Buffalo Flats Project: Little Creek

80% Basis of Design Report

Little Creek, Union County, Oregon

Columbia Pacific Northwest Region

Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photo: Little Creek existing channel, looking upstream, August 2020.

Acronyms and Abbreviations

Acronym or Abbreviation	Definition
BiOp	Biological Opinion
BPA	Bonneville Power Administration
BPLL	Buffalo Peak Land and Livestock Company
BSR	Biologically Significant Reach
°C	Degrees Celsius
cfs	Cubic Feet Per Second
CRITFC	Columbia River Inter-Tribal Fish Commission
DEQ	Oregon Department of Environmental Quality
DOI	Department of the Interior
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
GRMW	Grande Ronde Model Watershed
HAWS	Height Above Water Surface
HIP	Habitat Improvement Program
HMI	Holistic Management International
HUD	Department of Housing and Urban Development
LiDAR	Light Detection and Ranging
LWD	Large Woody Debris
LWS	Large Wood Structure
m^2	Square Meters
NIR	Near Infrared
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
ODFW	Oregon Department of Fish and Wildlife
ODOT	Oregon Department of Transportation

Acronym or Abbreviation	Definition
OTEC	Oregon Trail Electric Co-Op
OWRD	Oregon Water Resources Department
POD	Point of Diversion
Reclamation	Bureau of Reclamation
REM	Relative Elevation Modeling
RM	River Mile
RPA	Reasonable and Prudent Alternative
TAC	Technical Advisory Committee
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USWCD	Union Soil and Water Conservation District

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Executive Summary

The Little Creek Buffalo Flats Project is a fish habitat enhancement project located on private working lands immediately upstream of the City of Union, Oregon on Little Creek. The project is sponsored by the Union Soil and Water Conservation District (USWCD), in close collaboration with the property owners, Andrea and Tony Malmberg, and the United States Bureau of Reclamation (Reclamation). The project area, known as "Buffalo Flats" is 268-acres in size, and is a portion of the larger 628-acre cattle ranch owned by Buffalo Peak Land and Livestock Company.

Goals for the project include restoring historical creek and floodplain processes of Little Creek to maximize salmonid habitat benefits and ecological function while allowing private ranching to continue in a way that is compatible and supportive of long-term ecological function. Historically, Little Creek within the project area has been adversely affected by historical modifications associated with transportation infrastructure and land use. The channel has been straightened, leading to floodplain disconnection and reduced in-stream complexity. Project designs have been developed to support these multiple goals that ultimately will benefit endangered species act (ESA) listed salmonids in the Columbia Basin.

This report describes draft Permit Level (80%) Designs and follows the Bonneville Power Administration (BPA) Habitat Improvement Program (HIP) format (as described in FY 2023 HIP Handbook ((BPA, 2023). During the design process extensive documentation has been developed that describes various analyses and decision-making processes.

This Basis of Design Report (BDR) is submitted with the following documents:

- *80% Drawings* (December 2024)
- *80% Hydraulic Modeling Report – Appendix A*
- *Flood Risk Analysis Report – Appendix B*
- *No-rise analysis memorandum – Appendix C*
- *Subsurface Investigation – Appendix D*
- *Large Wood Stability Calculations – Appendix E*
- *Wetland Delineation – Appendix F*
- *Decision Making Process and Timeline – Appendix G*
- *Land Management Plan* – (submitted separately)

1 Project Background

The Little Creek Buffalo Flats Project is a fish habitat enhancement project located on private working lands immediately upstream of the City of Union, Oregon on Little Creek (Figure 1). The project area is 268-acres in size and is a portion of the larger 628-acre cattle ranch owned by Buffalo Peak Land and Livestock Company. River channels and floodplains within the project area have been negatively impacted by historical modifications associated with infrastructure and land use. Designs have been developed to enhance in-stream and floodplain habitats for ESA-listed Snake River spring Chinook (*Oncorhynchus tshawytscha,* threatened), steelhead (*Oncorhynchus mykiss,* threatened), and Bull Trout (*Salvelinus confluentus,* threatened). The private landowners, Andrea and Tony Malmberg, run their operation with the goal of operating a "working cattle ranch that successfully demonstrates how agriculture can coexist and benefit from good fishery habitat and functional ecosystems".

The Little Creek Buffalo Flats Restoration Project goals are:

1. Enhance and restore aquatic habitat conditions and increase habitat diversity and complexity for salmonids.
2. Improve water quality conditions (temperature and sediment) for salmonids.
3. Promote conditions for restoring ecological function and improving soil health within the project area.
4. Raise the water table within the project reach to support the establishment and growth of a diverse mosaic of herbaceous and woody riparian vegetation.
5. Reconnect Little Creek with its floodplains and expand quality floodplain habitat availability for salmonids within the project boundaries.
6. Increase the temporary floodplain storage of water, ice and woody debris during flood events.

The Catherine Creek Subbasin, which includes Little Creek has benefited from extensive planning processes to prioritize habitat enhancement actions for listed species. Documents published in support of restoration planning include the following:

- *The Grande Ronde Subbasin Plan* (Nowak, 2004)
- *Catherine Creek Tributary Assessment* (Reclamation, 2012)
- *The Catherine Creek Reach Assessment* (Reclamation, 2012)
- *Catherine Creek Atlas* (Atlas Partners, 2015)

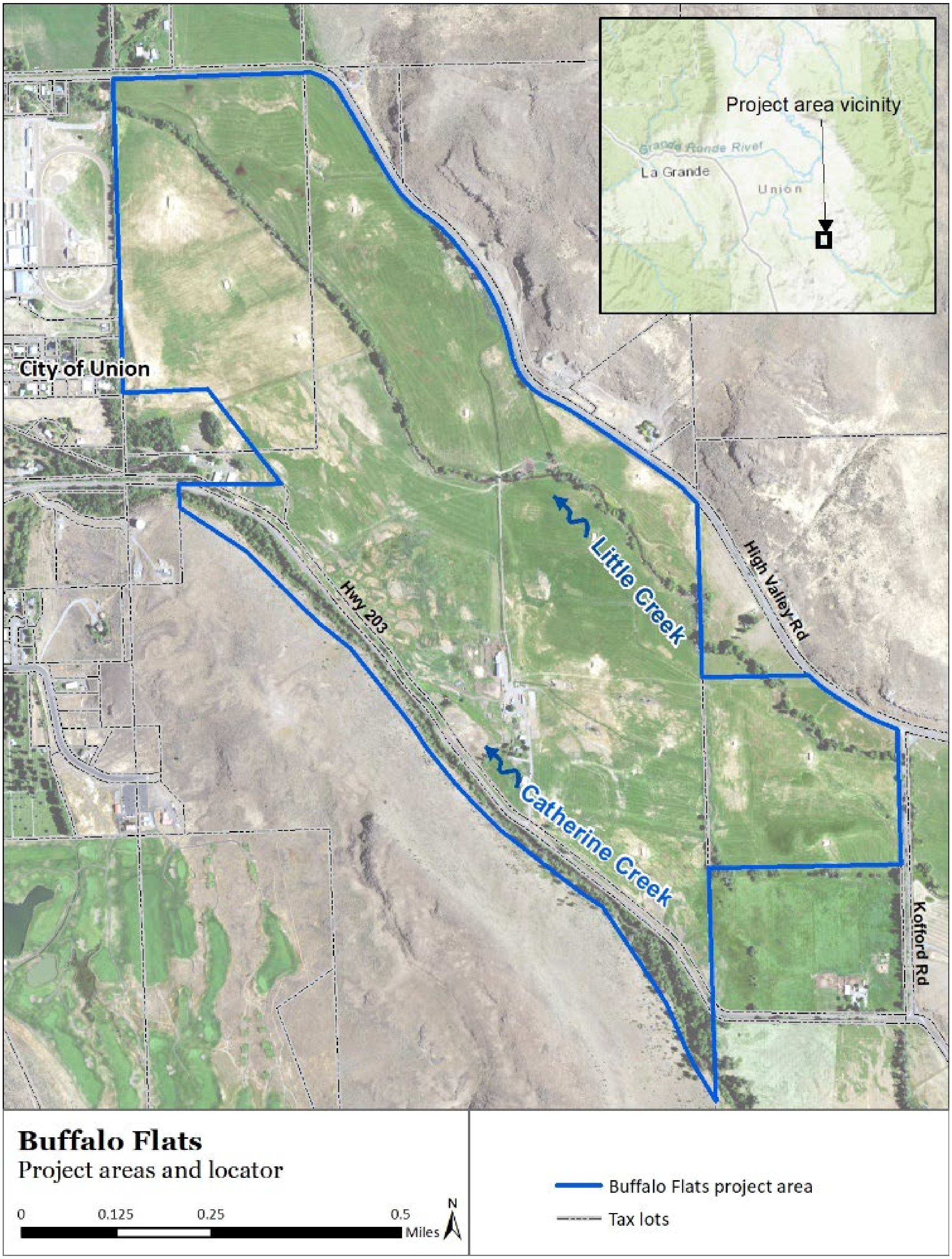


Figure 1. Buffalo Flats property. The Little Creek project is focused on the northern section of the property.

1.1 Name and Titles of Sponsor, Firms, and Individuals Responsible for Design

The project is sponsored by Union Soil and Water Conservation District (USWCD). US Bureau of Reclamation (Reclamation) is providing technical support and funding for design. Inter-Fluve, Inc. is the engineering design firm. The landowners are also involved in discussions of design elements to align their agricultural practices with the post-restoration conditions. Individuals that are currently core members of the design team are listed in Table 1.

Table 1. Design team members

Name, Title	Organization	Role in this project	Contact
Jim Webster, District Manager	Union Soil and Water Conservation District	Sponsor	jwebster@unionswcd.org
Aaron Bliesner, Project Manager	Union Soil and Water Conservation District	Sponsor	abliesner@unionswcd.org
Tony Malmberg, Landowner	Buffalo Peak Land and Livestock	Landowner	tony@holisticmanagement.guide
Andrea Malmberg, Landowner	Buffalo Peak Land and Livestock	Landowner	andrea@lifeenergy.guide
Jeff McLaughlin Habitat Program Manager	US Bureau of Reclamation	Design Support and Funding	JMclaughlin@usbr.gov
Michael Knutson, PE, Hydraulic Engineer	US Bureau of Reclamation	Design Support Technical Lead	mknutson@usbr.gov
Matt Cox, PE, Hydraulic Engineer	Inter-Fluve	Engineer of Record	mcox@interfluve.com
Peter Benchetler, PE Hydraulic Engineer	Inter-Fluve	Engineer, Modeling	pbenchetler@interfluve.com
Caitlin Alcott, CE Ecologist	Inter-Fluve	Project Manager, Inter-Fluve	calcott@interfluve.com
Joe Parzych, CFS Biologist	Inter-Fluve (former)	Wetland Delineation	

1.1.1 Coordination with BPA and other Stakeholders

In addition to the design team listed above, BPA, landowners, and other stakeholders have been involved in the design effort thus far, including those listed in Table 2.

Table 2. Additional Stakeholders

Name, Title	**Organization**	**Role in this project**	**Contact**
Thomas Delorenzo, Environmental Protection Specialist	Bonneville Power Administration	Environmental Compliance Lead	tdelorenzo@bpa.gov
Sean Welch, PE Tributary Habitat Policy Lead	Bonneville Power Administration	BPA Technical Lead	spwelch@bpa.gov
Richard Fitzgerald	Oregon Dept of State Lands	Aquatic Resource Coordinator	Richard.W.FITZGERALD@dsl.oregon.gov
Jesse Steele, Executive Director	Grande Ronde Model Watershed	Advisor	jesse@grmw.org
Allen Childs	Confederated Tribes of the Umatilla Indian Reservation	Advisor, conceptual stage	allenchilds@ctuir.org

1.2 List of Project Elements that have been Designed by a Licensed Professional Engineer

This Basis of Design report describes the draft permit level (80%) design elements. The following proposed project elements are designed by a licensed professional engineer.

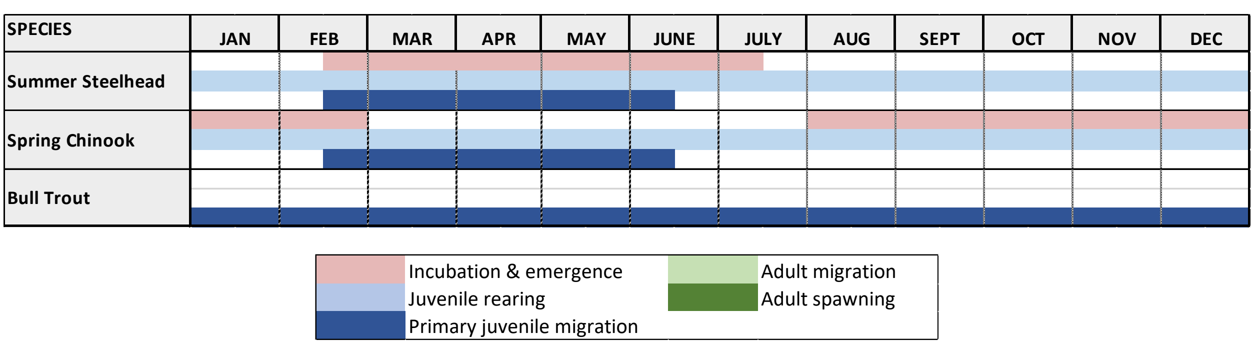
- Grade multi-thread channel network
- Large wood in-stream habitat structures
- Floodplain habitat complexity treatments
- Remove crossing
- Relocate irrigation ditch and headgate
- Constructed riffle
- Riparian and wetland planting

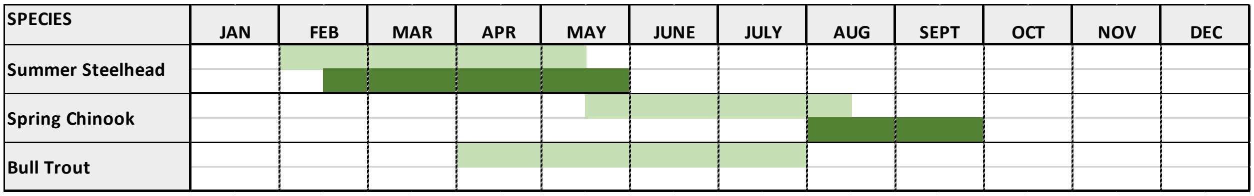
1.3 Explanation and background on fisheries use (by life stage – period) and limiting factors addressed by project

The project area is known to provide habitat for ESA-listed Chinook Salmon (threatened), steelhead (threatened), and Bull Trout (threatened) at various life stages (Table 3). In 1992, Chinook were listed as threatened under the Endangered Species Act and in 1996 steelhead were also listed as threatened. Habitat degradation in headwater streams has been identified as the significant source of these population declines.

The Little Creek project area is located in the CCC2C reach as mapped in the Grande Ronde Atlas. The CCC2C reach also includes sections of Lower Catherine Creek, and the Grande Ronde River mainstem near the Catherine Creek confluence. Therefore, salmonid life history timing in Little Creek is believed to be more similar to timing observed in the nearby CC4 reach mapped in Atlas. Timing for CC4 is shown below in Table 3. Note that neither spring Chinook spawning nor emergence have been documented in Little Creek, and the timing is included here because project actions have the potential to improve spawning conditions for these fish.

Table 3. Fish use timing for salmonids within the CC4 of Catherine Creek (GRMW 2021).





1.3.1 Spring Chinook Salmon

Adult spring Chinook spawning has not been documented in Little Creek; however, the project is expected to potentially improve habitat conditions in the reach and could lead to spawning in the future. Life history timing is expected to be similar to Chinook Salmon in adjacent Catherine Creek. Chinook Salmon migrate upstream through Catherine Creek near the project reach in late May through early June. Spawning occurs in late August through September, and juvenile emergence occurs in January and February. Most juveniles express a stream-type life history, where they rear in freshwater for one year prior to out-migrating the following spring during spring runoff. Of those stream-type fish, there are two life history strategies that have been identified. Early migrants migrate downstream and overwinter in lower Catherine Creek or the Grande Ronde mainstem before out-migrating the following spring. Late migrants rear in headwaters in which they were spawned prior to out-migrating in the spring (Jonasson et al. 2002).

While historical data have documented Chinook spawning in both Catherine Creek and Little Creek, contemporary surveys indicate that current fish use is more limited. Data collected by ODFW indicate that adult Chinook spawning has not been documented in Little Creek within the past 10 years, and juveniles detected from the mouth to RM 1.2 during electroshocking surveys are believed to be fish spawned in Catherine Creek, seeking thermal refuge in Little Creek during hot summer months. Juveniles were not observed upstream of RM 1.2, likely due to a passage barrier downstream of Godley Road (downstream of the project area).

1.3.2 Steelhead

Adult steelhead returning from the ocean appear at the project area as early as February, with spawning occurring in Little Creek within the project area and upstream from February through May. Juveniles emerge from February through June, and rear for one to several years prior to migrating to the ocean.

Juvenile steelhead have been documented in both Catherine Creek and Little Creek, and steelhead spawning has been observed in Little Creek within the project area.

1.3.3 Bull Trout

Little is known about how Bull Trout utilize the project area. The project area most likely functions as a migration corridor for fluvial Bull Trout between overwintering habitat downstream, and spawning and rearing habitat upstream. Spawning occurs in headwater streams in the fall, and juveniles display an extended rearing period before expressing either a resident life history where they remain in headwater streams as adults, or fluvial life history where they migrate downstream as sub-adults and reside in downstream reaches during winter months or when water temperatures are suitable.

Electroshocking surveys conducted by ODFW did not document Bull Trout in the project area vicinity, however it is possible these fish primarily use the project area as a seasonal migration corridor and were not present during the time of sampling.

1.3.4 Habitat conditions and limiting factors

Within the project area, a history of agricultural land use, grazing, channel straightening, and road building have resulted in reduced in-channel complexity, and impaired floodplain connectivity and habitat quality. Water temperature in Little Creek has remained within the thermal ranges preferred by salmonids (daily maximums below 18°C) in all stream reaches, with the exception of the lowest reach where stream temperatures were a few degrees warmer (ODFW Research 2019). These findings, along with the detection of juvenile Chinook Salmon in Little Creek despite a lack of spawning in the basin, suggest that Little Creek is an important cool-water refuge for salmonids during hot summer months.

Limiting factors within this reach were identified in the Atlas process, and include the following:

- Reduced instream flows
- High summer temperatures (downstream)
- Limited instream structural complexity
- Limited availability of peripheral and transitional habitats (side channels, floodplains, and wetlands)

1.4 List of Primary Project Features Including Constructed or Natural Elements

The following features are included in the Little Creek Buffalo Flats Habitat Restoration Project:

Grade multi-thread channel network: The project aims to restore natural floodplain connectivity and in-stream habitat complexity that was likely found in this area historically, and that would be naturally self-sustaining and dynamic. As observed in various other restoration projects and functioning floodplains, raising the water-table to support a robust aquatic and riparian vegetation community is a key determinant of the grading plan.

The proposed channel planform was evaluated extensively at the conceptual and preliminary design stages using a 2D hydraulic model. Attention was paid to existing hydrologic records, observed site conditions during floods, species and life stages likely to use the site, and native vegetation that will interact with the physical processes of the channel to support ongoing habitat complexity.

Large Wood Instream habitat complexity treatments: Instream habitat complexity will complement the channel grading. The intention is to increase roughness, drive geomorphic dynamism, provide habitat cover for aquatic organisms, support an aquatic and riparian plant community associated with a higher water table. Specific in-stream elements include:

Habitat Large Wood Structures: These structures are located on the outside of channel bends, where small debris would naturally accumulate and where woody plant roots would be exposed in a fully developed riparian zone. These structures will provide cover and habitat for juvenile salmonids.

Flow Splitting Large Wood Structures: These structures are located at flow split location within the multi-threaded channel complex. They are constructed at the head of floodplain "islands" of slightly higher ground intended to support the development of woody riparian vegetation. They will maintain scour pools for cover and capture small woody debris moving through the system to enhance complexity.

Channel Spanning Large Wood Structures: These structures are located periodically within the channel network, and the design intent is that they will capture fine sediments and organic material, provide some scaffolding for beaver dam construction, and maintain pools which will vary in size depending on the porosity, which will vary over their design life. These structures mimic location where a tree or riparian shrub has fallen across the channel and gathered material to create a porous channel spanning structure. Channel spanning wood perform important functions in small streams that are fundamentally different to non-channel-spanning wood (Livers & Wohl 2021).

Small Whole Tree Placement: Small Whole Trees will be used throughout the multi-threaded channel network to provide roughness, structure and complexity. These structures will not be constructed along with pools, but some may develop pools over time depending on local hydraulic forces. These elements mimic the role of small woody debris that would have been much more present in a fully developed riparian zone.

Floodplain habitat complexity treatments: Floodplain habitat complexity elements have been designed to provide roughness at high flows as well as to establish pockets of vegetation in the near channel floodplain zone.

Willow Trenches: These structures consist of linear rows of live willows. The structures will be augmented with dead native brush/branches to provide floodplain roughness as live willows establish. The primary intent of these structures is to re-route down valley flows and prevent significant flow concentrations and excessive velocities in shallow flows across the floodplain. This technique will also be used on vegetated islands and in certain habitat complexity treatments.

Flood Fences: These structures consist of a linear row of live willow bundles with live and dead native brush and stakes woven between. Posts can be utilized in place of live willow bundles in locations where the water table is not favorable for willow establishment (too wet). The intent of this structure is to provide floodplain roughness and narrow certain channels and swales. When placed in or near a channel or swale, this structure will capture fine sediment over time. Flood fence structures are designed such that they can be constructed either by hand crews or with light equipment in locations where access with heavier equipment is difficult or will cause significant impact to existing vegetation.

Small Whole Tree Placement: Small Whole Trees will be used in the floodplain in locations with higher velocity overbank flow. These structures are located on floodplain areas and existing swales to slow water, trap sediment and re-direct overland flow. These structures are secured by burial and bracing with angled pins. They are placed as an interim measure in the absence of robust riparian and floodplain vegetation to provide hydraulic resistance in the floodplain and to create potential habitat in channel swales during high flow conditions. They will be installed in conjunction with groupings of willow trenches in their lee to provide floodplain roughness as the wood degrades over time.

Riparian, floodplain, and wetland planting: Woody and herbaceous plants will be installed in the project area based on anticipated inundation patterns. Stream shading, geomorphic function, ecological complexity, and soil regeneration are key objectives guiding the riparian planting. All areas of disturbance will be planted with a native mix of herbaceous and woody plants that are appropriate to the site and post-project inundation patterns.

Remove crossing: Near the middle of the project area an existing farm crossing is causing a constriction and a grade break in the channel. Removal of this crossing is part of the proposed project.

Relocate irrigation ditch and headgate: A headgate will be relocated upstream on Little Creek as shown on the plans. Union SWCD and the water master have determined that as this location is not an official point of diversion, it does not have restrictions for relocation within the property. A channel matching the dimensions of the current ditch will connect the new headgate to the existing ditch. ODFW will design and install a fish screen.

Constructed riffle: A riffle is proposed in the project area to provides a fish passable diversion structure that provides water to the state ditch (associated with the new headgate).

Remove riprap: Riprap that exists within the existing Little Creek channel will be removed throughout the project area.

Soil Stockpiles: Excess material will be developed as a result of the grading plan that involves removing over 13,000 cubic yards of excess material from the floodplain. This material will be stockpiled outside of the 100-year flood footprint in the location designated on the plans, to be used at the landowner's discretion in the future.

Land management plan: The landowners operate a ranching operation at the project area based on Holistic Grazing principals and regularly monitor their ecosystem using a methodology called "Ecological Outcome Verification". They are committed to supporting endangered species recovery and overall ecological function on their property. To provide documentation of their proposed operation and its interaction with the designs described here, a land management plan has been drafted, including a monitoring and adaptive management plan. Multiple conversations with BPA and landowners have been held to find acceptable land management strategies and success criteria in the project area.

1.5 Description of Performance/Sustainability Criteria for Project Elements and Assessment of Risk of Failure to Perform, Potential Consequences and Compensating Analysis to Reduce Uncertainty

The primary purpose of this project is to restore natural floodplain processes and improve instream salmonid habitat conditions in Little Creek. Project goals are stated above.

Objectives in support of project goals include:

- Elevate the water table to provide improved growing conditions for a mosaic of woody and herbaceous vegetation across the floodplain.
- Improve aquatic habitat, with a particular focus on juvenile rearing habitat.
- Reduce solar gain both by using channel geometry where possible (narrow and deeper channels) and by focusing on encouraging conditions for vigorous riparian plant growth.
- Encourage channel evolution processes including deposition of gravel and fine material and associated lateral channel migration.

Objectives in support of risk reduction include:

- Support flood flows that maintain or improve the current flooding condition, including maintaining the existing flow-split at the downstream end of the project

In addition to meeting the project's landowner, biological, and ecological goals and objectives for improvements within the project area other important design criteria are discussed as follows:

Federal Emergency Management Agency (FEMA) no-rise to base flood conditions. Within the project area, the current adopted flood hazard zone has been defined by a detailed study within the Little Creek floodplain. For the City of Union, which is immediately downstream of the project area, the flood hazard zone has been defined through detailed study. Hydraulic analysis within the detailed study zones of the City of Union and Little Creek, will document the required FEMA base flood conditions required (See Appendix C: Technical Memorandum - No Rise Flood Analysis).

Large Wood Design. Placement and construction of large wood structures within the project area has been designed following Reclamation - Pacific Northwest Region - Risk-

Based Design Guidelines (US Bureau of Reclamation & US Army Corps of Engineers 2016). Calculations are provided in Appendix E.

Union County Planning Department Land Use Regulations. Required land use regulations will be followed and 80% plans will be provided.

State of Oregon Permitting Regulations, to include Division of State Lands removal-fill permits and wetland evaluations, Department of Environmental Quality permits.

Federal regulations, to include ESA, Section 106 of the National Historic Preservation Act, National Environmental Policy Act, Clean Water Act.

1.6 Description of Disturbance Including Timing and Areal Extent and Potential Impacts Associated with Implementation of Each Element

Areal extents of the project elements are provided in the attached drawings. The project is expected to be constructed using excavating equipment and off-road haul trucks. Timing will be dependent on regulatory permitting in-water work windows. In water work is expected to occur in a single construction year. The following approximate timeline is anticipated:

Year 0 (pre-construction):

- Fall-Spring: Mussel survey and possible relocation

Year 1:

- Late spring (May-June): mobilize construction equipment, excavate new ditch segment, other preparation tasks may occur
- July-August 15: divert flow, in stream excavation and filling, wood placement, crossing removal, riprap removal, sod salvage, headgate installation
- Late summer/Fall: install willow trenches and flood fencing, seed, stabilize site, demobilize

Year 2:

- Spring/summer: Observe flow patterns and growth of plants in the limits of disturbance and adjacent project areas. Determine woody and herbaceous plants to incorporate into the project
- Fall: Install plantings

2 Resource Inventory and Evaluation

2.1 Description of Past and Present Impacts on Channel, Riparian and Floodplain Conditions

2.1.1 Historical Land Use

The earliest impacts to the historical channel, riparian, and floodplain conditions were likely the extirpation of beaver beginning in the early 1800s and continuing as the late 1930's and early 1940's on the downstream end of Little Creek within the project area (Gildemeister 1998). The removal of beaver and beaver dams from the project area would have initiated multiple trends of stream and floodplain degradation. Increased water velocities and sediment transport would have resulted in local incision and simplification of channel planform, and reduced frequency and duration of floodplain inundation would have led to the lowering of the water table and altered evolution of the local plant community.

Analysis of historical aerial images show that prior to channelization, Little Creek had a multithread signature on the landscape. Prior to 1937 there was extensive conversion of riparian and floodplain vegetation to agricultural fields and pasture. This conversion continued through the mid to late 1950's. Channelization of Little Creek within the project area also occurred through the mid 1950's, resulting in channel incision, reduced instream roughness, and floodplain disconnection. Little Creek is currently listed as a Section 303(d) waterbody by the Oregon Department of Environmental Quality due to issues associated with dissolved oxygen, temperature, sediment, nutrients, and flow (DEQ 2010). All water quality issues are likely associated with anthropogenic disturbance from existing and past forest and agricultural practices in the watershed.

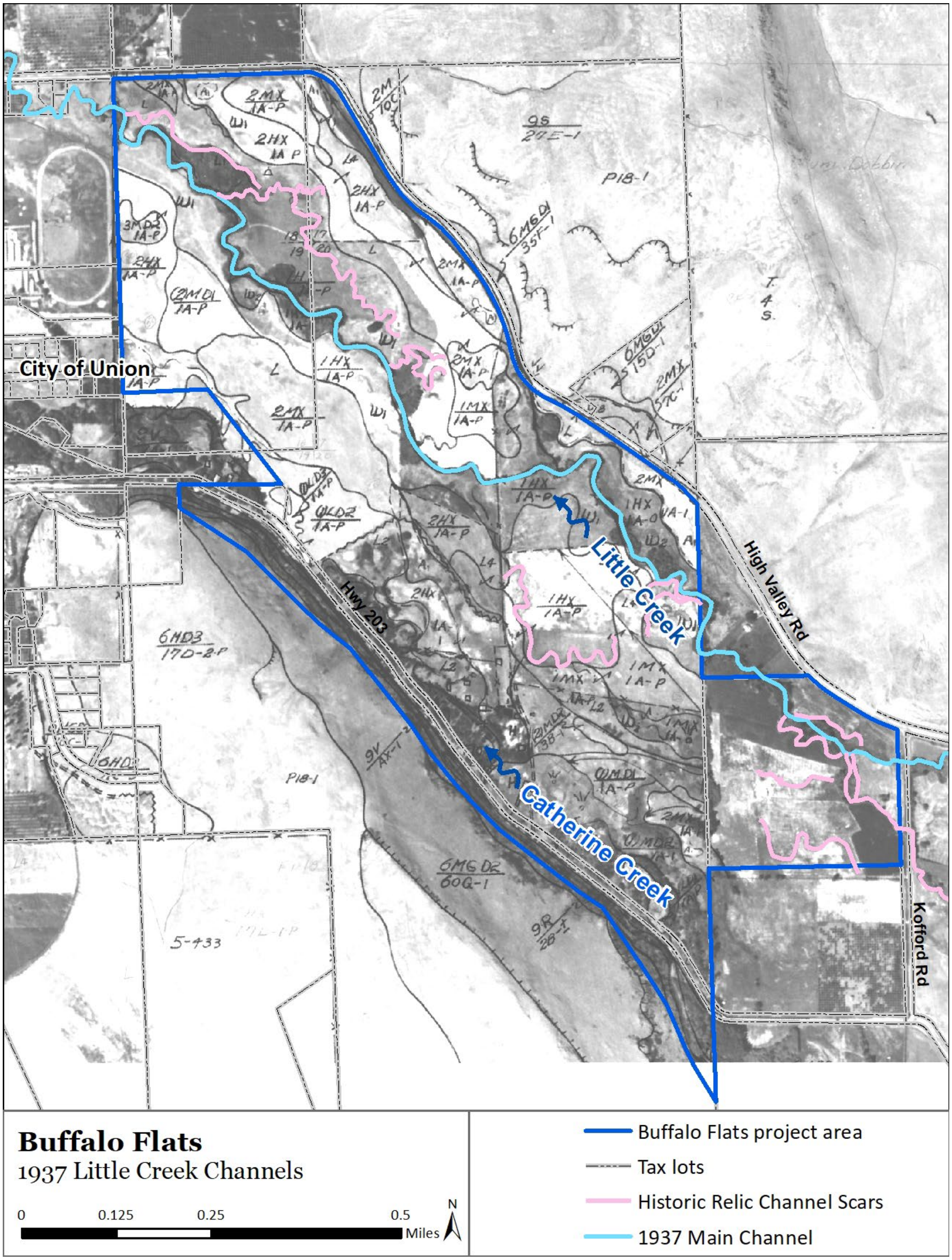


Figure 2: 1937 aerial image showing the digitized historical mainstem Little Creek Channel (light blue) and multiple Little Creek channel relicts (pink).

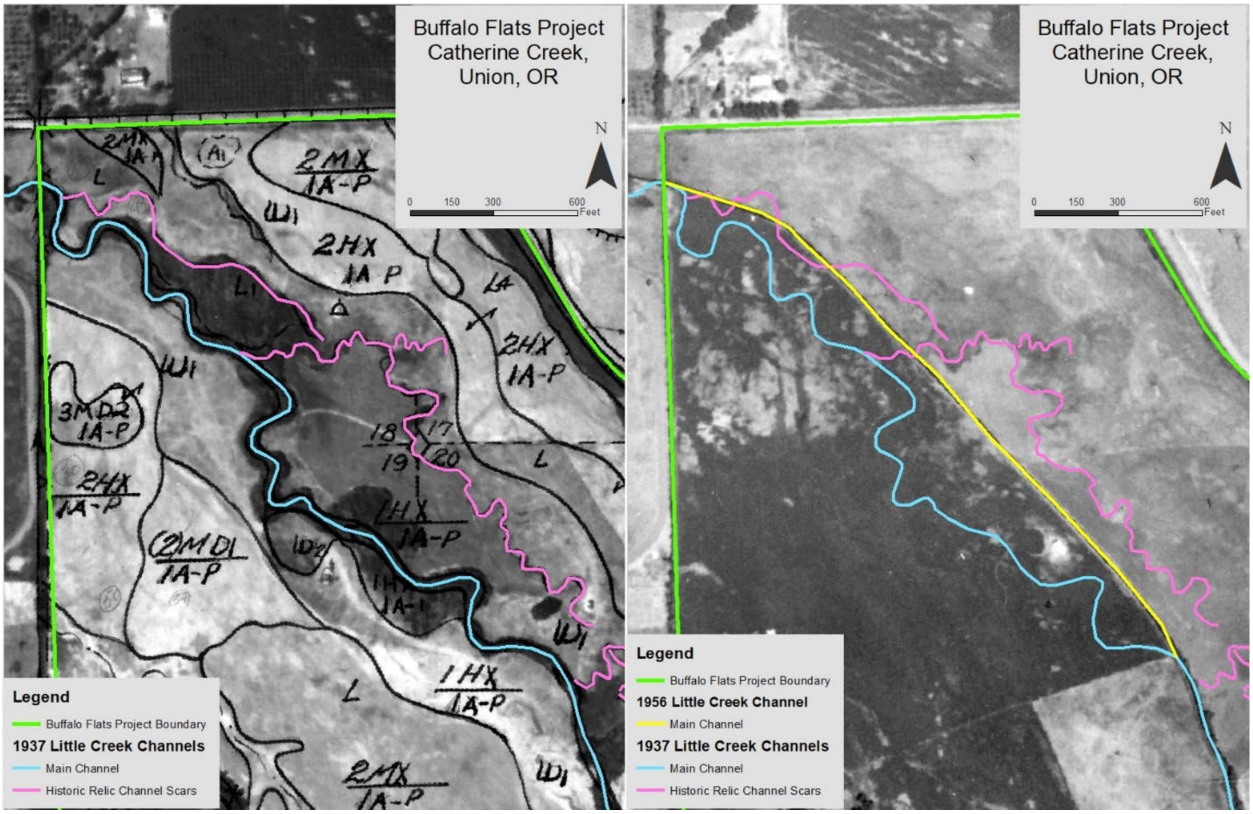


Figure 3: The 1937 aerial image (left) and 1956 aerial image (right) showing the degree of channelization that occurred on Little Creek between 1937 (main channel depicted in blue) and 1956 (main channel depicted in yellow) in the downstream region of the project area.

2.1.2 FEMA modeling of the floodplain within the project area

Base flood elevations (100-year flood elevations) near and within the project area were developed in 1978 using one-dimensional numerical modeling as part of the Union County and City of Union Flood Insurance Studies (HUD, 1978)). Modeling was performed using the U.S. Army Corps of Engineers Hydraulic Engineering Center's HEC-2 model, and model results are represented in currently adopted Flood Insurance Rate Maps (FIRMs) for Union County and the City of Union (UD, 1978)). Numerical hydraulic models were developed in "detailed" study areas only. Detailed studies were performed for Little Creek through the project area and downstream through the City of Union. Current Flood Insurance Rate Maps for the project area and adjacent City of Union are shown below in Figure 4. These maps have been identified by FEMA as an area that needs updating, although a definitive timeframe on the map update is unknown.

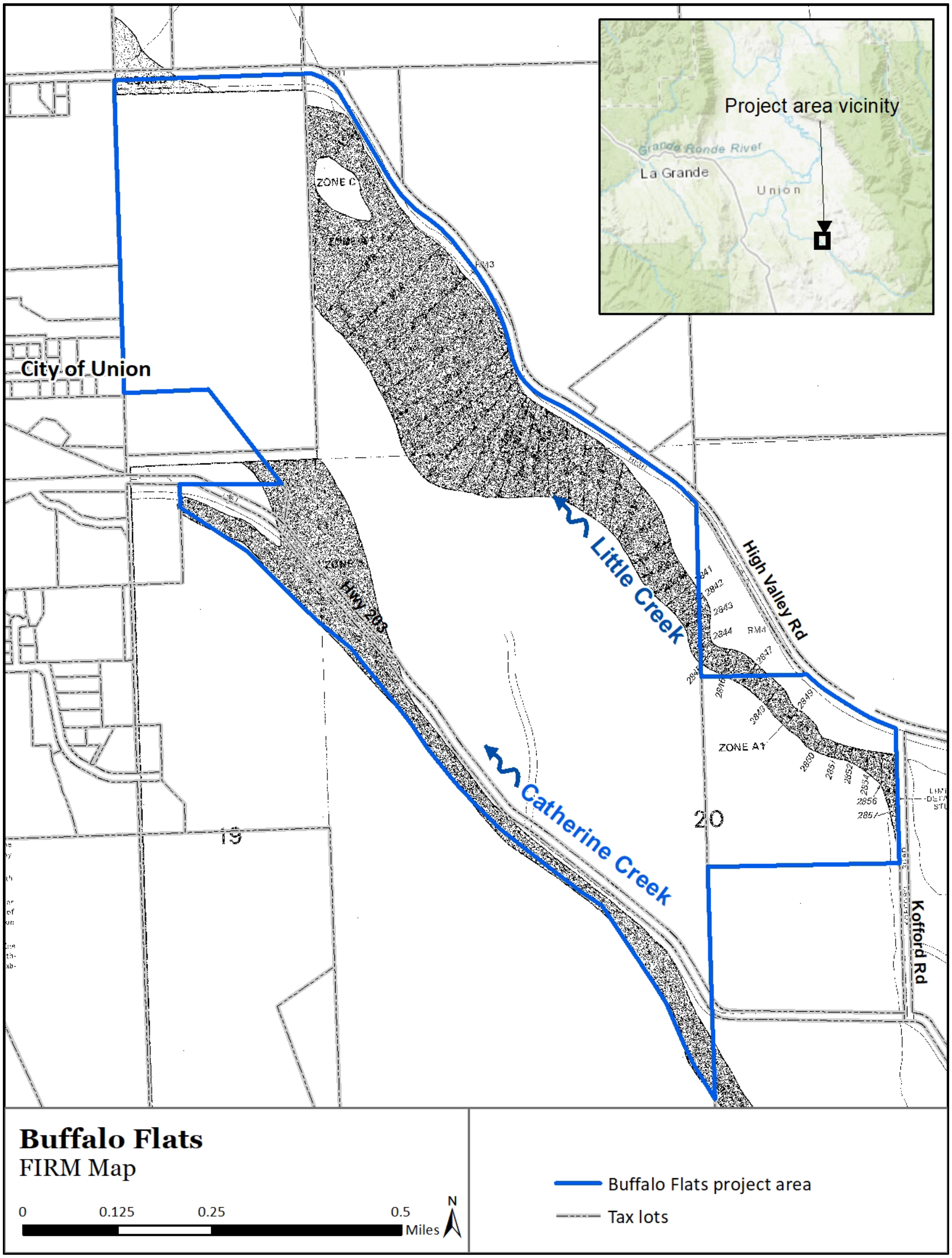


Figure 4. Adopted FEMA Flood Insurance Rate Maps (FIRMs) at project area (100-year flood) - Union County FIRM Map Panel 4102160429B and City of Union FEMA Map Panel 4102230001

2.2 Instream Flow Management and Constraints in the Project Reach

The State Ditch diversion brings water from Catherine Creek into Little Creek at the upstream end of the project area. This water is transported by Little Creek into another ditch, currently located mid-project. This project will move the location of the ditch takeoff to the upstream end of the proposed grading but will otherwise not alter either the inflow or the capacity of the State Ditch diversion.

2.3 Description of Existing Geomorphic Conditions and Constraints on Physical Processes

2.3.1 Historical forms and processes

Little Creek emerges from a relatively steeper and more confined reach into the open valley. Upon entering the valley, sediment transport capacity is rapidly reduced due to increases in channel width, and reductions in confinement and channel gradient. During the Pleistocene glacial period, the Little Creek channel would have been braided, or multithreaded, with lateral and mid channel bars, beginning at the slope inflection where the stream enters the valley. Sediment supply and transport mechanisms would have included debris flows, channelized water flow and sheet-flooding (Schumm et al., 1996). During this time an alluvial fan formed where the stream enters the open valley.

As the climate warmed and dried following the Pleistocene glacial period, Little Creek discharge decreased, thus lowering sediment transport competency and capacity. This changed the sediment transport regime from depositional to one characterized by channel incision and widening, creating inset surfaces in the upper sections of the fan (Schumm et al., 1996). After the channel incised into glacial outwash and floodplain surfaces were formed, large scale avulsions initiated by bank overtopping would have occurred on a much less frequent basis, if at all, compared to those experienced during the glacial period. Colonization of banks by vegetation would have further increased bank stability. However, localized reworking of sediment and colonization of vegetation on bars and inset surfaces would have increased levels of hydraulic roughness in certain areas enough to reinitiate divergence of flow between the terraces.

2.3.2 Contemporary forms and processes

Little Creek presently emerges from High Valley and flows across its Pleistocene-age alluvial fan in a northwest direction. The fan surface slope is approximately 0.8 percent as measured in the stream flow direction. The main channel is a single-thread planform with a riffle-run morphology with a few pools, sinuosity of 1.2, and a bed slope of 0.7 percent. Contemporary bank armoring, channel straightening, and incision have reduced lateral connectivity to the floodplain.

The sediment transport regime on Little Creek is assumed to be transport dominant in approximately the upstream third of the channel segment within the project area. Downstream, high flows can overtop the banks in some areas, and overbank flows can occur in lower lying areas. Sediment dynamics are described in more detail in Section 3.4.

2.3.3 Existing conditions of subreaches

For the purposes of analysis, the project area was subdivided into four subreaches (Figure 5, Table 4). Each subreach is illustrated below with existing geomorphic and habitat characteristics. All photos in this section were taking during an August 2020 site visit.

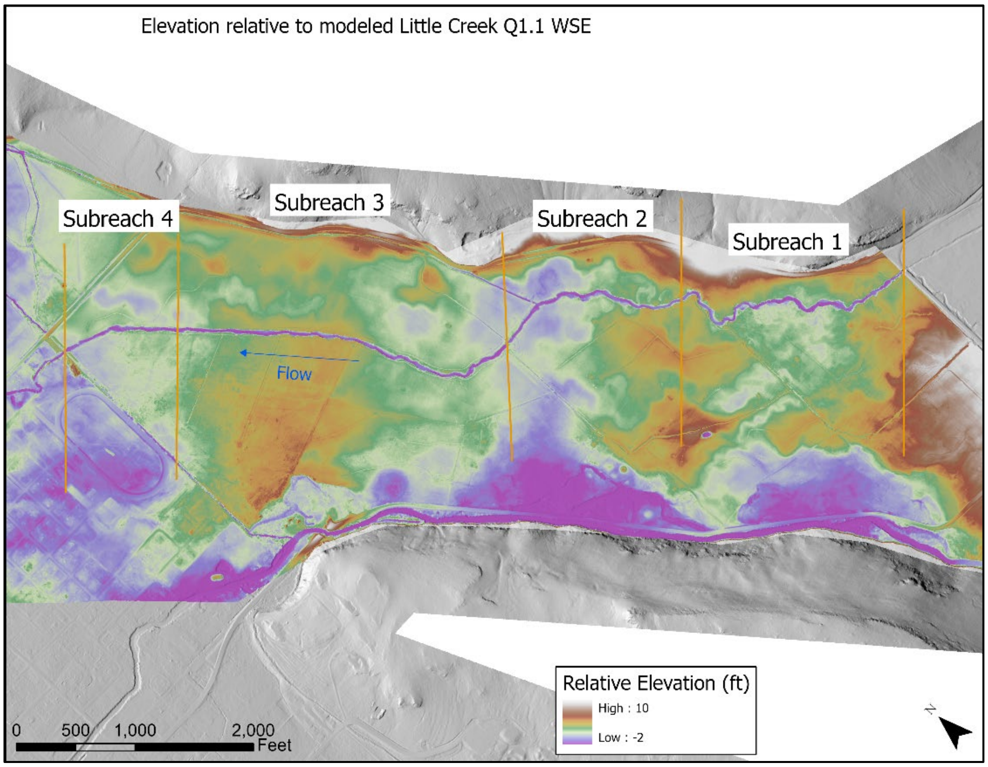


Figure 5. Approximate subreaches within the project area displayed on a relative elevation map

Subreach 1: starts on the upstream (eastern) end of the project area, at Kofford Road and extends to the downstream end of the McCrae property.

Subreach 2: starts at the downstream end of the McCrae property and extends to the existing farm crossing.

Subreach 3: starts at the existing farm crossing and extends through the main channelized downstream section.

Subreach 4: includes approximately 1000 feet of channel upstream of the downstream property boundary and is characterized by somewhat more floodplain connectivity.

Table 4. Summary of subreach characteristics

Subreach	Channel Slope	Valley Slope	Thalweg to top of bank
Subreach 1	– 0.64%	– 0.8%	3-4 ft and consistent
Subreach 2	– 0.61%	– 0.9%	2-4ft. Lower banks immediately upstream of bridge
Subreach 3	– 0.72%	– 0.75%	3-6ft. More entrenched in downstream direction
Subreach 4	– 0.54%	– 0.75%	3-6ft. Less entrenched in downstream direction

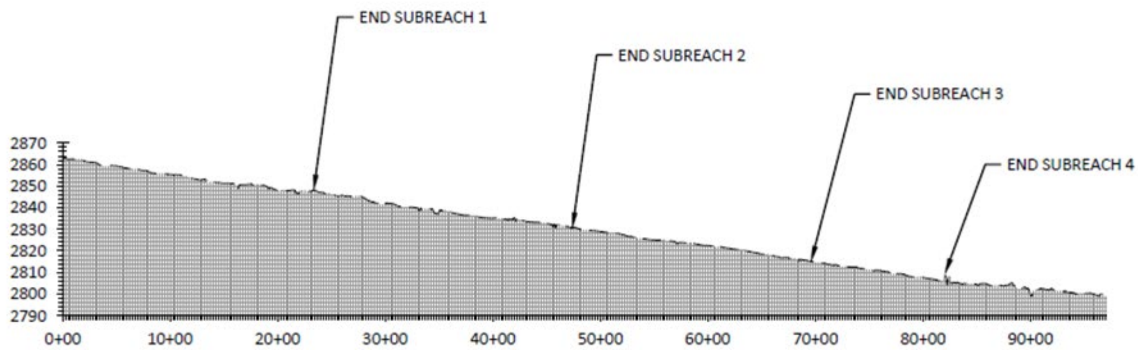


Figure 6. Longitudinal profile of the Little Creek channel with subreach breaks called out.

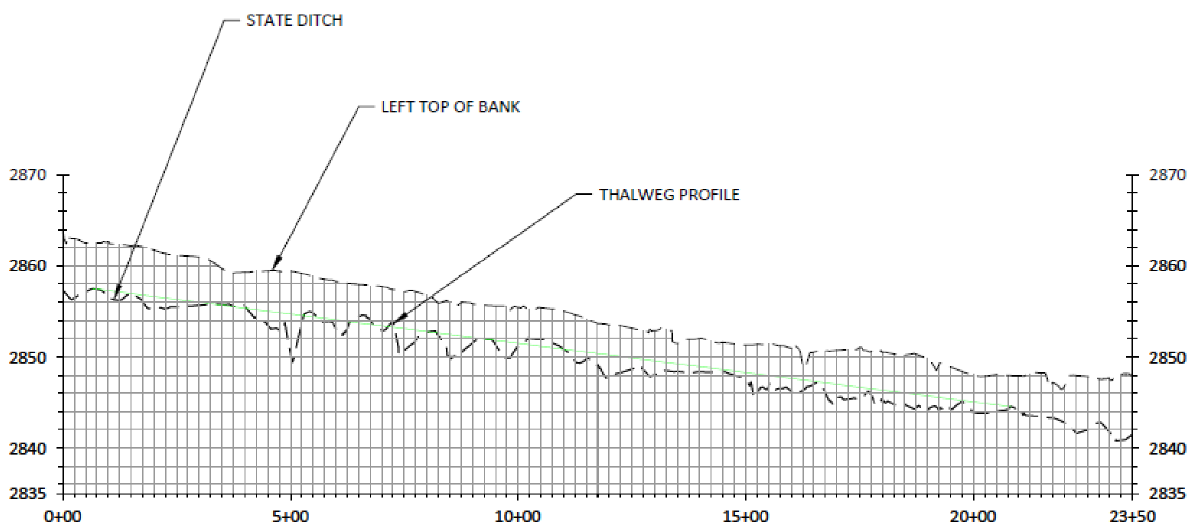


Figure 7. Subreach 1 profile (vertical exaggeration of 20:1)

Figure 8. Subreach 1 characteristic photos

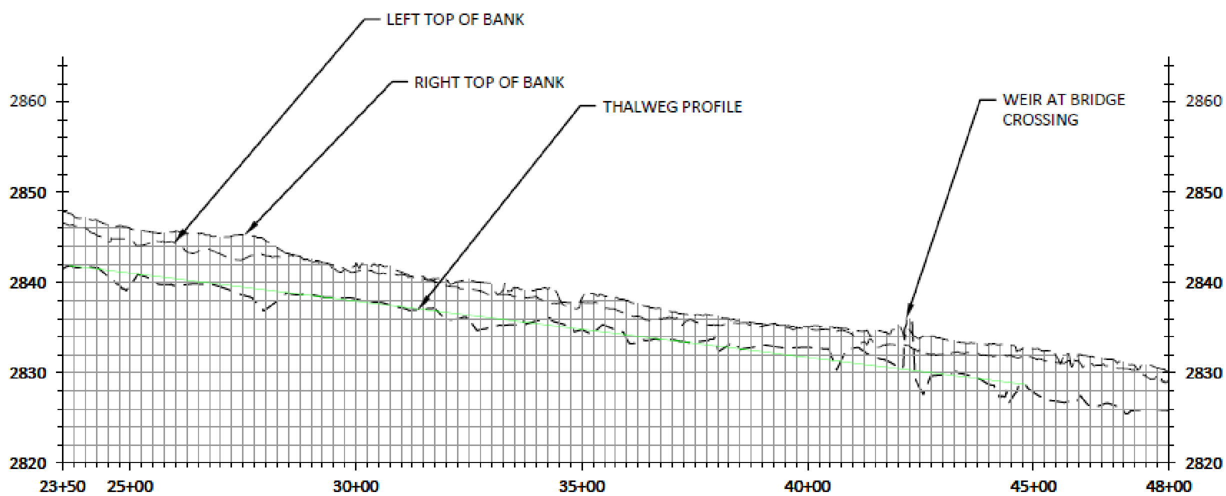


Figure 9. Subreach 2 profile (vertical exaggeration of 20:1)

Figure 10. Subreach 2 characteristic photos.

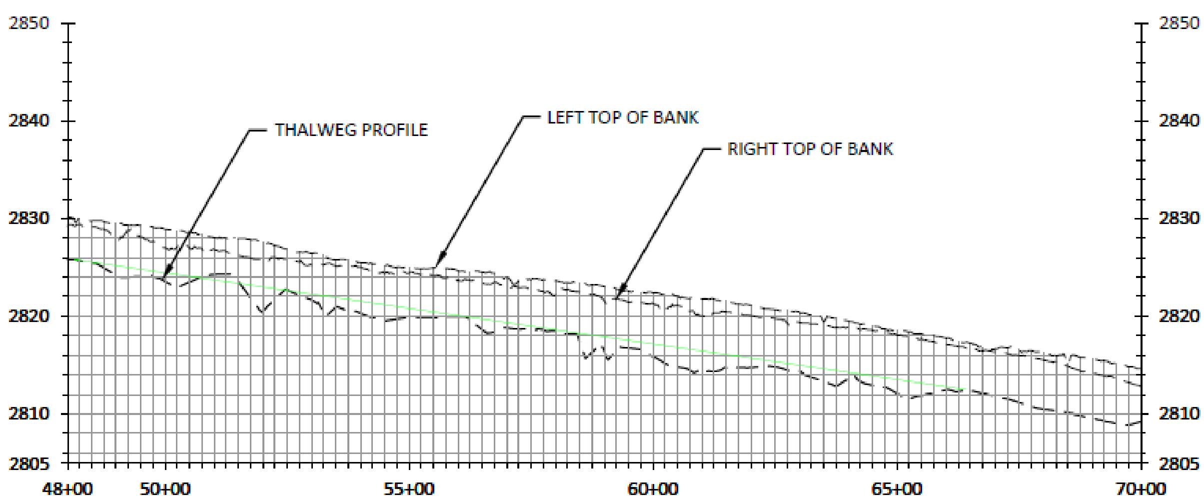


Figure 11. Subreach 3 profile (vertical exaggeration 20:1

Figure 12. Subreach 3 characteristic photos.

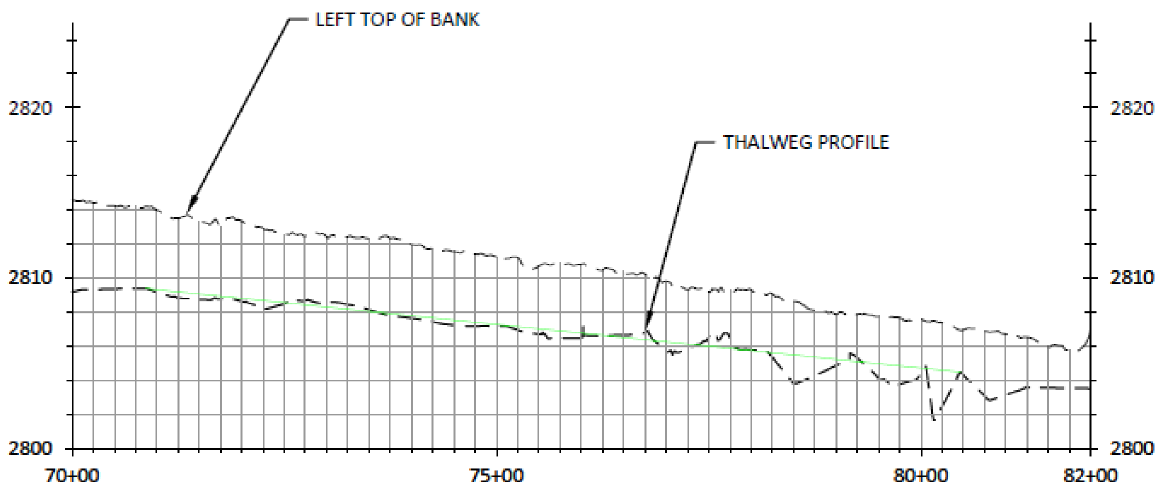


Figure 13. Subreach 4 profile (20:1 vertical exaggeration).

Figure 14. Subreach 4 characteristic photos.

2.3.4 Analog sites desktop analysis

Several potential analog sites were identified via personal communication with local staff and desktop analysis. While none of these sites is an ideal "analog", there are elements of each site that help inform project design as well as support a shared expectation of project outcomes among partners. The potential analog sites and associated projects are described in Table 5.

Table 5 - Buffalo Flats Little Creek Project Area, existing description

Site	Drainage Area (mi^2)	Valley Slope	Valley Width (ft)	Sinuosity	Lateral Migration	Notes
Little Creek, OR	*37.5*	*0.008*	*2,000*	*1.07*	Almost no lateral migration 1990s-present; confined by human alteration for agriculture. Currently high ground separating Little Creek and Catherine Creek. Large alluvial fan within the town of Union and downstream. Likely very complex in the past.	Valley bottom represents both Little Creek and Catherine Creek. Actual Little Creek bottom width 1000-1500 ft, approximately.

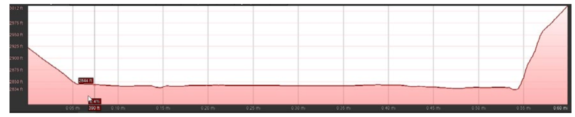
	representative valley cross section and aerial:  

Table 6 - Potential analog location – Hall Ranch Side Channel

Site	Drainage Area (mi^2)	Valley Slope	Valley Width (ft)	Sinuosity	Lateral Migration	Notes
Hall Ranch Side Channel, OR	n/a	0.015	1,500	1.13	Recently developed side channel (2011-present); confined on LB by road; blocked from extensive floodplain to the SW. Beaver are active in Catherine Creek, but no recent beaver activity in this channel has been observed	This valley is almost double the slope of the Little Creek project area. Hydrology may be similar depending on the flow split. The floodplain soils at this location are shallow and gravel is present on the surface throughout.

representative valley cross section shape and aerial:

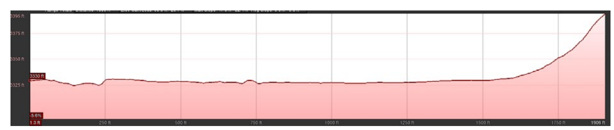


Table 7 - Potential analog location – Badger Creek, Warm Spring Reservation

Site	Drainage Area (mi^2)	Valley Slope	Valley Width (ft)	Sinuosity	Lateral Migration	Notes
Badger Ck., OR	37.8	0.008	750-1,000	1.28	Wide valley bottom with one to two main channels and many of small side channels & low relief areas in between. Large wood is present in valley bottom despite limited LW recruitment potential locally. Beaver are active. Limited anthropogenic disturbance visible, other than road crossings. No visible cut banks. Deep narrow channels.	Valley width is higher upstream of HWY26 crossing; CIR image (2011) captures plant growth in valley well. The "green line" spans the valley, with large shrubs dominant. Slope and drainage area are very similar to Little Creek (although hydrology differs on eastern flanks of Mt Jefferson and valley is narrower. Fringe herbaceous vegetation along channel, gives way to robust woody vegetation on most of the floodplain.

representative valley cross section shape and aerial:

Table 8 - Potential analog site - Catherine Creek Southern Cross Swale Complexes

Site	Drainage Area (mi^2)	Valley Slope	Valley Width (ft)	Sinuosity	Lateral Migration	Notes
Catherine Creek., OR	108	0.015	750-1,200	Imposed by channel construction	Increased lateral activity and sediment deposition due to increased planform complexity. Woody vegetation is thriving on the floodplain and in freshly deposited/sorted sediments.	Location in the upstream portion of the project identified as an analog for vegetative response to restoration. Wetland fringe and woody establishment similar to Badger Creek. More detailed field observations and data collection in the downstream reach of the site is included in the Vegetation Tech Memo 12/31/2022

representative valley cross section shape and aerial:

2.4 Description of Existing Riparian Condition and Historical Riparian Impacts

Riparian vegetation within the Little Creek project limited to a narrow, discontinuous strip along the top of the banks (Figure 15, Figure 16). Floodplain and upland vegetation have been removed for agricultural use and grazing practices. The wetland delineation (Appendix F) provides additional information about existing conditions. The historical aerial images from 1937 (Figure 2, Figure 3) show evidence of a more substantial riparian zone, albeit one already heavily impacted by agriculture.

Figure 15: An oblique aerial image (2021) showing the discontinuous strip of riparian vegetation along the bank and conversion of floodplain vegetation to agricultural.

Figure 16 - An oblique aerial image (2021) from the side, showing the mature willows scattered discontinuously along the existing riparian zone.

2.5 Description of Lateral Connectivity to Floodplain and Historical Floodplain Impacts

As described above in Section 2.2, existing lateral connectivity to the floodplain has been reduced through bank armoring, channel straightening and incision.

2.6 Tidal influence in project reach and influence of structural controls (dikes or gates).

There is no tidal influence in the project reach.

3 Technical Data

3.1 Incorporation of HIP IV Specific Activity Conservation Measures for all Included Project Elements

HIP conservation measures will be included throughout the project design process. HIP conservation measures are met for the project elements.

Description of proposed element	**Work element name**	**HIP category**	**HIP risk level (estimated)**
Grade multi-thread channel to mimic historical conditions at this site, including increased length, sinuosity, and floodplain connection	Improve secondary channel and floodplain connectivity Channel reconstruction	2a, 2f	Medium or high
Instream habitat wood (small trees, willow post structures)	Install habitat-forming instream structures	2d	Medium
Remove existing farm crossing and associated culvert	Bridge and culvert removal or replacement	1f	Medium
Relocate irrigation ditch.	Consolidate or replace existing irrigation diversions	1b	Low
Install constructed riffles	Headcut and grade stabilization	1c	Medium
Riparian and wetland planting	Riparian vegetation planting	2e	Low

3.1 Summary of Site Information and Measurements (Survey, Bed Material, Etc.) Used to Support Assessment and Design

3.1.1 Digital Terrain Model

The digital terrain model for this project was created from a mosaic of two LiDAR data sets. NIR-LiDAR data collected in 2020 (NV5 2022) and provided to the design team contains coverage for the majority of the project area, with the exception of the floodplain in the northeast corner of the site. This area was supplemented with publicly available LiDAR data collected in 2009 (Watershed Sciences, 2009), which provides elevation data along High Valley Road and extends approximately 300-ft into the floodplain. LiDAR data were compared to channel survey data collected in 2019 and floodplain survey data collected in 2020. Recent land use attributes contributed to variability in offsets between LiDAR and ground survey data in the floodplain areas, with recently grazed/mowed surfaces agreeing well with the LiDAR. Based on these comparisons, no adjustment of LiDAR derived floodplain elevations was recommended. Surveyed channel cross sections were compared to the LiDAR data throughout the project area. In all locations the LiDAR provided a more detailed representation of the channel bed and was therefore used exclusively to represent channel topography.

3.1.2 Aerial Photography and Historical Survey Records

See Figure 2 and Figure 3, section 2.1.1 Historical Land Use.

3.1.3 Fish Use Data

Fish use data analyzed include results of ODFW electroshock surveys and water temperature evaluations in Catherine Creek and Little Creek; fish species distribution data from the Grand Ronde Model Watershed Catherine Creek Restoration Atlas (GRMW, 2021); and life history timing data from "Investigations into the Early Life-history of Naturally Produced Spring Chinook Salmon and Summer Steelhead in the Grande Ronde River Basin" ((Jonasson et al., 2002)). These data are presented in section 1.4.

3.1.4 Vegetation Data

Location and species composition data for vegetation communities within the Buffalo Flats project area were collected during the 2020 site survey. Additional vegetation data were collected during the wetland delineation in spring/summer 2022 (see Appendix F).

In fall of 2022 the Southern Cross reach on Catherine Creek was identified as a potential reference site for target plant communities representative of post-project conditions at Buffalo Flats. In November 2022, members of the design team conducted a site visit to the Southern Cross reach and identified the most appropriate analogue vegetation communities present. Data were collected summarizing species composition and the elevational position of these vegetation communities on the floodplain relative to the low-water table (see Appendix).

3.1.5 Topographic and Bathymetric Survey

A summary of topographic and bathymetric survey data utilized, including sources and collection dates, are presented in Appendix A.

3.1.6 Soils and Test Pit Data

To support the project design, test pits were excavated in the project area to document subsurface sediment characteristics, and to enable the monitoring of groundwater levels throughout the duration that the test pits remain open. On September 6 and 7, 2023T. 29 test pits (Figure 17) were excavated up to a depth of approximately 8 feet using a mini excavator.

Subsurface conditions at all 29 test pits included silty topsoil underlain by a gravel layer encountered at depths ranging from 1.7 to 5.9 feet below the ground surface. The mean depth to the gravel layer across all 29 test pits was 3.5 feet, and gravels generally increased in diameter and frequency with depth. The surface of the gravel layer was generally above the groundwater surface. Groundwater was observed in 23 of the 29 test pits, at depths ranging from 3.3 to > 8 feet below the ground surface. Additional information is provided in Appendix D. The information generated in this investigation informed project design, in particular the relative location of gravels relative to proposed grading. In general, gravel will be at or below the finish grade surface in the majority of locations. The need to develop gravel materials in-situ (below finished grade) is described in the drawings.

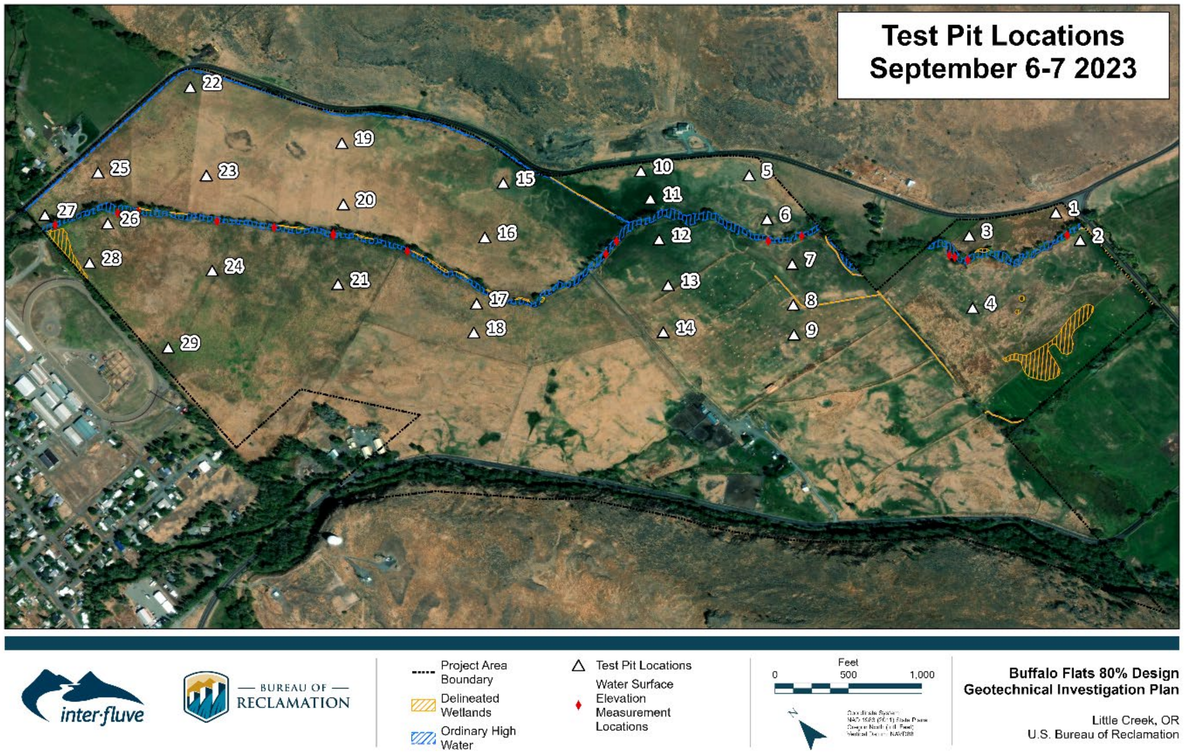


Figure 17. Locations of test pits excavated during an investigation into subsurface conditions at the project site.

3.2 Summary of Hydrological Analyses Conducted, Including Data Sources and Period of Record Including a List of Design Discharge (Q) and Return Interval (RI) for Each Design Element

See Appendix A, Hydraulic Modeling Report.

3.3 Summary of sediment supply and transport analyses conducted, including data sources including sediment size gradation used in streambed design

Field observations of the character of sediment in the existing Little Creek channel, and design considerations related to sediment continuity are described below.

Sediment input –The channel upstream of the project area is narrower than the channel within the project area and is routed through two 90 degree turns in its imposed alignment (Figure 20). If sediment input from upstream was significant in this system, we would expect to observe accumulations of sediments at these 90-degree bends. However, observations of these areas in August 2020 showed no signs of major sediment accumulation (Figure 18, Figure 19). Based on observations of the channel immediately upstream of the site, the existing Little Creek channel is unlikely to supply a large amount of sediment to the site, and nuisance sedimentation is unlikely to be a high risk at the upstream project boundary.

Figure 18 - Little Creek immediately upstream of the project area. Photo is taken from Kofford Road looking east. Main Little Creek channel comes in from the right of the photo, while the flow in the center of the photo is irrigation return.

Figure 19 - Little Creek to the east of Kofford Road.

Figure 20 - Little Creek channel alignment upstream of the project along Kofford Road.

Existing channel bed sediment – Grains in the existing bed are estimated to have a D50 of ~ 1" and D84 of ~ 2.5" from visual estimates (Figure 21). Sediment in the channels appears similar to material observed in cutbanks throughout the site. Given the assumptions about sediment input described above, coupled with observation from cutbanks within the project area (Figure 22), it is assumed that a significant portion of this material is derived from lateral migration of the of channel into the existing floodplain strata as it forms an inset floodplain.

Figure 21 - Typical material deposited in point bars in the main channel of Little Creek. The lower panel show a close up of the material, while the upper panel shows materials deposited above the grade control at the existing bridge in the middle of the project area.

Figure 22 - Cutbanks in Subreach 3 showing stratum of fine material, maintaining a vertical bank profile, above layers with mixed gravels and fines.

Sediment Transport trajectory post-project – We anticipate that deposition in the upstream portion of the channel will enhance floodplain connectivity over time and have designed channel spanning treatment elements to encourage deposition. As treatment elements gather sediment, the adjacent floodplain will become activated more frequently. If sediment accretes to the top of the installed structures, it is anticipated that additional incoming sediment would continue to be routed downstream. The design elevation of the upstream-most post assisted brush mound is lower than the channel bed at the crossing underneath Kofford Road. If this structure fills with sediment, it should not reduce conveyance capacity at the crossing. The existing channel alignment just downstream of Kofford Road is not very sinuous. More frequent overbank flows resulting from deposition will likely have longer flow paths across the floodplain compared to the flow path in the existing channel, making avulsion unlikely.

3.4 Summary of hydraulic modeling or analyses conducted and outcomes – implications relative to proposed design

See Appendix A, Hydraulic Modeling Report.

3.5 Stability Analyses and Computations for Project Elements, and Comprehensive Project Plan

3.5.1 - Riffle Stability

Modeled shear stress values from the Q100 proposed conditions model were utilized to analyze riffle gradation stability. Shear stress values near the constructed riffle location was utilized in this analysis and shear stress values are reported in Table 9.

Table 9 - Modeled shear stress near riffle location

Riffle Location	Modeled Shear Stress (lb/ft^2)
State Ditch Diversion	1.7

The Shields relationship for incipient motion describes the critical shear stress (Tc) needed to move a particular size of particle on the stream bed based on slope and hydraulic radius.

$$Tc = k * D_{50} * (\gamma_{sediment} - \gamma_{water})$$

Where Tc is critical shear stress, k is the Shields parameter (assumed to be 0.03 for gravel), D_{50} is the median grain size and γ is the unit weight of sediment and water.

Utilizing modeled shear stress outputs from the HEC-RAS 6.5.1 hydraulic model, D-50 for incipient motion was calculated at each of the constructed riffle locations utilizing the equation above. In both riffle locations material less than ~ 6 inches will be stable.

3.5.2 Large Wood Stability

Stability analysis and computations for project elements followed professional practice guidelines for large wood design (D'Aoust & Millar, 2000; Knutson & Fealko, 2014; and (US Reclamation & US Army Corps of Engineers, 2016), stream habitat restoration (Cramer, 2012), bank treatments (Cramer et al. 2002), and institutional knowledge combined with professional judgment for the design of specific project elements. Utilizing the risk matrices described in (Knutson & Fealko 2014), this project was determined to pose a low public safety risk and a moderate (Figure 23, Figure 24).

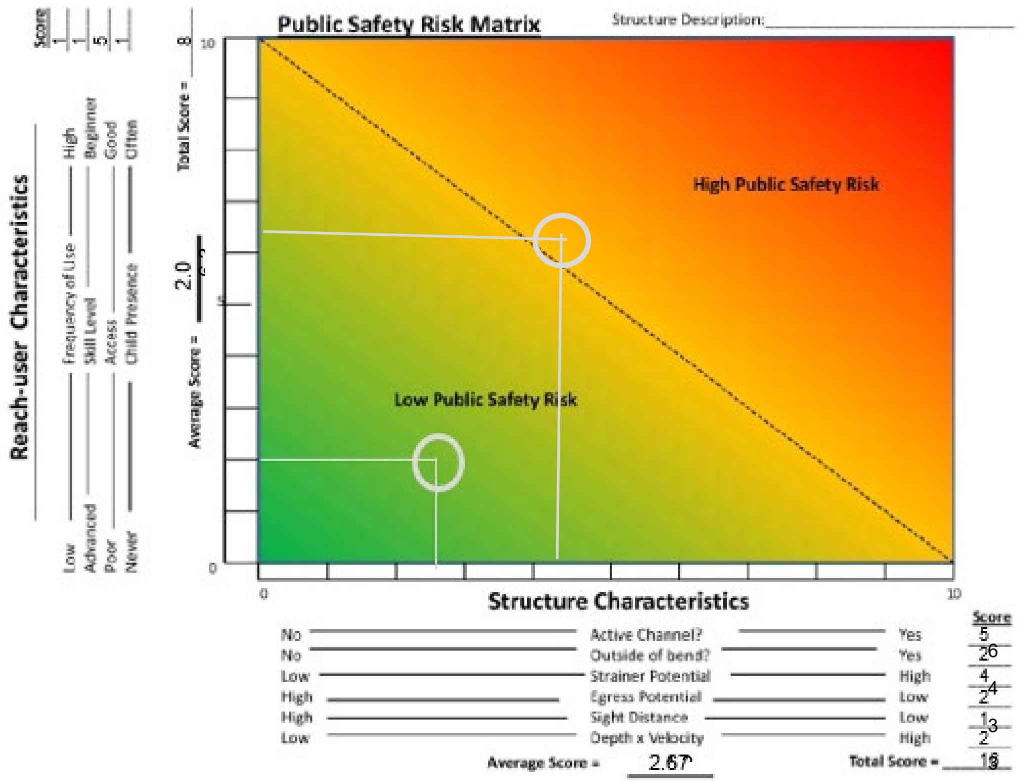


Figure 23 - Public Safety Risk Matrix

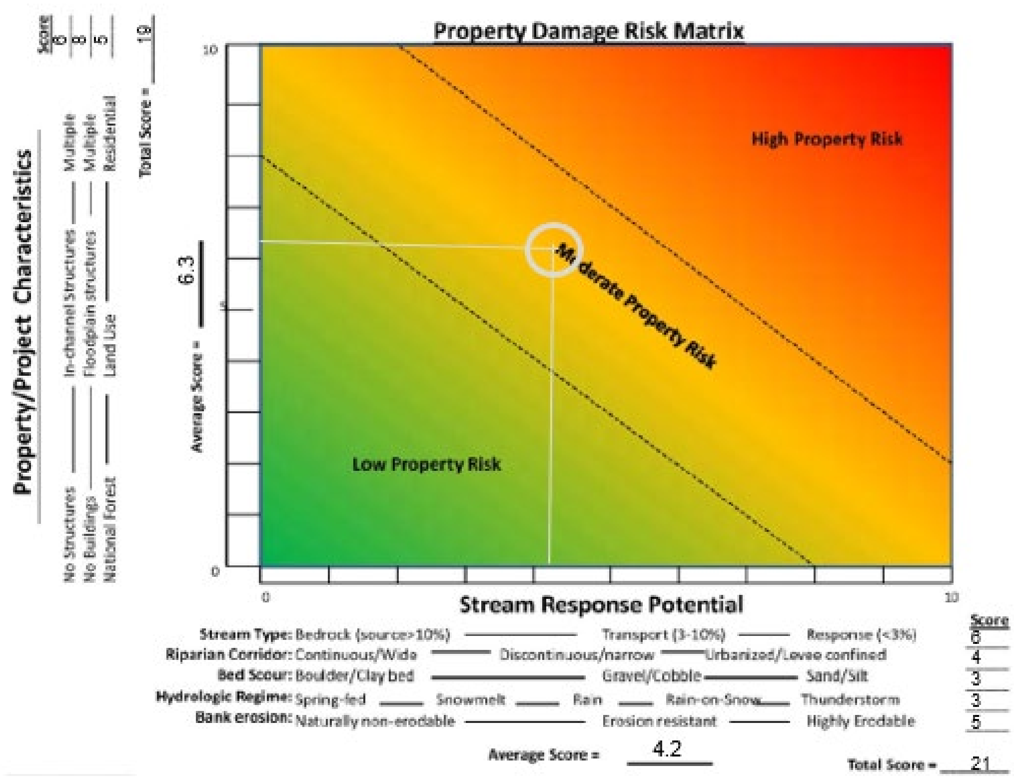


Figure 24 - Property Damage Risk Matrix

The LWM placements and LWS have been designed to meet the minimum recommended factors of safety provided in the USBR's Large Wood Material Risk Based Design Guidelines (Knutson & Fealko, 2014) for the risk categories identified in the matrices above (i.e. low public safety risk and high property damage risk). These values are provided in Table 10 below.

Table 10 - Minimum recommended factors of safety

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$
Low	Moderate	25-year	1.5	1.75

Note: Values are from Table 4 p. 47 (Knutson et. al. 2014). $FOS_{rotation}$ and $FOS_{overturning}$ are not reported as they are not critical to the project structure types.

Proposed conditions 2-D hydraulic model outputs for were used to determine conservative design velocities upstream of each structure type, and conservative assumptions relative to the sizes of individual log members were made in accordance with the design plans and specifications. The computed factor of safety equals or exceeds the recommended factors of safety for each structure type described in Table 11, suggesting that the structures can be considered stable for the assumed risk tolerance. Calculation details can be referenced in Appendix E.

Table 11 - Stability Analysis Summary - Large Wood Structures

Large Wood Structure Type	Target Factor of Safety (Buoyancy)	Design Velocity (ft/s)[1]	Calculated Factor of Safety	Stable Under modeled Design Conditions?
Flow Splitting Structure	1.75	3.5	2.08	Yes
Channel Spanning Structure	1.75	3.5	1.75	Yes
Habitat Large Wood Structure	1.75	3.5	1.97	Yes
Small Whole Tree (channel)	1.75	3.5	1.75	Yes
Small Whole Tree (flooplain)	1.5	2.0	1.76	Yes
Notes:				
[1] *Design velocites determined from HEC-RAS model results for the the 100-year flow event.*				

While the public safety and property damage risk assessments described above pertain to the footprint of the project site, its location upstream of the town of Union warrants additional consideration. To that end, additional model simulations were conducted to investigate the impacts of potential accumulations of ice and wood on the floodplain as well as changes to infrastructure that could occur during large flood events. Results from these simulations and discussion of the implication and considerations can be found in Appendix B.

3.6 Description of How Preceding Technical Analysis has been Incorporated into and Integrated with the Construction – Contract Documentation.

Integration of design analyses into the construction and contract documentation will be described at the Final Design phase.

4 Construction – Contract Documentation

4.1 Incorporation of HIP General and Construction Conservation Measures

This project is designed in accordance with HIP conservation measures. The measures are included in the drawings and will become part of the construction contract.

4.2 Design – construction plan set including but not limited to 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 project drawings are included with this Basis of Design report for review.

4.3 List of all proposed project materials and quantities.

Engineer's Opinion of Probable Construction Costs - 80%
Buffalo Flats Floodplain Restoration
19-Dec-24

Base Bid Items

No.	Bid Item	Unit	Unit Price	Quantity	Subtotal
1	Mobilization and demobilization	LS	$148,800	1	$148,800
2	Environmental controls (SWPPP, hydraulic fluids, etc...)	LS	$ 49,600	1	$49,600
3	Temporary Access, Haul Roads and Staging	LS	$ 33,100	1	$33,100
4	Dewatering and water management	LS	$ 66,100	1	$66,100
5	Construction Surveying	LS	$ 25,000	1	$25,000
6	Channel Excavation and Haul	CY	$ 17	35,760	$607,920
7	Channel Finish Grading	LF	$ 6	6,500	$39,000
8	Fill Placement and Stockpile	CY	$ 8	35,760	$286,080
9	Decomission access roads, Site Cleanup and Repair	LS	$ 11,500	1	$11,500
10	Construct Riffles	CY	$ 35.00	215	$7,525
11	Install Headgate	LS	$ 4,000	1	$4,000
12	Remove existing Bridge	LS	$ 5,750	1	$5,750
13	Install Large Wood - Channel Spanning Structure	EA	$ 4,000	20	$80,000
14	Install Large Wood - Habitat Wood	EA	$ 1,000	97	$97,000
15	Install Large Wood - Flow Splitting Structure	EA	$ 1,400	17	$23,800
16	Sod salvage, store, maintain and transplant	SY	$ 4.00	33,472	$133,889
17	Willow Trench	LF	$ 11.50	6680	$76,820
18	Flood Fence	LF	$ 11.50	1060	$12,190
19	Planting - Woody, Riparian and Transitional	AC	$ 4,600	17	$78,200
20	Planting - Woody, Upland	AC	$ 2,900	29	$84,100
21	Apply Seed and Mulch	AC	$ 2,300	46	$105,800
22	Medium Track Hoe (Weight greater than 20 tons)	HR	$ 250	40	$10,000
23	Small Track Hoe (Weight between 6 and 20 tons)	HR	$ 200	80	$16,000
24	Mini-Excavator (Weight 6 tons or less)	HR	$ 190	40	$7,600
25	Off-Road Dump Truck (i.e CAT 735 or similar)	HR	$ 225	40	$9,000
26	Dozer (i.e, CAT D6 or similar)	HR	$ 225	40	$9,000
	Total				**$2,027,774**

4.4 Description of best management practices that will be implemented and implementation resource plans including:

4.4.1 Site Access Staging and Sequencing Plan with description

Access will avoid wet/sensitive area to the degree practicable, and impact will be constrained to designated access route and locations where excavation or fill is planned. Staging/refueling areas will be located a minimum of 150 ft from open water. Suggested construction sequencing is described in the project drawings.

4.4.2 Work Area Isolation and Dewatering Plan with description of how aquatic organisms within the action area will be treated / protected.

Work area isolation and turbidity management strategies are described in the design drawings. In general, the State Ditch diversion will be used during construction as a bypass, with only a short segment of additional temporary bypass needed at the downstream end of the project. Fish rescue will be scheduled in coordination with the activation of the bypass and the dewatering of the main channel.

4.4.3 Erosion and Pollution Control Plan

The contractor will be required to submit an erosion and pollution control plan prior to the commencement of work.

4.4.4 Site Reclamation and Restoration Plan

All disturbed areas will be ripped to unconsolidated densities and will be mulched with certified weed-free straw and seeded with native forbs targeted to the proposed conditions hydrology of the site.

4.4.5 List proposed equipment and fuels management plan

The construction contractor will be responsible for developing and submitting an appropriate equipment and fuels management plan to be reviewed and accepted by the contracting agency and engineer of record. Low ground pressure equipment will be preferred.

4.5 Calendar schedule for construction/implementation procedures

The project will be constructed in the Summer of 2025.

4.6 Site or project specific monitoring to support pollution prevention and/or abatement

Turbidity monitoring, as described in the HIP IV protocols, will be required during construction.

5 Monitoring and Adaptive Management

5.1 Introduction

The Monitoring and Adaptive Management Plan will be developed by the project sponsor as part of the final design of this project and will be detailed in the Land Management Plan document.

6 References

Citation in Text	Bibliographic Reference
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US Bureau of Reclamation and U.S. Army Corps of Engineers 2016.	Bureau of Reclamation and U.S. Army Corps of Engineers. (2016*). National Large Wood Manual: Assessment, Planning, Design, and Maintenance of Large Wood in Fluvial Ecosystems: Restoring Process, Function, and Structure*. 628 pages + Appendix. Available: www.usbr.gov/pn/.
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