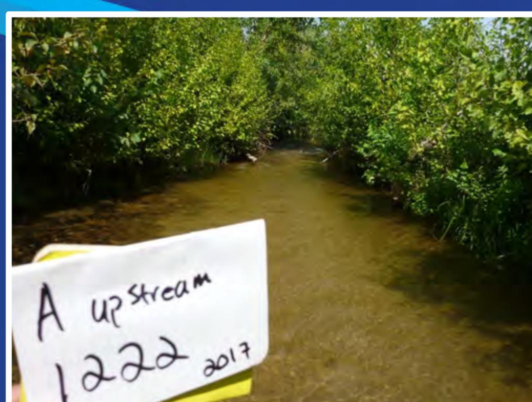
CONFLUENCE
ENVIRONMENTAL COMPANY

Lower Loup Loup Creek
REACH ASSESSMENT

Prepared for:

Okanogan Conservation District

July 2024



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Lower Loup Loup Creek
REACH ASSESSMENT

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TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

°C	Degrees centigrade
AC	Acceptable conditions
AR	At-risk conditions
AU	Assessment unit
cfs	Cubic feet per second
cm	Centimeter(s)
CTCR	Confederated Tribes of the Colville Reservation
D50	50th percentile (median) substrate diameter
D84	84th percentile substrate diameter
EDT	Ecosystem Diagnosis and Treatment
ESA	Endangered Species Act
FPC	Fish Passage Center
GIS	Geographic information system
HSTR	Habitat Status and Trends Report
km	Kilometer(s)
LiDAR	Light-detection and ranging
LWD	Large woody debris
m	Meter(s)
mm	Millimeter(s)
MSRF	Methow Salmon Recovery Foundation
MTBS	Monitoring Trends in Burn Severity
NAIP	National Agricultural Imaging Program
NDVI	Normalized Difference Vegetation Index
NRCS	Natural Resources Conservation Service
OBMEP	Okanogan Basin Monitoring and Evaluation Program
Okanogan CD	Okanogan Conservation District
Pa	Pascals
PVWUA	Pleasant Valley Water User Association
RA	Reach Assessment
REI	Reach-based ecosystem indicators
RKM	River kilometer
RM	River mile
SCS	Soil Conservation Service
SOE	Strength of effect
SRFB	Salmon Recovery Funding Board
SRP#	Salmon Recovery Proposal #
UCRTT	Upper Columbia Regional Technical Team
UCSRB	Upper Columbia Salmon Recovery Board
UN	Unacceptable conditions
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WA	Washington
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WDOE	Washington Department of Ecology
WCSA	Wildlife Conservation Society of America
WSDA	Washington State Department of Agriculture
WWT	Washington Water Trust

1.0 INTRODUCTION AND BACKGROUND

Confluence Environmental Company has prepared this reach assessment (RA), referred to hereafter as the Lower Loup Loup Creek RA or the RA, on behalf of the Okanogan Conservation District (Okanogan CD) to support ongoing habitat restoration planning efforts in lower Loup Loup Creek. Loup Loup Creek is a tributary to the Okanogan River that provides important spawning and rearing habitat for Upper Columbia summer steelhead, an anadromous species that is currently listed as threatened under the Endangered Species Act (ESA) of 1973 (50 CFR § 17.11).

The Lower Loup Loup Creek RA has been developed to support the Washington State Salmon Recovery Funding Board (SRFB) grant application process. The SRFB administers an annual grant program that provides funding for priority habitat restoration projects. The SRFB partners with regional lead entities to administer the grant funding process, relying on those lead entities to establish a process for soliciting habitat protection and restoration proposals and prioritizing those proposals for funding. The Upper Columbia Salmon Recovery Board (UCSRB) is the regional lead entity for the Upper Columbia recovery domain, which encompasses all salmon-bearing tributaries to the Columbia River between and including the Wenatchee and Okanogan rivers (NOAA Fisheries 2023). The UCSRB leads the initial review of restoration grant funding applications, ranking those applications based on alignment with identified habitat priorities and providing the SRFB with a prioritized list of projects recommended for funding.

The UCSRB and SRFB review process relies, in part, on RAs. An RA describes aquatic habitat conditions within a defined study area, identifies priority limiting factors and watershed processes contributing to limiting factor conditions, and recommends actions to address those limiting factors. The Upper Columbia Regional Technical Team has developed guidance for conducting RAs and developing RA reports (UCRTT 2022).

RAs are intended to fill critical gaps in information needed to support restoration planning. They are typically implemented in high priority watersheds that lack comprehensive habitat assessments and/or long-term habitat status and trends monitoring. They may not necessarily be required in watersheds that are intensively monitored and have established means for identifying priority limiting factors. For example, the UCRTT (2022) RA guidance states:

> *Importantly, reach assessments need to be completed in areas where no reach assessment data are currently available or where previous reach assessment data are outdated (>10 years old). Where data have been collected for Ecosystem Diagnosis and Treatment (EDT) modeling, most of the information in a reach assessment are collected as part of EDT or are outputs from EDT modeling. Thus, where EDT modeling has occurred (e.g., Okanogan and Methow River basins), reach assessments are likely not needed. Exceptions may be identification of geomorphic and hydrologic processes and locations upstream from anadromy.*

The Okanogan is unique in that it is the only tributary subbasin in the Upper Columbia Recovery Domain that has an established, long-term habitat status and trends monitoring program in place. The Okanogan Basin Monitoring and Evaluation Program (OBMEP), part of the Confederated Tribes of the Colville Reservation (CTCR) Fish and Wildlife Department, has continuously monitored aquatic habitat conditions in the Okanogan subbasin since 2005. OBMEP uses the Okanogan EDT model to synthesize habitat and biological monitoring data from each 4-year monitoring cycle into model inputs that are used to generate habitat performance metrics. These metrics are used to report on habitat status, evaluate changes in habitat performance over time, and identify priority habitats and limiting factors. OBMEP developed the web-based Okanogan Habitat Status and Trend Report (HSTR) to synthesize and report EDT model results (https://ecosystems.azurewebsites.net/hstr-okanogan/). OBMEP worked with subbasin partners to add additional functionality to the HSTR. The HSTR Implementation module links refined limiting factor prioritization to potentially suitable categories of restoration actions at reach and assessment unit (AU) scales. Doyle et al. (2022) provide an overview of the Okanogan EDT model and its application to OBMEP habitat status and trends monitoring, restoration planning, and resource management.

Consistent with UCRTT (2022) RA guidance, the extensive quantitative monitoring, EDT modeling, and restoration planning tools developed by OBMEP should provide sufficient information to support restoration planning. However, the UCSRB and SRFB are accustomed to using RAs as a basis for ranking habitat restoration proposals and comparing priorities between watersheds. Moreover, the EDT model does not provide a complete picture of the watershed processes that may be contributing to degraded habitat conditions. RAs are intended to provide this critical information. This limitation, and UCSRB and SRFB reliance on RAs for project prioritization, have placed Okanogan subbasin restoration proposals at a competitive disadvantage for SRFB funding.

The Lower Loup Loup Creek RA has been developed to address this shortcoming. This document demonstrates that Okanogan CD can produce a cost-effective equivalent to a traditional RA using a synthesis of OBMEP monitoring data, EDT model inputs and results, and publicly available geographic information system (GIS) and remote sensing data. The Okanogan CD and other watershed partners will use this report to support future restoration grant proposals in the Loup Loup Creek watershed and as proof of concept for future RA reports for other Okanogan subbasin AUs.

2.0 STUDY AREA CHARACTERISTICS

The study area for this RA comprises the Lower Loup Loup Creek-DS AU, which comprises the lower portion of Loup Loup Creek extending from its confluence with the Okanogan River approximately 3.5 kilometers (km) upstream to the location of a historical series of falls and boulder cascades that marked the upstream limit of anadromous habitat within the system (this natural barrier was removed in 2023). The study area contains 3 low- to moderate-gradient reaches located on the alluvial flood terrace of the Okanogan River. The study area reach configuration and location in the Loup Loup Creek watershed are shown in Figure 1.

Habitat conditions in these reaches are determined by both local and broader watershed conditions that influence the hydrology and geomorphology of the system. The remainder of this section provides an overview of the watershed-level conditions that influence the study area.

2.1 Watershed Geography and Physiography

Loup Loup Creek is a fourth order tributary of the Okanogan River system. Loup Loup Creek enters the Okanogan River at river kilometer (RKM) 27.2, in the community of Malott, Washington. The Loup Loup Creek watershed encompasses approximately 16,781 hectares (64.79 square miles) and ranges in elevation from a highest point of 1,868 meters (m) (6,130 feet) at Buck Mountain to approximately 244 m (800 feet) at the confluence. The watershed is mountainous with an average elevation of 1,018 m (3,340 feet) and includes several peaks approaching and exceeding 1,524 m (5,000 feet). Average precipitation is 43 centimeters (cm) (17 inches) per year, falling predominantly as snow at higher elevations (USGS 2024). The watershed contains approximately 122.1 km (75.9 miles) of perennial stream channel, including approximately 31.9 km (19.8 miles) comprising the Loup Loup Creek mainstem (NPCC 2004). Loup Loup Creek watershed hydrography and land ownership are displayed in Figure 2. Land ownership is summarized in Table 1.

Table 1. Land ownership within the Loup Loup Creek watershed

Ownership Type	Agency	Hectares	Acres	% of the Watershed
Federal	U.S. Department of the Interior Bureau of Land Management	358	885	2%
	U.S. Department of Agriculture Forest Service	592	1,462	4%
	Other Federal	19	46	<1%
	Total Federal Lands	969	2,393	6%
Washington State	Washington Department of Fish and Wildlife	466	1,151	3%
	Washington Department of Natural Resources	11,800	29,159	71%
	Other State	204	505	1%
	Total State Lands	12,470	30,815	75%
Other Public Land	Okanogan County	5	12	<1%
	Municipal	11	26	<1%
Total Public Lands		13,455	33,248	81%
Non-public Lands	Tribal	2	4	<1%
	Private	3,187	7,874	19%
	Total Non-public	3,189	7,878	19%
Total Land Area		16,643	41,125	

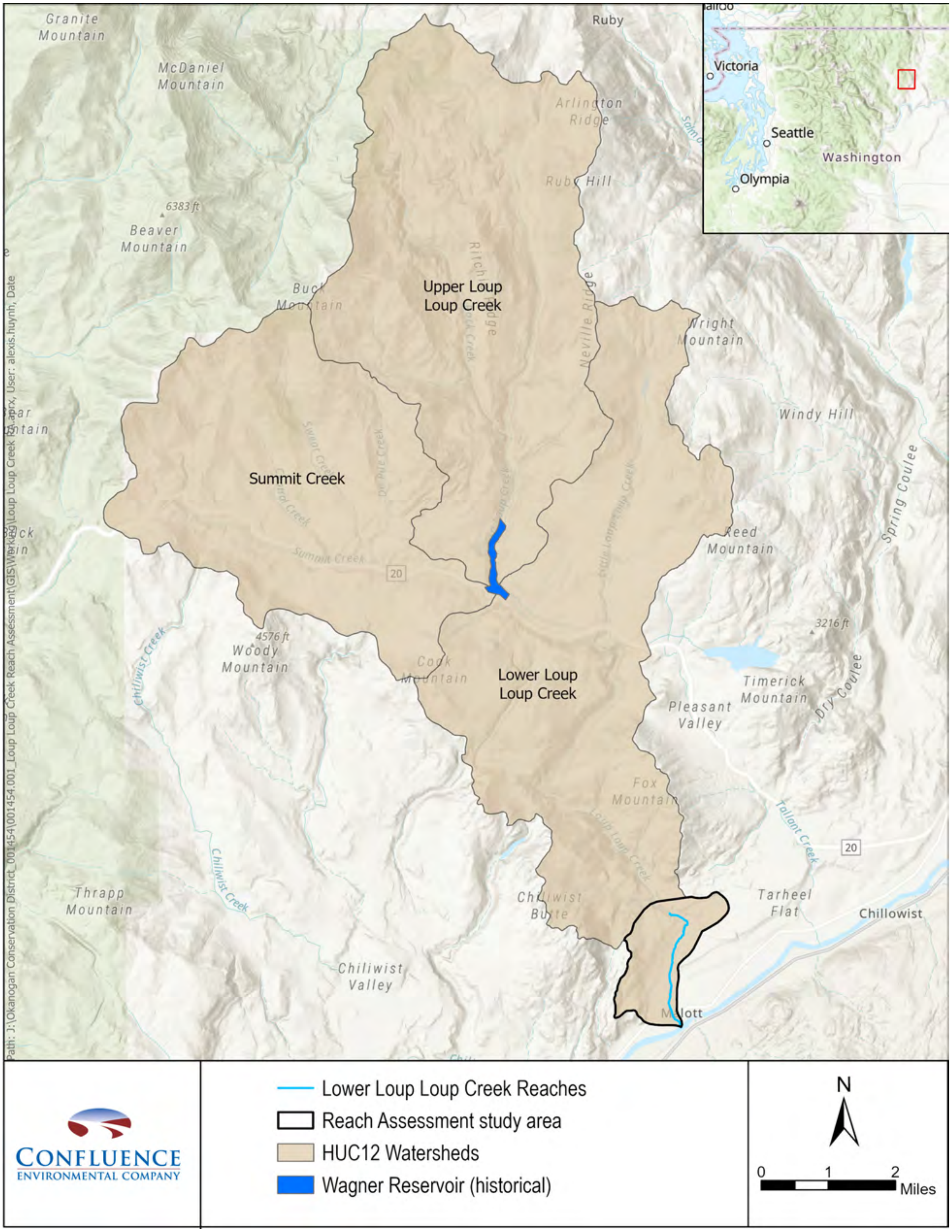


Figure 1. Lower Loup Loup Creek RA study area

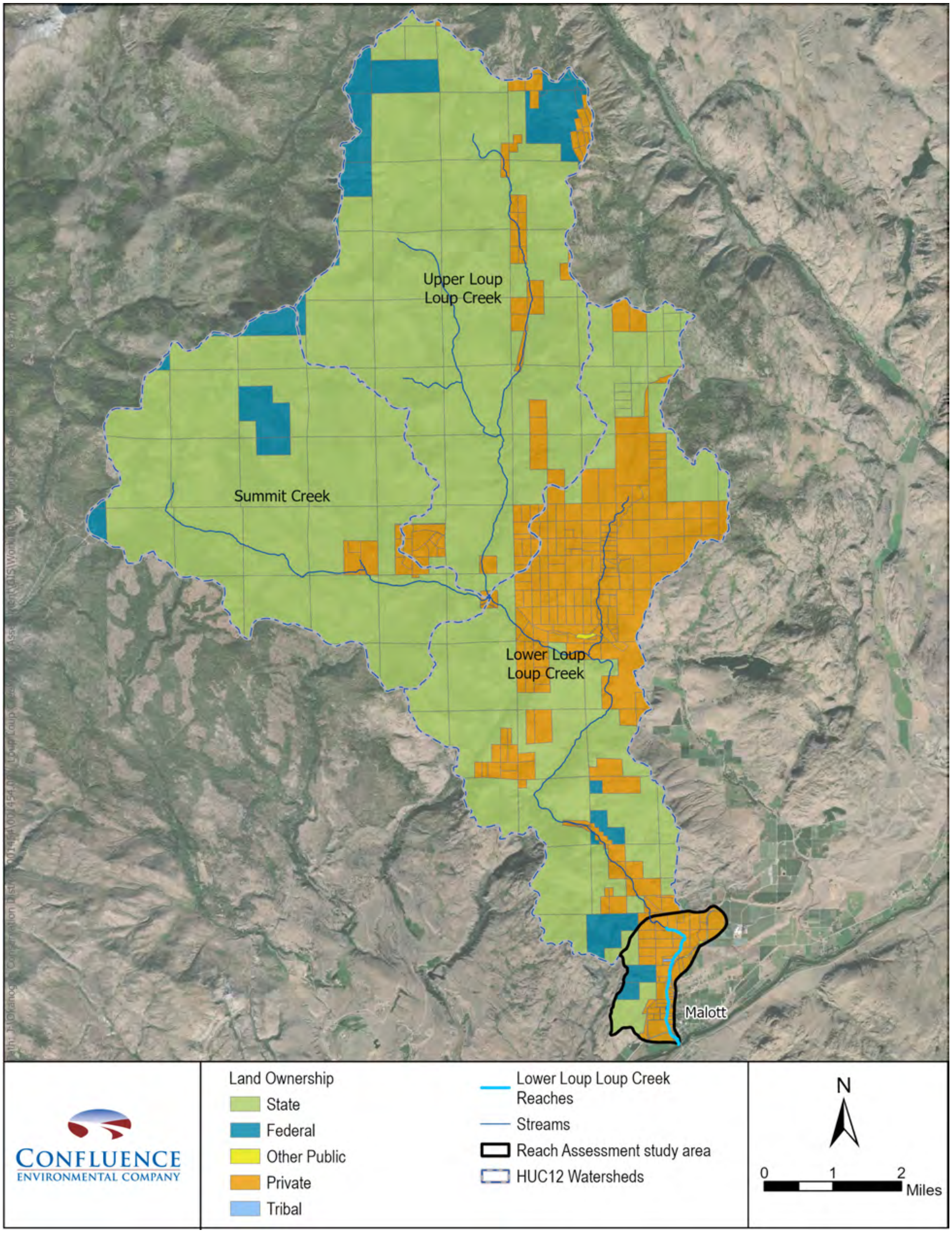


Figure 2. Loup Loup Creek watershed hydrography and land ownership

As shown in Figure 2, the watershed is predominantly owned by the Washington Department of Natural Resources (WDNR) transitioning to private land ownership in the lower watershed. The Loup Loup State Forest, managed by WDNR, comprises approximately 73% of the watershed area, or 11,800 hectares (29,159 acres). A small portion of the watershed, approximately 592 hectares (1,462 acres) is in the Okanogan-Wenatchee National Forest, managed by the U.S. Department of Agriculture (USDA) Forest Service. The U.S. Department of the Interior Bureau of Land Management owns small inholdings within the broader matrix of WDNR-owned lands (NPCC 2004). The watershed is categorized as predominantly ponderosa pine and fir forest (86.5%) transitioning to sagebrush steppe at lower elevations. The study area for this report is located in this sagebrush steppe zone on private land ownership. Much of the study area, particularly floodplain and riparian zones, has been converted to orchards and rural residential development.

The majority of development in the study area is concentrated around the Malott community. Situated near the mouth of the watershed, Malott has served as a center for agricultural activities since the early 1900s, primarily focused on orchards, hay production, and pastureland. Most agricultural practices historically and currently are located around Malott. As of 2023, approximately 2,058 hectares (~5,086 acres) of land within the Loup Loup Creek watershed is utilized for agricultural production. Private grazing land represents about 95% of that hectarage (~1,960 hectares) and is located near Malott and up into the forested regions of the watershed, with 4% (~88 hectares) of the agricultural lands utilized for orchard production in the lower elevations of the watershed near Malott (OCPD 2024; WSDA 2022). Private ownership makes up 19% of the watershed at 3,186 hectares (7,874 acres). There are 39 parcels adjacent to the stream within the study area, 1 owned by the CTCR and the remainder private.

2.2 Soils and Vegetation

The soils, geology, and vegetation of the Loup Loup Creek watershed all contribute to the watershed processes that contribute to the structure, condition, and health function of aquatic habitat. This section provides an overview of geology, soils, and vegetative community structure of the watershed to provide context for interpretation of existing watershed process conditions.

2.2.1 Geologic Summary

The Okanogan subbasin has been formed by tectonic uplift, volcanic activity, and ice age sculpting. During the Quaternary period, the Okanogan Lobe of the Cordilleran ice sheet covered much of what is now the Okanogan subbasin, shaping and forming what would eventually become the floodplains of the Okanogan River. Advancing and retreating ice sheet cycles left behind extensive areas of exposed bedrock and thin glacial sediments in uplands regions and thick sequences of glacial sediments in the valley bottoms of tributaries and the Okanogan River valley (Carlson et al. 2020).

The Loup Loup Creek watershed is representative of these broader geologic conditions. Approximately 98% of watershed area comprises exposed bedrock and thin glacial sediments. The remaining 2%, about 294 hectares (~727 acres), comprises valley bottoms composed of streambed sediments and alluvium, alluvial fans, terraces, and floodplains. Alluvial deposits can reach thicknesses of up to 20 m along the Okanogan River, transitioning from stratified coarse sand and pebbles at lower elevations to cobble and gravel and then to finer sand and silt in higher elevations (Gulick 1990). Deposits of this type extend from the Okanogan River confluence upstream to the confluence with Rock Creek.

Approximately 30% of the Loup Loup Creek watershed, or about 5,065 hectares (~12,517 acres), is composed of glacial outwash, till, and drift that were reworked and deposited by the Okanogan Lobe of the Cordilleran ice sheet as it advanced and retreated during the Quaternary Period. The remaining 68% of the watershed, about 11,235 hectares (~27,761 acres), is composed mainly of intrusive igneous bedrock, including granodiorite and tonalite formed during the Cretaceous Period, and of metamorphic rock, including orthogneiss formed in the Mesozoic Era (Gulick 1990). Much of the bedrock has been weathered to shallow soils (USDA SCS 1980).

The Loup Loup Creek watershed has a small area of sedimentary bedrock composed mainly of quartzite located on the northeastern part of the watershed, making up about 39 hectares (~96 acres).

2.2.2 Soil Summary

Soils in the lower reaches of Loup Loup Creek within T32N R25E S9, S8, and S4, were surveyed and compiled by the USDA Soil Conservation Service (SCS) in 1979. Soil associations include the Pogue-Cashmont Cashmere association, composed of deep, somewhat excessively drained and well drained soils formed in glacial till and outwash and located on terraces; the Conconully-Lithic Xerochrepts-Haley association composed of deep, shallow, and very shallow well drained soils and formed from glacial till and outwash and materials weathered from granite, found on plains and terraces; and the Rock outcrop-Nevine Donavon association, composed of rock outcrops and deep well drained soils and formed in a mantle of volcanic ash and the underlying glacial till, found on mountain uplands and toe slopes. (USDA SCS 1980).

The soil survey for the Okanogan National Forest area (USDA NRCS 2008) filled in the gaps left by a previous survey by the USDA SCS for the Loup Loup Creek watershed. The survey identified the soil series within the watershed, listed in descending order of prevalence. These series are Xerochrepts-Rock outcrop complex, Merkel, Loup Loup, Xerochrepts, Conconully, Lithic haploxerolls-Rock Outcrop Complex, Katar, Loup Loup-Rock Outcrop Complex, Leader, Newbell, as well as Xerorthents and other soils below 500 hectares (~1235 acres) within the Loup Loup Creek watershed (USDA NRCS 2008).

Potential soil erosion hazard ratings were developed to estimate the hazard or risk of soil loss from unsurfaced roads and trails (USDA NRCS and Soil Survey Staff 2023). These ratings are based on the soil's K factor (soil erodibility), slope percentage, and rock fragments in parent material to determine potential soil loss on the landscape. These ratings assess 1) the hazard or risk of soil loss from unsurfaced roads during natural precipitation events; 2) activities on roads and trails that results in bare ground, compaction, and the reshaping of the soils surfaces; 3) the use of trucks, skidders, off-road vehicles; and 4) the impact on compacted, bare road and trail surface using the representative value for slope gradient of the soil component.

Table 2 and Figure 3 show soil erodibility potential within the Loup Loup Creek watershed. A significant portion of the area has soils rated as severely erodible.

Table 2. Loup Loup Creek watershed soil erodibility

Soil Erosion Hazard Rating	Hectares	Acres	% of Watershed
Severe	13,076	32,311	78.6%
Moderate	3,259	8,054	19.6%
Slight	239	591	1.4%
Not Rated	69	169	0.4%

2.2.3 Ecoregions

The Loup Loup Creek watershed is broadly divided into 2 ecoregions by elevation. Approximately 6%, or about 954 hectares (2,358 acres) within the Okanogan Valley floor, is specified as Environmental Protection Agency Level IV Ecoregion type Okanogan Valley (10m). The Okanogan Valley ecoregion is a glacial trough spanning between the North Cascades Mountains and the Okanogan Highlands, featuring slopes, terraces, and alluvial flats enveloping the Okanogan River at elevations below 915 m (3,000 feet). Annual precipitation of 23 to 30 cm (9 to 12 inches) sustains sagebrush and grasses, with the upper boundary marked by increased precipitation at treeline. The permeable glacial till, covered by a thin layer of loess, sustains irrigated agriculture and orchards in the alluvial plains and grazing in the upland regions (Bryce et al. 2010).

The remaining 94% of the watershed, or about 15,703 hectares (38,802 acres), is classified as the Level IV Ecoregion type Okanogan Pine/Fir Hills (77e). This ecoregion encompasses the mountainous portion of the watershed uphill of the edge of the Okanogan River valley wall. Characterized by rounded mountains and U-shaped valleys, this glaciated region features gentler slopes and lower elevations compared to the North Cascades (77) further west. Annual precipitation ranges from 25 to 89 cm (10 to 35 inches), mostly as snow. Periodic drought conditions are common in this ecoregion. Vegetation varies with elevation, with ponderosa pine in lower areas and Douglas-fir at higher elevations. Bluebunch wheatgrass and Idaho fescue are common understory species (Bryce et al. 2010).

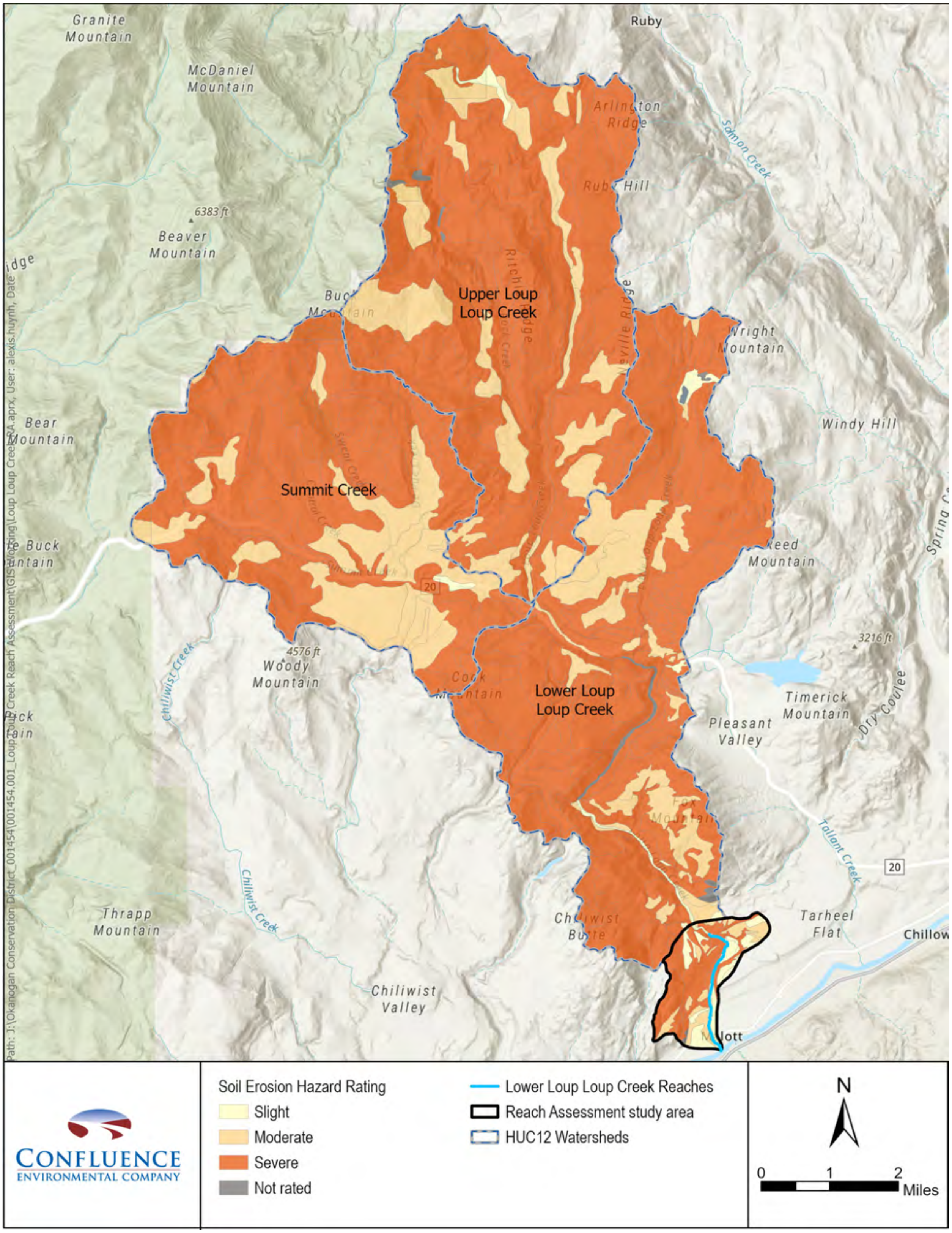


Figure 3. Soil erosion hazard ratings in Loup Loup Creek watershed (USDA NRCS and Soil Survey Staff 2023)

2.3 Development and Disturbance History

Watershed conditions in Loup Loup Creek have been influenced by a combination of human-caused events, landscape management decisions, and natural factors. This section provides a summary of watershed disturbance history useful for characterizing current hydrologic and sediment process conditions.

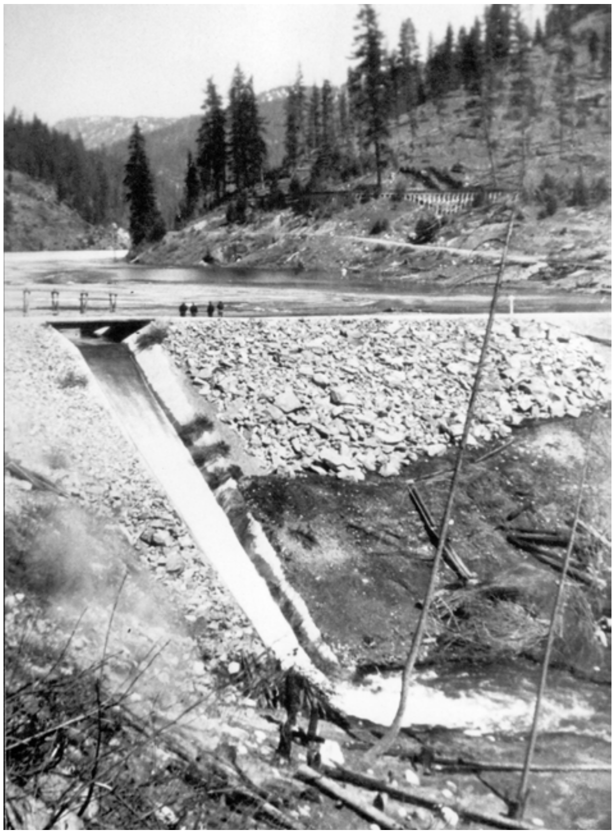
2.3.1 Diversions and Reservoirs

The Loop Loop-Leader Lake Ditch was dug in 1909 and was a surveyed for a length of 3,647 m (11,964 feet). It diverts water from Loup Loup Creek at approximately 48°24'04"N -119°45'29"W to Leader Lake, an off-channel irrigation reservoir located 5 miles west of the town of Okanogan in the Tallant Creek drainage (Paine 1909). Tallant Creek drains Leader Lake and is used primarily as irrigation water conveyance supplying the Pleasant Valley Water Users Association.

2.3.2 Floods

In 1920, the Pleasant Valley Water User Association (PVWUA) began development of a dam and reservoir on Loup Loup Creek to create an auxiliary reservoir for storing irrigation water. The original designer, John Chalmers, a well-known individual with knowledge of irrigation systems, proposed a dam with a rock reinforced spillway structure. However, the PVWUA selected a less expensive concrete spillway on top of earthen fill, leading to disagreements that delayed the project. In 1922, a 24 m (80 foot) earthen fill dam was constructed about 7.5 km (12 miles) upstream of the Malott townsite. According to blueprint plans, the Wagner Reservoir was proposed in a 1909 survey to have covered an area of 20.6 hectares (50.8 acres) and had a planned held capacity of 1,500 acre-feet. The PVWUA planned to fill the reservoir by constructing a diversion on Sweat Creek at 48°22'38"N 119°46'33"W and transporting the water via the Sweat Creek-Loop Loop Ditch (Paine 1909). The E. Wagner Sawmill used the reservoir as a millpond until August of 1931, when the mill was destroyed in a fire (Cain and Eller 1995).

On April 18, 1938, the Wagner Reservoir dam failed during a heavy snowmelt event. The resulting flood waters cascaded down the Loup Loup Creek valley and swept away or substantially damaged 26 houses and commercial buildings in Malott, some carried into the Okanogan River (Okanogan Independent 1938, Gavin 1966). This flooding event scoured portions of the stream to bedrock, possibly creating the recently removed historical natural barrier at Loup Loup Falls at the upstream end of the study area at RKM 3.5 (river mile [RM] 2.04). Figure 4 presents photographic documentation of impacts to the study area from this historical dam burst flood.



Wagner Mill-Pond and dam prior to failure: Geo. Carlton, John Chalmers, Bill Brown, Walter Carlton on dam (Unknown 1938a).

Photo of damage in Malott when Wagner Sawmill dam for mill pond up Loup Loup Creek broke on April 18, 1938. Looking upstream and north (Unknown 1938b).

Photo of damage in Malott when Wagner Sawmill dam for mill pond up Loup Loup Creek broke on April 18, 1938. Looking downstream and south toward the Okanogan River. Note the Malott bridge (Unknown 1938c).

Figure 4. Wagner Dam and impacts to Lower Loup Loup Creek RA study area from 1938 dam burst flood

Photos provided by Okanogan County Historical Society

2.3.3 Mining

In 1858, the discovery of gold and silver in the Okanogan region sparked an influx of settlers to Okanogan County. Mining related development in the subbasin continued until the silver market crash of 1893 (Wilma 2006). Extensive mineral extraction occurred in the Malott and Conconully mining districts between 1886 and 1967 where commodities like silver, gold, antimony, copper, tungsten, arsenic, lead, zinc were extracted in the northern portions of the watershed (Wolff 2011).

Tungsten and silver extraction occurred along Sweat Creek, a tributary to Summit Creek, in the Chloride, Windfall, and Buckhorn mines. Gold extraction occurred along Rock Creek at the Rock Creek Placer mine. Silver extraction occurred along the uppermost portions of Loup Loup

Creek at the Ruby Hill District. These mines were in production in 4 separate periods: 1886–1893, 1901–1924 intermittently, 1937–1940, and 1958-1967 (Wolff 2011). Massive quartz was also extracted near Little Loup Loup Creek and Buzzard Lake at 2 extraction points named Loup Loup and Howell. Washington occurrences of massive quartz may have been in production at any time during the period from 1948 to 1957 (Valentine 1960).

2.3.4 Roads

The upper Loup Loup Creek watershed have an abundance of unpaved forest roads, some of which are situated alongside streams. This proximity can result in heightened sedimentation within the streams, diminished riparian canopy, and compromised runoff hydraulic systems (OWSAC 2000). Road length surveyed by Okanogan County and WDNR totals approximately 450 km. However, these surveys likely do not capture all roads, particularly private roads (WDNR 2019).

Of the surveyed roads, about 21 km are paved. This includes roughly 15 km of Highway 20 and the remaining roads located in the town of Malott. Most roads in the watershed are unpaved, totaling approximately 429 km, and are made of crushed aggregate, soil, or other materials. Forest road density in the Loup Loup Creek watershed is summarized by soil erosion sensitivity and burn severity exposure in each HUC12 sub-watershed in Section 2.3.6.

2.3.5 Timber Harvest

Major timber harvest activities on state lands in the Loup Loup State Forest area began in the late 1960s and early 1970s. These historical harvests were often spread out over a large area and utilized a selective tree method, often referred to as risk tree removal. In the 1980s and 1990s, timber harvest strategies in this area shifted more towards large scale small tree thinning and smaller final harvest units. Recent timber harvests have included a wide range of management strategies focused on increasing overall forest health and generating revenue for the Common School Trust (Townsend, A., WDNR, pers. comm., February 26, 2024).

In the last 40 years, timber harvest in the Loup Loup Creek watershed has averaged about 142 to 202 hectares (350 to 500 acres) per year, equating to around 7,690 hectares (19,000 acres) treated over that time span. These treatments range from small tree thinning to final harvest. The WDNR conducted approximately 526 hectares (1,300 acres) of salvage logging following the 2009 Oden Road Fire in the Loup Loup watershed to reduce future fire risk (Townsend, A., WDNR, pers. comm., February 26, 2024).

2.3.6 Wildfire

Wildfire-driven alterations to soils significantly impact watershed processes, dictating the character and function of the watershed and other interconnected abiotic and biotic systems (Ice et al. 2004; Parise and Cannon 2012). Post-fire hydrology typically diverges from pre-fire behavior, typically resulting in a significant increase in the delivery of water, sediment, and debris to stream channels (Helvey 1980; Wissmar et al. 1994). Historically, the dry forests, sagebrush steppe, and other dryland ecosystems of Washington and much of western North America saw short fire return intervals that produced periodic low-intensity wildfires (Hessburg et al. 1999; Haydon 2018). These wildfires controlled the accumulation of fine ground fuels and wood debris, preventing excessive fuel loading that facilitates fires of greater intensity and spatial scale, moderating wildfire-derived impacts on watershed processes and function (Hessburg et al. 1999). Frequently originating from lighting strikes, naturally occurring fires were supplemented by fires intentionally lit by indigenous peoples to control the propagation and abundance of culturally significant plant species and other resources (Wissmar et al. 1994; Pyne 2015). The arrival of Euro-American settlers saw the reduction and eventual elimination of indigenous burning practices, which were replaced by robust fire suppression systems. This resulted in a significant reduction in the frequency and extent of wildfires on the landscape in the early and mid-20th Century (Pyne 2015; Hessburg et al. 2021). The alteration of natural fire dynamics coincided with significant alterations to plant communities across the region, facilitated by exotic plant introductions, widespread livestock grazing, and changes in succession patterns associated with non-fire-related disturbance agents such as logging (Wissmar et al. 1994).

The interruption of natural fire cycles within the Loup Loup Creek watershed has resulted in increased susceptibility to larger, more intense wildfire activity. Since 1970, over 77% of the watershed has been affected by large, often high-intensity fires (WDNR 2023). The most significant fire events in terms of acreage burned and overall disturbance to the watershed being the 2014 Carlton Complex Fire, burning 2,050 hectares (5,065 acres), and the 2015 Limebelt Fire (part of the Okanogan Complex), burning 9,492 hectares (23,455 acres) (WDNR 2023). Smaller burns within the watershed have impacted small segments in proximity to population centers, namely the unincorporated community of Malott, where Loup Loup Creek converges with the Okanogan River.

The Limebelt Fire burned the majority of the Loup Loup Creek watershed, with only a few small fire refugia surviving within the burn perimeter at the northern end of the watershed (BAER Team 2015; WDNR 2023). The burned area was assessed as part of an Interagency Burned Area Emergency Response (BAER) report for the Okanogan Complex Fire. Assessments of engineering-related values, threats, and risk determined a high to very high risk of road blockages, overtopping, culvert failure, slope failure, and large-scale erosion from post fire floods and debris flows, posing significant risk of damage to homes, outbuildings and irrigation infrastructure (BAER Team 2015). The majority of the Loup Loup Creek watershed burned at high intensity with high soil burn severity, creating hydrophobic soil conditions. Large portions of the watershed were denuded of vegetation, including riparian zones, eliminating stream shading and increasing erosion. The resulting negative impacts on riparian and watershed process conditions dramatically degraded habitat conditions for anadromous fish and other aquatic life throughout the watershed (BAER Team 2015).

Degraded sediment and hydrologic process conditions are reflected by the intersection of naturally erodible soils and areas exposed to high severity fire effects. The Okanogan CD used the following information to characterize soil sensitivity to erosion in the Lower Loup Loup Creek, Upper Loup Loup Creek, and Sweat Creek HUC12 sub-watersheds:

- Post-wildfire burn severity derived from vegetation cover remaining after the 2009 Oden Road Fire, the 2014 Carlton Complex Fire, and the 2015 Limebelt Fire using the Monitoring Trends in Burn Severity (MTBS) dataset as shown in Figure 5. The MTBS uses differenced Normalized Difference Vegetation Index (NDVI) images comparing pre-fire imagery to post-fire imagery captured 1 to 12 months after fire containment to distinguish burned areas from unburned areas and categorize vegetation burn severity classes (USDA et al. 2024). Definitions for the range of burn severity ratings can be found in the Burn Severity Portal Glossary available here: https://burnseverity.cr.usgs.gov/glossary.

- Erosion risk from unsurfaced roads and trail areas derived from the National Soil Information System Interpretations criteria-based road and trail erosion hazards (USDA NRCS 1998).

Table 3 describes the soil erosion hazard potential in the Loup Loup Creek watershed following 3 significant fires in the watershed, the 2009 Oden Road Fire, the 2014 Carlton Complex Fire, and the 2015 Limebelt Fire. As shown, most of the Lower Loup Loup Creek and Upper Loup Loup Creek sub-watersheds experienced a range of burn severity on severely and moderately erodible soils.

The Lower Loup Loup Creek sub-watershed has 2 areas that experienced repeated wildfires. One area totaling 900 hectares (2,225 acres) burned twice in the 2009 Oden Road and 2014 Carlton Complex fires. Within this burned area, 74% lies on severely erodible soils, and the remaining 24% is classified as moderately erodible. Additionally, a separate area of 126 hectares (311 acres) burned twice in the 2009 Oden Road and 2015 Limebelt fires. Here, 83% of the burned area consists of severely erodible soil, with the remaining 17% classified as moderately erodible.

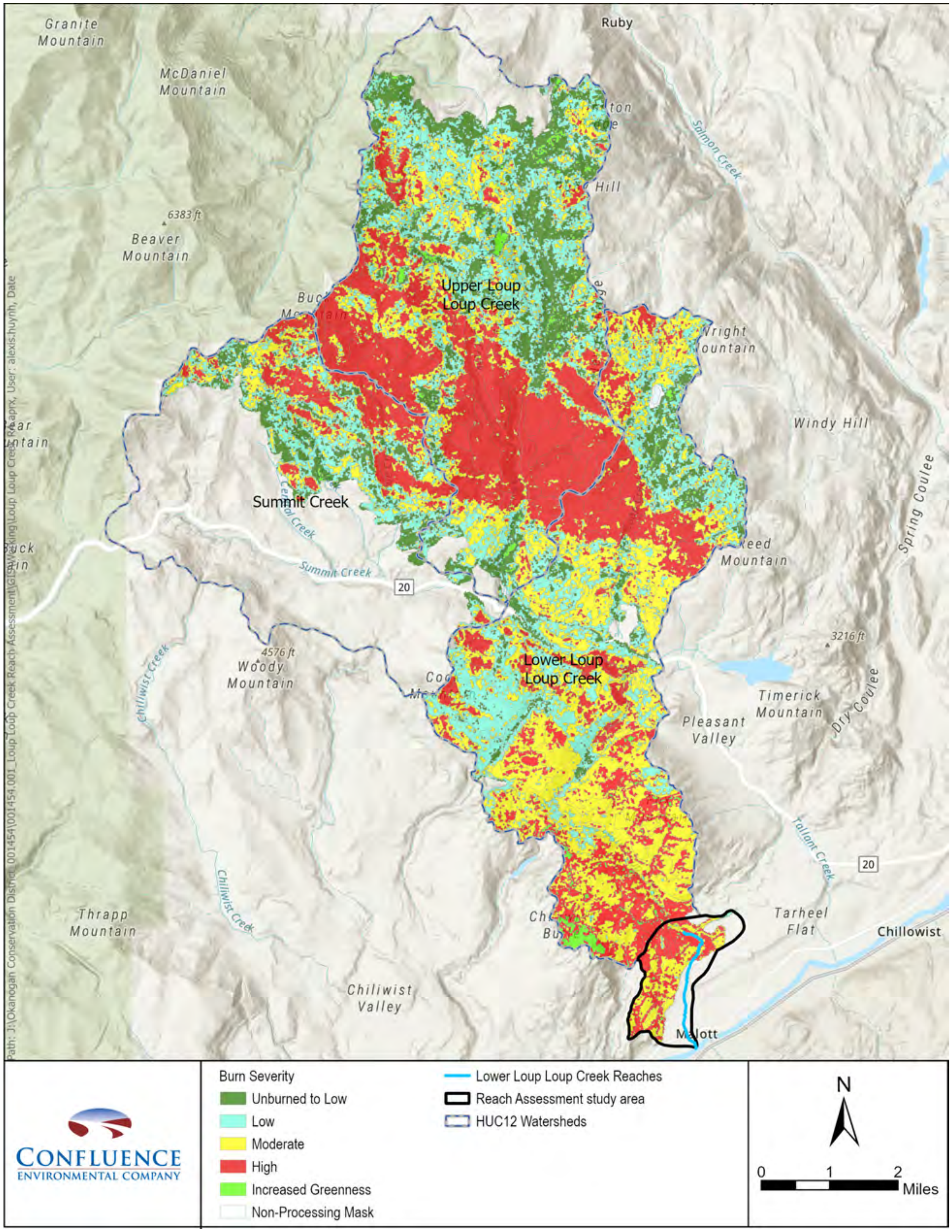


Figure 5. Burn severity ratings from the Oden Road (2009), Carlton Complex (2014), and Limebelt (2015) fires in Loup Loup Creek watershed (USDA et al. 2024)

Table 3. Loup Loup Creek watershed soil erodibility and wildfire burn severity exposure

HUC12	Soil Erosion Hazard Rating	Burn Severity	Acres	% of HUC12*	Unpaved Roads (km/sq km)
Lower Loup Loup Creek – 170200062203	Slight	Unburned to low	17	0.1%	5.47
		Low	42	0.3%	3.52
		Moderate	106	0.7%	2.67
		High	94	0.6%	2.11
	Moderate	Unburned to low	112	0.8%	2.79
		Low	796	5.5%	1.81
		Moderate	957	6.6%	2.14
		High	778	5.3%	2.07
	Severe	Unburned to low	842	5.8%	2.87
		Low	4,009	27.5%	2.07
		Moderate	5,369	36.8%	1.46
		High	3,039	20.8%	0.95
	Not Rated	Unburned to low	14	0.1%	<0.01
		Low	52	0.4%	<0.01
		Moderate	62	0.4%	<0.01
		High	30	0.2%	<0.01
Upper Loup Loup Creek – 170200062201	Slight	Unburned to low	2	0.0%	6.81
		Low	--	--	<0.01
		Moderate	--	--	<0.01
		High	--	--	<0.01
	Moderate	Unburned to low	448	2.9%	4.46
		Low	467	3.1%	2.72
		Moderate	439	2.9%	3.11
		High	1,150	7.5%	3.80
	Severe	Unburned to low	2,077	13.6%	1.85
		Low	2,996	19.6%	1.83
		Moderate	2,307	15.1%	1.93
		High	3,639	23.8%	2.64
	Not Rated	Unburned to low	7	--	<0.01
		Low	13	0.1%	<0.01
		Moderate	12	0.1%	<0.01
		High	5	--	<0.01

HUC12	Soil Erosion Hazard Rating	Burn Severity	Acres	% of HUC12*	Unpaved Roads (km/sq km)
Summit Creek – 170200062202	Slight	Unburned to low	--	--	<0.01
		Low	--	--	<0.01
		Moderate	--	--	<0.01
		High	--	--	<0.01
	Moderate	Unburned to low	133	1.2%	2.62
		Low	163	1.5%	4.37
		Moderate	99	0.9%	4.39
		High	151	1.3%	6.06
	Severe	Unburned to low	582	5.2%	3.43
		Low	978	8.7%	3.07
		Moderate	856	7.6%	2.63
		High	928	8.3%	2.72

* Percentages may sum to over 100% due to overlap in burned areas between Oden Road (2009) and Limebelt (2015) fires and between Oden Road (2009) and Carlton Complex (2014) fires. Overlapping burned areas total 2,536 acres.

All 3 sub-watersheds within the Loup Loup Creek watershed exhibit comparable densities of unpaved roads. These densities are around 29 km/sq km for each sub-watershed. However, as shown in Table 3, the erosion potential of these roads varies. Unpaved roads in the Lower Loup Loup Creek sub-watershed are less susceptible to erosion, while those in the Upper Loup Loup Creek and Summit Creek sub-watersheds are rated as moderate to severe for soil erosion potential. Areas with more severe fire effects, especially on moderately or severely rated soils, have a higher potential for sediment transport.

2.4 Fish Use and Population Status

Lower Loup Loup Creek currently supports westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) and potadromous and anadromous interior Columbia Basin redband trout/steelhead (*O. mykiss gairdneri*). Loup Loup Creek may have historically supported spring Chinook salmon (*O. tshawytscha*) prior to irrigation system development in the late 19th century (NMFS 2014). The CTCR is currently working to reintroduce spring Chinook to the Okanogan River system (NMFS 2014), indicating the potential for the study area to provide habitat for this species in the future.

Okanogan steelhead are the primary focus of habitat restoration efforts in Loup Loup Creek and the only species that is routinely monitored by OBMEP to track annual abundance trends in this system (Miller et al. 2023). Okanogan summer steelhead belong to the Upper Columbia River summer steelhead Distinct Population Segment, which is currently listed as threatened under the ESA (79 FR 20802). Loup Loup Creek is known to support steelhead spawning and juvenile rearing. As such, the protection and restoration of spawning and rearing habitat is a focus of restoration planning efforts. Those efforts are necessarily informed by the life history of Okanogan steelhead and habitat requirements at each life stage.

Doyle (2013) summarized available information on Okanogan steelhead life history to support EDT model development. Adult age structure is approximately evenly distributed between 1-salt and 2-salt migrants. The tributary spawning period extends from mid-March through the end of May, with a distinct peak in mid-April tied to peak spring runoff period (Miller et al. 2023). Steelhead access to many Okanogan River tributaries is limited by low streamflow conditions, meaning that a pulse of spring runoff is usually required for adults to enter the system. In the case of Loup Loup Creek, adult access to spawning habitats is entirely flow dependent.

The overwintering behavior of Okanogan steelhead is not fully understood, but PIT tag data indicate that pre-spawn adult steelhead do not use Loup Loup Creek and other small tributary streams as overwintering habitat (Miller et al. 2023), likely due to cold water temperatures and limited access under winter baseflow conditions. A significant percentage of adult Okanogan steelhead overwinter in the Wells Pool and possibly the mainstem Columbia downstream of Wells Dam. The 10-year average migration timing of steelhead past the Wells Dam observed by the Fish Passage Center (FPC 2013, 2024) shows migration past the dam from the beginning of July through mid-November. This is generally consistent with the observed timing of Columbia River entry and the predicted duration of Columbia mainstem migration. Notably, FPC monitoring data do not include the months of December through April. As such, there remains some potential for steelhead migration past Wells Dam in late-winter and early-spring before regular monitoring begins each year. Historically, steelhead migration past Rock Island Dam demonstrated a distinct bimodal peak prior to the completion of Columbia River hydrosystem development (Fish and Hanavan 1948). The majority of migrating steelhead passed Rock Island between mid-July and late-November, but a significant minority passed the dam from early-April through late-June. The behavior of the latter group is explained only by overwintering in the Columbia mainstem and large tributaries downstream of Rock Island.

Peven et al. (1994) observed that the average age structure of smolts captured at Rocky Reach Dam in 1988 and 1989 was 2.0% age 1, 45.4% age 2, 41.4% age 3, and 10.4% age 4, with the remainder distributed across older age classes. CTCR fisheries staff believe that this distribution is not representative of Okanogan steelhead, however, on the basis that the population is composed primarily of hatchery steelhead that smolt at age 1 and the relatively warm and productive conditions in this system promote faster growth and earlier age at smolting (Doyle 2013). Based on observed age at migration from screw trap studies, CTCR fisheries staff conclude that the representative distribution of age at smolting in Okanogan River tributaries is approximately 30% age 1, 50% age 2, and 20% age 3.

OBMEP uses the EDT model to characterize habitat performance in the Okanogan River and its tributaries, including Loup Loup Creek. Steelhead are the only species currently modeled in EDT in the Loup Loup Creek watershed. EDT equilibrium abundance is a modeled estimate of the theoretical population size that habitat of a given capacity and productivity can support. OBMEP has generated EDT equilibrium abundance estimates for lower Loup Loup Creek based on the average of observed habitat conditions during each 4-year status and trends monitoring cycle. A comparison of EDT-predicted and observed steelhead abundance in Loup Loup Creek during the 2018 to 2021 habitat status and trends monitoring cycle is provided in Table 4.

3.0 REACH ASSESSMENT METHODS

As stated in Section 1.0, the intent of the Lower Loup Loup Creek RA is to demonstrate that Okanogan CD can produce cost-effective RA reports for Okanogan subbasin tributaries using a synthesis of OBMEP monitoring data, EDT model inputs and results, and publicly available GIS and remote sensing data. This section describes the information sources and methods used to develop this RA report. Primary information sources include the following:

- Data obtained from OBMEP long-term habitat status and trends monitoring and other subbasin level monitoring efforts, using the OBMEP (2012) habitat protocol;
- Information derived from Okanogan EDT model inputs;
- EDT priority habitat limiting factors generated EDT model results generated by model inputs for the 2018-2021 monitoring cycle at the study area and reach levels, and;
- Outputs from other models (e.g., peak flow regression models).

These data and information sources and analysis methods used to develop this RA are described below.

3.1 Reach Delineation

The Lower Loup Loup Creek RA study area, also referred to as the Lower Loup Loup Creek-DS AU, is the downstream-most portion of the Loup Loup Creek watershed. It extends downstream from a gorge located at the edge of the valley wall to the creek’s confluence with the Okanogan River.

Table 4. Comparison of EDT-modeled and observed steelhead abundance, 2018-2021 OBMEP status and trends monitoring cycle

Population Parameter	Monitoring Cycle	EDT Modeled Equilibrium Abundance	Geomean of 2018-2021 Observed Abundance ± 90% CI (range) ‡		
			Natural Origin	Hatchery Origin	Total (Natural + Hatchery)
Adult Abundance	2005-2009	0	1 ± 0 (0-2)	4 ± 0 (1-15)	5 ± 0 (2-17)
	2010-2013	17	8 ± 1 (1-22)	44 ± 2 (12-103)	52 ± 3 (13-125)
	2014-2017	12	11 ± 1 (3-33)	19 ± 3 (6-121)	30 ± 4 (12-154)
	2018-2021	12	6 ± 0 (1-14)	19 ± 2 (5-58)	30 ± 2 (10-65)
Smolt Abundance	2005-2009	0	No data	0 ± 0 (0-0)	Insufficient data
	2010-2013	972	No data	0 ± 0 (0-0)	Insufficient data
	2014-2017	693	1,086 ± 270 (600-1,984)	0 ± 0 (0-0)	1,086 ± 270 (600-1,984)
	2018-2021	665	569 ± 108 (323-946)	0 ± 0 (0-0)	569 ± 108 (323-946)

† EDT equilibrium abundance estimate under modeled habitat conditions for the 2018-2021 status and trends monitoring cycle.

‡ Geomean of OBMEP observed abundance over the corresponding 4-year monitoring based on adult PIT-tag and redd count data and juvenile PIT-tag expansion. There were no juvenile hatchery origin steelhead releases in lower Loup Loup Creek during the 2018-2021 monitoring cycle.

The Lower Loup Loup Creek-DS AU is divided into 3 reaches following the "common spatial currency" concept. This reach structure was developed by OBMEP for use in the Okanogan and other Columbia tributary subbasins in the Upper Columbia River Recovery Domain. It emphasizes reaches defined by relatively uniform gradient and valley confinement with lengths ranging from 1 to 4 km. This structure is designed to optimize EDT model performance and provides a consistent framework for habitat monitoring, limiting factor prioritization, and restoration planning. Reach boundaries are identified using the following parameters:

- Geomorphic discontinuities: Changes in gradient and/or confinement that represent a clear shift in habitat conditions within the reach;
- Tributary confluences: Major tributaries or channel branches (not applicable in the Loup Loup Creek AU), or;
- Length optimization: Geomorphically uniform channels are divided at useful landmarks (e.g., road crossings, jurisdictional boundaries) to optimize length.

Reach characteristics are obtained from OBMEP monitoring data for Loup Loup Creek collected during the 2018-2021 monitoring cycle (see Section 3.4). Lower Loup Loup Creek RA reach configuration and characteristics are summarized in Section 4.1.

3.2 Hydrologic Conditions

Hydrologic conditions in Loup Loup Creek are characterized using the following sources of information:

- Real-time discharge data at U.S. Geological Survey (USGS) gage 12447285, Loup Loup Creek at Mallot, WA.
- March snowpack data for the Natural Resources Conservation Service National Water and Climate Center SNOTEL site at Muckamuck in the Salmon Creek watershed.
- April precipitation data from the NOAA National Centers for Environmental Information reporting site at Omak, WA.
- Peak flow recurrence interval estimates for Loup Loup Creek using regional regression equations developed by the USGS and watershed-level precipitation and land cover variables.

The available period of record for USGS gage 12447285 comprises daily 15-minute data discharge data collected from the beginning of water year 2013 to the present, or effectively 10 water years. The currently available data record for Loup Loup Creek is not sufficient for characterizing peak flow recurrence intervals. In general, 10 years is the minimum period of record needed to estimate peak flow magnitude, but at least 25 and ideally 35 years or more of daily flow data are required to develop reliable recurrence interval statistics (Interagency Advisory Committee on Water Data 1982). The period of record for Loup Loup Creek gage data has been highly variable, suggesting that a longer data record is needed to develop reliable peak flow statistics. Moreover, system hydrology is influenced by water withdrawals that artificially reduce the magnitude of the annual peak runoff event. Regardless, the Okanogan CD developed peak flow estimates for the 1.5 to 10-year return interval events from the available data record using the Log-Pearson Type III Distribution method (Interagency Committee on Water Data 1982).

As a point of comparison, the Okanogan CD developed peak flow recurrence interval estimates for Loup Loup Creek using regional regression equations developed by the USGS (Mastin et al. 2016). This approach provides a basis for evaluating how changes in land cover between 2014 and 2021 could affect peak runoff conditions, which provides valuable context for understanding effects of fire on habitat-forming processes at the watershed level. The results of this analysis are presented in Section 4.2.

3.3 Geomorphic Assessment

The Okanogan CD used the following sources of information to characterize current geomorphic and sediment transport conditions within the Lower Loup Loup Creek RA study area:

- Channel and floodplain characteristics derived from:
  - 10-year flood elevations derived from 2015 light-detection and ranging (LiDAR) data (Quantum Spatial 2016).
  - Geomorphic surfaces derived from LiDAR and regional assessments (Flint 1936; Kovanen and Slaymaker 2004; Okanagan Water Stewardship Council 2023)
  - Photographic documentation of channel evolution at fixed locations in Loup Loup Creek 16-1, 16-2, and 16-3, 2013 to 2017.
  - Hydromodifications as percent of overall affected bank length, documented by OBMEP, 2017 to 2021.[1]
- Observed changes in substrate composition between 2015 and 2021 at selected locations in reaches Loup Loup 16-1 and 16-2, obtained from:

[1] OBMEP records hydromodifications as a percentage of bank length within a reach. Hydromodifications are levees, revetments, bank armoring, road crossings, or other manmade features that artificially confine the channel. Mapping of individual features is not available.

  - Cumulative substrate composition trend obtained from periodic bulk subsurface samples collected by OBMEP, 2015 to 2021.
  - Trend in median substrate D50 and D84, obtained from OBMEP Wolman pebble counts, 2014 to 2021.[2]
  - Trend in mean substrate % fines <0.6 millimeter (mm), obtained from OBMEP Wolman pebble counts during the 2005-2009, 2010-2013, 2014-2017, and 2018-2021 monitoring cycles.
- Observed changes in channel configuration in reach Loup Loup 16-1 at monitoring location OBMEP-421,[3] comprising:
  - Trend in cross-sectional bankfull depth profile, 2014 to 2017.
  - Observed change in thalweg depth profile over 150 m of channel, 2014 to 2017.
- Channel incision trends observable in photographic evidence, 2013 to 2019.

Floodplain connectivity, substrate characteristics, and channel configuration in the study area are described in Sections 4.3.1, 4.3.2, and 4.3.3, respectively.

3.4 Habitat Data Summary

OBMEP surveys aquatic habitat composition, woody debris density, and riparian habitat function in each study area reach at least once during each a 4-year monitoring cycle. These data are used to parameterize the Okanogan EDT model for habitat status and trends reporting purposes. These information sources and their use in this RA are described in the following sections.

3.4.1 Habitat Composition

Current aquatic habitat composition in the study area was obtained from monitoring data collected by OBMEP during the 2018 to 2021 monitoring cycle. OBMEP conducts a reach-level census of aquatic habitat composition every 4 years, which is compiled into habitat composition inputs for the Okanogan EDT model. Habitat types are grouped into 4 categories for the purpose of quantifying habitat composition: primary channel; side channel; off-channel; and passage obstructions. EDT habitat type definitions are provided in Table 5.

[2] Pebble count data were collected at 10 equally spaced intervals across a total of 18 equally spaced transects and subtransects at each monitoring location (OBMEP 2012). Approximately 10 to 15 particles were measured at each interval.

[3] Transect bankfull depth and thalweg depth measurements were collected at evenly spaced transects sited relative to transect F, which is sited at the same fixed location each survey year.

Table 5. Habitat unit types used in the Okanogan EDT model

Habitat Class	Measured as	Habitat Unit Type	Definition†
Primary channel	Proportion of wetted main channel area by month	Backwater pools	Protected areas along channel margins that provide low water velocities. Often relatively shallow with fine-grained substrates. This habitat type provides important nursery areas for salmonid fry, summer rearing habitat, and winter refugia.
		Beaver ponds	Beaver ponds provide important ecological functions in riverine systems inhabited by salmonids. These functions include flood storage, nutrient retention, sediment trapping, and amelioration of flow and temperature extremes.
		Glides	Habitats having generally uniform depth and flow with no surface turbulence, generally in reaches of < 1% gradient. May display variable depths with some scour but are distinguished from pools by their overall homogeneity, consistent flow, and lack of structure. Generally deeper than riffles with low habitat complexity. Provides spawning for salmonids.
		Scour pools	Non-turbulent, low-velocity habitat types formed by scour. May form mid-channel or channel margins. Habitat type provides primary holding and rearing habitat for several salmonid species.
		Pool tailouts	Shallow, higher velocity areas at the downstream margin of pool habitats. Primary spawning habitat for salmonids.
		Large cobble riffle	Percentage of the wetted channel surface area comprising large cobble and boulder riffles. Particle sizes of substrate modified from Platts et al. (1983) based on information in Gordon et al. (1992) and Wolman (1954): gravel (0.2- to 2.9-inch/2- to 64-mm diameter), small cobble (2.9- to 5-inch/65- to 128-mm diameter), large cobble (5- to 11.9-inch/129- to 256-mm diameter), boulder (> 11.9-inch/512-mm diameter). Provides interstitial habitats for benthic invertebrates and juvenile salmonid winter rearing.
		Small cobble riffle	Percentage of the wetted channel surface area comprising small cobble/gravel riffles. Particle sizes of substrate modified from Platts et al. (1983), per above. Small cobble riffles provide secondary spawning habitat for salmonids.
Side channel	Proportion of wetted main channel area	Side channels	Side channels are active, secondary channels that are separated from the main channel by a stable island. Side channels are distinct from braided primary channels in anastomosing river environments. Typically carry 10% or less of total flow and have different flow and bed stability conditions from the mainstem. Provide high flow refuge. Can be active year-round or seasonally.
Off-channel	Proportion of wetted main channel, in addition to main	Groundwater channels	Floodplain channel features that are unconnected to the main river channel at their upstream end and fed primarily by spring-fed or hyporheic flow, although other sources of groundwater may also be present.

Habitat Class	Measured as	Habitat Unit Type	Definition†
	channel area, by month	Floodplain ponds	Floodplain ponds are natural or constructed ponds in or above the floodplain such as abandoned gravel pits, mill ponds, abandoned oxbows, and wetland depressions. They may be supplied by groundwater or surface water from streams, springs, or the mainstem, though they are frequently not connected to the mainstem river. Frequency of inundation by the mainstem depends on elevation and degree of connectivity.
Obstructions	Percent passage by species, life stage, and month	Dams	Structures that create impoundments.
		Irrigation diversion	Irrigation and diversion dams or weirs that divert water from the main channel to canals. May be screened or unscreened.
		Culverts	Corrugated pipe or arch, concrete box, open bottom or other culvert designs at road crossings.
		Waterfalls	Natural barriers formed by falls, cascades, or extended steep gradients.
EDT habitat-type definitions from Doyle and Lestelle (2021).			

Primary channel habitat composition is characterized using the proportional distribution of habitat types as percent of primary channel wetted area. Side channels are characterized as the percent of main channel wetted area, in addition to primary channel area (i.e., side channel and primary channel habitat unit percentages will sum to >100% when side channels are present). Off-channel habitats dimensions are characterized proportionally to the bankfull wetted area of the primary channel. For example, a floodplain pond that is 1.5 times the bankfull wetted area of the adjacent reach would have a proportional area of 150%.

3.4.2 Large Woody Debris

Data on the quantity of large woody debris (LWD) in Loup Loup Creek were collected by OMBEP between 2018 and 2021. All pieces of LWD that were at least partially within the active creek channel were recorded. The active channel was considered the area wetted during ordinary baseflow conditions (CTCR 2011). Wood pieces that were at least 1 m long and 4 inches in diameter at the larger end of the piece were counted as LWD. LWD was defined within 2 size class based on the largest diameter and length of each piece:

- >0.1 m (4 in) large end diameter and >1 m (3.28 feet) long
- >0.1 m (4 in) large end diameter and >2 m (6.56 feet) long

LWD pieces were considered "small" if they fell into the first size class (i.e., >1 m long but <2 m long) and large if they were within the second size class (i.e., >2 m long). Only the exposed portions of LWD pieces (as opposed to portions embedded within the stream bank) were measured for the purposes of the LWD inventory. Branches were not included in the measurements. In addition to LWD counts by size class, OBMEP also quantified LWD jams.

Jams are identified as 4 or more comingled pieces of small and/or large woody debris (CTCR 2011).

3.4.3 Riparian Composition

Riparian composition in the study area was derived from remote sensing data using a methodology developed by OBMEP, supplemented by Okanogan CD knowledge of local vegetation conditions. The spatial data processing steps used by OBMEP are as follows:

1. Acquire 2021 4-band National Agricultural Imaging Program (NAIP) orthoimagery.
2. Calculate NDVI using the Raster Calculator in the ESRI ArcGIS Spatial Analyst Module.[4]
3. Mask with 1.5 to 10-year recurrence interval (RI) floodplain polygon, modified to exclude open water or exposed gravel bars visible in orthophotos. Elevations lower than bankfull are not excluded from small (<20 m bankfull width) tributaries to characterize canopy closure.
4. Revise symbology of masked NDVI to identify no vegetation (<139), light vegetation (139-166), moderate vegetation (166-199) and heavy vegetation (199-255) ground cover categories. The NDVI thresholds may require readjustment between NAIP photo series to account for NDVI color scale variability (2021 min value = 124).
5. Reclassify NDVI raster by vegetation category.
6. Convert reclassified NDVI raster to masked polygons (no simplification).
7. Use Intersect to assign masked NDVI to reaches.
8. Dissolve polygons on reach and vegetation class.
9. Intersect human activity and disturbance polygons with masked NDVI to remove manmade features (e.g., orchards).
10. Calculate remaining polygon area by vegetation class for each reach.
11. Calculate proportional area by vegetation classification for each reach.

This method was used quantify the proportional distribution of established perennial riparian vegetation and unvegetated ground/seasonal forb and grass cover within the 10-year RI floodplain. These findings are summarized in Section 4.1. Okanogan CD used on-the-ground knowledge of vegetation community structure to identify the typical plant species that

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[4] NDVI algorithm: = Int(((Float("%Near IR Band%") - Float("%Red Band%")) / (Float("%Near IR Band%") + (Float("%Red Band%"))) + 1) * 127.5)

comprise these riparian vegetation categories in each reach. These findings are provided in Section 4.3.6.

3.5 REI Analysis

The reach-based ecosystem indicators (REI) analysis presented herein is based on the framework developed by the Upper Columbia Regional Technical Team (UCRTT 2022, Appendix A). This REI framework rates environmental conditions using 3 categorical tiers: Acceptable conditions (AC); at risk conditions (AR); unacceptable conditions (UN). The UCRTT condition tiers are comparable to the Properly Functioning, At Risk, and Not Properly Functioning condition tiers used in the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife (USFWS) matrices of pathways and indicators (NMFS 1996; USFWS 1998), and subsequent adaptions by the U.S. Bureau of Reclamation (USBR). The USBR has used these REI measures in numerous RAs conducted in the tributary subbasins to the Upper Columbia Recovery Domain.

The Loup Loup Creek REI rating approach assumes the use of EDT model inputs and selected model outputs for steelhead. REI analysis results are presented in Section 4.4. EDT-based REI pathways and indicators, and the model inputs, outputs, and other information sources used to characterize indicator conditions are detailed in Appendix A.

3.6 Limiting Factor Identification

OBMEP developed the Okanogan EDT model to support habitat status and trends reporting and identification of priority habitat limiting factors at AU and reach scales (Doyle et al. 2022). Consistent with UCRTT (2022) guidance, Okanogan CD is relying on EDT results for the 2018 to 2021 monitoring cycle, as reported on the Okanogan HSTR (https://ecosystems.azurewebsites.net/hstr-okanogan/), to identify AU and reach-level priority habitat limiting factors for the study area. These results are summarized in Section 4.1 and described in Section 4.5.

3.7 Identification of Restoration Opportunities

The Okanogan CD used a 3-step process to identify restoration opportunities in the study area.

- Step 1: Compile potentially suitable restoration actions for the study area identified on the Okanogan HSTR Implementation module (https://ecosystems.azurewebsites.net/hstr-okanogan/).
- Step 2: Select a subset of categorical actions that are suitable for the study area based on land ownership and ecological context.

- Step 3: Identify currently planned and potential projects that align with the list of categorical actions identified in step 2 and score those projects based on likely effectiveness and feasibility.

The HSTR Implementation module links EDT-identified priority limiting factors to categories of potentially suitable restoration actions at AU and reach scales. The list of categorical restoration actions used on the Implementation module was developed by the UCSRB for strategic restoration planning and grand funding purposes. The module links the limiting factors in the selected reach or AU to each UCSRB restoration action using "strength of effect" (SOE) ratings. OBMEP developed these SOE ratings in collaboration with the UCSRB, UCRTT, and other regional experts. The SOE ratings represent the anticipated effect of each UCSRB restoration action on each environmental attribute used in the EDT model. The Implementation module calculates a combined SOE score for each categorical restoration action by weighting its SOE ratings against the priority limiting factors in that reach or AU.

The Okanogan CD compiled the SOE scores for Loup Loup Creek grouped them into high, medium, and low priority actions by reach and for the study area as a whole. The high and medium priority actions identified for the study area are summarized in Section 5.1.

Several high-priority restoration actions have been completed in Loup Loup Creek that pre-date this RA. These actions are summarized in Section 5.2. Planned and recommended future restoration actions for the study area are described in Section 5.3. These actions are identified by their associated UCSRB restoration action category and priority rank and rated for feasibility using a modified version of the Bonneville Power Administration's Atlas feasibility scoring criteria (Kaplowe et al. 2018). Atlas feasibility criteria are described in Table 6.

Table 6. Modified Atlas project feasibility scoring criteria used in the Lower Loup Loup Creek RA

Criterion	Categorical Feasibility Score		
	3	2	1
Land ownership	Landowner is collaborative, work permission and property access would be easy to obtain.	Landowner permission possible but may be complex. Includes sites requiring permission from multiple willing landowners.	Landowner permission would be difficult to obtain.
Site access	Access is relatively easy via existing or historical road. No major road building or road decommissioning would be required.	Access moderate to difficult but possible. May require access road creation, with road decommissioning and site restoration. Alternatively, site may be accessible only by trail with small machinery and hand tools.	Access difficult. Road access not possible. May require fording, temporary bridge, or other complex and expensive means (e.g., helicopter delivery).
Regulatory and permitting complexity	Permitting is straightforward (e.g., action is covered under	Permitting is moderately complex. Individual ESA	Permitting is highly complex. May require NEPA EIS and

Criterion	Categorical Feasibility Score		
	3	2	1
	an existing programmatic NEPA and ESA consultation).	consultation and NEPA EA may be required.	individual ESA consultation. Mitigation for wetland and buffer impacts, etc.
Design and planning complexity	Projected costs range from $25,000 to $75,000.	Projected costs range from $75,000 to $150,000.	Projected costs exceed $150,000.
Construction cost	Projected costs range from $50,000 to $200,000.	Projected costs range from $200,000 to $500,000.	Projected costs exceed $500,000.
Site management (dewatering and erosion control)	Minimal site management and construction monitoring required.	A moderate level of site management effort required. May include dewatering and some erosion control measures, fish exclusion, construction monitoring.	Significant level of site management effort required. Includes fish salvage, dewatering, extensive erosion control measures, and construction monitoring.
Risk – Safety and property	Low risk (flooding, impacts to river users, or impacts of displaced project elements are not likely to result from the project).	Medium risk (flooding, impacts to river users, or impacts from displaced project elements could result from the project).	High risk (flooding, impacts to river users, or impacts from displaced project elements are likely if the project or a project element fails).

4.0 REACH ASSESSMENT RESULTS

This section presents the findings of the Lower Loup Loup Creek RA. The study area is divided into 3 reaches, Loup Loup 16-1, 16-2 and 16-3, as shown in Figure 6. These reaches were previously established by OBMEP using the UCSRB common spatial currency concept and are used for habitat status and trends monitoring. The reach nomenclature represents the stream name (Loup Loup), the year in which the reach delineation was established (2016), and the sequential reach number extending from downstream to upstream from the confluence of Loup Loup Creek with the Okanogan River.

4.1 Reach Characteristics

The Loup Loup Creek reaches evaluated in this RA are described in Table 7 and displayed in Figure 7. A summary of reach characteristics derived from OBMEP monitoring data and EDT model inputs is provided by reach in the following sections.

Table 7. Reach structure in the Lower Loup Loup Creek RA study area

Reach Name	Reach Length (km)	Average Gradient (rise/run)	Valley Confinement Ratio	Reach Break Type	Description
Loup Loup 16-1	1.247	0.015	>4	Length optimization	Unconfined reach on lower alluvial terrace. Extends from confluence with Okanogan River to dirt road crossing 1.247 km upstream from mouth.
Loup Loup 16-2	1.248	0.017	3.7	Geomorphic	Unconfined to partially confined reach extending from upstream end of Loup Loup 16-1 to gradient break at upstream edge of alluvial terrace. Encroaching alluvial fans are present along the western edge of the active floodplain.
Loup Loup 16-3	1.002	0.036	2.5	Geomorphic	Moderate gradient, moderately confined reach extending from the downstream edge of the primary alluvial fan to the recent upstream limit of anadromous habitat at a series of natural falls and cascades. This barrier was removed in late 2023..

Figure 6. Lower Loup Loup Creek RA reach structure

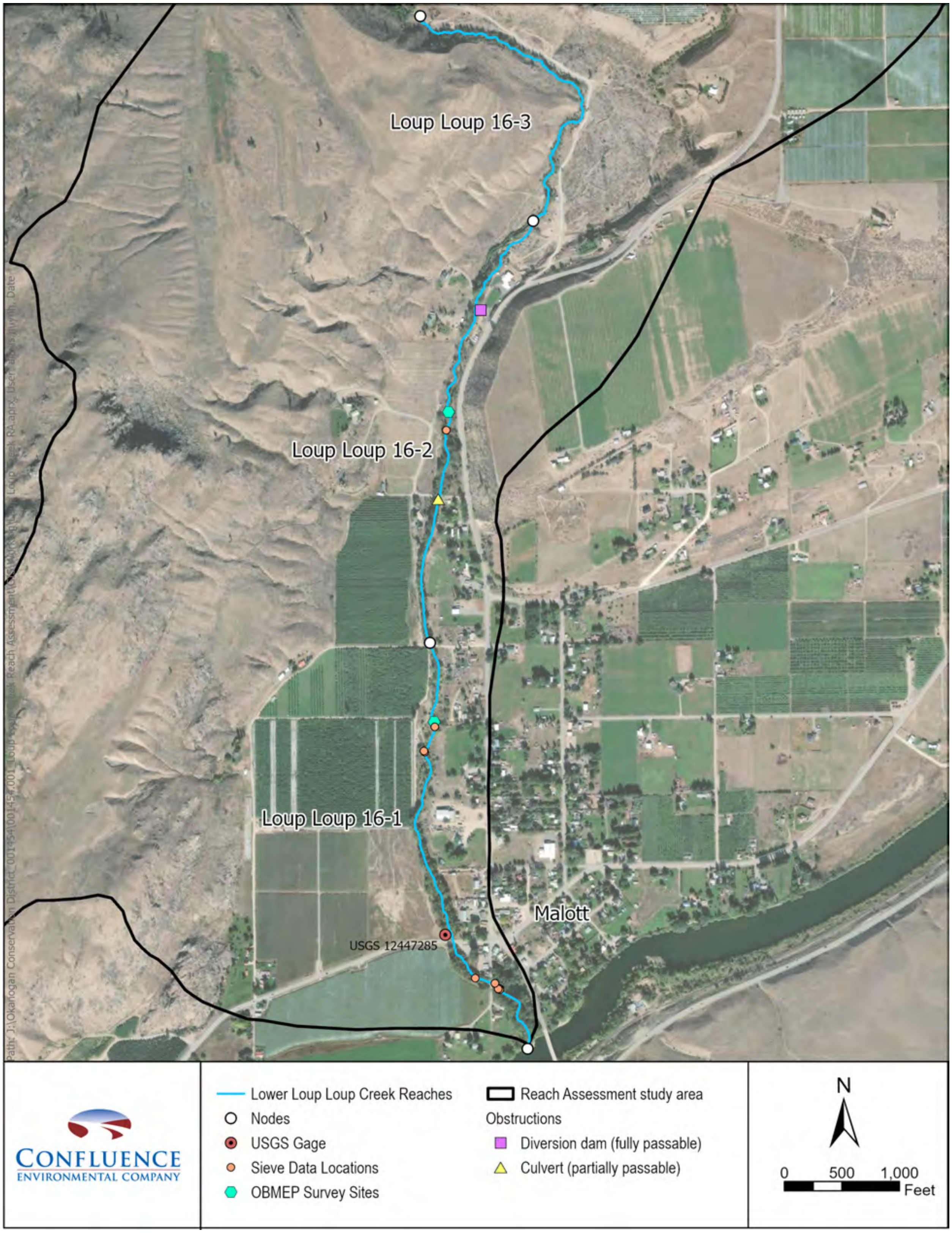

Figure 7. Lower Loup Loup Creek RA reaches, OBMEP monitoring locations, and other relevant features in the study area

4.1.1 Loup Loup 16-1

Reach Loup Loup 16-1 is 1.247 km in length, extending from the confluence of Loup Loup Creek with the Okanogan River upstream to a private unpaved road crossing at the upstream end of Okanogan County Assessor parcel number 7250170003. OBMEP monitoring activities in this reach comprise a complete habitat census every 4 years, intensive annual monitoring data collection at location OBMEP-421, and periodic bulk subsurface sample collection to evaluate changes in sediment composition. Reach topography and geomorphic surfaces in Loup Loup 16-1 are shown in Figure 8.

Table 8 provides a summary of reach parameters and representative photographs for Loup Loup 16-1. As shown, this reach is an unconfined Rosgen type G3 channel, with a moderate average gradient of 0.015 (1.5%), a sinuosity index of 1.16, and an average bankfull width of 4.0 m. Bank armoring or other hydromodifications are present over approximately 50% of channel length.

Notable channel incision has occurred in portions of this reach during the last decade. This development is evident in a photographic comparison of channel conditions in 2014 and 2019 at monitoring location OBMEP-421, transect F (Table 8) and changes in channel cross-section and thalweg depth profile observed at this location from 2014 through 2017 (see Section 4.3.3).

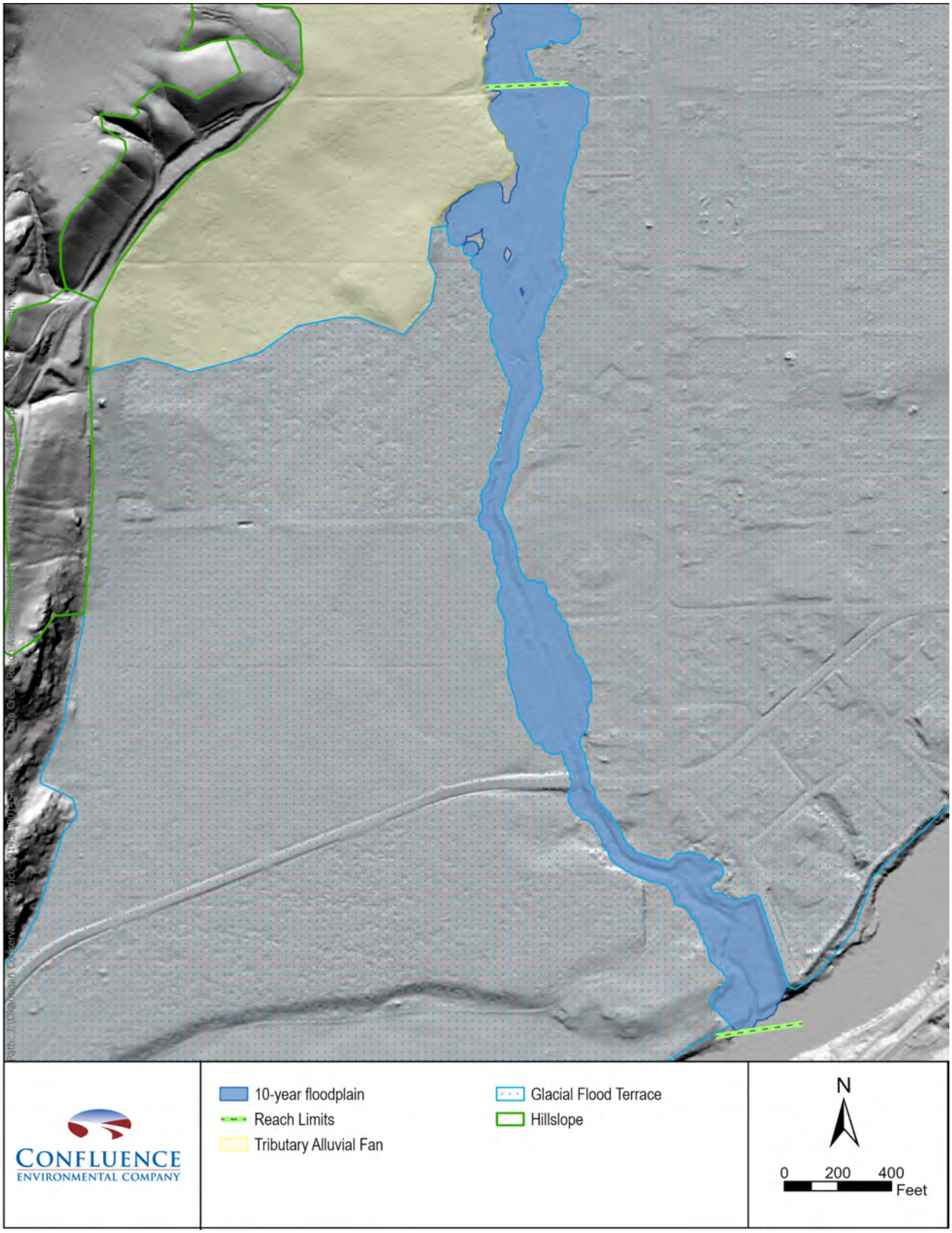

Figure 8. Loup Loup 16-1 reach topography and geomorphic surfaces

Table 8. Reach Loup Loup 16-1 physical characteristics and representative photos

Reach Parameter	Value	Representative Photos
Reach length (km)	1.247	
Rosgen type	Type G3	
Gradient (rise/run)	0.015	
Sinuosity (ratio)	1.14	
Bankfull width (m)	4.0	
Width-depth ratio	5.0	
Confinement ratio (valley/bankfull width)	>4 (unconfined)	
Entrenchment ratio	1.4	
Dominant substrate (% of total mass)	Small cobble <128 mm (51-53%)	
Bank armoring (% of length)	50%	
Riparian composition‡	Established perennial: 62.4%; Unvegetated/seasonal: 37.6%	
Woody debris (pieces/mile)	100.7 (in 2021)	
Woody debris jams (jams/mile)	10.3 (in 2021)	
Habitat composition∆	Backwater pools: 0%; Beaver ponds: 0; Glides: 23%; Large cobble riffles: 36%; Scour pools: 23%; Pool tailouts: 1%; Small cobble riffles: 17%; Side channel: 11%	
Obstructions	Two historical barrier culverts in Malott (removed in 2011).	
Pools frequency (pools/km)	33.7	
Hydraulic radius (m)†	0.54	
Basal shear stress (Pa)†	6.4	
EDT Priority Attributes	Temperature (daily maximum); Woody debris; Confinement (artificial); Embeddedness	

‡ Vegetation composition within the 10-year recurrence interval floodplain. Vegetation composition derived from 2021 NAIP imagery. Floodplain polygon derived from LiDAR using the Inverse Distance Weighted interpolation method.

∆ Percent of bankfull wetted area by habitat type (see Section 3.4)

† Median basal shear stress interpolated from OBMEP transect depth measurements in pool tailout, glide, and small cobble riffle habitat types (Doyle et al. 2015).

4.1.2 Loup Loup 16-2

Reach Loup Loup 16-2 is 1.248 km in length, extending from the upstream end of Loup Loup 16-1 to a geomorphic discontinuity formed by a change in valley confinement and channel gradient beginning approximately 1 km downstream from the current upstream terminus of anadromous habitat. OBMEP monitoring activities in this reach comprise a complete habitat census every 4 years, periodic monitoring data collection at location OBMEP-1222, and periodic bulk subsurface sample collection to evaluate changes in sediment composition. The latter are supplemented by additional bulk subsurface samples collected by Windward Environmental (2023) to support restoration design development in this reach. Reach topography and geomorphic surfaces in Loup Loup 16-2 are shown in Figure 9.

Table 9 provides a summary of reach parameters and representative photographs for Loup Loup 16-2. As shown, this reach is a partially confined Rosgen type G4 channel, with a moderate average gradient of 0.017 (1.7%), low sinuosity (sinuosity index of 1.08), and an average bankfull width of 5.4 m. Bank armoring or other hydromodifications are present over approximately 21% of channel length.

As with Loup Loup 16-1, notable channel incision and changes in substrate composition have occurred in reach Loup Loup 16-2 over the last decade. This development is evident in a photographic comparison of channel conditions in 2014 and 2019 at monitoring location OBMEP-1222, transect A (Table 9). As shown, the predominantly cobble and gravel sized substrates present in 2014 have shifted clearly towards sand-sized substrates. Measured changes in cumulative substrate distribution in Loup Loup 16-2, derived from subsurface bulk samples, indicate that the gravel to cobble sized substrates have largely been scoured and replaced by sand (see Section 4.3.2, Figure 18).

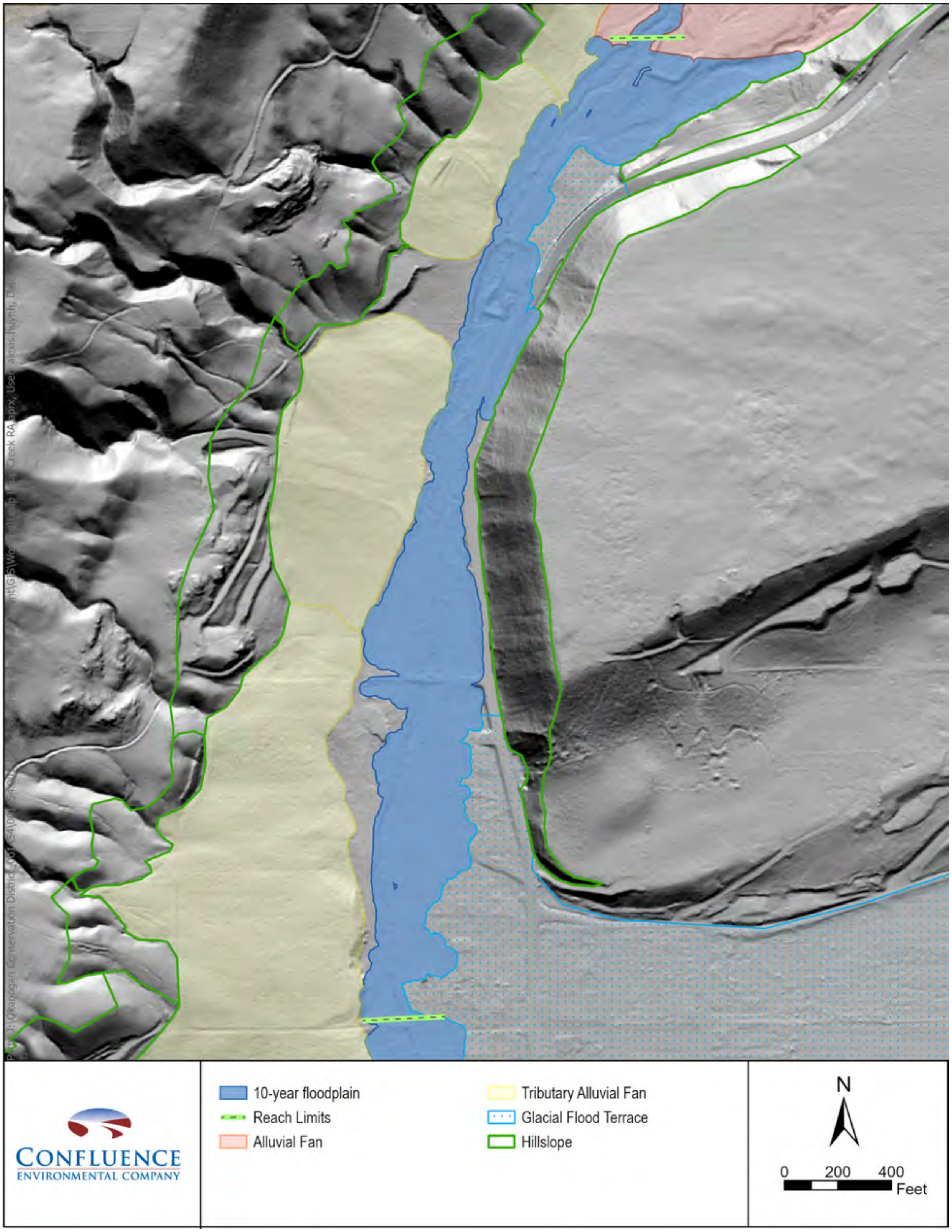

Figure 9. Loup Loup 16-2 reach topography and geomorphic surfaces

Table 9. Reach Loup Loup 16-2 physical characteristics and representative photos

Reach Parameter	Value	Representative Photos
Reach length (km)	1.248	
Rosgen type	Type G4	
Gradient (rise/run)	0.017	
Sinuosity (ratio)	1.08	
Bankfull width (m)	5.4	
Width-depth ratio	12.2 (in 2017)	
Confinement ratio (valley/bankfull width)	3.7 (unconfined)	
Entrenchment ratio	2.2	
Dominant substrate (% of total mass)	Very fine gravel <4 mm (36%)	
Bank armoring (% of length)	21%	
Riparian composition‡	Established perennial: 36.6% Unvegetated/seasonal: 63.4%	
Woody debris (pieces/mile)	87.7 (in 2021)	
Woody debris jams (jams/mile)	9.0 (in 2021)	
Habitat compositionΔ	Backwater pools: 0%; Beaver ponds: 33%; Glides: 5%; Large cobble riffles: 41%; Scour pools: 14%; Pool tailouts: 0%; Small cobble riffles: 8%; Side channel: 6%	
Obstructions	Private road culvert at RKM 1.29. Minor partial barrier to adult passage, complete barrier to juvenile passage.	
Pools frequency (pools/km)	11.8	
Hydraulic radius (m)†	0.41	
Basal shear stress (Pa) †	25.7	
EDT Priority Attributes	Fine sediment; Temperature (daily maximum); Woody debris; Riparian/stream interface	

‡ Vegetation composition within the 10-year recurrence interval floodplain. Vegetation composition derived from 2021 NAIP imagery. Floodplain polygon derived from LiDAR using the Inverse Distance Weighted interpolation method.

Δ Percent of bankfull wetted area by habitat type (see Section 3.4)

† Median basal shear stress interpolated from OBMEP transect depth measurements in pool tailout, glide, and small cobble riffle habitat types (Doyle et al. 2015).

4.1.3 Loup Loup 16-3

Reach Loup Loup 16-3 is 1.002 km in length, extending from the upstream end of Loup Loup 16-2 to at a series of cascades at the edge of the alluvial valley wall that markes the current upstream terminus of anadromous habitat. OBMEP monitoring activities in Loup Loup 16-3 are currently limited to a complete habitat census conducted once during each 4-year monitoring cycle. Reach topography and geomorphic surfaces in Loup Loup 16-3 are shown in Figure 10.

Table 10 provides a summary of reach characteristics, estimated 10-year flood elevations, and representative photographs. As shown, this reach is a partially confined Rosgen type G3 channel, with a moderate to high average gradient of 0.036 (3.6%), moderate sinuosity (sinuosity index of 1.15), and an average bankfull width of 3.3 m. Minimal bank armoring and hydromodifications are present, affecting only 6% of channel length.

As with Loup Loup 16-1 and 16-.2, notable channel incision and changes in substrate composition have occurred in reach Loup Loup 16-3 over the last decade. While comparison photographs are lacking, a representative photograph from 2020 demonstrates extensive sand accumulation (Table 10) and the transformation from historical boulder step pool composition to predominantly glide habitat (Klett, R., CTCR, pers. comm., 2024). As shown, the predominantly cobble to boulder sized substrates in this reach have been scoured and replaced by gravel sand. No substrate composition or channel configuration data are available for this reach, but based on anecdotal observations (Klett, R., CTCR, pers. comm., 2024), photographic evidence, and documented changes in downstream reaches it is reasonable to conclude that substrate conditions in this reach have been adversely impacted by an increase in fine sediment supply from the burned portion of the watershed upstream of the study area.

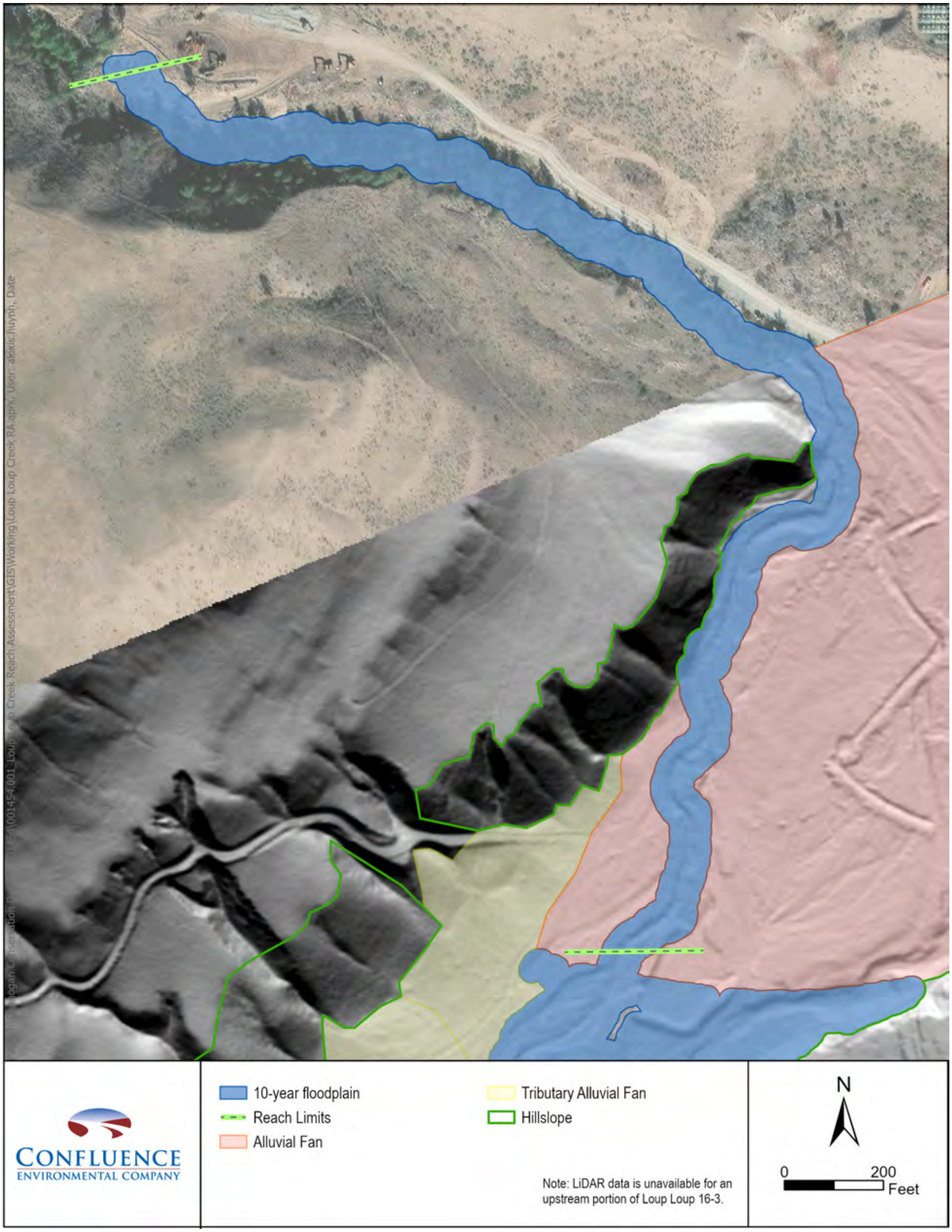

Figure 10. Loup Loup 16-3 reach topography and geomorphic surfaces

Table 10. Reach Loup Loup 16-3 physical characteristics and representative photos

Reach Parameter	Value	Representative Photo
Reach length (km)	1.002	
Rosgen type	Type G3	
Gradient (rise/run)	0.036	
Sinuosity (ratio)	1.15	
Bankfull width (m)	3.3	
Width-depth ratio	Insufficient data	
Confinement ratio (valley/bankfull width)	3 (partially confined)	
Entrenchment ratio	1.4	
Dominant substrate (% of total mass)	Insufficient data	
Bank armoring (% of length)	6%	
Riparian composition[‡]	Established perennial: 58.1% Unvegetated/seasonal: 41.9%	
Woody debris (pieces/mile)	295.5 (in 2018)	
Woody debris jams (jams/mile)	19.3 (in 2018)	
Habitat composition[Δ]	Backwater pools: 0%; Beaver ponds: 0%; Glides: 0%; Large cobble riffles: 55%; Scour pools: 42%; Pool tailouts: 2%; Small cobble riffles: 1%; Side channel: 3%	
Obstructions	None. Historical diversion dam removed in 2011.	
Pools frequency (pools/km)	53.3	
Hydraulic radius (m)[†]	0.58	
Basal shear stress (Pa)[†]	58.9	
EDT Priority Attributes	Fine sediment; Temperature (daily maximum); Woody debris; Confinement (artificial)	

‡ Vegetation composition within the 10-year recurrence interval floodplain. Vegetation composition derived from 2021 NAIP imagery. Floodplain polygon derived from LiDAR using the Inverse Distance Weighted interpolation method.

Δ Percent of bankfull wetted area by habitat type (see Section 3.4)

† Median basal shear stress interpolated from OBMEP transect depth measurements in pool tailout, glide, and small cobble riffle habitat types (Doyle et al. 2015).

4.2 Hydrology

Current hydrologic conditions in Loup Loup Creek are influenced by changes in baseline watershed conditions, hydromodification, and water exports to support irrigated agriculture. Specifically, the natural hydrology of the watershed has been affected by changing climatic conditions and a notable increase in fire frequency between 2010 and the present. Hydrologic conditions in the watershed were interpreted from available streamflow data and regional regression equations developed by the USGS. USGS collects real-time discharge data at USGS gage 12447285, Loup Loup Creek at Mallot, WA. The available period of record for this gage comprises daily 15-minute data discharge data collected from the beginning of water year 2013 to the present, or effectively 10 water years. Observed streamflows over the period of record are displayed in Figure 11.

Loup Loup Creek displays classical snowmelt hydrology. Peak streamflows occur most commonly in spring, typically beginning in April and extending into May. The baseflow period extends from mid-summer through fall, with the lowest observed streamflows occurring most commonly in October. This pattern is variable and snowpack dependent, with some years in the data record lacking a discernable spring snowmelt event (Figure 11). Figures 12 and 13 display the March 1 to March 30 snow-water equivalent (in inches), and the snow-water equivalent on April 1 and accumulated April precipitation for 2015 to 2023, respectively, at a SNOTEL site proximal to the watershed.[5] As shown, observed peak flows during the period of record correlate with April snowpack and precipitation. Notably, the large runoff events in 2017 and 2018 coincide with high snowpack volume and unusually heavy April rainfall. Conversely, 2015 and 2022 were years with no remaining snowpack and little to no rain in April (Figure 13).

Peak streamflows are also influenced by withdrawals from headwater diversions in Loup Loup Creek, Little Loup Loup Creek, and Sweat Creek. These withdrawals are diverted into an unlined canal that exports flows into Leader Lake, a reservoir in the adjacent Talent Creek drainage to the east of Loup Loup Creek. Diversions begin in spring and extend throughout the irrigation season. Diversion rates in 2015 measured 21 and 17 cubic feet per second (cfs) in April and May and 2.8 to 3.4 cfs in June and October of 2015, respectively (Doyle 2020).[6] Based on observed inflows to Leader Lake, between 39% and 51% of withdrawals are lost to evaporation and leakage. While some percentage of leakage returns to Loup Loup Creek, the overall effect of irrigation withdrawals on peak is significant, likely reducing naturally occurring peak flows by at least 5 to 10 cfs (Carlson 2020).

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[5] Snow-water equivalent and precipitation data were obtained from the Muckamuck SNOTEL station, located in the Salmon Creek watershed approximately 5 miles north of the headwaters of little Loup Loup Creek.

[6] Diversion data were provided by the WRIA 49 watershed planning unit to support Streamflow Restoration Act (RCW 90.94) compliance. This information supported the development of the WRIA 49 Watershed Plan Addendum (Carlson et al. 2020).

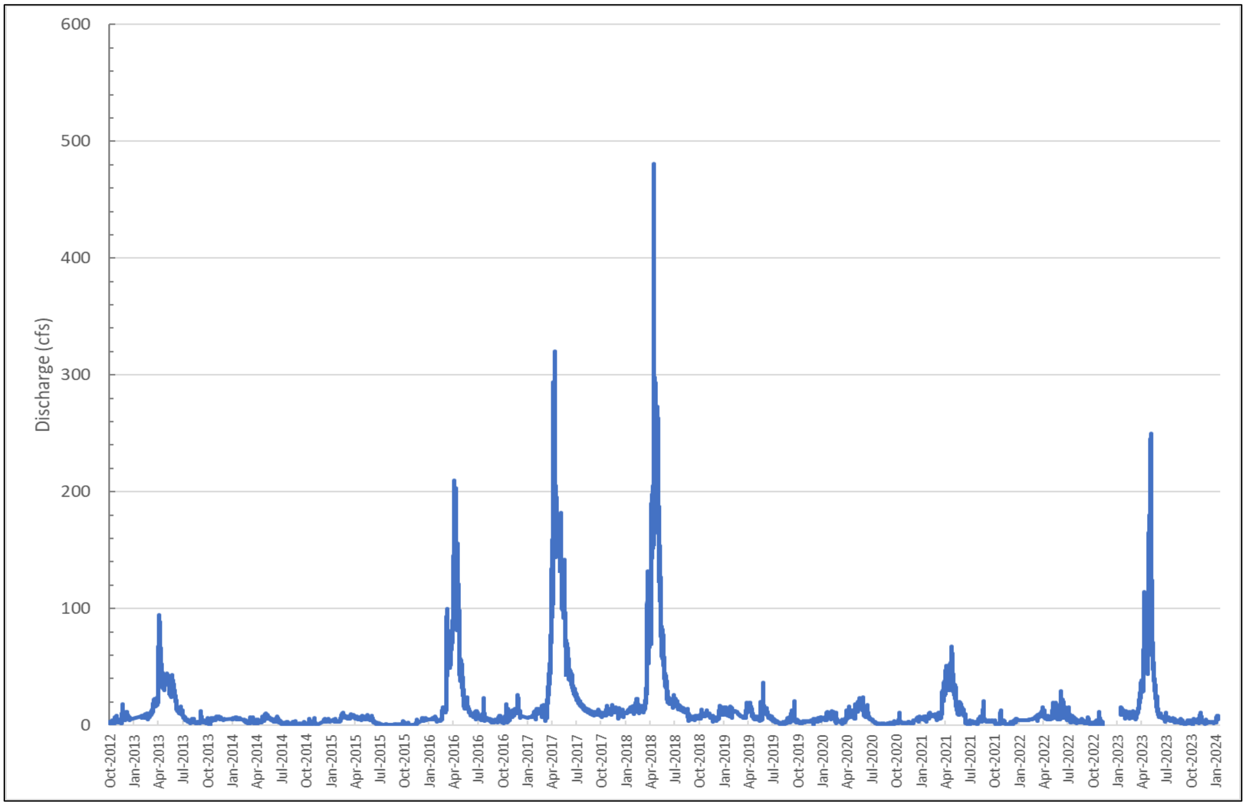


Figure 11. Observed streamflow at USGS 12447285, Loup Loup Creek at Mallot, WA, 2013 to present

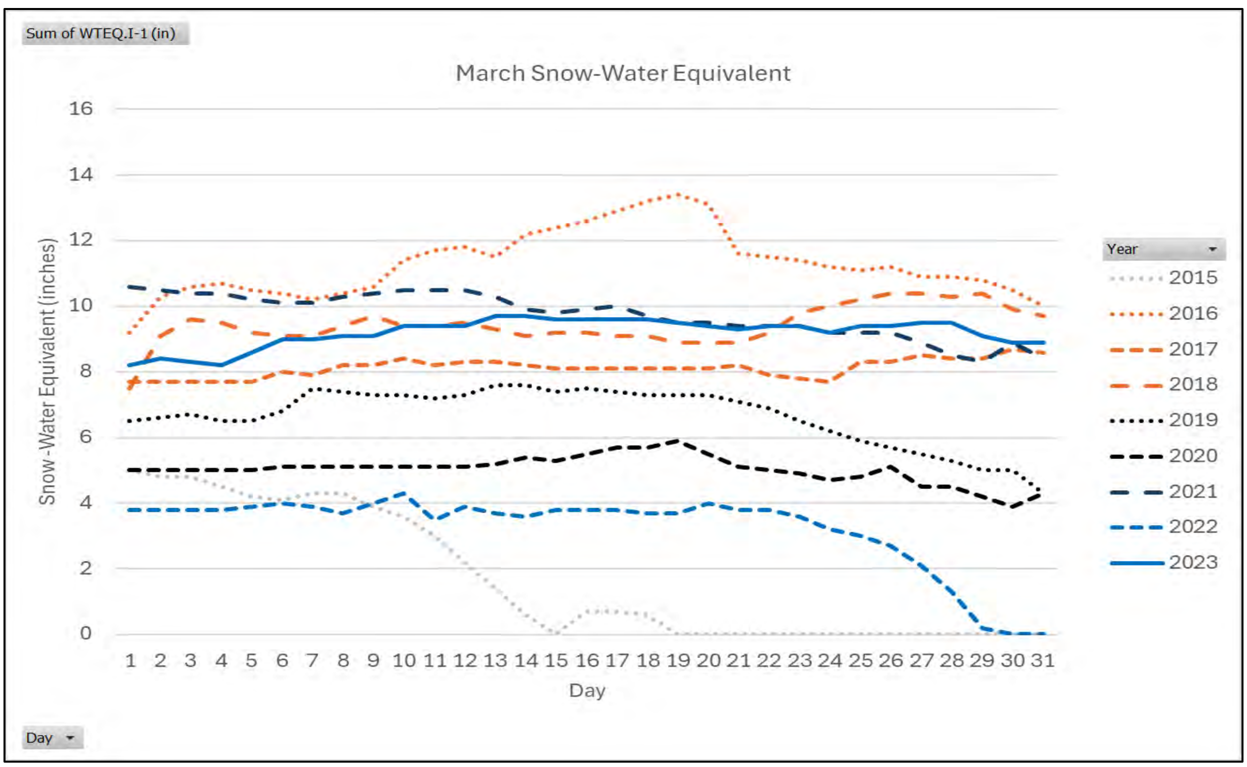


Figure 12. March snow-water equivalent at SNOTEL Site Muckamuck, 2015 to 2023

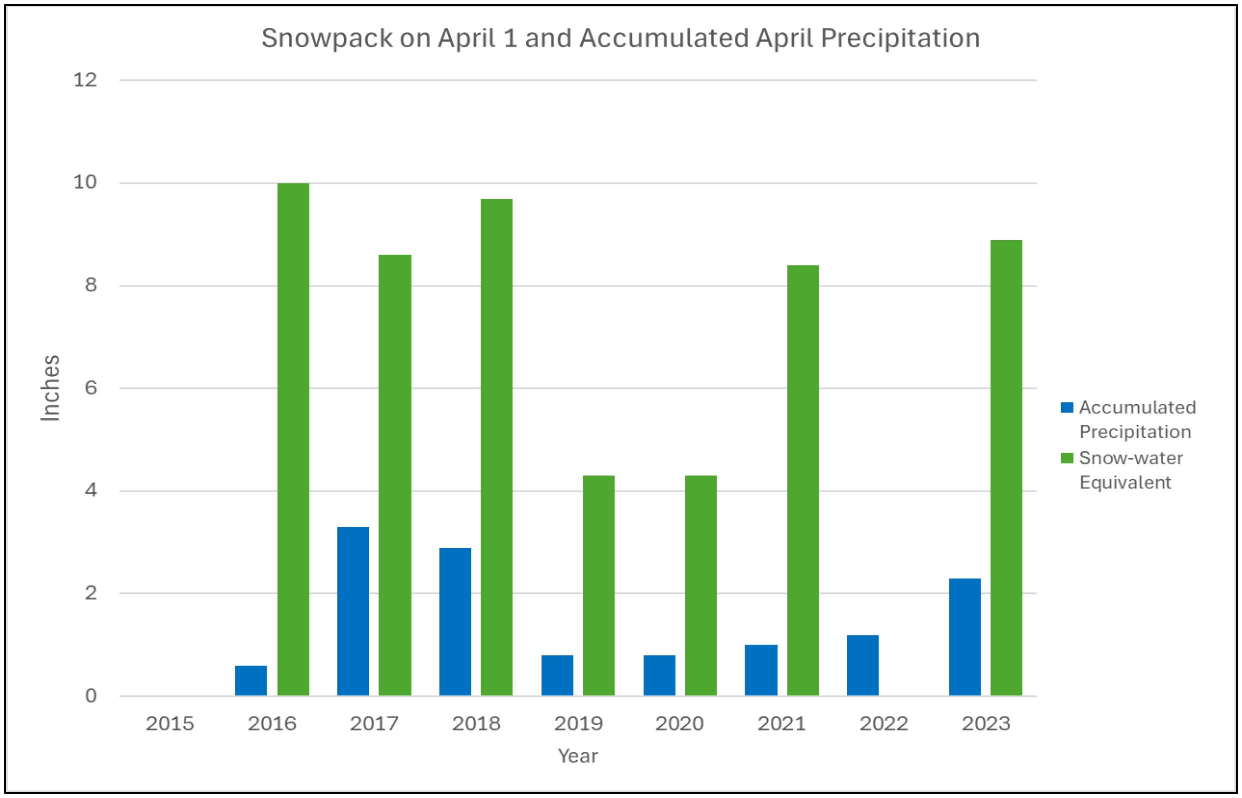


Figure 13. April 1 snow-water equivalent and accumulated April precipitation at SNOTEL Site Muckamuck, 2015 to 2023

The currently available data record for Loup Loup Creek has limited utility for characterizing peak flow recurrence intervals. In general, 10 years is the minimum period of record needed to estimate peak flow magnitude, but at least 25 and ideally 35 years or more of daily flow data are required to develop reliable recurrence interval statistics. However, the available record can be used to estimate higher-frequency (i.e., 1.5 to 10-year return interval) peak flow events (Interagency Advisory Committee on Water Data 1982). Record-based estimates for 1-year to 10-year return interval peak flows are shown in Table 11. When interpreting these statistics, it is important to consider that they are based on a period that was affected by watershed-altering fires that likely had a strong influence on watershed hydrology (see Section 2.3.6).

As a point of comparison, Okanogan CD developed peak flow recurrence interval estimates for Loup Loup Creek using regional regression equations developed by the USGS (Mastin et al. 2016). While the peak flow estimates generated by this model have large standard error of prediction, the relative difference between predictions provides a useful basis for evaluating fire-related effects on watershed hydrology. The Mastin et al. (2016) method considers geographic region, drainage basin area, average annual precipitation, and percent canopy coverage. The latter metric can be interpreted from Landsat data, providing a measure of change over time. A comparison of satellite imagery data for 2014 and 2021, before and after the 2014 Carlton Complex and 2015 Limebelt fires, indicate a decrease in canopy coverage from

43.4% to 21%. Table 11 and Figure 13 provide a comparison of 2-year to 500-year peak flow predictions at the mouth of Loup Loup Creek under 2014 and 2021 canopy coverage conditions. As shown, the predicted differences in higher frequency return interval flows are relatively small (e.g., the predicted 2-year flow increased by approximately 10%).

As shown, model-based peak discharges for the 2-year to 10-year flow events have increased by 10% to 53%, respectively. The predicted changes in peak discharge increase as the return interval duration increases, with the 100-year event effectively doubling in magnitude. As shown, the flow-based predictions for the 2-year to 10-year events are well below the model-based predictions (although within the 90% confidence intervals) for both periods. However, it is important to note that the model-based predictions do not account for irrigation withdrawals on the order of 15-20 cfs during the annual peak flow period.

Table 11. Peak flow statistics for the Loup Loup Creek watershed

Annual Exceedence Probability	Recurrence Interval (years)	Flow-based Peak Discharge Prediction (cfs)†	Model-based Peak Discharge Prediction – 2014 Canopy Coverage (cfs)			Model-based Peak Discharge Prediction – 2021 Canopy Coverage (cfs)		
			Peak Discharge	Lower 90% CI	Upper 90% CI	Peak Discharge	Lower 90% CI	Upper 90% CI
100%	1	9	--	--	--	--	--	--
67%	1.5	22	--	--	--	--	--	--
50%	2	63	124	40	381	137	44	425
20%	5	148	262	94	730	359	128	1,011
10%	10	291	390	135	1,128	596	204	1,744
4%	25	--	592	184	1,901	1,020	314	3,317
2%	50	--	780	222	2,739	1,440	405	5,124
1%	100	--	987	259	3,767	1,950	504	7,547
0.50%	200	--	1,220	292	5,091	2,570	607	10,883
0.20%	500	--	1,600	340	7,520	3,620	758	17,279

† Values estimated for the 2013 to 2023 data record for USGS gage # 12447285 Loup Loup Creek at Malott, WA using the Log-Pearson Type III Distribution method (Interagency Committee on Water Data 1982).

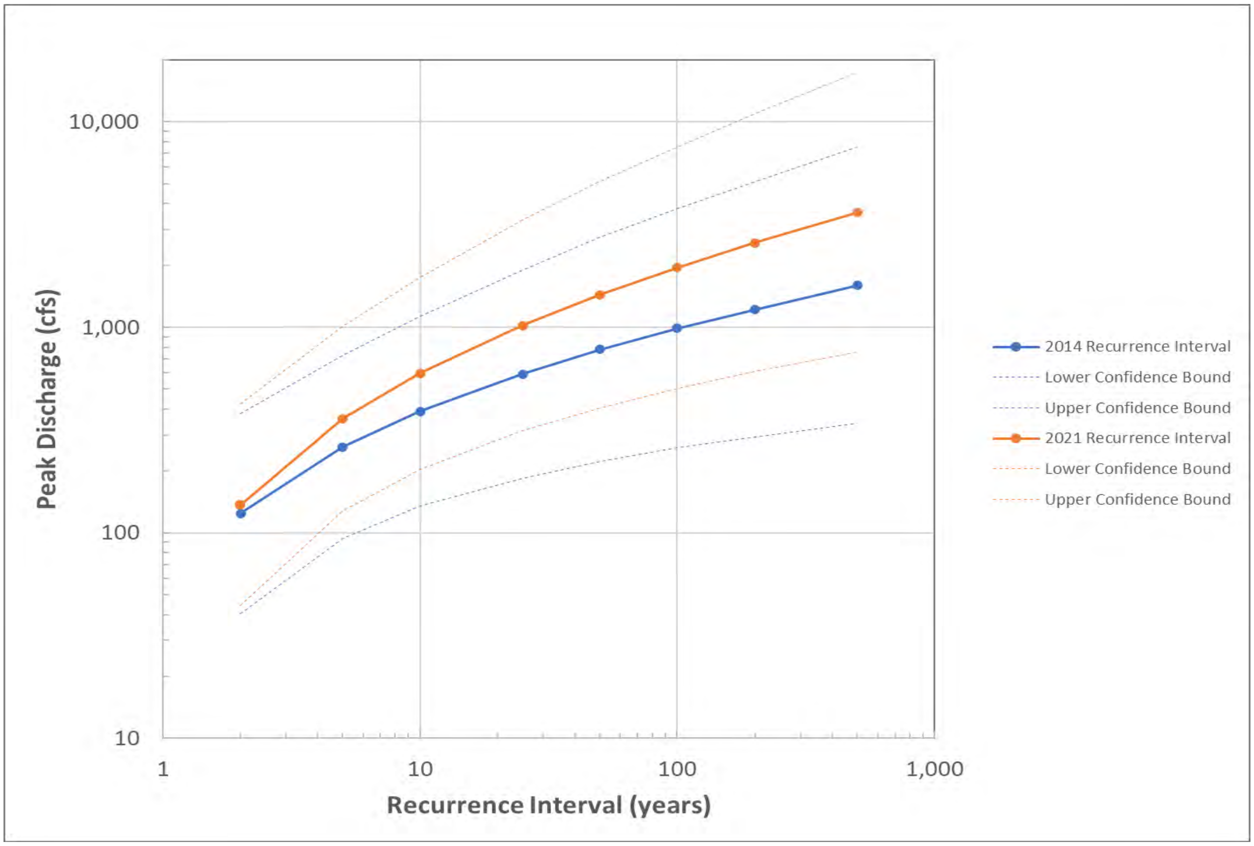


Figure 14. Predicted change in peak discharge recurrence intervals in the Loup Loup Creek watershed, 2014 to 2021

The peak period of steelhead migration into Okanogan River spawning tributaries typically occurs during a 2-week window in April, coinciding with annual snowmelt runoff. Migratory adult steelhead access to Loup Loup Creek requires minimum flows of at least 15 cfs up to 50 cfs (Klett, R., CTCR, pers. comm., 2024). Steelhead will delay migration and are unable to spawn effectively at flows above this upper threshold. Therefore, under existing habitat conditions steelhead spawning success in Loup Loup Creek is dependent on optimal flow conditions in April.

Table 12 displays April flow duration statistics at USGS 12447285 Loup Loup Creek at Malott over the 2013 to 2023 period of record. As shown, suitable fish passage flows occurred on an average of 15% of April days from 2013 to 2023. The result is misleading as conditions vary considerably from year to year. For example, in 2013 and 2021, 65% and 93% of measured April flows were between 15 and 50, cfs respectively. In 5 of the remaining 8 years (2014, 2015, 2017, 2018, 2022) there were no April days with suitable flows for steelhead migration and spawning.

This information is presented graphically in Figure 15. As shown, average daily April streamflows are outside of the optimal zone for steelhead migration and spawning in most of the years in the data record. These findings suggest that projects designed to improve adult passage and provide suitable habitat for spawning and incubation over a broader range of flows could provide a substantial restoration benefit.

Table 12. Flow duration curve for Loup Loup Creek during April (flows suitable for fish passage shown in bold)

Discharge (cfs)	Exceedance Duration	Days/month Exceeded
2.2	99.4%	30
2.7	97.8%	29
3.3	94.4%	28
5.5	90%	27
6.0	84%	25
6.5	79%	24
7.0	75%	22
8.1	69%	21
9.8	64%	19
13	59%	18
14	57%	17
15	56%	17
17	55%	16
35	50%	15
44	40%	12
50	36%	11
62	30%	9
116	20%	6
171	10%	3
268	1%	0.3

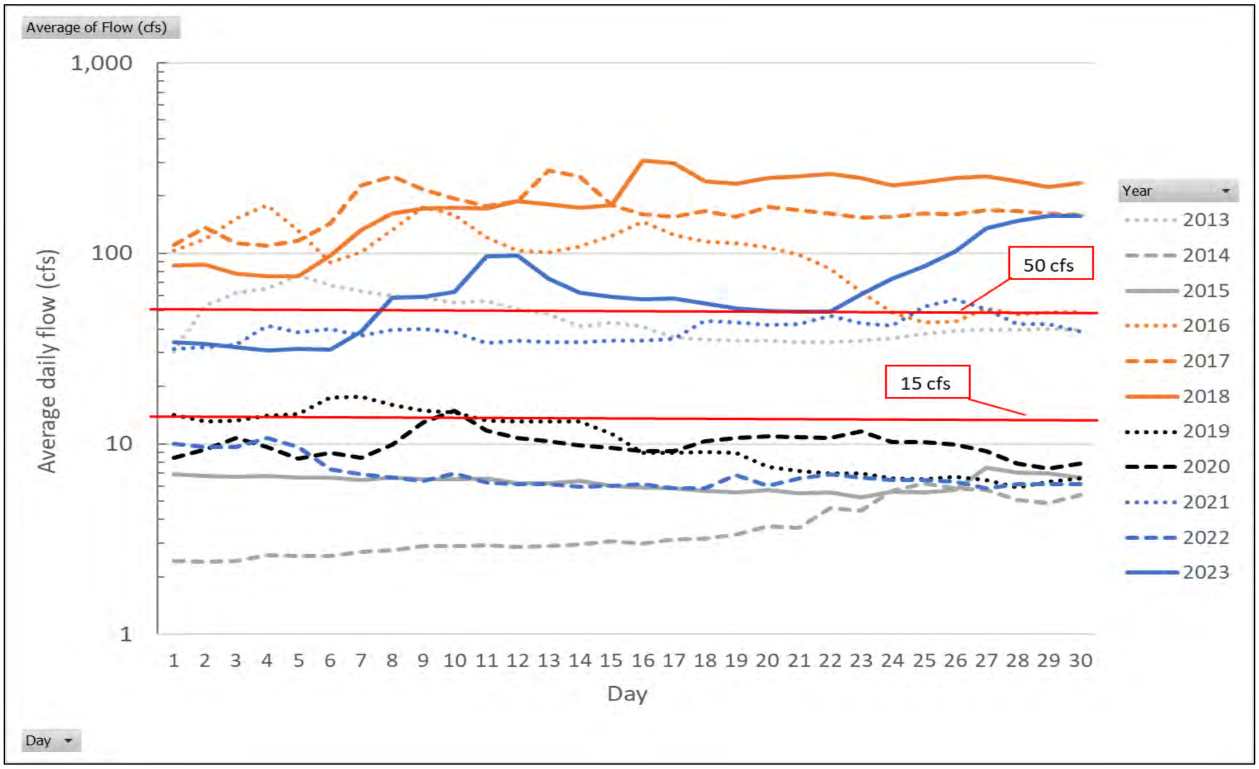


Figure 15. Average April daily stream flows in Loup Loup Creek, 2013-2023

4.3 Geomorphology and Habitat

This section describes existing conditions and recent trends in floodplain connectivity, substrate composition, channel structure, and aquatic habitat characteristics in the study area as documented by OBMEP habitat status and trends monitoring. Each of these parameters has shown a notable trend towards more degraded conditions since 2013, corresponding to hydrologic changes and increased erosion attributable to recent fire history in the watershed.

4.3.1 Floodplain Connectivity

Notable channel incision has occurred in the study area over the last decade. This development is evident in comparisons of representative photographs taken in reaches Loup Loup 16-1 and 16-2 before and after the sequence of exceptional peak flow events that occurred in 2016, 2017, and 2018. The magnitude of change is evident in channel in channel cross-section and thalweg depth profile measurements taken in Loup Loup 16-1 at monitoring location OBMEP-421, transect F (see Section 4.3.3). As shown, bankfull depths in this reach increased by 0.1 to as much 0.8 m between 2014 and 2017, the last year consistent transect and thalweg depth measurements were taken at this location.

Similar channel incision occurred in reach Loup Loup 16-2 during the same period, accompanied by a notable shift in substrate composition. This development is evident in a photographic comparison of channel conditions in 2014 and 2019 at monitoring location

OBMEP-421, transect F (Table 8). As shown, evidence of downcutting and a clear shift from predominantly gravel to cobble sized substrates have occurred in this reach. While transect-level bankfull depth measurements are not routinely measured in this reach, OBMEP has observed extensive downcutting over successive habitat surveys conducted from 2016 to 2019 (Klett, R., CTCR, pers. comm., 2024). These developments have effectively disconnected Loup Loup Creek from its adjacent floodplain, limiting access to side channels and floodplain habitats during typical flow events.

Windward Environmental (2023) surveyed habitat conditions within a portion of reach Loup Loup 16-2 to support habitat restoration design development. They identified floodplain reactivation as a high-priority habitat restoration objective. Increased floodplain connectivity would provide greater juvenile salmonid access to high flow refugia and promote fine sediment deposition on the floodplain. The measures used to increase floodplain connectivity would also theoretically improve spawning habitat conditions for adult steelhead and allow access to and use of these habitats over a broader range of flows.

4.3.2 Sediment Supply and Substrate Characterization

Substrate conditions in Loup Loup Creek have shown a clear trend in response to recent fire history. Notably, the dominant substrate composition in primary steelhead spawning habitat in reaches Loup Loup 16-1 and Loup Loup 16-2 has transitioned from predominantly cobble and gravel towards gravel and sand. This shift is evident in the change in cumulative substrate composition observed since 2015, which is presented graphically in Figures 14 to 16. These changes have occurred in concert with the observed changes in floodplain connectivity and channel configuration described in the preceding and following sections.

As shown, while substrate composition near the mouth of Loup Loup Creek at RKM 0.02 (Figure 14) has remained relatively stable, locations further upstream at RKM 1.02 and 1.5 (Figures 15 and 16) have shifted towards finer gravel and sand-sized substrates. This shift coincided with 3 exceptional peak flow events that occurred between 2016 and 2018 (Section 4.1) and increasing channel entrenchment (Section 4.3.3). OBMEP field observations and photographic evidence (see Table 9) indicate substantial bed scouring has occurred and spawning substrates have been replaced by fine gravel and sand. The median and 84th percentile substrate diameter (D50 and D84) Loup Loup 16-1, derived from annual Wolman pebble count data, decreased between 2014 and 2021 (Figure 17). The percentage of fine sediments <0.86 mm has increased, from 5% in 2013 to over 40% in 2021 (Figure 18).

OBMEP (Doyle et al. 2015) developed an incipient motion model to estimate bed scour depths in salmonid spawning habitat. This model predicts bed scour depths using a Monte Carlo simulation of incipient motion based on hydraulic geometry, bed gradient, flow velocity and channel roughness, and substrate composition. The median of model-predicted basal shear stress values for channel conditions observed during the 2018-2021 monitoring cycle ranged from 58.9 Pascals (Pa) in Loup Loup 16-3, to 25.7 Pa in Loup Loup 16-2, and 6.4 Pa in Loup Loup 16-1. This represents a substantial shift compared to model predictions for the 2014-2017 monitoring period, which produced basal shear stress values of 5.7 and 37.7 Pa, respectively. The difference is attributable to measured changes in hydraulic geometry, bed gradient, and substrate composition that occurred between the 2 periods. Observed changes in hydraulic geometry are described in the following section.

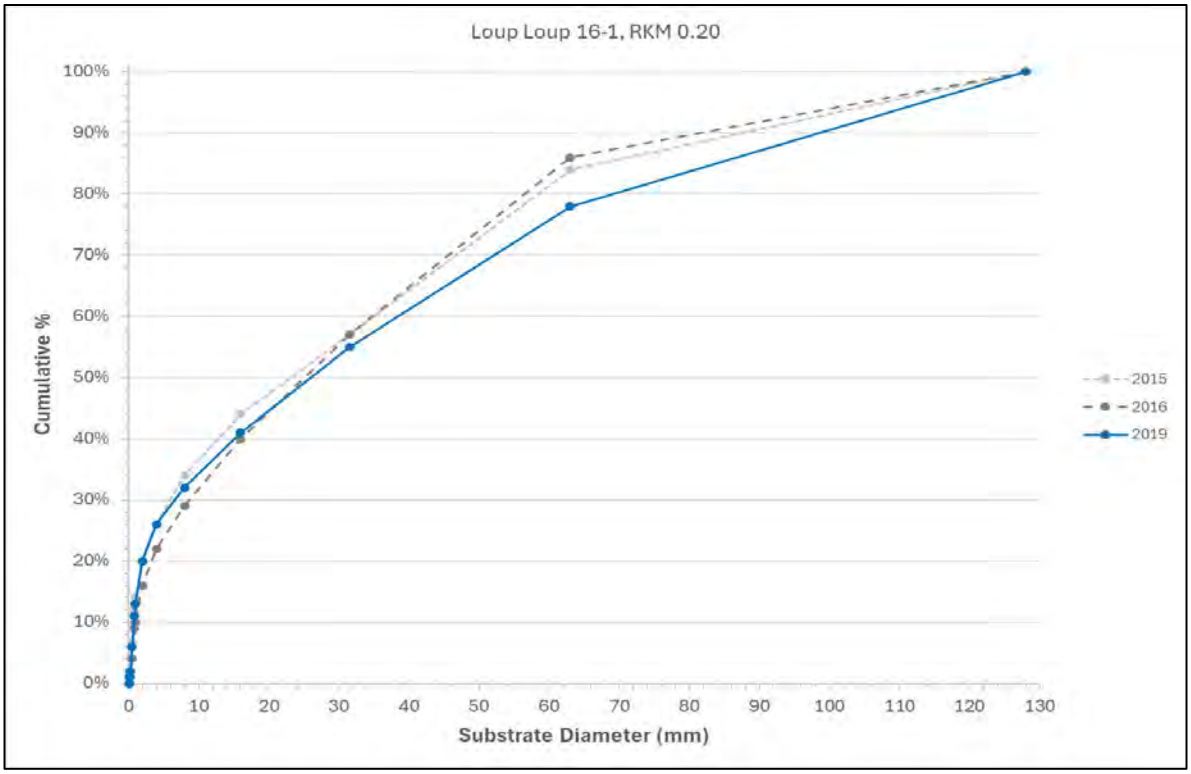


Figure 16. Trend in cumulative substrate composition in Loup Loup 16-1 at RKM 0.20, 2015-2019

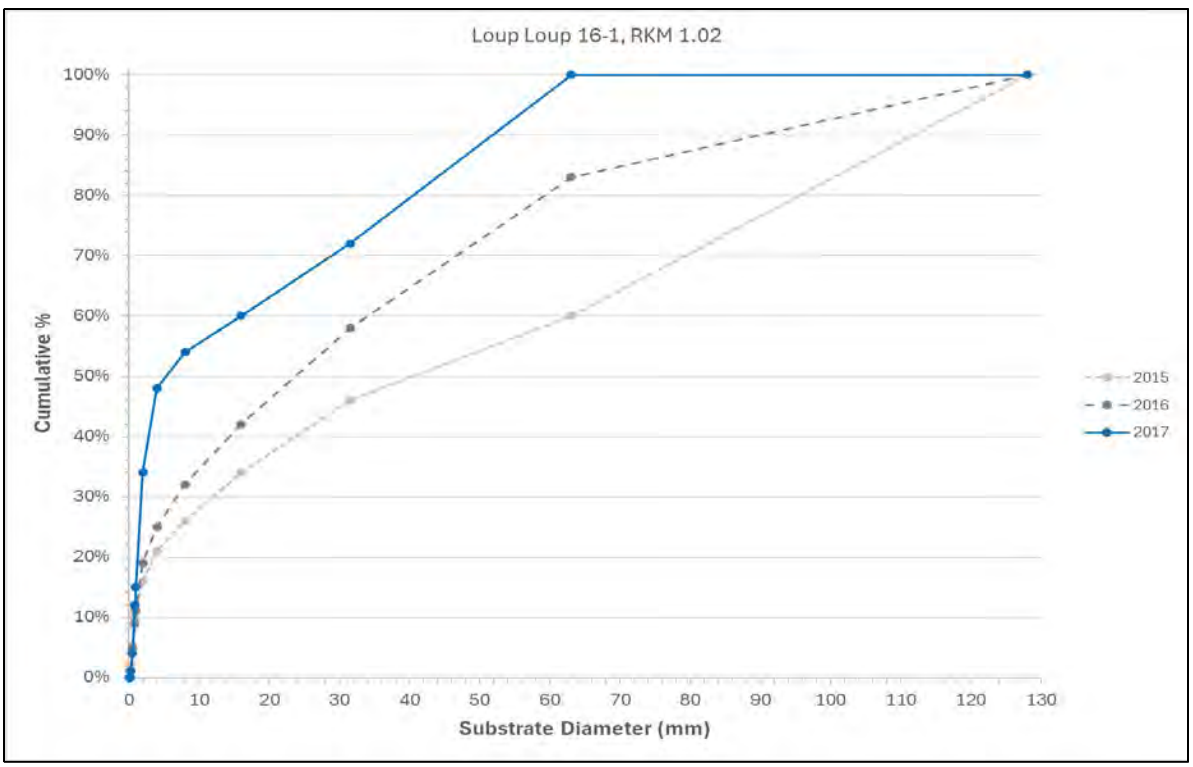


Figure 17. Trend in cumulative substrate composition in Loup Loup 16-1 at RKM 1.02, 2015-2017

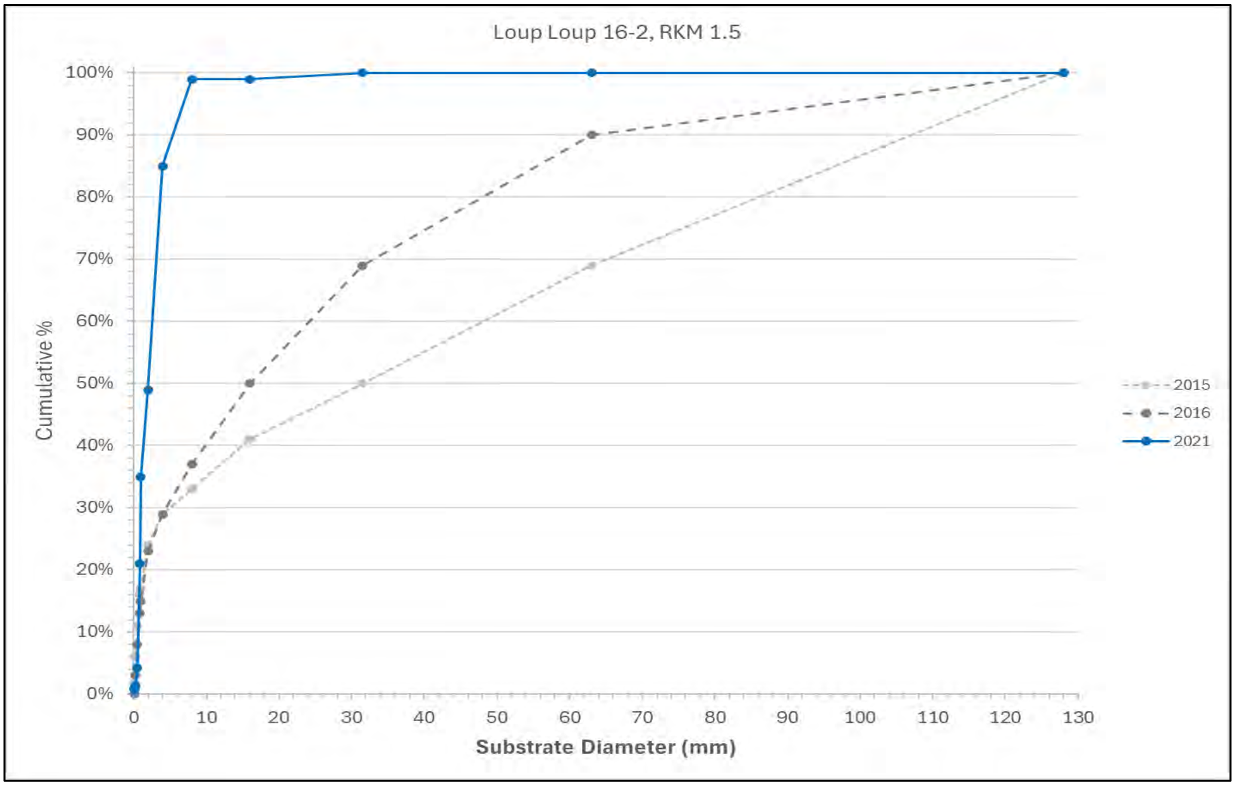


Figure 18. Trend in cumulative substrate composition in Loup Loup 16-2 at RKM 1.5, 2015-2021

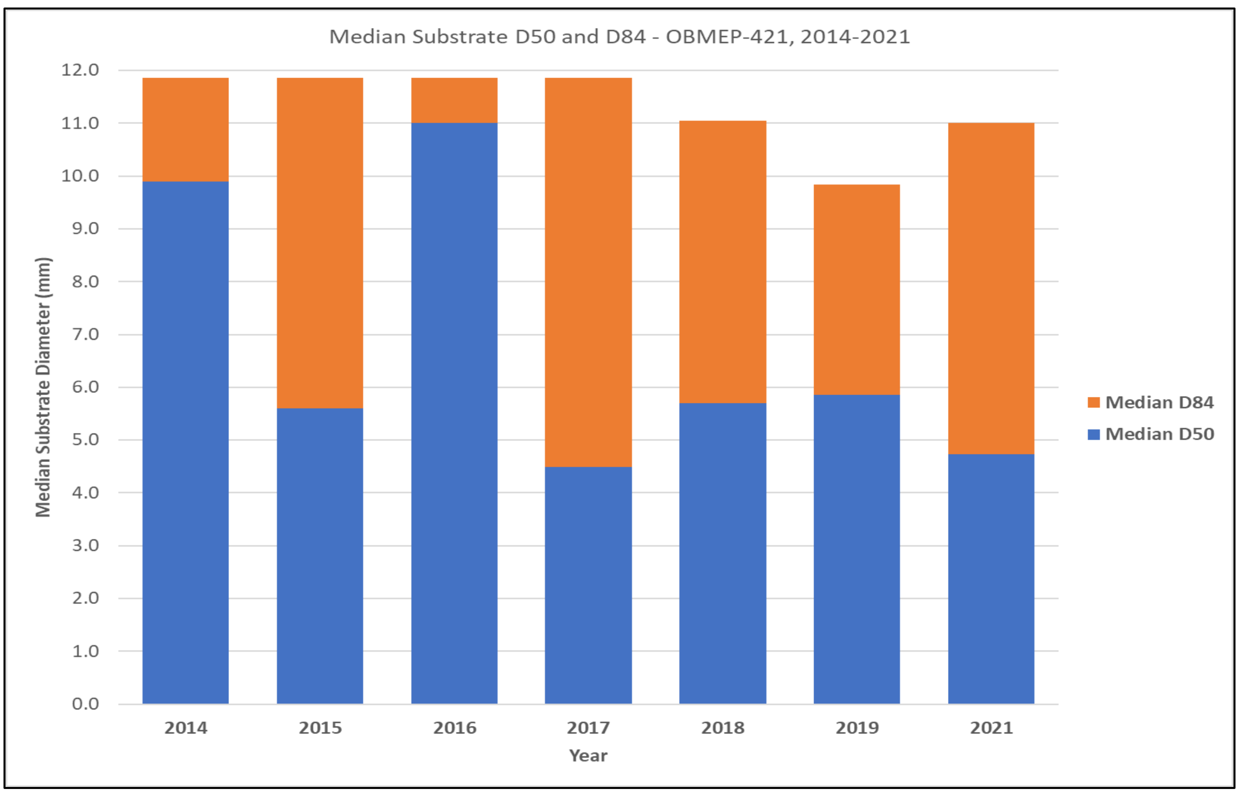


Figure 19. Trend in median substrate D50 and D84 in steelhead spawning substrates in Loup Loup 16-1, 2014-2021

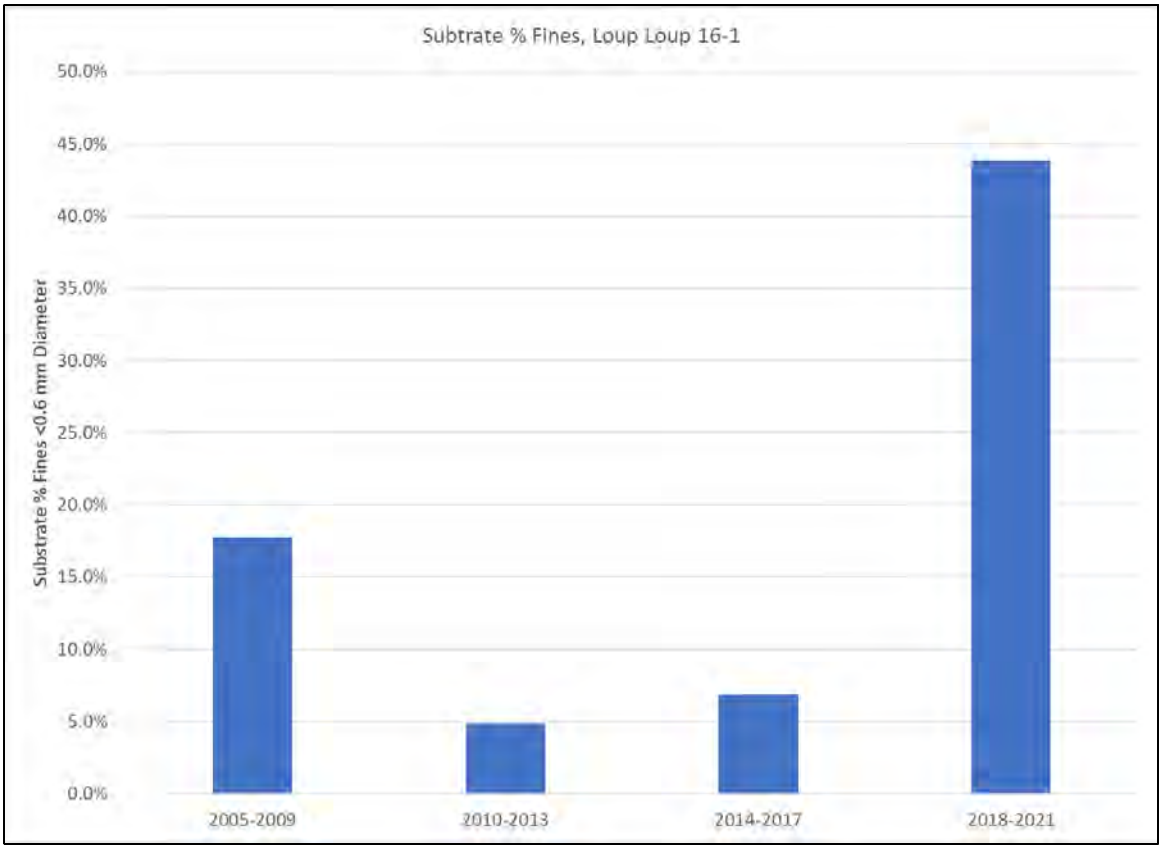


Figure 20. Trend in mean substrate % fines <0.86 mm in steelhead spawning substrates in Loup Loup 16-1 by 4-year OBMEP monitoring cycle

4.3.3 Channel Configuration

The Loup Loup Creek channel is evolving in response to changes in watershed hydrology and sediment dynamics resulting in part from the effects of recent fire history in the watershed. Based on observed conditions in Loup Loup 16-1, portions of the lower Loup Loup Creek channel are incising into the underlying alluvial flood terrace. This trend is observable in OBMEP channel cross-sections measurements repeated at established transect locations from 2014 through 2017, displayed graphically in Figure 19. The transect depth graphs display the change in bankfull depth at monitoring location OBMEP-421 over a four-year period. The F-transect location is monumented to fixed coordinates on the left bank, and the A-E and G-I transects are measured at fixed distances downstream and upstream of the F-transect, respectively. These data have some limitations, in that each individual time series is not monumented in three dimensions. Therefore, it is not possible to determine from the data alone if changes in bankfull depth are due to incision or overbank sediment deposition. However, the photographs of the F-transect site shown in Table 8 are indicative of the former. In the 2019 photograph, riparian root systems are exposed and visible downcutting is occurring at the edge of the root ball. These observations are not consistent with overbank sediment deposition.

This trend does not appear to be localized, as evidenced by the change in thalweg bankfull depth measurements across a 150-m segment of Loup Loup 16-1 repeated annually over the same period. As shown in Figure 20, the channel has deepened by 0.2 to 0.4 m across this channel segment. The most significant changes in channel configuration occurred between 2016 and 2017, following a large (5-year to 10-year) peak flow event in 2017. An even larger, perhaps 20-year, peak flow event occurred in 2018, which may have accelerated these observed trends.

Windward Environmental (2023) identified channel degradation and floodplain disconnection as significant habitat concerns in Loup Loup Creek 16-1. They noted that spawning gravels were largely absent from their project reach, having been scoured to the armor layer and replaced by sand. The large floods of 2016 and 2017 had created a secondary overflow channel on the floodplain, but this potential habitat feature is disconnected from the main channel at all but the highest streamflows. Windward Environmental (2023) concluded that increased sediment yield from the upper watershed would continue to exceed the sediment transport capacity of the creek. This would likely result in ongoing deterioration of habitat for anadromous and resident salmonids. These conclusions align with the observed changes in substrate conditions and channel configuration described in this report.

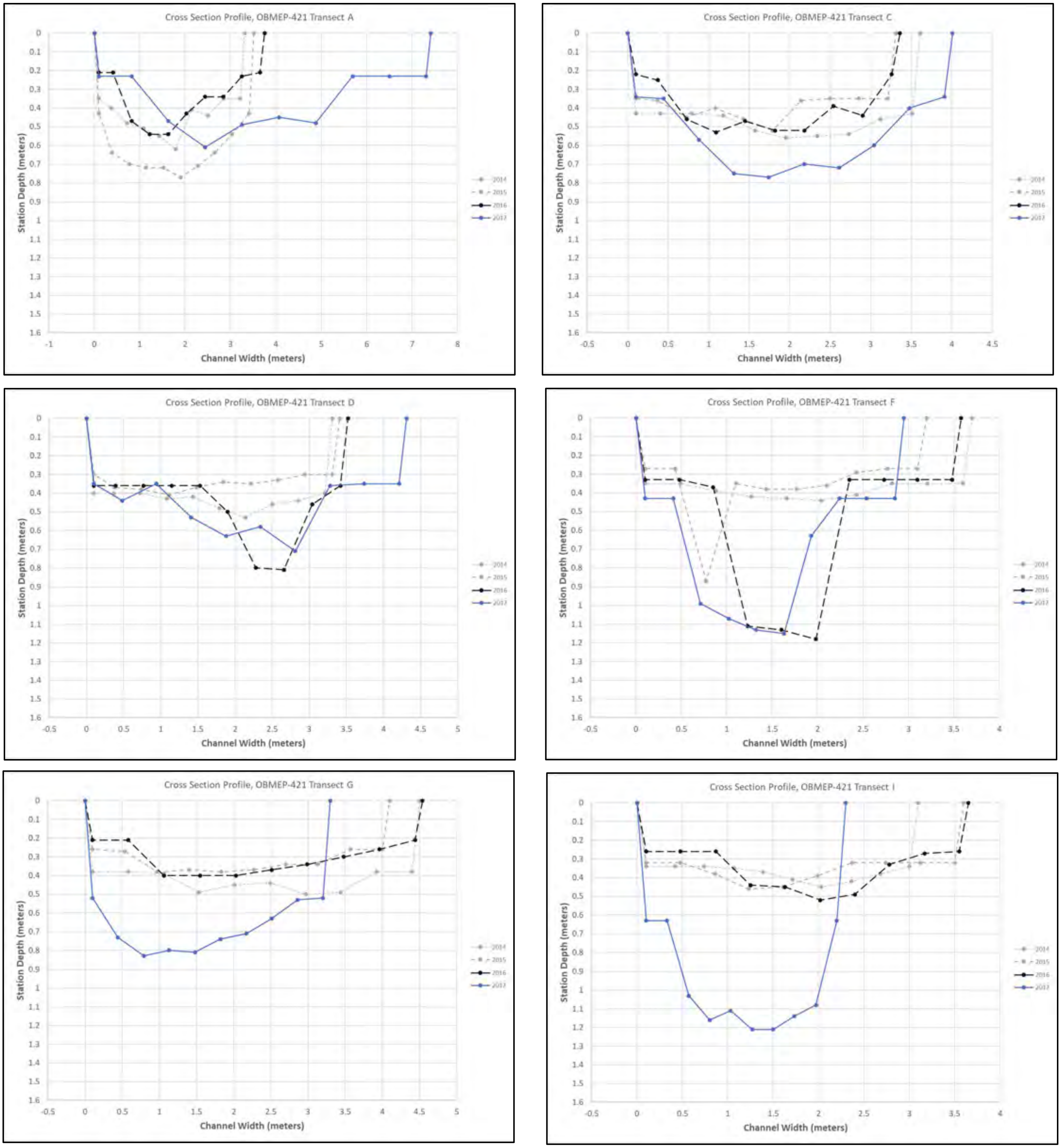


Figure 21. Change in channel cross section at selected transects in Loup Loup 16-1, 2014-2017

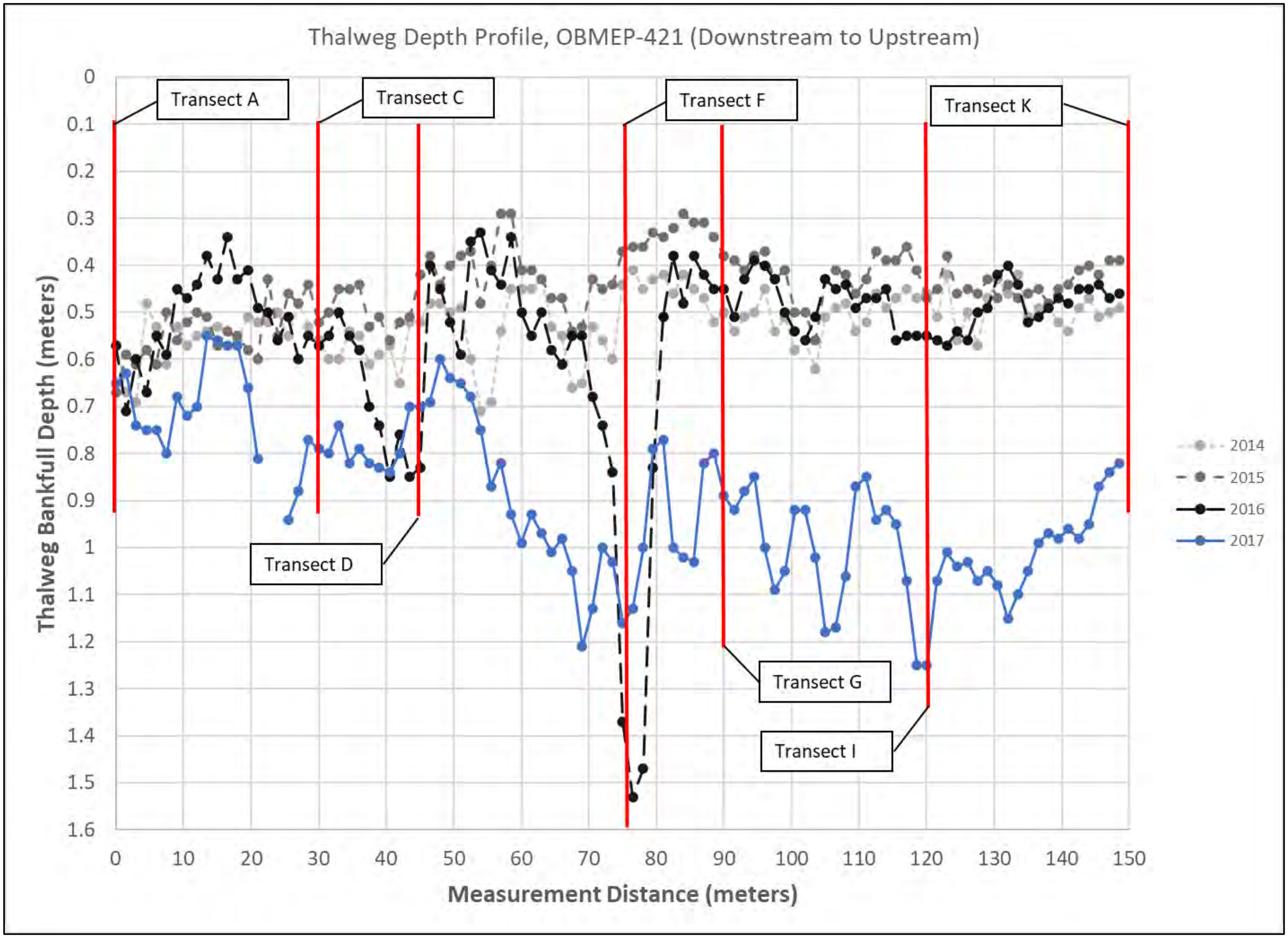


Figure 22. Change in thalweg depth profile in Loup Loup 16-1 at site OBMEP-421, 2014-2017

(Transect positions shown in red.)

4.3.4 Habitat Composition

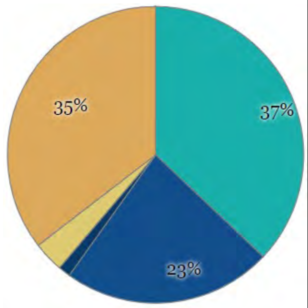
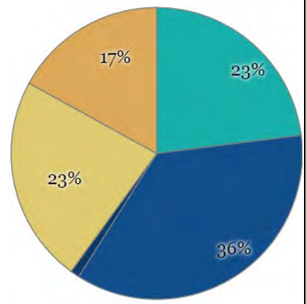
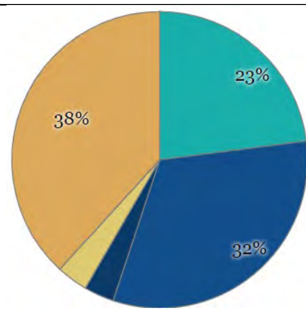
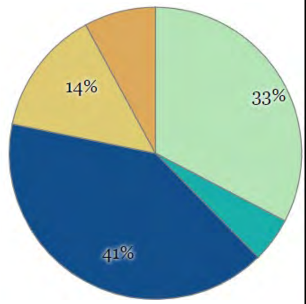
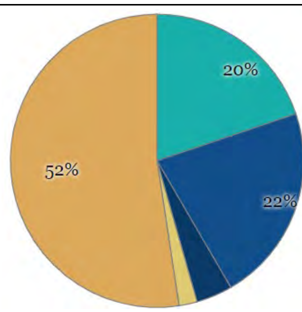
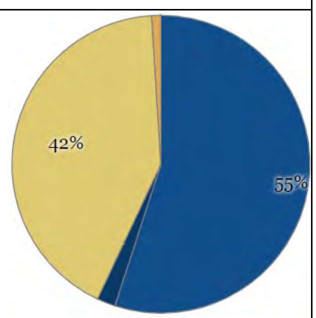
Aquatic habitat composition in the study area observed during the 2018-2021 OBMEP monitoring cycle is summarized by reach in Section 4.1. Observed changes in habitat composition between the 2011-2013 and 2018-2021 monitoring cycles are displayed graphically in Table 13. As shown, the proportion of total main channel wetted habitat area comprised of glides, small cobble riffles and pool tailouts declined markedly between the 2013 and 2021 OBMEP monitoring cycles. These are the primary steelhead spawning habitat types in Loup Loup Creek. The observed changes in habitat composition, combined with changes in channel configuration and substrate composition described in the previous sections, indicate that the watershed level effects of repeated large fires have contributed to a dramatic reduction in the quantity and quality of steelhead spawning habitat in the study area.

4.3.5 Large Woody Debris

The most recent OBMEP LWD counts in the study area were conducted between 2018 and 2021, varying by reach. Recurring reach counts were conducted in Reach 16-1 every year during this period, allowing for evaluation of trends. The number of small pieces of LWD in Loup Loup 16-1 declined from 109 in 2018 to 57 in 2020; however, the quantity of small LWD increased from 57 to 73 between 2020 and 2021 (Figure 21). In this same reach, the number of pieces of large LWD ranged from 26 pieces in 2020 to 5 pieces in 2021 (with the quantities in 2018 and 2019 falling within that range).

Only 1 year of LWD data was available for each Reaches 16-2 and 16-3 (Figure 22). Reach 16-2 contained 65 pieces of small LWD and 3 pieces of large LWD in 2021. Reach 16-3 contained 170 pieces of small LWD and 14 pieces of large LWD in 2018. The quantity of small LWD in Reach 16-3 was higher than any other reach, and the quantity of large LWD in Reach 16-2 was the lowest of any reach. However, the most recent wood counts in Loup Loup 16-3 are from 2018. Current wood density in this reach could be lower based on the observed trend in Loup Loup 16-1.

Table 13. Change in primary channel habitat composition in Loup Loup Creek between 2013 and 2021

Reach	2013 Habitat Composition	2021 Habitat Composition	Habitat Types
Loup Loup 16-1			
Loup Loup 16-2			
Loup Loup 16-3			

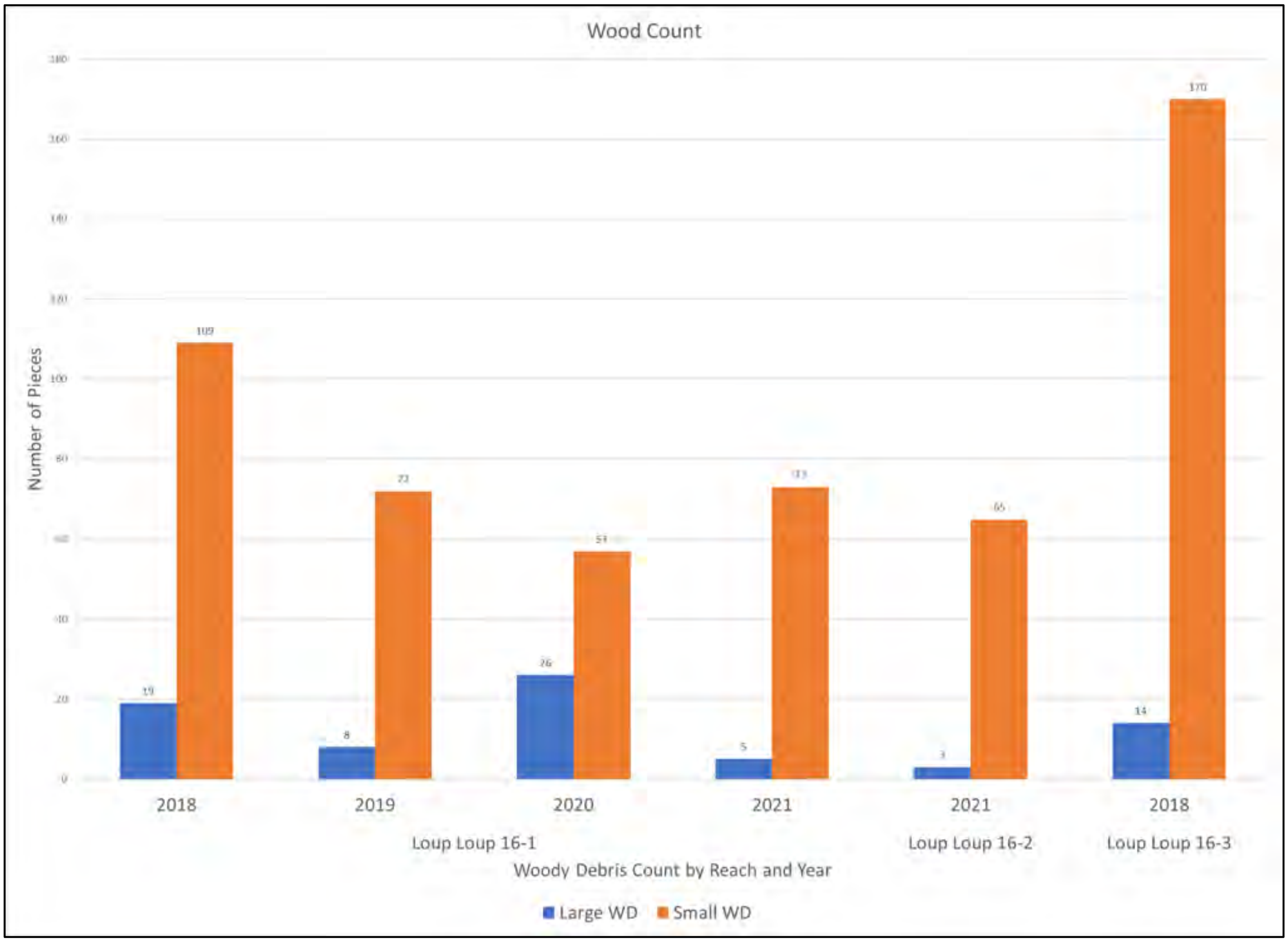


Figure 23. LWD counts in lower Loup Loup Creek

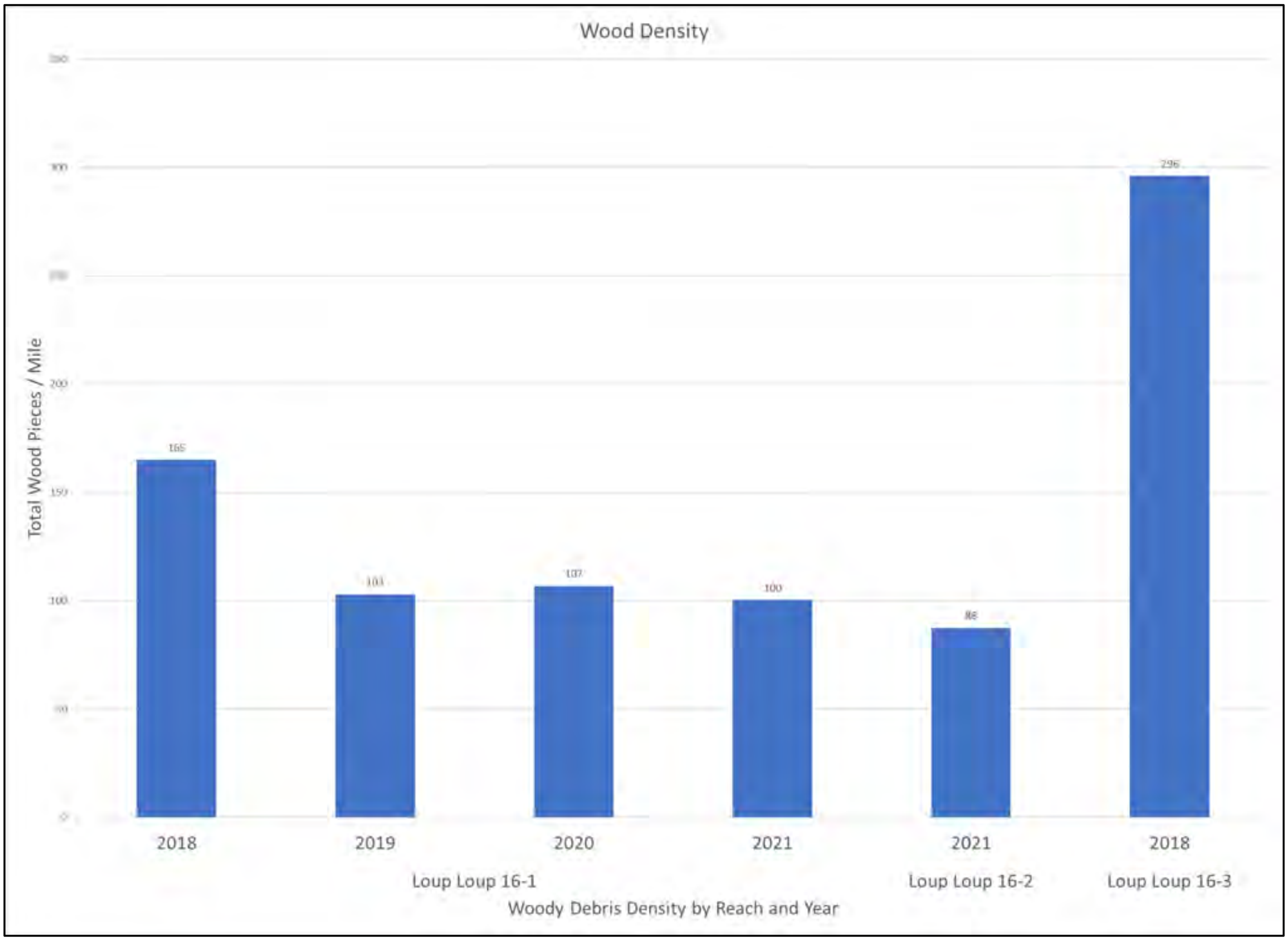


Figure 24. Observed woody debris density in lower Loup Loup Creek, 2018 to 2021

LWD density was highest in Reach 16-3, which had a density of 296 pieces/mile in 2018 (Figure 22). LWD density in Reach 16-1 fell from 165 pieces/mile in 2018 to 101 pieces/mile in 2021. The greatest reduction in LWD density in Reach 16-1 occurred between 2018 and 2019, with density stabilizing between 2019 and 2021. LWD density was 88 pieces/mile in Reach 16-2 in 2021. LWD density was calculated using the quantities of both small and large pieces.

Woody debris jam density is generally low in lower Loup Loup Creek. Jam densities of 10.3 and 9.0 jams/mile were observed in 2021 in Loup Loup 16-1 and Loup Loup 16-2, respectively. In Loup Loup 16-3, the most recent observed jam density was 19.3 jams/mile in 2018.

The median wood loading density in "undisturbed" streams of similar bankfull width within the Douglas fir – ponderosa pine forest zone of Eastern Washington is 15 pieces per 100 m of channel length (Fox and Bolton 2007). This equates to a median density of approximately 240 pieces/mile. The 25th percentile is <5 pieces per 100 m of channel length (Fox and Bolton 2007), which equates to a 25th percentile of approximately 80 pieces/mile. Observed LWD density in was slightly higher this threshold in reach Loup Loup 16-3, but below this threshold in reaches Loup Loup 16-1 and 16-2. However, the most recent measurements in all 3 reaches were above the 25th percentile (80 pieces/mile) for undisturbed streams of similar size. Fox and Bolton (2007) recommend that streams be managed to achieve LWD densities at or above the 75th percentile.

4.3.6 Riparian Vegetation

OBMEP characterized riparian vegetation composition in the study area 10-year floodplain using the methods described in Section 3.4.3. They used NAIP imagery to differentiate areas within the floodplain vegetated predominantly by established perennial trees and shrubs from areas that are unvegetated or covered predominantly by seasonal grasses and forbs. Riparian vegetation zones are displayed in Figure 23. Typical vegetation composition within these zones are summarized in Table 14 and described by reach below. The larger tree species present in the Lower Loup Loup Creek RA study area have the potential to reach over 100 feet in height at maturity. This suggests some potential for recovery of functional riparian conditions with appropriate habitat protection and management.

Within reach 16-1 of Loup Loup Creek, approximately 62% of the 10-year floodplain contains established perennial vegetation, while approximately 38% is unvegetated or contains vegetation that is seasonally dormant. Typical perennial tree and shrub species within the riparian zone of reach 16-1 are listed in Table 14. Seasonal herbaceous species typical to this reach include: native common horsetail (*Equisetum arvense*) and goldenrod (*Solidago* spp.); non-native reed canarygrass (*Phalaris arundinacea*), white sweet clover (*Melilotus albus*), and bittersweet nightshade (*Solanum dulcamara*); and native and non-native species of smooth brome (*Bromus* spp.).

Within reach 16-2, approximately 37% of the 10-year floodplain contains established perennial vegetation, while approximately 63% is unvegetated, or contains vegetation that is seasonally dormant. Typical perennial tree and shrub species within the riparian zone of reach 16-2 are listed in Table 14. Seasonal herbaceous species typical to this reach include common horsetail, reed canarygrass, bittersweet nightshade, and smooth brome.

Within reach 16-3, approximately 58% of the 10-year floodplain contains established perennial vegetation, while approximately 42% is unvegetated, or contains vegetation that is seasonally dormant. Typical perennial tree and shrub species within the riparian zone of reach 16-3 are listed in Table 14. Seasonal herbaceous species typical to this reach include common and scouringrush horsetail and various native and introduced species of mint (*Mentha* spp.).

Figure 25. Riparian vegetation composition in the Lower Loup Loup Creek RA study area

Table 14. Woody riparian vegetation within Loup Loup Creek reaches

Reach	Species	Status (N, I)	Typical Mature Height (feet)
Loup Loup 16-1	Siberian elm (*Ulmus pumila*)	I	50 – 70
	black cottonwood (*Populus balsamifera trichorcarpa*)	N	100 – 200
	quaking aspen (Populus tremuloides)	N	16 – 50
	various other poplar species (*Populus* spp.)	NR	various
	gray alder (*Alnus incana*)	N	20 – 35
	boxelder (*Acer negundo*)	N	≤65
	coyote willow (*Salix exigua*)	N	3 – 20
	various other willow species (*Salix* spp.)	NR	various
	various rose species (*Rosa* spp.)	NR	various
	Saskatoon serviceberry (*Amelanchier alnifolia*)	N	≤23
Loup Loup 16-2	black cottonwood (*Populus balsamifera trichorcarpa*)	N	100 – 200
	gray alder (*Alnus incana*)	N	20 – 35
	quaking aspen (*Populus tremuloides*)	N	16 – 50
	various other poplar species (*Populus* spp.)	NR	various
Loup Loup 16-3	Douglas-fir (*Pseudotsuga menziesii*)	N	70 – 330
	Ponderosa pine (*Pinus ponderosa*)	N	55 - 90
	Siberian elm (*Ulmus pumila*)	I	50 – 70
	black cottonwood (*Populus balsamifera trichorcarpa*)	N	100 – 200
	quaking aspen (*Populus tremuloides*)	N	16 – 50
	gray alder (*Alnus incana*)	N	20 – 35
	various willow species (*Salix* spp.)	NR	various
	various rose species (*Rosa* spp.)	NR	various
I - introduced N - native NR – not reported			

4.4 REI Indicators

EDT-based REI ratings were developed for lower Loup Loup Creek using EDT model inputs and results generated for the 2021 patient scenario. The full REI report is presented in Appendix A. Most REI measures are derived from EDT model inputs and are therefore species independent. Selected REI measures, specifically juvenile habitat capacity, habitat access, and dominant substrate, are species specific. Summer steelhead are the only EDT-modeled species that currently uses Loup Loup Creek as spawning and are therefore used to generate the REI results for those specific indicators.

REI functional condition ratings for each of the 3 EDT habitat reaches comprising the Loup Loup Creek AU are presented in Table 15. The methods used to rate functional conditions, functional scores for each indicator, and narrative interpretation pathway conditions are provided in the full REI report in Appendix A.

The Loup Loup Creek REI report was developed in 2023 using EDT model inputs for the template and 2018-2021 habitat scenarios. During Lower Loup Loup Creek RA development, the authors identified an inconsistency between the 2023 REI peak flow condition indicator ratings and the findings of the RA analysis. Specifically, EDT inputs do not accurately characterize the probable increase in peak flow magnitude relative to historical conditions resulting from loss of canopy cover, as predicted by the USGS peak flow model (Mastin et al. 2016). Per the EDT attribute rating guidelines (Doyle and Lestelle 2021), the predicted 10% increase in the 2-year recurrence interval peak flow generally corresponds to "at risk" conditions in the study area. The values presented in Table 15 have been provisionally revised to these modeled conditions.

Based on these findings, the authors recommend that OBMEP revise the methods used to parameterize the peak flow attribute used in the Okanogan EDT model. EDT model inputs for this attribute will be revised for all EDT Okanogan EDT patient habitat scenarios used in the 2025 HSTR. A summary of recommendations is provided in Section 6.0.

Table 15. REI functional condition ratings for Loup Loup Creek based on habitat and environmental data collected during the 2018 to 2021 OBMEP monitoring cycle

Pathway	General Indicator	Specific Indicator	Loup Loup 16-1	Loup Loup 16-2	Loup Loup 16-3
Hydrology	Peak flow condition[†]	TQMean% change from historical	AR	AR	AR
	Low flow condition	60-day low flow change from historical	AR	AR	AR
	Baseflow capacity	Patient/template juvenile capacity ratio	AR	AR	AR
Temperature	Peak temperature conditions	# days/month above high temperature thresholds	UN	UN	UN
	Low temperature conditions	#days/month below low temperature thresholds	AC	AC	AC
Habitat Access	Effect of obstructions on abundance	Proportion of total restoration benefit attributable to obstructions.	AC	AC	AC
Habitat Quality	Substrate conditions	Dominant substrate – spawning gravel D50	UN	UN	AR
		% Fines	AC	AR	AR
		Embeddedness	AR	AC	AC
	Large woody debris	Pieces/km	UN	UN	AR
	Pools	Pool frequency	UN	UN	AR
		Pool quality, based on woody debris and riparian vegetation condition	UN	UN	UN
	Off channel habitat	Proportion of available habitat in accessible side channel and off-channel habitat	AC	AC	AC
Channel Condition	Dynamics	Floodplain connectivity	UN	AR	AR
		Vertical channel stability – bed scour	AC	AC	AC
		Vertical channel stability - incision	AR	AR	AR
Riparian Vegetation	Riparian condition	Vegetation structure	AR	AR	AR

(green) = Acceptable conditions (AC); (yellow) = At risk conditions (AR); (red) = Unacceptable conditions (UN)

† Peak flow condition indicator ratings have been provisionally revised based on the findings of this analysis.

4.5 EDT Priority Limiting Factors

Priority habitat limiting factors in lower Loup Loup Creek identified by Okanogan EDT for the 2018-2021 OBMEP monitoring cycle are summarized by reach and across the study area as a whole in Table 16. Limiting factors are listed in order of priority, ranked by the Factor Weight function on the Okanogan HSTR. The factor weight is a numerical scale that ranks the relative importance of each limiting factor on a scale of 0-10, with a weighting value of 10 identifying the limiting factor having the greatest impact on habitat performance for ESA-listed steelhead in that geographic unit. These limiting factor ratings reflect conditions observed during the 2018-2021 OBMEP habitat status and trends monitoring cycle.

Table 16. Priority limiting factors and factor weight in the Lower Loup Loup Creek RA study area

Scale/Location	Priority Limiting Factor	Factor Weight
Study area	Fine sediment	9.3
	Temperature: Daily maximum	8.9
	Woody debris	4.6
	Confinement: Artificial	1.4
Loup Loup 16-1	Temperature: Daily maximum	10
	Woody debris	6.0
	Confinement: Artificial	2.4
	Embeddedness	1.4
Loup Loup 16-2	Fine sediment	9.8
	Temperature: Daily maximum	6.5
	Woody debris	4.1
	Riparian-stream interface	0.9
Loup Loup 16-3	Fine sediment	10
	Temperature: Daily maximum	6.1
	Woody debris	1.4
	Confinement: Artificial	0.7

EDT attributes and rating guidelines are described by Doyle and Lestelle (2021). Attribute definitions for identified priority limiting factors in the study area are summarized as follows:

- **Confinement: Artificial** – The extent that man-made structures within or adjacent to the stream channel constrict flow (as at bridges) or restrict flow access to the stream's floodplain (due to streamside roads, revetments, diking or levees) or the extent that the channel has been ditched or channelized. Parameterized as the proportion of total bank length affected by hydromodification.

- **Fine sediment** – Percentage of fine sediment within salmonid spawning substrates, located in pool-tailouts, glides, and small cobble-gravel riffles. Per the OBMEP (2012) monitoring protocol, "fine sediments" comprise substrates <0.6 mm in diameter.
- **Embeddedness** – The extent that larger cobbles or gravel are surrounded or buried by fine sediment, such as sands, silts, and clays. Embeddedness is determined by examining the extent (as an average %) that cobble and gravel particles on the substrate surface are visibly buried by fine sediments. This attribute only applies to riffle and tailout habitat units and only where cobble or gravel substrates occur.
- **Temperature: Daily maximum** – Maximum water temperatures within the stream reach during a month. The EDT rating is based on the median of daily temperatures to reflect the mitigating effect of diurnal temperature variation on thermal tolerance. This EDT model input is rated by month based on the following temperature thresholds:
  - Warmest day in month is >10°C and <16°C.
  - More than 1 day in month with median temperatures between 22°C and 25°C or 1-12 days with >16°C.
  - More than 1 day in month with median daily temperatures between 25°C and 27.5°C or more than 4 days (nonconsecutive) with median daily temperatures between 22°C and 25°C, or more than 12 days with median temperatures >16°C.
  - More than 1 day in month with median temperature >27.5°C, or 3 days (consecutive) with median temperature >25°C, or more than 24 days with median temperature >21°C.

4.6 Climate Change

Climate change is already affecting Washington State. A warming trend averaging 0.25 °C per decade has been observed since the mid-20th century in the Northwestern U.S., and additional warming of 1.5 – 3.2 °C is expected by the middle of the 21st century (Battin et al. 2007). Spring precipitation has also increased in Eastern Washington over the past 100 years (Mote 2003, cited by Gaines et al. 2012). Warming air temperatures contribute to a reduction in total snowpack and earlier snowmelt. Snover et al. (2013) estimate that predicted warming could result in 38 to 46 percent reduction in average spring (April 1) snowpack of relative to historical (1916–2006) conditions in Washington State by the 2040s.

These projected changes in climate, snowpack, and rainfall patterns will alter flowing water environments throughout the watersheds draining the eastern slopes of the Cascade Mountains. Anticipated trends include a shift from predominantly snowmelt towards a mixed rain and snowmelt driven hydrology, warming water temperatures, reduced baseflows in summer and fall, and reduced groundwater levels. Warmer and drier conditions are likely to increase the frequency and severity of forest fires and extend the forest fire seasons (Battin et al. 2007; Cristea and Burges 2010; Crozier and Siegel 2018; Gaines et al. 2012). Fire impacts also contribute to changes in riparian function, woody debris recruitment, sediment loading, and channel degradation.

Climate change impacts, expressed through increased fire frequency, have measurably impacted the hydrology and geomorphology of the Loup Loup Creek watershed (as discussed in Sections 2.3, 4.2, and 4.3). The resulting effects on water temperature, peak flows, spawning habitat suitability, and habitat complexity are likely to persist, negatively impacting the habitat suitability of the creek for steelhead. EDT modeling conducted by the CTCR projects that, in the absence of interventions and under the influence of future climate change, the equilibrium abundance (i.e., theoretical population size) of both adult and juvenile summer steelhead in Loup Loup Creek will decline by approximately 50% by 2040 compared to historical conditions (Doyle et al. 2022). These projected impacts will also negatively affect the CTCR's efforts to reintroduce extirpated spring Chinook salmon to the Okanogan subbasin.

Some negative impacts of climate change on Loup Loup Creek could be offset by habitat restoration, meaning that at least some of the projected decline in habitat potential for ESA-listed salmonids could be avoided. Restoring canopy cover, both at the watershed level and in riparian zones, can ameliorate projected increases in water temperatures in eastern Washington streams (Cristea and Burges 2010). Protection and enhancement of thermal refugia can benefit salmonids by reducing heat stress and metabolic demand (Brewitt et al. 2017). The mainstem Okanogan is already prone to elevated summer temperatures. Loup Loup Creek and other Okanogan tributaries provide important thermal refuges from elevated mainstem temperatures. Like many Okanogan tributaries, Loup Loup Creek historically had a natural fish passage barrier in the valley wall at upstream edge of the alluvial terrace. The CTCR and Okanogan CD recognize that providing access to the higher elevation reaches of these tributaries by providing passage above natural and man-made barriers could greatly increase the quantity of thermal refugia available to steelhead and other salmonids.

Beechie et al. (2013) identified restoration actions that ameliorate higher stream temperatures, moderate streamflow impacts, and increase habitat diversity and population resilience would provide the greatest climate resilience. In addition to providing access to high elevation thermal refugia, the projects most likely to support climate resilience are re-aggrading incised channels, restoring floodplain connectivity, and restoring stream flow regimes. These restoration approaches were more effective than in-stream rehabilitation efforts. The restoration of floodplain connectivity increases salmonid habitat diversity, restores essential stream flows, and improves the downstream transport of wood, sediment, and organic matter. Restoring incised channels can increase floodplain and hyporheic connectivity. The reintroduction of beavers can provide many of these restoration benefits.

When planning forest and riparian habitat restoration projects, land managers should consider both historical and potential future variations in the ranges of plant species to help determine the composition, structure, and spatial pattern of plantings and should focus on providing habitat connectivity that will allow species to adjust their ranges as the climate warms (Gaines et al. 2012). Managers should also plan for and incorporate expected periodic incidences of large fires and other disturbances into management plans.

5.0 RESTORATION STRATEGY

This RA documents the habitat conditions and priority limiting factors present within the Lower Loup Loup Creek RA study area and describes the causal factors that have contributed to these existing conditions. Like many eastern Washington watersheds, Loup Loup Creek has been negatively impacted by a combination of human activities and natural factors. Historical streamflow diversions and fish passage obstructions created by diversion dams and road crossings effectively eliminated anadromous access to the study area. The lowland floodplain and riparian habitats in the study area have been developed for agriculture, transportation, and rural residential uses. At the broader watershed scale, timber harvest, forest roads, streamflow diversions, and transportation development have altered natural hydrologic and sediment transport regimes. Hydrologic and sediment processes have been further degraded by the recent fire history in the watershed. As documented in Section 4.6, climate change is likely to contribute to and exacerbate these ongoing trends. The habitat conditions documented in this RA, and the habitat limiting factors identified by Okanogan EDT are the product of these historical factors. The restoration strategy for Loup Loup Creek must recognize and address the causal mechanisms.

A significant amount of research effort has been dedicated to the development of effective habitat restoration strategies for ESA-listed salmonids over the past 2 decades. Current theory (e.g., Beechie et al. 2008, 2010, 2013; Roni et al. 2002, 2003; Roni and Beechie 2012) emphasizes identifying and addressing the degraded watershed process conditions that are contributing to poor habitat function. Applying this approach to historical and current limiting factors and causal mechanisms identified in this report, a conceptual restoration strategy for Loup Loup Creek should emphasize the following elements:

1. Instream flow acquisition, protection, and restoration.
2. Fish passage restoration and reconnection of fragmented habitats.
3. Implementing landscape-level management actions to protect and restore hydrologic and sediment processes (e.g., acquisition, reforestation, forest road management).
4. Channel modifications to restore floodplain, side channel, and hyporheic connectivity (e.g., grade controls, and/or beaver reintroduction to restore incised stream channels).

5. Implementing site-scale actions to restore riparian vegetation and instream habitat complexity.

The remainder of this section is organized as follows:

- Section 5.1 – Describes the restoration actions that have been implemented to date, the conceptual restoration strategy elements addressed by those actions, and associated Okanogan HSTR priority rank based on EDT habitat limiting factor results for the contemporary OBMEP monitoring cycle.

- Section 5.2 – Presents a prioritized list of categorical restoration actions generated by the Okanogan HSTR that may be suitable for addressing priority EDT limiting factor results for the 2021 monitoring cycle.

- Section 5.3 – Lists currently planned and proposed restoration projects in Loup Loup Creek by priority ranking, associated restoration strategy elements and HSTR priority rankings, and Atlas project feasibility scoring using the criteria described in Section 3.7.

5.1 Actions Completed to Date

Restoration actions completed in the Loup Loup Creek watershed through 2023 are summarized in Table 17. As shown, restoration actions completed to date have focused the first 2 elements of the conceptual restoration strategy identified in section 5.0. The completed projects focused on restoring perennial instream flows and barrier removal to reestablish steelhead access to historical habitats within the study area and allow access to new cold water refugia in the upper watershed.

As of 2011, the highest priority need in Loup Loup Creek was restoring fish passage and streamflow in lower Loup Loup Creek. That year, the CTCR replaced 2 barrier culverts near the Okanogan confluence with bridges and removed an irrigation diversion weir from the upstream end of Loup Loup 16-2. The diversion, which had been active for nearly a century, effectively dewatered reaches Loup Loup 16-1 and 16-2 throughout the summer irrigation season. A companion CTCR project installed a pumped diversion on the mainstem Okanogan to replace the water supplied by the weir. By 2012, these efforts had restored steelhead access to the study area.

The beneficial effects of these projects are evident in the subsequent increase in steelhead production in the Loup Loup Creek watershed (see Table 4). In September 2023, the CTCR completed channel modifications that provided fish passage above the historical natural barrier at the upstream end of the study area. This project theoretically provides steelhead access to 27.2 km of new, high-elevation tributary habitat. However, some of this habitat may be inaccessible due to additional fish passage barriers in the watershed upstream of the study area.

Table 17. Habitat restoration and protection projects implemented in the Loup Loup Creek watershed, 2008 to present

Geographic Scale	SRP #/ Agreement #	Sponsors	Completed	Conceptual Strategy Element	HSTR Priority Rank†	Action Categories	Description
Watershed	#BPA-73548 REL 153	CTCR	2023	2	High	Fish Passage Restoration	Channel modifications to provide steelhead passage through a historical natural barrier located at a series of falls and cascades beginning at RM 2.2. This project provides steelhead access to up to 16.9 miles of high elevation cold water refugia in Upper Loup Loup Creek.
Watershed	#SRP-04-1749	Fisheries Consultants, Inc., RCO-FFFPP	2009	2	High	Fish Passage Restoration	Partial barrier culvert removed, providing upstream access to WDNR lands in Upper Loup Loup Creek (170200062201). Two WDNR fish-blocking culverts, 1 upstream and 1 downstream of site, are scheduled for repair. Project supports future restoration of resident and anadromous fish access to and throughout upper Loup Loup Creek.
Watershed	PRISM # 19-1471	CCFEG, WDFW, RCO	2022	2	n/a	Okanogan Basin Barrier Assessment	CCFEG worked in cooperation with WDFW, to conduct a comprehensive fish passage barrier assessment throughout the Okanogan subbasin to all the region to prioritize investments and to leverage funding to systematically repair/remove fish passage barriers. CCFEG will develop correction analysis forms (CAFs) for up to 5 high priority barriers.
Study area	#SRP-11-16291	CTCR	2012	1	High	Instream Flow Acquisition, Protection, Restoration	Replaced lower Loup Loup Creek gravity diversion with pumped diversion from main stem Okanogan River. Completed irrigation and pumping infrastructure upgrades and formalized landowner/water user agreements to restore instream flows.
Study area	#SRP-08-11008	Okanogan County, CTCR, UCSRB	2011	1	High	Fish Passage Restoration	Removed irrigation diversion structure in Loup Loup 16-3 to restore passage. Replaced complete barrier culvert at RM 0.1 and partial barrier culvert at RM 0.2 with fully passable bridge and bottomless box culvert, respectively. Channel improvements at RM 0.1 to control incision.

Geographic Scale	SRP #/ Agreement #	Sponsors	Completed	Conceptual Strategy Element	HSTR Priority Rank†	Action Categories	Description
Loup Loup 16-1	#SRP- 20-1469	Okanogan CD	Incomplete	5	Moderate+	Riparian Restoration and Management, Channel Modification, Instream Structures	This project will utilize riparian restoration and the addition of instream structures and spawning gravel to improve the quality and quantity of steelhead spawning and rearing habitat in Loup Loup Creek.
Loup Loup 16-1	n/a	Okanogan Land Trust	Ongoing	3	Moderate	Land Protection	Parcel donated by individual owner to Malott Improvement Club in 2018. Mallot Improvement Club donated parcel to Okanogan Land Trust in 2022 under an active MOU. Possibility of transfer of ownership to other entities interested in restoration in the future.
Loup Loup 16-2	#SRP-10-17081	CTCR	2011	3	High	Land Protection, Instream Flow Acquisition, Protection, Restoration	Acquisition of 4.01 acres of property to increase in-streamflow for summer steelhead and potential future fish acclimation site. 0.30 acres of floodplain protected, 0.25 miles of streambank and/or shoreline protected by acquisition, 0.13 miles of stream protected for adequate flow.

† Priority rank based on EDT model results for the OBMEP status and trends monitoring cycle concurrent with project development.

Moderate+ = Project combines multiple moderate priority action categories. n/a = Project is located upstream of current EDT model domain.

Cascade Fisheries, previously known as Cascade Columbia Fisheries Enhancement Group, completed the Okanogan Basin fish passage assessment in 2022. This assessment identified additional previously undocumented fish passage barriers in tributaries throughout the Okanogan subbasin, including Loup Loup Creek upstream of the study area. Okanogan CD anticipates that information about passage barriers in existing and newly accessible anadromous habitat will be incorporated into future Okanogan EDT model runs and HSTR reporting. This will provide useful information for prioritizing fish passage barriers for removal projects for consideration in future RA reports developed for upper Loup Loup Creek and other Okanogan subbasin tributaries.

5.2 Potentially Suitable Actions

The findings of this RA report indicate that the priority habitat limiting factors present in the study area have resulted, at least in part, from the ongoing effects of multiple large-scale fires that have occurred in the Loup Loup Creek watershed over the last 20 years. The limiting factors identified by the Okanogan EDT model (see Section 4.5) are consistent with these broader findings. The Okanogan CD used the Okanogan HSTR Implementation module (see Section 3.7), to develop a prioritized list of categorical restoration actions that could be used to address these priority limiting factors. Categorical restoration actions are presented by priority rank and location in Table 18. These ranked actions are based on Okanogan EDT model results for the OBMEP 2018-2021 monitoring cycle.

5.3 Planned and Potential Actions

The Okanogan CD has identified 7 planned restoration projects in Loup Loup Creek that have applied for or obtained funding through available funding mechanisms. As shown in Table 19, each of these proposed projects aligns with at least 1 of the core conceptual restoration strategy elements identified and addresses 1 or more of the moderate to high priority Okanogan HSTR habitat actions identified in the previous section.

The Okanogan CD has scored the 8 projects listed in Table 19 for implementation feasibility using the modified Atlas scoring criteria identified in Section 3.7. As shown in Table 19, the CCT F&W are continuing to prioritize protection and acquisition of instream flow Multiple practitioners are pursuing restoring stream complexity and flood plain connectivity above the AU to produce desired effects in the response reach of the watershed. A significant advantage of these projects is that they leverage the existing relationships that practitioners have cultivated with landowners and land managers over time.

Table 18. Potentially suitable categories of restoration actions identified for the Lower Loup Loup Creek RA study area

Geographic Scale	Action Category	Action Type	Priority Rank
Assessment Unit/Watershed	Instream Flow Acquisition, Protection, Restoration	Acquire/protect/restore >10–100% of historical flows	High
	Fish Passage Restoration	Barrier removal or breaching	High
	Fine Sediment Management	Road decommissioning or abandonment	High
		Upland vegetation treatment/management	High
		Road grading/drainage improvements	High
	Riparian Restoration and Management	Forest practices	High
		Riparian buffer planting	High
	Side Channel/Off-channel Habitat Restoration	Beaver reintroduction/ beaver dam analogs	High
		Restore perennial side channel (w/groundwater)	Moderate
	Floodplain Reconnection and Management	Buffer restoration, vegetation management	Moderate
		Levee removal or breaching	Moderate
		Floodplain construction	Moderate
		Levee setback	Moderate
	Instream Structures	Large woody debris/engineered logjam placement	Moderate
	Land Protection	Habitat acquisition or conservation easement	Moderate
	Bank Restoration	Restore stream banks using bioengineering techniques	Moderate
	Channel Modification	Channel reconstruction	Moderate
		Spawning gravel cleaning and placement	Moderate

Geographic Scale	Action Category	Action Type	Priority Rank
Loup Loup 16-1	Side Channel/Off-channel Habitat Restoration	Restore perennial side channel (w/groundwater)	High
		Beaver reintroduction/ beaver dam analogs	High
		Alcove restoration (w/groundwater)	Moderate
		Restore perennial side channel (w/o groundwater)	Moderate
		Restore perennial side channel (w/o groundwater)	Moderate
	Floodplain Reconnection and Management	Restore floodplain connectivity	Moderate
		Buffer restoration, vegetation management	Moderate
		Levee removal or breaching	Moderate
		Floodplain construction	Moderate
	Instream Structures	Large woody debris/engineered logjam placement	Moderate
	Riparian Restoration and Management	Riparian buffer planting	Moderate
		Riparian fencing	Moderate
	Channel Modification	Channel reconstruction	Moderate
Loup Loup 16-2	Side Channel/Off-channel Habitat Restoration	Beaver reintroduction/beaver dam analogs	High
		Restore perennial side channel (w/groundwater)	Moderate
		Hyporheic or off-channel groundwater restoration	Moderate
		Alcove restoration (w/groundwater)	Moderate
		Restore perennial side channel (w/o groundwater)	Moderate
	Floodplain Reconnection and Management	Restore floodplain connectivity	High
		Buffer restoration, vegetation management	High
		Floodplain construction	Moderate
		Levee removal or breaching	Moderate
		Levee setback	Moderate
	Instream Structures	Large woody debris/engineered logjam placement	Moderate
	Bank Restoration	Restore stream banks using bioengineering techniques	Moderate
	Channel Modification	Channel reconstruction	Moderate
		Spawning gravel cleaning and placement	Moderate
		Riffle construction	Moderate

Geographic Scale	Action Category	Action Type	Priority Rank
Loup Loup 16-3	Riparian Restoration and Management	Riparian buffer planting	High
		Riparian fencing	High
	Floodplain Reconnection and Management	Restore floodplain connectivity	High
		Buffer restoration, vegetation management	Moderate
		Floodplain construction	Moderate
	Side Channel/Off-channel Habitat Restoration	Beaver reintroduction/beaver dam analogs	Moderate
		Restore perennial side channel (w/groundwater)	Moderate
		Hyporheic or off-channel groundwater restoration	Moderate
		Alcove restoration (w/groundwater)	Moderate
	Bank Restoration	Restore stream banks using bioengineering techniques	Moderate
		Modification or removal of bank armoring	Moderate
	Channel Modification	Spawning gravel cleaning and placement	Moderate
		Channel reconstruction	Moderate
		Riffle construction	Moderate
		Pool development	Moderate

Table 19. Proposed restoration actions in the Lower Loup Loup Creek RA study area, priority ranking, and feasibility scoring

Geographic Scale	Project Description							Implementation Feasibility Scoring							
	Action type	Conceptual Strategy Element	HSTR Priority†	Project	Sponsor	Completion Year	Description	Land ownership	Site access	Regulatory/permitting	Design/planning	Construction Cost	Site management	Risk	Combined Feasibility
Watershed/ Study area	Acquire/protect/ restore >10–100% of historical flows	1	High	#SRP-24-4	CTCR, WWT	2033	Replace unlined diversion ditch with pipe to eliminate leakage and evaporation losses. Water savings will be dedicated to instream flows.	3	3	2	1	1	1	1	12
	Beaver reintroduction/ beaver dam analogs	1, 4	High	WRSRP-2020-MSRF-00010	MSRF, WCSA, WDNR, WDOE, WDFW	2025	Methow Beaver Project initiated beaver reintroduction on Loup Loup Creek in 2022, comprising wood loading, riparian restoration, and beaver reintroduction on private and WDNR lands over RM 6-7. Successive treatments followed in 2023. Wood loading will continue on DNR property in 2024. Beaver reintroduction will continue through 2025.	3	3	3	3	3	3	1	19

Geographic Scale	Project Description							Implementation Feasibility Scoring							
	Action type	Conceptual Strategy Element	HSTR Priority†	Project	Sponsor	Completion Year	Description	Land ownership	Site access	Regulatory/permitting	Design/planning	Construction Cost	Site management	Risk	Combined Feasibility
Loup Loup 16-1	Riparian buffer planting, Large woody debris/ engineered logjam placement	5	Moderate+	#SRP-24-14	Okanogan CD	2033	Improve instream habitat and riparian conditions along 600 feet of documented steelhead spawning habitat; increase riparian buffer width from existing 10 feet to 30-100 feet. Design riparian restoration, instream structures, and spawning gravel augmentation to improve the quality and quantity of steelhead spawning and rearing habitat.	1	3	3	2	2	2	1	14
	Large woody debris/engineered logjam placement	5	Moderate	Conceptual	CTCR	TBD	Wood supplementation on public land upstream of natural barrier passage project.	3	2	2	2	1	2	2	14
	Barrier removal or breaching	2	High	Conceptual	CTCR	TBD	Address additional fish passage barriers in the reach.	1	3	2	2	2	2	1	13

Sponsor acronyms: Confederated Tribes of the Colville Reservation (CTCR), Methow Salmon Recovery Foundation (MSRF), Okanogan Conservation District (Okanogan CD), Wildlife Conservation Society of America (WCSA), Washinton Department of Ecology (WDOE), Washington Department of Natural Resources (WDNR), Washington Department of Fish and Wildlife (WDFW), Washington Water Trust (WWT).

† High = Project is Okanogan HSTR high priority action; Moderate+ = Project comprises 2 or more Okanogan HSTR moderate priority actions. See Table 18.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The Okanogan CD has developed the Lower Loup Loup Creek RA Report to support habitat restoration planning and implementation in this important Okanogan subbasin assessment unit. As discussed in Section 1.0, this report synthesizes available OBMEP monitoring data, EDT model results, and other supporting information to provide an RA report that aligns with UCSRB guidance (UCRTT 2022). The Okanogan CD and other watershed partners will use this report to support current and future restoration grant proposals in this watershed. This proof of concept will provide a basis for the development of RA reports in other Okanogan subbasin assessment units.

The recommendations provided in Sections 6.1 and 6.2 are intended to support the development and evaluation of habitat restoration strategies and project proposals. Section 6.1 summarizes recommended priority habitat restoration actions for the study area based on the results of EDT modeling and the observed conditions summarized in this report. Section 6.2 summarizes additional studies needed to support the development of project designs. The Okanogan CD recommends that project developers integrate these additional studies into the design process. These recommendations may also be used by SRFB and other grant programs to evaluate and prioritize restoration proposals for funding.

Section 6.3 summarizes lessons learned from RA development that will guide the development of future RAs in the Okanogan subbasin, potential improvements to the Okanogan EDT model, and refinement of OBMEP status and trends monitoring methods.

6.1 Recommended Priority Habitat Restoration Actions

As summarized in Section 5.1, several restoration actions have been completed in the Loup Loup Creek watershed in the last 15 years. These actions addressed clear high priority habitat needs, restoring perennial instream flow and anadromous access into and upstream of the study area. The planned irrigation efficiency projects would expand on this core strategic need, providing instream flow benefits throughout the majority of existing and newly accessible anadromous habitat in the watershed. However, the clear restoration benefits provided by fish passage and instream flow restoration are being partially offset by the detrimental effects of repeated watershed-scale fires on hydrologic and sediment delivery processes. Accordingly, future restoration efforts should focus on elements 3 through 5 of the conceptual restoration strategy for Loup Loup Creek, with emphasis on the following objectives:

- Watershed-level landscape management actions to restore peak flow hydrology and sediment delivery processes and increase climate change resiliency, including:
  - Forest management to improve sustainable canopy cover and vegetive coverage.

  - Forest road management and retirement to control sediment delivery and reduce landslide risk.

  - Beaver restoration in higher elevation and headwater areas to promote peak flow attenuation, alluvial storage, and baseflow restoration.

- Reach-level actions to increase floodplain connectivity and channel complexity within the study area, designed to:

  - Re-aggrade the stream channel and restore spawning substrates.

  - Increase transport of fine sediment at typical flows and deposition in overbank habitats during flood events.

  - Provide suitable habitats for spawning and rearing over a broader range of instream flows.

- Reach and site-level actions to protect and restore riparian and instream habitat complexity.

WDNR is the majority landowner in the Loup Loup Creek watershed. As such, the state is responsible for developing and implementing the landscape-level management actions needed to restore hydrologic and sediment delivery processes. These types of actions are complex and measurable improvements in process conditions may take years to realize. They must also account for and, where possible, offset anticipated climate change impacts.

In contrast, many of the suitable locations for reach and site level actions are located on fragmented private land ownership within the study area. Achieving reach- and site-level restoration such as improving floodplain connectivity, channel complexity, protecting riparian and instream habitat can be challenging when dealing with fragmented land ownership. Coordinating with numerous landowners with diverse priorities and willingness and negotiating access across properties requires trusting relationships built over time between practitioners and private landowners.

The Okanogan CD, CTCR, and our other subbasin partners are well positioned to develop and implement strategic actions at this scale. We commonly work with willing private and tribal landowners to find suitable sites for priority restoration actions and work with our project partners and regional lead entity to fund, design, and implement these projects. Consistent with the restoration strategy presented in this report, these projects will be designed to address the reach and site level objectives identified above. The Okanogan CD recommends that future project concepts address these same objectives.

6.2 Recommended Project Planning and Design Requirements

The Lower Loup Loup Creek RA describes the current environmental conditions within the study area, identifies priority habitat limiting factors and contributing watershed process conditions, and provides a prioritized list of recommended restoration actions. This information is suitable for developing a habitat restoration strategy for the study area and identifying potential projects. However, additional information and analysis may be needed to support actual project design. This is particularly the case for projects that would modify the channel and floodplain. Specifically:

- Hydrologic analysis: The available hydrologic record is limited and overlaps a period of substantial landscape change at the watershed level. Additional analysis may be needed to determine reasonable estimates for low-frequency (i.e., 50-year and 100-year) return interval floods to meet project engineering requirements.
- Sediment transport analysis: The study area shows strong evidence of a change in the rate of fine sediment delivery in response to repeated large scale fires. Additional analysis is needed to understand the current rate and trajectory of sediment transport in the study area.
- Hydraulic modeling: Site-level hydraulic modeling will be necessary to support the design of any large site or reach-scale channel modification project.

The Okanogan CD recommends that restoration practitioners consider and incorporate these study recommendations into future project design and funding proposals where appropriate. We also recommend that these recommendations provide a checklist for evaluation of these proposals.

6.3 Recommended Okanogan EDT and Reach Assessment Improvements

In the process of developing this report, Okanogan CD and their contractors identified several recommendations for addressing near-term information needs in Loup Loup Creek and improving the information framework used to develop this analysis as a proof of concept for future Okanogan subbasin RA reports. These recommendations fall into 3 categories:

1. Okanogan EDT model improvements

    - Adapt the Mastin et al. (2016) peak flow prediction model to improve the methods used to characterize the magnitude of peak flow degradation relative to historical conditions.

    - Revise the methods used to characterize channel degradation (i.e., downcutting and floodplain fragmentation).

2. OBMEP monitoring improvements
   - Conduct periodic channel cross section and substrate composition surveys at previously used survey locations (e.g., OBMEP-421, transect F) to support evaluation of change over time.
   - Where practicable, align data collection with implemented restoration actions to support effectiveness monitoring.
   - Initiate habitat characterization and monitoring surveys in Upper Loup Loup Creek.
3. Okanogan HSTR updates:
   - Incorporate Upper Loup Loup Creek into Okanogan EDT model runs for 2024 HSTR.
4. Okanogan RA improvements:
   - Incorporate standardized mapping of geomorphic surfaces.
   - Develop companion RA analysis and RA report for Upper Loup Loup Creek.

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Appendix A

Loup Loup Creek REI Report

CONFLUENCE
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Okanogan Ecosystem Diagnosis and Treatment Model
REACH-BASED ECOSYSTEM INDICATORS – LOUP LOUP CREEK

Prepared for:

Okanogan Basin Monitoring and Evaluation Program
March 2023

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Okanogan Ecosystem Diagnosis and Treatment Model
REACH-BASED ECOSYSTEM INDICATORS: LOUP LOUP CREEK

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TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

AC	Acceptable conditions (REI condition rating)
AR	At risk (REI condition rating)
AU	Assessment Unit (analysis subwatershed used for habitat monitoring and recovery planning)
C	centigrade
D50	50th percentile (median) substrate particle diameter in millimeters
EDT	Ecosystem Diagnosis and Treatment model
HSTR	Habitat status and trend report
km	kilometer
LiDAR	Light detection and ranging
m	meter
mm	millimeter
NAIP	National Agricultural Imagery Program
Neq	Equilibrium abundance (EDT model result)
NMFS	National Marine Fisheries Service
OBMEP	Okanogan Basin Monitoring and Evaluation Program
OBMEP RA	OBMEP rapid assessment survey
REI	Reach-based ecosystem indicators
UNRTT	Upper Columbia Regional Technical Team
UNSRB	Upper Columbia Salmon Recovery Board
UN	Unacceptable conditions (REI condition rating)
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service

1.0 INTRODUCTION

This report describes a method for developing reach-based ecosystem indicators (REIs) from Ecosystem Diagnosis and Treatment (EDT) model input and result parameters. This method allows the user to develop REI indicator ratings at the EDT reach and assessment unit (AU) level in the Okanogan and Methow subbasins. EDT models have been developed in these Upper Columbia River tributary subbasins to support status and trend monitoring and restoration planning. The proposed indicators are consistent with regional guidance (UCRTT 2022) and comparable to those used in existing reach assessments conducted in the Upper Columbia (e.g., YNF 2019). This approach relies on EDT input and results where practicable, using information that can be downloaded from the web-based EDT Habitat Status and Trend Reports, or HSTRs (https://ecosystems.azurewebsites.net/hstr-okanogan/, https://ecosystems.azurewebsites.net/hstr-methow/).

The following REI terminology is used in this report:

- Pathway: An ecological function or process through which actions can impact salmonids and their habitats.
- General indicator: Qualitative parameter used to characterize the condition of the parent pathway. A pathway comprises one or more general indicators.
- Specific indicator: Quantitative parameter used to characterize the condition of the parent general indicator. A general indicator comprises one or more specific indicators.
- Measure: The quantitative metric used to parameterize the parent specific indicator. Measures presented in this report are designed to use EDT model inputs and results that are downloadable from the Methow and Okanogan HSTRs, except where indicated.

This report presents provisional REI results for Loup Loup Creek, a tributary watershed AU in the Okanogan subbasin as a proof-of-concept. This REI report demonstrates the application of Okanogan EDT environmental input data and model results to derive REI indicator ratings at the reach scale. A summary of findings and recommendations are provided at the end of this report.

2.0 METHODS

The REI presented herein is based on the framework developed by the Upper Columbia Regional Technical Team (UCRTT 2022, Appendix A). This framework rates environmental conditions using three categorical tiers: Acceptable conditions (AC); at risk conditions (AR); unacceptable conditions (UN). The UCRTT condition tiers are comparable to the Properly Functioning, At Risk, and Not Properly Functioning condition tiers used in the National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife (USFWS) matrices of pathways and indicators (NMFS 1996; USFWS 1998), and subsequent adaptions by the United States Bureau of Reclamation (USBR). The USBR has used these REI measures in numerous reach assessments conducted in the tributary subbasins to the Upper Columbia Recovery Domain.

The REI rating approach assumes the use of EDT model inputs and selected model outputs for a representative target species. Proposed EDT-based REI pathways and indicators, EDT model inputs and results outputs and other information sources used to characterize indicator conditions, and categorical functional condition thresholds are described in Table 1. Most proposed REI indicators are derived from EDT patient and template scenario ratings for relevant Level 2 habitat attributes, identifiable by the term "EDT attribute rating" in the in the Information Source/Description column. Indicator functional condition ratings are based on the % of Template condition presented on the HSTR Implementation Tab. The % of Template rating is calculated from EDT input attributes for the template and selected patient scenario using the formula presented in Appendix A and attribute data downloaded from the HSTR website. Selected % of Template ratings for the top 5 priority attributes for restoration in each AU and reach can also be obtained directly from the HSTR Implementation Tab.

Indicators that are derived from other data and information sources are as follows:

- Hydrology/Habitat capacity: Derived from the ratio of juvenile habitat capacity under EDT patient and template scenario conditions (see Appendix A).
- Habitat Access/Effect of obstructions: Proportion of total habitat restoration benefit attributable to restoring fish passage (see Appendix A).
- Habitat Quality/Dominant substrate:
  - Based on the 50th percentile substrate diameter (D50) in mm, derived from OBMEP substrate survey data using an interpolation algorithm based on methods described by Bundt and Abt (2001) and Doyle et al. (2015).
  - D50 values for surveyed habitat reaches in Okanogan subbasin are generated automatically by an Okanoganmonitoring.org database export query.

- Habitat Quality/Pool frequency: Derived from an assumed relationship between EDT % pool composition and average pool length as a function of wetted channel width (see Appendix A).
- Channel Condition/Vertical channel stability - aggradation/incision: Cannot be derived from EDT inputs or results. Requires site-specific knowledge or information.

Data sources and formulae for calculating these REI indicators are presented in Appendix A by associated method.

Table 1. Data sources and methods for deriving Reach-based Ecosystem Indicators from EDT model inputs and HSTR results.

Pathway	General Indicator	Specific Indicator	Measure/ EDT attribute	Information Source/Description	Available from HSTR?[‡]	REI Condition Rating		
						Adequate	At Risk	Unacceptable
Hydrology	Peak flow condition	TQMean% change from historical	Flow: Inter-annual high flow variation	EDT attribute rating. Ratio of maximum monthly template and 2021 peak attribute ratings. Represents change in peak flow volume relative to template.	Yes[¥]	>80% of template	40-80% of template	<40% of template
	Low flow condition	60-day low flow change from historical	Flow: Inter-annual low flow variation	EDT attribute rating. Ratio of maximum monthly template and 2021 peak attribute ratings. Represents change in base flow volume relative to template.	Yes[¥]	>80% of template	40-80% of template	<40% of template
	Habitat capacity	Juvenile habitat capacity/km	% of template capacity/km	Ratio of VSP parameters generated by EDT. Represents effect of flow on available habitat capacity for juvenile rearing. Derived from EDT model results.	Yes[Δ]	>80% of template	40-80% of template	<40% of template
Temperature	Peak temperature conditions	Count of days/month above range of thermal thresholds (10, 16, 22, 25, 27.5 degrees C)	Temperature: Daily maximum	EDT attribute rating. Ratio of maximum monthly template and 2021 peak attribute ratings. Represents change in peak summer temperature conditions relative to template. Derived from EDT inputs.	Yes[¥]	>80% of template	40-80% of template	<40% of template
	Low temperature conditions	Count of days/month below 4 degrees/1 degree C.	Temperature: Daily minimum	EDT attribute rating. Ratio of maximum monthly template and 2021 peak attribute ratings. Represents change in minimum winter temperature conditions relative to template.	Yes[¥]	>80% of template	40-80% of template	<40% of template
Habitat Access	Effect of passage obstructions	Effect of obstructions as proportion of restoration potential	Obstruction effect as % of total increase in Neq with restoration to template conditions, modeled at AU level.	EDT results. Ratio of potential increase in Neq with restoration to template conditions attributable to obstructions. Result is calculated at assessment unit level. Value is the ratio of the sum of potential increase in Neq from restoration of all obstructions in AU to template conditions to the increase in Neq at the AU level with full restoration of all environmental attributes to template conditions.	Yes[Δ, ▲]	<5% of restoration benefit	5-30% of restoration benefit	>30% of restoration benefit

Pathway	General Indicator	Specific Indicator	Measure/ EDT attribute	Information Source/Description	Available from HSTR?‡	REI Condition Rating		
						Adequate	At Risk	Unacceptable
Habitat Quality	Substrate	Dominant Substrate	Spawning gravel D50 (mm)	Bed Scour Model input. Ranges based on Kondolf and Wolman 1993 (Fig 7). AC is central tendency, AR is 0-25th/75-100th percentile ranges, UN is outside of observed ranges.	No D50 value is generated by Sitka from OBMEP gravelometer, sieve measurements. Used as input to OBMEP bed scour model.	Steelhead: 19<D50<35mm Chinook: 22<D50<48mm	Steelhead: 10<D50<19mm, 35<D50<48mm Chinook: 10<D50<22mm, 48<D50<80mm	Steelhead: D50<10mm, >48mm Chinook: D50<10mm, >80mm
			% Fines	EDT attribute rating. OBMEP sieve and ocular measurements. Represents proportion of spawning substrates composed of fine sediments.	Yes¥	>80% of template	40-80% of template	<40% of template
			Embeddedness	EDT attribute rating. OBMEP sieve and ocular measurements. Represents proportion of juvenile rearing substrates affected by substrate embeddedness.	Yes¥	>80% of template	40-80% of template	<40% of template
	Large woody debris	Pieces/km at bankfull	Woody Debris	EDT attribute rating. OBMEP RA. Presence of functional woody debris in stream channel. Derived from EDT inputs.	Yes¥	>80% of template	40-80% of template	<40% of template
	Pools	Pool frequency	Scour pools % of composition	EDT attribute rating. OBMEP RA. Pool frequency interpolated from % pools and minimum reach area (EDT minimum width x length). Number of pools interpolated from minimum pool size of 3x average EDT channel width.	Yes¥, §	≥AC frequency for width class	50-99% of AC frequency for width class	<50% of AC frequency for width class
		Pool quality	Presence of AC woody debris and riparian/stream interface conditions	EDT attribute ratings. OBMEP RA. Applies REI ratings for pool frequency, woody debris, and riparian/stream interface.	Yes Combination of ratings.	AC pool frequency with AC woody debris and riparian/stream interface conditions	AC pool frequency with AR woody debris and/or riparian/stream interface conditions	AR or UN pool frequency with AR or UN woody debris and/or riparian/stream interface conditions

Pathway	General Indicator	Specific Indicator	Measure/ EDT attribute	Information Source/Description	Available from HSTR?‡	REI Condition Rating		
						Adequate	At Risk	Unacceptable
Habitat quality (continued)	Off channel habitat	Connectivity with main channel	Proportion of reach area in seasonally inundated floodplain, floodplain ponds, groundwater channels and side channels, as % of template habitat composition	EDT attribute rating. Proportional habitat composition.	Yes¥	Side channels and off channel habitat present, combined proportion is >80% of combined proportion under template conditions.	Side channels and off channel habitat present, combined proportion is 40-80% of combined proportion under template conditions.	Side channels and off channel habitat present, combined proportion is 40-80% of combined proportion under template conditions.
Channel Condition	Dynamics	Floodplain connectivity	Confinement: Artificial	EDT attribute rating. OBMEP RA. . Proportion of stream channel affected by artificial confinement.	Yes¥	>80% of template	40-80% of template	<40% of template
			Confinement: Natural	EDT attribute rating. OBMEP RA. Qualifier for above attribute. AR thresholds are beginning and end of inflection point on EDT rule curve. AC and UN are values above and below AR range.	Yes¥	≤1.5 Unconfined reach with high natural habitat potential.	>1.5-2.5 Moderately confined reach with moderate to high natural habitat potential.	>2.5 Confined reach with low to moderate natural habitat potential.
		Vertical channel stability	Bed Scour	EDT attribute rating. OBMEP RA and Bed Scour Model. Attribute rating based on modeled scour depth in spawning habitats, generated by ICF Bed Scour Model.	Yes¥	>80% of template	40-80% of template	<40% of template

Pathway	General Indicator	Specific Indicator	Measure/ EDT attribute	Information Source/Description	Available from HSTR?‡	REI Condition Rating		
						Adequate	At Risk	Unacceptable
Channel Condition (cont.)	Dynamics (cont.)	Vertical channel stability (cont.)	Channel incision/ aggradation	Observational data. EDT input attributes and model results do not provide a reliable measure of this indicator. Must be derived from observational data.	No	No measurable trend of aggradation or incision and no visible change in channel planform 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).	Floodplain and off-channel habitat from the main channel by channel incision; or visible change in channel planform due to aggradation (e.g., single thread to braided).
Riparian Vegetation	Condition	Vegetation structure	Riparian/Stream Interface	EDT attribute rating. OBMEP RA. LiDAR and NAIP imagery analysis. Attribute ratings generated by OBMEP from LiDAR and NAIP imagery.	Yes¥	>80% of template	40-80% of template	<40% of template

‡ "Yes" means source data table can be downloaded directly from the HSTR web database. For Okanogan data, follow the links provided below for the indicated data table and press *Enter*. For Methow data, use the same links replacing "-okanogan" with "-methow". Data tables will download automatically to your default directory.

¥ HSTR export table https://ecosystems.azurewebsites.net/hstr-okanogan/data/reach_environment_data.csv.

Δ HSTR export table https://ecosystems.azurewebsites.net/hstr-okanogan/data/performance_by_geometry_member.csv.

§ HSTR export table https://ecosystems.azurewebsites.net/hstr-okanogan/data/dimensional_data.csv.

▲ HSTR export table https://ecosystems.azurewebsites.net/hstr-okanogan/data/obstruction_splices.csv.

3.0 RESULTS

EDT-based REI ratings were developed for the Loup Loup Creek , a tributary watershed of the Okanogan subbasin, using EDT model inputs and results generated for the 2021 patient scenario. This scenario is based on habitat and environmental monitoring data collected by OBMEP during the 2018 to 2021 monitoring cycle. As stated in Section 2, most REI measures are derived from EDT model inputs and are therefore species independent. Selected REI measures, specifically juvenile habitat capacity, effect of obstructions, and dominant substrate, are species specific. Summer steelhead are the only species using Loup Loup Creek as spawning habitat in Okanogan EDT and are therefore used to generate the REI results presented herein.

The Loup Loup Creek AU comprises three reaches, Loup Loup 16-1, 16-2, and 16-3, representing currently available anadromous habitat between the confluence with the Okanogan River and a natural fish passage barrier created by a waterfall and boulder cascade located approximately 3.5 km upstream. The three reaches are 1,250, 1,250, and 1,000 meters in length, respectively, ranging from 1.5% to 3.6% in gradient with bankfull widths ranging from 3.2 to 5.4 meters. Loup Loup 16-1 and 16-2 are naturally unconfined while Loup Loup 16-3 is moderately confined naturally. The headwater portions of the watershed upstream of the AU have experienced two moderate to high-intensity fires in the past 15 years, adversely affecting hydrologic and sediment transport processes resulting in detrimental effects on habitat conditions within the anadromous AU.

REI functional condition ratings for each of the three EDT habitat reaches comprising the Loup Loup Creek AU are presented in Table 2. The calculated functional scores for each specific indicator are presented by reach in Appendix B, Table B-1. Interpretation of indicator conditions for each REI pathway is provided below. These REI ratings apply to currently modeled habitat between the mouth and the falls at the current upstream limit of anadromous habitat in EDT reach Loup Loup 16-3.

3.1 Hydrology

The Hydrology pathway comprises three specific indicators. Two of these indicators are based on % of Template ratings for EDT Level 2 flow attributes, while one, the baseflow habitat capacity indicator, is based on EDT modeled habitat capacity for juvenile steelhead.

As shown in Table 2, the functional condition of the peak flow indicator is rated AC under 2021 patient scenario conditions. This result is influenced by prevailing drought conditions during the 2018 to 2021 monitoring cycle that contributed to decreased peak flow volumes relative to template conditions, as measured by the *Flow: Interannual High Flow* attribute. In contrast, drought conditions and ongoing irrigation water withdrawals contributed to degraded base flow conditions relative to template and an AR rating for this indicator, as measured by the *Flow: Interannual Low Flow* attribute. Baseflow habitat capacity for juvenile steelhead, a useful indicator of baseflow conditions, is also rated as AR. The associated measure, calculated from AU level EDT results, indicates that juvenile habitat capacity is currently functioning at 54% of template conditions. Considered collectively, these indicators suggest that the hydrology pathway is functioning AR in the Loup Loup Creek AU.

3.2 Temperature

The Temperature pathway comprises two EDT-based habitat indicators. The peak and low temperature condition indicators are based on the % of Template values for the T*emperature: Daily Maximum* and *Temperature: Daily Minimum* Level 2 attributes. As shown in Table 2, low temperature conditions in Loup Loup Creek are rated as AC. These ratings reflect a general increase in minimum winter temperatures and a reduced duration of extreme cold periods compared to historical template conditions. This would in turn reduce the negative effect of cold temperatures on juvenile growth and survival, producing a productivity benefit compared to template conditions. In contrast, peak summer temperatures have increased substantially compared to template under 2021 patient scenario conditions, resulting in a UN rating for this REI.

HSTR Implementation tab results indicate that *Temperature: Daily Maximum* was the second highest priority EDT Level 2 habitat attribute affecting steelhead habitat in Loup Loup Creek from 2018 through 2021. HSTR Habitat Trend tab results indicate that temperature is the third highest priority survival factor when temperature effects are combined, indicating that the negative effects of peak summer temperatures override any beneficial effect from increased temperatures in winter. This warrants a combined REI rating of UN for the temperature pathway.

3.3 Habitat Access

The REI rating for the habitat access pathway is based on the proportion of the total habitat restoration benefit attributable to restoring fish passage at the AU level (see Appendix A). The associated passage effect indicator considers the increase in adult abundance that would result if each obstruction modeled in EDT in the AU were restored to template passage conditions. In the case of Loup Loup Creek there are four obstructions modeled in EDT, two culverts near the downstream end of EDT reach Loup Loup 16-1, and one culvert and one diversion dam located near the downstream end of reach Loup Loup 16-2. All these obstructions were modified or replaced during the 2013 monitoring cycle to improve fish passage. The passage conditions modeled for each of these obstructions in the 2021 patient scenario indicate little opportunity for further improvement. Modest fish passage improvements could be achieved at EDT reach Loup Loup 16-2.1 (culvert) but this would account for an increase of less than 1 adult steehead, or only 2.5% of the projected benefit from restoring the entire AU to template habitat conditions. As such, this REI indicator is rated as AC for the entire Loup Loup Creek AU.

Table 2. REI functional condition ratings for Loup Loup Creek based on habitat and environmental data collected during the 2018 to 2021 OBMEP monitoring cycle.

Pathway	General Indicator	Specific Indicator	Loup Loup 16-1	Loup Loup 16-2	Loup Loup 16-3
Hydrology	Peak flow condition	TQMean% change from historical	AC	AC	AC
	Low flow condition	60-day low flow change from historical	AR	AR	AR
	Baseflow capacity	Patient/template juvenile capacity ratio	AR	AR	AR
Temperature	Peak temperature conditions	# days/month above high temperature thresholds	UN	UN	UN
	Low temperature conditions	#days/month below low temperature thresholds	AC	AC	AC
Habitat Access	Effect of obstructions on abundance	Proportion of total restoration benefit attributable to obstructions.	AC	AC	AC
Habitat Quality	Substrate conditions	Dominant substrate – spawning gravel D50	UN	UN	AR
		% Fines	AC	AR	AR
		Embeddedness	AR	AC	AC
	Large woody debris	Pieces/km	UN	UN	AR
	Pools	Pool frequency	UN	UN	AR
		Pool quality, based on woody debris and riparian vegetation condition	UN	UN	UN
	Off channel habitat	Proportion of available habitat in accessible side channel and off-channel habitat	AC	AC	AC
Channel Condition	Dynamics	Floodplain connectivity	UN	AR	AR
		Vertical channel stability – bed scour	AC	AC	AC
		Vertical channel stability - incision	AR	AR	AR
Riparian Vegetation	Riparian condition	Vegetation structure	AR	AR	AR

= Adequate conditions (AC); = At risk conditions (AR); = Unacceptable conditions (UN)

3.4 Habitat Quality

The habitat quality pathway comprises four general indicators (Table 1), substrate conditions, large woody debris, pools, and off-channel habitat. The condition of these general and component specific indicators in the Loup Loup Creek AU are described below.

3.4.1 Substrate Conditions

The substrate conditions general indicator comprises three specific indicators, dominant substrate conditions, substrate % *fines*, and *embeddedness*. The latter two indicators are rated using the % of Template values for the associated EDT Level 2 habitat attributes. Dominant substrate conditions are based on D50 values derived from OBMEP monitoring data using an algorithm derived from methods described by Bundt and Abt (2001). Categorical rating thresholds for dominant substrates are based on species-specific spawning substrate preferences described by Kondolf and Wolman (1993).

As shown in Table 2 and in Appendix B, Table B-2, the % *Fines* indicator is functioning at 96% of template in reach Loup Loup 16-1 and 67% of template in 16-2 and 16-3, or AC and AR conditions, respectively. *Embeddedness* is functioning at 75%, 92%, and 100% of template in these three reaches, or AR, AC, and AC conditions respectively. These findings indicate a degree of recovery from degraded substrate conditions observed during the 2014 to 2017 monitoring cycle, attributable to the effects of repeated high-intensity fires in the headwaters of this watershed. However, the dominant substrate indicator is rated as UN in all three reaches based on interpolated D50 values that fall below the minimum diameter preferred by steelhead for spawning habitat. Collectively, these findings indicate that the substrate general indicator is functioning at AR to UN conditions in the Loup Loup Creek AU.

3.4.2 Large Woody Debris

The large woody debris general indicator comprises one specific indicator, woody debris density measured in pieces/km at bankfull depth, stratified by reach class. The EDT Level 2 *woody debris* attribute provides a direct measure of indicator condition, which is rated using % of Template value. The woody debris indicator is functioning at 18%, 12%, and 75% of template capacity in reach Loup Loup 16-1, 16-2, and 16-3, respectively (Appendix B, Table B-1). This equates to an REI rating of UN in reaches 16-1 and 16-2, and AR in 16-3 (Table 2).

3.4.3 Pools

The pools general indicator comprises two specific indicators, pool frequency and pool quality, which are compiled from different sources of information. Pool frequency is measured as the number of pools per kilometer of stream length, with functional thresholds stratified by wetted channel width. The pool frequency thresholds referenced for AC in Table 1 are minimum values derived from the NMFS (1996) matrix of pathways and indicators, AR and UN are proportional ranges within this minimum threshold. Pools/km in Loup Loup Creek are estimated from EDT proportional habitat composition using the methods described in Appendix A. Pool quality is determined from a combination of pool frequency and the condition of two other specific REI indicators, woody debris and riparian conditions (see Table 1).

Pool frequency in Loup Loup Creek is estimated at 34, 12, and 53 pools/km in reaches Loup Loup 16-1, 16-2, and 16-3, which equates to 39%, 24%, and 71% of AC conditions, and UN, UN, and AR condition ratings, respectively. Pool quality is rated as UN in all three reaches, as determined by lower than AC woody debris and riparian conditions (see Sections 3.4.2 and 3.6).

As stated in Appendix A, the assumption of average pool length being equal to 3 times wetted width provides a reasonable estimate of pool frequency. However, it appears that average pool lengths by reach can easily be derived from OBMEP survey data (R. Klett, pers. comm. 2023). The pool quantity indicator could be improved by incorporating these data into the proposed REI report generation function described in Section 4.

3.4.4 Off-channel Habitat

The off-channel habitat general indicator comprises one specific indicator, the presence and connectivity of off-channel habitat to the main channel. The condition of this indicator is measured using a combination of EDT Level 2 environmental attributes, proportional composition of *seasonally inundated floodplain* and *side channels*, and natural channel confinement as measured by the Level 2 *confinement: natural* attribute. This attribute is rated using a modified % of Template function rating schema as described in Appendix A. Off-channel habitats are less prevalent in confined channels, increasing the importance of side channels in this habitat type.

The EDT *confinement: natural* Level 2 attribute has ratings of 0, 0.6, and 2 in reaches Loup Loup 16-1, 16-2, and 16-3, respectively, corresponding to unconfined, unconfined, and moderately confined conditions, respectively. Side channels comprised 11%, 6%, and 3% of wetted reach area during the 2018 to 2021 monitoring cycle, respectively. No seasonally inundated floodplain habitats were documented in the AU during this period. Ratings for all three reaches are within 80% of template. Applying the REI rating criteria in Table 1, observed side channel frequency equates to AC condition ratings in Loup Loup 16-1 and 16-2, and 16-3 (Table 2).

3.5 Channel Dynamics

The channel dynamics general indicator comprises three specific indicators, floodplain connectivity, vertical channel stability – bed scour, and vertical channel stability – incision. Floodplain connectivity and bed scour conditions can be derived directly from EDT data. EDT does not explicitly consider channel incision, which presents a challenge. EDT inputs and model results provide no useful measures for evaluating channel incision. Therefore, site-specific knowledge is necessary to develop REI ratings for this specific indicator.

The floodplain connectivity measure is derived from the EDT *confinement: artificial* Level 2 environmental attribute. REI condition ratings for this attribute are based on % of Template condition, with the understanding that template conditions assume that no artificial confinement was historically present. This indicator is functioning at 31%, 53% and 75% of template conditions in reaches Loup Loup 16-1, 16-2, and 16-3, which equates to REI ratings of UN, AR, and AR, respectively (Table 2). Vertical channel stability – bed scour conditions are rated using the *bed scour* Level 2 environmental attribute. Bed scour conditions are estimated using a bed scour simulation model developed to support Okanogan EDT model development (Doyle et al. 2015). This model was used to estimate bed scour conditions under template and patient scenario conditions, updated using channel conditions data collected during each OBMEP monitoring cycle. Bed scour is functioning at 98 to 100% of template in all reaches in the Loup Loup Creek AU, which equates to an REI rating of AC (Table 2).

The functional condition ratings for bed scour are confounded by observed channel incision in the Loup Loup Creek AU. Observational data indicate that significant channel incision occurred during the 2014 to 2017 monitoring cycle. OBMEP concluded that incision was caused by a dramatic increase in peak flow volumes attributable to higher than usual precipitation on areas repeatedly burned by wildfires. Figure 1 shows representative incision conditions observed in reach Loup Loup 16-1. The attributed cause of these incision effects, extreme peak flows, affected all three habitat reaches in the Loup Loup Creek AU. As such, similar incision effects are anticipated throughout the watershed. Consistent with the rating criteria defined in Table 1, these observed conditions equate to an REI rating of AR in all three reaches in the AU.

As stated, channel incision is not considered in EDT and incision conditions cannot be meaningfully derived from model inputs or results. The vertical channel stability indicator rating method could be improved by incorporating REI indicator condition ratings developed by OBMEP staff. These standardized ratings could be incorporated into a hidden HSTR data table supporting the proposed REI report generation function described in Section 4.

Figure 1. Observed channel incision in reach Loup Loup 16-1, summer 2017 (source: OBMEP).

3.6 Riparian Condition

The riparian condition general indicator comprises one specific indicator, vegetation structure. The EDT *riparian/stream interface* Level 2 attribute provides a direct measure of indicator condition, which is rated using % of Template (see Table 1). This indicator is functioning at 76%, 64%, and 76% of Template conditions in reaches Loup Loup 16-1, 16-2, and 16-3, respectively, which equates to an REI rating of AR in all three reaches (Table 2).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The REI functional condition ratings generated for Loup Loup Creek provide a reasonable representation of existing environmental conditions that are compatible with UCRTT (2022) reach assessment terminology and methods. This proof-of-concept analysis demonstrates that ratings for most proposed REI indicators can be generated directly from EDT inputs and results that are downloadable from the web-based Okanogan and Methow HSTR report cards. A subset of REI indicators requires additional information that can't be obtained directly from HSTR inputs or outputs. This could be addressed by adding new hidden data tables to the HSTR web database and developing an automatic report generating function. These recommended improvements could be implemented with the following steps:

- Update Okanogan HSTR to include a user-selectable REI report generator function, implement with proposed 2023 HSTR improvements.
- Improving the rating process for non-EDT-based REI indicators:
  - Dominant substrate/spawning gravel D50:
    - Create okanoganmonitoring.org database query to generate a substrate D50 data table export for Okanogan EDT model reaches.
    - Update Okanogan HSTR to include import function for hidden D50 data table.
  - Pool frequency:
    - Develop a data table format and standardized process for generating reach-level pool frequency data from OBMEP survey data.
    - Update Okanogan HSTR to include import function for hidden pool frequency table.
  - Channel incision/degradation
    - Revise OBMEP monitoring and reporting protocols to include development of reach-based channel incision/degradation condition ratings using REI indicator condition thresholds.
    - Develop data table template for indicator condition ratings.
    - Update Okanogan HSTR to include import function for hidden incision/degradation data table.

We propose that these recommendations be incorporated into planned Okanogan HSTR improvements in 2023. The planned REI indicators report for the Antoine Creek AU presents an opportunity to develop and refine these recommendations as part of Confluence's contracted scope of work with the Confederated Tribes of the Colville Reservation for various EDT and HSTR model improvements in the OBMEP 2023 budget year. These proposed improvements would provide proof of concept for potential updates to the Methow HSTR in a future project, if desired.

5.0 REFERENCES

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Appendix A — REI Attribute Rating Formulas

Introduction

This appendix documents the formulae used to generate the REI metrics described in the main body of this report.

% of Template Function – Habitat Quality Attributes

The *% of Template* metric is generated for the associated EDT environmental attribute at the individual reach level. Reach and AU level *% of Template* ratings are available on the STR Implementation Tab (e.g., https://ecosystems.azurewebsites.net/hstr-okanogan/) for the 5 highest-priority environmental attributes in the selected spatial unit. The top 5 environmental attributes are the attributes resulting in the largest theoretical increase in adult abundance that would occur if they were restored to template conditions.

In practice, several of the EDT attributes used to generate REI metrics will not be visible on the STR implementation tab. The *% of Template* metric can be generated for any EDT patient environmental scenario using the following formula:

$$\%T = \frac{(4-R_P)}{(4-R_T)} \qquad \text{Eq. A-1}$$

Where:

$\%T$ = *% of Template*, i.e., EDT environmental attribute condition rating under the selected patient scenario as a percentage of the EDT template scenario attribute rating

R_P = Maximum monthly attribute rating for the selected reach under the selected EDT patient scenario

R_T = Maximum monthly attribute rating for the selected reach under the EDT template scenario

Attribute ratings for the template and all patient scenarios in a specific EDT model can be downloaded directly from the STR by entering the following link into a web browser: https://ecosystems.azurewebsites.net/hstr-<subbasin>/reach_environment_data.csv, replacing '<subbasin>' with the appropriate STR identifier (e.g., Okanogan, Methow).

% of Template Function – Off-channel Habitat

The functional condition of off-channel habitats is rated at the individual reach level using a modified *% of Template* measure. This measure considers the ratio of available off-channel and side channel habitat as a proportion of total wetted reach area under patient and template conditions. This measure necessarily requires that template and patient attribute ratings are usefully representative of historical and current habitat conditions. When these conditions are met, this ratio will accurately reflect inherent limitations imposed by channel gradient and confinement on the formation of side channel and off-channel habitats.

$$\%T = \frac{(OSH_P)}{(OSH_T)} \qquad \text{Eq. A-2}$$

Where:

%T = *% of Template*, i.e., EDT environmental attribute condition rating under the selected patient scenario as a percentage of the EDT template scenario attribute rating

$OS\ \ _P$ = Sum of monthly side channel, seasonally inundated floodplain, groundwater channel, and floodplain pond composition ratings for the selected reach under the selected EDT patient scenario

$OS\ \ _T$ = Sum of monthly side channel, seasonally inundated floodplain, groundwater channel, and floodplain pond composition ratings for the selected reach under the EDT template scenario

abitat composition ratings for the template and all patient scenarios in a specific EDT model can be downloaded directly from the STR by entering the following link into a web browser: https://ecosystems.azurewebsites.net/hstr-<subbasin>/reach_environment_data.csv, replacing '<subbasin>' with the appropriate STR identifier (e.g., Okanogan, Methow). The sum of monthly habitat composition ratings can be calculated by reach using the pivot table function in Microsoft Excel.

Habitat Access

The *abitat Access* REI characteristic considers the combined effect of obstructions on habitat potential for the target species at the assessment unit level. The measure used to rate this characteristic is the proportion restoration potential attributable to obstructions, as measured by the proportion of restorable adult abundance that could be achieved by restoring full fish passage. This measure is calculated using the following formula:

$$\%Neq_T = \frac{\Delta Neq_{TO}}{\Delta Neq_{RT}} \qquad \text{Eq. A-3}$$

Where:

$\%Neq_T$ = Percent of total restoration benefit attributable repairing obstructions.

ΔNeq_{TO} = Sum of change in adult abundance for obstructions in an assessment unit assuming passage is increased to template conditions for all life stages.

ΔNeq_{RT} = Combined increase in adult abundance if all habitat conditions in an assessment unit are restored to template conditions.

ΔNeq_{RT} values can be calculated from EDT results obtained directly from the STR VSP Criteria Summary tab. over your cursor over the Adult Abundance bar for the selected patient and template scenarios to obtain the Neq values. ΔNeq_{RT} is the difference between these two values. Obstruction performance results can be obtained for all obstructions under all EDT patient scenarios in STR subbasins by entering the following link into a web browser: https://ecosystems.azurewebsites.net/hstr-<subbasin>/obstruction_splices.csv, replacing '<subbasin>' with the appropriate STR identifier (e.g., Okanogan, Methow). ΔNeq_{TO} ratings for each assessment unit are obtained by summing the obstruction results for all obstructions in that AU under the selected habitat scenario.

Pool Frequency

Pool frequency is a commonly used metric for assessing the condition of salmonid bearing streams (NMFS 1996; UCRTT 2022). Pool frequency is a measure of the proportional composition and distribution of pool habitats as a function of reach length, expressed as the number of pools per unit length (e.g., mile or km). Pool frequencies associated with adequate habitat conditions (AC) are a function of reach width, with pool frequency increasing as channel width decreases.

The Ecosystem Diagnosis and Treatment (EDT) model does not consider pool frequency as a measure of habitat condition. The current salmonid species-habitat rule sets used in EDT consider the proportional distribution of habitat types as a percentage of wetted reach area. For example, in a typical AC reach pools may comprise 30% of total wetted channel area. This attribute is useful for characterizing pool habitat for modeling purposes but cannot be used to estimate pool frequency without additional information.

This appendix describes the methods used to address this limitation. The number of pools occurring in each reach of Loup Loup Creek are estimated from reach length and EDT proportional habitat composition assuming that the length of the average pool is 3 times greater than the average wetted channel width of the reach. The proposed pool length/wetted width ratio of 3.0 is generally consistent with observed conditions. OBMEP (R. Klett, pers. comm. 2023) provided average pool length and wetted width data collected on 94 EDT reaches in the Okanogan subbasin during the 2018 to 2021 monitoring cycle. The mean, median, and geomean of observed pool length to wetted width ratio were 3.3, 3.1, and 3.0, respectively, with a standard deviation of 1.4.

Applying this assumption to reach Loup Loup 16-2:

$$PF = \frac{L\times\%P}{3\times W}\times\frac{1,000}{L} = \frac{1,250\times 0.14}{3\times 4.0}\times\frac{1,000}{1,250} = 12\ pools/km \qquad \text{Eq. A-3}$$

Where:

PF = Pool frequency (# of pools/km)

L = Reach length = 1,250 meters (m)

W = Average wetted width = 4.0 m

$\%P$ = Proportion of reach in pool habitat (from EDT) = 14%

The average measured pool length in Loup Loup 16-2 during the 2018 to 2021 monitoring cycle was 10.3 m, which equates to a pool length to wetted width ratio of 4.4 and 13.5 pools/km. The estimation method presented here slightly underestimates pool frequency but the estimate is sufficiently accurate for REI purposes.

REI pool frequency condition ratings were then calculated by comparing interpolated pool frequencies to available width-based pool frequency thresholds representing properly functioning, or AC, conditions (NMFS 1996) and the threshold ranges defined in Table 1 (Section 2.0).

Table A-1. Pools/km thresholds for Properly Functioning pool frequency conditions, converted to metric from NMFS (1996).

Channel width (m)	Pools/km Threshold	Acceptable (AC)	At Risk (AR)	Unacceptable (UN)
1.5	114	≥114	57-113	<57
3.0	60	≥60	30-59	<30
4.6	43	≥43	22-42	<22
6.1	35	≥35	17-34	<17
7.6	29	≥29	15-28	<15
15.2	16	≥16	8-15	<8
22.9	14	≥14	7-13	<7
30.5	11	≥11	6-10	<6

Table A-2. Interpolated pool frequency in Loup Loup Creek based on stream width and length parameters used in 2018-2021 EDT patient scenario.

Reach	Reach Length (m)	Average Wetted Width (m)†	% Pools	Interpolated Values‡				Observed Values§		REI RatingΔ
				Pool Length (m)	Pools/km	AC Pool Frequency	% of AC Frequency	Pools/km	% of AC Frequency	
Loup Loup 16-1	1,250	2.3	23%	6.83	34	87	39%	20	23%	UN
Loup Loup 16-2	1,250	4.0	14%	11.90	12	50	24%	14	27%	UN
Loup Loup 16-3	1,000	2.6	42%	7.87	53	75	71%	52	52%	AR

† Average pool width is average of EDT monthly wetted width ratings.

‡ Interpolated values assume pool length is 3x average reach wetted width, value us used to estimate the number of pools from % pools as a proportion of habitat composition. Acceptable conditions (AC), at-risk conditions (AR), and unacceptable conditions (UN) for pool frequency are interpolated using wetted width and the width-based properly functioning condition thresholds for pool frequency defined by NMFS (1996).

§ Observed pool frequency values calculated from average of measured pool lengths during the 2018 to 2021 monitoring cycle. Data provided by OBMEP (R. Klett, pers. comm., 2023).

Δ REI ratings are based on ratio of interpolated pool frequency to AC pool frequency (see Table 1, Section 2.0). Estimated and observed pool frequencies resulted in the same REI ratings in all Loup Loup Creek reaches.

Appendix B —

REI Ratings and Measure Values for Loup Loup Creek

Table B-1. REI indicator functional condition ratings and associated measure values for Loup Loup Creek.

General Characteristic	General Indicator	Specific Indicator	EDT Reach		
			Loup Loup 16-1	Loup Loup 16-2	Loup Loup 16-3
Hydrology	Peak flow condition	TQMean% change from historical	AC (110% of template)	AC (110% of template)	AC (110% of template)
	Low flow condition	60-day low flow change from historical	AC (96% of template)	AC (96% of template)	AC (96% of template)
	Baseflow capacity	Ratio of AU juvenile habitat capacity under Patient and Template scenarios generated by EDT	AR (54% of template capacity of 1,832 juveniles)		
Temperature	Peak temperature conditions	Number of days/month above range of thresholds (10, 16, 22, 25, 27.5 degrees C)	UN (36% of template)	UN (36% of template)	UN (36% of template)
	Low temperature conditions	Number of days/month below 4 degrees/1 degree C.	AC (>100% of template)	AC (>100% of template)	AC (>100% of template)
Habitat Access	Effect of obstructions on AU restoration potential	% of potential increase in Neq if obstructions are returned to template condition	AC (2.5% of total restoration potential)		
Habitat Quality	Substrate	Dominant Substrate – spawning gravel D50 (mm)	UN (4.7 mm)	UN (3.6 mm)	AR (11 mm)
		% Fines	AC (96% of template)	AR (67% of template)	AR (67% of template)
		Embeddedness	AR (75% of template)	AC (92% of template)	AC (100% of template)
	Large woody debris	Pieces/km at bankfull	UN (18% of template)	UN (12% of template)	AR (75% of template)
	Pools	Pool frequency (interpolated, assuming typical pool length 3x average wetted width)	UN (34 pools/km, 39% of AC conditions)	UN (12 pools/km, 24% of AC conditions)	AR (53 pools/km, 71% of AC conditions)
		Pool quality	AR (AC frequency, UN woody debris and AR riparian/stream interface)	AR (AR frequency, UN woody debris and AR riparian/stream interface)	AR (AR frequency, AR woody debris and riparian/stream interface)

General Characteristic	General Indicator	Specific Indicator	EDT Reach		
			Loup Loup 16-1	Loup Loup 16-2	Loup Loup 16-3
Habitat Quality (cont.)	Off channel habitat	Connectivity with main channel	AC Combined side channel and off-channel habitat area as proportion of wetted reach area is 100% of template.	AC Combined side channel and off-channel habitat area as proportion of wetted reach area is 100% of template.	AC Combined side channel and off-channel habitat area as proportion of wetted reach area is 100% of template.
Channel Condition	Dynamics	Floodplain connectivity – artificial confinement % of template	UN (31% of template)	AR (53% of template)	AR (75% of template)
		Vertical channel stability – bed scour	AC (100% of template)	AC (98% of template)	AC (100% of template)
		Vertical channel stability - incision	AR Measurable channel incision	AR Measurable channel incision	AR Measurable channel incision
Riparian Vegetation	Riparian condition	Vegetation structure – riparian/stream interface	AR (76% of template)	AR (64% of template)	AR (76% of template)

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