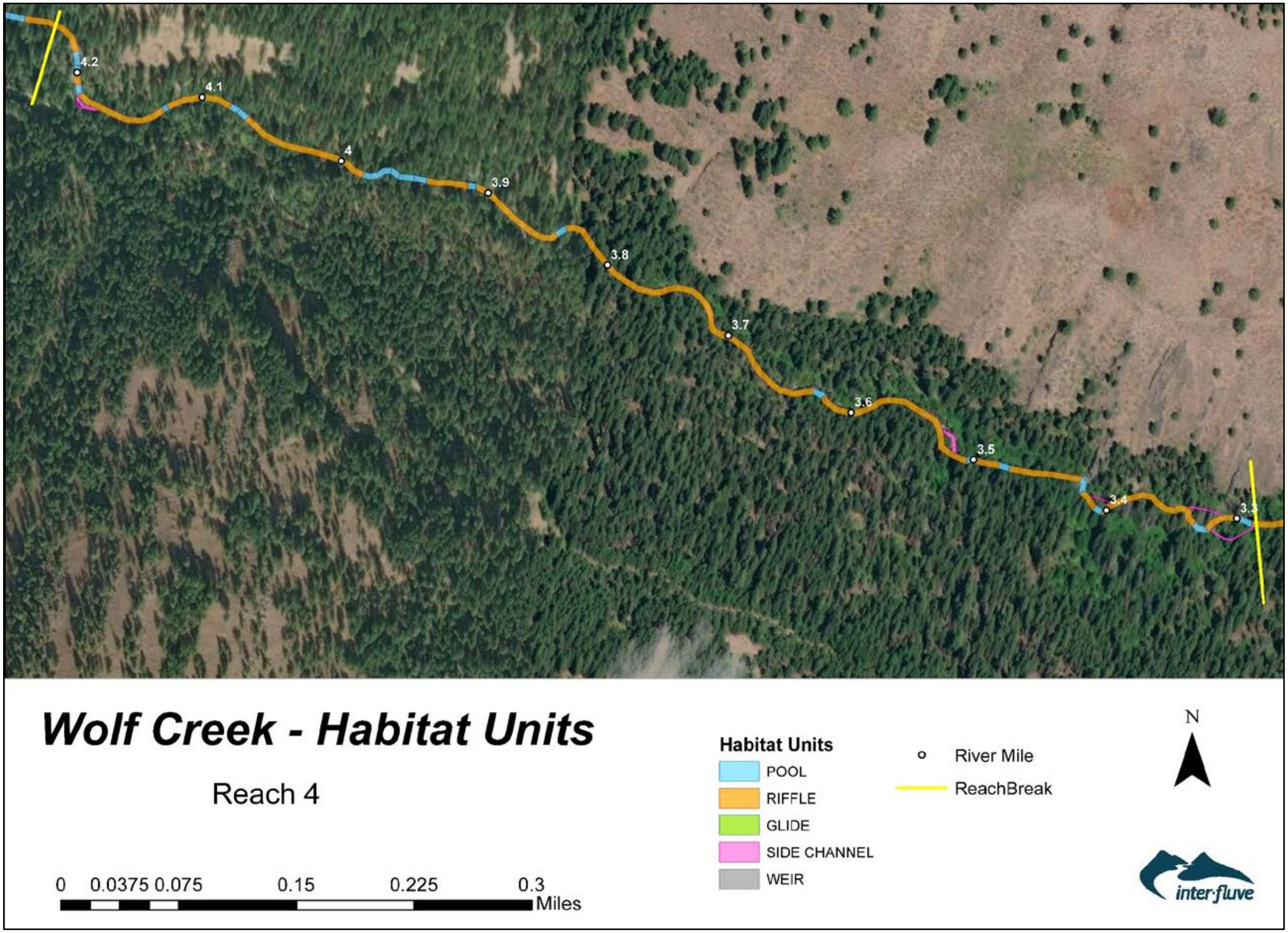


Figure 36. Wolf Creek, Reach 4–channel unit distribution: RM 3.27-4.21. Basemap: ESRI Bing imagery

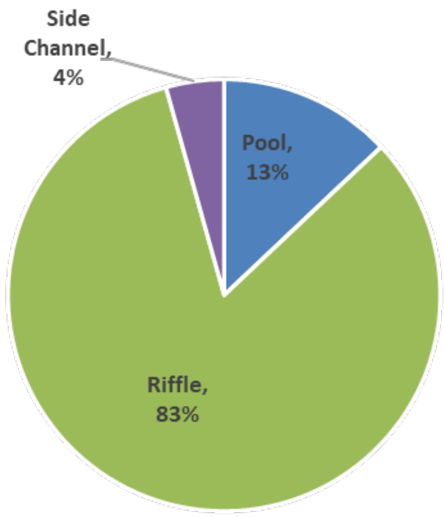


Figure 37. Stream habitat unit composition for Reach 4.

4.4.2 Pools

A total of 18 pools were identified in Reach 4, averaging 19 pools per mile. The average residual pool depth is 1.9 feet and mean pool spacing is 8.4 channel widths per pool, the highest mean pool spacing in the project area. Two of the eighteen pools observed maintain a residual depth of greater than three feet deep.

4.4.3 Side Channel Habitat

Six side channels were identified in Reach 4 (Table 11) comprising 4% of the habitat area in the reach. Three of the side channels were identified as slow water units and three were identified as fast water at the time of the survey. The total length of all five side channels is 578 feet, averaging 96 feet. A total of 15 pieces of wood were observed in the side channel: one Large piece, seven Medium pieces, and seven Small pieces.

Table 11. Secondary channel habitat in Reach 4.

Location	Length (ft)	Dominant unit type	Wood count
SIDE11S	165	Slow water	6
SIDE12S	120	Slow water	
SIDE13F	68	Slow water	3
SIDE14F	95	Fast water	3
SIDE15F	90	Fast water	1
SIDE16S	40	Fast water	2
Total	413		9

4.4.4 Large Woody Material

Reach 4 had the highest count of large wood both per mile and total number. A total of 209 pieces of LWM were identified in Reach 4, averaging 222 pieces per mile. There are 42 pieces of Medium wood (measuring more than 12 inches diameter and 35 feet in length); 21 pieces of Large wood (greater than 20 inches diameter and at least 35 feet long), and 146 Small pieces of large wood (Table 12). This equates to 67 pieces of quality LWM per mile. Six log jams were observed in Reach 4.

Table 12. Large woody material in Reach 4.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	155	48	22	225
Number of pieces per mile	165	74		239
Number of jams	7			
Number of jams per mile	7			

4.4.5 Substrate & Fine Sediment

Two gravel counts were performed in Reach 4 at glide-riffle crests (GC 4.1 and GC 4.2). Cobble is the combined averaged dominant substrate at 58% and gravel at 35%, with 6% boulder and 1% sand (Figure 38). At GC 4.1, only 2% of the surface sampled grains were sized at 1mm-5.8mm (sand-small gravels) and at GC 4.2, 0%. The cumulative distribution curves and grain size class of the gravel counts completed in Reach 4 are provided below in Figure 39 and Table 13.

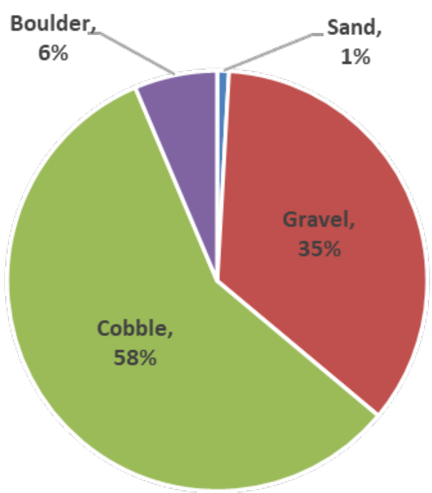
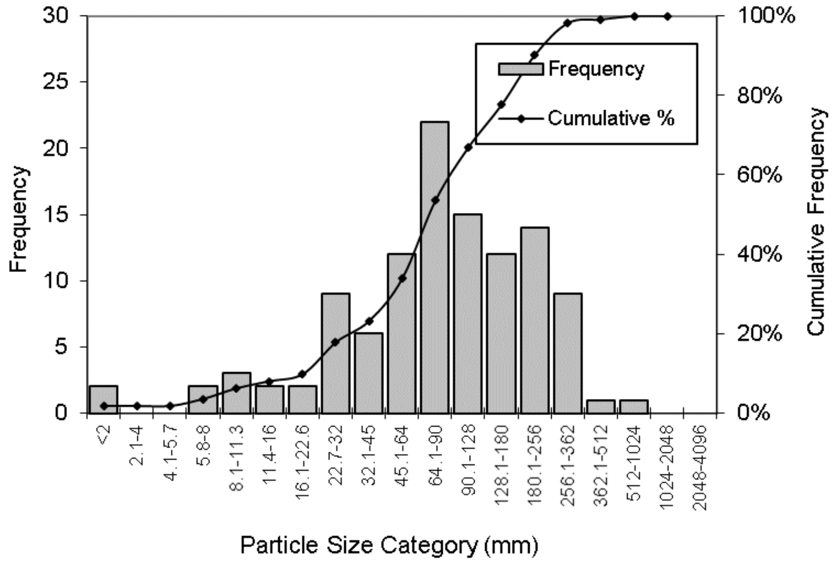


Figure 38. Percent composition of bed substrate based on two gravel counts at exposed bars in Reach 4.

GC 4.1



GC 4.2

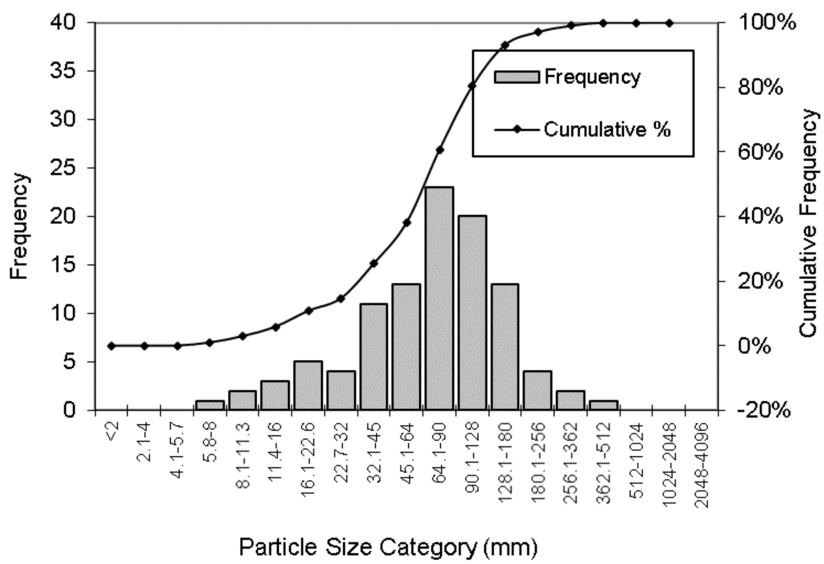


Figure 39. Cumulative grain size distribution for Gravel count 4.1 and Gravel Count 4.2. (assumed linear interpolation)

Table 13. Grain size class for Gravel Count 4.1 and 4.2.

	4.1	**4.2**
Size Class	**Size percent finer than (mm)**	**Size percent finer than (mm)**
D5	10	15
D16	45	35
D50	93	78
D84	211	143
D95	285	216

4.4.6 Riparian Corridor

Based on five n^{th} unit measurements, 75% of the riparian vegetation identified within 100 feet of the river in Reach 4 is small tree (9.0-20.9 in. diameter) and 25% is sapling/pole (5.0-8.9 in. dbh) (Figure 40). The overstory is dominated by mature Douglas fir (100%). The understory is also dominated by one species, Dogwood (Figure 41). A natural vegetation condition of mature conifer forest on the floodplain surfaces with a thick riparian buffer understory of native vegetation are present throughout Reach 4, except where bedrock bank/hillslope exposures occur.

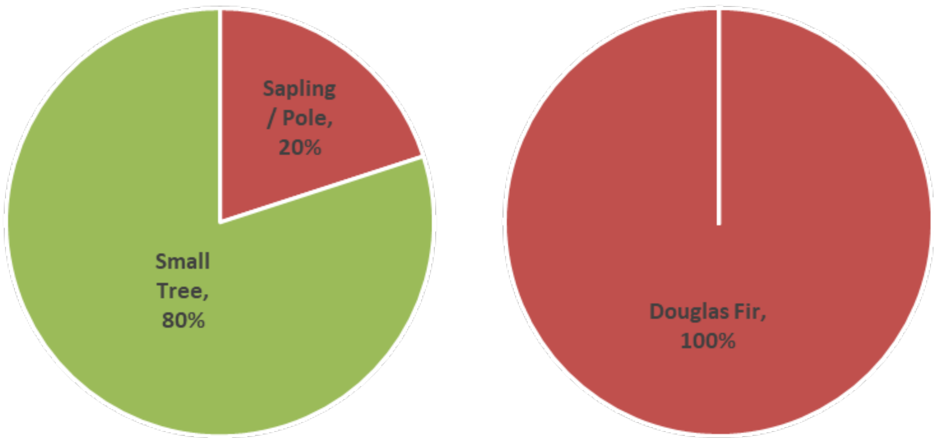


Figure 40. Dominant overstory riparian vegetation size and species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

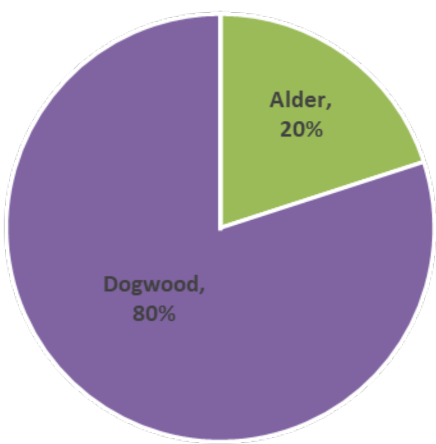


Figure 41. Dominant understory riparian vegetation size and species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

4.5 REACH 5

Location: River mile 4.21 – 4.53
Total length: 0.32 miles
Survey date: October 5, 2019

Figure 42. Representative view of Reach 5. (Photo: IFI Staff – 10/05/2019)

4.5.1 Habitat Unit Composition

Reach 5 is the shortest reach in the project area at 0.32 miles long (Figure 43) because the geomorphic reach extends upstream of the project area boundary at RM 4.53. Habitat unit composition in Reach 5 within the project area is dominated by extended riffles. Composition distribution is 80% riffle and 20% pool (Figure 44). No glides or side channels were observed in the reach. Reach 5 has the steepest gradient in the project area at 7.10%.

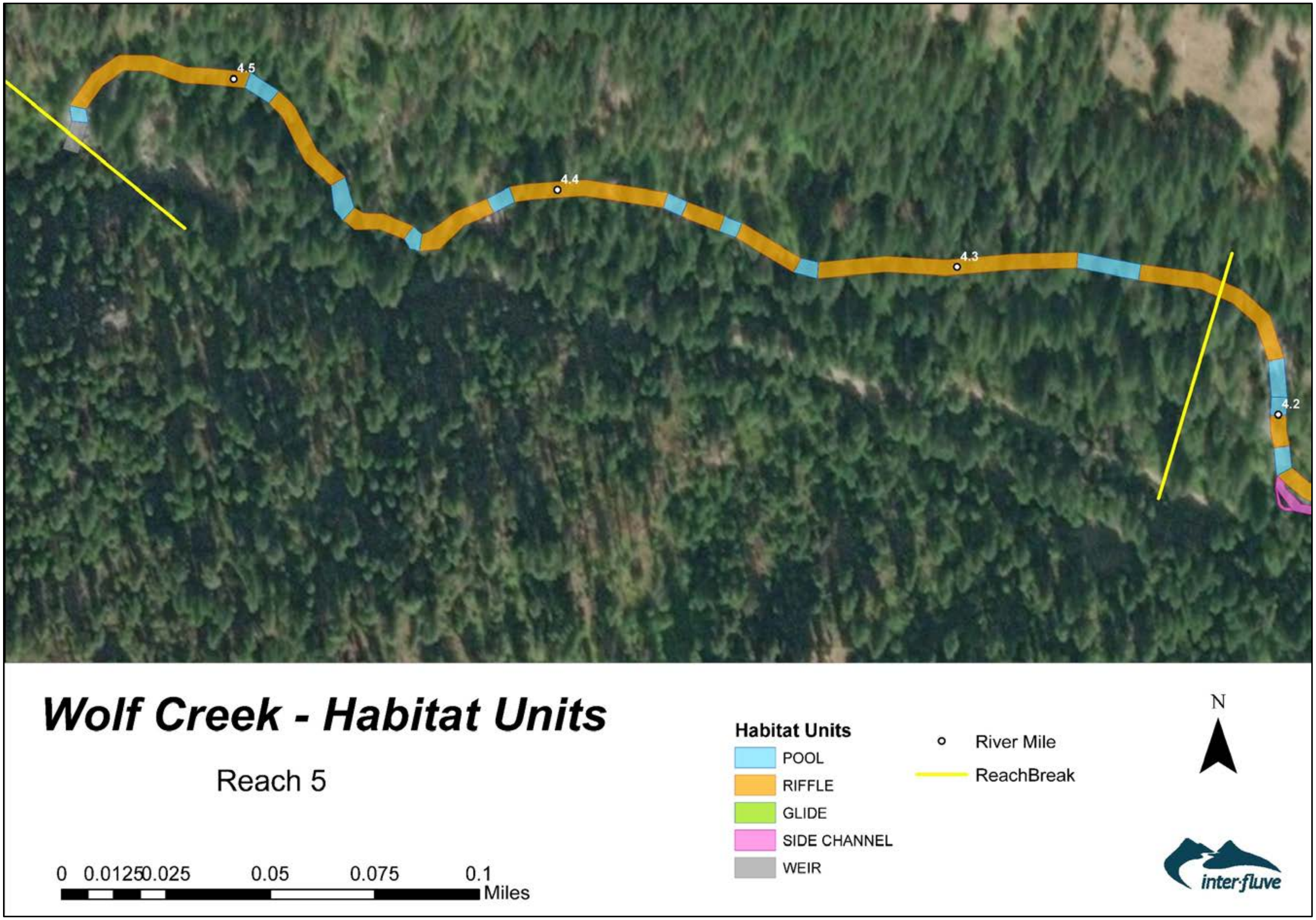


Figure 43. Wolf Creek, Reach 5–channel unit distribution: RM 4.21-4.53. Basemap: ESRI Bing imagery

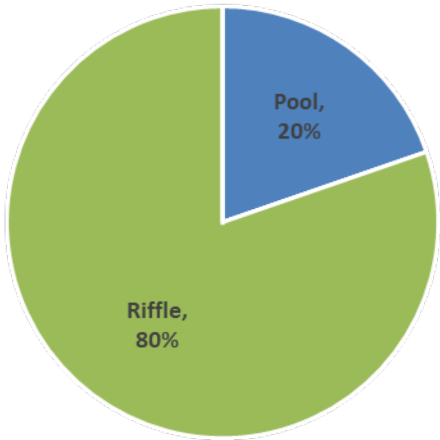


Figure 44. Stream habitat unit composition for Reach 5.

4.5.2 Pools

While Reach 5 has the lowest count of pools in the study area (11 pools), it has the highest number of pools per mile in the study area (34 pools per mile). Of the 11 pools observed, nine have residual depths of less than three feet and two have residual depths over three feet. Residual depths average 1.9 feet, equal to the residual pool depth in Reach 4 and the greatest residual pool depth in the study area. The deepest pool recorded in the study area is also in Reach 5 (4.1 feet). Mean pool spacing is 4.6 channel widths per pool, the lowest mean pool spacing in the project area.

4.5.3 Side Channel Habitat

No side channels were identified in Reach 5.

4.5.4 Large Woody Material

A total of 62 pieces of LWM were identified in Reach 5, averaging 193 pieces per mile (the study area average was 160). There are 14 pieces of medium wood (measuring more than 12 inches diameter and 35 feet in length); 3 pieces of large wood (greater than 20 inches diameter and at least 35 feet long), and 45 small pieces of large wood. One jam was observed (Table 14).

Table 14. Large woody material in Reach 5.

	Small (6 in x 20 ft)	Medium (12 in x 35 ft)	Large (20 in x 35 ft)	Total
Number of pieces	45	14	3	62
Number of pieces per mile	141	53		194
Number of jams	1			
Number of jams per mile	1			

4.5.5 Substrate & Fine Sediment

One gravel count was performed within Reach 5 at an exposed side bar (GC 5.1). The dominant substrate type is cobble (68%) with 21% gravel, 3% sand and 9% boulder (Figure 45). No bedrock was identified in the gravel count. At GC 5.1, only 3% of the surface sampled grains were sized at 1mm-5.8mm (sand-small gravels). The cumulative distribution curve and grain size class of the gravel count completed in Reach 5 are provided below in Figure 46 and Table 15.

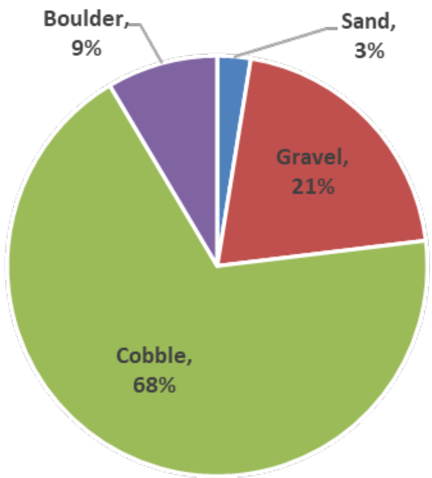


Figure 45. Percent composition of bed substrate based on one gravel count at an exposed bar in Reach 5.

GC 5.1

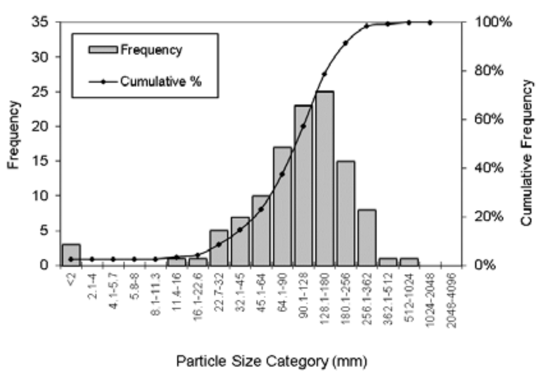


Figure 46. Cumulative grain size distribution for Gravel count 5.1.

Table 15. Grain size class for Gravel Count 5.1. (assumed linear interpolation)

Size Class	Size percent finer than (mm)
D5	28
D16	48
D50	112
D84	193
D95	277

4.5.6 Riparian Corridor

Based on four n^{th} unit measurements, 100% of the riparian vegetation, is classified as small tree (9.0-20.9 in. diameter) (Figure 47). The overstory is half (50%) Douglas fir, and half (50%) Cedar. The understory is 100% Dogwood (Figure 48). A natural vegetation condition of mature conifer forest on the floodplain surfaces with a thick riparian buffer understory of native vegetation are present throughout Reach 4, except where bedrock bank/hillslope exposures occur.

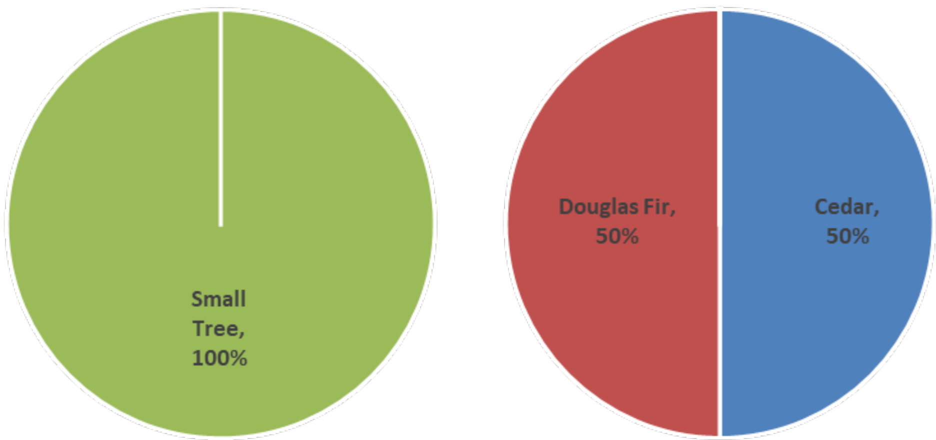


Figure 47. Dominant overstory riparian vegetation size and species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

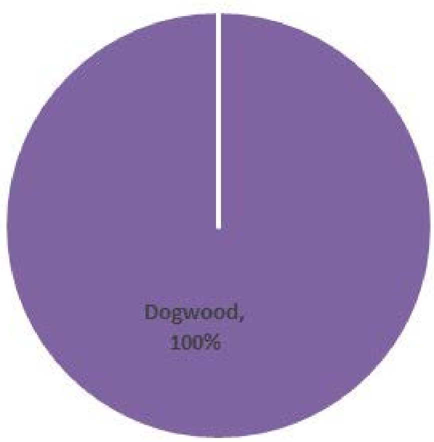


Figure 48. Dominant understory riparian vegetation species identified within 100 feet of Wolf Creek based on n^{th} unit ocular estimates.

4.6 SUMMARY DATA

Table 16. Summary of all data collected for the 2019 Habitat Assessment of Reaches 1-5 (RM 0 – 4.53) of Wolf Creek.

Reach	***1***	***2***	***3***	***4***	***5***	***All Reaches***
Reach Mileage boundaries	1.34	0.97	0.96	0.94	0.32	4.53
Stream Gradient (Average)	1.41%	3.91%	4.73%	4.03%	7.10%	3.6%
			Wetted Width (ft)			
Pool						Averages
Mean	15.4	18.7	20.1	19.5	18.1	18.1
Median	14.0	20.0	20.0	19.5	18.0	18
StDev	3.6	3.2	3.0	3.3	2.3	3.6
Glide						
Mean	14.7	0.0	19.0	0.0	0.0	15.8
Median	12.0	0.0	19.0	0.0	0.0	15.5
StDev	4.6	0.0	N=1	0.0	0.0	4.4
Riffle						
Mean	15.8	22.3	21.1	21.1	19.8	19.7
Median	15.5	22.0	21.0	20.0	20.0	20.0
StDev	2.5	3.4	2.4	3.5	2.5	3.9
Side Channel						
Mean	0.0	5.0	3.8	9.7	0.0	6.6
Median	0.0	4.0	3.5	10.5	0.0	4.5
StDev	0.0	1.8	1.7	6.3	0.0	4.6
			Water Depth (ft)			
Pool Maximum Depth						Averages
Mean	3.6	3.5	3.8	4.0	4.1	4.1
Median	2.1	2.6	2.5	2.6	2.6	2.5
StDev	0.6	0.4	0.4	0.6	0.7	0.6

Reach	1	2	3	4	5	All Reaches
Pool Residual Depth						
Mean	1.6	1.7	1.7	1.9	1.9	1.7
Median	1.6	1.7	1.6	1.8	1.6	1.6
StDev	0.6	0.4	0.4	0.7	1.0	0.6
Riffle/Glide Average Depth						
Mean	3.7	3.3	2.6	2.7	2.3	1.1
Median	1.0	1.7	1.8	1.2	1.8	1.2
StDev	1.0	0.4	0.4	0.4	0.5	0.3
Side Channel Average Depth						
Mean	0.0	0.7	0.6	0.7	0.0	0.7
Median	0.0	0.7	0.6	0.8	0.0	0.7
StDev	0.0	0.6	0.2	0.4	0.0	0.4
Bankfull Characteristics						
Width (ft)						Averages
Mean	38.4	32.8	42.3	34.7	33.5	35.8
StDev	19.9	5.3	3.2	4.2	4.9	7.6
Average Depth (ft)						
Mean	3.7	3.3	2.7	2.6	2.3	2.9
StDev	1.0	0.4	0.5	0.3	0.5	0.5
Maximum Depth (ft)						
Mean	4.2	3.8	3.2	2.9	2.6	3.3
StDev	0.5	0.4	0.5	0.5	0.5	0.5
Width: Depth Ratio						
Mean	47.6	27.0	36.0	29.6	25.6	33.1
Floodprone Width						
Mean	249.7	103.0	130.0	126.7	110.5	144.0
StDev	115.7	42.3	32.0	98.2	85.6	74.7

Reach	***1***	***2***	***3***	***4***	***5***	***All Reaches***
			Habitat area %			
Pool	18%	11%	15%	13%	20%	14%
Glide	3%	0%	1%	0%	0%	1%
Riffle	79%	85%	81%	83%	80%	82%
Side Channel	0%	4%	3%	4%	0%	3.1%
			Pools			
Pools per mile	17.9	21.6	16.7	19.1	34.4	21.95
Residual Depth (% of pools)						Average
Pools < 3 ft	96%	100%	100%	89%	82%	93%
Pools 3-6 ft	4%	0%	0%	11%	18%	7%
Riffle:Pool ratio	1.0	1.0	1.1	0.7	0.9	0.93
Mean Pool Spacing (bankfull channel widths per pool)	7.7	7.4	7.7	8.4	4.6	7.4
			Large Woody Material			
Total Number Pieces						Total
Total	52	198	121	225	62	658
Large	2	32	24	22	3	83
Medium	8	33	24	48	14	127
Large and Medium	10	65	48	70	17	210
Small	42	133	73	155	45	448
Number of Pieces/Mile						Average
Total	39	204	126	239	194	160
Large (20 in by 35 ft)	1	33	25	23	9	18
Medium (12 in by 35 ft)	6	34	25	51	44	32
Large and Medium	7	67	50	75	53	50
Small (6 in x 20 ft)	31	137	76	165	141	110
			Jams			
Total jams per reach	0	3	2	7	1	13

Reach	*1*	*2*	*3*	*4*	*5*	*All Reaches*
Unstable Banks						
Total Unstable Banks (% of total bank)	0%	0%	0%	0%	0%	0%
Substrate: at 9 gravel count (GC) locations						
Total	2 GCs	2 GCs	2 GCs	2 GCs	1 GC	Average
% Sand	0%	0%	2%	1%	3%	1%
% Gravel	56%	38%	36%	35%	21%	37%
% Cobble	39%	54%	57%	58%	68%	55%
% Boulder	4%	8%	6%	6%	9%	7%
% Bedrock	0%	0%	0%	0%	0%	0%
Vegetation (% of sampled units in 100-foot-wide zone averaged between both banks)						
Dominant Overstory Size Class						Average
Shrub/Seedling	22%	0%	0%	0%	0%	6%
Sapling/Pole	33%	14%	0%	20%	0%	16%
Small Tree	44%	86%	100%	80%	100%	77%
Overstory Species Composition						
Cedar	0%	0%	50%	0%	50%	17%
Douglas Fir	71%	71%	50%	100%	50%	69%
Ponderosa Pine	14%	0%	0%	0%	0%	3%
Alder	0%	14%	0%	0%	0%	3%
Cottonwood	14%	14%	0%	0%	0%	7%
Dominant Understory Species						
Cedar	0%	0%	17%	0%	0%	4%
Grassland/Forb	100%	0%	0%	0%	0%	21%
Alder	0%	14%	17%	20%	0%	11%
Dogwood	0%	57%	66%	80%	100%	57%
Snowberry	0%	14%	0%	0%	0%	4%
Vinemaple	0%	14%	0%	0%	0%	4%

5 References

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Appendix B

Reach-Based Ecosystem Indicators (REI)

Wolf Creek (RM 0 – 4.53)

December 2020

Contents

1 Introduction

1.1 BACKGROUND

The Reach-based Ecosystem Indicators (REI) provide a consistent means of evaluating biological and physical conditions of a watershed in relation to regional standards and known habitat requirements for aquatic biota. These indicators, along with other scientific evaluations, describe the current quality of stream biophysical conditions and can help inform restoration targets and actions. The REI indicators used in this assessment are adaptations from previous efforts including the NMFS matrix of pathways and indicators (NMFS 1996) and the USFWS (1998). With a few exceptions, the REI are based on the USBR's latest adaptations and use of these indicators (USBR 2012).

The REI evaluation for Wolf Creek was conducted using field data, observations, previous studies, and available data for the study area. In particular, the rankings were developed based on: 1) quantitative inventory information from the Habitat Assessment performed as part of the Reach Assessment using USFS (2015) protocols, 2) assessment of geomorphic patterns and processes and how they have deviated, if at all, from historical conditions, and 3) analysis of existing watershed assessments and data (e.g. available ArcMap layers and shapefiles). Functional ratings include **Adequate**, **At Risk**, or **Unacceptable**. The REI analysis helps to summarize habitat impairments and to distill the impairments down to a consistent value that can be compared among reaches.

1.2 SUMMARY OF RESULTS

Watershed-scale ratings for the Wolf Creek study area vary, ranging from **Adequate** to **Unacceptable**. Both the Drainage Network and Disturbance Regime indicators were rated **Adequate** for the study area, while the Streamflow indicator received an **At Risk** rating. Water temperature monitoring in the study area indicates temperatures often exceed thermal criteria for salmonids in the summer and early fall, therefore, the Temperature indicator was rated **Unacceptable**.

In the reach-scale metrics, Reach 1 is the most impacted reach with eight **Unacceptable** ratings, the most of all the reaches and one **At Risk**. Reach 2 had only one **Unacceptable** rating and three **At Risk** ratings. The legacy of historical and ongoing human disturbances – including timber harvests, development of residential homes, confining infrastructure, and lack of instream large wood – have contributed to the ecosystem impacts in Reach 1 and 2. Reaches 3 through 5 were the least impacted to varying degrees; Reach 3 had the most **Adequate** ratings (10) with one **Unacceptable** rating, while Reach 4 has the most **Adequate** ratings with just one At Risk rating and Reach 5 has three **At Risk** ratings while all other metrics are **Adequate**.

All reaches received **Adequate** ratings for the Habitat Access Pathway- Main Channel Barriers and Dominant Substrate/Fine Sediment indicators since there were no barriers within the main channel that completely excluded fish passage and a lack of sands and small gravels that can be detrimental to egg incubation.

LWM ratings increased from **Unacceptable** in Reach 1 and **At Risk** in Reach 2 to **Adequate** in Reaches 3 – 5. The lower reaches had low numbers of large wood pieces, especially quality pieces of large wood and lacked potential large wood recruitment. Pool frequency was rated **Unacceptable** in Reaches 1 – 3 and **At Risk** in Reaches 4 – 5 due to low pool frequency and low quality of the pools (low residual depths and minimal/no large wood cover or habitat). The Off-channel Habitat indicator was rated as **Unacceptable** for Reach 1 and **At Risk** for Reaches 3 and 5 due to either the complete lack or very infrequent occurrence of connected alcoves and side channels or floodplains.

Riparian vegetation condition indicators – Structure and Canopy Cover – were both rated **Unacceptable** for Reach 1 and **At Risk** for Reach 2. Though the observed seral stage of the riparian vegetation in Reaches 3 – 5 was classified as primarily small trees, these reaches were rated **Acceptable** in both Structure and Canopy Cover indicators because there is no modern history of human disturbances in these reaches and mature forests are established on the floodplains -- suggesting this is the natural condition of the riparian buffer. Reaches 1 and 5 received **At Risk** ratings in the Human Disturbance indicator due to the number of residences, confinements, and developed areas within the riparian zone of Reach 1 and the irrigation withdrawal infrastructure at the upstream boundary and access road running adjacent to the river in Reach 5. Reaches 2 – 4 received ratings of **Adequate** for this indicator due to minimal roads and development located within the riparian zone of these reaches.

Channel dynamics for Reach 1 is unsatisfactory. Reach 1 received **Unacceptable** ratings in all three indicators: Floodplain Connectivity, Bank Stability/Channel Migration, and Vertical Channel Stability due to anthropogenic channel entrenchment/confinement. Reaches 2 – 5 were rated **Adequate** for all three Channel Dynamics indicators.

For the study area as a whole, **Adequate** was the most common rating (36), followed by **At Risk** (9) and **Unacceptable** ratings (10 each). A summary of the ratings is presented in Table 1.

Table 1. Summary ratings for the Wolf Creek reach assessment study area. Ratings are color-coded, with green shading for Adequate condition, yellow for At Risk condition, and red for Unacceptable condition.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Habitat Access	Physical Barriers	Main Channel Barriers	Adequate	Adequate	Adequate	Adequate	Adequate
Habitat Quality	Substrate	Dominant Substrate / Fine Sediment	Adequate	Adequate	Adequate	Adequate	Adequate
	LWM	Pieces per Mile at Bankfull	Unacceptable	At Risk	Adequate	Adequate	Adequate
	Pools	Pool Frequency and Quality; Presence of Large Pools	Unacceptable	Unacceptable	Unacceptable	At Risk	At Risk
	Off-Channel Habitat	Connecivity with Main Channel	Unacceptable	Adequate	At Risk	Adequate	At Risk
Riparian Vegetation	Condition	Structure	Unacceptable	At Risk	Adequate	Adequate	Adequate
		Disturbance (Human)	At Risk	Adequate	Adequate	Adequate	At Risk
		Canopy Cover	Unacceptable	At Risk	Adequate	Adequate	Adequate
Channel	Dynamics	Floodplain Connecivity	Unacceptable	Adequate	Adequate	Adequate	Adequate
		Bank Stability / Channel Migration	Unacceptable	Adequate	Adequate	Adequate	Adequate
		Vertical Channel Stability	Unacceptable	Adequate	Adequate	Adequate	Adequate

2 Metrics & Indicators

2.1 WATERSHED-SCALE METRICS

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Watershed Scale					
Watershed Condition	Drainage Network and Hydrologically Impaired Surfaces	Increase in Drainage Network/ Hydrologically Impaired Surfaces	Zero or minimal increases in the drainage network that is correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total < 8%. Road density <1 mile/miles^2.	Low to moderate increase in the drainage network correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total between 8 and 14.9%. Road density 1-2.4 miles/miles^2.	Substantial increase in the drainage network correlated with human caused disturbances. Hydrologically impaired surfaces in watershed total > 15%. Road density >2.4 miles/miles^2.
	Disturbance Regime	Natural/Human Caused	Environmental disturbance is short-lived; predictable hydrograph, high-quality habitat and watershed complexity providing refuge and rearing space for all life stages or multiple life-history forms. Natural processes are stable.	Localized events of hillslope contributions, avulsion, lateral migrations, minor bed incision, or wildfires. Resiliency of habitat to recover from environmental disturbances is moderate.	Frequent flood or drought producing highly variable and unpredictable flows, hillslope contributions, avulsion, lateral migrations, minor to major bed incision (head cuts), or wildfires throughout a majority of the watershed. The channel is simplified, providing little hydraulic complexity in the form of pools or side channels. Natural processes are unstable.
Flow/Hydrology	Streamflow	Alterations to Peak/Base Flows	Magnitude, timing, duration, and frequency of peak flows within a watershed are not altered relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Some evidence of altered magnitude, timing, duration and/or frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.	Pronounced changes in magnitude, timing, duration and/or frequency of peak flows relative to natural conditions of an undisturbed watershed of similar size, geology, and geography.
Water Quality	Temperature	7-day average maximum temperatures	**Bull Trout:** incubation 2 - 5°C rearing 4 - 12°C spawning 4 - 9°C **Other salmonids:** spawning <13°C rearing <15°C holding & migration <15°C Lamprey: rearing 10 – 18 °C, migration <18°C And, temperatures do not exceed 15°C in areas used by adults during migration (no thermal barriers)	**Bull Trout:** incubation <2 or 6°C rearing <4 or 13 - 15°C spawning <4 or 10°C **Other salmonids:** spawning 14-15.5°C rearing <14 – 17.5°C holding & migration <14 – 17.5°C Lamprey: rearing 18 – 22°C, migration 18 – 22°C And, temperatures in areas used by adults during migration sometimes exceed 15°C	**Bull Trout:** incubation <1 or >6°C rearing >15°C spawning <4 or >10°C **Other salmonids:** spawning >15.5°C rearing >17.5°C holding & migration >17.5°C Lamprey: rearing >22°C, migration >22°C And, temperatures in areas used by adults during migration regularly exceed 15°C (thermal barriers present)

2.2 REACH-SCALE METRICS

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Reach Scale					
Habitat Access	Physical Barriers	Main Channel Barriers	No man-made barriers present in the mainstem that limit upstream or downstream migration at any flow.	Man-made barriers are present in the mainstem that have the potential to prevent or inhibit upstream or downstream migration at a subset of flows.	Man-made barriers present in the mainstem that prevent upstream or downstream migration at multiple or all flows.
Habitat Quality	Substrate	Dominant Substrate/Fine Sediment	Gravels or small cobbles make up >50% of the bed materials in spawning areas. ≤12% of substrates <6 mm in spawning gravel.	Gravels or small cobbles make up 30-50% of the bed materials in spawning areas. 12-20% of substrates <6 mm in spawning gravel.	Gravels or small cobbles make up <30% of the bed materials in spawning areas. >20% of substrates <6 mm in spawning gravel.
	LWM	Pieces per Mile at Bankfull	Based on Fox and Bolton (2007) metrics for Eastern Washington, at least 32 pieces/mile of large wood. Qualifying pieces are those classified as Medium or Large in the USFS Stream Inventory protocol (2015), under the Eastside Forests criteria: Medium = diameter > 12 in, length > 35 ft, and Large = diameter > 20 in, length > 35 ft). In addition to a minimum of 32 pieces of large wood/mile, an adequate rating also indicates there are sources of woody debris available for both long- and short-term recruitment within the reach.	Current levels are able to maintain the minimum requirements for an "adequate" rating, but potential sources for long-term woody debris recruitment, as determined by the Riparian Structure reach metrics, are lacking in order to maintain these current levels.	Current levels are not meeting the minimum requirements for an “adequate” rating, and potential source of woody debris for short- and/or long-term recruitment are lacking as well.
	Pools	Pool Frequency and Quality; presence of large pools.	Pool frequency: Number of pools/mile for a given wetted or channel width. Wetted width: 15 – 20 ft 39 pools/mi 20 – 30 ft 23 pools/mi Channel width: 25 ft 47 pools/mi To be considered adequate, at least 50% of the total pools are large pools >1 m (3 ft) deep. Pools must also have good fish cover (as determined by riparian vegetation and canopy cover metrics) and cool water with only a minor reduction in pool volume from fine sediment.	Pool frequency meets the values for the "adequate" rating, but pools have inadequate cover/temperature and/or there has been a moderate reduction of pool volume by fine sediment. Reaches have between 20-50% large pools (>1 m deep) present with good fish cover.	Pool frequency does not meet the pools/mile metric given in the “adequate” rating. Pools also have inadequate cover/temperature and/or there has been a major reduction of pool volume by fine sediment. Reaches have <20% large pools (>1 m deep).
	Off-Channel Habitat and Refugia	Connectivity with Main Channel	Reach has side channels and/or groundwater fed tributaries. Aquatic refugia such as backwaters, alcoves, large boulder eddies exist within the channel. Well-vegetated floodplains with healthy riparian community are inundated on a 1-2-year recurrence frequency. No man-made barriers along the mainstem that prevent access to off-channel areas.	Reach provides some aquatic off-channel and refugia features but access varies or is at risk of disconnection due to human impacts or man-made barriers. Floodplains along the off-channel habitat are well-vegetated with inundation recurrence of 2-5-years.	Reach provides no or only minimal off-channel or in-channel refugia. Floodplains are disconnected by processes of incision and/or human structures (levee, bridges, etc.) and riparian vegetation has been altered.

Pathway	General Indicators	Specific Indicators	Adequate Condition	At Risk Condition	Unacceptable Risk Condition
Riparian Vegetation	Condition	Structure	>80% large trees (>21" DBH; USFS 2013) in the riparian buffer zone (defined as a 100ft buffer along each bank) based on habitat assessment data.	50-80% large trees (>21" DBH; USFS 2013) in the riparian buffer zone (defined as a 100ft buffer along each bank) based on habitat assessment data.	<50% large trees (>21" DBH; USFS 2013) in the riparian buffer zone (defined as a 100ft buffer along each bank) based on habitat assessment data.
		Disturbance (Human)	<20% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and <2 mile/miles^2 road density in the 200-foot riparian buffer zone.	20-50% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and 2-3 miles/miles^2 road density in the 200-foot riparian buffer zone.	>50% disturbance in the 200-foot riparian buffer zone (e.g. agriculture and grazing, residential, roads, etc.) and >3 miles/miles^2 road density in the 200-foot riparian buffer zone.
		Canopy Cover	Trees and shrubs within one site potential tree height distance (~100 feet) have >80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have 50-80% canopy cover that provides thermal shading to the river.	Trees and shrubs within one site potential tree height distance have <50% canopy cover that provides thermal shading to the river.
Channel	Dynamics	Floodplain Connectivity	Floodplain areas are hydrologically linked to main channel within the context of the local process domain; overbank flows occur and maintain wetland functions, and riparian vegetation. Naturally confined channels are considered adequate.	Reduced linkage of floodplains and riparian areas to main channel in reaches with historically strong connectivity; overbank flows are reduced relative to historic frequency, as evidenced by moderate degradation of floodplain soil accumulations and riparian vegetation/succession.	Severe reduction in hydrologic connectivity between off-channel, floodplain, and riparian areas relative to historical connectivity; riparian vegetation/succession is altered significantly.
		Bank Stability/Channel Migration	Channel is migrating at or near natural rates within the geomorphic construct of the reach.	Channel migration is occurring at a faster or slower rate relative to natural rates, but significant change in channel width or planform is not detectable; large woody debris is still being recruited.	Little or no channel migration is occurring because of human actions preventing reworking of the floodplain and large woody debris recruitment; or channel migration is occurring at an accelerated rate such that channel width has at least doubled, possibly resulting in a channel planform change, and sediment supply has noticeably increased from bank erosion.
		Vertical Channel Stability	No measurable trend of aggradation or incision beyond the natural geomorphic processes of the reach.	Measurable trend of aggradation or incision that has the potential to, but has not yet caused, disconnection of the floodplain or a visible change in channel planform (e.g. single thread to braided.)	Enough incision or human infrastructure has occurred that the floodplain and off-channel habitat areas have been disconnected from the main channel; or enough aggradation has occurred to create a visible change in channel planform (e.g. single thread to braided.)

3 REI Ratings

This section discusses the results for each indicator, rated at either the reach-scale or watershed-scale for all four reaches.

3.1 WATERSHED-SCALE RATINGS

General Characteristics	General Indicators	Specific Indicators	Rating	Discussion
Watershed Scale				
Watershed Condition	Drainage Network and Hydrologically Impaired Surfaces	Increase in Drainage Network/ Hydrologically Impaired Surfaces	Adequate Condition	Watershed hydrologically impaired surfaces (roads, parking lots, and buildings) were calculated based on data from Washington State Department of Ecology. A GIS shapefile of land use data based on 2010 tax parcels from the Washington Department of Revenue was used to classify parcels as "hydrologically impaired" or "Not hydrologically impaired" for the watershed. Hydrologically impaired parcel polygon areas were summed and compared to the total watershed area, as determined using the StreamStats online mapper application (USGS, 2020). The average percentage of hydrologically impaired surfaces for the entire contributing watershed was 0.9%. Road density was calculated using state roads GIS data from Washington Department of Natural Resources. Length of roads in the Wolf Creek watershed were summed and compared to the total watershed area, giving an overall watershed road density of 0.7 miles of road per square mile of watershed. The upper Wolf Creek watershed has no roads or buildings, while the lower portions of the watershed have higher densities of roads, including both public and private roads. As the percentage of hydrologically impaired surfaces for the entire contributing watershed is low, road density is low, and few roads are located very close to the active channel in Wolf Creek, this indicator receives a rating of Adequate at the watershed scale.
	Disturbance Regime	Natural/Human Caused	Adequate Condition	This disturbance history rating reflects the protected nature of a majority of the upper watershed, which lies within the Chelan-Sawtooth Wilderness Area. Though there are historical accounts of riparian and hillslope timber harvest, mining, grazing, agriculture and roads, and residential development, much of this was restricted to the lower portion of the watershed. Previous timber harvests have occurred mainly in the Little Wolf Creek drainage and south of Wolf Creek or in the Virginia Ridge area. Future timber harvests in the watershed are restricted due to the Wilderness Area designation and steep slopes. The watershed historically had a naturally frequent regime of low intensity fires that rejuvenated vegetation but fire suppression means the watershed has a higher risk of stand-replacing wildfire (USFS 2005). The Hubbard Fire burned a portion of the upper watershed in 1985. Wolf Creek has annual spring flooding and frequent rain-on-snow floods. As a result of largely human-caused modifications, the channel within the lower portion of the study area has reduced complexity and floodplain/alluvial fan connection and is incised in the lower sections. Some historical timber harvest, wildfires, and historical and on-going uses for livestock ranging have likely influenced riparian vegetation. Private ownership within the watershed is restricted almost entirely to Reach 1, and consists primarily of residential housing and agricultural uses. Similarly, roads are present in the highest density in the lower reaches. No roads are present in the watershed above approximately RM 4. The watershed is used for many recreational purposes, with low density trails and dispersal campsites present throughout. The Wolf Creek watershed is designated a Tier 1 watershed for three listed species by the USFS, limiting future road construction and land uses. Based on all this information and the current protected nature of a majority of the watershed, Wolf Creek receives a rating of Adequate.

Flow/Hydrology	Streamflow	Alterations to Peak/Base Flows	At Risk Condition	The hydrology of the watershed contributing to Wolf Creek is driven by a combination of precipitation and snowmelt. Annual snowmelt flooding in the spring with infrequent rain-on-snow floods dominate the seasonal streamflow pattern in the basin. Snowmelt runoff is primarily driven by changes in ambient air temperature, snowpack mass, and the elevation of the season's snowpack. Peak runoff usually occurs in May and June, typically returning to baseflow by late summer. Water diversions in Wolf Creek have impacted streamflow and habitat conditions, with the mouth of the Creek historically going dry during the late summer and early fall periods (USFS 2005). Wolf Creek, from the mouth to the confluence with Little Wolf Creek (encompassing approximately Reaches 1 – 3 of this effort), is listed as a Category 4C waters for insufficient instream flow by the Washington Department of Ecology. This listing was on the 1996 and 1998 303(d) lists, but was moved to the new Category 4C (impaired by a non-pollutant) in 2004, and remains Category 4C. Recent modifications to irrigation diversion practices have increased baseflows and reduced occurrences of complete channel drying, but these alterations may have legacy impacts to aquatic species and habitats that persist today. Climate change models indicate that winter precipitation is expected to increase as rain in the Cascade Mountains (Mote and Salanthe 2009) and likely result in an increase in winter stream flows, earlier and lower peak runoff, and lower summer baseflows. Drier and warmer conditions in the lower, Eastern portion of the basin may exacerbate the low summer flows. These analyses suggest that human-induced climate change is likely to have an effect on the magnitude, timing, duration, and frequency of stream flows in Wolf Creek. Based on the effects of past watershed management, and the potential effects of climate change, this indicator is rated At Risk.
Water Quality	Temperature	Daily maximum and 7-day mean daily maximum temperatures	Unacceptable Condition	Lower mainstem Wolf Creek water temperature data from 2005 and 2016-2019 show water temperatures in the assessment area exceeded USFWS standards for bull trout rearing and migration (7-day average maximums ≤ 12°C), and exceeded NOAA Fisheries standards (water temperatures ≤14°C) for anadromous fish habitat. Water temperatures in Wolf Creek can exceed Washington State water quality standards for salmonids and Class AA streams and criteria set by the Wenatchee Forest Plan (<60.8 and 61°F, respectively) during the summer. Therefore, this indicator is rated Unacceptable for Wolf Creek.

3.2 REACH-SCALE RATINGS

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Habitat Access	Physical Barriers	Main Channel Barriers	Adequate There are no anthropogenic barriers in the main channel.	Adequate There are no anthropogenic barriers in the main channel.	Adequate There are no anthropogenic barriers in the main channel. There is a natural channel-spanning log jam in this reach creating a 4-foot drop that is currently fish passable.	Adequate There are no anthropogenic barriers in the main channel.	Adequate There are no anthropogenic barriers in the main channel within the reach (the diversion acts as the upstream boundary of the reach and is not classified as a barrier to fish passage).
Habitat Quality	Substrate	Dominant Substrate/ Fine Sediment	Adequate Based on two gravel counts, gravels dominate (56%) the channel substrate with some cobbles (39%). Substrates <6mm averaged 1% for the reach, and fine sediments were noted in the reach behind log jams and boulder eddies.	Adequate Based on two gravel counts, cobbles dominate (54%) with some gravels (38%) and boulders (8%). Substrates <6mm averaged 1% for the reach, and fine sediments were noted in the reach behind log jams and boulder eddies.	Adequate Based on two gravel counts, cobbles dominate (57%) with some gravels (36%) and boulders (6%). Only 2% sand (<2mm) was recorded in the gravel counts, and substrates <6mm also averaged 2% for the reach. Gravel sized sediments were noted in the reach behind log jams and boulder eddies.	Adequate Based on two gravel counts, cobbles dominate (58%) with some gravels (35%) and boulders (6%). Only 1% sand (<2mm) was recorded in the gravel counts, and substrates <6mm also averaged 1% for the reach. Gravel sized sediments were noted in the reach behind log jams and boulder eddies.	Adequate Based on two gravel counts, cobbles dominate (68%) with some gravels (21%) and boulders (9%). Only 3% sand (<2mm) was recorded in the gravel counts, and substrates <6mm also averaged 3% for the reach. Gravel sized sediments were noted in the reach behind log jams and boulder eddies.
	LWM	Pieces per Mile at Bankfull	Unacceptable M+L pieces/mi = 7.5 Does not meet minimum criteria of 32 M+L pieces/mile, and no/limited availability of large wood for future recruitment.	At Risk M+L pieces/mi = 67 Meets minimum criteria of 32 M+L pieces/mile, with limited availability of large wood for future recruitment.	Adequate M+L pieces/mi = 50 Meets minimum criteria of 32 M+L pieces/mile, with moderately acceptable availability of large wood for future recruitment.	Adequate M+L pieces/mi = 74 Meets minimum criteria of 32 M+L pieces/mile, with moderately acceptable availability of large wood for future recruitment.	Adequate M+L pieces/mi = 53 Meets minimum criteria of 32 M+L pieces/mile, with moderately acceptable availability of large wood for future recruitment.
	Pools	Pool Frequency and Quality; presence of large pools.	Unacceptable Total Pools = 24 Pools/mi = 17.9 Pools > 3 ft = 1 (4%) Avg residual pool depth: 1.6 ft Does not meet either wetted width or bankfull width pool frequency criteria (39 and 47 pools/mi, respectively). Does not meet pool quality indicators for depth or cover.	Unacceptable Total Pools = 21 Pools/mi = 21.6 Pools > 3 ft = 0 (0%) Avg residual pool depth: 1.7 ft Does not meet either wetted width or bankfull width pool frequency criteria (23 and 47 pools/mi, respectively). Does not meet pool quality indicators for depth. Pools associated with LW jams had adequate cover from large wood.	Unacceptable Total Pools = 16 Pools/mi = 16.7 Pools > 3 ft = 0 (0%) Avg residual pool depth: 1.7 ft Does not meet either wetted width or bankfull width pool frequency criteria (23 and 47 pools/mi, respectively). Does not meet pool quality indicators for depth. Pools associated with LW jams had adequate cover from large wood.	At Risk Total Pools = 18 Pools/mi = 19 Pools > 3 ft = 2 (11%) Avg residual pool depth: 1.9 ft Does not meet either wetted width or bankfull width pool frequency criteria (39 and 47 pools/mi, respectively). Does not meet pool quality indicators for depth. Pools associated with LW jams had adequate cover from large wood.	At Risk Total Pools = 1 Pools/mi = 34 Pools > 3 ft = 2 (18%) Avg residual pool depth: 1.9 ft Does not meet either wetted width or bankfull width pool frequency criteria (39 and 47 pools/mi, respectively). Does not meet pool quality indicators for depth. Pools associated with LW jams had adequate cover from large wood.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
	Off-Channel Habitat and Refugia	Connectivity with Main Channel	Unacceptable	Adequate	At Risk	Adequate	At Risk
			Total SC = 0 Lacking off-channel habitats that are connected at a higher range of flows. Floodplains are disconnected by human structures / incision.	Total SC = 7 Fast water = 0 Slow water = 7 Cover = moderate Off-channel habitats are connected at a range of flows that provide refugia. Well-vegetated floodplains are connected at 1-5 year.	Total SC = 3 Fast water = 0 Slow water = 3 Cover = moderate Some off-channel habitats are present and connected at a range of flows that provide refugia. Well-vegetated floodplains are connected at 1 – 5 year.	Total SC = 6 Fast water = 3 Slow water = 3 Cover = moderate Many of the off-channel habitat units are short, but are connected at a range of flows. Well-vegetated floodplains are connected at 1 – 5 year.	Total SC = 0 Lacking off-channel habitats that are connected at a higher range of flows. However, steep channel gradient, plus the presence of large boulders in the channel provide some refugia, make this only At Risk. Well-vegetated floodplains are connected at 1 – 5 year
Riparian Vegetation	Condition	Structure	Unacceptable	At Risk	Adequate	Adequate	Adequate
			The riparian canopy overstory composition within the 100-foot riparian buffer was recorded as 44% small tree, 33% sapling/pole, and 22% shrubs/seedlings. Human disturbance in this reach has reduced the width of the riparian buffer and impacted stand age and structural complexity in many areas of this reach.	The riparian canopy overstory composition within the 100-foot riparian buffer was recorded as 86% small tree and 14% sapling/pole. Human disturbance in this reach has impacted stand age and structural complexity, as historically more patches of mature trees would have been present.	The riparian canopy overstory composition within the 100-foot riparian buffer was recorded as 100% small tree. Because there is no history of human disturbance indicating this is the natural condition of the riparian buffer and outside of the riparian buffer, large and mature patches of trees were noted, this reach is given an acceptable rating.	The riparian canopy overstory composition within the 100-foot riparian buffer was recorded as 80% small tree and 20% sapling/pole. Because there is no history of human disturbance indicating this is the natural condition of the riparian buffer and outside of the riparian buffer, large and mature patches of trees were noted, this reach is given an acceptable rating.	The riparian canopy overstory composition within the 100-foot riparian buffer was recorded as 100% small tree. Because there is no history of human disturbance indicating this is the natural condition of the riparian buffer and outside of the riparian buffer, large and mature patches of trees were noted, this reach is given an acceptable rating.
		Disturbance (Human)	At Risk	Adequate	Adequate	Adequate	At Risk
			3.9% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 11.0 miles/miles2 road density in the 200-foot riparian buffer zone.	0.6% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 1.6 miles/miles2 road density in the 200-foot riparian buffer zone.	No disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and no roads in the 200-foot riparian buffer zone.	0.5% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 2.3 miles/miles2 road density in the 200-foot riparian buffer zone.	2.4% disturbance in the 200-foot buffer zone (e.g. residential, roads, etc.) and 8.8 miles/miles2 road density in the 200-foot riparian buffer zone.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Riparian Vegetation		Canopy Cover	Unacceptable	At Risk	Adequate	Adequate	Adequate
			Estimate >50% canopy closure from trees and shrubs within one site potential tree height distance (100 ft riparian buffer). Residential and/or agricultural clearing throughout the reach, in some cases up to the top of the river bank, and the number of roads adjacent or crossing the channel results in minimal thermal shading to the river. Determined using recent aerial photography and based on the extent of canopy closure within riparian areas, not percentage of stream that is covered.	Estimate 50-80% canopy closure from trees and shrubs within one site potential tree height distance (100 ft riparian buffer). Some residential and/or agricultural clearing throughout the reach results in moderate thermal shading to the river. Determined using recent aerial photography and based on the extent of canopy closure within riparian areas, not percentage of stream that is covered.	Estimate >80% canopy closure from trees and shrubs within one site potential tree height distance (100 ft riparian buffer) providing thermal shading to the river. Determined using recent aerial photography and based on the extent of canopy closure within riparian areas, not percentage of stream that is covered.	Estimate >80% canopy closure from trees and shrubs within one site potential tree height distance (100 ft riparian buffer) providing thermal shading to the river. Determined using recent aerial photography and based on the extent of canopy closure within riparian areas, not percentage of stream that is covered.	Estimate >80% canopy closure from trees and shrubs within one site potential tree height distance (100 ft riparian buffer) providing thermal shading to the river. Determined using recent aerial photography and based on the extent of canopy closure within riparian areas, not percentage of stream that is covered.
Channel	Dynamics	Floodplain Connectivity	Unacceptable	Adequate	Adequate	Adequate	Adequate
			The channel is entrenched in this reach. Channel straightening, bridges, and levees along a large portion of the channel exaggerate floodplain disconnection.	Where valley width allows, vegetated floodplains exist below historical floodplain terraces. Connectivity to the existing modern floodplains is adequate.	Where valley width allows, vegetated floodplains exist below historical floodplain terraces. Connectivity to the existing modern floodplains is adequate.	Where valley width allows, vegetated floodplains exist below historical floodplain terraces. Connectivity to the existing modern floodplains is adequate.	Where valley width allows, vegetated floodplains exist. Connectivity to the existing floodplains is adequate.
		Bank Stability/ Channel Migration	Unacceptable	Adequate	Adequate	Adequate	Adequate
			Due to human-imposed channel confinement, no channel migration is occurring in the upper portion and only marginal floodplain (relative to the historically available alluvial fan) occur in the lower portion.	Where valley-width and channel complexity allow, lateral processes do periodically occur.	Where valley-width and channel complexity allow, lateral processes do occur.	Where valley-width and channel complexity allow, lateral processes do occur.	Where valley-width and channel complexity allow, lateral processes periodically occur.

Pathway	General Indicators	Specific Indicators	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Channel	Dynamics	Vertical Channel Stability	Unacceptable	Adequate	Adequate	Adequate	Adequate
			The channel is entrenchment due to human impacts. Continued incision is possible but not expected to be rapid because of the coarse bed load.	Periodic inputs from hillslopes and ephemeral tributaries provide irregular sediment pulses that influence channel processes. Bedload suggests that temporary localized incision may occur in association with obstructions (large boulder or large wood jams). Scour pools are maintained at bedrock outcrops.	Periodic inputs from hillslopes and tributaries provide irregular sediment pulses that influence channel processes. Bedload size and the presence of large boulders suggest that related periods of aggradation are naturally followed by stream gradient re-adjustments. Localized incision may occur in association with obstructions (large boulder or large wood jams). Scour pools are maintained at bedrock outcrops.	Periodic inputs from hillslopes and tributaries provide irregular sediment pulses that influence channel processes. Bedload size and the presence of large boulders suggest that related periods of aggradation are naturally followed by stream gradient re-adjustments. Localized incision may occur in association with obstructions (large boulder or large wood jams). Scour pools are maintained at bedrock outcrops.	Periodic inputs from hillslopes and tributaries provide irregular sediment pulses that influence channel processes. Bedload size and the presence of large boulders suggest that related periods of aggradation are naturally followed by stream gradient re-adjustments. Localized incision may occur in association with obstructions (large boulder or large wood jams). Scour pools are maintained at bedrock outcrops.

4 References & Sources

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Appendix C

Project Opportunities and Prioritization

Wolf Creek Reach Assessment (RM 0 – 4.53)

December 2020

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1 Project Opportunity Areas Map

Wolf Creek (RM 0 - 4.53)

Project Opportunity Areas
Reaches 1 - 5

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

0 0.25 0.5 1 Miles

2 Project-Based Restoration Recommendations

This table describes project opportunities by project area within the Wolf Creek Assessment area. Concept maps of the project opportunities are included below the table.

<table>
<tr><th>Reach</th><th>River Miles</th><th>Project Area Name</th><th>Project Description</th><th>Considerations</th></tr>
<tr><td>1</td><td>0 – 0.3</td><td>Lobos</td><td>
Narrative:
The Lobos area includes a combination of in-channel and floodplain treatments as well as infrastructure upgrades. All of the in-channel mainstem treatments can be installed separately and provide improved habitat and complexity. The extent of the floodplain treatments will be dependent on infrastructure upgrades.

Installation of large wood (LW) jams and related scour hole development is recommended to greatly improve the quality and quantity of aquatic habitat and increase geomorphic complexity in Reach 1, where minimal large wood and limited complexity currently exists. Installation of LW jams at the mouth will provide habitat complexity for both lower Wolf Creek and the Methow River. Lateral channel migration and inset floodplain development that increases activation of local sediment supply and future riparian/floodplain wood recruitment within a designated area are encouraged via LW placement in the Lobos project area. Wolf Creek Rd bridge crossing is the existing infrastructure and private property on floodplain. Increasing the span and upgrading footings and bank treatment of the Wolf Creek Road bridge (RM 0.3) will decrease local channel confinement and allow for increased channel, floodplain, and delta processes. Floodplain treatments include excavating an inset floodplain, to the width allowable by infrastructure, that supports riparian vegetation. Riparian restoration is focused on planting appropriate riparian trees and shrubs to create wider vegetated riparian buffer and to remediate areas disturbed by inset floodplain development and bridge upgrade actions. There is potential for the excavated materials to be used in the mainstem to augment spawning gravels on bars but this will need to be modeled and designed in detail. Temporary fencing that excludes cattle and other grazing undulates is strongly recommended to promote establishment of and protect riparian vegetation. These treatments are intended to reduce channel entrenchment and create an active functioning riparian floodplain while improving the quantity and quality of available mainstem habitat. Restoration treatments here will also improve and increase available habitat for fish utilizing the Methow River.

Project Elements:
Riparian Restoration
• Plant native vegetation to improve riparian vegetation buffer.
• Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions, including development of inset floodplain, LW installations, and bridge expansion.
• Utilize exclusion fencing to protect riparian and floodplain plantings from grazing ungulates until established.
Upgrade or Remove Anthropogenic Features
• Upgrade the existing Wolf Creek Road bridge (RM 0.3) by increasing the bridge span and footings to accommodate floodplain development as well as channel and delta processes.
Enhance Aquatic Habitat
• Install bank buried LW jam (≥18 root wad logs) at the mouth the Wolf Creek (RM 0) to provide and maintain habitat at the confluence for fish using both the Methow River and Wolf Creek.
• Install bank-buried LW jams (>6 root wad logs) in designated areas to enhance aquatic habitat conditions (cover, pool scour, sediment accumulation).
Increase Complexity
• Floodplain excavation: excavate sections of the abandoned historical alluvial fan to create inset connected floodplain benches for the entrenched channel that is capable of supporting desired riparian vegetation. Plant inset surface with appropriate native riparian vegetation.
• Installation of bank buried LW apex jams (≥10 root wad logs) at designated areas where available floodplain exists to promote and maintain split flow potential, channel scour, and sediment retention.
• Installation of bank buried LW jams (≥6 root wad logs) along a high-flow side channel (RM 0.16 – 0.23, river left) to promote and maintain lateral and split flow process.
Note: LW log jams scour pools will be dug during installation but jams and pools will be designed to maintain pool scour, promote lateral processes, and increase gravel retention downstream of jams. This will notably increase channel complexity and improve aquatic habitat.
</td><td>
Accessible, but permission will need to be granted by property owners. Land-owner communication is highly recommended.

LW installations will need to be bank buried or otherwise ballasted for infrastructure protection.

Wolf Creek Road bridge crossing upgrade will require collaboration with WSDOT and/or county.

Modelling and analysis will be necessary to predict potential changes to flood event inundation patterns.

In-water work and bridge upgrade will require permit acquisition.

An inset floodplain the width of the new bridge will provide floodplain and lateral process function– will likely require bank protection near bridge to protect infrastructure and maintain flow path under bridge.

All treatments in this project area will require detailed analysis, modeling, and design to address existing infrastructure and homes.
</td></tr>
</table>

Reach	River Miles	Project Name	Project Description	Considerations
1	0.39 and 0.86	Wolf Den	**Narrative:** The Wolf Den Project Area includes in-channel mainstem large wood treatments and recommendations for improving a private road bridge crossing. These treatments can be installed separately. Installation of large wood (LW) jams and related scour hole development and downstream sediment retention is recommended to improve the quality and quantity of aquatic habitat and increase geomorphic complexity in Reach 1, where minimal large wood and limited complexity currently exists. **Project Elements:** ***Upgrade or Remove Anthropogenic Features*** • Upgrade the existing private bridge crossing (RM 0.6) by increasing freeboard and bridge span as well as footings. If the bridge can be removed, consider that option. ***Enhance Aquatic Habitat*** • Install bank buried LW jam (≥6 root wad logs) in the mainstem in designated areas to improve existing habitat or create and maintain additional aquatic habitat (cover, pool scour, sediment accumulation. ***Increase Complexity*** • Installation of bank buried LW apex jams (≥10 root wad logs) at RM 0.74 river right where available floodplain exists to promote floodplain connectivity and quality pool habitat. • Installation of bank buried LW jams (≥6 root wad logs) along existing high-flow side channel (RM 0.75-0.78, river left) to promote and maintain lateral and split flow process. • Install mid-channel LW jam (≥6 root wad logs) at RM 0.78 to support island and split flow development. ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions *Note: LW log jams will most likely be designed with scour pools that will be dug during installation but jams and pools will be designed to maintain pool scour and/or increase gravel retention downstream of jams. This will notably increase channel complexity and improve aquatic habitat.*	Accessible, but permission will need to be granted by property owners. Early land-owner communication is highly recommended. In-water work will require permit acquisition. Proximity of homes to the channel and flood control dependence on the existing levees and ditches limit treatment recommendations. **All treatments in this project area will require detailed analysis, modeling, and design to address existing infrastructure and homes.**
1	Near RM 1.0	Ponds	**Narrative:** The Ponds Project Area is focused on upgrading connectivity and enhancing habitat of the existing ponds that are currently connected to the mainstem channel via a formal irrigation withdrawal gate, ditches, and a culvert. Treatment recommendations include evaluating the probable upstream fish barrier that the culvert and withdrawal gate pose to native fish species of concern. If necessary, upgrade the culvert to be passable or, remove the culvert and construct a passable connector channel. Another option, if landowners are willing, is to convert the existing ponds (probable warming and predation area) and ditches into a constructed side channel from the inlet to the outlet with quality habitat components. Conversion of the culvert and/or ponds to a channel would require installation of a crossing bridge to access existing home. Development of an off-channel refugia with buried LW jam for cover and maintenance of alcove scour home at the outlet of the existing ditch could provide much needed off-channel refugia in Reach 1, where none currently exist. The area of the Ponds is the most confined section of the reach with the highest stream energy. Providing off-channel habitat here would be beneficial. **Project Elements:** ***Upgrade or Remove Anthropogenic Features*** • Evaluate and upgrade existing pond-connector culvert. Or, replace culvert with constructed channel. • Culvert upgrade or conversion to channel will require installation of bridge to access existing homes–assuming structures need to remain in existing locations. ***Enhance Aquatic Habitat*** • Install bank buried LW jam and scour hole and potentially an alcove at mouth of existing ditch to improve off-channel refugia. • Convert ditch(s) and/or ponds into constructed side channel with quality fish habitat. ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions	Assume home and existing structures have to remain in place. Accessible, but construction will need to be coordinated and approved with land owners. In-water work will require permit acquisition. **All treatments in this project area will require detailed analysis, modeling, and design to address existing infrastructure and homes.**

Reach	River Miles	Project Name	Project Description	Considerations
1	1.24 – 1.34	Wildflower	**Narrative:** The Wildflower Project Area includes adding bank buried large wood (LW) jams in discrete locations, the removal of an irrigation out-take and associated cement wall, and the creation of a small off-channel habitat alcove feature with LW at the existing out-take location. The mainstem LW treatments can be installed separate from the removal of the irrigation out-take. The off-channel/side-margin refugia with LW would likely need to be done in conjunction with the removal of the out-take. Installation of large wood (LW) jams and related scour hole development and downstream sediment retention is recommended to improve the quality and quantity of aquatic habitat and increase geomorphic complexity, where no large wood and limited complexity currently exists. Removal of a cement wall and irrigation out-take will provide space along the channel's edge (river left) to install a LW jam and scour hole that provides off-channel or side margin refugia. The existing ditch will likely need to be filled to avoid flood-water routing to the floodplain. **Project Elements:** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. ***Remove Anthropogenic Features*** • Remove cement wall and associated irrigation out-take on river left at RM 1.25. Fill associated ditch to avoid unwanted flood-water routing to the historical floodplain (home protection). ***Enhance Aquatic Habitat*** • Install bank buried LW jam (≥6 root wad logs) in the mainstem at RM 1.24 on river right, and RM 1.26 on river left to improve and maintain aquatic habitat (cover, pool scour, sediment accumulation. ***Increase Complexity*** • Install bank buried apex LW jam (≥10 root wad logs) on river left at RM 1.34 where available floodplain exists to increase potential for floodplain connectivity and maintain quality scour pool habitat • Create off-channel or side margin refugia at RM 1.25 after removing existing irrigation out-take. Install bank buried LW jam (≥6 root wad logs) and scour hole to provide and maintain habitat at the site. *Note: LW log jam scour pools will be dug during installation but jams and pools will be designed to maintain pool scour, promote lateral processes, and increase gravel retention downstream of jams. This will notably increase channel complexity and improve aquatic habitat.*	Removal of the cement wall and out-take entrance will need to be approved through water rights agency and potentially the Wolf Creek property owner association (WCPOA) All actions accessible from private land or Wildflower Road – though banks are steep and high. In-water permits will be required. **All treatments in this project area will require detailed analysis, modeling, and design to address existing infrastructure and homes downstream.**

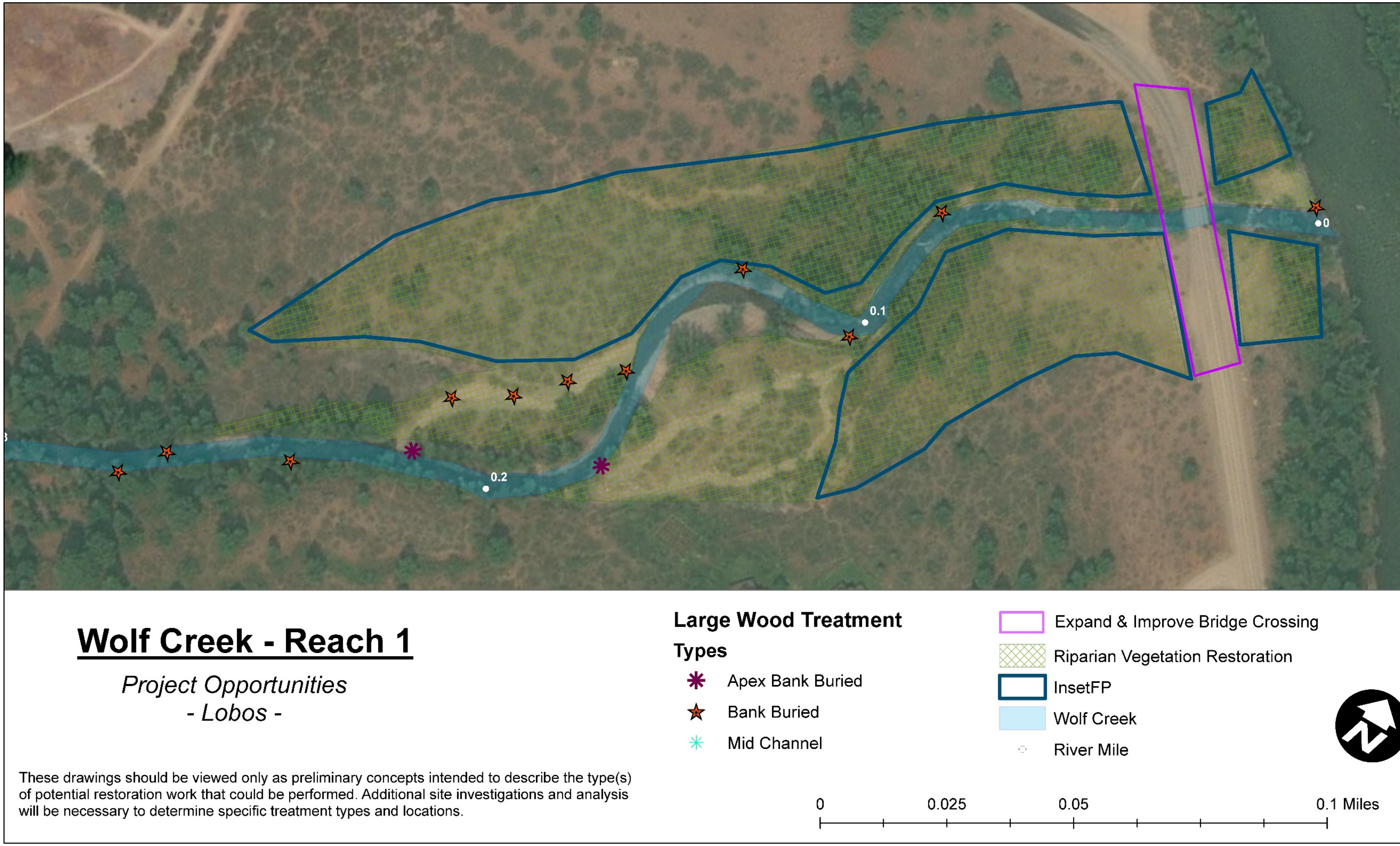
Reach	River Miles	Project Name	Project Description	Considerations
2	1.35 – 1.68	R2a HeliLW	**Narrative:** The R2a HeliLW Project Area includes installation of large wood by helicopter and evaluation of potential upgrade to the irrigation withdrawal at RM 1.44. All treatment locations and actions are complimentary to each other but would provide habitat and function benefits if installed independently. Helicopter installation of large wood (LW) jams is recommended at locations where available floodplain, appropriate channel form, and/or large boulders for natural ballasting exist. Treatment is expected to instigate some side channel and floodplain activation as well as develop and maintain scour pools and support localized sediment retention. Evaluation of the Wolf Creek Property Owner Association surface water withdrawal is recommended (quantity and seasonality) to determine if the domestic water needs can be met with off-channel sources such as well(s). **Project Elements:** ***Upgrade or Remove Anthropogenic Features*** • If evaluation supports it, remove the surface water withdrawal gate, cement wall, and ditch at RM 1.44 on river left. ***Enhance Aquatic Habitat*** • If the irrigation out-take is removed, place LW (3-10 logs) with a helicopter in the old out-take location. • Helicopter placement of LW (3-10 logs) at RM 1.35 to enhance existing split-flow confluence habitat and pool development ***Increase Complexity*** • Helicopter placement of LW accumulations (10-30 logs) in the mainstem channel at RM 1.46, 1.55, 1.63, 1.64, 1.66, and 1.67 (add to existing LW jam) to increase floodplain connectivity, potentially instigate side-channel activation, increase and maintain quality scour pool habitat, and provide habitat cover. *Note: Placed LW jams are expected to adjust with high flow events and collect additional debris. The installation locations will be designed but placement will be guided in the field. LW will extend into and across the channel and floodplain (between standing large trees) - notably increasing channel complexity and thus improving aquatic habitat.*	The project area is bordered by private property. Recommend coordination with land owners. Accessible by helicopter, no sufficient road access. In-water permits will be required. LW source to be determined. Helicopter and LW staging areas to be determined.

Reach	River Miles	Project Name	Project Description	Considerations
2	1.75 and 1.95	R2b HeliLW	**Narrative:** The R2b HeliLW Project Area includes installation of large wood by helicopter All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently. Helicopter installation of large wood (LW) jam accumulations and mainstem channel LW loading is recommended at locations where available floodplain, appropriate channel form, and/or large boulders for natural ballasting exist. LW pieces in loaded areas will be organized by high flow events and, through that process, eventually create accumulation jams and dynamic channel complexity. Treatments are expected to instigate some side channel and floodplain activation. **Project Elements:** ***Enhance Aquatic Habitat*** • Helicopter placement of LW accumulation jam (3-10 logs) at RM 1.73 (existing small LW accumulation) and RM 1.99 (existing pool) to enhance existing aquatic habitat and create/maintain covered high-quality pool habitat. ***Increase Complexity*** • Helicopter placement of LW accumulation jams (10-30 logs) in the mainstem channel at RM 1.79, 1.80, 1.87, 1.9, and 1.96 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of LW accumulation jams (30+ logs) in the mainstem channel at RM 2.12, 2.2, 2.3, 2.5, and 2.9 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of mainstem channel loading LW between RM 1.73-1.75, RM 1.8-1.87, RM 1.9-1.95, and RM 2.3-2.5. LW loading occurs upstream of jams or in areas where channel form or features will support flow-organized accumulations and accommodate channel response. *Note: Placed LW jams and loading logs are expected to adjust with high flow events and collect additional debris. The installation locations will be designed but placement will be guided in the field. LW will extend into and across the channel and floodplain (between standing large trees). These treatments will notably increase channel complexity and improve aquatic habitat*.	The project area is bordered by private property to RM 1.99, otherwise within the Okanogan National Forest. Privately owned section of floodplain with access road and utilities on river left at RM 1.99 – will need to be considered in design. Coordination with land owners and USFS will be necessary. Accessible by helicopter. Only private road access at RM 1.99, river right. In-water permits will be required. LW source to be determined. Investigate potential to source LW locally from Okanogan National Forest. Helicopter and LW staging areas to be determined.

Reach	River Miles	Project Name	Project Description	Considerations
3	2.64 – 3.26	R3 HeliLW	**Narrative:** The R3 HeliLW Project Area includes installation of large wood by helicopter. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently. Helicopter installation of large wood (LW) jam accumulations and mainstem channel LW loading is recommended at locations where available floodplain, appropriate channel form, and/or large boulders for natural ballasting exist. LW pieces in loaded areas will be organized by high flow events and, through that process, eventually create accumulation jams and dynamic channel complexity. Treatments are expected to instigate some side channel and floodplain activation. Recommend formal evaluation and assessment of impact to habitat and water quality to Wolf Creek and lower Little Wolf Creek as a result of seasonal Wolf Creek irrigation ditch withdrawals. Ideally, no dry-season withdrawals would occur and the tributary would remain connected to the mainstem perennially, providing off-channel habitat and surface water to the mainstem channel. **Project Elements:** ***Enhance Aquatic Habitat*** • Helicopter placement of LW accumulation jam (3-10 logs) at RM 2.5 (existing LW jam) to enhance existing aquatic habitat and create/maintain covered high-quality pool habitat. ***Increase Complexity*** • Helicopter placement of LW accumulation jams (10-30 logs) in the mainstem channel at RM 2.64, 2.69, 2.75, 2.77, 2.79, 2.82, 2.83, 2.85, 2.96, and 3.04 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of LW accumulation jams (30+ logs) in the mainstem channel at RM 2.46, 2.9, 3.01, 3.11, 3.16, 3.22, and 3.26 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of mainstem channel loading of LW between RM 2.37-2.46, RM 2.65-2.75, RM 2.9-2.95, RM 3-3.11, RM 3.07-3.08, RM 3.11-3.12, RM 3.15-3.16, RM 3.22-3.24, and RM 3.25-3.26. LW loading occurs in conjunction with LW jams or in areas where channel form or features will support flow-organized accumulations and accommodate channel response. *Note: Placed LW jams and loading logs are expected to adjust with high flow events and collect additional debris. The installation locations will be designed but placement will be guided in the field. LW will extend into and across the channel and floodplain (between standing large trees). These treatments will notably increase channel complexity and improve aquatic habitat.*	The project is within the Okanogan National Forest. Collaboration with USFS will be necessary. Accessible by helicopter. In-water permits will be required. LW source to be determined. Investigate potential to source locally from Okanogan National Forest. Helicopter and LW staging areas to be determined. Formal evaluation should include registered irrigation withdrawal rights information.
4	3.35 – 4.19	R4 HeliLW	**Narrative:** The R4 HeliLW Project Area includes installation of large wood by helicopter. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently.Helicopter installation of large wood (LW) jam accumulations and mainstem channel LW loading is recommended at locations where available floodplain, appropriate channel form, and/or large boulders for natural ballasting exist. LW pieces in loaded areas will be organized by high flow events and, through that process, eventually create accumulation jams and dynamic channel complexity. Treatments are expected to instigate some side channel and floodplain activation. **Project Elements:** ***Enhance Aquatic Habitat*** • Helicopter placement of LW accumulation jam (3-10 logs) at RM 3.41, 3.98, and 4.05 (at existing pools or small LW accumulations) to enhance existing aquatic habitat and create/maintain covered high-quality pool habitat. ***Increase Complexity*** • Helicopter place LW accumulation jams (10-30 logs) in the mainstem channel at RM 3.64, 3.75, 3.95, 4.07, 4.09, and 4.15 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter place LW accumulation jams (30+ logs) in the mainstem channel at RM 3.35, 3.54, 3.70, 3.79, 3.86, 4.2, and 4.18 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of mainstem channel loading of LW between RM 3.35-3.36, RM 3.54-3.55, RM 3.72-3.75, and RM 3.79-3.8. LW loading occurs in conjunction with LW jams or in areas where channel form or features will support flow-organized accumulations and accommodate channel response. *Note: Placed LW jams and loading logs are expected to adjust with high flow events and collect additional debris. The installation locations will be designed but placement will be guided in the field. LW will extend into and across the channel and floodplain (between standing large trees). These treatments will notably increase channel complexity and improve aquatic habitat.*	The project is within the Okanogan National Forest. Collaboration with USFS will be necessary. Accessible by helicopter. In-water permits will be required. LW source to be determined. Investigate potential to source locally from Okanogan National Forest. Helicopter and LW staging areas to be determined.

Reach	River Miles	Project Name	Project Description	Considerations
5	3.08-3.73	R5 HeliLW	**Narrative:** The R5 HeliLW Project Area includes installation of large wood by helicopter. All treatment locations are complimentary to each other but would provide habitat and function benefits if installed independently. Helicopter installation of large wood (LW) jam accumulations and mainstem channel LW loading is recommended at locations where available floodplain, appropriate channel form, and/or large boulders for natural ballasting exist. LW pieces in loaded areas will be organized by high flow events and, through that process, eventually create accumulation jams and dynamic channel complexity. Treatments are expected to instigate some side channel and floodplain activation. **Project Elements:** ***Enhance Aquatic Habitat*** • Helicopter placement of LW accumulation jam (3-10 logs) at RM 4.42 (LW accumulation) to enhance existing aquatic habitat and create/maintain covered high-quality pool habitat. ***Increase Complexity*** • Helicopter placement of LW accumulation jams (10-30 logs) in the mainstem channel at RM 4.26, 4.35, 4.36, 4.37, and 4.46 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of LW accumulation jams (30+ logs) in the mainstem channel at RM 4.27, 4.34, 4.47, and 4.48 to increase floodplain connectivity, create/maintain covered high-quality pool habitat and promote sediment local sediment retention, and potentially instigate side-channel activation. • Helicopter placement of mainstem channel loading of LW between RM 4.27-4.28, RM 4.32-4.34, RM 4.35-4.355, RM 4.36-4.363, RM 4.37-4.39, and RM 4.47-4.48. LW loading occurs in conjunction with LW jams or in areas where channel form or features will support flow-organized accumulations and accommodate channel response. *Note: Placed LW jams and loading logs are expected to adjust with high flow events and collect additional debris. The installation locations will be designed but placement will be guided in the field. LW will extend into and across the channel and floodplain (between standing large trees). These treatments will notably increase channel complexity and improve aquatic habitat.*	The project is within the Okanogan National Forest. Collaboration with USFS will be necessary. Accessible by helicopter. In-water permits will be required. LW source to be determined. Investigate potential to source locally from Okanogan National Forest. Helicopter and LW staging areas to be determined.
5	4.53	Wolf Weir	**Narrative:** The Wolf Weir Project Area includes upgrading the existing grade-control weirs associated with the irrigation withdrawal for the Wolf Creek Ditch. Treatments would improve fish passage and increase longevity of the structure. The existing weirs are a set of vertical steel plates with center notches that direct flow down the middle of the channel. Boulders and cobbles reinforce and occupy the weir steps. The upgrade would likely entail constructing a set of boulder steps with pools that are connected via off-set flow paths and boulder drops conducive to adult and juvenile migration requirements. Each grade step would include a slightly concave area to direct low-flow discharge through a flow-path that remains passable and slightly off-set from the downstream step to dissipate flow energy at higher flows and maintain connectivity and passage at low flows. The boulder weirs would likely have buried boulder wings that extend across the floor of the valley to sustain grade and function over the long-term, including during floodplain inundating events. The floodplain buried portion of the wings would be revegetated with native vegetation. **Project Elements:** ***Riparian Restoration*** • Plant and maintain appropriate riparian and floodplain vegetation in all areas disturbed as a result of restoration actions. ***Upgrade Anthropogenic Features*** • Upgrade fish passage and long-term structure stability at the existing grade-control weir associated with the irrigation withdrawal for the Wolf Creek Ditch at RM 4.53.	Existing access road is maintained to the site. In-water permits will be required. Collaboration with USFS and water user will be necessary. Structures needs to be designed to facilitate protection of existing infrastructure.

3 Project Opportunity Reach Maps



Wolf Creek - Reach 1

Project Opportunities
- Wolf Den -

Large Wood Treatment

Types

- Apex Bank Buried
- Bank Buried
- Mid Channel

Wolf Creek
River Mile

0 0.05 0.1 0.2 Miles

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Wolf Creek - Reach 1

Project Opportunities
- Ponds -

Large Wood Treatment

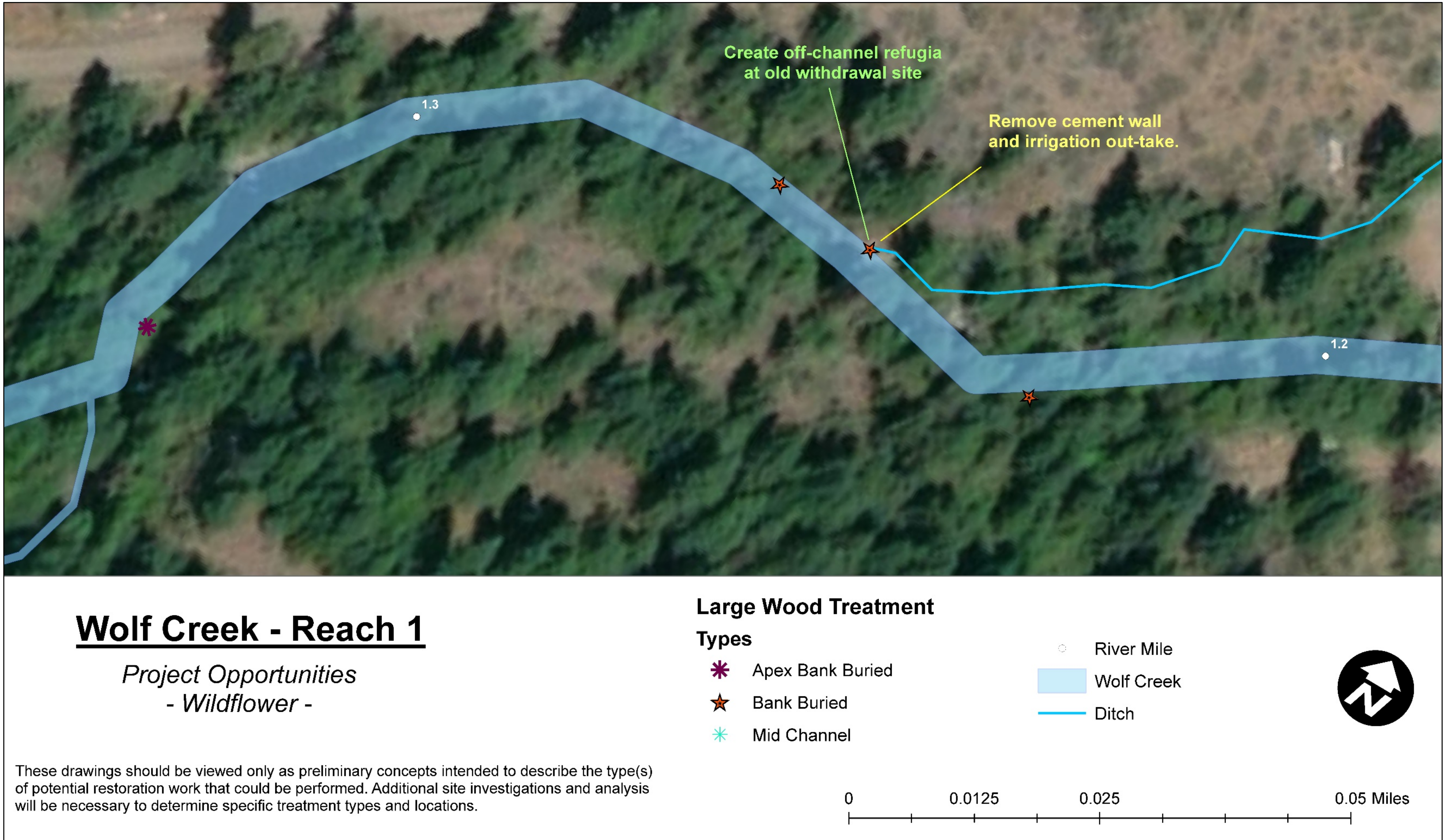
Types

- Apex Bank Buried
- Bank Buried
- Mid Channel

- improve cluvert or convert to stream
- River Mile
- Wolf Creek
- Ditch

0 0.0125 0.025 0.05 Miles

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.



Wolf Creek - Reach 1

Project Opportunities
- Wildflower -

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Wolf Creek - Reach 2

Project Opportunities
- R2a Heli LW -

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Heli LW Loading

Heli LWM Treatment size

- 30+ LW pieces
- 10-30 LW pieces
- 3-10 LW pieces

Wolf Creek
River Mile

0 0.02 0.04 0.08 Miles

Wolf Creek Reach 2

Project Opportunities
- R2b Heli LW -

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Heli LW Loading

Heli LWM Treatment size

- 30+ LW pieces
- 10-30 LW pieces
- 3-10 LW pieces

Wolf Creek

River Mile

0 | 0.0325 | 0.065 | 0.13 Miles

Wolf Creek - Reach 3

Project Opportunities
- R3 Heli LW -

Heli LW Loading

Heli LWM Treatment size

- 30+ LW pieces
- 10-30 LW pieces
- 3-10 LW pieces

Wolf Creek
River Mile

0 0.05 0.1 0.2 Miles

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Wolf Creek - Reach 4

Project Opportunities
- R4 Heli LW -

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Heli LW Loading

Heli LWM Treatment size

- 30+ LW pieces
- 10-30 LW pieces
- 3-10 LW pieces

Wolf Creek

River Mile

0 0.05 0.1 0.2 Miles

Wolf Creek - Reach 5

Project Opportunities
- R5 Heli LW & Wolf Weirs -

These drawings should be viewed only as preliminary concepts intended to describe the type(s) of potential restoration work that could be performed. Additional site investigations and analysis will be necessary to determine specific treatment types and locations.

Heli LW Loading

Heli LWM Treatment size

- 30+ LW pieces
- 10-30 LW pieces
- 3-10 LW pieces

Wolf Creek

River Mile

0 0.02 0.04 0.08 Miles

N

4 Project Ranking Summary

Project Area						Benefit Score									Cost Score		Cost Benefit	Feasibility Designation	
						Restoration Gap Analysis				Existing and Potential Fish Use		Root Causes							
Tiers	Project Name	Reach	Down-stream RM	Up-stream RM	Total Length (mi)	Existing Condition (1-7)	Achievable Target (1-7)	Final Gap Score (Target - Existing) (0-6)	Rationale/ assumption	Score (1-3)	Rationale/ assumption	Score (1-3)	Rationale/ assumption	Total Benefit Score	Cost Score (1-4)	Rationale/ assumption	Benefit-to-Cost Score	Feasibility Designation	Rationale/ assumption
1	R2b HeliLW	2	1.73	2.29	0.56	4	7	3	Moderate function. High potential to improve channel complexity and quantity of available quality habitat.	3	Available substrate not being retained. Improve channel complexty and available quality habitat.Potential off-channel habitat activation on available floodplain.	2	Increases LWM quantities in the channel and support floodplain old growth forest development over time. Does not eliminate history of fire supression.	8	2	Helicopter installation of LWM. Distance to staging area will influence project cost.	4.0	High	Minimal downstream infrastructure of concern. Easy access. Assumes minimal land-owner restrictions. Assumes heli-pad and staging area is within proximity of project area.
	R2a HeliLW	2	1.35	1.68	0.33	4	6.5	2.5	Moderate existing function. High potential to increase quantity and quality of habitat and geomorphic complexity in the mainstem.	3	Some observed available salmonid habitat; available sediment but not retained locally.Available floodplain for increasing quantity and quality of off-channel habitat.	2	Improves habitat and geomorphic function. Time necessary for riparian forest to mature to old-growth. Potential WCPOA irrigation withdrawal removal and installation of off-channel well.	7.5	2	Helicopter installation of LWM. If irrigation withdrawal is evaluated to pose risk(s) to aquatics, decommissioning of withdrawal and installation of off-channel well.	3.8	High	WCPOA willingness to improve or change water source.Landowner willingness needed. Assumes heli-pad and staging area is within proximity of project area.
	R5 HeliLW	5	4.25	4.48	0.23	5	7	2	Moderate-high existing function. High potential to increase quantity and quality of habitatt and geomorphic compleixty, including off-channel development and floodplain connectivity.	2	Available substrate not being retained locally. Improve channel complexity and available quality habitat. High gradient (better for bull trout than salmon). Potential off-channel habitat activation.	3	LWM installation improves habitat and geomorphic function. Does not eliminate history of fire suppression.	7	2	Helicopter installation of LWM. Distance to staging area will influence project cost.	3.5	High	No downstream infrastructure of concern. Located on the Okanogan National Forest (USFS). Assumes heli-pad and staging area is within proximity of project area.
	R3 HeliLW	3	2.64	3.26	0.62	5	7	2	Moderate-high existing function. High potential to increase quantity and quality of habitatt and geomorphic compleixty, including off-channel development and floodplain connectivity.	3	Available substrate not being retained locally. Improve channel complexty and available quality habitat.Potential off-channel habitat activation.	3	LWM installation improves habitat and geomorphic function. Does not eliminate history of fire suppression.	8	2.5	Helicopter installation of LWM. Distance to staging area will influence project cost.	3.2	High	No downstream infrastructure of concern. Located on the Okanogan National Forest (USFS). Assumes heli-pad and staging area is within proximity of project area.
	R4 HeliLW	4	3.34	4.19	0.85	5.5	7	1.5	Moderate-high existing function. High potential to increase quantity and quality of habitatt and geomorphic complexity, including off-channel development and floodplain connectivity	3	Available substrate not being retained locally. Improve channel complexty and available quality habitat.Potential off-channel habitat activation.	3	LWM installation improves habitat and geomorphic function. Does not eliminate history of fire suppression.	7.5	2.5	Helicopter installation of LWM. Distance to staging area will influence project cost.	3.0	High	No downstream infrastructure of concern. Located on the Okanogan National Forest (USFS). Assumes heli-pad and staging area is within proximity of project area.
	Lobos	1	0.00	0.30	0.30	2	6	4	Low existing functionn (entrenched, and confined by Wolf Creek Rd bridge). Moderate-high potential assuming bridge crossing can be upgraded and adacent floodplain available for treatment.	3	Chinook and steelhead redds surveyed historically. Available gravels.	2	Increases channel, side channel, and floodplain proceses but does not activate historical fan or raise bed elevations to pre-incision/entrenchment elevation	9	3	Reconstruct Wolf Creek Bridge crossing (temporary access across river requied). Excavate inset floodplain and revegetate. Install large wood structures. Assumes access to site is granted.	3.0	High	WSDOT collaboration in improving/extending bridge crossing. Adjacent landowner willingness. Floodplain not currently formally developed.
2	Wolf Den	1	1.23	1.34	0.11	3	5.5	2.5	Low existing function. High potential to increase localized habitat quantity and quality. Assumes access via home owner's assocation will be granted.	2.5	Available substrate for mainstem spawning if captured by iincreased complexity. Potential to increase connectivity of high-flow side channel on river left. Potential to increase quantity and quality of rearing habitat. Potential to remove or reduce surface water withdrawal.	2	Improves habitat and geomorphic function. Does not eliminate entrechment of Wolf Creek. Evaluate WC irrigation withdrawal guidelines and upgrade or replace with off-channel well.	7	2.5	Installation of designed large wood structures.	2.8	Low	Wolf Creek Property Owner Association approval needed nd current landowner unwilling to allow access or restoration treatment.
	Pond	1	0.99	NA	NA	2	5	3	Potential to increase off-channel fish use and habitat quality in moderately functioning and connected ponds and ditch. Existing pond connector culvert is an upstream migrating fish barrier.	2.5	Reported past use for releasing hatchery fish and assumed seasonal use (YNF).	1	The features are man-made and wetted via a surface water withdrawal on the mainstem. Improves quality of potential off-channel habitat.and fish passage.	6.5	2.5	replace culvert so it is fish passable or remove and build connector channel with bridge crossing. Construct downstream connector ditch with alcove	2.6	Moderate	Right-of-way exists. Landower willingness unknown; permit requirements unknown;
	Wolf Wiers	5	NA	4.53	NA	3	6	3	Moderately functioning grade control with central flow path on notched wiers. Treatment will improve passage at high and low flow condtions.	3	Any fish migrating up or downstream needs to pass through this location.	1.5	Improve passage and longevity of structure. Does not remove irrigation withdrawal or constructed grade control in the channel.	7.5	3	detailed design and analysis required. Likely require imported rock material. Mainstem excavation and construction. Permitting will be required.	2.5	HIgh	existing access road; existing low-flow re-route pathway (irrigation and fish screen return).
3	Wildflower	1	0.39	0.86	0.47	1.5	5	3.5	Low existing function.Confined by levees and private bridge footings. Moderate potential. Assumes access to channel via private lands. Potential to increase flood risk to adjacent property needs to be carefully considered and analyzed.	2	Available substrate for mainstem spawning if captured by iincreased complexity features. Potential for notable increase in quantity and quality of rearing habitat.	1	Enhances local habitat conditions. Does not elimnate channel entrenchement and does not activate historical fan or terrace/floodplain surfaces	6.5	3	Construct large wood structures. Reconstruct private bridge crossing. Assumes access to the site via private property is granted. Detailed analysis and design required due to proximity of homes.	2.2	Low	Current landowner unwilling to partiicipate in restoration actions.

4.1 PROJECT RANKING METHODS (AUGUST 2020)

Step 1: **Benefit Score**: Projects are scored according to 3 benefit categories, which include a "recovery gap" category and 2 additional categories. Scores for each category are summed to obtain the ***Benefit Score***.

Step 2: **Cost Score**: Projects are given a ***Cost Score***, which reflects the overall *relative cost* for the project based on techniques, access, and construction feasibility issues.

Step 3: **Benefit-to-Cost Score**: Total benefit score (sum of all 4 benefit scores) is divided by the cost score to obtain the ***Benefit-to-Cost Score***.

Step 4: **Feasibility Designation:** Projects are given a ***Feasibility Designation*** based on the overall likely feasibility of being able to implement the project within a 10-year timeframe.

Benefit Score

The Benefit Score includes the summation of scores from 3 categories. These include the Recovery Gap score (0-6 points), the Fish Use score (1-3 points), and the Root Causes score (1-3 points). The guidelines for scoring are provided below.

Recovery Gap

Existing Condition Rating (1-7)

1 – Very low ecosystem function and habitat quality. Highly altered systems.
2 – Low ecosystem function and habitat quality.
3 – Low-to-moderate ecosystem function and habitat quality.
4 – Moderate ecosystem function and habitat quality.
5 – Moderate-to-high ecosystem function and habitat quality.
6 – High ecosystem function and habitat quality.
7 – Very high level of natural ecosystem function and habitat quality. Pristine, unaltered systems.

Achievable Condition Rating (1-7)

These ratings use the same categories as above but reflect the future potential recovery trajectory. This is a rating of what can realistically be achieved given past and on-going impacts and constraints of land use, infrastructure, social acceptance, and ownership. Ratings should reflect an "optimistic potential scenario" in order to not discount large potential changes.

Final Gap Score (0-6)

This is simply the achievable condition rating minus the existing condition rating. This represents the gap that can be filled between existing and target conditions through restoration measures.

Fish Use

3 – High existing or potential productivity area for spawning or rearing for multiple species
2 – Moderate existing or potential productivity area for one or more species
1 – Low existing or potential productivity area for one or two species

Root Causes

3 – Restoration of root causes and key physical processes that create and maintain habitat over time
2 – Partial restoration of root causes
1 – Primarily a structurally-focused restoration strategy that doesn't significantly address underlying causes

Cost Score

The cost score reflects the relative cost for the project based on techniques, access, and feasibility issues. This is a relative cost, not an absolute cost, so the scale of the project is NOT factored into this score. The cost score ranges from 1 to 3, with 1 reflecting relatively lower cost projects. The following guidelines/examples can help to determine the cost score.

4 – High relative cost

- Requires high-cost techniques or materials (e.g., highly engineered log jams, extensive channel shaping, water crossings or bridges)
- Deep excavation or long-distance hauling of spoils
- Entails construction of additional new flood control or bank erosion features (e.g. set-back levees or buried rip-rap)
- Intensive de-watering requirements
- Limited, difficult, or remote access

2-3 – Moderate relative cost

- Uses moderate cost techniques (e.g. typical log jam structures)
- Moderate excavation and hauling distance of spoils
- Typical planting or invasive weed control
- Moderate access conditions
- Standard or no de-watering requirements

1 – Low relative cost

- Uses low cost techniques (e.g. non-ballasted log placements)
- Minimal excavation and hauling distance of spoils
- Little to no planting or weed control
- Easy access conditions
- No de-watering required
- Availability of free materials or volunteer labor

Benefit-to-Cost Score

The benefit-to-cost score is simply the benefit score divided by the cost score. This is a relative value used to compare project benefits.

Feasibility Designation

The feasibility designation is the overall likely feasibility of being able to implement the project within a 10-year timeframe. This is based on landownership, as well as economic, regulatory, political, social, permitting, or other considerations that are known to impact the feasibility of conducting projects within a reasonable timeframe. The feasibility designation is not used as part of the project scoring because feasibility issues may change over time and it is desirable to evaluate project benefits independent of feasibility. The designations include the following:

High feasibility

- No known feasibility issues.
- One or two landowners; or landowner(s) has already indicated willingness

Moderate feasibility

- There are potential feasibility constraints that could affect the likelihood of project implementation within a 10-year timeframe
- Three to five landowners; or there is reason to believe landowner(s) would grant permission

Unlikely feasibility

- There are known feasibility constraints that would be expected to limit the ability to implement the project within a 10-year timeframe
- More than five landowners: or there is reason to believe landowner(s) would not grant permission

Appendix D

Preliminary Hydraulic Model Results

Wolf Creek Reach Assessment – REACH 1 (RM 0 – 1.34)

December 2020

Contents

1 Introduction

1.1 BACKGROUND

A preliminary-level 2-dimensional (2-D) hydraulic model was completed for a suite of estimated flood discharges for existing conditions in Reach 1 (RM 0-1.34). The model was developed to evaluate flood flow hydraulics (velocity) and inundation patterns to better understand degree of channel entrenchment and current flood risk to existing homes and bridges currently located on the historical alluvial fan (Reach 1) of Wolf Creek. This analysis provided information about existing flow hydraulic conditions for and thus guided restoration treatment options for the reach. Only Reach 1 was modeled because it is the only reach in the assessment area with substantial human infrastructure and was the only reach with available LiDAR (2016) at the time of analysis, which was necessary to complete a 2-D modeling effort. The 2-D hydraulic model results for Reach 1 are meant to compliment the comparative stream energy hydraulic analysis completed for all reaches as part of the Reach Assessment. The model results included in this document are preliminary-level flow velocity, for the estimated peak flow events for the 2, 5, 10, 25, 50, 100, 200, and 500-year flood events.

1.2 METHODOLOGY

A two-dimensional (2D) hydraulic model was developed in the U.S. Army Corps of Engineers HEC-RAS 5.0.7 software (USACE 2019), which can compute hydraulic properties related to the physical processes governing water flow through natural rivers and other channels. A model was developed for assumed existing conditions (LiDAR 2016) to assess the current channel and floodplain dynamics, as well as assess the overall impacts of a wide range of flows on the existing landscape.

1.3 MODEL INPUTS

The model terrain was created using 2016 LiDAR data (Figure 1). The computational mesh consists of grid cells ranging from 5-30 feet, with the smallest grid cells utilized to provide higher resolution results closer to the channel (Figure 2). Breaklines were added along topographic high points to align cell faces along high ground and to appropriately represent the underlying terrain.

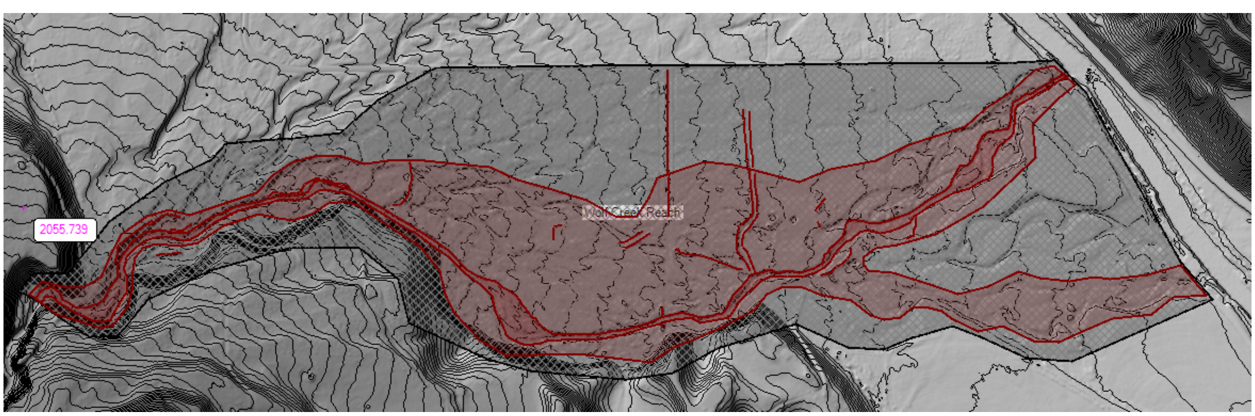


Figure 1. 2D model domain for Wolf Creek. Existing conditions topography shown as background with 5 ft contours.

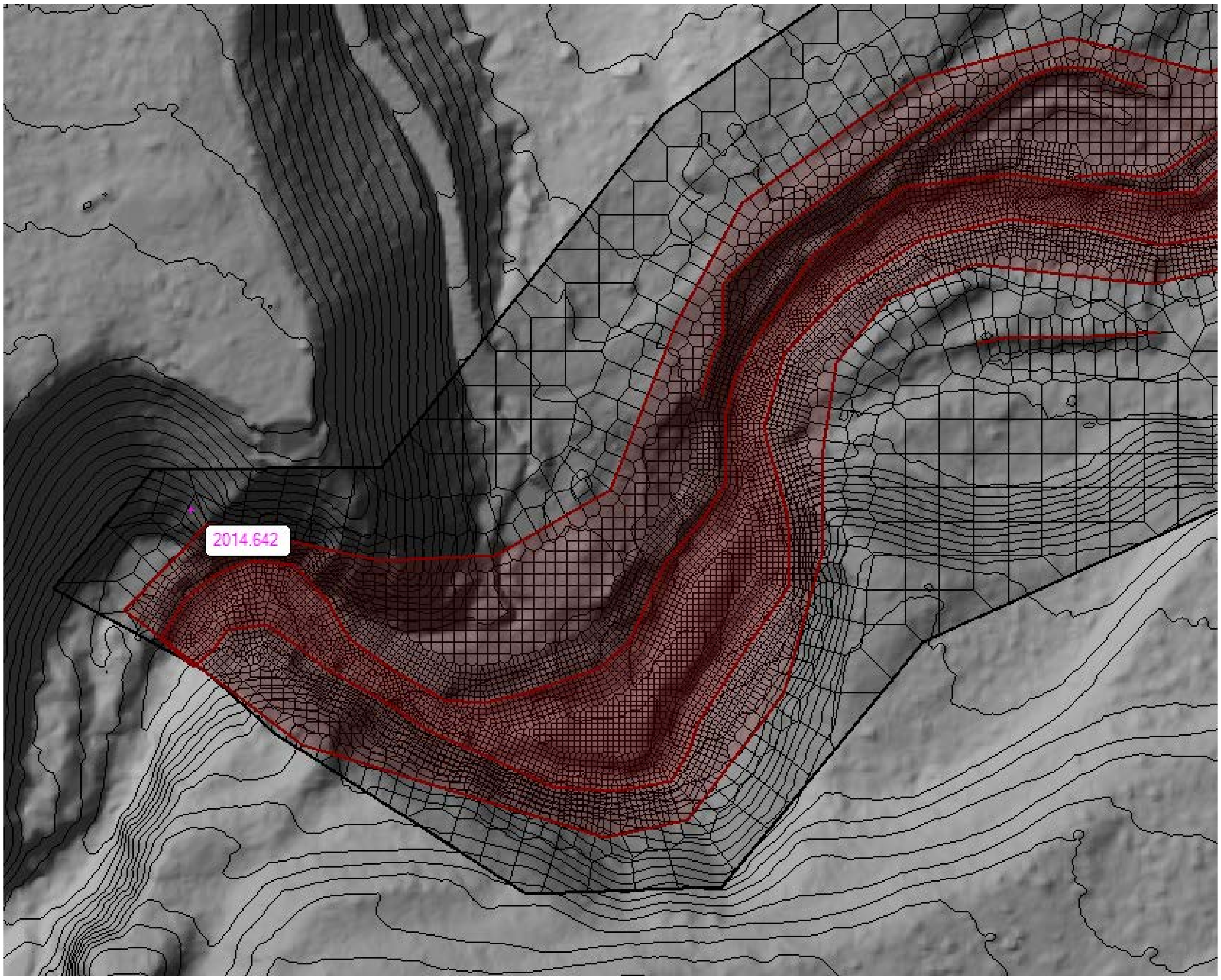


Figure 2. Example cell size at the upstream end of the model. Cells near the channel are 5 ft in width. A wider corridor of 10 ft cells was used around the channel. The outer floodplain cells are 30 ft.

A spatially varying hydraulic roughness (Manning's n) layer was developed using ArcGIS tools to represent hydraulic roughness throughout the model domain. The roughness layer was developed by reclassifying a LiDAR derived vegetation height layer with manning's n coefficients based on varying vegetation heights (Figure 3). These data were supplemented with hand digitized channel polygons. Additional refinements were made in certain areas, such as forests with light understories, based on field observations. A table of hydraulic roughness coefficients and their associated classifications is provided in Table 2. Channel roughness coefficient was set to 0.04. Floodplain roughness coefficients range from 0.03 to 0.12.

Table 1. Roughness coefficients (Manning's n values) utilized in the Reach 1 preliminary existing conditions modeling.

Area Description based on Vegetation Height	**Roughness Coefficeint (Manning's n Value)**
Channel	0.04
Bare Ground	0.03
Ground Cover (0.5 – 5 ft)	0.04
Shrub (5 – 20 ft)	0.12
Small Tree (20 – 50 ft	0.10
Mature Tree (50-100 ft)	0.08

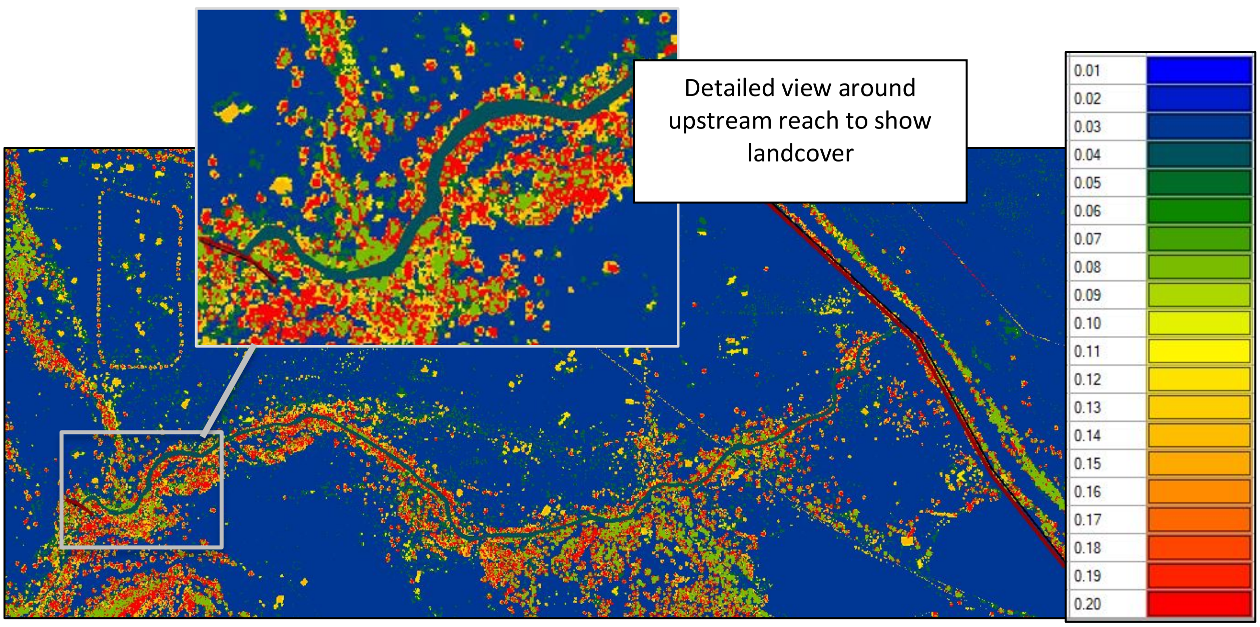


Figure 3. Roughness values assigned to the existing conditions model. Boundary condition locations shown with a red line.

The hydraulic model was used to evaluate existing conditions at flow events ranging from the 2-year flow event to the 500-year flow event (Table 2). A synthetic "stepped" hydrograph that contains gradual rising limbs between discharges of interest (e.g., 25-year flow) was used as the input hydrograph to simulate steady-state flow conditions (Figure 4). The discharges of interest remain unchanged for long enough to allow the model to reach a steady-state, before rising to the next step. It's worth noting that allowing the model to reach a steady state during large flood events may overestimate flooding results, as floodplain storage throughout the model domain must reach capacity to reach steady-state conditions, which in reality may not occur during actual floods, especially short duration events. The receding limb of a typical flood hydrograph is also not represented when using this methodology.

The upstream boundary condition was set to the stepped flow hydrograph using flow events in Table 2. An EG slope of 0.03 was found in the terrain at the location of the upstream boundary condition and used as an input in the flow hydrograph. The downstream boundary condition was set to normal depth with a friction slope of 0.018.

Table 2: Modeled flow events (estimated from StreamStats at downstream end or Reach 1) used in hydraulic modeling.

Discharge (cfs)	Flow Event
263	2 - year
467	5 - year
637	10 - year
886	25 - year
1110	50 - year
1340	100 - year
1580	200 - year
1980	500 - year

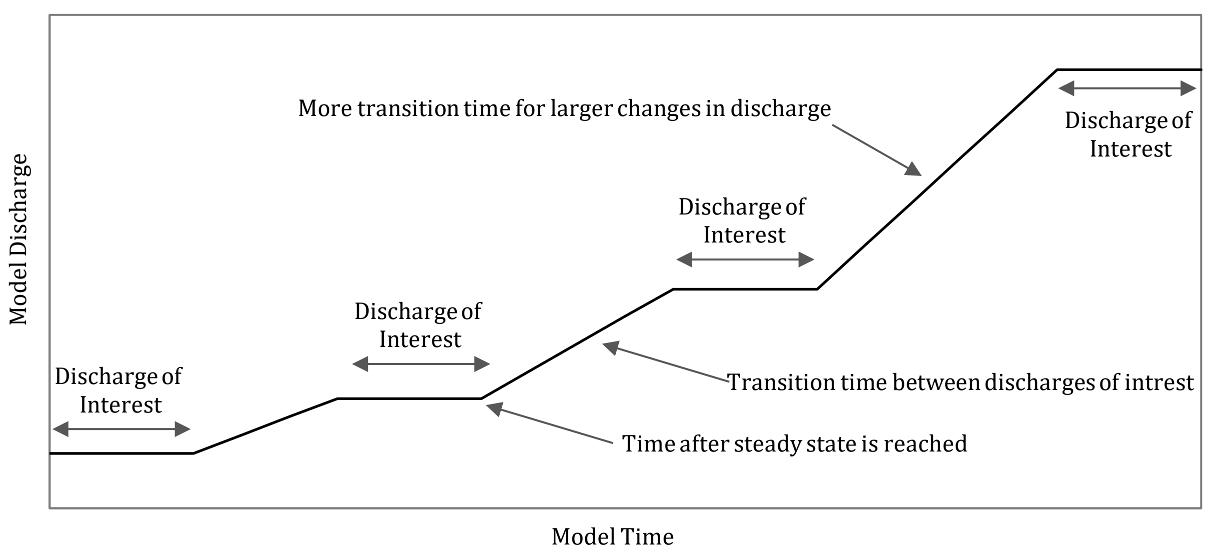


Figure 4: Demonstrative "stepped" flow input hydrograph.

2 Preliminary-Level 2-D Hydraulic Model Results

2.1 MODELED VELOCITY RESULTS

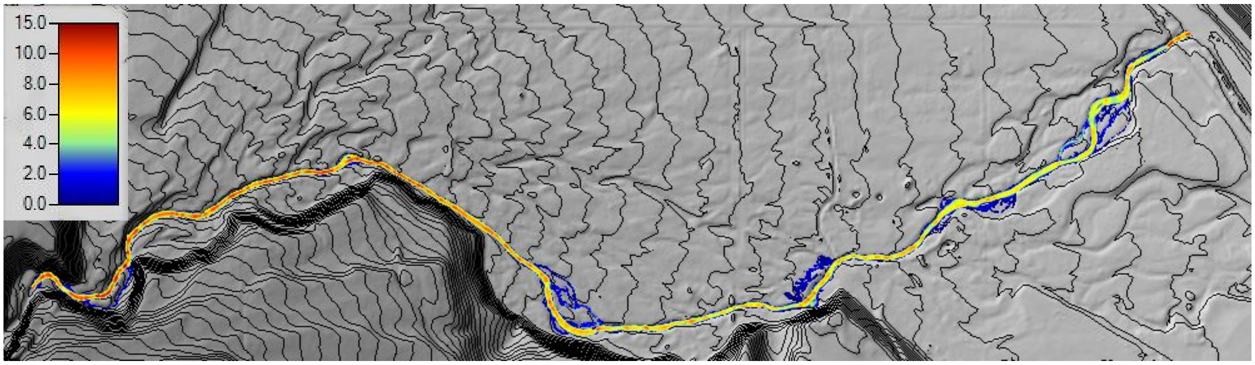


Figure 5. Modeled velocities under existing conditions at the 2-year flow event (263 cfs).

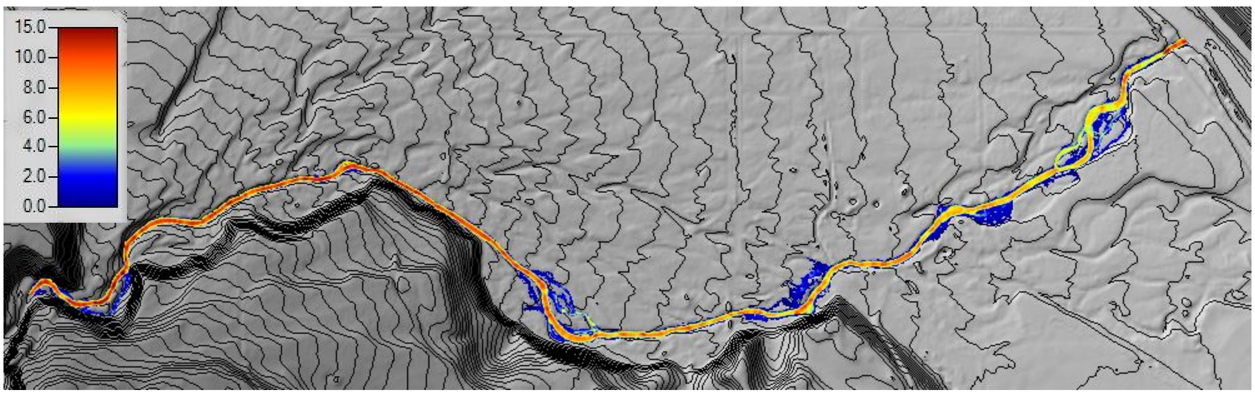


Figure 6. Modeled velocities under existing conditions at the 5-year flow event (467 cfs).

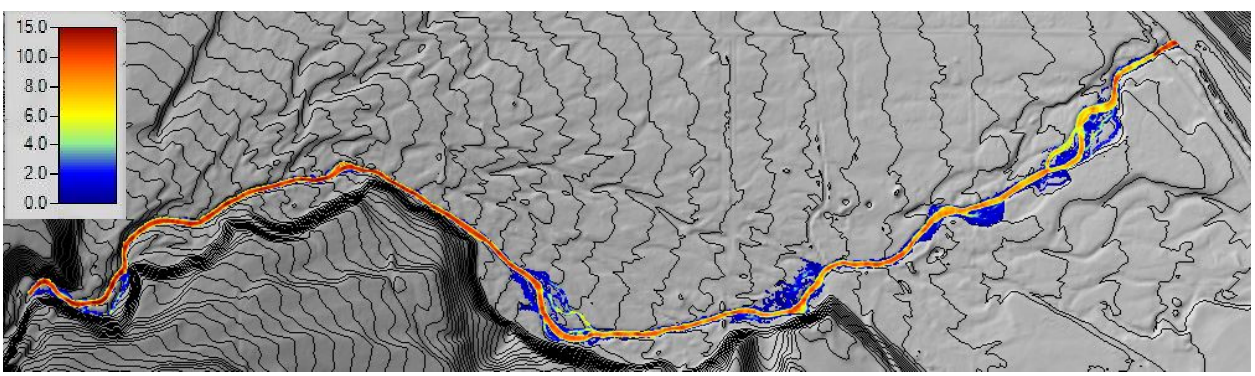


Figure 7. Modeled velocities under existing conditions at the 10-year flow event (637 cfs).

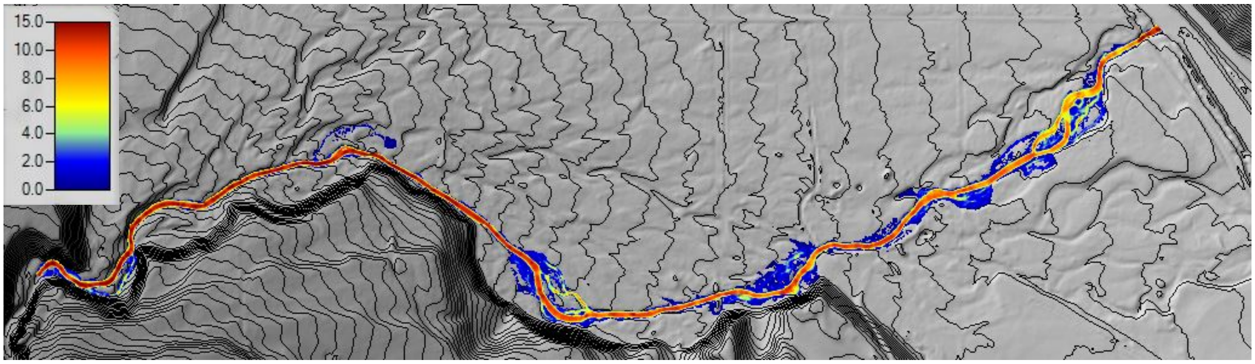


Figure 8. Modeled velocities under existing conditions at the 25-year flow event (886 cfs).

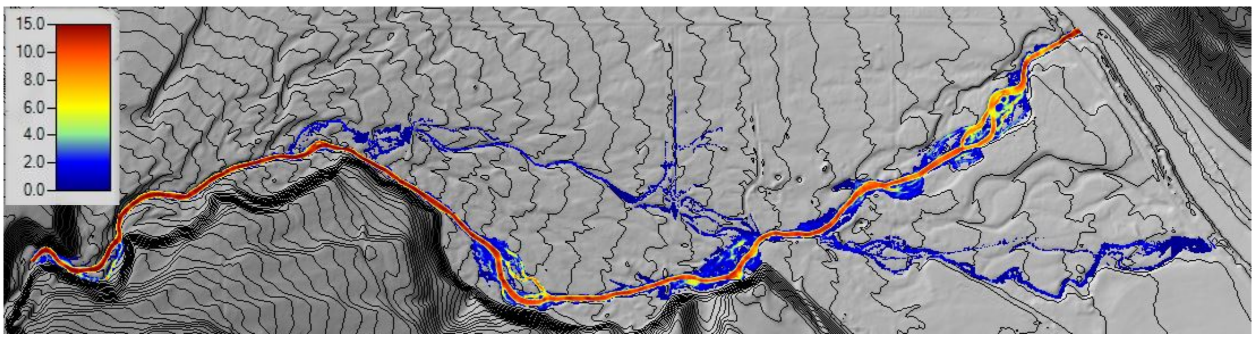


Figure 9. Modeled velocities under existing conditions at the 50-year flow event (1,110 cfs).

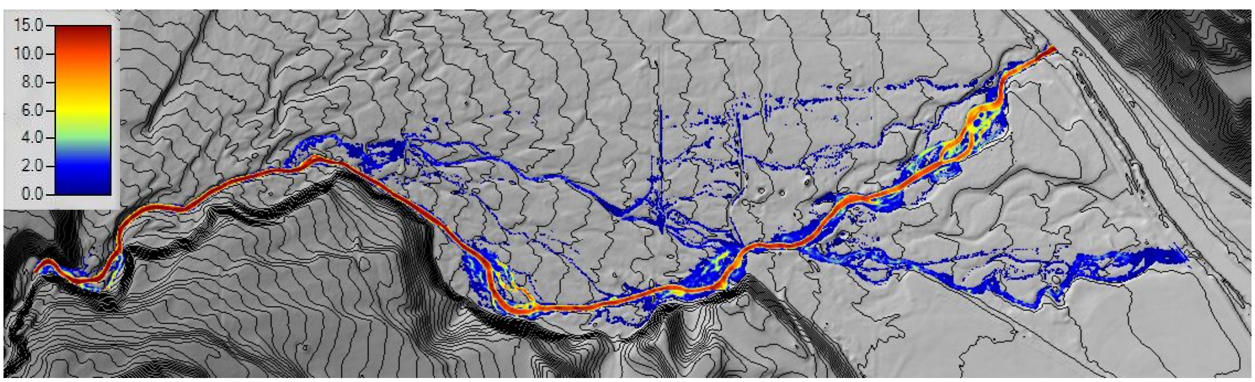


Figure 10. Modeled velocities under existing conditions at the 100-year flow event (1,340 cfs).

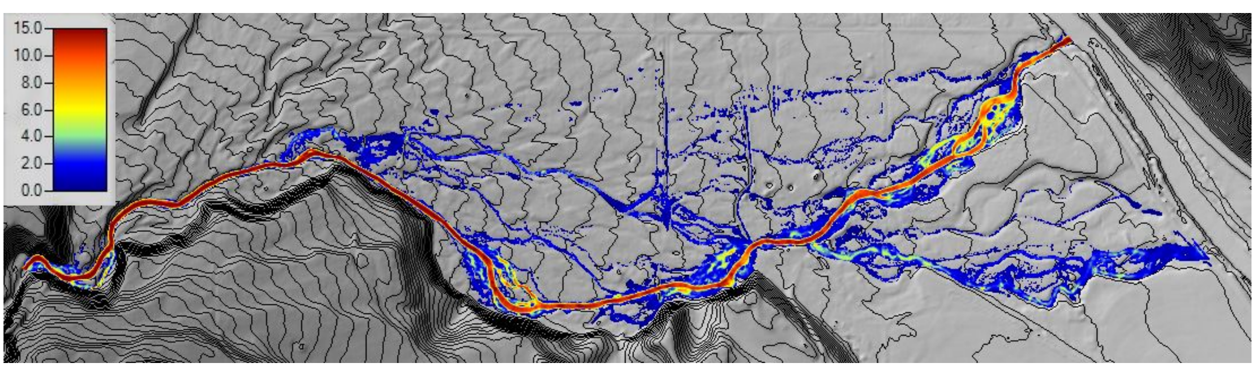


Figure 11. Modeled velocities under existing conditions at the 200-year flow event (1,580 cfs).

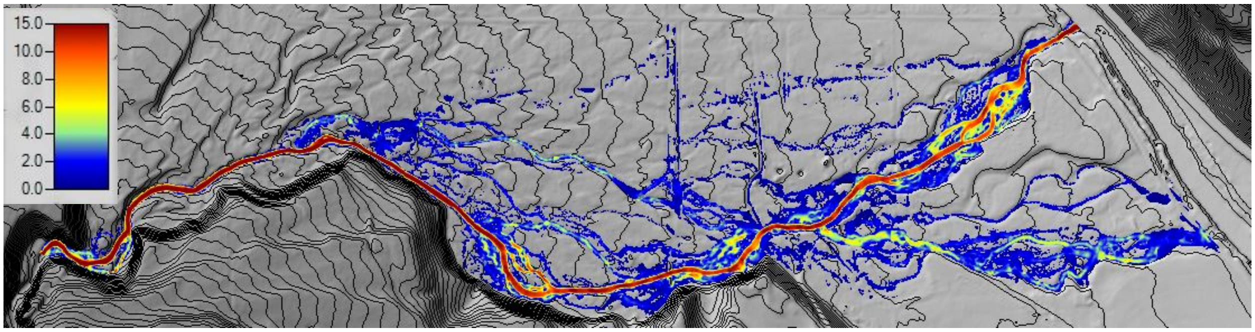


Figure 12. Modeled velocities under existing conditions at the 500-year flow event (1,980 cfs).

2.2 CONSIDERATIONS

- Flow velocities in the upstream confined channel section of the channel are relatively high, even at the two-year estimated flood event discharge. This coincides with field observations of larger sized cobble and more prevalent boulders in this portion of Reach 1, reflecting higher stream energies (transport capacity) in the upstream section.
- Inset small floodplain pockets throughout and the high-flow side channels in the downstream section of Reach 1 are wetted by the 2-year estimated flood event discharge.
- Confined floodplain inundation increases in areas with increased flood discharges but does not activate the historical floodplain until the 50-year estimated discharge.
- Levees along the channel and perpendicular levees and ditches on the floodplain capture and redirect a portion of flood flow back to the channel and away from homes when it does inundate the historical fan surface.
- The existing Ponds (RM 1) and associated irrigation out-take and ditch on the river left side of the channel are a route of large flood event surface flow to the historical alluvial fan.
- The defunct irrigation out-take and ditch on river left at RM 1.26 is not a route for large flood event surface flow to access the historical alluvial fan due to mainstem channel entrenchment.
- Confinement at the mouth of Wolf Creek inhibits complex delta process at all flows modeled, including the 500-year estimated flood event.
- The channel in Reach 1 is severely anthropogenically entrenched and confined below its historical alluvial fan.
- Existing homes, structures, and infrastructure will need to be considered for any treatment design in Reach 1. However, installations upstream of RM 1.2 and downstream of RM 0.3 have less of a potential to impact private property.