Loup Loup Creek Fish Passage Project

Basis of Design Report – 30% Design

Loup Loup Creek Waterfall

Submitted To:
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Executive Summary

The Confederated Tribes of the Colville Reservation Fish and Wildlife Department retained River Design Group, Inc. to prepare 30% designs for the Loup Loup Creek Fish Passage Project. Primary project tasks included site survey, stream reconnaissance, hydraulic modeling and design development to address fish passage conditions at a series of natural barriers on Loup Loup Creek. This project is intended to assist in achieving recovery goals for steelhead in the Upper Columbia River system. The Loup Loup Creek Fish Passage Project is being funded by Bonneville Power Administration under the Northwest Power and Conservation Council's Fish and Wildlife Program.

The stream corridor is characterized by alternating low to moderate gradient alluvial reaches and adjacent colluvium-influenced confined reaches with higher energy stream environments. Large wood, channel bed materials and vegetation exert varying degrees of influence on the channel morphology and habitats. High gradient channel reaches may not create distinct fish passage barriers, but when considered with discrete drops in the channel profile, high gradient channel segment may inhibit passage for adult steelhead.

A conceptual design report outlining alternatives that would improve fish passage at the barrier locations was prepared in June 2021. The report concluded that improving fish passage at the barrier sites could be accomplished using varying levels of intervention. Channel morphology could be addressed by filling the existing channel and constructing a step-pool channel by adding boulders and large wood to create resting pools for fish migrating through the reach. A second option would be to construct a nature-like fish bypass channel or technical fishway to provide passage around the barriers. The third option considered was a trap-and-haul operation.

The preferred alternative, construction of a series of step-pool channels, was selected following discussions with the landowner, project partners and permitting agencies. This report provides the basis of design for the preferred alternative. Permit-level designs were prepared for each of the three barriers. The proposed step-pool channel is designed to provide passage for adult steelhead over the course of the spring migration period with flows ranging from 15 cfs to 50 cfs. A one-dimensional HEC-RAS model was used to model existing and proposed conditions. Design considerations are summarized in this report.

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Acknowledgements

The Confederated Tribes of the Colville Reservation Fish and Wildlife Department is the project sponsor for the *Loup Loup Creek Fish Passage Project*. Bonneville Power Association provided funding for the development of the project. We would also like to thank the landowners for their continued support of the project.

Glossary

Aggradation: The geologic process by which streambeds, floodplains and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas. The opposite of degradation.

Alluvial: Deposited by running water.

Bankfull (Stage): Water surface elevation at which a stream first overflows its natural banks, spilling water onto the floodplain.

Bedload: Sediment particles transported on or near the streambed by rolling and bouncing.

Colluvium: Loose, unconsolidated sediments that have been deposited at the base of hillslopes by erosion, downslope creek, or a combination of these processes.

Energy Dissipation Factor: A measure of turbulence, a hydraulic condition that affects fish passage.

Floodplain: A level, low-lying area adjacent to streams that is periodically flooded by stream water. It includes lands at the same elevation as areas with evidence of moving water, such as active or inactive flood channels, recent fluvial soils, sediment on the ground surface or in tree bark, rafted debris, and tree scarring.

Fluvial: Of or pertaining to rivers or streams; produced by stream or river action.

Large Wood: Coarse woody material (conventionally greater than 10 cm in diameter and 1 m long), such as twigs, branches, logs, trees, and roots, that falls into a stream.

Meander: A sinuous channel form in flatter river grades formed by the erosion on one side of the channel (pools) and deposition on the other side (point bars).

Off-channel: Bodies of water adjacent to the main channel that have surface water connections to the main river channel at summer discharge levels.

Riffle: A shallow section of a stream or river characterized by rapid current and a surface broken by completely or partially submerged obstructions such as gravel or boulders.

Riparian (Area): An area of land adjacent to a stream, river, lake or wetland that contains vegetation that, due to the presence of water, is distinctly different from the vegetation of adjacent upland areas. The riparian area is influenced by and influences the adjacent body of water.

Thalweg: Line of deepest water in a stream channel as seen from above. Normally associated with the zone of greatest velocity in the stream. If there is no stream, it is the line of lowest points of a valley.

Watershed: Also referred to as a drainage basin or catchment area. Watersheds are the natural landscape units from which hierarchical drainage networks are formed. Watershed boundaries typically are the height of land dividing two areas that are drained by different river systems.

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1 Project Background

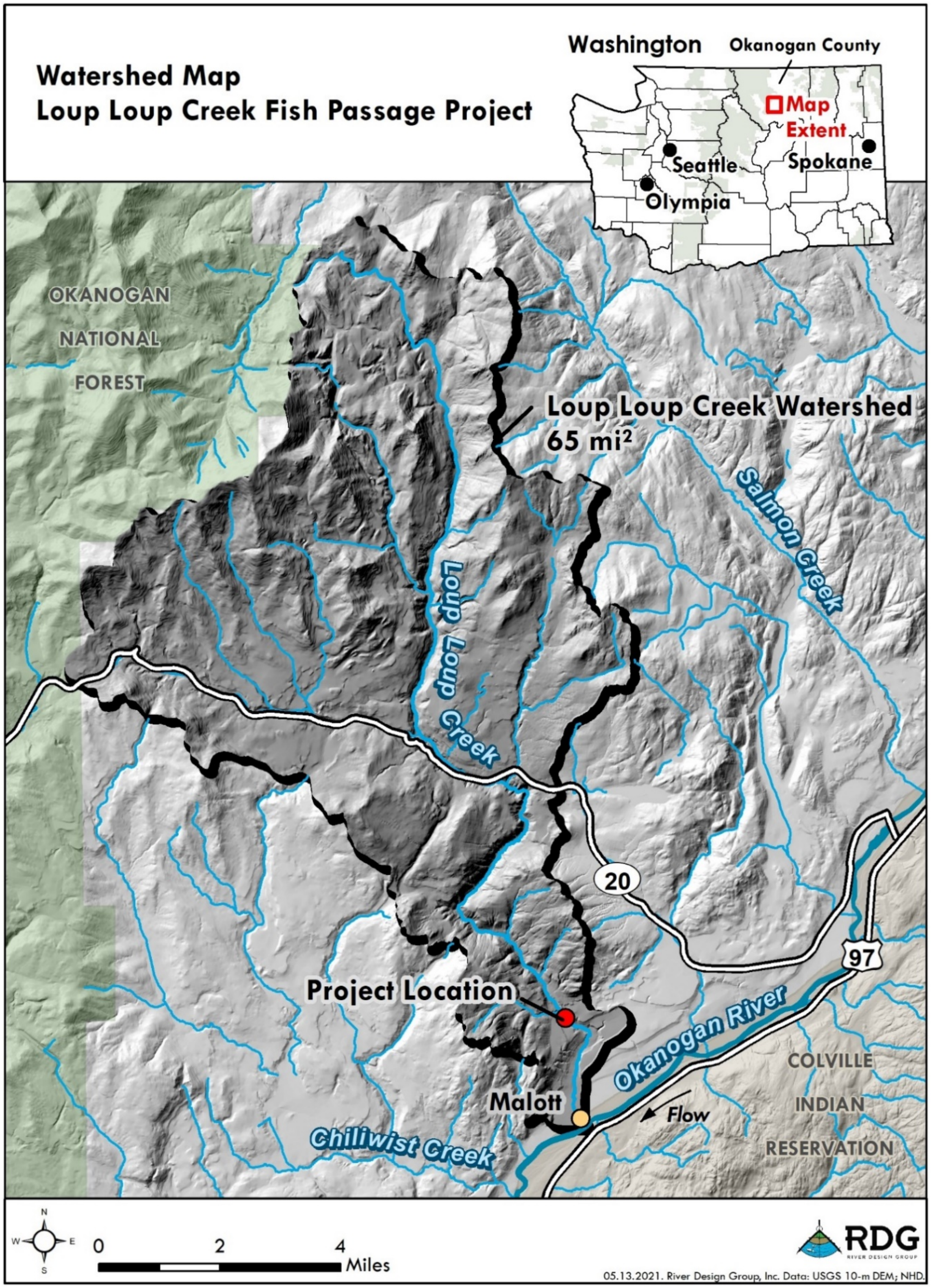
1.1 Project Overview

The Confederated Tribes of the Colville Reservation (CTCR) Fish and Wildlife Department retained River Design Group, Inc. (RDG) to evaluate fish passage options at five natural barriers on Loup Loup Creek approximately two miles upstream of the stream's confluence with the Okanogan River. RDG completed stream corridor reconnaissance and a topographic survey to characterize stream corridor conditions and to collect data necessary for preliminary design of fish passage alternatives. The surveys were used to develop hydraulic models to assess the passage potential for summer steelhead, federally-listed Endangered Species Act (ESA) fish that inhabit the lower reaches of Loup Loup Creek, but that may be excluded from the upper watershed by the two discrete waterfalls and multiple smaller cascades located approximately 2 miles upstream of confluence with the Okanogan River. RDG prepared a conceptual design report outlining alternatives that would improve fish passage at the barrier locations (June 2021). The preferred alternative, construction of a series of step-pool channels, was selected following discussions with the landowner, project partners and permitting agencies. This report provides the basis of design for the preferred alternative.

Loup Loup Creek is a tributary to the Okanogan River located near Malott, Washington (Figure 1-1). The project site is accessed by taking the B and O Road north from Malott and turning left onto B and O West Road about 2.5 miles from Mallott. The walking access is located about 1.2 miles west of the turnoff from the paved B and O Road. The locations of the five barriers surveyed are listed in Table 1-1 and shown in Figure 1-2.

Table 1-1. Loup Loup Creek fish passage barrier sites.

Barrier #	Latitude	Longitude	Description
1	48.305093	-119.708919	17-foot sloping waterfall
2	48.305578	-119.710105	12-foot sloping waterfall
3 - 5	48.306111	-119.712614	Series of 6-foot to 8-foot cascades



05.13.2021. River Design Group, Inc. Data: USGS 10-m DEM; NHD.

Figure 1-1. Map of Loup Loup Creek watershed in the Okanogan River drainage near Malott, Washington.

Figure 1-2. Loup Loup Creek fish passage barrier sites.

1.2 Fisheries Background

Historically, Loup Loup Creek provided access to about 2.04 miles of potential summer steelhead and spring Chinook spawning and rearing habitat (Arterburn, Kistler and Fisher 2007). Surveys completed in 2007 verified the historic terminus for steelhead fish passage as Loup Loup Falls. A perched culvert at river mile 0.14 within the town of Malott, Washington was recently replaced to provide year-round access to eliminate the partial barrier that it created. In addition, CTCR has entered into an agreement with the Helensdale Irrigation District that changes their point of diversion to the mainstem Okanogan River to ensure that Loup Loup Creek does not go dry at the irrigation withdrawal at river mile 1.34. As a result of those efforts, utilization of Loup Loup Creek by summer steelhead has increased substantially (pers comm. CCT 2021). This project is designed to provide upstream passage for adult Steelhead.

1.3 Project Features

The primary goal of this project is to provide upstream passage for adult steelhead. This will be accomplished through construction of a step-pool channel and associated floodplain. The channel will consist of a step-pool morphology of appropriate dimensions to emulate the geomorphic conditions observed in the existing channel upstream and downstream of the project area. The reconstructed stream system will provide unimpeded passage for the target species by creating suitable hydraulic conditions (pool depth, step height and water velocities). It will also allow for the temporary storage of water, sediment, and organic material that is anticipated to be transported through the reach. The reconstructed channel is designed to be dynamically stable and some adjustment to the prevailing flow regime can be expected over time, especially in response to large magnitude flood events.

The reconstructed channel will include the following elements:

1. **Subgrade fill**. Engineered fill will be placed in areas where the subgrade needs to be raised to facilitate construction of the step-pool channel. A well-graded fill is specified that will resist erosion and infiltration of water through incorporation of fines. The subgrade fill will be placed in lifts and compacted prior to construction of the channel and floodplain elements.

2. **Step-pool channel**. The step pool channel will be a series of drop structures consisting of a sequence of weirs and pools with gradients ranging from approximately 8 percent to 11 percent. The step-pool channel will extend from the crest of the uppermost waterfall or cascade at each site and a sufficient distance downstream to tie into the existing channel. The drop over each weir will range from 1.5 feet to 2.0 feet. Weirs will be approximately 15 feet wide by 2.5 feet deep and will be spaced an average of 18 feet longitudinally which is roughly one channel width. Weirs will be separated by 5-foot deep pools that will provide fish with resting areas between steps and adequate depth for burst acceleration

prior to jumping. The drop structures will be constructed from stacked boulders backfilled with engineered fill. Geotextile fabric will be placed upstream of each weir to prevent seepage and piping of fill through the voids.

Boulder weirs will be the primary structural element used for construction of the step-pool channel. Large boulders will be placed atop a row of keyed-in rock to form the weir face. Weirs will be placed perpendicularly across the channel or in an upstream pointing “V” or “U” shape. The weirs will be keyed into both banks to prevent water from cutting around the structure. Material used to construct the weirs will be durable and of suitable quality to ensure longevity of the structure.

The throat of the weir will be shaped to form a compound channel that concentrates low flows with progressively larger openings to accommodate higher flows. The weirs will be constructed so that they are completely overtopped during channel-forming flow events (~1.5-year flow). Large wood will be incorporated into the weirs in lower-gradient areas (~8%) where suitable depth of fill provides for adequate anchoring.

Geotextile fabric will be installed along the upstream face of each weir to minimize the potential for piping of fines and water through gaps in the weir rocks and logs. A well-graded mix of boulders, cobble, gravel, sand and fines will be used to construct the channel bed and banks. The mix will incorporate large boulders to resist erosion as well as fines to minimize to help seal the weir and channel bed and minimize the potential for subsurface flow.

3. **Channel Banks**. Banks will be constructed primarily from large boulders. Boulders will be placed two to three rows high to form the outer edges of the pool. Using boulders will help to ensure that the width and depth of the pools are maintained. Large wood elements will be incorporated into the banks in lower-gradient areas (~8%) where suitable depth of fill provides adequate ballast for anchoring the wood.

4. **Floodplains**. Floodplains will be constructed by placing floodplain fill material at slopes suitable for establishment of permanent woody vegetation (approximately 3H:1V) with the goal of providing long-term stabilization through the establishment of self-sustaining vegetation. The floodplain will be graded to incorporate higher and lower areas (microtopography) to create complexity and provide diverse habitat for terrestrial species. Rows of willows or other suitable woody species will be planted to provide a seed source for floodplain vegetation. Large boulders and partially buried large wood elements will provide roughness for energy dissipation. Large wood will be ballasted with backfill and boulders as necessary to provide stability. No cable or other mechanical anchors will be used to secure the large wood. Boulders will be seeded onto the floodplain as a surrogate for colluvial material that naturally occur in this setting. As erosion occurs, the

boulders will be incorporated into the banks by gravitational forces and will serve to increase roughness of the channel boundary and thereby minimize potential for migration of the channel.

1.4 Project Elements

The following project elements were designed by a Professional Engineer licensed in the State of Washington:

- Step-pool channel
- Roughened floodplain

1.5 Performance Criteria and Risk Analysis

1.5.1 Performance Criteria

The primary performance criteria for the step-pool system is to provide conditions suitable for upstream passage of adult steelhead. Specific criteria include:

- Water depth > 1 ft
- Velocity < 4 ft/sec
- Vertical drop < 2 ft

1.5.2 Risk Analysis

This section describes the assessment of risk of failure to perform, risk to infrastructure, potential consequences, and analyses completed to reduce uncertainty. Risk is broadly related to three categories: data gaps, construction related risks, and inherent uncertainty in construction of nature-like channels.

Design-related data gaps include:

- **Hydrology** – discharge records are available at the USGS gage for the water years 2013 through 2020. At least two additional years of peak flow data would be needed to develop minimally reliable peak flow estimates for use in the design analysis. An alternative method for improving the reliability of design flow estimates is use of record extension techniques, however, no suitable gages were found nearby to use in a record-extension analysis. It was also noted that the Mallott gage was installed in 2014, shortly before the Carlton Complex fire burned a significant portion of the watershed. It is possible that the high flows observed in 2015 - 2018 could be higher than normal relative to historical flows due to the recent disturbance, thus skewing the assumption that recorded flows fit a normal distribution as required for a Log-Pearson III peak flow analysis.

- **Stream channel profile** – a longitudinal profile survey of reference stream channel metrics including thalweg, bankfull indicators and width/depth is needed to supplement existing reference data and confirm the proposed channel dimensions.
- **Sediment transport** – assumptions regarding sediment transport in the system are based on observations made during the initial site visit. High flows limited the ability of the survey crew to collect detailed sediment data. A survey of material that is being transported through the existing channel is needed to confirm the initial sediment supply and transport assumptions.

Construction-related considerations include:

- **Site Access** – The project is located in a steep canyon and access to the sites will require significant improvements to existing roads and construction of new access roads.
- **Steep Slopes** - Construction efforts should take account of the unstable conditions of the surrounding hillslopes. Disturbance at the toe and on the face will increase the likelihood of hillslope failure and should be carefully considered.
- **Materials specification** - construction materials including boulders, fill, logs and brush would need to be imported or acquired from a nearby source. Rectangular-shaped boulders are preferred for step pool construction. Material availability may influence the design and should be determined prior to finalization of the design.
- **Construction complexity** – step pool construction will require precision placement and stacking of irregularly shaped boulders by a specialty stream restoration contractor. Construction workspace is tight with difficult access. Some specialty construction items include materials acquisition (large boulders), temporary dewatering pipe installation and step pool installation.

Risks inherent to nature-like channel design include:

- **Fish passage effectiveness** – the design provides a sensible level of fish passage and habitat given geomorphic constraints. Several alternatives were investigated during the concept design phase, including construction of a step-pool channel with step heights of less than 1.5 feet (<8% slope) were found to be infeasible given the overall reach average slope of 7.5%.
- **Maintenance** – the step-pool channel will require long-term monitoring and may require maintenance to ensure that it functions as expected. Maintenance may be required following large magnitude flow events (> 5-year return interval) which have the potential to reorganize step-pool structure and deposit sediment in constructed pools. Construction access roads should be designed as permanent roads to be left in place to facilitate future monitoring and maintenance activities.

1.6 Description of Disturbance

The timing, areal extent and potential impacts associated with implementation of each element are described as follows.

- **Access roads.** Access roads will be constructed prior to the start of the in-channel work. Access roads will be designed as permanent roads to be left in place following construction. This will provide access for future monitoring and maintenance activities. Roads will be designed by a professional engineer with experience in steep-slope gravel road construction. Drainage and other design features will be incorporated to minimize future maintenance requirements for the access roads.

  Proposed access road alignments are provided in the 30% Design Plan Set. Access to the three sites will be via two access roads with a total length of 1.25 miles. Approximately 75% of the access roads follow existing roads or two-tracks. Approximately 25% of the access roads, or 1,600 feet, are new roads.

- **Staging areas.** Staging areas will be developed prior to the start of the in-channel work. Staging areas will be designed as temporary areas to be reclaimed and returned to pre-disturbance conditions following the completion of channel construction activities.

  Proposed staging areas are shown in the 30% Design Plan Set. The two proposed staging areas are approximately 0.25 acres each for a total temporary disturbance area of about 0.5 acres.

- **Constructed channel and floodplain.** The approximate extent of constructed channel and floodplain for each site is shown in the 30% Design Plan Set. The total area occupied by the new channel and floodplain is estimated at approximately one acre. The area of impact was estimated based on using a nominal 3:1 (H:V) side slope extending upward from the proposed channel margins. These extents may change based on refinements to the design following the collection of detailed topographic data through the project area. Channel and floodplain construction will occur in the existing streambed and channel dewatering measures will be required to implement the project. Work area isolation and fish salvage operations will be required during construction.

2 Resource Inventory and Evaluation

2.1 Past and Present Impacts

The reach of Loup Loup Creek where the project area is located is relatively unaltered. Some logging and roadbuilding appears to have taken place on hillslopes above the left bank. This roadbuilding and logging may have contributed to the hillslope failures described in section 2.3. The riparian area appears intact with well-established riparian vegetation along the streambanks through the project area.

2.2 Instream Flow Management

CTCR is in the process of developing instream flow management projects for Loup Loup Creek. Loup Loup Creek was prone to going dry during the summer due to an irrigation withdrawal at river mile 1.34, downstream of the project site. CTCR has acquired water rights at this and other irrigation diversions and has plans to implement an instream efficiency program with a long-term target minimum low flow of 5 cfs.

2.3 Existing Geomorphic Conditions

Loup Loup Creek is a tributary to the Okanogan River in the Columbia River watershed. The creek is a fourth order stream with a watershed dissected into three distinct zones. The headwaters are steep and forested with a wide dendritic pattern. The middle zone is confined by an incised canyon that is cutting through granitic bedrock serving as the transition between the headwaters and the much lower Okanogan valley floor. The lower zone is a highly altered and straightened zone that passes through Malott, WA.

The geology of this region is driven by the Late Miocene orogeny that created the Washington Cascade Range (Reiners et al. 2002). The uplift exhumed granitic bedrock formed from previous subduction activity along the western North American Plate margin. These mountain building events have forced channels, including Loup Loup Creek, to incise through bedrock to reach base level which is controlled locally by the Columbia River. In addition to uplift, baselevel lowering applies pressure on these watersheds to incise. Glaciation and glacial floods have lowered both the Okanogan and Columbia River valleys. Large glacial floods from Glacial Lake Missoula lowered the Columbia River valley during the Holocene sending incision up its tributaries.

The project reach on Loup Loup Creek is located in the steepest section outside of the upper headwaters. The reach-average slope is 7.5% with an average channel width of 15 feet. A series of five bedrock knickpoints ranging from 6 to 17 feet high occur over a distance of 1,600 feet. The knickpoints consist of granitic bedrock with pegmatitic intrusions rich in quartz and feldspar. Bedrock jointing characteristics drive the slow headward migration of these features with blocks of bedrock being plucked off the face of the drops. This erosive process out paces scour and abrasion of bedrock with few potholes present at the site (Tinkler & Wohl 1998). The bed material in the reach is highly bimodal with large cobble dominating the steeper sections and large amounts of sand in the flat sections between knickpoints.

The project reach is confined by steep hillslopes that connect to an alluvial fan terrace (Figure 2-1). Loup Loup Creek enters the Okanagan Valley through a steep confined valley that is dissecting a former alluvial fan. The fan was formed during a period where Loup Loup Creek headwaters were glaciated and had hydrology that could support mobilization of large cobbles across the wide fan. Following the loss of snowpack and glaciers, the sediment loads could no longer support the fan and incision would have occurred. This, in conjunction with the base level changes from uplift and glacial floods mentioned above, has led to Loup Loup Creek cutting down through the fan and underlying bedrock.

Hillslope processes have a significant impact on the geomorphology of Loup Loup Creek. The channel is confined between steep unstable hillslopes with limited vegetation. Hillslope failures are common on the slopes connecting the terrace to Loup Loup Creek. These failures are driven by toe erosion from the channel. Following large failures, the channel is pushed to opposite slope and steepened, as can be seen in the photograph of Site 1 (Figure 2-2). These events are a natural process that creates fish barriers. The hillslope is composed predominately of sand and large cobble. The majority of the large cobble present in the bed of Loup Loup Creek was recruited from the hillslope rather than from bedload. While the steeper sections of Loup Loup Creek can transport large cobble during regular flood events, the flat sections between knickpoints cannot transport this size material outside of extreme flood events. Construction efforts should take account of the unstable conditions of the surrounding hillslopes. Disturbance at the toe and on the face will increase the likelihood of hillslope failure and should be carefully considered.

2.4 Existing Riparian Condition

The riparian area appears intact with well-established riparian vegetation along the streambanks through the project area. No historical riparian impacts are evident in the project reach.

2.5 Floodplain Connectivity and Historical Impacts

There is limited lateral connectivity to floodplain through the project reach. What little floodplain exists appears to be intact with well-established riparian vegetation along the streambanks through the project area. No historical floodplain impacts are evident in the project reach.

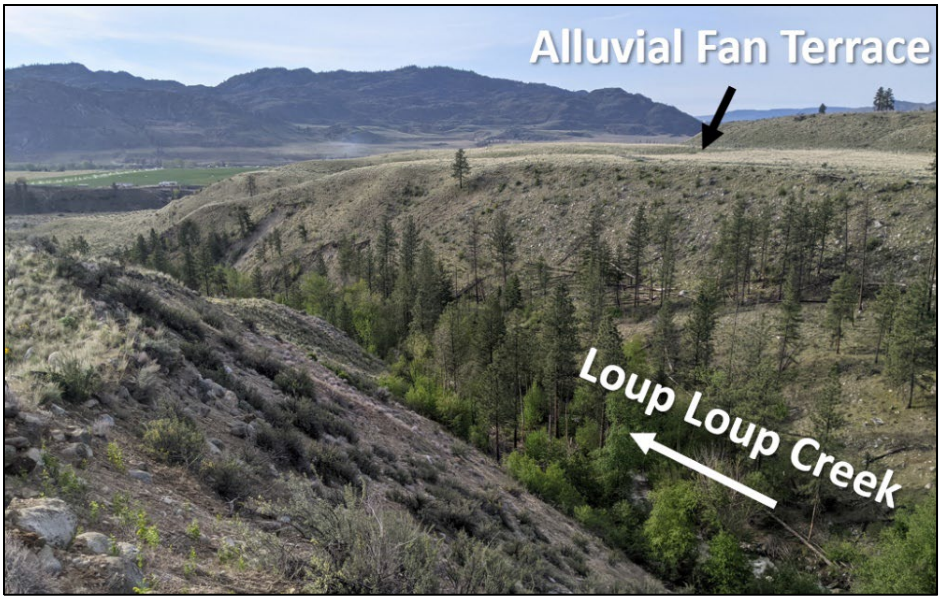


Figure 2-1. Loup Loup Creek project site looking down valley with alluvial fan terrace labeled.

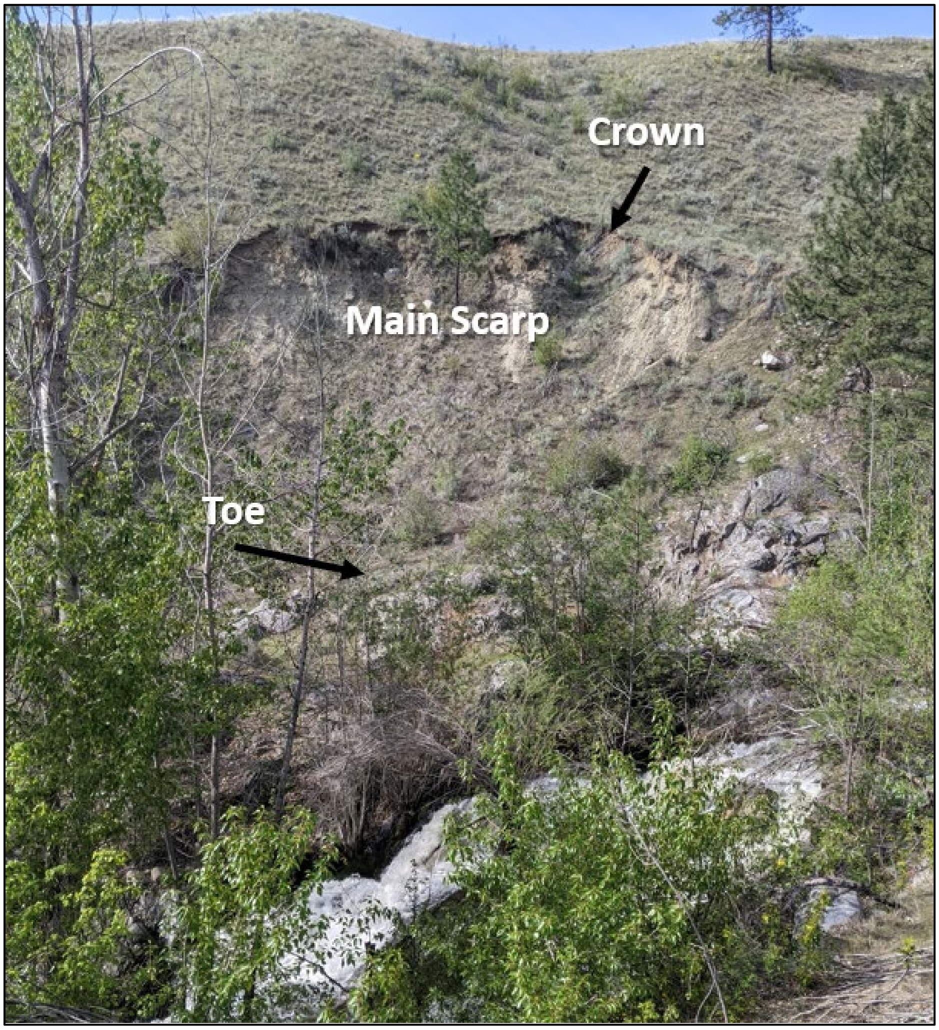


Figure 2-2. Landslide at Site 1 with features labeled.

3 Technical Data

3.1 Site Information

RDG completed a reconnaissance and survey of Loup Loup Creek on April 22-23, 2021. The reconnaissance included walking the stream and noting general aquatic and riparian habitat conditions, potential fish passage concerns, geomorphology, and land use effects. The stream reconnaissance was completed by RDG's engineer and geomorphologist and generally followed an upstream-to-downstream orientation. Ground photos were taken throughout the reconnaissance reach and observations were recorded by field personnel.

3.1.1 Survey

Topographic and channel bathymetry data were collected at the five fish passage barrier sites using a Trimble GNSS RTK GPS system and Leica total station. Monumented survey control benchmarks were located at each survey location and the GNSS GPS was used to establish vertical and horizontal position. The primary benchmark used for the survey is located on the top of the hill near the pullout from the B and O road. It was monumented with a 2-inch aluminum RDG Hydro-cap set on a 30-inch long 5/8 inch diameter rebar. Temporary benchmarks established by others during previous surveys were surveyed as they were encountered. The survey was solely completed for stream characterization and conceptual restoration design purposes. The survey data were corrected using the OPUS system and managed in AutoCAD Civil 3D 2021.

3.1.2 Bed material

Deposits of fine sediment (mostly sand) were noted during the field reconnaissance, primarily in the lower gradient reaches between the waterfalls and cascades. Bed material sampling was not completed due to the high flows during the site visit. Sampling is planned for the next site visit.

3.2 Hydrologic Analysis

Streamflow data was available for Loup Loup Creek from the gage at Malott (USGS #12447285) for the eight year period of WY 2013 – 2020 at the time the 30% design was completed (Figure 3-1). The eight years of daily flow data was used for development of flow duration statistics; however, the record is not long enough to use for peak flow analysis. The minimum period of record for development of estimates of peak flow magnitude is ten years and reliable statistics generally require 25 years of record or more. Nearby gages for use in record extension methods were not available. Due to the lack of available peak flow data, peak flow estimates were developed using regional equations (Mastin Et.al. 2016). Table 3-1 reports basin characteristics for the gage at Malott and the fish passage project site. Predicted flood flows based on regression equations are presented in Figure 3-2 and Table 3-2.

Streamflow data from the gage at Malott (USGS #12447285) was used to calculate exceedance flows (Figure 3-2). Table 2-3 reports exceedance stream flows for the month of April during time when steelhead are typically migrating upstream. The range of flows from 15 cfs to 50 cfs that were identified as the design fish passage flows (Table 2-4) by the area fisheries biologists are typically exceeded for 12 to 15 days based on the analysis of daily flow data. This correlates well with the typical 2-week migration period observed by area fisheries biologists and demonstrated in PIT tag data.

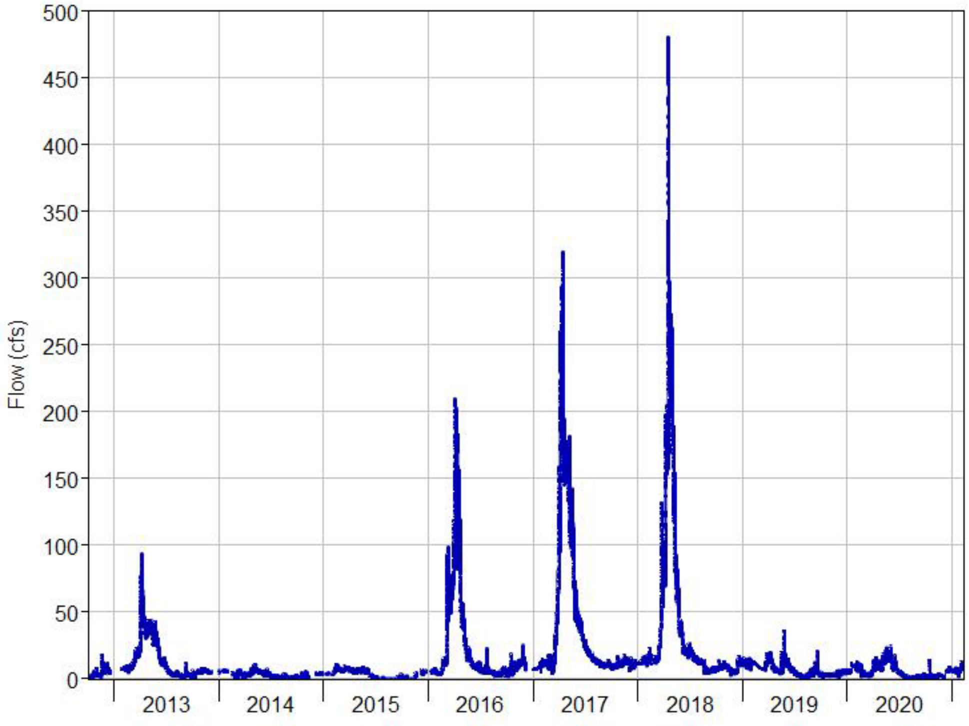


Figure 3-1. Hydrograph for Loup Loup Creek at Malott (USGS # 12447295).

Table 3-1. Loup Loup Creek drainage area and average annual precipitation at USGS gage and fish passage project site.

Location	Drainage Area (square miles)	Average Annual Precipitation (inches/year)	Canopy Cover (percent)
Gage (USGS #12447285)	64.8	17.0	43.4
Barrier Site (~RM 2)	62.5	17.1	44.8

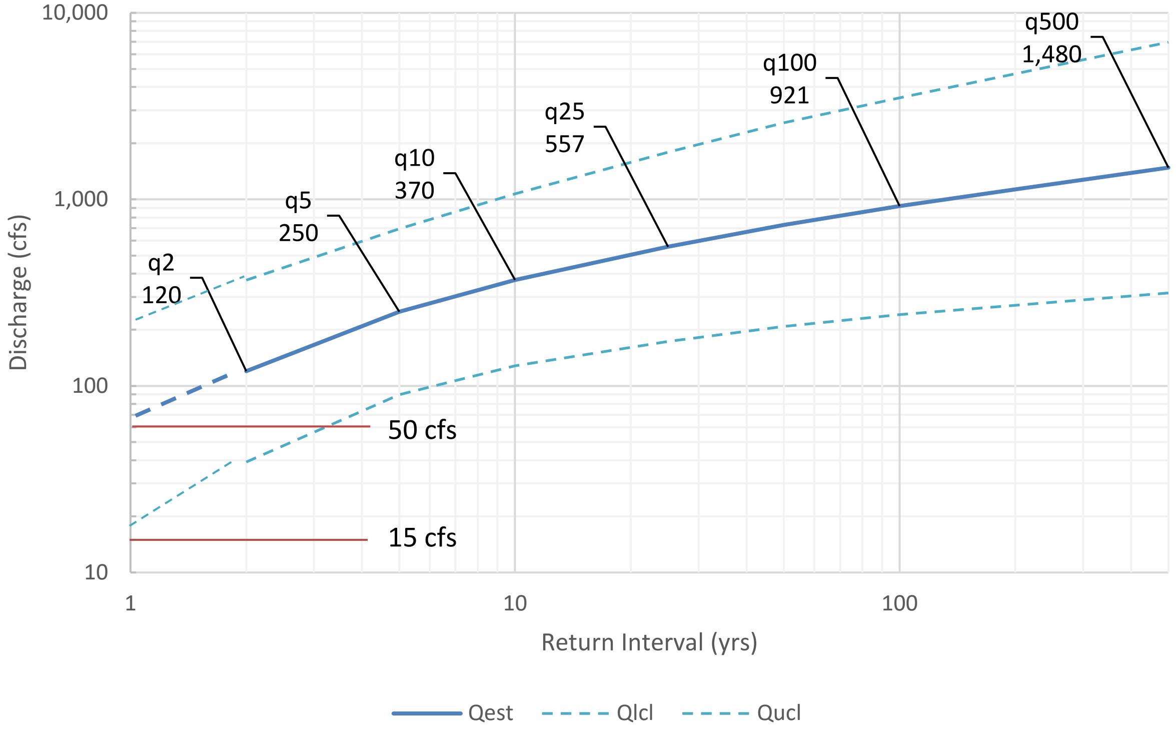


Figure 3-2 Loup Loup Creek regression equation results**.**

Table 3-2. Design flood discharge for Loup Loup Creek based on regional regression equations.

Annual exceedance probability	Return Interval (yrs)	Design Discharge (cfs)
50%	2	120
20%	5	250
10%	10	370
4%	25	557
2%	50	731
1%	100	921
0.5%	200	1130
0.2%	500	1480

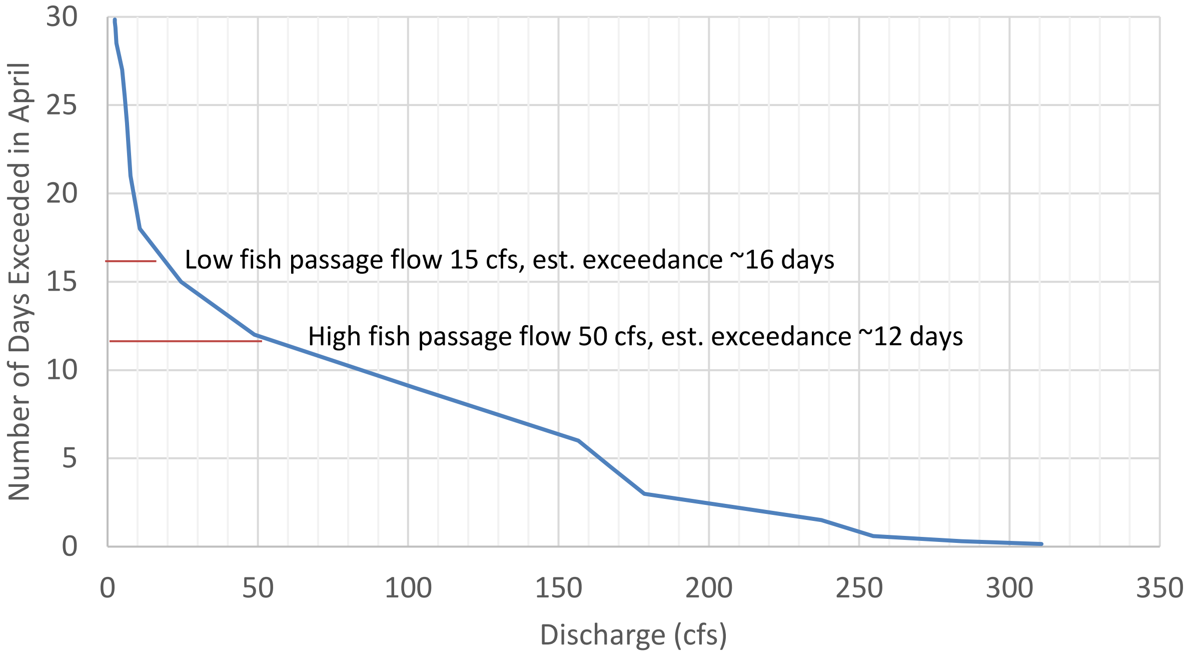


Figure 3-3 Loup Loup Creek flow duration curve.

Table 3-3. Loup Loup Creek flow duration for April.

Percent of time exceeded	Number of days exceeded	Discharge (cfs)
0.5%	0.2	311
1%	0.3	284
2%	0.6	255
5%	1.5	237
10%	**3.0**	**179**
15%	4.5	167
20%	6.0	157
30%	9.0	102
40%	12.0	49
50%	**15.0**	**24**
60%	18.0	11
70%	21.0	7.6
80%	24.0	6.4
85%	25.5	5.8
90%	**27.0**	**4.9**
95%	28.5	2.9
98%	29.4	2.6
99%	29.7	2.4
100%	29.9	2.4

Table 3-4. Exceedance flows for summer steelhead migration period based area fisheries biologist observations.

Fish Species	Migration Period	Low Fish Passage Flow (cfs)	High Fish Passage Flow (cfs)
Steelhead	April 12 - 26	15	50

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3.3 Hydraulic Modeling

The U.S. Army Corps of Engineer's HEC-RAS model was used to model existing and proposed hydraulic conditions at the fish passage barrier sites. The model evaluated steady-state flow, one-dimensional hydraulics over a channel bed of fixed topography.

The existing conditions model schematic is shown in Figure 3-4. Calibration of the existing conditions model was based on surveyed water surface elevations collected during the April 2021 field data collection at a flow of 40 cfs. Flows modeled include the low and high fish passage flows of 15 cfs and 50 cfs, the observed calibration flow of 40 cfs, and the design flows reported in Table 3-2. Existing condition model water surface profiles for the low and high fish passage flows of 15 cfs and 50 cfs and the 25-year design stability flow of 557 cfs are shown in Figure 3-5.

The proposed conditions model schematic is shown in Figure 3-6. Flows modeled include the low and high fish passage flows of 15 cfs and 50 cfs, the observed calibration flow of 40 cfs, and the design flows reported in Table 3-2. Proposed condition model water surface profiles for the low and high fish passage flows of 15 cfs and 50 cfs and the 25-year design stability flow of 557 cfs are shown in Figure 3-7.

Channel depths range from 2.2 feet to 7.6 feet in pools and 1.2 feet to 2.1 feet at the weir throats (upstream, sub-critical sections) in the proposed condition model at the low fish passage flow of 15 cfs. Average channel velocities range from 0.3 fps to 1.6 fps in pools and 1.1 fps to 2.6 fps at the weir throats (upstream, sub-critical sections) for the low fish passage flow of 15 cfs.

Channel depths range from 3.8 feet to 8.5 feet in pools and 2.3 feet to 3.0 feet at the weir throats (upstream, sub-critical sections) in the proposed condition model at the low fish passage flow of 50 cfs. Average channel velocities range from 0.8 fps to 2.2 fps in pools and 1.7 fps to 3.0 fps at the weir throats (upstream, sub-critical sections) for the high fish passage flow of 50 cfs.

Hydraulic modeling output tables are included in Appendix B.

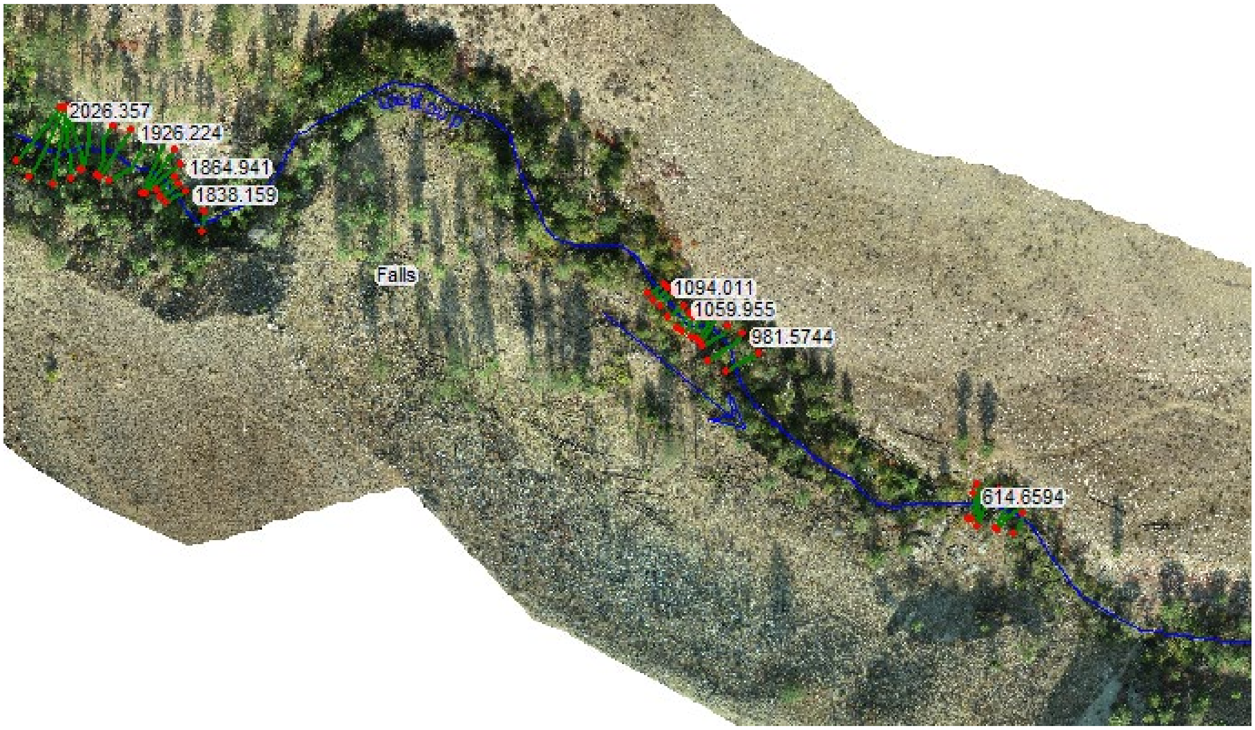

Figure 3-4 Existing conditions HEC-RAS model schematic.

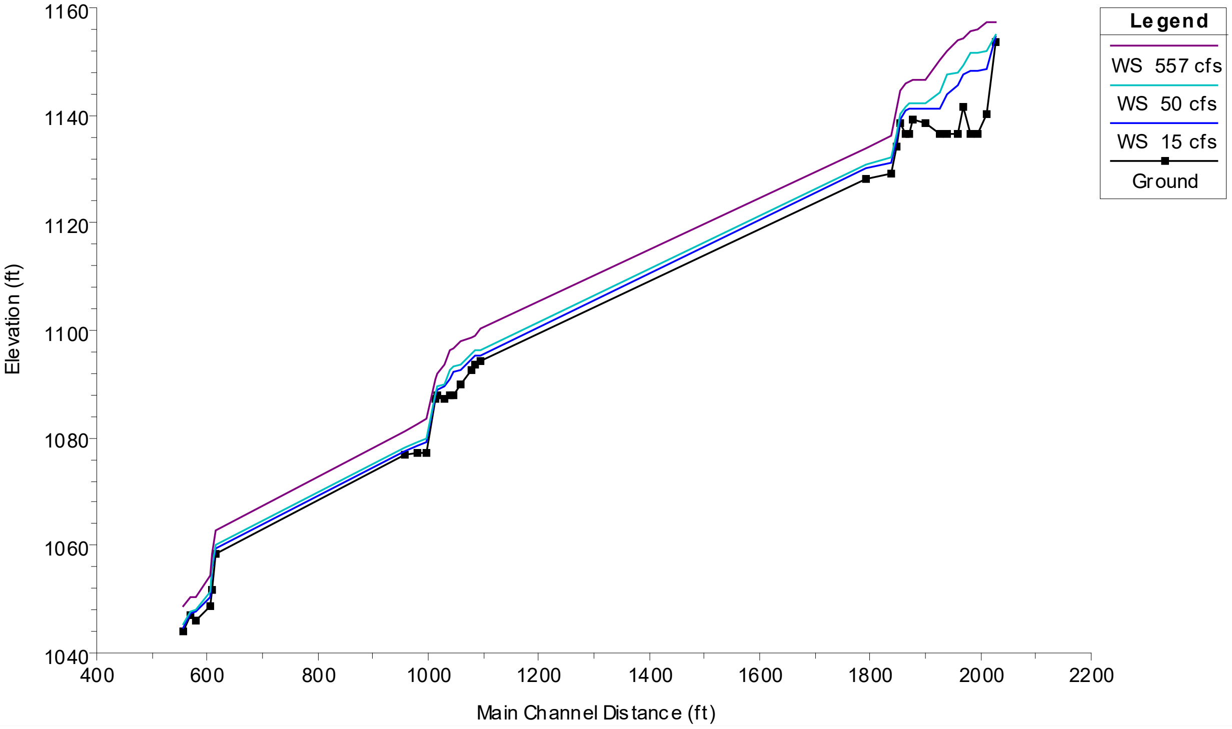

Figure 3-5 Existing conditions HEC-RAS water surface elevation profile plot.

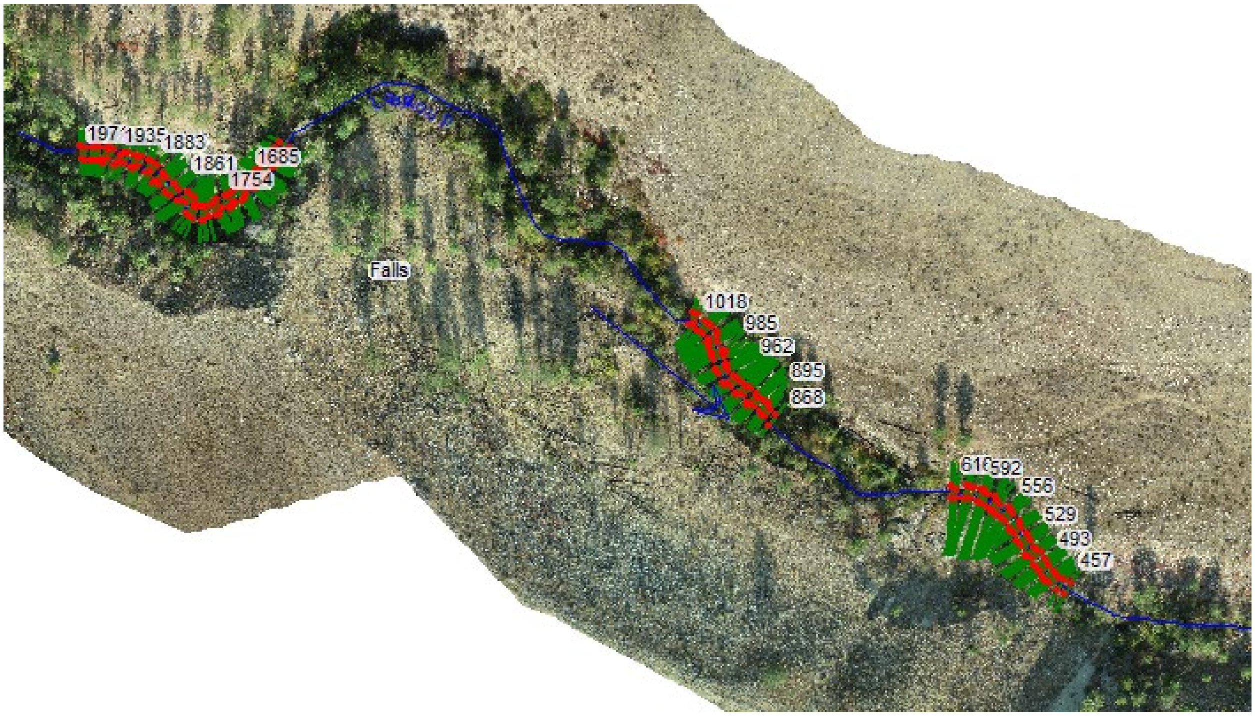

Figure 3-6 Proposed conditions HEC-RAS model schematic**.**

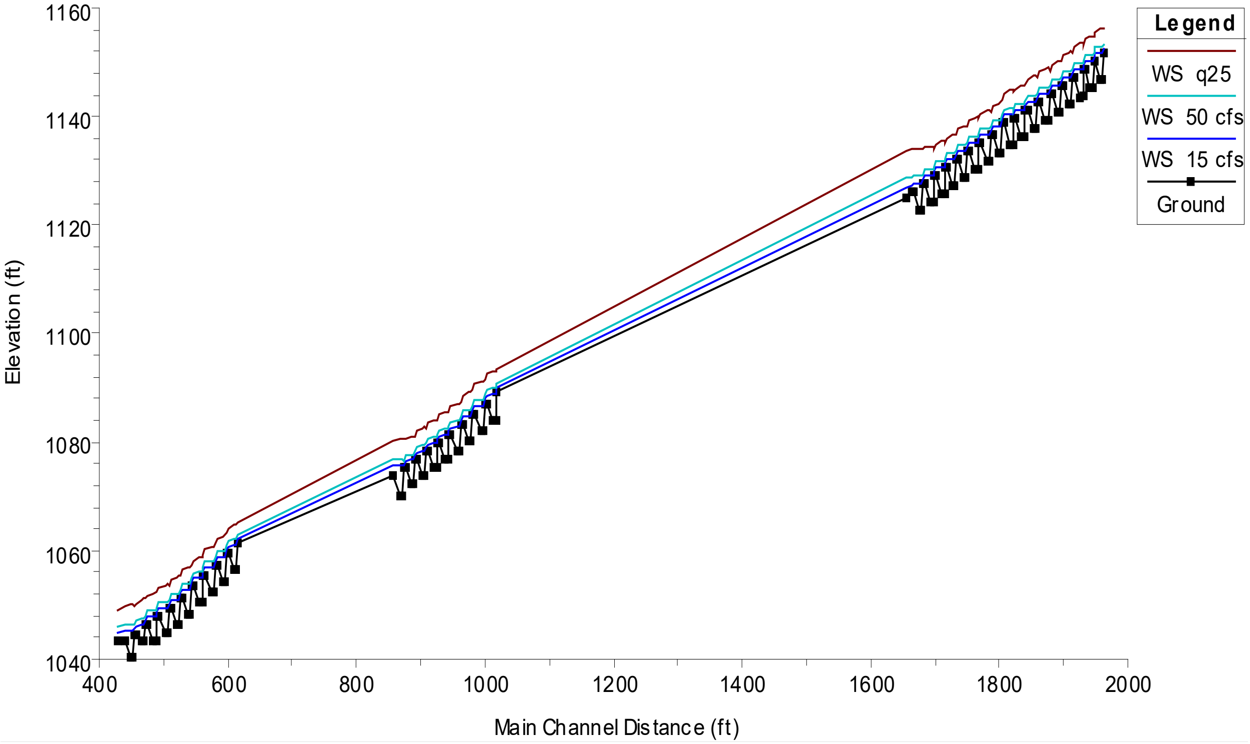

Figure 3-7 Proposed conditions HEC-RAS water surface elevation profile plot**.**

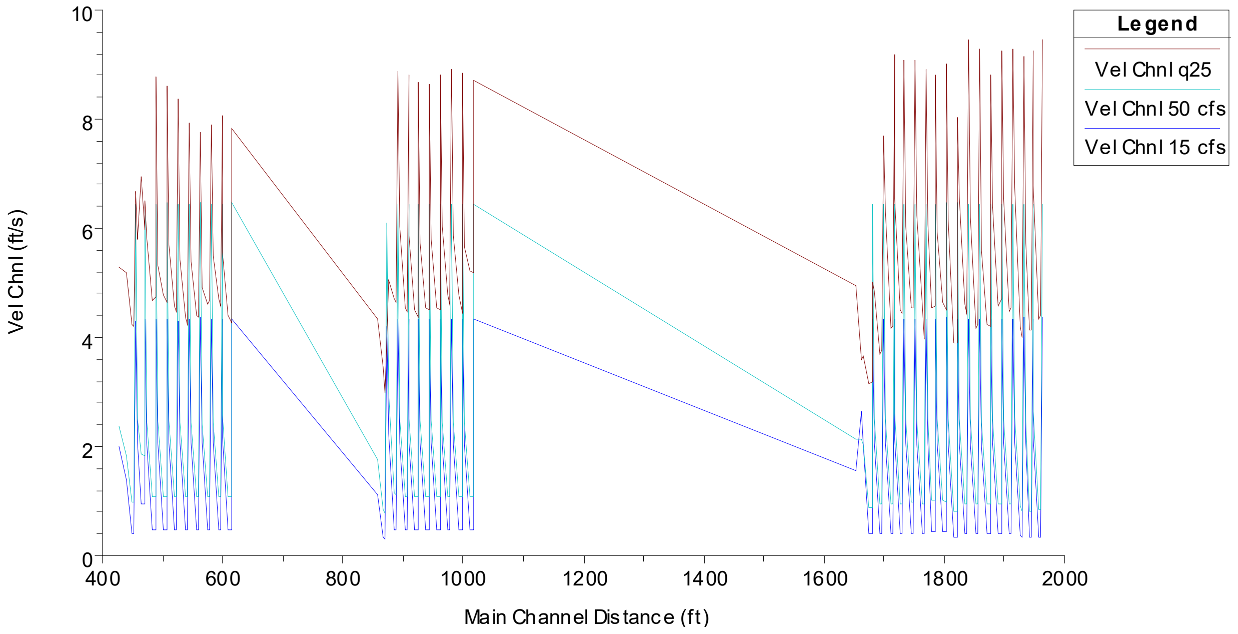

Figure 3-8 Proposed conditions HEC-RAS velocity profile plot**.**

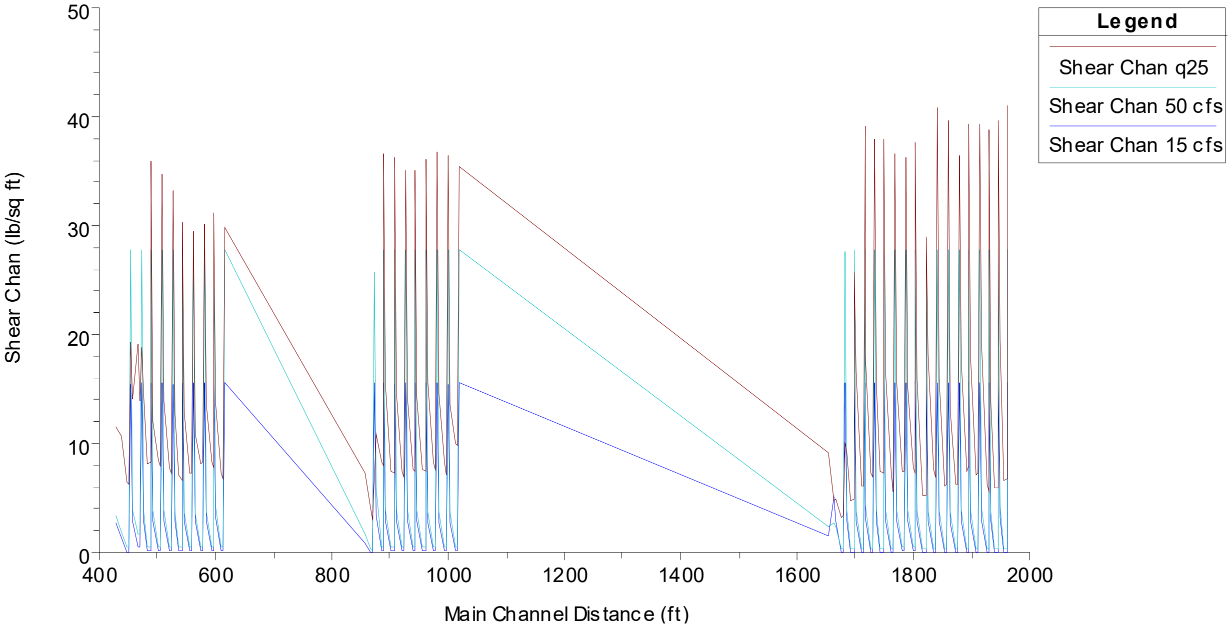

Figure 3-9 Proposed conditions HEC-RAS shear stress profile plot**.**

3.3.1 Hydraulic Modeling Implications for Proposed Design

Hydraulic modeling results from the proposed condition model demonstrate that desired fish passage conditions will be realized over the design fish passage flow range of 15 cfs to 50 cfs. Minimum channel depths at the low fish passage flow of 15 cfs range from 2.2 to 7.6 feet. Average channel velocities at the high fish passage flow of 50 cfs range from 0.8 to 2.1 fps. This range of conditions in the pools will provide adequate depth for resting and recovery between jumps and appropriate velocities for the run up to the next step. The lower depths and higher velocities of up to 6.5 fps that occur at the downstream weir cross sections as flow transitions to critical depth across the lip of the weir and drops into the pool section do not exceed the upper limit of burst swimming speeds (6 sec duration) for adult steelhead of 14 - 27 fps reported by Bell (1973) and Powers and Orsborn (1985).

3.4 Stability Analysis

Stability analyses were completed for the following project elements: boulder step pool weirs, wood and boulder step pool log weirs, and large wood floodplain roughness elements. Calculations are provided in Appendix C.

3.4.1 Boulder Weirs

Minimum boulder size (d30) for the weirs was computed using the method outlined in Thomas and others (2000) which is based on USACE riprap sizing guidelines. This method suggests minimum boulder sizes of 2.5 feet for the 8% reaches and 3.0 feet for the 11% reaches. These results generally agree with mobile particle sizes computed using output from the hydraulic modeling and the Shields curve as described in section 3.6.1 below. Wood and boulder step pool weirs

3.4.2 Large Wood

Incorporation of wood into the step pool weirs, as habitat logs and as floodplain roughness elements will increase diversity and improve aquatic habitat. Construction specifications for the proposed structures were developed based on a stability evaluation for the 25-year flood event. Potential modes of failure that were evaluated for the large wood structures include failure due to buoyant forces and failure due to sliding forces.

For the buoyancy check, the proposed structures were evaluated to determine the ballast required to offset buoyant forces. The factor of safety against buoyant forces for a typical proposed structure was evaluated using a standard mechanistic approach based on vertical equilibrium and the following assumptions:

- Full submergence of the structure including the logs and ballast boulders; and
- The structure is assumed to act as a composite structure which remains fully connected at all discharges and flow depths.

Failure potential due to sliding was evaluated using several assumptions including:

- No resistance from burial of log elements;
- The structure is solid with minimal void space;
- Frictional resistance derived from streambed material and normal force; and
- The structure is fully submerged.

Table 3-2. Summary of structure stability checks during a 1% annual flood event.

Structure	Failure Mode	Predicted Factor of Safety	Recommended Factor of Safety
Boulder and Log Step Pool Weir Logs (buried 6' and ballasted with 10 boulders)	Buoyancy Sliding	2.4 2.0	>1.5 >1.5
Pool Habitat Logs (ballasted with 4 boulders)	Buoyancy Sliding	2.2 2.4	>1.5 >1.5
Large Wood Floodplain Roughness Logs (buried 12')	Buoyancy Sliding	4.0 1.6	>1.5 >1.5

The proposed structures are designed to withstand forces anticipated for the 25-year flood. Computations used to evaluate structure stability and factor of safety calculations for structure buoyancy and sliding are included in Appendix C.

3.5 Sediment Supply and Transport

3.5.1 Sediment Transport Analysis

Channel average shear stress values for the 25-year discharge of 557 cfs ranged from 4.7 lb/sqft to 29.0 lb/sqft. This correlates to mobile particle sizes of 0.6 feet to 3.6 feet with an average of 1.8 feet using Shields equation as reported in the USFS Stream Simulation Manual (2008). The higher shear stress values of up to 6.5 lb/sqft that occur at the downstream weir cross sections as flow transitions to critical depth across the lip of the weir and drops into the pool section will be dissipated by turbulence as the water enters the pool below.

3.5.2 Sediment Size Gradation Analysis

A well-graded mix of material was specified using the 2.5 foot – 3.0 foot boulders as the d30 particle size, with material up to 60 – 72 inches comprising the larger, immobile framework. Smaller, mobile materials (d15, d5) in the 2-inch to 10-inch range were specified based on the Fuller-Thompson method (USFS 2008) and 5% to 10% fines were specified to help seal the voids in the larger materials. Resulting gradation curves are presented in Figure 3-10.

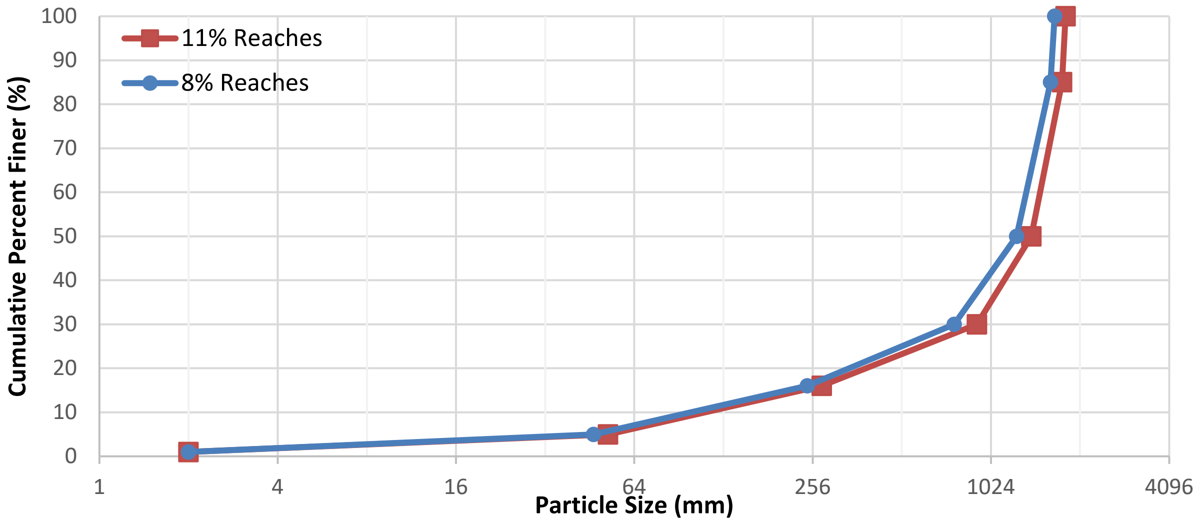

Figure 3-10 Proposed rock weir and streambed fill sediment gradation plot**.**

3.6 Profile Discontinuities

HIP4 guidance for grade stabilization, small dam and structure removal projects suggest surveying a longitudinal profile of the stream channel thalweg for 10 channel widths upstream and 10 channel widths downstream of the structure shall be used to determine the potential for channel degradation. In addition, a minimum of three cross-sections – one downstream of the structure, one through the reservoir area upstream of the structure, and one upstream of the reservoir area outside of the influence of the structure) should be used to characterize the channel morphology and quantify the stored sediment.

A longitudinal profile of the existing stream channel is shown in Figure 3-5. Vertical adjustment potential is limited by the exposed bedrock at the tie-in points upstream and downstream of the project area. Existing stream channel cross sections are included in the plan set which characterize the existing channel morphology. Thirty-four surveyed cross sections were used in the development of the existing conditions hydraulic model. While there is some fine sediment evident in the lower gradient reaches between the waterfalls, the volume of sediment is small relative to the estimated transport capacity of the stream.

3.7 Incorporation of Design Analyses into Contract Documentation

Data from the preceding technical analyses was used in the development of the channel design and integrated into the 30% Design Plan Set. Channel dimensions were initially developed using reference-reach survey data and verified using analytical methods including hydraulic modeling. Material sizes were determined using analytical methods described above and specified on the materials sheet as a suitable range that will provide flexibility for material sourcing while meeting the minimum size requirements for construction of a stable channel.

4 Construction – Contract Documentation

4.1 Incorporation of HIP General and Construction Conservation Measures

Per HIP4 guidance on channel reconstruction (BPA 2021), and in addition to the standard conservation measures noted on Sheet 7 of the 30% Design Plan Set, the following conservation measures will be implemented:

- Materials shall be assessed for contaminants (HIP4 S 3.1.1.2).
- Staged Rewatering Plan (HIP4, S 3.2)
- Monitoring and Adaptive Management Plan (HIP4, S 2.5)

4.2 Design

Per HIP4 guidance, a 30% Design Plan Set has been developed that includes plan, profile, section and detail sheets that identify all project elements and construction activities of sufficient detail to govern competent execution of project bidding and implementation. The following items are contained in the 30% Design Plan Set:

- List of all proposed project materials and quantities.
- Description of best management practices that will be implemented and implementation resource plans including:
    - Site Access Staging and Sequencing Plan with description
    - Work Area Isolation and Dewatering Plan with description of how aquatic organisms within the action area will be treated / protected
    - Erosion and Pollution Control Plan
    - Site Reclamation and Restoration Plan

The following items will be added at the 80% Design stage:

- List proposed equipment and fuels management plan
- Calendar schedule for construction/implementation procedures
- Site or project specific monitoring to support pollution prevention and/or abatement

4.3 Project Cost

A summary of the cost opinion developed for the 30% design is shown in Table 4-1. Detailed cost data is included in Appendix D. The cost opinion is based on unit cost data from recently completed projects and materials costs provided by the project sponsor.

Table 4-1. Cost Opinion Summary.

Description	Cost	Low (-20%)	High (+30%)
Step pool channel	$ 1,030,000	$ 820,000	$ 1,340,000

5 References Cited

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Thomas, D.B., Abt, S.R., Mussetter, R.A., Harvey, M.D., 2000. A Design Procedure for Sizing Step-Pool Structures. September 2000.

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APPENDIX A:
HYDROLOGIC DATA

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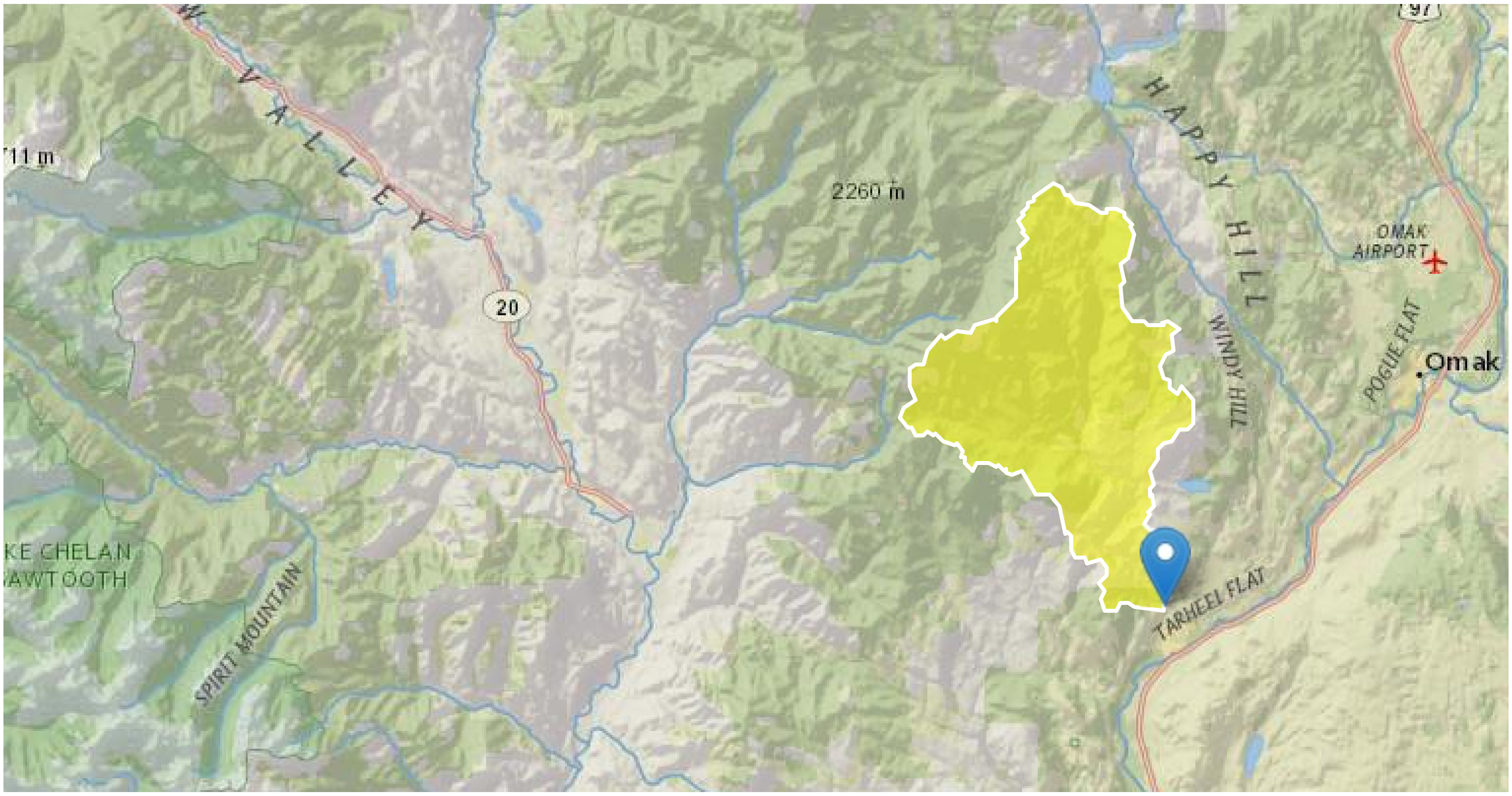
StreamStats Report - Loup Loup Creek at lower falls

Region ID: WA
Workspace ID: WA20210219205228386000
Clicked Point (Latitude, Longitude): 48.30458, -119.70692
Time: 2021-02-19 14:00:14 -0700



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	62.45	square miles
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM	17.1	inches
CANOPY_PCT	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267	44.8	percent

Peak-Flow Statistics Parameters[Peak Region 2 2016 5118]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	62.45	square miles	0.42	1330
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	17.1	inches	8.86	84.2
CANOPY_PCT	Percent Area Under Canopy	44.8	percent	0	81.8

Peak-Flow Statistics Flow Report[Peak Region 2 2016 5118]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	SEp
50_percent_AEP_flood	120	ft^3/s	39.1	369	77.2
20_percent_AEP_flood	250	ft^3/s	89.8	696	69.1
10_percent_AEP_flood	370	ft^3/s	128	1070	72.2
4_percent_AEP_flood	557	ft^3/s	173	1790	81.2
2_percent_AEP_flood	731	ft^3/s	208	2570	89.2
1_percent_AEP_flood	921	ft^3/s	241	3510	96.9
0_5_percent_AEP_flood	1130	ft^3/s	271	4710	106
0_2_percent_AEP_flood	1480	ft^3/s	315	6960	120

Peak-Flow Statistics Citations

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E.,2016, Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.1, October 2016): U.S. Geological Survey Scientific Investigations Report 2016–5118, 70 p. (http://dx.doi.org/10.3133/sir20165118)

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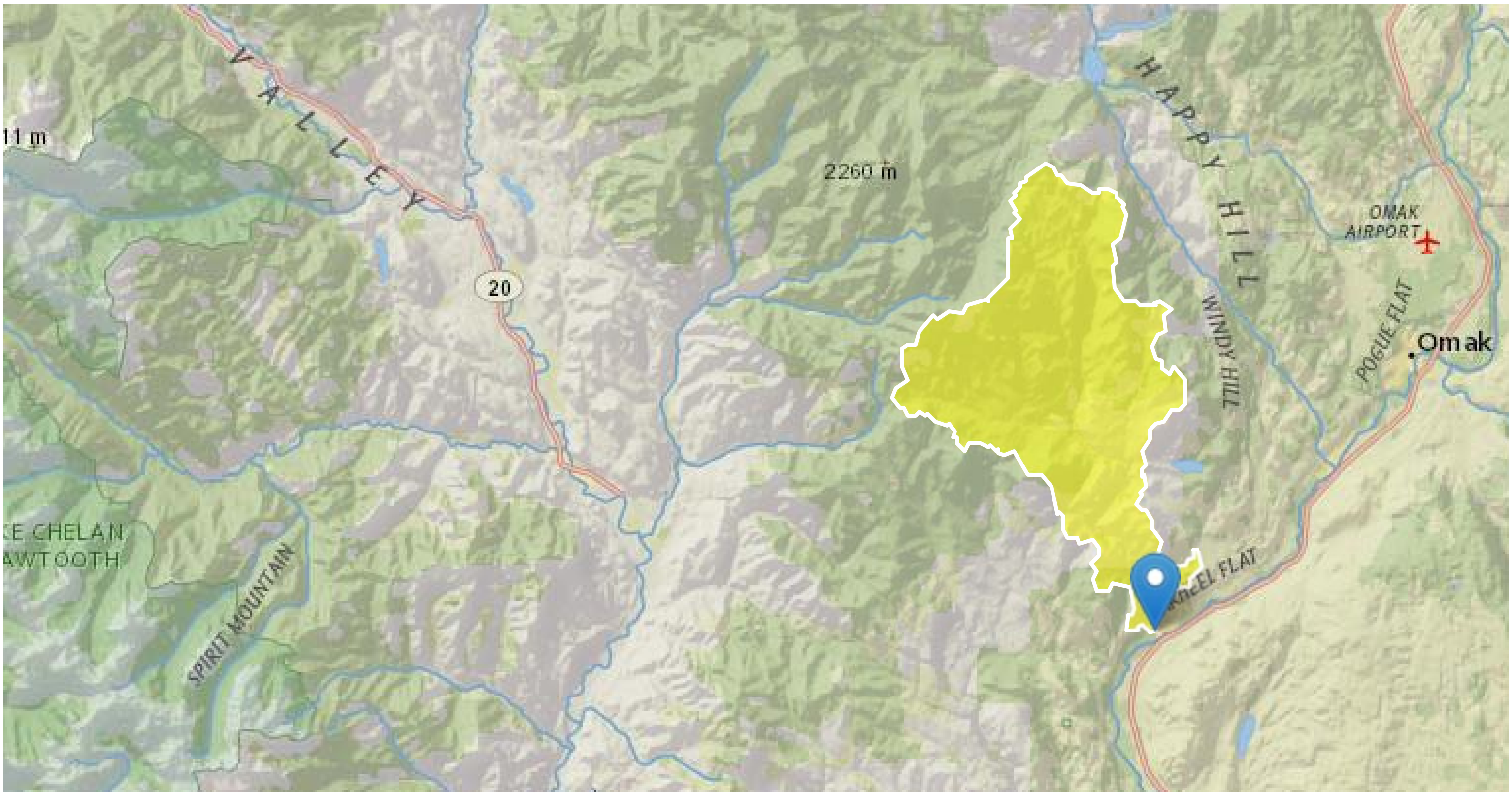
Application Version: 4.4.0

StreamStats Report - Loup Loup Creek at USGS Gage nr Mallott (#12447285)

Region ID: WA
Workspace ID: WA20210219211642415000
Clicked Point (Latitude, Longitude): 48.28344, -119.70859
Time: 2021-02-19 14:24:27 -0700



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
DRNAREA	Area that drains to a point on a stream	64.74	square miles
PRECPRIS10	Basin average mean annual precipitation for 1981 to 2010 from PRISM	17	inches
CANOPY_PCT	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267	43.4	percent

Peak-Flow Statistics Parameters[Peak Region 2 2016 5118]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	64.74	square miles	0.42	1330
PRECPRIS10	Mean Annual Precip PRISM 1981 2010	17	inches	8.86	84.2
CANOPY_PCT	Percent Area Under Canopy	43.4	percent	0	81.8

Peak-Flow Statistics Flow Report[Peak Region 2 2016 5118]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	PIu	SEp
50_percent_AEP_flood	123	ft^3/s	40	378	77.2
20_percent_AEP_flood	262	ft^3/s	94	730	69.1
10_percent_AEP_flood	390	ft^3/s	135	1130	72.2
4_percent_AEP_flood	591	ft^3/s	184	1900	81.2
2_percent_AEP_flood	779	ft^3/s	222	2740	89.2
1_percent_AEP_flood	987	ft^3/s	259	3770	96.9
0_5_percent_AEP_flood	1220	ft^3/s	292	5090	106
0_2_percent_AEP_flood	1590	ft^3/s	338	7470	120

Peak-Flow Statistics Citations

Mastin, M.C., Konrad, C.P., Veilleux, A.G., and Tecca, A.E.,2016, Magnitude, frequency, and trends of floods at gaged and ungaged sites in Washington, based on data through water year 2014 (ver 1.1, October 2016): U.S. Geological Survey Scientific Investigations Report 2016–5118, 70 p. (http://dx.doi.org/10.3133/sir20165118)

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Application Version: 4.4.0

APPENDIX B:
HYDRAULIC MODELING OUTPUT

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Table B-1. Proposed condition HEC-RAS model output for low fish passage flow (15 cfs).

River Sta		Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
1971	Weir	FP_low	15	1151.70	1152.53	4.36	0.57	0.83	1.01
1969	Pool	FP_low	15	1146.70	1151.70	0.35	2.84	5.00	0.04
1965	Pool	FP_low	15	1146.70	1151.70	0.35	2.84	5.00	0.04
1956	Weir	FP_low	15	1150.20	1151.61	2.16	1.14	1.41	0.36
1953	Weir	FP_low	15	1150.20	1151.04	4.35	0.57	0.84	1.01
1951	Pool	FP_low	15	1145.20	1150.26	0.35	2.85	5.06	0.04
1947	Pool	FP_low	15	1145.20	1150.25	0.35	2.85	5.05	0.04
1938	Weir	FP_low	15	1148.70	1150.18	2.05	1.20	1.47	0.33
1935	Weir	FP_low	15	1148.70	1149.53	4.36	0.57	0.83	1.01
1933	Pool	FP_low	15	1143.70	1148.76	0.35	2.86	5.05	0.04
1929	Pool	FP_low	15	1143.60	1148.75	0.39	2.98	5.15	0.04
1920	Weir	FP_low	15	1147.20	1148.67	2.06	1.20	1.47	0.33
1917	Weir	FP_low	15	1147.20	1148.04	4.35	0.58	0.84	1.01
1915	Pool	FP_low	15	1142.20	1147.25	0.40	3.02	5.05	0.04
1911	Pool	FP_low	15	1142.20	1147.25	0.40	3.01	5.05	0.04
1901	Weir	FP_low	15	1145.70	1147.17	2.07	1.20	1.47	0.33
1898	Weir	FP_low	15	1145.70	1146.54	4.34	0.58	0.84	1.01
1897	Pool	FP_low	15	1140.70	1145.76	0.40	3.01	5.06	0.04
1893	Pool	FP_low	15	1140.70	1145.76	0.40	3.00	5.06	0.04
1883	Weir	FP_low	15	1144.20	1145.67	2.06	1.20	1.47	0.33
1880	Weir	FP_low	15	1144.20	1145.04	4.35	0.58	0.84	1.01
1879	Pool	FP_low	15	1139.20	1144.28	0.40	3.00	5.08	0.04
1874	Pool	FP_low	15	1139.20	1144.28	0.40	2.99	5.08	0.04
1865	Weir	FP_low	15	1142.70	1144.20	2.02	1.22	1.50	0.32
1862	Weir	FP_low	15	1142.70	1143.54	4.35	0.57	0.84	1.01
1861	Pool	FP_low	15	1137.70	1142.76	0.40	3.01	5.06	0.04
1856	Pool	FP_low	15	1137.70	1142.76	0.40	3.00	5.06	0.04
1847	Weir	FP_low	15	1141.20	1142.68	2.05	1.20	1.48	0.33
1844	Weir	FP_low	15	1141.20	1142.04	4.35	0.57	0.84	1.01
1843	Pool	FP_low	15	1136.20	1141.26	0.40	3.02	5.06	0.04
1838	Pool	FP_low	15	1136.20	1141.26	0.40	3.02	5.06	0.04
1829	Weir	FP_low	15	1139.70	1141.17	2.06	1.20	1.47	0.33
1826	Weir	FP_low	15	1139.70	1140.54	4.34	0.58	0.84	1.01
1825	Pool	FP_low	15	1134.70	1140.36	0.33	2.87	5.66	0.03
1820	Pool	FP_low	15	1134.70	1140.36	0.33	2.84	5.65	0.03
1811	Weir	FP_low	15	1138.80	1140.28	2.05	1.20	1.48	0.33
1808	Weir	FP_low	15	1138.80	1139.63	4.36	0.57	0.83	1.02
1806	Pool	FP_low	15	1133.30	1138.16	0.43	2.97	4.86	0.04
1802	Pool	FP_low	15	1133.30	1138.16	0.43	2.96	4.86	0.04
1793	Weir	FP_low	15	1136.60	1138.07	2.06	1.20	1.47	0.33
1790	Weir	FP_low	15	1136.60	1137.44	4.35	0.57	0.84	1.01
1788	Pool	FP_low	15	1131.90	1136.76	0.43	2.97	4.86	0.04
1784	Pool	FP_low	15	1131.90	1136.76	0.43	2.96	4.86	0.04
1775	Weir	FP_low	15	1135.20	1136.67	2.06	1.20	1.47	0.33
1772	Weir	FP_low	15	1135.20	1136.04	4.35	0.57	0.83	1.01
1770	Pool	FP_low	15	1130.20	1135.27	0.40	2.97	5.07	0.04
1766	Pool	FP_low	15	1130.20	1135.26	0.40	3.01	5.06	0.04
1757	Weir	FP_low	15	1133.70	1135.18	2.05	1.21	1.48	0.33
1754	Weir	FP_low	15	1133.70	1134.54	4.35	0.57	0.84	1.01
1752	Pool	FP_low	15	1128.80	1133.76	0.41	3.02	4.96	0.04
1748	Pool	FP_low	15	1128.80	1133.76	0.41	3.02	4.96	0.04
1739	Weir	FP_low	15	1132.20	1133.67	2.06	1.20	1.47	0.33
1736	Weir	FP_low	15	1132.20	1133.04	4.35	0.57	0.83	1.01
1734	Pool	FP_low	15	1127.20	1132.22	0.41	3.02	5.02	0.04
1730	Pool	FP_low	15	1127.20	1132.21	0.41	3.02	5.01	0.04
1721	Weir	FP_low	15	1130.70	1132.12	2.14	1.15	1.42	0.35
1718	Weir	FP_low	15	1130.70	1131.54	4.35	0.57	0.83	1.01
1716	Pool	FP_low	15	1125.70	1130.76	0.40	3.00	5.06	0.04
1712	Pool	FP_low	15	1125.70	1130.76	0.40	2.99	5.06	0.04
1703	Weir	FP_low	15	1129.20	1130.67	2.06	1.20	1.47	0.33
1700	Weir	FP_low	15	1129.20	1130.04	4.35	0.57	0.83	1.01
1698	Pool	FP_low	15	1124.20	1129.26	0.40	3.01	5.06	0.04
1694	Pool	FP_low	15	1124.20	1129.26	0.40	3.00	5.06	0.04
1685	Weir	FP_low	15	1127.70	1129.17	2.06	1.20	1.47	0.33
1682	Weir	FP_low	15	1127.70	1128.54	4.35	0.57	0.84	1.01
1680	Pool	FP_low	15	1122.70	1127.77	0.40	3.00	5.07	0.04
1676	Pool	FP_low	15	1122.70	1127.77	0.40	2.99	5.07	0.04
1667	Weir	FP_low	15	1126.20	1127.68	2.04	1.21	1.48	0.33
1664	Weir	FP_low	15	1126.20	1127.41	2.64	0.94	1.21	0.48
1654	Pool	FP_low	15	1124.90	1127.08	1.55	1.36	2.18	0.23
1018	Weir	FP_low	15	1089.20	1090.04	4.34	0.58	0.84	1.01
1016	Pool	FP_low	15	1084.20	1088.79	0.47	2.81	4.59	0.05
1012	Pool	FP_low	15	1084.20	1088.78	0.47	2.81	4.58	0.05
1003	Weir	FP_low	15	1087.20	1088.69	2.02	1.22	1.49	0.32
1000	Weir	FP_low	15	1087.20	1088.04	4.32	0.58	0.84	1.00
998	Pool	FP_low	15	1082.20	1086.79	0.47	2.81	4.59	0.05

Table B-1. Proposed condition HEC-RAS model output for low fish passage flow (15 cfs).

River Sta		Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
994	Pool	FP_low	15	1082.20	1086.79	0.47	2.81	4.59	0.05
985	Weir	FP_low	15	1085.20	1086.70	2.02	1.22	1.50	0.32
982	Weir	FP_low	15	1085.20	1086.04	4.35	0.57	0.84	1.01
980	Pool	FP_low	15	1080.20	1084.79	0.47	2.81	4.59	0.05
976	Pool	FP_low	15	1080.20	1084.78	0.47	2.81	4.58	0.05
967	Weir	FP_low	15	1083.20	1084.70	2.02	1.22	1.49	0.32
964	Weir	FP_low	15	1083.20	1084.04	4.34	0.58	0.84	1.01
962	Pool	FP_low	15	1078.20	1082.77	0.47	2.80	4.57	0.05
958	Pool	FP_low	15	1078.20	1082.76	0.47	2.80	4.56	0.05
949	Weir	FP_low	15	1081.20	1082.67	2.06	1.20	1.47	0.33
946	Weir	FP_low	15	1081.20	1082.04	4.34	0.58	0.84	1.01
944	Pool	FP_low	15	1076.70	1081.26	0.47	2.80	4.56	0.05
940	Pool	FP_low	15	1076.70	1081.26	0.47	2.80	4.56	0.05
931	Weir	FP_low	15	1079.70	1081.17	2.07	1.19	1.47	0.33
928	Weir	FP_low	15	1079.70	1080.54	4.35	0.57	0.84	1.01
926	Pool	FP_low	15	1075.20	1079.76	0.47	2.80	4.56	0.05
922	Pool	FP_low	15	1075.20	1079.76	0.47	2.79	4.56	0.05
913	Weir	FP_low	15	1078.20	1079.66	2.07	1.19	1.46	0.33
910	Weir	FP_low	15	1078.20	1079.04	4.32	0.58	0.84	1.00
908	Pool	FP_low	15	1073.70	1078.26	0.47	2.80	4.56	0.05
904	Pool	FP_low	15	1073.70	1078.26	0.47	2.80	4.56	0.05
895	Weir	FP_low	15	1076.70	1078.17	2.07	1.20	1.47	0.33
892	Weir	FP_low	15	1076.70	1077.54	4.35	0.57	0.84	1.01
890	Pool	FP_low	15	1072.20	1076.69	0.49	2.75	4.49	0.05
886	Pool	FP_low	15	1072.20	1076.68	0.49	2.75	4.48	0.05
877	Weir	FP_low	15	1075.20	1076.57	2.24	1.11	1.37	0.38
874	Weir	FP_low	15	1075.20	1075.92	4.20	0.48	1.08	1.09
872	Pool	FP_low	15	1070.20	1075.86	0.31	2.62	7.55	0.03
868	Pool	FP_low	15	1070.20	1075.86	0.33	2.76	5.66	0.03
859	Weir	FP_low	15	1073.70	1075.83	1.12	0.84	2.13	0.21
616	Weir	FP_low	15	1061.40	1062.24	4.35	0.57	0.84	1.01
614	Pool	FP_low	15	1056.40	1060.92	0.48	2.77	4.52	0.05
610	Pool	FP_low	15	1056.40	1060.92	0.48	2.77	4.52	0.05
601	Weir	FP_low	15	1059.40	1060.81	2.16	1.14	1.41	0.36
598	Weir	FP_low	15	1059.40	1060.24	4.34	0.58	0.84	1.01
596	Pool	FP_low	15	1054.40	1058.97	0.47	2.80	4.57	0.05
592	Pool	FP_low	15	1054.40	1058.96	0.47	2.80	4.56	0.05
583	Weir	FP_low	15	1057.40	1058.87	2.06	1.20	1.47	0.33
580	Weir	FP_low	15	1057.40	1058.24	4.35	0.57	0.83	1.01
578	Pool	FP_low	15	1052.40	1056.97	0.47	2.80	4.57	0.05
574	Pool	FP_low	15	1052.40	1056.96	0.47	2.80	4.56	0.05
565	Weir	FP_low	15	1055.40	1056.87	2.06	1.20	1.47	0.33
562	Weir	FP_low	15	1055.40	1056.23	4.36	0.57	0.83	1.01
560	Pool	FP_low	15	1050.40	1054.97	0.47	2.80	4.57	0.05
556	Pool	FP_low	15	1050.40	1054.96	0.47	2.80	4.56	0.05
547	Weir	FP_low	15	1053.40	1054.87	2.06	1.20	1.47	0.33
544	Weir	FP_low	15	1053.40	1054.24	4.35	0.57	0.84	1.01
542	Pool	FP_low	15	1048.40	1052.97	0.47	2.80	4.57	0.05
538	Pool	FP_low	15	1048.40	1052.96	0.47	2.80	4.56	0.05
529	Weir	FP_low	15	1051.40	1052.87	2.06	1.20	1.47	0.33
526	Weir	FP_low	15	1051.40	1052.24	4.32	0.58	0.84	1.00
524	Pool	FP_low	15	1046.40	1050.97	0.47	2.80	4.57	0.05
520	Pool	FP_low	15	1046.40	1050.96	0.47	2.80	4.56	0.05
511	Weir	FP_low	15	1049.40	1050.87	2.06	1.20	1.47	0.33
508	Weir	FP_low	15	1049.40	1050.24	4.35	0.57	0.84	1.01
506	Pool	FP_low	15	1044.90	1049.47	0.47	2.80	4.57	0.05
502	Pool	FP_low	15	1044.90	1049.46	0.47	2.80	4.56	0.05
493	Weir	FP_low	15	1047.90	1049.37	2.06	1.20	1.47	0.33
490	Weir	FP_low	15	1047.90	1048.74	4.34	0.58	0.84	1.01
488	Pool	FP_low	15	1043.40	1047.97	0.47	2.80	4.57	0.05
484	Pool	FP_low	15	1043.40	1047.97	0.47	2.80	4.57	0.05
475	Weir	FP_low	15	1046.40	1047.87	2.06	1.20	1.47	0.33
472	Weir	FP_low	15	1046.40	1047.24	4.35	0.57	0.84	1.01
470	Pool	FP_low	15	1043.40	1046.36	0.95	1.86	2.96	0.12
466	Pool	FP_low	15	1043.40	1046.34	0.96	1.85	2.94	0.12
457	Weir	FP_low	15	1044.70	1046.17	2.06	1.20	1.47	0.33
454	Weir	FP_low	15	1044.70	1045.54	4.32	0.58	0.84	1.00
452	Pool	FP_low	15	1040.40	1045.41	0.41	3.02	5.01	0.04
448	Pool	FP_low	15	1040.40	1045.41	0.41	3.03	5.01	0.04
439	Weir	FP_low	15	1043.40	1045.36	1.38	0.82	1.96	0.27
429	Weir	FP_low	15	1043.40	1044.92	1.99	1.24	1.51	0.31

Table B-2. Proposed condition HEC-RAS model output for high fish passage flow (50 cfs).

River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
1971 Weir	FP_high	50	1151.70	1153.25	6.45	1.27	1.55	1.01
1969 Pool	FP_high	50	1146.70	1152.83	0.83	3.31	6.13	0.07
1965 Pool	FP_high	50	1146.70	1152.82	0.83	3.22	6.12	0.07
1956 Weir	FP_high	50	1150.20	1152.68	2.64	1.08	2.48	0.42
1953 Weir	FP_high	50	1150.20	1151.75	6.46	1.27	1.55	1.01
1951 Pool	FP_high	50	1145.20	1151.37	0.82	3.13	6.17	0.07
1947 Pool	FP_high	50	1145.20	1151.36	0.82	3.08	6.16	0.07
1938 Weir	FP_high	50	1148.70	1151.24	2.47	1.05	2.54	0.38
1935 Weir	FP_high	50	1148.70	1150.25	6.45	1.27	1.55	1.01
1933 Pool	FP_high	50	1143.70	1149.89	0.82	3.30	6.19	0.07
1929 Pool	FP_high	50	1143.60	1149.88	0.93	2.96	6.28	0.08
1920 Weir	FP_high	50	1147.20	1149.74	2.53	1.16	2.54	0.39
1917 Weir	FP_high	50	1147.20	1148.75	6.45	1.27	1.55	1.01
1915 Pool	FP_high	50	1142.20	1148.39	0.96	3.06	6.19	0.08
1911 Pool	FP_high	50	1142.20	1148.38	0.95	2.92	6.18	0.08
1901 Weir	FP_high	50	1145.70	1148.24	2.52	1.13	2.54	0.39
1898 Weir	FP_high	50	1145.70	1147.25	6.45	1.27	1.55	1.01
1897 Pool	FP_high	50	1140.70	1146.89	0.95	2.96	6.19	0.08
1893 Pool	FP_high	50	1140.70	1146.88	0.95	2.84	6.18	0.08
1883 Weir	FP_high	50	1144.20	1146.74	2.50	1.07	2.54	0.39
1880 Weir	FP_high	50	1144.20	1145.75	6.45	1.27	1.55	1.01
1879 Pool	FP_high	50	1139.20	1145.41	0.95	2.90	6.21	0.08
1874 Pool	FP_high	50	1139.20	1145.40	0.95	2.84	6.20	0.08
1865 Weir	FP_high	50	1142.70	1145.27	2.44	1.04	2.57	0.37
1862 Weir	FP_high	50	1142.70	1144.25	6.46	1.27	1.55	1.01
1861 Pool	FP_high	50	1137.70	1143.90	0.95	2.93	6.20	0.08
1856 Pool	FP_high	50	1137.70	1143.89	0.95	2.87	6.19	0.08
1847 Weir	FP_high	50	1141.20	1143.75	2.51	1.14	2.55	0.39
1844 Weir	FP_high	50	1141.20	1142.75	6.45	1.27	1.55	1.01
1843 Pool	FP_high	50	1136.20	1142.40	0.95	2.98	6.19	0.08
1838 Pool	FP_high	50	1136.20	1142.39	0.96	3.01	6.19	0.08
1829 Weir	FP_high	50	1139.70	1142.24	2.51	1.11	2.54	0.39
1826 Weir	FP_high	50	1139.70	1141.25	6.46	1.27	1.55	1.01
1825 Pool	FP_high	50	1134.70	1141.48	0.81	2.98	6.78	0.06
1820 Pool	FP_high	50	1134.70	1141.48	0.80	2.93	6.77	0.06
1811 Weir	FP_high	50	1138.80	1141.35	2.49	1.09	2.55	0.38
1808 Weir	FP_high	50	1138.80	1140.35	6.46	1.27	1.55	1.01
1806 Pool	FP_high	50	1133.30	1139.30	1.00	2.69	6.00	0.09
1802 Pool	FP_high	50	1133.30	1139.29	1.00	2.70	5.99	0.09
1793 Weir	FP_high	50	1136.60	1139.14	2.49	1.04	2.54	0.39
1790 Weir	FP_high	50	1136.60	1138.15	6.45	1.27	1.55	1.01
1788 Pool	FP_high	50	1131.90	1137.90	1.00	2.80	6.00	0.09
1784 Pool	FP_high	50	1131.90	1137.89	1.00	2.73	5.99	0.09
1775 Weir	FP_high	50	1135.20	1137.74	2.50	1.07	2.54	0.39
1772 Weir	FP_high	50	1135.20	1136.75	6.45	1.27	1.55	1.01
1770 Pool	FP_high	50	1130.20	1136.40	0.94	2.67	6.20	0.08
1766 Pool	FP_high	50	1130.20	1136.39	0.95	2.97	6.19	0.08
1757 Weir	FP_high	50	1133.70	1136.25	2.49	1.10	2.55	0.38
1754 Weir	FP_high	50	1133.70	1135.25	6.46	1.27	1.55	1.01
1752 Pool	FP_high	50	1128.80	1134.89	0.98	2.88	6.09	0.08
1748 Pool	FP_high	50	1128.80	1134.88	0.98	2.79	6.08	0.08
1739 Weir	FP_high	50	1132.20	1134.74	2.50	1.08	2.54	0.39
1736 Weir	FP_high	50	1132.20	1133.75	6.45	1.27	1.55	1.01
1734 Pool	FP_high	50	1127.20	1133.35	0.96	2.87	6.15	0.08
1730 Pool	FP_high	50	1127.20	1133.34	0.96	2.84	6.14	0.08
1721 Weir	FP_high	50	1130.70	1133.20	2.63	1.07	2.50	0.41
1718 Weir	FP_high	50	1130.70	1132.25	6.45	1.27	1.55	1.01
1716 Pool	FP_high	50	1125.70	1131.90	0.95	2.83	6.19	0.08
1712 Pool	FP_high	50	1125.70	1131.89	0.95	2.77	6.19	0.08
1703 Weir	FP_high	50	1129.20	1131.74	2.52	1.13	2.54	0.39
1700 Weir	FP_high	50	1129.20	1130.75	6.45	1.27	1.55	1.01
1698 Pool	FP_high	50	1124.20	1130.39	0.95	2.91	6.19	0.08
1694 Pool	FP_high	50	1124.20	1130.38	0.95	2.79	6.18	0.08
1685 Weir	FP_high	50	1127.70	1130.25	2.51	1.13	2.54	0.39
1682 Weir	FP_high	50	1127.70	1129.25	6.43	1.28	1.55	1.00
1680 Pool	FP_high	50	1122.70	1129.13	0.89	2.95	6.43	0.07
1676 Pool	FP_high	50	1122.70	1129.12	0.89	2.83	6.42	0.07
1667 Weir	FP_high	50	1126.20	1129.03	2.03	1.33	2.83	0.28
1664 Weir	FP_high	50	1126.20	1128.92	2.15	1.23	2.72	0.31
1654 Pool	FP_high	50	1124.90	1128.67	2.15	2.34	3.77	0.25
1018 Weir	FP_high	50	1089.20	1090.75	6.46	1.27	1.55	1.01
1016 Pool	FP_high	50	1084.20	1089.93	1.09	2.92	5.73	0.10
1012 Pool	FP_high	50	1084.20	1089.92	1.09	2.88	5.72	0.10
1003 Weir	FP_high	50	1087.20	1089.77	2.44	1.04	2.57	0.37
1000 Weir	FP_high	50	1087.20	1088.75	6.45	1.27	1.55	1.01
998 Pool	FP_high	50	1082.20	1087.94	1.08	2.60	5.74	0.10

Table B-2. Proposed condition HEC-RAS model output for high fish passage flow (50 cfs).

River Sta		Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
994	Pool	FP_high	50	1082.20	1087.93	1.08	2.68	5.73	0.10
985	Weir	FP_high	50	1085.20	1087.77	2.44	1.07	2.57	0.37
982	Weir	FP_high	50	1085.20	1086.75	6.45	1.27	1.55	1.01
980	Pool	FP_high	50	1080.20	1085.93	1.08	2.61	5.73	0.10
976	Pool	FP_high	50	1080.20	1085.92	1.09	2.63	5.72	0.10
967	Weir	FP_high	50	1083.20	1085.77	2.44	1.07	2.57	0.37
964	Weir	FP_high	50	1083.20	1084.75	6.45	1.27	1.55	1.01
962	Pool	FP_high	50	1078.20	1083.91	1.08	2.47	5.71	0.10
958	Pool	FP_high	50	1078.20	1083.90	1.09	2.43	5.70	0.10
949	Weir	FP_high	50	1081.20	1083.74	2.48	1.01	2.54	0.38
946	Weir	FP_high	50	1081.20	1082.75	6.45	1.27	1.55	1.01
944	Pool	FP_high	50	1076.70	1082.41	1.09	2.47	5.71	0.10
940	Pool	FP_high	50	1076.70	1082.39	1.09	2.41	5.69	0.10
931	Weir	FP_high	50	1079.70	1082.24	2.49	1.01	2.54	0.39
928	Weir	FP_high	50	1079.70	1081.25	6.45	1.27	1.55	1.01
926	Pool	FP_high	50	1075.20	1080.91	1.09	2.47	5.71	0.10
922	Pool	FP_high	50	1075.20	1080.89	1.09	2.46	5.69	0.10
913	Weir	FP_high	50	1078.20	1080.73	2.51	1.03	2.53	0.39
910	Weir	FP_high	50	1078.20	1079.75	6.45	1.27	1.55	1.01
908	Pool	FP_high	50	1073.70	1079.41	1.09	2.55	5.71	0.10
904	Pool	FP_high	50	1073.70	1079.40	1.09	2.52	5.70	0.10
895	Weir	FP_high	50	1076.70	1079.24	2.50	1.05	2.54	0.39
892	Weir	FP_high	50	1076.70	1078.25	6.45	1.28	1.55	1.01
890	Pool	FP_high	50	1072.20	1077.77	1.13	2.53	5.57	0.11
886	Pool	FP_high	50	1072.20	1077.76	1.14	2.50	5.55	0.11
877	Weir	FP_high	50	1075.20	1077.54	2.98	0.88	2.34	0.50
874	Weir	FP_high	50	1075.20	1076.55	6.09	1.01	1.71	1.03
872	Pool	FP_high	50	1070.20	1076.79	0.78	2.57	8.48	0.06
868	Pool	FP_high	50	1070.20	1076.78	0.84	2.78	6.58	0.07
859	Weir	FP_high	50	1073.70	1076.71	1.76	1.35	3.01	0.23
616	Weir	FP_high	50	1061.40	1062.95	6.46	1.27	1.55	1.01
614	Pool	FP_high	50	1056.40	1062.06	1.09	2.03	5.66	0.10
610	Pool	FP_high	50	1056.40	1062.05	1.10	2.02	5.65	0.10
601	Weir	FP_high	50	1059.40	1061.88	2.57	0.86	2.48	0.41
598	Weir	FP_high	50	1059.40	1060.95	6.45	1.27	1.55	1.01
596	Pool	FP_high	50	1054.40	1060.10	1.08	2.14	5.70	0.10
592	Pool	FP_high	50	1054.40	1060.09	1.08	2.11	5.69	0.10
583	Weir	FP_high	50	1057.40	1059.94	2.43	0.86	2.54	0.38
580	Weir	FP_high	50	1057.40	1058.95	6.45	1.27	1.55	1.01
578	Pool	FP_high	50	1052.40	1058.09	1.08	2.04	5.69	0.10
574	Pool	FP_high	50	1052.40	1058.08	1.08	1.93	5.68	0.10
565	Weir	FP_high	50	1055.40	1057.93	2.39	0.79	2.53	0.37
562	Weir	FP_high	50	1055.40	1056.95	6.46	1.27	1.55	1.01
560	Pool	FP_high	50	1050.40	1056.10	1.08	2.00	5.70	0.10
556	Pool	FP_high	50	1050.40	1056.08	1.08	1.94	5.68	0.10
547	Weir	FP_high	50	1053.40	1055.94	2.42	0.86	2.54	0.38
544	Weir	FP_high	50	1053.40	1054.95	6.45	1.27	1.55	1.01
542	Pool	FP_high	50	1048.40	1054.10	1.08	2.15	5.70	0.10
538	Pool	FP_high	50	1048.40	1054.09	1.08	2.14	5.69	0.10
529	Weir	FP_high	50	1051.40	1053.94	2.45	0.93	2.54	0.38
526	Weir	FP_high	50	1051.40	1052.95	6.45	1.27	1.55	1.01
524	Pool	FP_high	50	1046.40	1052.11	1.08	2.42	5.71	0.10
520	Pool	FP_high	50	1046.40	1052.10	1.09	2.41	5.70	0.10
511	Weir	FP_high	50	1049.40	1051.94	2.48	1.00	2.54	0.38
508	Weir	FP_high	50	1049.40	1050.95	6.46	1.27	1.55	1.01
506	Pool	FP_high	50	1044.90	1050.61	1.09	2.55	5.71	0.10
502	Pool	FP_high	50	1044.90	1050.60	1.09	2.54	5.70	0.10
493	Weir	FP_high	50	1047.90	1050.44	2.48	0.99	2.54	0.38
490	Weir	FP_high	50	1047.90	1049.45	6.45	1.27	1.55	1.01
488	Pool	FP_high	50	1043.40	1049.11	1.09	2.59	5.71	0.10
484	Pool	FP_high	50	1043.40	1049.10	1.09	2.50	5.70	0.10
475	Weir	FP_high	50	1046.40	1048.94	2.48	1.02	2.54	0.38
472	Weir	FP_high	50	1046.40	1047.95	6.45	1.27	1.55	1.01
470	Pool	FP_high	50	1043.40	1047.58	1.82	2.58	4.18	0.20
466	Pool	FP_high	50	1043.40	1047.52	1.86	2.55	4.12	0.21
457	Weir	FP_high	50	1044.70	1047.24	2.50	1.08	2.54	0.39
454	Weir	FP_high	50	1044.70	1046.25	6.45	1.27	1.55	1.01
452	Pool	FP_high	50	1040.40	1046.46	0.98	2.76	6.06	0.09
448	Pool	FP_high	50	1040.40	1046.45	0.99	2.75	6.05	0.09
439	Weir	FP_high	50	1043.40	1046.36	1.85	1.38	2.96	0.25
429	Weir	FP_high	50	1043.40	1046.00	2.38	1.10	2.60	0.36

Table B-3. Proposed condition HEC-RAS model output for 25-year flow (557 cfs).

River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
1971 Weir	q25	557	1151.70	1156.20	9.45	2.39	4.50	0.92
1969 Pool	q25	557	1146.70	1156.25	4.42	4.88	9.55	0.29
1965 Pool	q25	557	1146.70	1156.19	4.35	4.75	9.49	0.28
1956 Weir	q25	557	1150.20	1155.56	6.78	2.88	5.36	0.59
1953 Weir	q25	557	1150.20	1154.62	9.25	2.25	4.42	0.91
1951 Pool	q25	557	1145.20	1154.82	4.13	4.69	9.61	0.27
1947 Pool	q25	557	1145.20	1154.75	4.14	4.51	9.55	0.27
1938 Weir	q25	557	1148.70	1154.35	5.74	3.07	5.65	0.48
1935 Weir	q25	557	1148.70	1153.21	9.15	2.23	4.51	0.91
1933 Pool	q25	557	1143.70	1153.60	4.01	4.75	9.90	0.25
1929 Pool	q25	557	1143.60	1153.54	4.22	4.50	9.94	0.26
1920 Weir	q25	557	1147.20	1152.82	6.75	3.07	5.62	0.57
1917 Weir	q25	557	1147.20	1151.81	9.29	2.31	4.61	0.89
1915 Pool	q25	557	1142.20	1151.98	4.53	4.39	9.78	0.29
1911 Pool	q25	557	1142.20	1151.90	4.48	4.36	9.70	0.28
1901 Weir	q25	557	1145.70	1151.25	6.54	2.94	5.55	0.56
1898 Weir	q25	557	1145.70	1150.21	9.25	2.23	4.51	0.90
1897 Pool	q25	557	1140.70	1150.17	4.70	3.99	9.47	0.30
1893 Pool	q25	557	1140.70	1150.10	4.57	3.73	9.40	0.30
1883 Weir	q25	557	1144.20	1149.47	6.40	2.59	5.27	0.56
1880 Weir	q25	557	1144.20	1148.53	8.82	2.04	4.33	0.89
1879 Pool	q25	557	1139.20	1148.92	4.20	3.78	9.72	0.27
1874 Pool	q25	557	1139.20	1148.84	4.22	3.60	9.64	0.27
1865 Weir	q25	557	1142.70	1148.37	5.59	2.90	5.67	0.47
1862 Weir	q25	557	1142.70	1147.17	9.28	2.25	4.47	0.91
1861 Pool	q25	557	1137.70	1147.58	4.23	4.11	9.88	0.26
1856 Pool	q25	557	1137.70	1147.52	4.17	4.12	9.82	0.26
1847 Weir	q25	557	1141.20	1146.91	6.22	2.99	5.71	0.52
1844 Weir	q25	557	1141.20	1145.75	9.45	2.37	4.55	0.92
1843 Pool	q25	557	1136.20	1145.89	4.44	4.36	9.69	0.28
1838 Pool	q25	557	1136.20	1145.78	4.62	4.16	9.58	0.30
1829 Weir	q25	557	1139.70	1145.13	6.56	2.74	5.43	0.57
1826 Weir	q25	557	1139.70	1144.46	8.05	2.30	4.76	0.76
1825 Pool	q25	557	1134.70	1144.87	3.90	4.17	10.17	0.24
1820 Pool	q25	557	1134.70	1144.82	3.88	4.09	10.12	0.24
1811 Weir	q25	557	1138.80	1144.25	6.14	2.64	5.45	0.53
1808 Weir	q25	557	1138.80	1143.23	9.02	2.08	4.43	0.89
1806 Pool	q25	557	1133.30	1142.56	4.50	3.83	9.26	0.29
1802 Pool	q25	557	1133.30	1142.45	4.63	3.64	9.15	0.30
1793 Weir	q25	557	1136.60	1141.93	5.94	2.55	5.33	0.52
1790 Weir	q25	557	1136.60	1140.96	8.82	1.94	4.36	0.88
1788 Pool	q25	557	1131.90	1141.25	4.57	3.76	9.35	0.30
1784 Pool	q25	557	1131.90	1141.17	4.54	3.70	9.27	0.30
1775 Weir	q25	557	1135.20	1140.62	6.06	2.72	5.42	0.52
1772 Weir	q25	557	1135.20	1139.64	8.91	2.06	4.44	0.88
1770 Pool	q25	557	1130.20	1139.94	3.96	4.15	9.74	0.25
1766 Pool	q25	557	1130.20	1139.78	4.58	4.04	9.58	0.29
1757 Weir	q25	557	1133.70	1139.19	6.25	2.73	5.49	0.53
1754 Weir	q25	557	1133.70	1138.15	9.08	2.11	4.45	0.89
1752 Pool	q25	557	1128.80	1138.30	4.54	3.90	9.50	0.29
1748 Pool	q25	557	1128.80	1138.21	4.54	3.87	9.41	0.29
1739 Weir	q25	557	1132.20	1137.70	6.03	2.72	5.50	0.51
1736 Weir	q25	557	1132.20	1136.65	9.07	2.11	4.45	0.89
1734 Pool	q25	557	1127.20	1136.80	4.43	4.01	9.60	0.28
1730 Pool	q25	557	1127.20	1136.71	4.50	3.98	9.51	0.29
1721 Weir	q25	557	1130.70	1136.09	6.55	2.77	5.39	0.57
1718 Weir	q25	557	1130.70	1135.12	9.20	2.20	4.42	0.91
1716 Pool	q25	557	1125.70	1135.48	4.19	4.11	9.78	0.26
1712 Pool	q25	557	1125.70	1135.41	4.18	4.07	9.71	0.26
1703 Weir	q25	557	1129.20	1134.79	6.32	2.87	5.59	0.53
1700 Weir	q25	557	1129.20	1134.21	7.68	2.54	5.01	0.70
1698 Pool	q25	557	1124.20	1134.58	3.75	4.61	10.38	0.23
1694 Pool	q25	557	1124.20	1134.54	3.71	4.64	10.34	0.23
1685 Weir	q25	557	1127.70	1134.23	4.84	3.46	6.53	0.37
1682 Weir	q25	557	1127.70	1134.10	5.03	3.42	6.40	0.39
1680 Pool	q25	557	1122.70	1134.21	3.17	5.43	11.51	0.18
1676 Pool	q25	557	1122.70	1134.18	3.15	5.42	11.48	0.18
1667 Weir	q25	557	1126.20	1134.04	3.68	4.33	7.84	0.25
1664 Weir	q25	557	1126.20	1134.00	3.60	4.36	7.80	0.25
1654 Pool	q25	557	1124.90	1133.66	4.97	3.45	8.76	0.34
1018 Weir	q25	557	1089.20	1093.52	8.70	1.97	4.32	0.87
1016 Pool	q25	557	1084.20	1093.16	5.17	3.35	8.95	0.34
1012 Pool	q25	557	1084.20	1093.05	5.23	3.08	8.85	0.35
1003 Weir	q25	557	1087.20	1092.60	5.67	2.53	5.40	0.49
1000 Weir	q25	557	1087.20	1091.56	8.84	1.93	4.36	0.88
998 Pool	q25	557	1082.20	1091.33	4.45	3.39	9.13	0.29

Table B-3. Proposed condition HEC-RAS model output for 25-year flow (557 cfs).

River Sta		Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Hydr Depth (ft)	Max Chl Dpth (ft)	Froude # Chl
994	Pool	q25	557	1082.20	1091.18	4.78	3.41	8.98	0.32
985	Weir	q25	557	1085.20	1090.64	5.88	2.54	5.44	0.51
982	Weir	q25	557	1085.20	1089.59	8.90	2.00	4.39	0.88
980	Pool	q25	557	1080.20	1089.23	4.60	3.34	9.03	0.30
976	Pool	q25	557	1080.20	1089.11	4.77	3.31	8.91	0.32
967	Weir	q25	557	1083.20	1088.56	6.05	2.50	5.36	0.53
964	Weir	q25	557	1083.20	1087.56	8.80	1.93	4.36	0.88
962	Pool	q25	557	1078.20	1087.09	4.51	3.11	8.89	0.30
958	Pool	q25	557	1078.20	1086.99	4.55	3.02	8.79	0.31
949	Weir	q25	557	1081.20	1086.48	5.78	2.35	5.28	0.51
946	Weir	q25	557	1081.20	1085.53	8.66	1.86	4.33	0.87
944	Pool	q25	557	1076.70	1085.58	4.51	3.11	8.88	0.30
940	Pool	q25	557	1076.70	1085.49	4.53	3.00	8.79	0.31
931	Weir	q25	557	1079.70	1084.98	5.74	2.35	5.28	0.50
928	Weir	q25	557	1079.70	1084.03	8.67	1.87	4.33	0.87
926	Pool	q25	557	1075.20	1084.17	4.39	3.13	8.97	0.29
922	Pool	q25	557	1075.20	1084.06	4.50	3.08	8.86	0.30
913	Weir	q25	557	1078.20	1083.54	5.85	2.44	5.34	0.51
910	Weir	q25	557	1078.20	1082.56	8.82	1.94	4.36	0.88
908	Pool	q25	557	1073.70	1082.74	4.47	3.26	9.04	0.30
904	Pool	q25	557	1073.70	1082.64	4.53	3.18	8.94	0.30
895	Weir	q25	557	1076.70	1082.07	6.04	2.51	5.36	0.52
892	Weir	q25	557	1076.70	1081.08	8.87	1.97	4.38	0.88
890	Pool	q25	557	1072.20	1081.01	4.63	3.09	8.81	0.31
886	Pool	q25	557	1072.20	1080.89	4.71	3.00	8.69	0.32
877	Weir	q25	557	1075.20	1080.56	5.04	2.36	5.36	0.44
874	Weir	q25	557	1075.20	1080.53	3.97	2.93	5.69	0.35
872	Pool	q25	557	1070.20	1080.57	2.99	4.59	12.26	0.18
868	Pool	q25	557	1070.20	1080.48	3.45	4.57	10.28	0.21
859	Weir	q25	557	1073.70	1080.23	4.34	3.79	6.53	0.33
616	Weir	q25	557	1061.40	1065.39	7.83	1.39	3.99	0.83
614	Pool	q25	557	1056.40	1064.83	4.27	2.50	8.43	0.30
610	Pool	q25	557	1056.40	1064.72	4.41	2.45	8.32	0.31
601	Weir	q25	557	1059.40	1064.22	5.55	1.88	4.82	0.52
598	Weir	q25	557	1059.40	1063.49	8.07	1.51	4.09	0.84
596	Pool	q25	557	1054.40	1062.79	4.57	2.59	8.39	0.32
592	Pool	q25	557	1054.40	1062.67	4.71	2.52	8.27	0.33
583	Weir	q25	557	1057.40	1062.19	5.50	1.85	4.79	0.51
580	Weir	q25	557	1057.40	1061.42	7.90	1.42	4.02	0.84
578	Pool	q25	557	1052.40	1060.61	4.67	2.44	8.21	0.33
574	Pool	q25	557	1052.40	1060.50	4.62	2.31	8.10	0.33
565	Weir	q25	557	1055.40	1060.13	4.91	1.76	4.73	0.46
562	Weir	q25	557	1055.40	1059.37	7.78	1.36	3.97	0.83
560	Pool	q25	557	1050.40	1058.74	4.38	2.46	8.34	0.31
556	Pool	q25	557	1050.40	1058.65	4.40	2.37	8.25	0.31
547	Weir	q25	557	1053.40	1058.20	5.38	1.84	4.80	0.50
544	Weir	q25	557	1053.40	1057.43	7.93	1.43	4.03	0.84
542	Pool	q25	557	1048.40	1057.03	4.24	2.69	8.63	0.29
538	Pool	q25	557	1048.40	1056.93	4.36	2.64	8.53	0.30
529	Weir	q25	557	1051.40	1056.49	5.41	2.10	5.09	0.49
526	Weir	q25	557	1051.40	1055.59	8.37	1.66	4.19	0.86
524	Pool	q25	557	1046.40	1055.25	4.47	3.04	8.85	0.30
520	Pool	q25	557	1046.40	1055.14	4.59	2.98	8.74	0.31
511	Weir	q25	557	1049.40	1054.64	5.71	2.30	5.24	0.50
508	Weir	q25	557	1049.40	1053.70	8.60	1.82	4.30	0.87
506	Pool	q25	557	1044.90	1053.79	4.65	3.20	8.89	0.31
502	Pool	q25	557	1044.90	1053.67	4.77	3.13	8.77	0.32
493	Weir	q25	557	1047.90	1053.27	5.32	2.42	5.37	0.46
490	Weir	q25	557	1047.90	1052.25	8.77	1.91	4.35	0.88
488	Pool	q25	557	1043.40	1052.27	4.75	3.23	8.87	0.32
484	Pool	q25	557	1043.40	1052.18	4.69	3.15	8.78	0.32
475	Weir	q25	557	1046.40	1051.66	5.83	2.35	5.26	0.51
472	Weir	q25	557	1046.40	1051.30	6.52	2.11	4.89	0.60
470	Pool	q25	557	1043.40	1051.20	5.97	2.55	7.80	0.43
466	Pool	q25	557	1043.40	1050.75	6.94	2.42	7.35	0.53
457	Weir	q25	557	1044.70	1050.28	5.80	2.68	5.58	0.49
454	Weir	q25	557	1044.70	1049.88	6.69	2.47	5.18	0.59
452	Pool	q25	557	1040.40	1050.06	4.20	3.81	9.66	0.27
448	Pool	q25	557	1040.40	1049.98	4.25	3.76	9.58	0.27
439	Weir	q25	557	1043.40	1049.62	5.18	3.19	6.22	0.41
429	Weir	q25	557	1043.40	1049.15	5.29	2.92	5.75	0.44

APPENDIX C:

STRUCTURE STABILITY CALCULATIONS

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Structure Buoyancy Analysis

Developed by Scott Wright, P.E. - revision 2.0

Project: Loup Loup Creek Fish Passage
Client: CTCR
Description: Buoyancy calculations for Wood and Boulder Step Pool Structure
Engineer: Chris Nelson, P.E.
Date: 9/9/2021

RDG
RIVER DESIGN GROUP

Methods:

Methodology based on a standard force balance approach and information adapted from D'aoust & Millar (2000). The designer should attain a minimum factor of safety of 2.0 for the ELJ.

The ELJ should act as a fully connected structure and all Soil Ballast should be designed against predicted scour forces.

Material schedule (per structure)

Item	Quantity	Diameter	Length	Rootwad
Category 1 Wood	4	18 - 24 in	25 ft	Yes
Boulders	40	30 - 60 in		

LARGE LOGS				**Calculated Variables**			
Number of Logs	N_L =	**4**		**Wood Volume =**	**70**	cubic feet per member	
pine, ponderosa ▼	S_L =	**0.40**	specific gravity	**F_{BL} =**	**10,541**	pounds	↑
Average Rootwad Fan Diameter	D_{RW} =	**4**	feet				
Average Rootwad Length	L_{RW} =	**1.5**	feet				
Proportion of Voids in Rootwad	p =	**0.2**	decimal %				
Tree Stem Average Diameter	D_{TS} =	**1.75**	feet				
Tree Stem Average Length	L_{TS} =	**23**	feet				

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

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MEDIUM LOGS				**Calculated Variables**			
Number of Logs	N_L =	**0**		**Wood Volume =**	**14**	cubic feet per member	
pine, ponderosa ▼	S_L =	**0.40**	specific gravity	**F_{BL} =**	**0**	pounds	↑
Average Rootwad Fan Diameter	D_{RW} =	**0**	feet				
Average Rootwad Length	L_{RW} =	**0**	feet				
Proportion of Voids in Rootwad	p =	**0.2**	decimal %				
Tree Stem Average Diameter	D_{TS} =	**0.791667**	feet				
Tree Stem Average Length	L_{TS} =	**27.5**	feet				

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

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SMALL LOGS				**Calculated Variables**			
Number of Logs	N_L =	**0**		**Wood Volume =**	**33.748**	cubic feet per member	
pine, lodgepole ▼	S_L =	**0.41**	specific gravity	**F_{BL} =**	**0.0**	pounds	↑
Average Rootwad Fan Diameter	D_{RW} =	**0**	feet				
Average Rootwad Length	L_{RW} =	**0**	feet				
Proportion of Voids in Rootwad	p =	**0.2**	decimal %				
Tree Stem Average Diameter	D_{TS} =	**1.25**	feet				
Tree Stem Average Length	L_{TS} =	**27.5**	feet				

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

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BOULDER BALLAST				**Calculated Variables**			
Specific Gravity of Boulders	S_S =	**2.65**					↓
Equivalent Diameter of Boulder	D_B =	**3.0**	feet				
Number of Boulders Submerged	$N_{B\ (SUB)}$ =	**10**		**W' =**	**1,456**	(pounds) effective weight per submerged boulder	
Number of Boulders above water level	$N_{B\ (ABV)}$ =	**0**		**W =**	**2,338**	(pounds) weight per boulder	
				Total Effective Weight for all Boulders =	**14,560**	pounds	

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

SOIL BALLAST				**Calculated Variables**			
Specific Gravity of Soil Particles	S_{soil} =	**2.65**					
Minimum Soil Dry Density	$g_{d\ min}$=	**90**	lbs/ft^3				
Maximum Soil Dry Density	$g_{d\ max}$=	**115**	lbs/ft^3				
Medium ▼	Dr =	**50%**	Percent Relative Density				
Unit Weight of Dry Soil Backfill	g_d=	**111**	lbs/ft^3				
Unit Weight of Water	g_w=	**62.4**	lbs/ft^3				
Void Ratio	e=	**0.49**					
Porosity	n=	**0.33**					
Degree of Saturation Below Water Level	S=	**100%**					↓
Weight of Pore Water	*w=*	**18.48**	lbs/ft^3				
Saturated Unit Weight of Soil Backfill	g_{sat}=	**129.48**	lbs/ft^3	**W' =**	**2,683**	(pounds) effective weight per 40 cubic feet of submerged Soil Ballast	
Buoyant Unit Weight of Soil Backfill	g'_b	**67.08**	lbs/ft^3				
Nominal Footprint Area of Soil Backfill	A_{BF}=	**40**	ft^2	(10' L x 10' W)			
Depth of Soil Backfill Submerged	Z_B =	**4**	feet	**W =**	**4,440**	(pounds) weight per 40 cubic feet of Soil Ballast	
Depth of Soil Backfill above Water Level	Z_{BU} =	**0**	feet				
				Total Effective Weight for all Soil Lifts =	**10,733**	pounds	

4

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the structure are fully submerged. In addition, the logs and boulders act as a composite structure and are assumed fully connected. Water velocity inside the structure is near zero, therefore vertical uplift forces are assumed negligible. A minimum factor of safety (F.O.S.) against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$\sum (W+W^\wedge') =$ 25,293

$\sum F\_BL =$ 10,541

$$FS_B=\frac{\sum(W+W')}{\sum F_{BL}}$$

FS_B = 2.40

Structure Sliding Analysis

Developed by Scott Wright, P.E. - revision 2.0

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Project: Loup Loup Creek Fish Passage
Client: CTCR
Description: Sliding calculations for Wood and Boulder Step Pool Structure (q25)
Engineer: Chris Nelson, P.E.
Date: 9/9/2021

Input Variables			Notes
Effective waterway area obstructed=	**30**	sq ft	*Estimated as 2' high * 15' wide*
Cross-sectional area upstream of structure (A)=	**80**	sq ft	*Minimum area from HEC-RAS*
Max Stream Velocity at structure (V) =	**8.1**	ft/s	*Maximum velocity from HEC-RAS*
Drag Coefficient (C_D) =	**1.2**		
Density of water (ρ_w)	**1.94**	slugs/ft^3	
Type of streambed sediment =	**Cobble**		*From Design*
Φ =	**38**	degrees	
Friction Factor of logs on streamebd (f) =	0.78		*Tangent of internal angle of streambed material*
B =	0.37	ft	*Eqn. 1* $B=A\_ELJ/A$
∑▒(W+W^′) = 0.8	25,293	pounds	*Sum of Effective Ballast and Soil Weight from Bouyancy Analysis*
∑▒F_BL =	10,541	pounds	*Sum of Uplift Force from Bouyancy Analysis*

Calculated Variables			Notes	
Apparent Drag Coefficient (C_D^{app}) =	3		*Eqn.1*	
Horizontal Drag Force on ELJ (F_{DB})=	5,767	pounds	*Eqn.2*	→
1.3 on ELJ (F_F)=	11,525	pounds	*Eqn.3*	←

FACTOR OF SAFETY: SLIDING

$$FS_S = \frac{\sum F_F}{\sum F_{DB}}$$

FS_S = 2.00

Sliding Factor of Safety Explanation: Based on the design factor of safety (F.O.S.) of 2 which is greater than than the desired 2.0 - 2.5, the typical Large Wood Matrix flow area obstruction is sufficiently designed to resist sliding movement due to a bankfull flood event. Note that final wood placement in the field may deviate from design.

Methods:

Calculations make several simplifying assumptions including:
1) no resistance from burial of ELJ elements
2) ELJ is a solid structure
3) frictional resistance is based on streambed material and normal force
4) ELJ is fully submerged.

Henderson pg. 420

Streambed	Φ
Boulder	40
Cobble	38
Gravel	35
Sand	25

Apparent Drag Coefficient (Eqn. 1)

$$C_D^{app} = \frac{C_D}{(1-B)^2} \; where \; B = \frac{A_{ELJ}}{A}$$

Horizontal Drag Force on ELJ (Eqn. 2)

$$F_{DB} = C_D^{app} \cdot A_{ELJ} \cdot \frac{V^2}{2} \cdot \rho_w$$

Horizontal Streambed Friction Resistance on ELJ (Eqn. 3)

$F\_F=(W^{\prime}-F\_BL-F\_LB$

Structure Buoyancy Analysis

Developed by Scott Wright, P.E. - revision 2.0

Project: Loup Loup Creek Fish Passage
Client: CTCR
Description: Buoyancy Calculations for Pool Habitat Logs
Engineer: Chris Nelson, P.E.
Date: 9/9/2021

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LARGE LOGS

				Calculated Variables		
Number of Logs	N_L =	1		**Wood Volume =**	**70**	cubic feet per member
pine, ponderosa ▼	S_L =	0.40	specific gravity	**F_{BL} =**	**2,635**	pounds ↑
Average Rootwad Fan Diameter	D_{RW} =	4	feet			
Average Rootwad Length	L_{RW} =	1.5	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	1.75	feet			
Tree Stem Average Length	L_{TS} =	23	feet			

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

30

MEDIUM LOGS

				Calculated Variables		
Number of Logs	N_L =	0		**Wood Volume =**	**14**	cubic feet per member
pine, ponderosa ▼	S_L =	0.40	specific gravity	**F_{BL} =**	**0**	pounds ↑
Average Rootwad Fan Diameter	D_{RW} =	0	feet			
Average Rootwad Length	L_{RW} =	0	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	0.791667	feet			
Tree Stem Average Length	L_{TS} =	27.5	feet			

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

30

SMALL LOGS

				Calculated Variables		
Number of Logs	N_L =	0		**Wood Volume =**	**33.748**	cubic feet per member
pine, lodgepole ▼	S_L =	0.41	specific gravity	**F_{BL} =**	**0.0**	pounds ↑
Average Rootwad Fan Diameter	D_{RW} =	0	feet			
Average Rootwad Length	L_{RW} =	0	feet			
Proportion of Voids in Rootwad	p =	0.2	decimal %			
Tree Stem Average Diameter	D_{TS} =	1.25	feet			
Tree Stem Average Length	L_{TS} =	27.5	feet			

$$F_{BL} = \left(\frac{\pi D_{TS}^2 L_{TS}}{4} + \frac{\pi D_{RW}^2 L_{RW}}{4} \cdot (1-p) \right) \cdot \rho_w g (1 - S_L) \cdot N_L$$

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BOULDER BALLAST

$$W' = \frac{\pi D_B^3}{6} \cdot \rho_w g (S_S - 1)$$

↓

				Calculated Variables		
Specific Gravity of Boulders	S_S =	2.65				
Equivalent Diameter of Boulder	D_B =	3.0	feet			
Number of Boulders Submerged	$N_{B\,(SUB)}$ =	4		**W' =**	**1,456**	(pounds) effective weight per submerged boulder
Number of Boulders above water level	$N_{B\,(ABV)}$ =	0		**W =**	**2,338**	(pounds) weight per boulder
				Total Effective Weight for all Boulders =	**5,824**	pounds

SOIL BALLAST

				Calculated Variables		
Specific Gravity of Soil Particles	S_{soil} =	2.65				
Minimum Soil Dry Density	$g_{d\ min}$=	90	lbs/ft^3			
Maximum Soil Dry Density	$g_{d\ max}$=	115	lbs/ft^3			
Medium ▼	Dr =	50%	Percent Relative Density			
Unit Weight of Dry Soil Backfill	g_d=	111	lbs/ft^3			
Unit Weight of Water	g_w=	62.4	lbs/ft^3			
Void Ratio	e=	0.49				
Porosity	n=	0.33				
Degree of Saturation Below Water Level	S=	100%				↓
Weight of Pore Water	*w=*	18.48	lbs/ft^3			
Saturated Unit Weight of Soil Backfill	g_{sat}=	129.48	lbs/ft^3	**W' =**	**0**	(pounds) effective weight per 0 cubic feet of submerged Soil Ballast
Buoyant Unit Weight of Soil Backfill	g'_b	67.08	lbs/ft^3			
Nominal Footprint Area of Soil Backfill	A_{BF}=	0	ft^2	(10' L x 10' W)		
Depth of Soil Backfill Submerged	Z_B =	4	feet	**W =**	**0**	(pounds) weight per 0 cubic feet of Soil Ballast
Depth of Soil Backfill above Water Level	Z_{BU} =	0	feet			
				Total Effective Weight for all Soil Lifts =	**0**	pounds

4

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the structure are fully submerged. In addition, the logs and boulders act as a composite structure and are assumed fully connected. Water velocity inside the structure is near zero, therefore vertical uplift forces are assumed negligible. A minimum factor of safety (F.O.S.) against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$\sum (W+W^\wedge{}') =$ 5,824

$\sum F\_BL =$ 2,635

$$FS_B = \frac{\sum (W + W')}{\sum F_{BL}}$$

FS_B = **2.21**

Methods:

Methodology based on a standard force balance approach and information adapted from D'aoust & Millar (2000). The designer should attain a minimum factor of safety of 2.0 for the ELJ.

The ELJ should act as a fully connected structure and all Soil Ballast should be designed against predicted scour forces.

Material schedule (per structure)

Item	Quantity	Diameter	Length	Rootwad
Category 1 Wood	1	18 - 24 in	25 ft	Yes
Boulders	4	36 - 60 in		

Structure Sliding Analysis

Developed by Scott Wright, P.E. - revision 2.0

Project:	Loup Loup Creek Fish Passage
Client:	CTCR
Description:	Sliding Calculations for Pool Habitat Logs (q25)
Engineer:	Chris Nelson, P.E.
Date:	9/9/2021

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Input Variables			Notes
Effective waterway area obstructed=	**30**	sq ft	*Estimated as 2' high * 15' wide*
Cross-sectional area upstream of structure (A)=	**162**	sq ft	*Average area from HEC-RAS*
Max Stream Velocity at structure (V) =	**4.4**	ft/s	*Average velocity from HEC-RAS*
Drag Coefficient (C_D) =	**1.2**		
Density of water (ρ_w)	**1.94**	slugs/ft^3	
Type of streambed sediment =	**Cobble**		*From Design*
Φ =	**38**	degrees	
Friction Factor of logs on streamebd (f) =	0.78		*Tangent of internal angle of streambed material*
B =	0.18	ft	*Eqn. 1* $B=A_{ELJ}/A$
$\sum(W+W')=$	5,824	pounds	*Sum of Effective Ballast and Soil Weight from Bouyancy Analysis*
$\sum F_{BL}=$	2,635	pounds	*Sum of Uplift Force from Bouyancy Analysis*

Methods:

Calculations make several simplifying assumptions including:
1) no resistance from burial of ELJ elements
2) ELJ is a solid structure
3) frictional resistance is based on streambed material and normal force
4) ELJ is fully submerged.

Henderson pg. 420	
Streambed	Φ
Boulder	40
Cobble	38
Gravel	35
Sand	25

Calculated Variables			Notes	
Apparent Drag Coefficient (C_D^{app}) =	2		*Eqn.1*	
Horizontal Drag Force on ELJ (F_{DB})=	1,034	pounds	*Eqn.2*	→
Horizontal Streambed Friction Resistance on ELJ (F_F)=	2,491	pounds	*Eqn.3*	←

Apparent Drag Coefficient (Eqn. 1)

$$C_D^{app} = \frac{C_D}{(1-B)^2} \ where \ B = \frac{A_{ELJ}}{A}$$

Horizontal Drag Force on ELJ (Eqn. 2)

$$F_{DB} = C_D^{app} \cdot A_{ELJ} \cdot \frac{V^2}{2} \cdot \rho_w$$

Horizontal Streambed Friction Resistance on ELJ (Eqn. 3)

$F_F=(W'-F_{BL}-F_{LB}$

FACTOR OF SAFETY: SLIDING

$$FS_S = \frac{\sum F_F}{\sum F_{DB}}$$

FS_S = 2.40

Sliding Factor of Safety Explanation: Based on the design factor of safety (F.O.S.) of 2.4 which is greater than than the desired 2.0 - 2.5, the typical Large Wood Matrix flow area obstruction is sufficiently designed to resist sliding movement due to a bankfull flood event. Note that final wood placement in the field may deviate from design.

Structure Buoyancy Analysis

Developed by Scott Wright, P.E. - revision 2.0

Project:	Loup Loup Creek Fish Passage
Client:	CTCR
Description:	Buoyancy Calculations for Floodplain Roughness Logs
Engineer:	Chris Nelson, P.E.
Date:	9/9/2021

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Methods:

Methodology based on a standard force balance approach and information adapted from D'aoust & Millar (2000). The designer should attain a minimum factor of safety of 2.0 for the ELJ.

The ELJ should act as a fully connected structure and all Soil Ballast should be designed against predicted scour forces.

Material schedule (per structure)

Item	Quantity	Diameter	Length	Rootwad
Category 2 Wood	1	6 - 12 in	25 ft	Yes
Boulders	4	36 - 60 in		

LARGE LOGS

				Calculated Variables				
Number of Logs	N_L =	0		**Wood Volume =**	70	cubic feet per member		
pine, ponderosa ▼	S_L =	0.40	specific gravity	**F_{BL} =**	0	pounds	↑	30
Average Rootwad Fan Diameter	D_{RW} =	4	feet					
Average Rootwad Length	L_{RW} =	1.5	feet					
Proportion of Voids in Rootwad	p =	0.2	decimal %					
Tree Stem Average Diameter	D_{TS} =	1.75	feet					
Tree Stem Average Length	L_{TS} =	23	feet					

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

MEDIUM LOGS

				Calculated Variables				
Number of Logs	N_L =	1		**Wood Volume =**	8	cubic feet per member		
pine, ponderosa ▼	S_L =	0.40	specific gravity	**F_{BL} =**	298	pounds	↑	30
Average Rootwad Fan Diameter	D_{RW} =	0	feet					
Average Rootwad Length	L_{RW} =	0	feet					
Proportion of Voids in Rootwad	p =	0.2	decimal %					
Tree Stem Average Diameter	D_{TS} =	0.75	feet					
Tree Stem Average Length	L_{TS} =	18	feet					

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

SMALL LOGS

				Calculated Variables				
Number of Logs	N_L =	0		**Wood Volume =**	33.748	cubic feet per member		
pine, lodgepole ▼	S_L =	0.41	specific gravity	**F_{BL} =**	0.0	pounds	↑	29
Average Rootwad Fan Diameter	D_{RW} =	0	feet					
Average Rootwad Length	L_{RW} =	0	feet					
Proportion of Voids in Rootwad	p =	0.2	decimal %					
Tree Stem Average Diameter	D_{TS} =	1.25	feet					
Tree Stem Average Length	L_{TS} =	27.5	feet					

$$F_{BL}=\left(\frac{\pi D_{TS}^2 L_{TS}}{4}+\frac{\pi D_{RW}^2 L_{RW}}{4}\cdot(1-p)\right)\cdot\rho_w g(1-S_L)\cdot N_L$$

BOULDER BALLAST

Calculated Variables

$$W'=\frac{\pi D_B^3}{6}\cdot\rho_w g(S_S-1)$$

Specific Gravity of Boulders	S_S =	2.65					↓
Equivalent Diameter of Boulder	D_B =	3.0	feet				
Number of Boulders Submerged	$N_{B\,(SUB)}$ =	0		**W' =**	1,456	(pounds) effective weight per submerged boulder	
Number of Boulders above water level	$N_{B\,(ABV)}$ =	0		**W =**	2,338	(pounds) weight per boulder	
				Total Effective Weight for all Boulders =	0	pounds	

SOIL BALLAST

				Calculated Variables				
Specific Gravity of Soil Particles	S_{soil} =	2.65						
Minimum Soil Dry Density	$g_{d\ min}$=	90	lbs/ft^3					
Maximum Soil Dry Density	$g_{d\ max}$=	115	lbs/ft^3					
Medium ▼	Dr =	50%	Percent Relative Density					4
Unit Weight of Dry Soil Backfill	g_d=	111	lbs/ft^3					
Unit Weight of Water	g_w=	62.4	lbs/ft^3					
Void Ratio	e=	0.49						
Porosity	n=	0.33						
Degree of Saturation Below Water Level	S=	100%					↓	
Weight of Pore Water	w=	18.48	lbs/ft^3					
Saturated Unit Weight of Soil Backfill	g_{sat}=	129.48	lbs/ft^3	**W' =**	1,207	(pounds) effective weight per 18 cubic feet of submerged Soil Ballast		
Buoyant Unit Weight of Soil Backfill	g'_b	67.08	lbs/ft^3					
Nominal Footprint Area of Soil Backfill	A_{BF}=	18	ft^2	(12' L x 1.5' W)				
Depth of Soil Backfill Submerged	Z_B =	1	feet	**W =**	1,998	(pounds) weight per 18 cubic feet of Soil Ballast		
Depth of Soil Backfill above Water Level	Z_{BU} =	0	feet					
				Total Effective Weight for all Soil Lifts =	1,207	pounds		

FACTOR OF SAFETY: BUOYANCY

A simplified approach is used to estimate buoyancy where the logs and ballast boulders in the structure are fully submerged. In addition, the logs and boulders act as a composite structure and are assumed fully connected. Water velocity inside the structure is near zero, therefore vertical uplift forces are assumed negligible. A minimum factor of safety (F.O.S.) against buoyancy should be 1.5 with an ideal F.O.S. greater than 2.0.

$\sum(W+W^\wedge{}') =$ 1,207

$\sum F\_BL =$ 298

$$FS_B=\frac{\sum(W+W')}{\sum F_{BL}}$$

FS_B = 4.06

Structure Sliding Analysis

Developed by Scott Wright, P.E. - revision 2.0

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Project:	Loup Loup Creek Fish Passage
Client:	CTCR
Description:	Sliding Calculations for Floodplain Roughness Logs (q25)
Engineer:	Chris Nelson, P.E.
Date:	9/9/2021

Input Variables			Notes
Effective waterway area obstructed=	**16**	sq ft	*Estimated as 2' high * 8' wide*
Cross-sectional area upstream of structure (A)=	**162**	sq ft	*Average area from HEC-RAS*
Max Stream Velocity at structure (V) =	**4.4**	ft/s	*Average velocity from HEC-RAS*
Drag Coefficient (C_D) =	**1.2**		
Density of water (ρ_w)	**1.94**	slugs/ft^3	
Type of streambed sediment =	**Cobble**		*From Design*
Φ =	**38**	degrees	
Friction Factor of logs on streamebd (f) =	0.78		*Tangent of internal angle of streambed material*
B =	0.10	ft	*Eqn. 1* $B=A\_ELJ/A$
$\sum (W+W^{\prime}) =$	1,207	pounds	*Sum of Effective Ballast and Soil Weight from Bouyancy Analysis*
$\sum F\_BL$ =	298	pounds	*Sum of Uplift Force from Bouyancy Analysis*

Calculated Variables			Notes	
Apparent Drag Coefficient (C_D^{app}) =	1		*Eqn.1*	
Horizontal Drag Force on ELJ (F_{DB})=	451	pounds	*Eqn.2*	→
Horizontal Streambed Friction Resistance on ELJ (F_F)=	711	pounds	*Eqn.3*	←

FACTOR OF SAFETY: SLIDING

$$FS_S = \frac{\sum F_F}{\sum F_{DB}}$$

FS_S = 1.60

Sliding Factor of Safety Explanation: Based on the design factor of safety (F.O.S.) of 1.6 which is greater than than the required 1.5, the typical Large Wood Matrix flow area obstruction is sufficiently designed to resist sliding movement due to a bankfull flood event. Note that final wood placement in the field may deviate from design.

Methods:

Calculations make several simplifying assumptions including:
1) no resistance from burial of ELJ elements
2) ELJ is a solid structure
3) frictional resistance is based on streambed material and normal force
4) ELJ is fully submerged.

Henderson pg. 420	
Streambed	Φ
Boulder	40
Cobble	38
Gravel	35
Sand	25

Apparent Drag Coefficient (Eqn. 1)

$$C_D^{app} = \frac{C_D}{(1-B)^2} \; where \; B = \frac{A_{ELJ}}{A}$$

Horizontal Drag Force on ELJ (Eqn. 2)

$$F_{DB} = C_D^{app} \cdot A_{ELJ} \cdot \frac{V^2}{2} \cdot \rho_w$$

Horizontal Streambed Friction Resistance on ELJ (Eqn. 3)

$$F\_F=(W^{\prime}-F\_BL-F\_LB$$

APPENDIX D:

30% DESIGN COST OPINION

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Loup Loup Creek Fish Passage Project

30% Design Cost Opinion

August 27, 2021

Step-pool Construction w/ 1.5 - 2 ft Steps

ITEM	TASK	ESTIMATED QUANTITY	UNIT	UNIT PRICE	ESTIMATE
DESIGN					**$103,000**
1	Additional Field Survey and Data Collection	1	lump sum	$ 10,700	$10,700
2	Geotechnical Investigation	1	lump sum	$ 18,000	$18,000
3	80% & Final Fish Passage Design	1	lump sum	$ 44,000	$44,000
4	Roadway Design	1	lump sum	$ 15,000	$15,000
5	Geotechnical Engineering	1	lump sum	$ 15,000	$15,000
PERMITTING					**$23,000**
1	Joint permitting, assumes HIP4 programmatic (no BA)	1	lump sum	$ 15,000	$15,000
2	BPA Reviews and Coordination, including environmental & fisheries	1	lump sum	$ 7,500	$7,500
CONSTRUCTION					**$783,000**
1	Mobilization of Construction Equipment	1	lump sum	$ 12,000	$12,000
2	BMPs: Work Area Isolation, Fish Salvage, and Control of Water	1	lump sum	$ 69,943	$69,943
3	Fire Protection Provisions	80	days	$ 285	$22,800
4	Access and Traffic Control: ~1mi. temporary access road construction, Signage	1	lump sum	$ 28,000	$28,000
5	Excavation - general	250	CY	$ 35	$8,750
6	Excavation - rock	100	CY	$ 250	$25,000
9	Streambed Fill - placed - imported	3000	CY	$ 60	$180,000
10	Streambed Fill - on-site, assumes 100% re-use of bulk excavation	350	CY	$ 15	$5,250
11	Boulders - import	1400	CY	$ 60	$84,000
12	Large Wood - import	230	CY	$ 60	$13,800
13	Step-pool construction	80	days	$ 3,000	$240,000
14	Mulching and Seeding	2	acre	$ 1,000	$2,000
15	Road Rehabilitation - Gravel	9100	lf	$ 9	$79,625
16	Demobilization and Clean-up	1	lump sum	$ 12,000	$12,000
CONSTRUCTION ADMINISTRATION					**$ 118,000**
1	Solicitation Package and Advertisment	1	lump sum	$ 6,300	$ 6,300
2	Construction Staking and Construction Surveying	1	lump sum	$ 7,690	$ 7,690
3	Construction Oversight - assumes 100% of construction period	1	lump sum	$ 104,240	$ 104,240
30% DESIGN COST OPINION				**Estimated Total**	**$ 1,030,000**
				Low Estimate -20%	**$ 820,000**
				High Estimate +30%	**$ 1,340,000**

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