Entiat River Upper Burns & Angle Point Areas Habitat Enhancement Project

Final Design Report

SUBMITTED TO
Yakama Nation Fisheries

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Table of Contents

List of Appendices

List of Figures

List of Tables

1. Introduction

1.1 OVERVIEW

This report presents engineering designs for aquatic habitat enhancement within the Upper Burns and Angle Point reach of the Entiat River in Chelan County, WA (Figure 1). This report includes support and rationale for the project design.

The purpose of this project is to enhance habitat for Endangered Species Act (ESA) listed Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss).* Property within the project area is owned by the United States Forest Service (USFS). The Upper Burns and Angle Point Areas Habitat Enhancement Project (hereafter referred to simply as the Upper Burns project) area consists of approximately 0.35 miles of the mainstem Entiat River between river miles (RM) 25.7 and 26.05, including floodplains on both sides of the river. Several historical meander scars are located on these surfaces and provide an opportunity to increase off-channel habitat area. The proposed project includes creating three perennial side channels and placing large wood structures throughout the project reach.

The lower and upper side channel improvements, along with several large wood habitat structures in the main stem Entiat River, are scheduled to be constructed in 2020. The middle side channel improvements are tentatively planned to be constructed during a future construction phase.

This project was originally identified in the Upper Stillwaters Reach Stream Corridor Assessment and Habitat Restoration Strategy (Inter-Fluve 2013). The analyses and design presented herein builds upon the conceptual (10%) level design for the Upper Stillwaters Reach (TetraTech 2018).

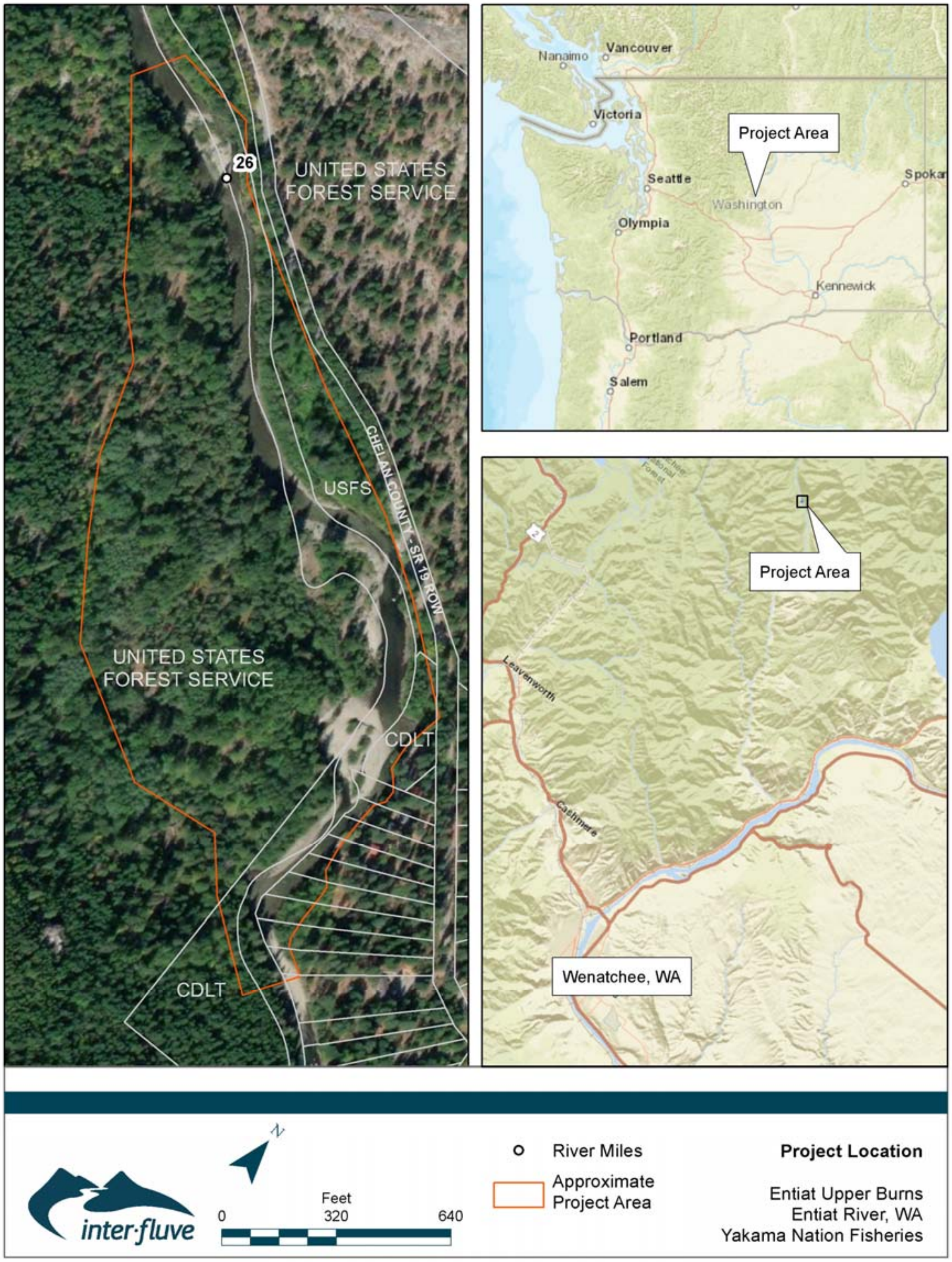

Figure 1. Upper Burns and Angle Point project area locator map.

1.2 GOALS AND OBJECTIVES

1.2.1 Regional Habitat Objectives and Priorities

Regional objectives for salmonid habitat protection and restoration in the Upper Columbia Region have been evaluated and summarized in the document *A Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region* (2017) by the Upper Columbia Salmon Recovery Board (UCSRB) Regional Technical Team (RTT). This Biological Strategy is part of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (UCSRB 2007) and recommends region-wide biological considerations and approaches for salmonid habitat restoration and protection actions. The RTT guides the development and evaluation of salmonid recovery projects within the Upper Columbia Region.

The Biological Strategy has identified four assessment units within the major watersheds of the Entiat River. The Upper Burns project area is located near the upstream extent of the Middle Entiat assessment unit, which is considered the highest priority for restoration. It is also designated as the highest priority (Tier 1) for protection (UCRTT 2017). The following ecological concerns for the Upper Middle Entiat have been identified and ranked by the RTT in priority order as follows:

1. Channel structure and form (bed and channel form)
2. Peripheral and transitional habitat (side channels, wetlands, and floodplain condition)
3. Channel structure and form (instream structural complexity)
4. Riparian condition
5. Food (altered primary productivity)
6. Sediment conditions (increased sediment quantity)
7. Injury or mortality (mechanical injury)
8. Habitat quantity (anthropogenic barriers)
9. Water quantity (decreased water quantity)
10. Water quality (temperature, turbidity, pH)

1.2.2 Upper Burns Reach Assessment

Inter-Fluve worked with the Yakama Nation in 2013 to evaluate aquatic habitat and watershed process conditions and identify habitat restoration strategies in the Upper Stillwaters Reach of the Entiat River (Inter-Fluve 2013). Geographically, the assessment covered the mainstem Entiat River corridor from Entiat Falls at RM 33.83 to RM 25.0, as well as RM 23.98 to RM 23.3. The Upper Burns project reach (RM 25.7 to RM 26.05) is situated within a 0.45-mile long segment that was designated as Reach 2 (RM 25.6 to RM 26.05). The primary deficiencies targeted for restoration in the Upper Burns reach were alterations to the riparian corridor, a lack of large wood, and limited off-channel habitat. Large wood placements throughout the reach would help to address existing wood loading and pool quantity deficiencies within the reach, while enhancing pool scour, cover, and complexity in the mainstem and existing side channels. Also, riparian restoration could help achieve species composition goals and improve structural complexity within the reach.

2. Site Conditions & Analysis

2.1 HYDROLOGY

The Entiat River watershed upstream of the project area is approximately 157 square miles in area. Mean annual precipitation in the basin is 51.3 inches (USGS 2019). The Entiat River has a snowmelt-driven hydrograph with glacier-fed low flows in late summer and peak stream flows occurring during snow melt in spring and early summer. Runoff timing and extent are affected by ambient air temperatures, snowpack mass, and the distribution of the season's snowpack. A peak flow USGS gaging station is operated on the Entiat River near Ardenvoir from 1958 to 2019 (USGS #12452800). Baseflow occurs from late September through late February (Figure 2).

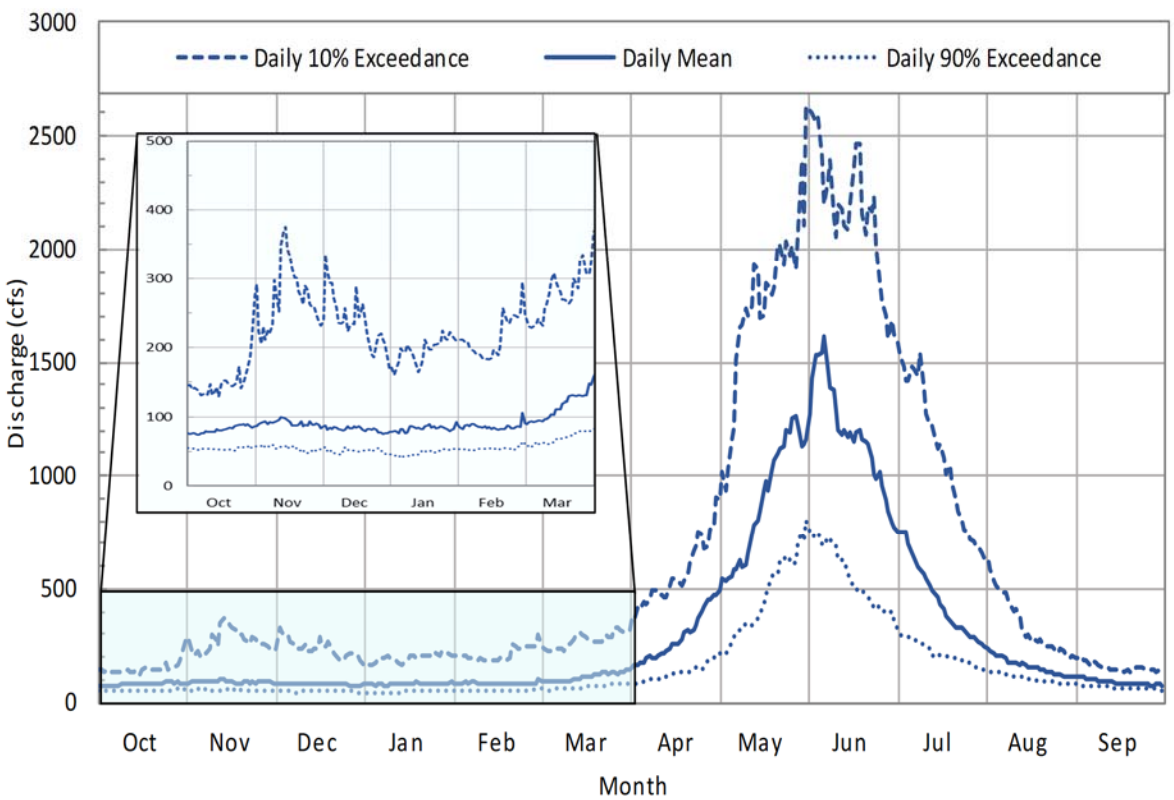

Figure 2. Daily mean, 10%, and 90% exceedances with low-flow expanded from October through March. Data derived from USGS gage at Ardenvoir (#12452800).

The United States Bureau of Reclamation (USBR 2009) performed a flood frequency analysis of the Ardenvoir gage data. Recurrence interval flows were developed using the Log Pearson Type III statistical technique for fitting frequency distribution data to help predict flood flows. These estimated peak flows were then corrected for each river mile between the mouth and RM

32. The reported recurrence interval flows for the Upper Burns project site at RM 26 are shown in Table 1. The peak flows were used in the hydraulic model to evaluate flood flows and their potential effect on nearby structures.

Table 1. Flood recurrence flows for Entiat River at RM 26 as reported by USBR.

Recurrence Interval (years)	Discharge (cfs)
2	2,540
5	3,470
10	4,090
25	4,860
50	5,430
100	5,990

To estimate base flow rates for the project reach, flow duration statistics were evaluated using mean daily flow data for the period of record at the Ardenvoir gage. Early January was found to have the lowest 95% exceedance rate at approximately 40 cfs, and this value was selected for the design of the perennial side-channels.

2.2 GEOMORPHOLOGY

2.2.1 Reach Overview

The Upper Burns reach is a low-gradient (0.48%) alluvial reach in a U-shaped valley, with active high-flow channels and point and midchannel bars active at regular high flow events (e.g. Q1 to Q5). Bars are primarily cobble, gravel, and sand, and the lack of vegetation establishment on these surfaces indicates they are scoured regularly. Bed substrate ranges from sand to boulder, and is dominated by gravel (55%), with cobble subdominant (43%). Channel units are comprised of long riffle-pool sequences. The reach meanders slightly with a sinuosity of 1.17.

The channel is currently located adjacent to the left valley wall, and has been in this general location throughout the aerial photo record (since 1945). The lower frequency of confining features such as fans have translated to a relatively large flood prone width (average 350 feet, maximum 880 feet). This floodplain has developed inset to abandoned terrace surfaces that have remnants along fan scarps on both sides of the channel. Contemporary large floods (1972 and 1945) have scoured and reworked the active floodplain surface, resulting in split flow conditions and active high flow and side channels.

Due to its low gradient and wide flood prone width, this reach provides relatively high sediment storage capacity. Coarse sediments are stored in point- and mid-channel bars and atop contemporary floodplain surfaces. This reach lacks inputs from colluvial sources relative to adjacent reaches. Rates of channel incision appear to be natural as the river continues to down-cut into valley fill deposited during periods of higher sediment input (glacial periods).

Much of the valley floor is inundated at the Q100 and many of the off-channel habitat features are active at more frequent flows (e.g. Q2). These floodplains have developed within two distinct abandoned floodplain elevations, presumably early Holocene set within late Pleistocene surfaces (Long 1951). As the channel has adjusted to its drier contemporary hydrologic regime and reduced sediment input, it has incised through these historical floodplain surfaces.

The reach has 24% pool habitat, which is created by two long pools. These pools are lacking in cover, with the exception of overhanging vegetation on the channel margins (Figure 3). The reach has relatively few pieces of large woody material at 44 pieces total; 35 of these are classified as small (6 inches DBH x 20 feet long) or medium (12 inches DBH x 35 feet long). The depositional nature and geomorphic complexity of this reach indicates that the reach historically may have had much higher wood numbers. Large wood would have likely accumulated at island apexes, throughout side channels, and on the outside of meander bends.

Channel scars visible in the floodplain suggest that the channel has historically followed a more sinuous path, utilizing the entire valley bottom throughout most of the project area (Figure 4). Historically, large log jams and old growth logs would have formed stable hard-points in the channel and along the banks, promoting an increase in split flow conditions.

The riparian canopy is intact throughout the project area except for a couple of locations where the Entiat River Road lies within the riparian zone. The floodplain is well-vegetated, providing ample hydraulic roughness across the active floodplain. The overstory is predominantly cottonwood and is dominated by shrubs/saplings (<5'' DBH). The forest throughout the reach appears to be largely in the stem exclusion phase, indicating some recent disturbance, possibly historical burning (pre-1902, 1970) and/or timber harvest.

2.2.2 Historical Change and Channel Adjustments

The Entiat River has been subject to a range of direct river channel and watershed scale disturbances starting in the late 1800's. Road building, grazing, timber harvest, riparian clearing, log drives, timber harvest, river channel large wood removal, grazing, fire, bank revetment, and development within the river meander corridor have cumulatively disrupted or altered natural processes and historical fish habitats. Much of the direct in-channel loss of habitat was likely due to large wood removal. Valley bottom clearing during logging and for agriculture removed existing large diameter standing trees that would have provided meaningful in-channel large wood habitat as the Entiat River meandered across the valley bottom.

Although much of the channel riparian area is healthy, the large cottonwood trees and valley bottom forests essential to create large complex log jams, slow bank erosion rate, create side channels and fish habitat are limited due to previous land clearing. Relative erosion appears faster on the Entiat than similar streams running within relatively un-impacted valley bottoms. It is thought this is due to both low volumes of in channel large wood jams and adjacent mature riparian forests. Both in channel and standing trees reduce bank erosion rates and both are in limited within the Entiat River (Woodsmith, 2009).

Godaire (2009) found many large Entiat River meanders cut off (avulsed) between 1962 and 1975 decreasing channel sinuosity and increasing local channel slope. Large floods in 1948 (100-year) and 1972 (50-year) likely played significant roles in channel changes (reduced sinuosity). In recent decades, changes in sinuosity have been relatively small and limited to slower lateral bank erosion which is increasing sinuosity and overtime will continue to reduce channel slope.

Current conditions show that past removal of in channel wood and clearing of valley bottom trees have both eliminated pre-existing habitat and a key tool (large trees) necessary for natural processes to recover that habitat loss naturally. Growing trees of the size necessary to create stable longer lasting naturally recovery will require significant time.

The majority of development-related alterations within the Upper Burns project area are elevated out of the active 100-year floodplain. Floodplain disturbance is limited—primarily focused in a small residential development on river-left at the downstream end of the reach (RM 25.6 to RM 25.7). Only a small amount of riparian and floodplain clearing and grading associated with this development appear to have taken place, and likely have minimal impact on channel processes. A limited amount of riparian clearing and bank armoring are associated with 220 feet of Entiat River Road along river-left near RM 25.8. The impact of the road appears to be localized, providing some accelerated scour processes, reduced hydraulic roughness, and reduced potential for large wood recruitment.

Figure 3. Aerial image of upper project reach showing lack of key wood pieces in channel.

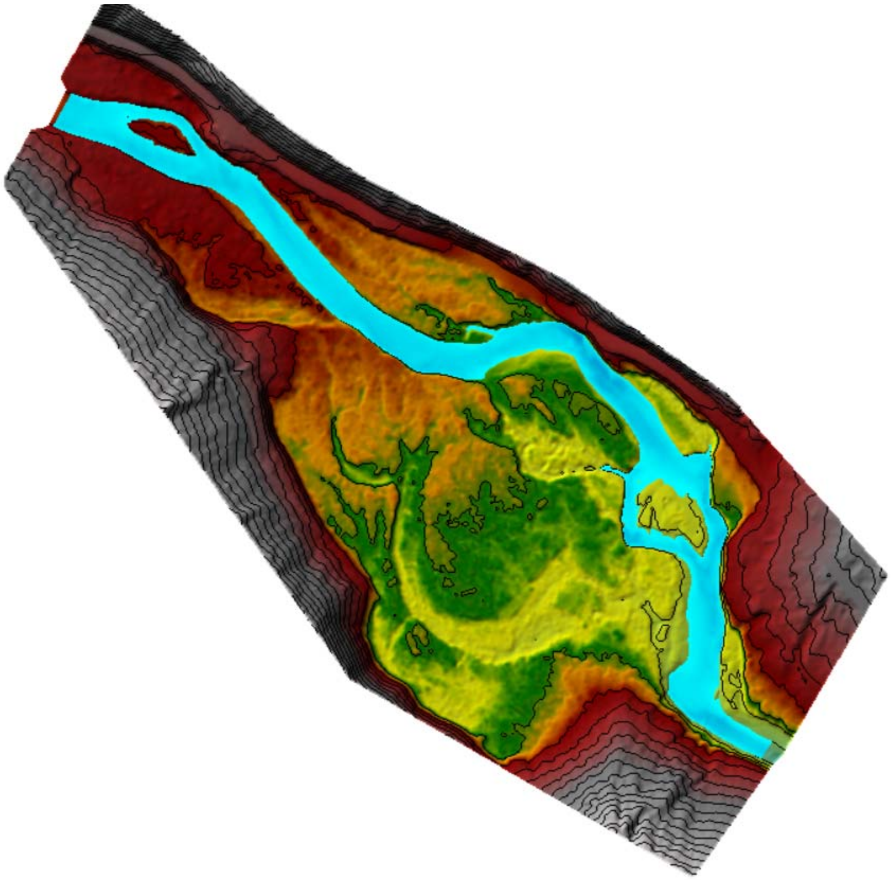

Figure 4. Existing conditions elevation map of the project area revealing meander scars on floodplain.

2.3 SUBSURFACE INVESTIGATION

Yakama Nation, Inter-Fluve and Wildlands completed six soil pits at the Upper Burns site on October 24, 2019 (Figure 5). These field investigations were completed to gather data on subsurface substrate composition and groundwater dynamics to inform project design. Pits were dug 1.9 to 3 feet below ground, and a PVC piezometer fitted with a water level logger was installed in each pit. Data from water level loggers will be included in the planning for the implementation phase as more data are available. A detailed description of each test pit is included in Appendix B. The following is a brief summary of the test pit results.

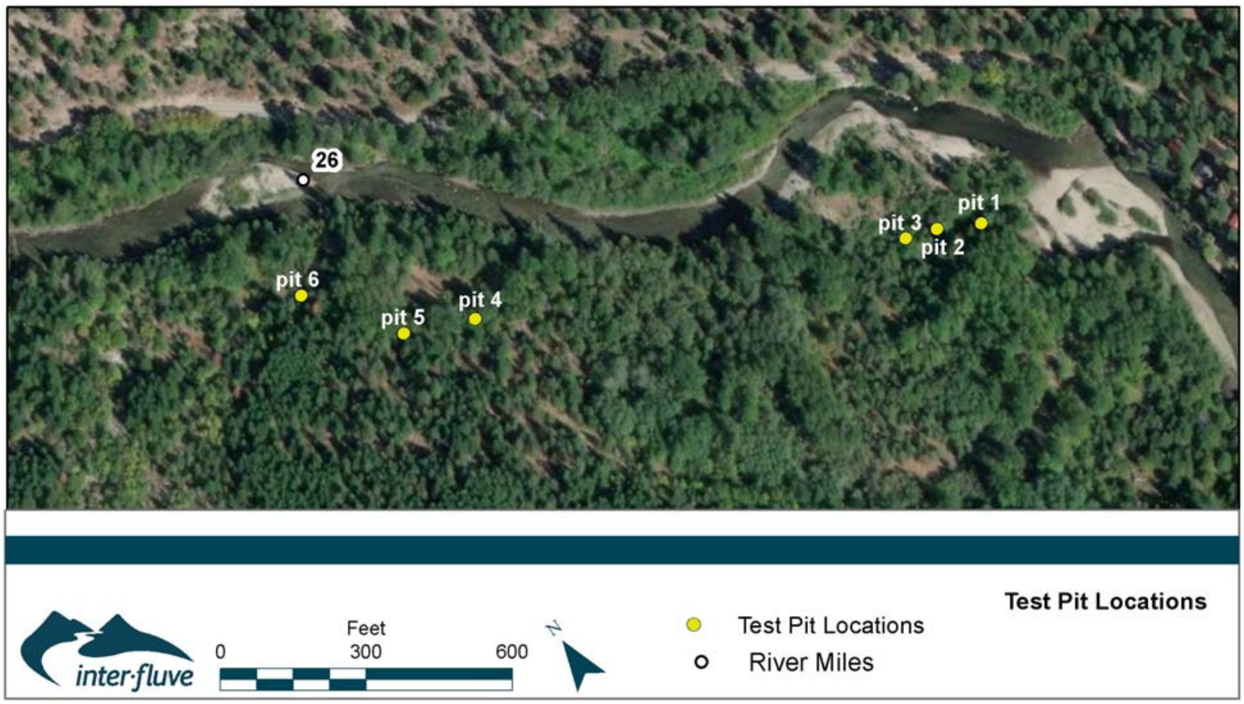

Figure 5. Location of test pits within the project area.

All the test pits were dug in the river right floodplain. Pits 1, 2, and 3 were situated along the proposed lower side channel alignment, and Pits 4, 5, and 6 were dug along the upper side channel. Floodplain silty sands were found from 1 to at least 3 feet below ground in lower side channel soil pits, and 2.6 to at least 3 feet below ground along the upper side channel. Groundwater was encountered at depths ranging from 0.8 to 1.25 feet along the lower side channel, and 1.8 to 2 feet below ground for the upper side channel. In four of the six pits, Coarse alluvium was encountered under the silty sand, and extended to the pit bottom. Alluvium was characterized as 3 to 10 inches minus cobble and gravel with some sand. In general, alluvium was encountered at relatively deeper depths in the upper side channel when compared to the lower side channel. The soil pit data was used to establish target depths for the proposed side channel excavations in order to encounter native alluvium and intercept groundwater.

2.4 FISH USE AND HABITAT CONDITIONS

The project area provides migrating, spawning and rearing habitat for endangered Upper Columbia Spring Chinook salmon, and threatened Upper Columbia steelhead and Bull Trout (Figure 6). Redd surveys have identified redds within the project area from 2003 to 2017 (Figure 7). These data suggest that this is an important spawning reach for spring Chinook Salmon, and steelhead have also been observed spawning in this area.

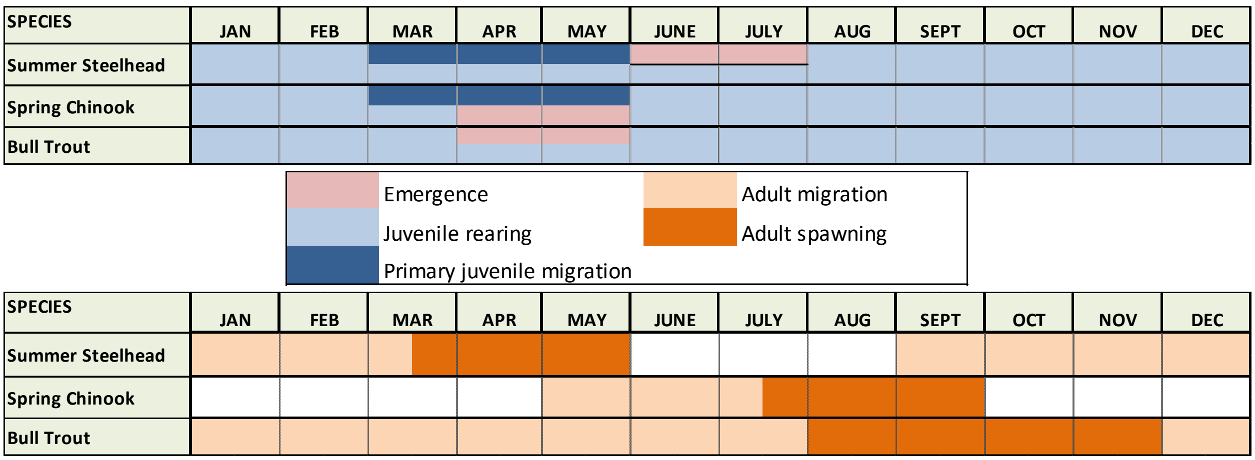

Figure 6. Life history timing of summer steelhead and spring Chinook salmon within the project area.

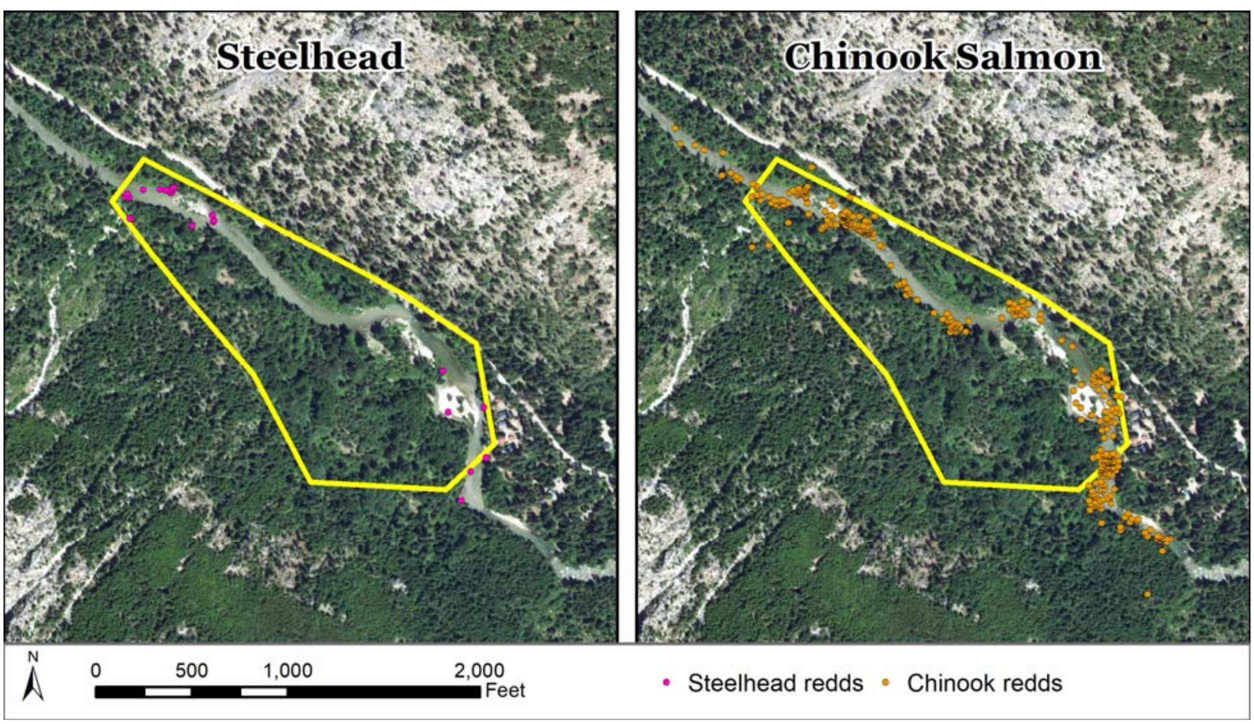

Figure 7. Steelhead and Chinook redds within the project area from 2005 to 2017 (steelhead) and 2003 to 2017 (Chinook) (UCSRB 2018).

2.4.1 Steelhead

Adult steelhead enter the Entiat basin from August through the following April, holding in deep pools with overhead cover. Spawning begins in very late March, peaks in mid to late-April, and lasts through May. Egg survival is highly sensitive to intra-gravel flow and temperature (NWPCC 2004) and is particularly sensitive to siltation earlier in the incubation period (Healy 1991). Fry emerge from the redds 6-10 weeks after spawning (Peven 2004). River flows encountered by post-emergent steelhead are highly variable. The emergence period ranges from peak flows at the end of May, to near-baseflow conditions at the end of July (Figure 8). Therefore, habitats that are inundated at a range of flows from baseflows to peak discharge are important.

Age-0 juveniles spend their first year primarily in shallow riffle habitats, feeding on invertebrates and utilizing overhanging riparian vegetation and undercut banks for cover (Moyle et al. 2002, US Fish and Wildlife Service 1995). Age-0 steelhead use slower, shallower water than Chinook Salmon, preferring small boulder and large cobble substrate (Hillman et al. 1989). Older juveniles prefer faster moving water including deep pools and runs over cobble and boulder substrate (US Fish and Wildlife Service 1995). Juveniles outmigrate between ages one and three, though some hold over and display a resident life history form. Smolts begin migrating downstream from natal areas in March (NWPCC 2004).

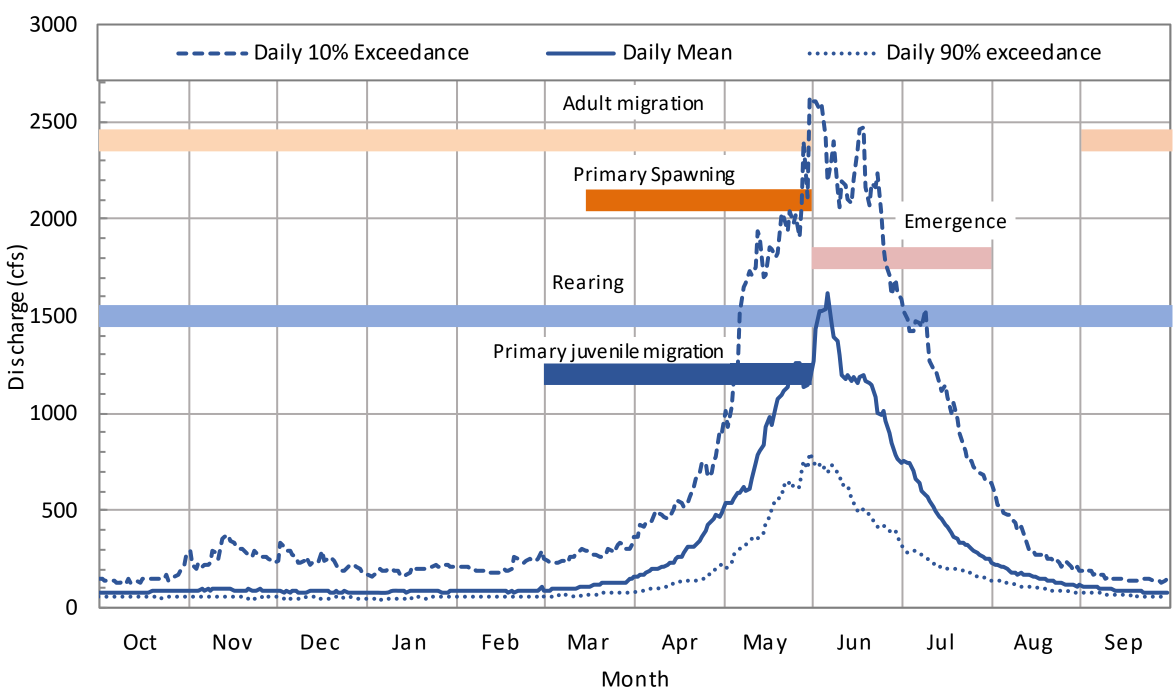

Figure 8. Steelhead life history timing and hydrology at the project site.

2.4.2 Spring Chinook

Adult spring Chinook enter the Entiat basin in May, holding in deep pools under overhead cover in the Entiat River. Spawning occurs from very late July through September with a peak in mid to late August. Spawning typically begins when temperatures drop below 16°C (NWPCC 2004). Eggs are very sensitive to changes in oxygen levels and percolation, both of which are affected by sediment deposition and siltation in the redd (Healy 1991, Peven 200).

Fry emerge in the spring, which coincides with the rising hydrograph, forcing juveniles to seek out backwater or margin areas with lower velocities, dense cover, and abundant food (Quinn 2005) (Figure 10). Because Chinook fry emerge as flows are rising, they are more likely to experience high flows compared to steelhead, which emerge on the falling limb of the hydrograph. Therefore, low velocity off-channel habitats are extremely important for these vulnerable fish that have poor swimming ability. These habitat types can include near-shore areas with eddies, large wood, undercut tree roots, and other cover, or low velocity floodplain areas, side channels, or alcoves (Hillman et al. 1989, Healy 1991).

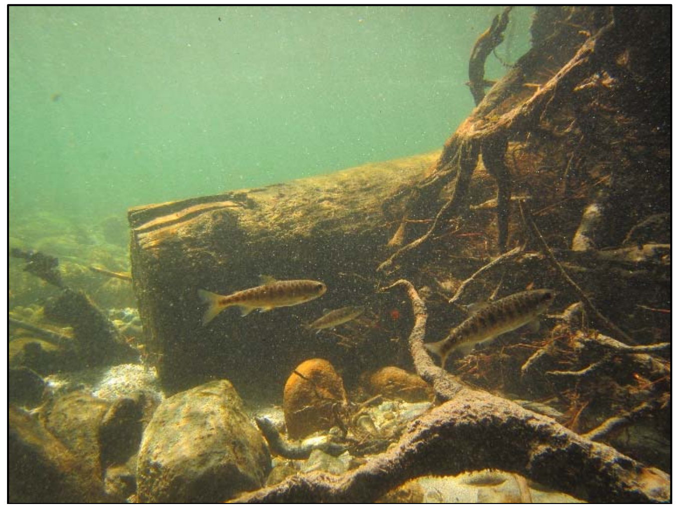

Figure 9. Chinook Salmon parr resting behind a constructed log jam in the Entiat River mainstem between feeding forays.

Age-1 parr utilize deeper pools with resting cover in mainstem habitats more than post-emergent individuals (Figure 9). Spring Chinook express a stream-type life history where they rear for 1 year in freshwater before outmigrating as yearlings. Out-migration typically begins in March (NWPCC 2004).

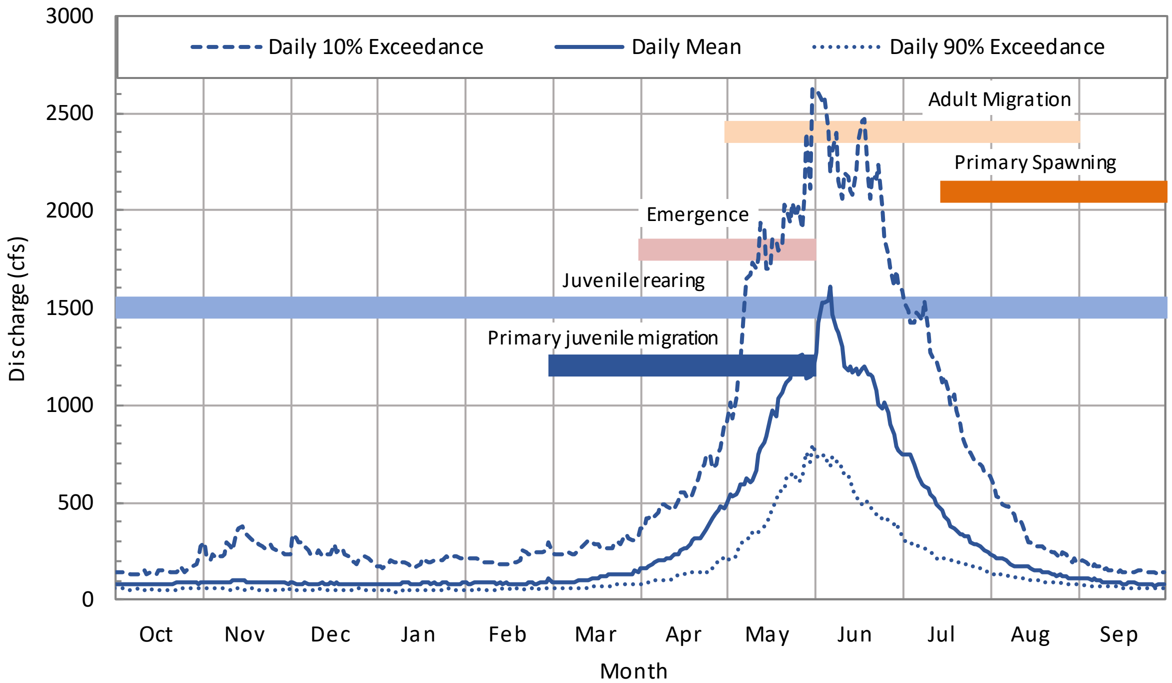

Figure 10. Spring Chinook life history timing and hydrology at the project site.

2.4.3 Bull Trout

Bull Trout spawn and rear in the upper Entiat River, while the Mad River, located downstream, supports the largest populations of Bull Trout in the Entiat Basin. Bull Trout in the Entiat basin were listed as threatened under the ESA in 1999 (US Fish and Wildlife Service 1999). Bull Trout may exhibit both resident and migratory life-history strategies (Rieman and McIntyre 1993). Resident Bull Trout complete their life cycles in the tributary streams in which they spawn and rear. Compared to other salmonids, Bull Trout have more specific habitat requirements that appear to influence their distribution and abundance. Critical parameters include water temperature, cover, channel form and stability, valley form, spawning and rearing substrates, and migratory corridors (US Fish and Wildlife Service 1999).

Bull Trout normally reach sexual maturity in 4 to 7 years and can live 12 or more years. Bull Trout typically spawn from August to November during periods of decreasing water temperatures (Figure 11). Preferred spawning habitats are generally low gradient stream reaches or in areas of loose, clean gravel in higher gradient streams (Fraley and Shepard 1989) and where water temperatures are between 5 to 9° C (41 to 48° F) in late summer to early fall (Goetz 1989). Spawning areas are often associated with cold-water springs, groundwater infiltration, and are typically the coldest systems in a given watershed (US Fish and Wildlife Service 1999). Depending on water temperature, egg incubation can last between 100–200 days, and juveniles remain in the substrate after hatching. Fry normally emerge from early April through May depending upon water temperatures and increasing stream flows (US Fish and Wildlife Service 1999).

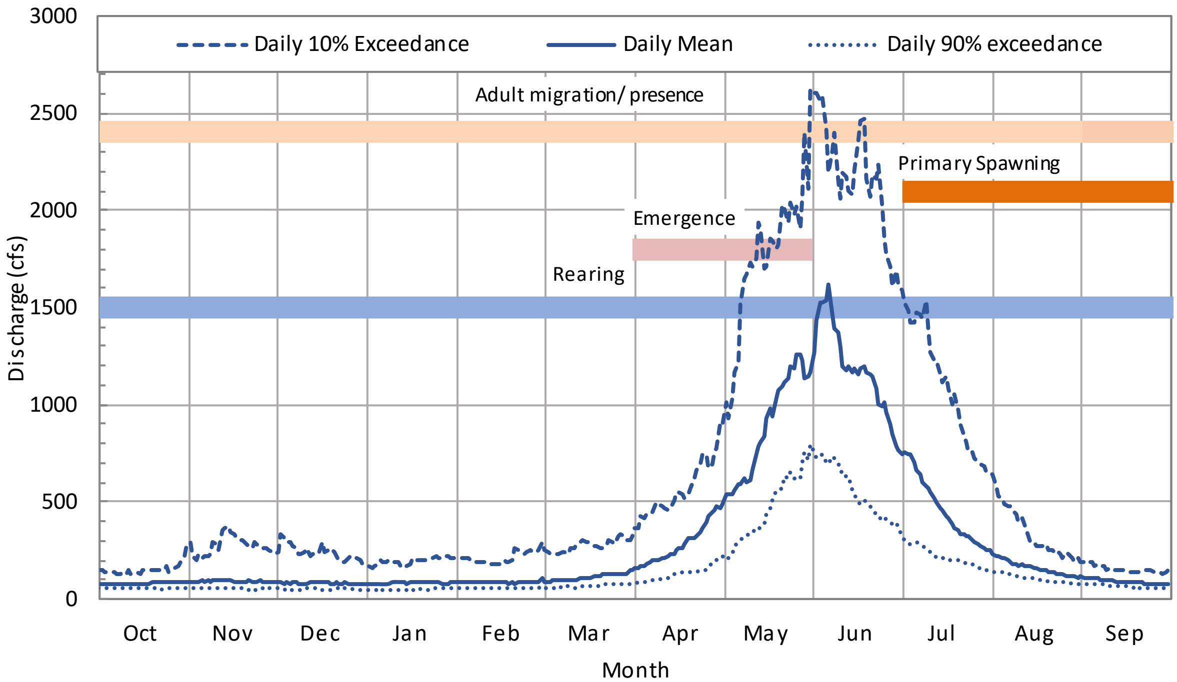

Figure 11. Bull Trout life history timing and hydrology at the project site.

2.4.4 Depth and Velocity Preferences

Depth and velocity preferences of yearling Chinook Salmon and steelhead are well studied, and will be used to develop habitat criteria for proposed off-channel habitats. Subyearling Chinook preferences were also investigated because they represent a particularly vulnerable life stage in their life cycle. Preference curves for yearling Chinook and steelhead were sourced from Instream Flow Study Guidelines, a document published by Washington Department of Fish and Wildlife and Washington Department of Ecology that combines suitability curves from multiple studies from the State of Washington into a single curve for each species/ life stage and variable (depth and velocity) combination (Beecher et al. 2016 and Beecher et al. 2002) (Figure 12). Curves for subyearling Chinook Salmon were sourced from Raleigh et al. 1986 and modified based on relevant literature (Everest and Chapman 1972, Thompson et al. 1972, Bjornn and Reiser 1991).

Depth and velocity preferences of yearling Chinook and steelhead are quite similar. Depths from 2-5 feet show the highest preference, while 0.5 feet to just under 6 feet are tolerated. Velocities of 1 foot per second (fps) showing the highest preference, while velocities from 0-3.5 fps are tolerated. Subyearling Chinook depth preferences are slightly lower, with 1-2 feet deep showing the highest preference, and 0.5-5.0 feet deep being tolerable. The suitable velocities for these fish are much lower than yearling fish, with velocities less than 0.5 fps being preferred, and up to 1.0 fps being tolerable. These criteria were utilized to design off-channel habitat features that provide suitable depths and velocities for juveniles.

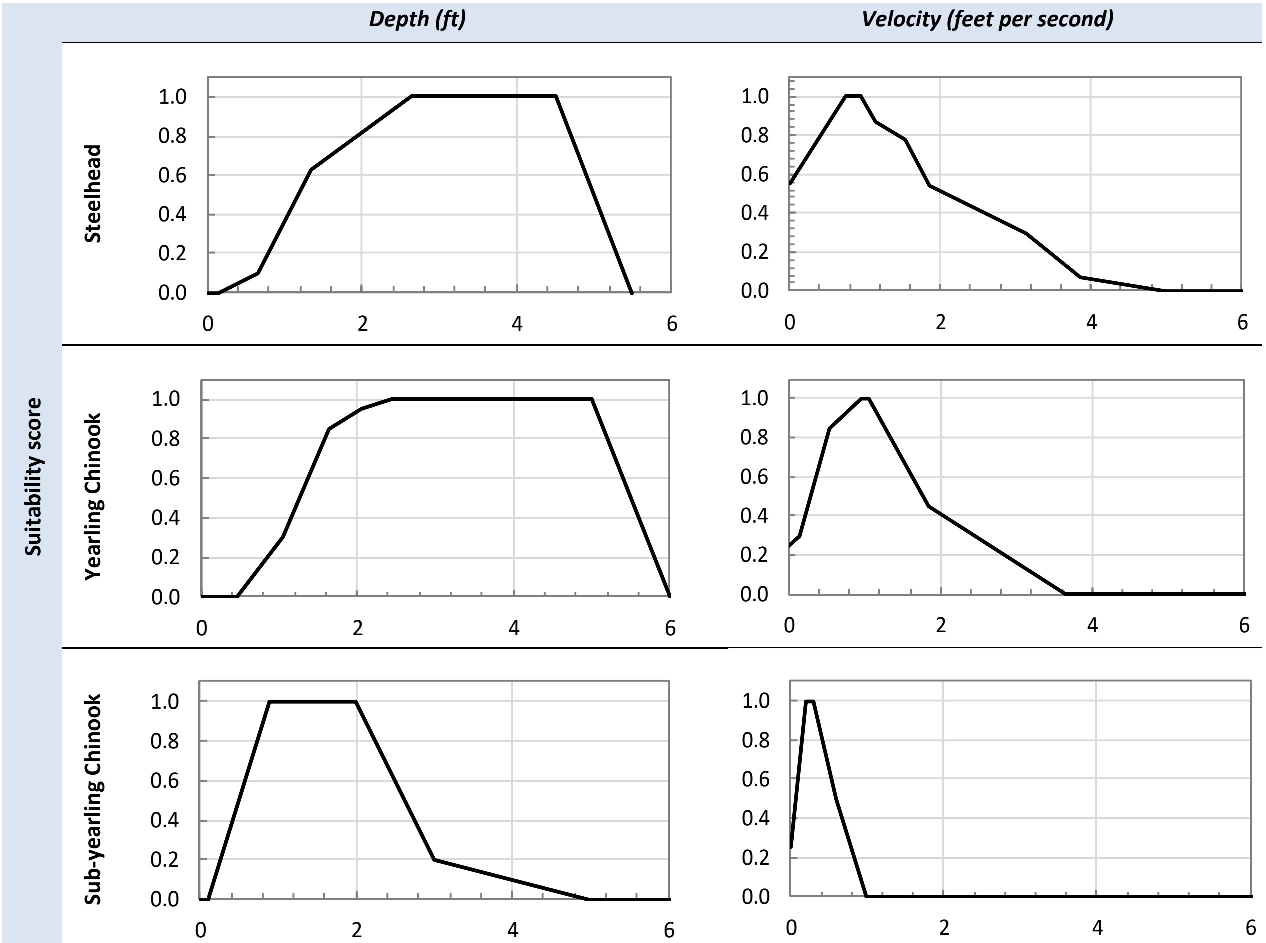

Figure 12. Suitability curves for depth and velocity of target species.

2.5 SITE SURVEY AND DATA COLLECTION

Topographic and bathymetric data were collected from October 21-22, 2019 using real time kinetic (RTK) GPS and total station survey equipment. The data collection focused on capturing topographic points in floodplain areas to inform enginering design and side channel alignment. Temporary control points were placed throughout the project site for future reference. Survey data collected by Inter-Fluve was used to verify and supplement previous topographic and bathymetric data collected by TetraTech under contract to Yakama Nation on April 5-6, 2018. Wetland and ordinary high water (OHW) boundaries were delineated by Hamer Environmental in October 2019 (Hamer 2019).

To translate the survey data to known horizontal and vertical datum, static data at the RTK GPS base station were collected and adjusted using the National Geodetic Survey's Online Positioning User Service. The surveyed data were referenced to the Washington State Plane North coordinate system with vertical datum of NAVD88.

Traditional 1-meter resolution LIDAR data were collected in 2015 for the Oregon LiDAR Consortium Okanogan Federal Emergency Management Agency (FEMA) Study (Quantum Spatial 2016). Traditional LiDAR laser pulses do not penetrate water surfaces, but rather reflect off the surface. Therefore, to produce an accurate surface for hydraulic modeling and designs, the water surface data was removed and replaced with field collected GPS bathymetric data. LiDAR data were compared against field collected points to determine if any adjustments of the data were required. The survey data was merged with the LiDAR data to provide a final surface for hydraulic modeling and design development.

3. Design Criteria

A suite of design criteria has been developed by Inter-Fluve based on conversations with Yakama Nation and based on prior experience with other projects with similar objectives. The design criteria listed below helped to guide the development of the engineering designs. Design criteria serve three primary purposes: 1) to clearly document and communicate specific project objectives and constraints, 2) to help inform and guide the design process so that objectives are met, and 3) provide a basis for future performance monitoring. The design criteria are divided into 4 categories: habitat, geomorphology/hydrology, engineering and risk, and construction impacts.

3.1 HABITAT

- Increase in-stream and floodplain habitat quality and quantity for juvenile steelhead and Chinook salmon rearing at a range of flows
- Design and build habitat elements that have a low risk of creating fish passage barriers
- Promote natural habitat forming processes to the maximum extent practicable
- Increase floodplain inundation extent and frequency

3.2 GEOMORPHOLOGY/HYDROLOGY

- Design and build channels and floodplains that are consistent with current and projected hydrologic and geomorphic regimes, including those affected by beaver activity
- Promote dynamic, habitat-forming processes
- Maintain sediment transport continuity to maximize design life and reduce sediment in-filling
- Promote sediment sorting

3.3 ENGINEERING AND RISK

- Do not increase flooding or erosion risk to Entiat River Road or privately-owned riverfront parcels along the river-left (RM 25.6 to RM 25.7)

- Provide adequate ballasting of placed logs to withstand high flows that overtop the structures (i.e. compensate for buoyancy)
- Consider recreational user safety for log jam design

3.4 CONSTRUCTION IMPACTS

- Minimize impacts to existing wetland habitat and mature vegetation
- If sensitive plants are determined to be present by a USFS botanist, the project will be adjusted to minimize impacts

4. Alternatives Analysis

4.1 ALTERNATIVES

Three general alternative strategies were considered for this project. Excerpts from the Conceptual Design Report (TetraTech 2018) are inserted below, including a description for each alternative and the recommendation of the preferred alternative.

Alternative 1 – Full Floodplain, Fish Passage and Habitat Restoration

- This alternative included restoring stream and watershed processes that create and maintain habitats and biota in an effort to return the project area to its historic and normative state as described by Beechie et al. (2010). Restoration actions under this alternative should address the root causes of degradation.

Alternative 2 – Partial Floodplain, Fish Passage, and Habitat Restoration

- This alternative considered an intermediate approach to restore or improve selected processes to partially return the project area to its historic and normative state.

Alternative 3 – Habitat Enhancement

- This alternative considers a more site-specific approach to improve the quality of habitat by treating specific symptoms such as lack of pools or large woody debris through the creation of locally appropriate habitat structures within the project area. Restoration actions under this alternative provide some local habitat improvements when more holistic process-based options are not available, or may not occur in the short term.

4.2 PREFERRED ALTERNATIVE

The selection of the preferred restoration strategy focused mainly on Alternative 1, except where existing infrastructure such as the Entiat River Road and private residences were concerned. The specific restoration actions chosen are listed below for this restoration alternative.

- Adding stable engineered log structures in the stream channel to increase pool frequency and quality, retain mobile sediment and wood to aggrade the streambed and reduce channel incision, facilitate reconnection of side channels and adjacent floodplains to increase habitat quantity and to create hydraulic diversity and dissipate energy.
- Enhance existing backwater alcoves and pools with additional large woody material instream cover.
- Improve the connectivity of existing side channels or create new side channels and increase high flow relief.
- Plant all disturbed areas with native vegetation that are currently deficient and as well as those impacted by the proposed restoration strategy alternative.

4.3 PROJECT RATIONALE

It is advantageous to do this project now rather than later due to design funding assurances as well as landowner willingness and alignment with their goals and objectives for the proposed project area. Additionally, funding this action would help support the restoration that was already completed by the Yakama Nation in 2017; thereby creating a more contiguous restoration corridor.

Currently the Yakama Nation has funding in place to further the conceptual designs for this project through final stamped plans as well as provide the construction oversight during the actual implementation. Additionally, revegetation costs will also be incurred by the Yakama Nation. The Yakama Nation has a financial agreement in place with the USFS.

Lastly, the project aligns closely with the goals and objectives of the USFS and the Yakama Nation has been given assurances that projects of this scope and scale will fit into the overarching environmental analysis for that agency and for this region.

This project area was identified in the Upper Stillwaters Reach Stream Corridor Assessment and Habitat Restoration Strategy (Inter-Fluve 2013) in the project spreadsheet. Distinct restoration segmented areas were identified and the Yakama Nation has been working with the USFS to implement stretches of the identified restoration corridor. Approximately five geomorphically distinct project areas were identified in the restoration strategy. The proposed project area lies within the lower most reach of restoration.

Additionally, the Yakama Nation Fisheries is focused on implementing science-based restoration projects in the Upper Columbia Basin that benefit ESA-listed fish species. This project is in support of that mission as well as following the habitat restoration priorities and areas as outlined in the Upper Columbia Spring Chinook Salmon, Steelhead Recovery Plan (UCSRB 2007), the Entiat River Subbasin Plan (NWPPC 2004) as well as the Revised Biological Strategy to Protect and Restore Salmonid Habitat in the Upper Columbia Region (UCRTT 2017).

5. Hydraulic Modeling

5.1 METHODOLOGY

A two-dimensional (2D) hydraulic model was developed in the U.S. Army Corps of Engineers HEC-RAS 5.0.7 software (USACE 2019), which can compute hydraulic properties related to the physical processes governing water flow through natural rivers and other channels. Models were developed for both existing and proposed conditions to assess the current and proposed channel/ dynamics, as well as assess the overall impacts of a wide range of flows on the existing landscape with and without the proposed design improvements.

5.2 MODEL INPUTS

The model terrain was created by combining 2015 LiDAR data with topography and bathymetry obtained through the surveys completed in April 2018 by TetraTech and October 2019 by Inter-Fluve. The proposed conditions model terrain was constructed by merging design grading and features with the existing model terrain.

The extent of bathymetric data for the mainstem Entiat River informed the model domain, which extends from approximately 85 feet upstream of the upper side channel inlet to approximately 750 feet downstream of the lower side channel outlet. The computational mesh consists of grid cells ranging from 10-20 feet, with the smallest grid cells utilized to provide higher resolution results at key design locations. Breaklines were added along topographic high points to align cell faces along high ground and to appropriately represent the underlying terrain.

A spatially varying hydraulic roughness layer was developed to represent the impacts of land cover and bedforms on the hydraulic properties of flow throughout the computational domain (Figure 13). Land cover was classified with respect to characteristics that relate to hydraulic roughness, and corresponding Manning's n coefficients were assigned to the classifications. Manning's n values ranged from 0.02 for road surfaces to 0.065 for sparse vegetation and rural residential, with a river channel coefficient of 0.035 and floodplain coefficients ranging from 0.06 for the side channel to 0.08 for forested (Arcement and Schneider 1989). Vegetated bars were given a 0.05 roughness coefficient. Proposed Large Wood Structure locations were modeled using Manning's override regions with a 0.2 – 0.3 roughness coefficient.

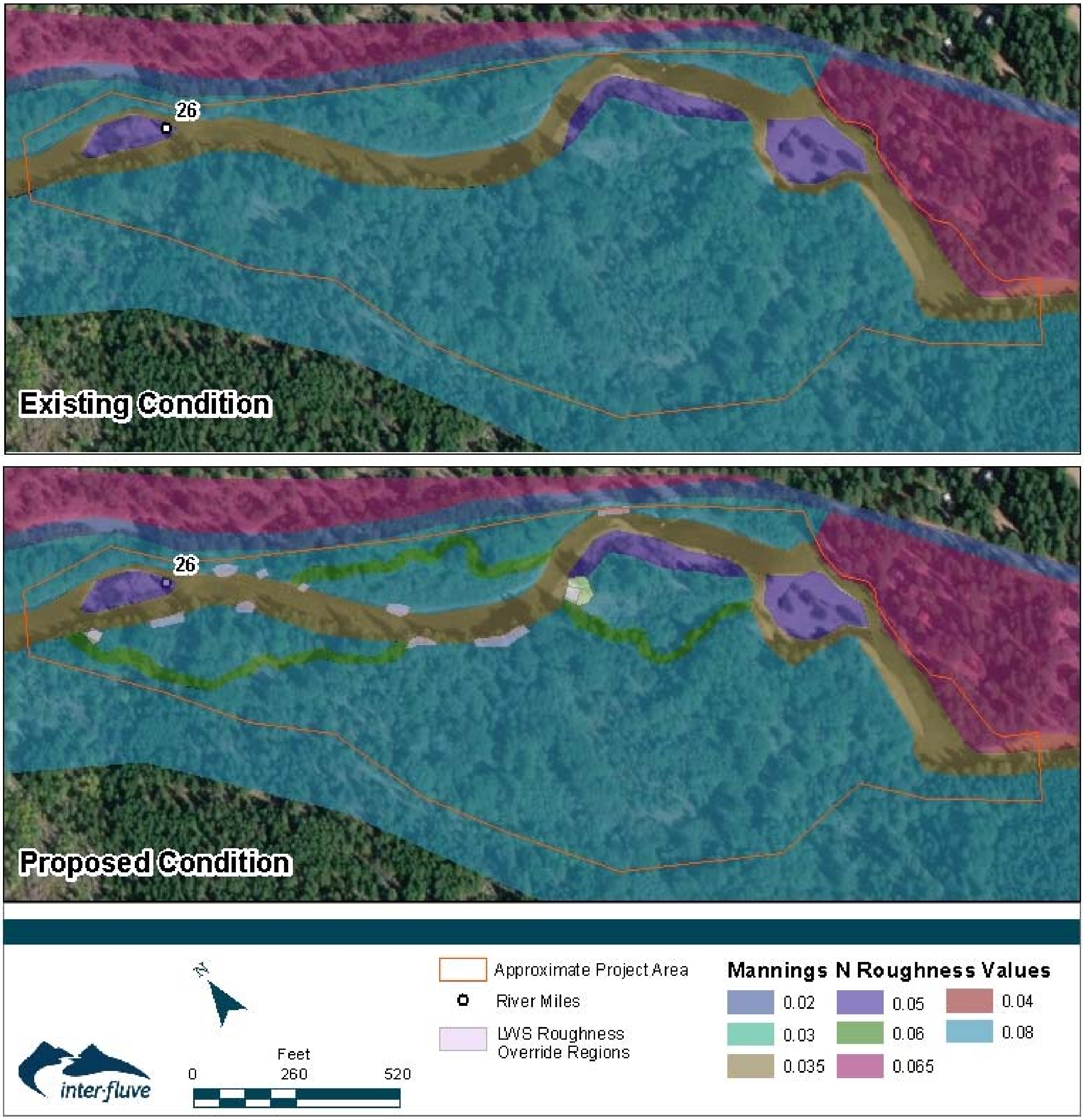

Figure 13: Manning's roughness values used in hydraulic modeling.

Boundary conditions representing inflow/outflow from the model domain consisted of an input flow hydrograph at the upstream end and normal depth at the downstream end. A synthetic "stepped" hydrograph that contains gradual rising limbs between discharges of interest (e.g., 100-year flow) was used as the input hydrograph to simulate steady-state flow conditions (Figure 14). The discharges of interest remain unchanged for long enough to allow the model to reach a steady-state, before rising to the next step. It's worth noting that allowing the model to reach a steady state during large flood events may overestimate flooding results, as floodplain storage throughout the model domain must reach capacity to reach steady-state conditions, which in reality may not occur during actual floods, especially short duration events. The receding limb of a typical flood hydrograph is also not represented when using this methodology. Modeled flows events were taken from USBR flood frequency estimates for the Entiat river at mile 26 (USBR, 2009) and from observed base flow and low flow conditions

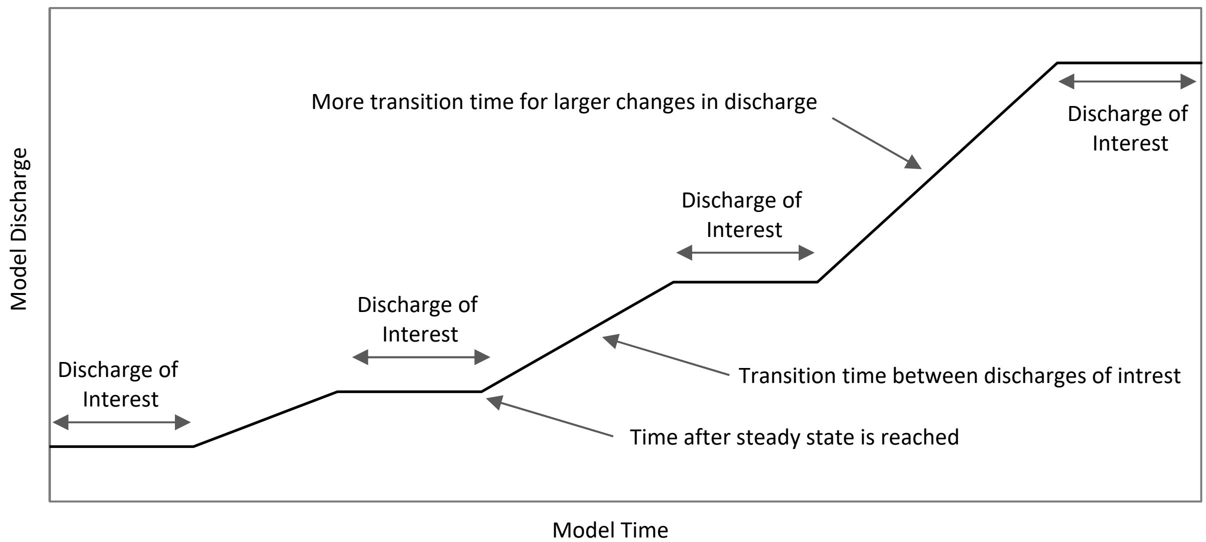

Figure 14: Demonstrative "stepped" flow input hydrograph.

The hydraulic models were used to evaluate existing and proposed conditions at key design flow events ranging from base flow events (40-80 cfs) to the 100-year event (Table 2). Existing conditions hydraulics were used to understand the hydraulics of the pre-project conditions at various flow rates, such that project elements could be designed to achieve desired hydraulic conditions.

The downstream boundary condition (flow out of the model domain) was set as normal depth, with an assumed friction slope of 0.007 ft/ft, which was approximated from the topographic slope at the downstream end of the reach. The boundary condition points were placed as far as possible away from the project area to dampen the effects of any uncertainties associated with the boundary specifications and assumptions.

Table 2: Modeled flow events used in hydraulic modeling.

Discharge (cfs)	Flow Event
40	Base Flow
60	Low Flow 1
80	Low Flow 2
200	Low Flow 3
500	Low Flow 4
1,110	1 - year
2,370	1.5 - year
2,540	2 - year
3,470	5 - year
4,090	10 - year
4,860	25 - year
5,430	50 - year
5,990	100 - year

5.3 EXISTING CONDITIONS HYDRAULICS

Existing conditions hydraulic outputs for velocity can be observed in Appendix A: Hydraulic Model Results. These figures illustrate minimal floodplain connectivity in the upper and middle sections below the 2-year event. In the lower region of the project area, a relic side channel is activated at the 1.5-year event (2,370 cfs). The 100-year event shows extensive floodplain activation. Existing conditions modeling also shows that the river remains contained in the channel on river left in the downstream reach where private property abuts the river. While the hydraulic model does not show flow connecting around the right side of the lower island across from the private property parcels, field survey observations confirm that there is minimal connectivity. This flow is likely hypoheric and thus can not be detected by the model. At lower flow events (40 cfs – 200 cfs), velocities mostly remain below approximately 4 ft/s with some hot spots observed up to approximately 6 ft/s.

5.4 PROPOSED CONDITIONS HYDRAULICS

Proposed designs were iteratively adjusted until the model demonstrated that project features were functioning as desired. Key design criteria for project functionality consisted of:

- Adequate flow distribution between the main channel and side channels. Less than 20% of the total flow volume will be conveyed in the proposed side channels for events up the bankfull discharge (conservatively estimated as the 2-year flood for this analysis)
- Maintain connectivity of side channels during base flow events
- Maintaining consistent flood elevations and innundation extents for surrounding private property during the 100-year flood event between existing and proposed conditions.

The proposed conditions hydraulic model results also was used to inform additional engineering analyses such as channel sizing, channel bed and bank stability calculations, and large wood structure stability calculations.

The existing conditions models were modified, as appropriate, to represent the proposed side channel design features and some large wood structures. In general, the proposed conditions model results demonstrate that the design adds habitat complexity at low to moderate flows. For instance, when compared to existing conditions, the model of the proposed enhancments suggests the area of inundation and hydraulic suitability for rearing juvenile salmon increases substantially at base flows.

Analysis of flow partitioning between the mainstem Entiat River and the proposed side channels show that each side channel conveys less than 20% of the total flow volume (Table 3).

***Table 3:** Flow Distribution at flow events up to the 2-year discharge.*

Flow event	Percentage of Total Flow in Side Channel		
	Lower Side Channel	Middle Side Channel	Upper Side Channel
40 cfs	8.4%	1.1%	0.3%
60 cfs	9.4%	2.9%	0.5%
80 cfs	9.6%	4.1%	0.9%
200 cfs	9.2%	6.5%	2.6%
500 cfs	9.4%	7.5%	4.6%
1,110 cfs (Q1)	10.1%	8.3%	5.7%
2,370 cfs (Q1.5)	11.7%	10.2%	6.6%
2,540 cfs (Q2)	12.0%	10.8%	6.7%

Proposed conditions velocity maps are paired with corresponding existing conditions flow event and can be seen in Appendix A. According to the hydraulic model, proposed side channel design for upper, middle and lower alignments remain active at base flows as low as 40 cfs. Additionally, the proposed 100-year event remains contained in the channel along the river left downstream portion of the project area, as is seen in existing conditions.

Velocities in the proposed upper side channel remain at or below 1 ft/s up to the 80 cfs flow in the main stem Entiat River (Figure 15). As discussed in Section 2.4.4, this velocity has been determined to be highly suitable for sub-yearling Chinook, Yearling Chinook, and Steelhead. The middle side channel shows velocities below 1 ft/s up to 60 cfs. At 80 cfs, velocities are found to increase up to 2 ft/s in places in this proposed side channel (Figure 16). The lower side channel maintains velocities below 1 ft/s along the channel margins and up to 2 ft/s in places up to the 80 cfs flow event (Figure 17). At the 2-year flow event, velocities in all three proposed side channels increase up to 4 ft/s in locations, while also maintaining velocities below 2 ft/s along the margins.

It should be noted that the proposed conditions hydraulic model does recognize slower moving pockets of water within pools or behind individual logs placed as part of this project. These features are expected to further increase habitat suitability for salmonids.

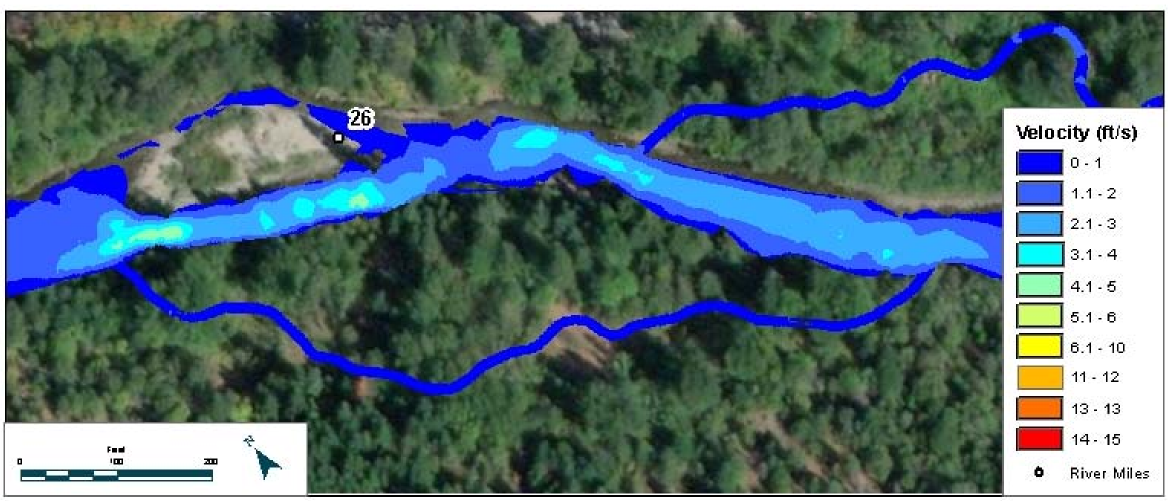

Figure 15: Proposed upper side channel velocities at the 80 cfs flow event.

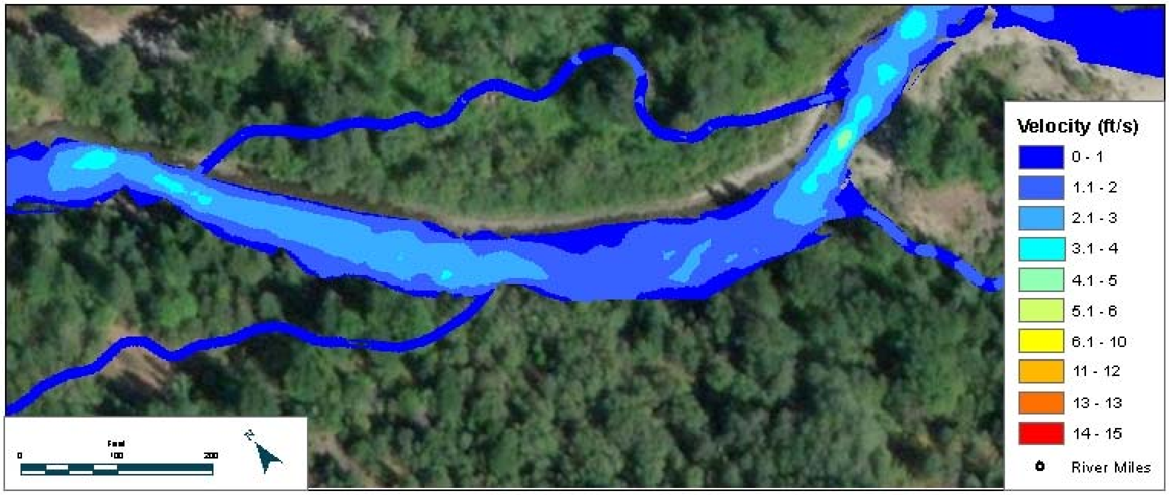

Figure 16: Proposed middle side channel velocities at the 80 cfs flow event.

Figure 17: Proposed lower side channel velocities at the 80 cfs flow event.

6. Project Design

Previously discussed site conditions, analyses, and design criteria were used to inform the engineering design discussed below. The design evolved based on additional stakeholder feedback and the availability of new information. The proposed project includes creating perennial and high flow side channels in the floodplain and placing large wood structures throughout the main stem, side channels, and floodplain.

6.1 PERENNIAL SIDE CHANNELS

6.1.1 Description and Benefits

A perennial side channel is a flow-through side channel connected to the mainstem that will flow year-round. The side channel will provide additional stream margin and low velocity conditions, which in combination with pools and woody debris, will provide habitat for Chinook salmon and steelhead. Fish use these types of habitats to search for food, to rest, and to avoid predators. Construction includes excavation to form the channel and pools, placement of logs, and management of the surrounding vegetation.

6.1.2 Application

Three perennial side channels (referred to as the lower, middle, and upper alignments) are proposed within the Upper Burns and Angle Point reaches. The inlet to each perennial side channel will typically be located near the downstream end of river meanders and at elevations slightly higher than the river thalweg. Each selected side channel alignment follows an existing floodplain scar for at least a portion of its length to minimize excavation quantities and riparian impacts.

The lower side channel is approximately 600 feet long and is situated on river-right within an existing overflow channel. The 775-foot-long middle side channel is proposed on river-left and follows a shallow existing depression with limited existing floodplain connectivity. The upper side channel alignment hugs the steeper hillslope on the right floodplain and will pass 950 feet through a more mature forest. Natural depressional channels branch off the lower and upper alignments during the 1-year peak discharge event and will further encourage wetland formation and habitat diversity.

An apex-style log jam is proposed at each side channel inlet to help maintain the inlet depth via scour and to constrict the mainstem cross-section to encourage flow to enter the side channel. Log placements and structures are proposed throughout the side channels for added channel complexity and diversity, similar in the configuration shown in Figure 18. Pools and riffles will be graded into the side channel to increase habitat and geomorphic complexity. Pools will be associated with log structures to help maintain pool scour and complexity.

Figure 18: Example of off-channel habitat with large wood placements | Chewuch River Right Project, WA

6.1.3 Considerations

Excavation of these features will impact approximately 0.30 acres of existing wetland. The risk of main channel capture will be addressed through roughness features and large wood structure placements. To the extent feasible, the channel bed is designed to be deep enough to both encounter underlying alluvium material and intercept groundwater throughout much of the year. If alluvium is not encountered during excavations, coarse substrate will be placed.

6.2 LOG STRUCTURES

6.2.1 Description and Benefits

Log placements include a variety of different enhancement types. The different log structure types, and their purpose/benefits are described in Table 4.

6.2.2 Application

Log placements will be stabilized through a range of techniques to discourage mobility along the project reach. Large wood structures and placement types are described in detail in Table 4. Wood will be stabilized using burial or through installation of vertical timber plies driven into the ground. Slash will be incorporated in wood structures for added complexity. Typical sections and details are included on the drawings, although it will be necessary to conform these typical approaches to the specifics of each installation location at the time of construction.

Table 4. Matrix of design considerations of large woody material (LWM) structures proposed in the designs.

Type	Location	Purpose/Application	Structural/Physical Characteristics	Site Specifics
Side Channel Inlet Log Structure	Main Channel	Large accumulations of LWM to create immobile channel margin elements that force channel redirection into side channel inlet. Designed to help maintain interface between main channel and lateral habitats, ensuring <20% of main channel flow is captured to prevent overbank avulsion.	Layered installation of 16 or 17 logs and logs with rootwads spaced around vertical snags. Ballasted via threaded rod attachment to vertical snags, and addition of boulders and backfill. Includes one whole tree with rootwad for added ballast and cover.	Apex jam type structure will be placed at the flow inlets of the side channels. Pools will be excavated at structure locations during construction using a fit-in-the-field approach. Spoils will be placed to create riffle and bar features local to the structures.
Buried Bank Structure – Types 1 & 2	Main Channel	Banks of side channel inlet defined by LWM, utilized to constrain inlet and discourage degradation of banks / bed in the area of the side channel inlet. Can be tied into an adjacent inlet logjam.	Installed with rootwads primarily facing flow to discourage bank erosion. Ballasted via partial burial and vertical snags. Structures consist of 13 to 45 logs.	Structures will be placed at bank margins periodically throughout the constructed side channel and at outer bends of the mainstem. One large structure will be constructed at the outlet of the Upper Side Channel.
Side Channel Habitat Wood	Side Channel Margins	Moderate accumulations of LWM placed along margins of side channels, partially-submerged, and projecting into pools to create cover and habitat diversity.	Ballasted via partial burial of key members and vertical snags. Small placements consist of 4-8 logs; large structures will consist of up to 15 logs.	Smaller structures will be placed along straighter segments. Larger structures will be placed at the most acute bends of the side channel.
Floodplain LWM	Floodplain and Overbanks	Small accumulations of LWM oriented normal to overbank flow paths to create roughness, slow floodwaters, and stabilize floodplain along overbank flow paths.	Generally horizontally oriented LWM spaced around and braced against vertical snags. Ballasted with vertical snags.	These placements will range in size and configuration, but will generally consist of slash and salvaged logs. They will be placed within the cut-off paths to provide hydraulic roughness expected from natural wood accumulations.

6.2.3 Considerations

Localized impacts to flood water elevations have been considered on a case-by-case basis, and the size of habitat wood structures has been modified accordingly. Structures have been designed to minimize the potential for displacement during high flows according to location-specific risk assessments. Consideration of the mobility and longevity of placed wood has been carefully assessed and incorporated into the projected design life of the project. The installation of bumper logs may be considered to address potential boater safety concerns.

6.3 FLOODPLAIN COMPLEXITY

6.3.1 Description and Benefits

Floodplain wetlands evolve within river systems to accommodate high flows, slow floodwaters, and provide refuge habitat for aquatic species. Encouragement of the natural processes that form these features can be accomplished through mimicking the roughness of a pre-human-disturbance floodplain and lowering surfaces to become inundated at more frequent flows. Enhanced and reconnected floodplain surfaces will:

- Increase residence time of floodwaters
- Encourage sediment and nutrient cycling
- Reduce high flow velocities
- Provide nutrient-enriched floodwater that returns to the channel
- Raise and/or maintain a higher water table for longer duration enabling improved plant root access to the water table during summer months

6.3.2 Application

Floodplain complexity will be incorporated into this project as the addition of topographic complexity (or microtopography), floodplain hydraulic roughness wood placement, and native plantings in floodplain areas. These floodplain enhancement measures will provide numerous benefits to the main channel of and constructed side channels to the Entiat River, as well as balance any potential impacts to wetlands within the project area. This design element will recreate conditions identified elsewhere at the site that promote and sustain wetland and riparian growth.

6.3.3 Considerations

Floodplain enhancement through the placement of roughness features has been proposed only in locations that are relatively frequently inundated (e.g., Q2 to Q5) and in the vicinity of other proposed enhancement actions to limit riparian impacts. Roughness logs will be pinned to vertical snags and between standing trees.

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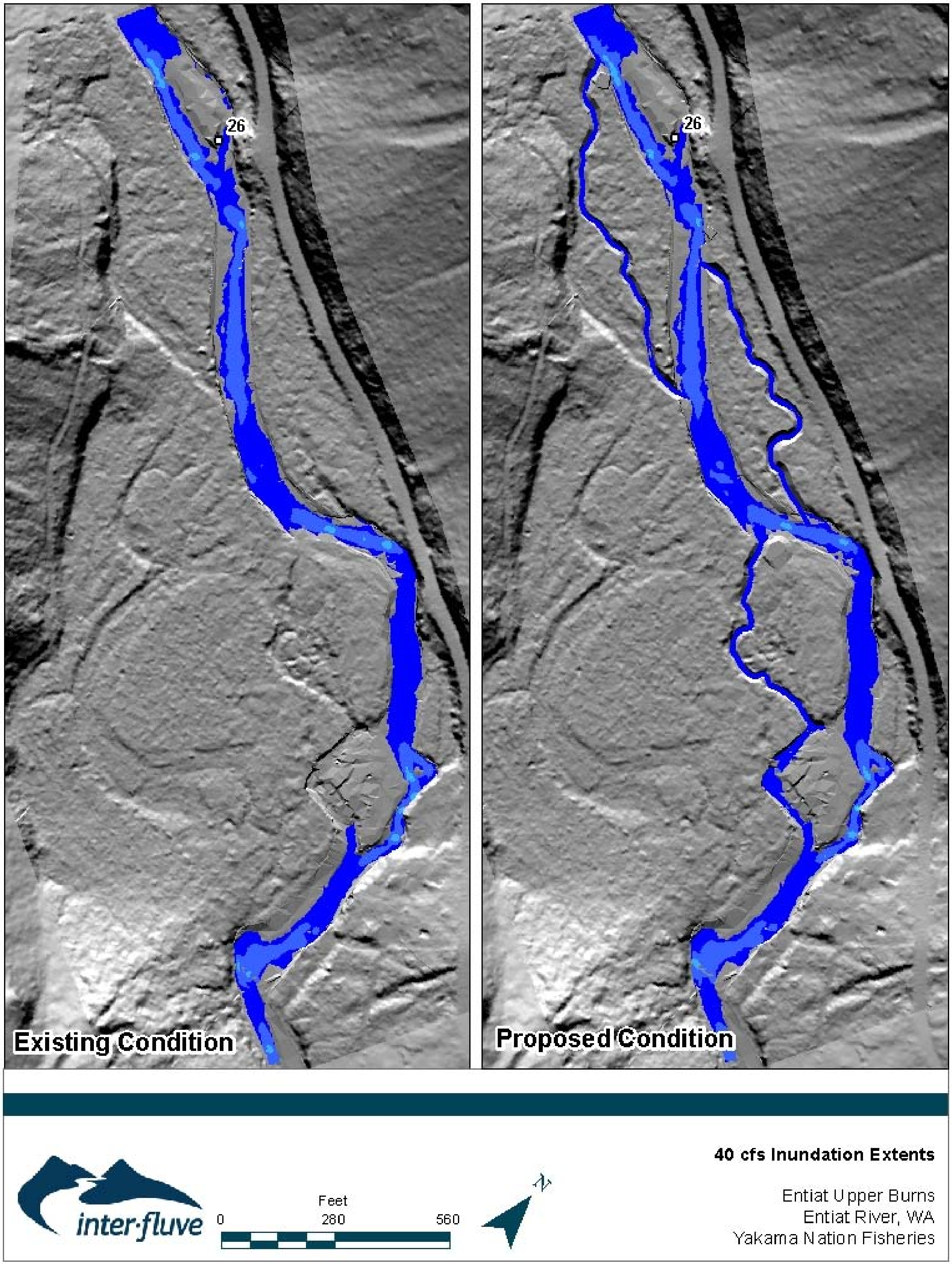
Appendix A – Hydraulic Model Outputs


26
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Existing Condition
Proposed Condition
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Yakama Nation Fisheries
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560
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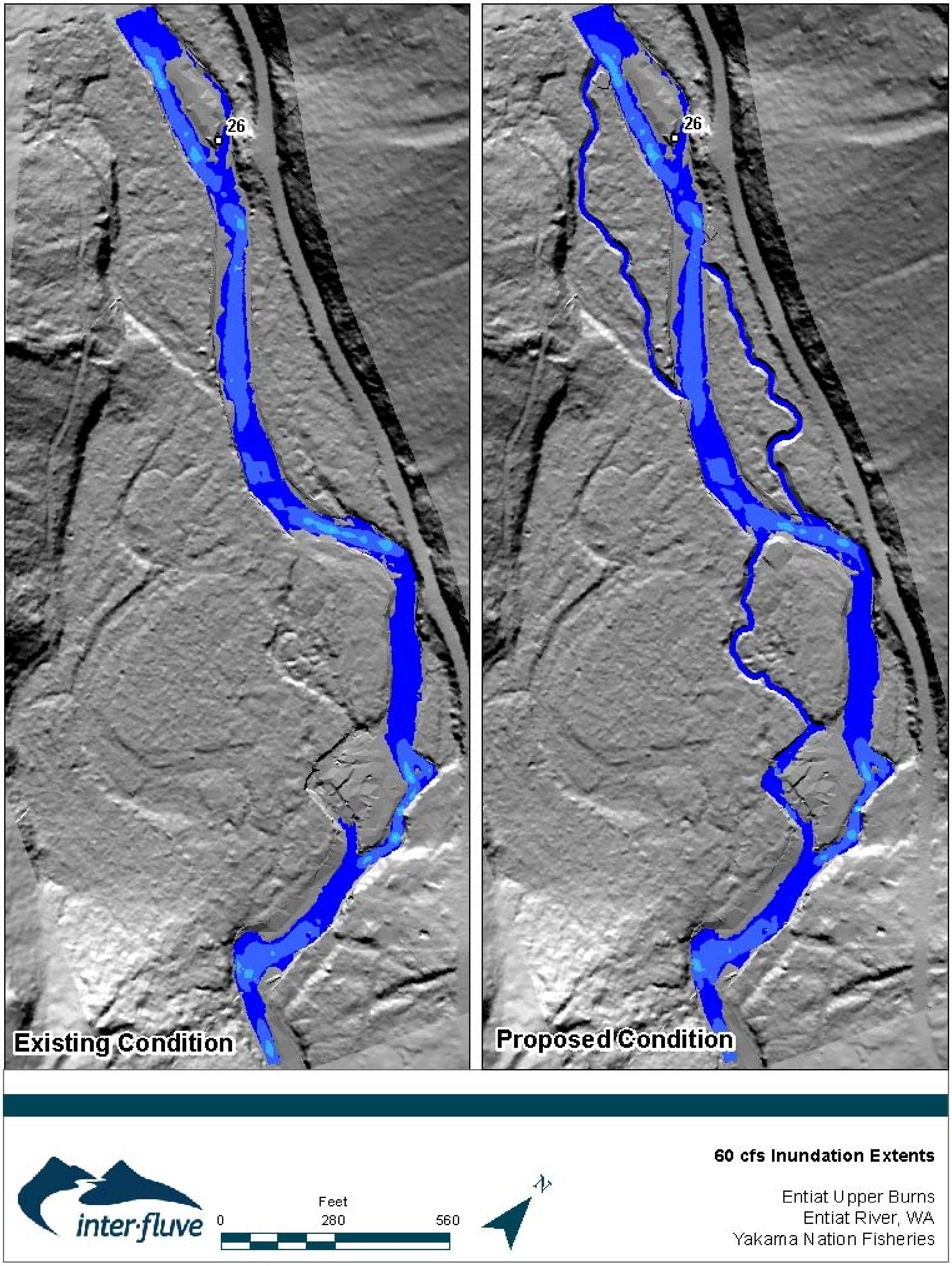
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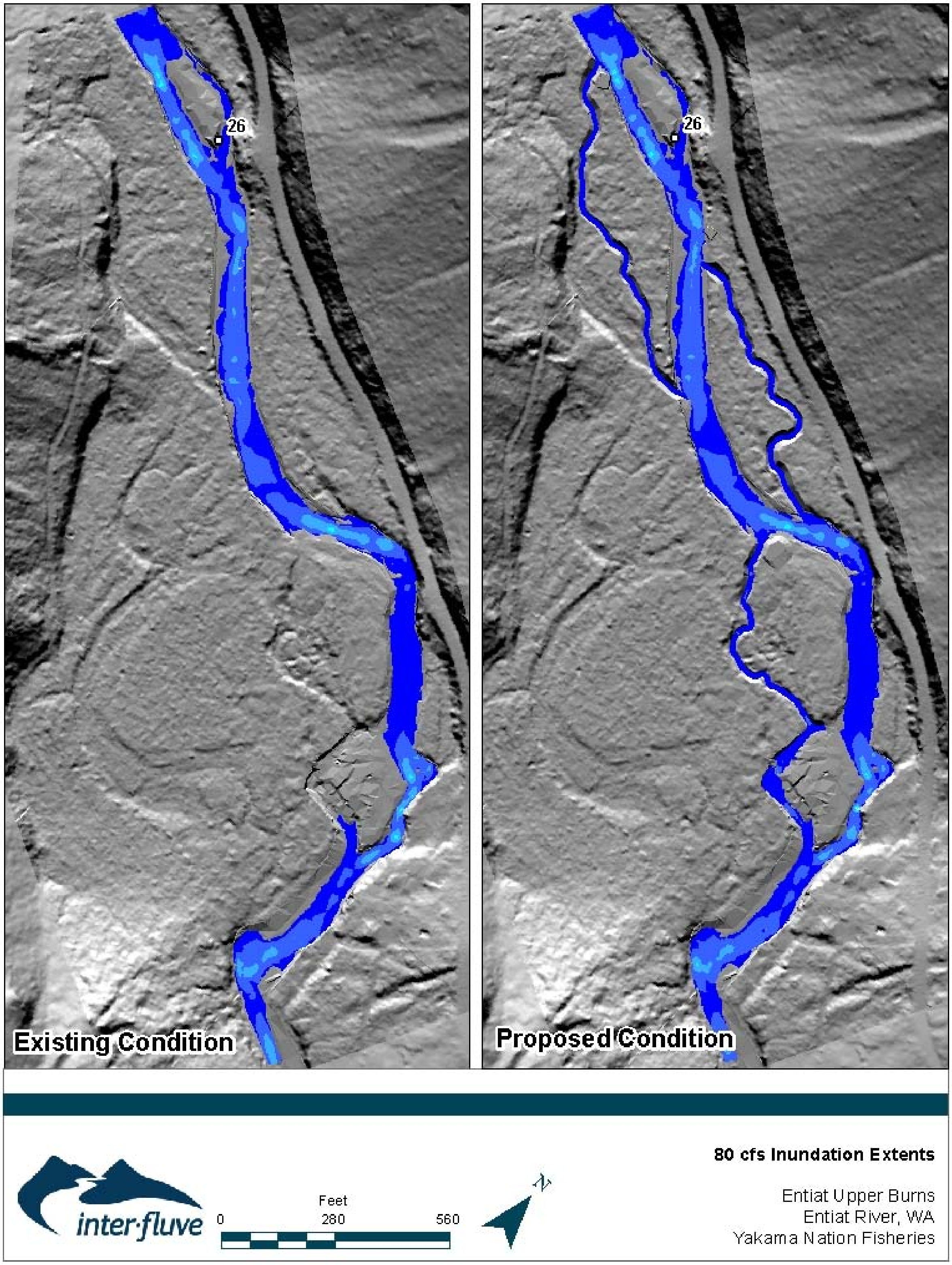
Entiat Upper Burns
Entiat River, WA
Yakama Nation Fisheries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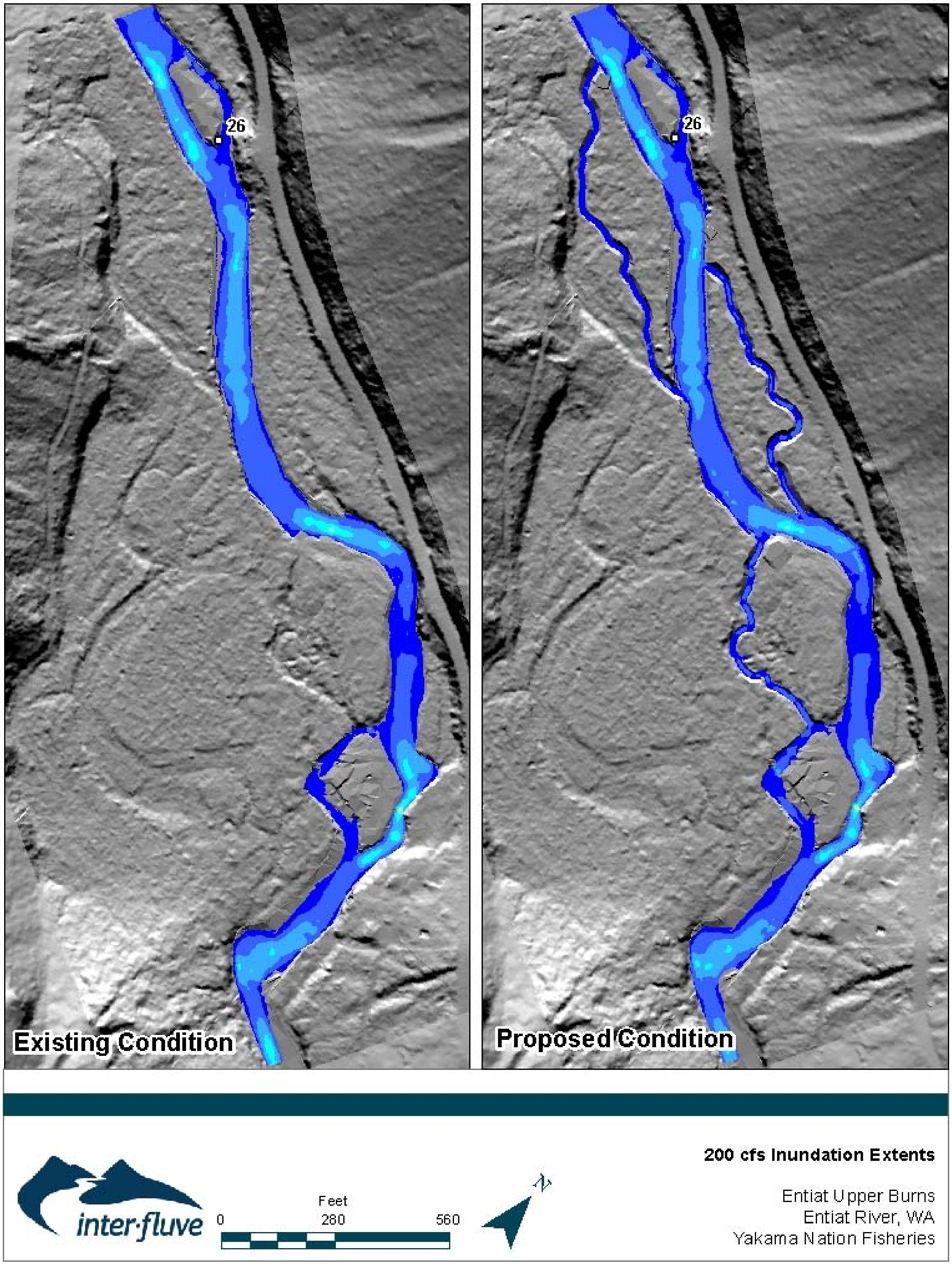
Yakama Nation Fisheries
inter·fluve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Proposed Condition
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Feet
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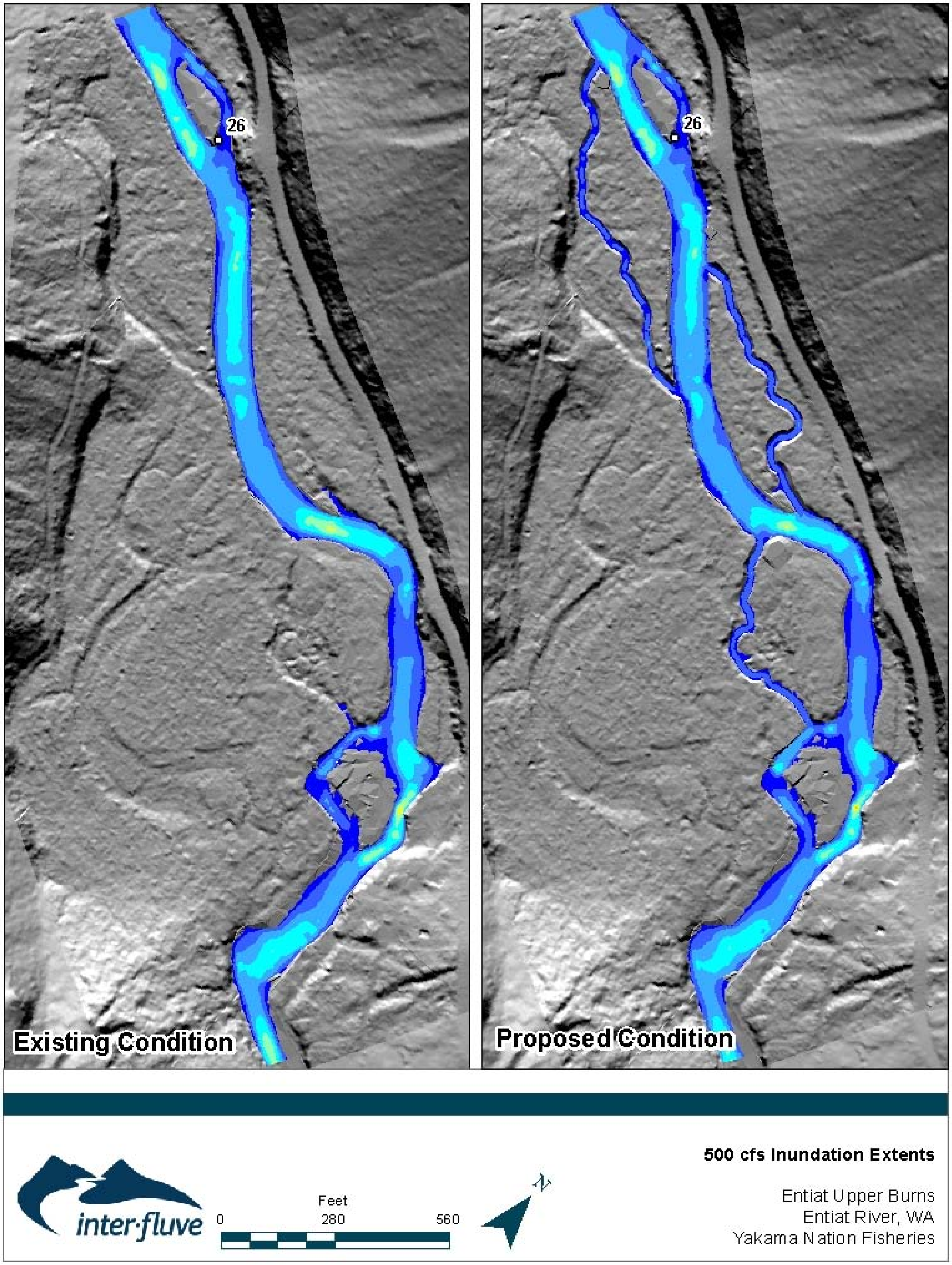
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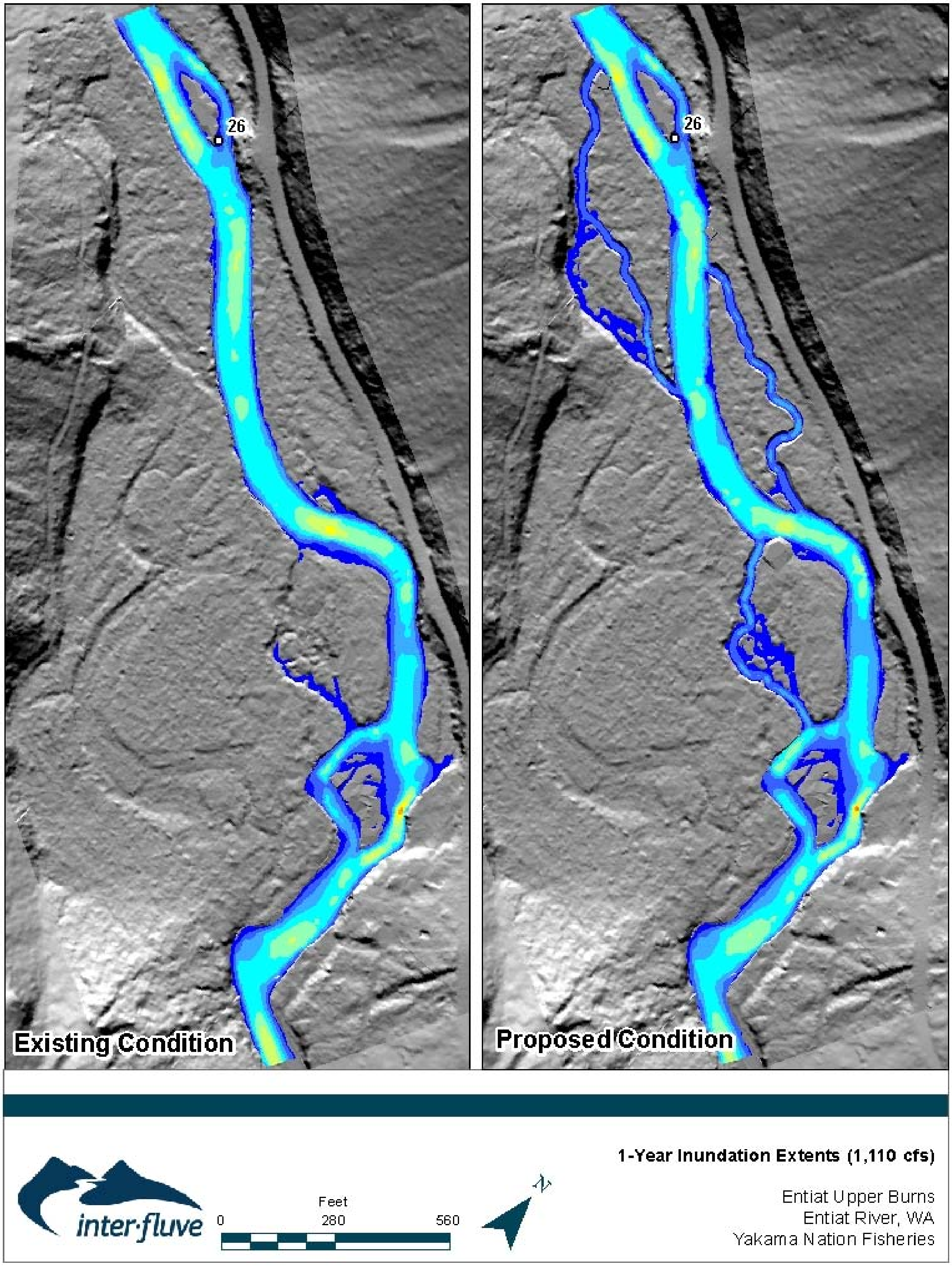
Yakama Nation Fisheries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Proposed Condition
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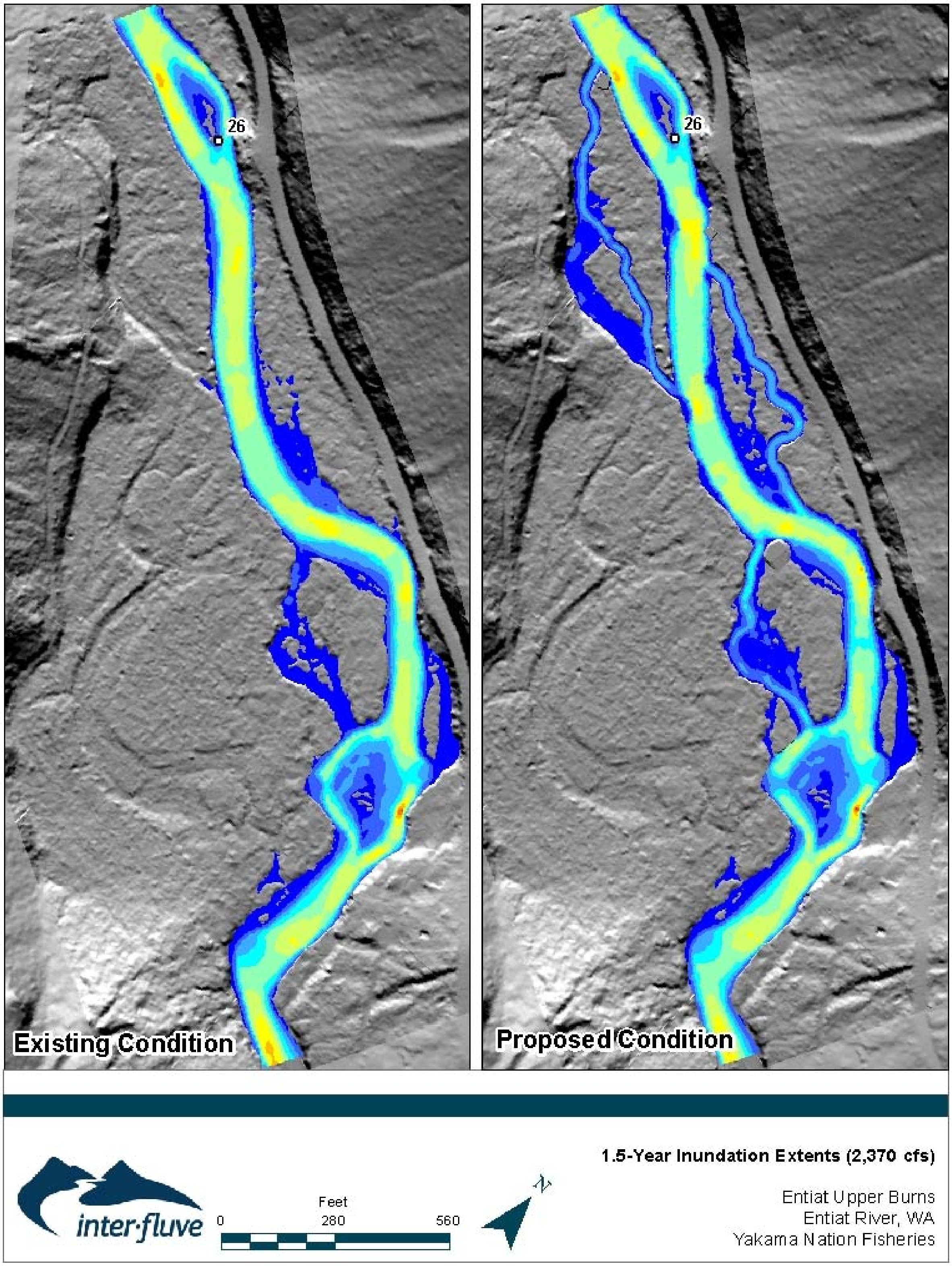
Entiat Upper Burns
Entiat River, WA
Yakama Nation Fisheries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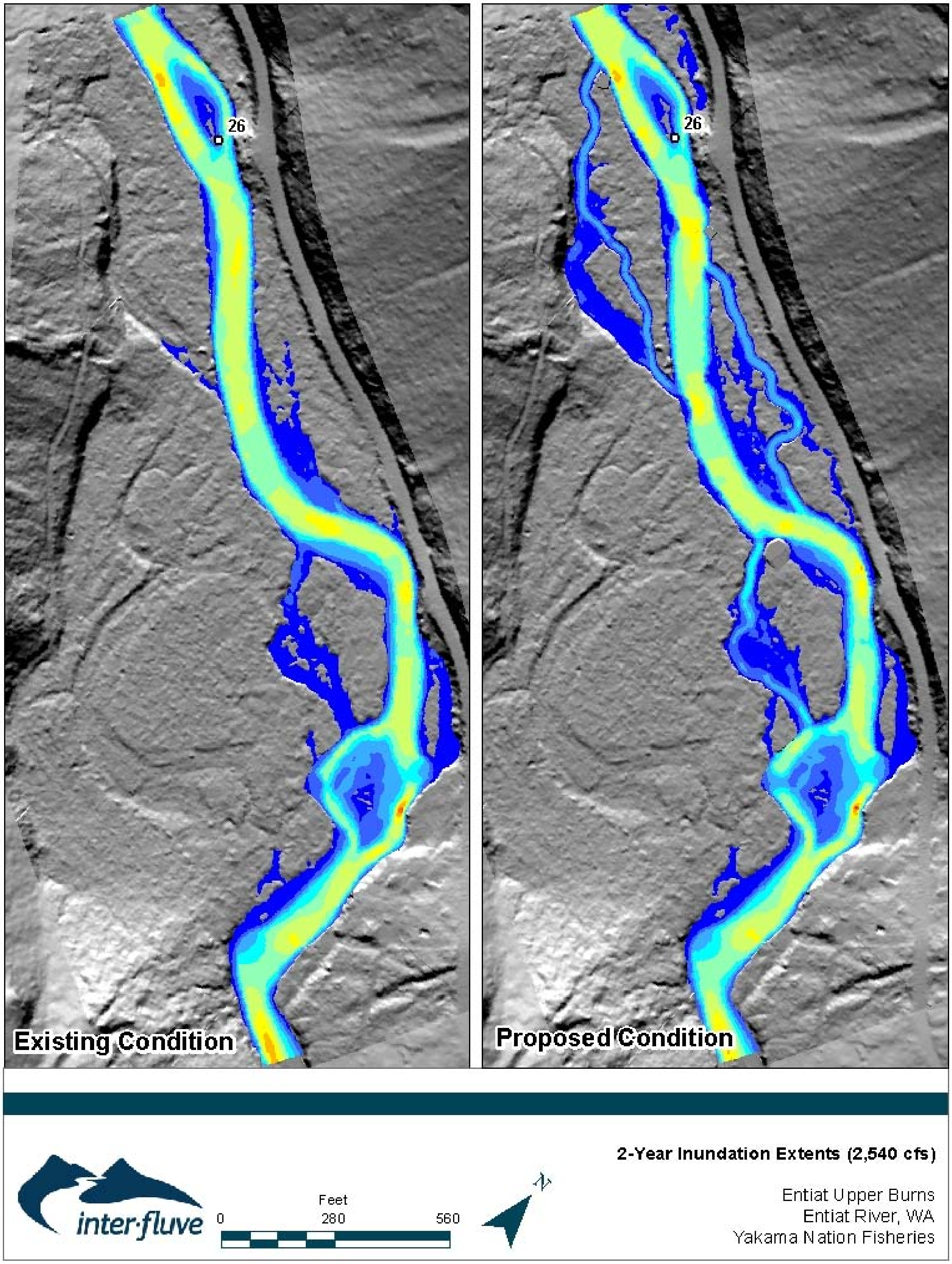
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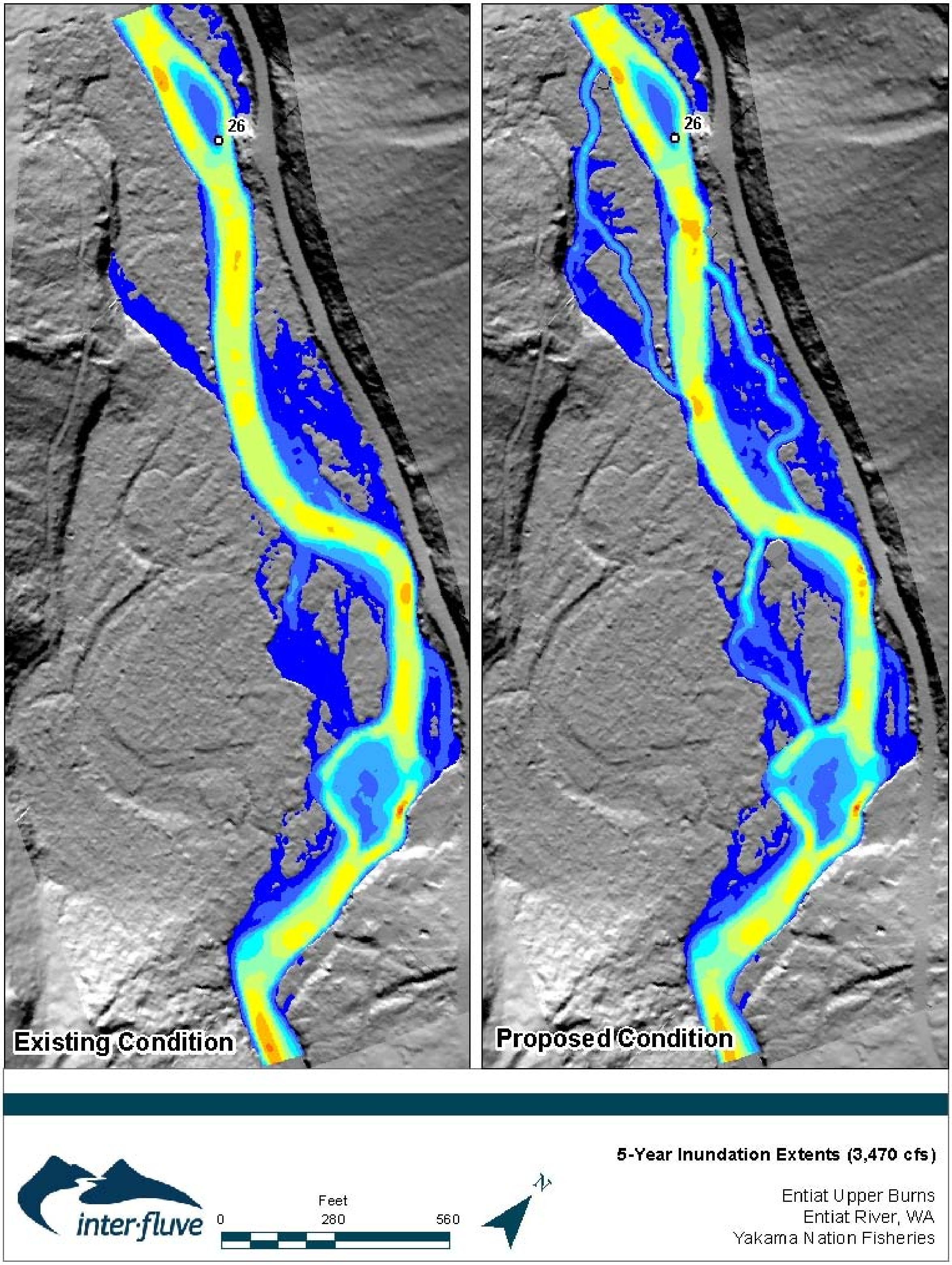
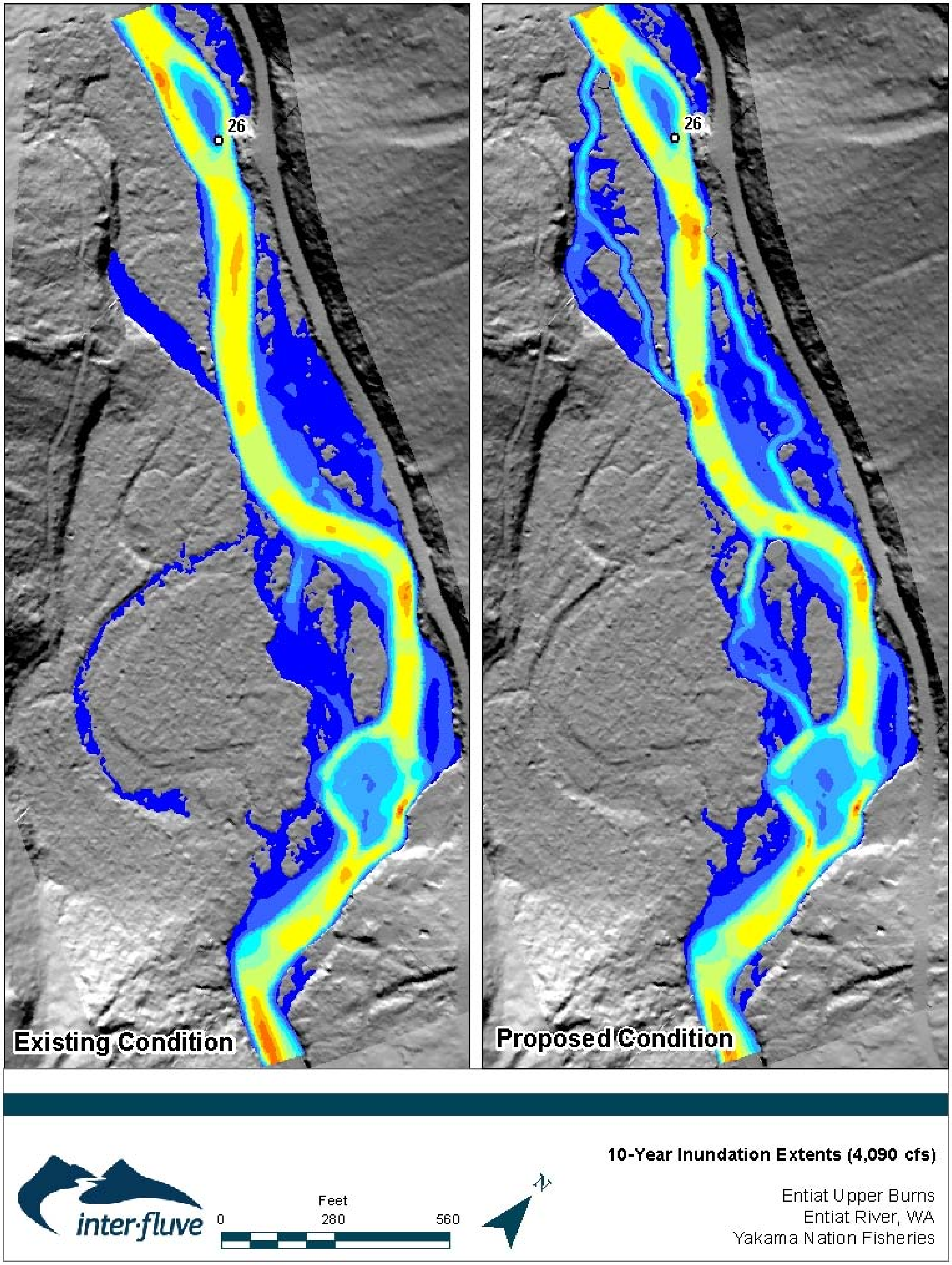
Entiat River, WA
Yakama Nation Fisheries



5-Year Inundation Extents (3,470 cfs)

Entiat Upper Burns
Entiat River, WA
Yakama Nation Fisheries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Proposed Condition
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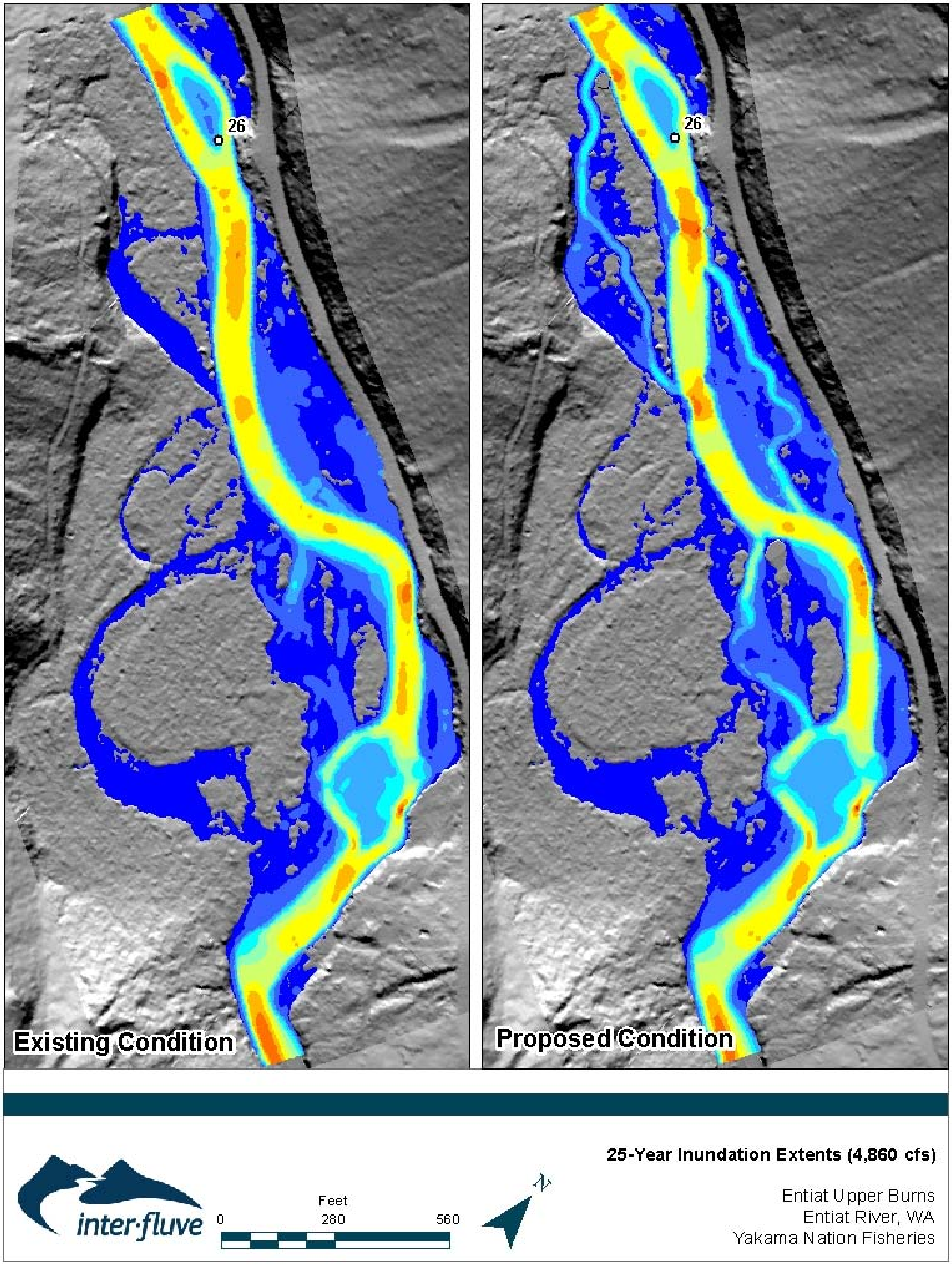

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Existing Condition
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Proposed Condition
25-Year Inundation Extents (4,860 cfs)
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Yakama Nation Fisheries
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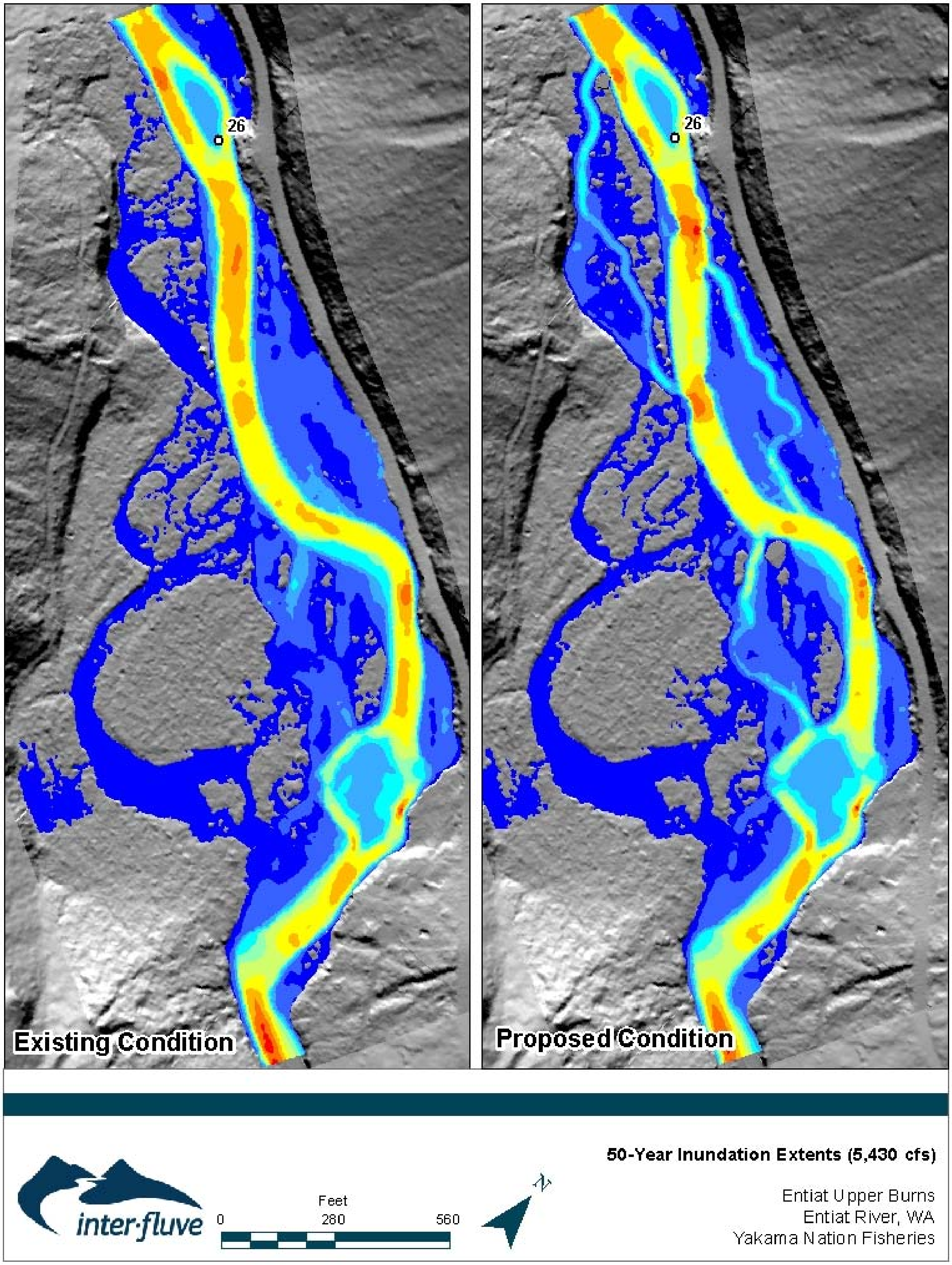
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Existing Condition
Proposed Condition
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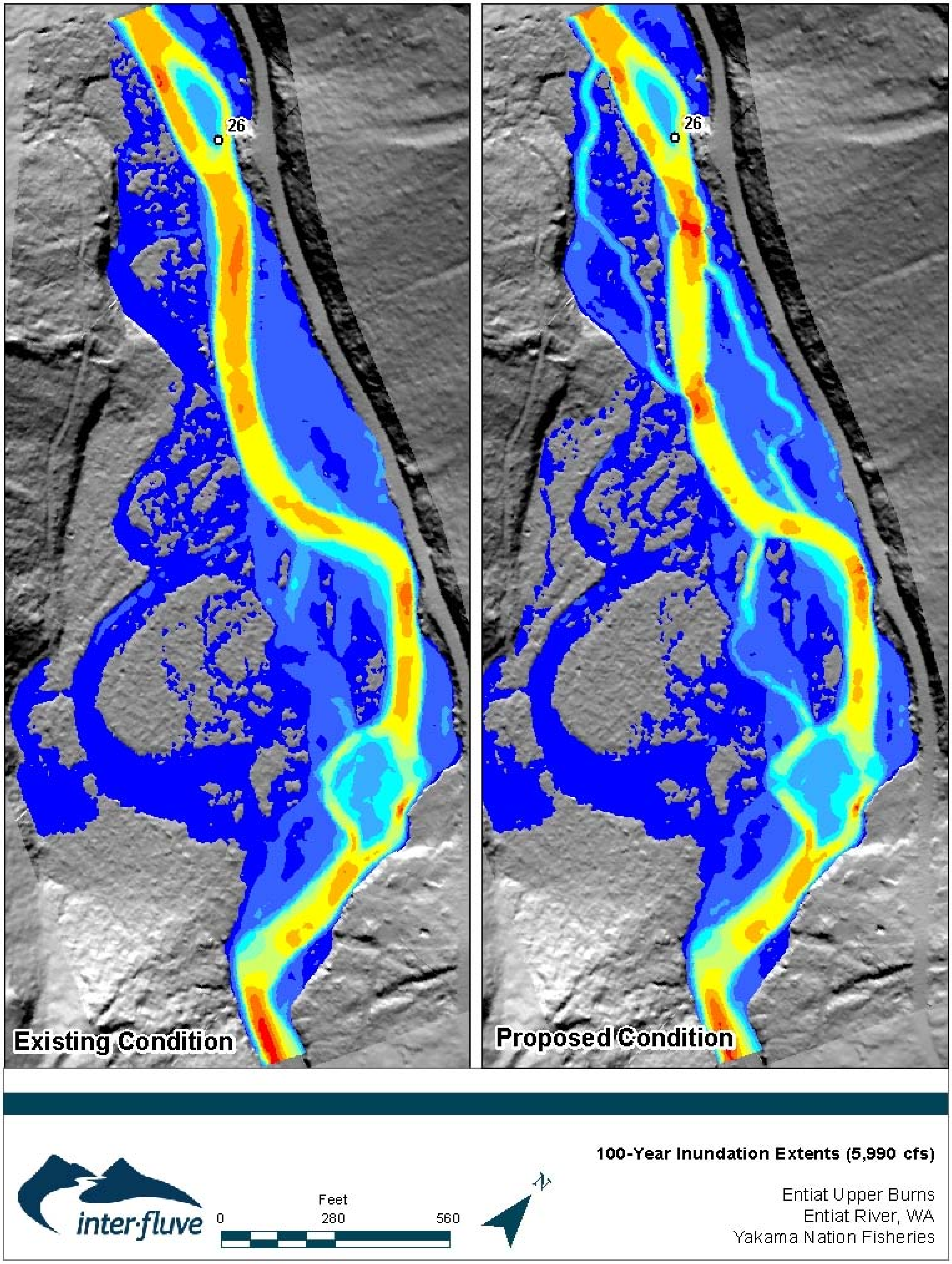
Entiat River, WA
Yakama Nation Fisheries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Proposed Condition
100-Year Inundation Extents (5,990 cfs)
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Feet
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Entiat Upper Burns
Entiat River, WA
Yakama Nation Fisheries

Appendix B – Soil Pits Summary Memorandum

Appendix C – Cost Estimate

Appendix D – Engineering Plans