90 PERCENT FINAL BASIS OF DESIGN REPORT

WHITEFISH ISLAND HABITAT IMPROVEMENT PROJECT

Prepared for

U.S. Bureau of Reclamation

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LIST OF ACRONYMS AND ABBREVIATIONS

1-D	one-dimensional
2-D	two-dimensional
AER	Alternatives Evaluation Report
BEGS	below existing ground surface
BFE	base flood elevation
BODR	Basis of Design Report
cfs	cubic feet per second
CPAA	Conceptual Project Alternatives Assessment
ELJ	engineered log jams
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
fps	feet per second
HEC-RAS	Hydraulic Engineering Center–River Analysis System
LWD	large woody debris
M2	Middle Methow
MSRF	Methow Salmon Recovery Foundation
psi	pounds per square inch
RA	Reach Assessment
RM	river mile
Reclamation	U.S. Bureau of Reclamation
TA	Tributary Assessment
WFI	Whitefish Island

1 INTRODUCTION

The following Basis of Design Report (BODR) documents engineering and supporting calculations for the Whitefish Island Habitat Improvement Project Bid Set Drawings and Specifications. The Bureau of Reclamation (Reclamation) proposes to design and construct (with project partners) a salmonid habitat project in the upper part of the middle Methow River (and side channel) near Twisp, Washington, in the summer of 2012 identified as Whitefish Island (WFI). The following report builds upon a previous 90 percent draft design drawings and design report completed by Anchor QEA in March 2012 (Anchor QEA 2012a).

The goal of this project is to improve habitat conditions in the main channel Methow River and side channel in support of Endangered Species Act (ESA) listed species. Specific habitat enhancement goals include (Anchor QEA 2011a):

- Increase hydraulic and habitat complexity in the main channel and side channel
- Increase the duration and extent of surface water flow in the side channel
- Improve structural complexity and cover through the side channel by promoting natural processes through the installation of a series of engineered log jams (ELJs) and large woody debris (LWD) structures
- Improve overwintering habitat
- Protect and improve the quantity and function of riparian vegetation by stabilizing banks, promoting bar deposition and the potential for natural establishment of vegetation, and planting appropriate riparian vegetation
- Increase floodplain/channel connectivity through promotion of natural processes

The 90 percent final design addresses these habitat goals with the construction of LWD structures ELJs throughout the side channel to improve habitat conditions. Seven distinct types of structure designs were developed to achieve the habitat goals of this project (ELJ types A, As, and Bp; and LWD types L, S, and Z; and a Live Crib).

1.1 Project Setting

The Whitefish Island subreach is located between river miles (RM) 49.1 to 48.6 of the Methow River (identified as the Upper Middle Methow [M2] Reach). A prominent side channel , located on the right bank between Stations 416+00 to 396+00 (see Bid Set Drawings, Proposed Condition Site Plan [Sheet 5 of 19]), is separated from the main channel by a forested island. At the upstream end of the subreach, the main channel exits a straight, confined run and bends to the west. The channel alternates between runs and riffles through a majority of the subreach. The reach is generally devoid of any functional pool habitat with the exception of one large pool located at the downstream confluence of the side channel with the main channel. A bedrock outcrop is located along the riverbed that extends across a majority of the main stem channel cross-section from approximately Stations 411+00 to 408+00. The surface of the main channel bed in the upper half of the subreach is composed of large cobble and gravel, transitioning to a high-velocity rapid section in the lower half of the main channel with several large immobile boulders protruding from the bed.

The side channel is seasonally connected to the main channel and is typically active when the main channel discharge is approximately 800 cubic feet per second (cfs) (approximately a seasonal [spring] flow exceeded 120 days per year); therefore, it does not convey water during low late-summer flows and low flows that also occur in winter (late August through March). The side channel flows along the toe of the forested island (left bank) for approximately 880 linear feet; it then flows along the toe of the State Route 20 road prism (on the right bank). Two pools of less than 3 feet of residual depth are present along the toe of the highway. The side channel then flows slightly towards the east away from the road prism and joins the main channel.

1.2 Previously Completed Studies

Previous studies completed in support of the Whitefish Island project are presented below in chronological order:

- The Tributary Assessment (TA) (Reclamation 2008)
- The Middle Methow Reach Assessment (RA) (Reclamation 2010)
- Conceptual Project Alternatives Assessment (CPAA) (Anchor QEA 2010)
- Alternatives Evaluation Report (AER) (Anchor QEA 2011b)
- 30 Percent Design Report Upper Middle Methow Reach (Anchor QEA 2011a)
- 60 Percent Basis of Design Report Whitefish Island (Anchor QEA 2012b)
- 90 Percent Draft Basis of Design Report Whitefish Island (Anchor QEA 2012a)

As a part of the CPAA, AER, and 30 percent design efforts, ELJs were considered throughout the main channel. This included mid-channel structures and structures placed primarily along the left bank. During the AER process, Reclamation decided that main channel projects upstream and adjacent to Bear Creek, approximately Stations 422+00 to 416+00, would be deferred to a later planning and design process. This would be associated with potential revisions or decommissioning of the Barkley Diversion. Downstream of Station 416+00, the left bank is owned by one landowner. This landowner was approached during the AER process and habitat enhancement options, including ELJs along the left bank through her property, were discussed. This landowner was not supportive of placing ELJs in the main channel along her property. In summary, the WFI project does not include features along the left bank of the main channel because of landowner concerns and Reclamation's desire to include ELJ evaluation in concert with potential Barkley Diversion modifications.

2 DESIGN ASSUMPTIONS AND CONSIDERATIONS

2.1 Depth to Bedrock

Bedrock is present within the project site and is exposed in the main channel (from approximately Stations 411+00 to 408+00 and 395+00 to 393+00). Exposed bedrock has not been observed in the side channel. Bedrock conditions are not expected to constrain the construction and function of the structures. Depth to bedrock was not determined at each of the proposed structure locations throughout the subreach. The 90 percent design assumes depth to bedrock is adequate for structure construction per the Drawings. Log pile embedment depths are not expected to reach bedrock throughout the project site.

2.2 Hydraulic Modeling

A one-dimensional (1-D) Hydraulic Engineering Center–River Analysis System (HEC-RAS) model was used to support the 90 percent design development and design analysis calculations. A summary of the 1-D modeling analysis is included in the 30 percent design report (Anchor QEA 2011b). Reclamation has completed preliminary two-dimensional (2-D) modeling of the proposed condition with the structures in place. These preliminary modeling results were used to guide the structure design modifications for the draft 90% design.

2.3 Zero-rise Policy

Placement of ELJs in the floodway (including the channel) can cause localized water surface elevation rise. This is created by the backwater effect the structure creates when placed in the active flow of the channel. Generally, a zero-rise policy states that if structures (e.g., buildings or structures) or fill are placed in the floodway, they cannot cause a rise in the base flood elevation (BFE) as a result of their placement. At this time, Okanogan County does not have a zero-rise policy for such actions. However, the Federal Emergency Management Agency (FEMA) regulations require jurisdictions to prohibit encroachments in regulated floodways (for coverage under the National Floodplain Insurance Program) unless provided with a no-rise analysis showing the action does not cause a rise in the BFE. FEMA does make the exceptions to this no-rise rule for fish enhancement structures (see Section 2.4).

2.4 FEMA Policy on Fish Enhancement Structures in the Floodway

FEMA recognizes that listings of certain anadromous fish species as Threatened or Endangered under ESA requires habitat improvement that may encroach on the floodway to ensure their survivability. To resolve this conflict, FEMA Region 10 issued a Policy on Fish Enhancement Structures in the Floodway. This policy states that a qualified professional should, at a minimum, provide a feasibility analysis and certification that the project was designed to keep any rise in 100-year flood levels as close to zero as practically possible and that no structures would impacted by the rise.

2.5 River Safety Evaluation

Anchor QEA will complete a River Safety Evaluation as part of the final project work products. This evaluation will address the potential hazard of wood placement in the Methow River main channel and side channel. This information will be presented in a memorandum and will include information about sight distances, expected instream velocities, reaction times, and expected boater usage. Results of the Reclamation 2-D model will be used to support this assessment.

2.6 Signage

Based on the results of the River Safety Evaluation, signage will be placed at the project site and in the vicinity of the project site. Signage placement and content will be the responsibility of Methow Salmon Recovery Foundation (MSRF).

3 ENGINEERED LOG JAM STRUCTURE DESIGN

The Whitefish Island Habitat Improvement Project will add approximately 50 structures (including the single-log-piece Type S structures and the Live Crib) in the main channel and side channel. These structures are comprised of approximately 373 rootwad logs, 164 log poles, and 113 log piles. The wood will help to create hydraulic complexity throughout the existing plane-bed channel and will create areas of sediment deposition in the side channel. Appendix B of the 30 percent design report Upper Middle Methow Reach Whitefish Island (Anchor QEA 2011a) describes in detail the function and benefits of the proposed ELJ types.

The Project includes the following structure types (see Appendix A: Whitefish Island Habitat Improvement Project, Bid Set Drawings, Proposed Conditions Site Plan [Sheet 5 of 19]):

- **Type A Structure**: One Type A bar apex structures will be placed at the head of the Whitefish Island (approximately main channel Station 415+30). The structure is designed to interact with main channel flow throughout the flow regime and will promote scour of a large, deep pool adjacent to and directly upstream of the ELJ. This Type A flow structure will consist of 10 rootwad log layers and one log pole layer. The structure will be approximately 50 feet long by 36 feet wide. The top elevation of this structure will be above the existing grade of Whitefish Island and is designed to be overtopped only during discharges greater than the 100-year flood event. The Type A structural stability design flow is the 100-year event.
- **Type As Structure:** One Type As structure will be placed in the side channel along the left bank of the side channel at approximately Station 8+00. Placement of this structure will promote scour of a large, deep pool adjacent to and directly upstream of the ELJ. The side channel Type As structure will consist of 10 rootwad log layers and one log pole layer. The structure will be approximately 36 feet long by 24 feet wide. The placement of this structure in the side channel is near the inlet of the over-island channel activation point. The top elevation of this structure will be above the existing grade of Whitefish Island and may be overtopped during the 100-year flood event. The Type As structural stability design flow is the 100-year event.
- **Type Bp Structures**: Five Type Bp bank structures will be placed along the left bank of the side channel. These structures will add hydraulic and habitat complexity along this uniform side channel reach and will help promote a pool-riffle morphology through the side channel. They are also intended to promote deepening and narrowing of the thalweg through the side channel (in conjunction with the other

structures). These structures will consist of seven log piles (20-inch diameter) and logs with rootwads and will extend into the channel approximately 17 feet (normal to flow). Log piles will be embedded to a depth of at least 17.0 feet below the existing ground surface. These structures will consist of seven rootwad log layers with several pieces partially excavated into the bank. The length of these structures will be approximately 23 feet. The lower two rootwad log layers will be excavated into the channel bed (below existing grade). The top elevation of these structures will closely match the grade of Whitefish Island and is designed to be overtopped during a 100-year flood event. The total height of these structures will be approximately 9 feet (above existing grade). The Type Bp structural stability design flow is the 100-year event.

- **Type L Structures**: Two Type L bank roughness structures will be placed along the left bank in the side channel. These structures are intended to help deepen and narrow the thalweg through the side channel, as well as help develop a pool-riffle sequence through the side channel to improve habitat. These structures will have three layers consisting of one rootwad log each. Construction will also include excavation of a pool along the channel side of the structure. Each structure will be constructed using five log piles (12-inch diameter). Four of these log piles will be embedded to a depth of at least 14.0 feet below the existing ground surface. The fifth log pile (located along the bank at the upstream end of the structure) will be embedded to a depth of at least 6.5 feet below the existing ground surface. Type L structures are designed to be overtopped during a 2-year flood event. The Type L structural stability design flow is the 10-year event.
- **Type S LWD**: Twenty-three Type S floodplain and channel roughness LWD (consisting of individual rootwad logs) will be placed throughout the unvegetated areas of the side channel on exposed bars. These LWD are intended to interact with spring freshets and promote deposition of finer sediment along the bar areas, as well as promote a sorted gradation of surface sediments along the bar areas. Individual rootwad logs will be placed roughly perpendicular to flow. These individual pieces are placed in locations where they may be overtopped during a 2-year flood event. These rootwad logs will be embedded in the substrate, or, where possible, placed between existing trees. The Type S rootwad logs will be 30 feet in length and 18 inches in diameter. The Type S stability design flow is the 10-year event.
- **Type Z Structures:** A total of 17 Type Z bar roughness structures will be placed along the right bank in the main channel and along both banks in the side channel. Similar

to the Type L structures, these structures are intended to help deepen and narrow the thalweg through the side channel, as well as help develop a pool-riffle sequence through the side channel. The structures are also intended to function as "planting boxes" for regeneration of cottonwood and other riparian vegetation. Each structure consists of two rootwad log layers and will be constructed with four rootwad log piles (12-inch diameter) that will be embedded to a depth of at least 7.0 feet. The structures are approximately 18 feet by 24 feet. These structures are designed to be overtopped during a 2-year flood event. The Type Z structural stability design flow is the 10-year event.

- **Live Crib**: One Live Crib structure will be placed along the right bank at the downstream extent of the side channel, located at the base of the State Route 20 road prism. This structure is intended to protect and improve the existing groundwater-fed pool and widen the local riparian zone. The thalweg of the side channel flows at the base of this slope. This structure will extend for approximately 180 feet along the right bank of the side channel and will extend 25 feet into the channel. The Live Crib consists of 14 log layers. This is a gravity structure and will not have log piles. The Live Crib structural stability design flow is the 100-year event.

3.1 Modifications to the 60% Design Structures Types (Anchor QEA 2012)

Anchor QEA modified the draft 90% design based on additional analysis and, to accommodate comments provided by Reclamation and MSRF, the following changes were made.

3.1.1 Main Channel:

- **Type Z Structures**: The Type Z structures were re-designed to the 10-year flow. These structures are designed such that design certainties begin to be exceeded at flows greater than the 10-year flow. The structures will also use natural fiber rope to secure the logs together. This rope will deteriorate over time and will not withstand forces should the structure become dislodged during the extreme flow events. The minimum rootwad log pile diameter was reduced to 12 inches. The specification for the rootwad log piles was revised to allow a wider range of species and timber grades to make securing materials easier and less costly. The length of the rootwad log on the top layer was increased slightly to allow the rootwad to be located farther away from the nearest rootwad log pile.

3.1.2 Side Channel:

- **Type A Structures**: The bottom elevation of the structures was decreased by 2 feet. One additional rootwad log was added to layers 3, 5, 7, and 9 to increase the rootwad density in the front of the structure. Notes were added to the plans to specify the placement of small woody debris and slash in the void spaces not backfilled with native material during construction. Elevation and structural modifications were made to better address scour potential and improve the stability factor of safety. Slash was added to improve habitat and help maintain backfill materials in the structures.
- **Type As Structures**: Two additional rootwad log layers were added under the top layer of log poles. The new layer 9 consists of three rootwad logs parallel to flow. The new layer 10 consists of six rootwad logs perpendicular to flow. The length of the rootwad logs on the odd numbered layers was increased by 3 feet. One additional rootwad log was added to layers 3, 5, and 7 to increase the rootwad density in the front of the structure. The rootwad log spacing on the even-numbered layers was revised to be 6 feet on center for all rootwad logs. The bottom elevation of the structure was decreased by 1.5 feet. Notes were added to the plans to specify the placement of small woody debris and slash in the void spaces not backfilled with native material during construction. Elevation and structural modifications were made to better address scour potential and improve the stability factor of safety. Slash was added to improve habitat and help maintain backfill materials in the structures.
- **Type Bp Structures**: The minimum log pile depth below existing grade was increased to 17.0 feet. The log pile specification was revised to require a higher bending stress capacity. Additional connections where added between log layers and the buried log piles to increase the rigidity of the structure. The wire rope diameter specified for the connections was reduced from 5/8 inch to 3/8 inch to account for the strength provided by the additional connections. These modifications were made to better address scour potential and improve the stability factor of safety. Slash was added to improve habitat and help maintain backfill materials in the structures.
- **Type L Structures**: The Type L structural design flow was modified to the 10-year event. Accordingly, the minimum log pile diameter was reduced to 12 inches. The specification for the four downstream-most log piles was revised to require a higher bending stress capacity. The specification for the upstream-most log pile was revised to allow a wider range of species and timber grades. The connection material was revised from 5/8-inch diameter wire rope to 5/8-inch diameter manila rope to reduce the use of wire rope while being consistent with the design flow. The proposed 5/8-inch diameter manila rope has a much lower rope breaking strength (3,960 pounds)

than the 3/8-inch diameter wire rope (breaking strength of 14,400 pounds). This will allow the logs to break apart separately and mobilize as single logs downstream. These modifications were made based upon the design team's (MSRF and Reclamation) recommendation to design for 10-year flow conditions rather than to 100-year conditions.

- **Type S Structures**: The type of rope fiber specified to secure the rootwad log to existing trees was changed to a natural fiber to minimize the use of wire rope while being consistent with the design flow. This modification was made based on MSRF's desire to minimize the use of cable in the project.
- **Type Z Structures**: The Type Z structures were re-designed to the 10-year flow. These structures are designed such that design objectives and certainty of success begins to be exceeded at flows greater than the 10-year flow. Similar to the Type L structures, the Type Z structures will also manila rope to secure the logs together. This rope will not hinder the intentional break-apart if the structure is dislodged during the 10-year flow and will allow the logs to break apart separately and mobilize as single logs downstream. The minimum rootwad log pile diameter was reduced to 12 inches. The specifications for the rootwad log piles were revised to allow a wider range of species and timber grades. The length of the rootwad log on the top layer was increased slightly to allow the rootwad to be located farther away from the nearest rootwad log pile. These modifications were made based upon the design team's (MSRF and Reclamation) recommendation to design for 10-year flow conditions rather than to 100-year conditions.
- **Live Crib Structure**: Four additional log layers were added to the bottom of the structure to account for the potential scour depths anticipated along this bank.

4 HYDRAULIC ANALYSIS

4.1 HEC-RAS Model

A 1-D HEC-RAS model was developed by Anchor QEA for the M2 reach. The HEC-RAS modeling overview is presented in Appendix A of the 30 percent design report (Anchor QEA 2011b). The results were used to support the structure design calculations and scour calculations presented below (see Section 5).

4.2 Reclamation Model

Reclamation developed a 2-D model of the proposed project condition with structure placement at Whitefish Island. The 2-D modeling results will be included in the separate modeling report for Whitefish Island that will be completed at a later date by Reclamation. The 2-D model results available to date support the design decisions that are based on the HEC-RAS 1-D model.

5 DESIGN ANALYSES

The design analyses completed for the proposed structures include scour, stability, pile analyses, and river user safety (see separate River Safety Report to be completed at a later date). Forces considered in these analyses include structure and log buoyancy, structure and log weight, upstream and downstream hydrostatic forces, friction, velocity, drag, ballast, and the resisting forces of the substrate. These design calculations were used to set footprint elevations, determine the stability of each of the structures and the resulting factors of safety that apply to the structure. The factor of safety can generally be defined as a ratio of the structure's strength to the actual applied load.

5.1 Scour Analysis

Bed scour at the proposed structures (except the Type A structure) was estimated using an equation originally presented by Liu et al. (1961) for scour at bridge abutments. This equation has since been recommended by others, including Drury (1999) for use in calculating scour at ELJs. The equation relates flow conditions (i.e., flow depth and velocity), obstruction dimensions, and Froude number to maximum scour depth below existing grade. Approach velocities, water depth, and Froude number were obtained from the hydraulic output of a HEC-RAS steady-state model completed by Anchor QEA. Scour at the bar-apex (Type A) structure was estimated using the simplified Chinese equation developed for bridge piers in coarse bed rivers.

Results of this analysis were used to determine the maximum probable depths of bed scour that could potentially undercut the structures. However, final footprint elevations and log pile placement depths will be determined based on scour estimates and professional judgment.

5.1.1 Scour Equation (Liu et al. 1961)

The Liu et al. (1961) scour equation was selected for use at ELJs developed from laboratory tests in a flume and prototype measurements, and was subsequently verified with field experiments. This equation was developed to estimate scour at abutments where the groins are placed perpendicular to the flow. Results indicate that the contraction ratio and approach flow depths are the critical parameters. This equation is recommended for when the ratio of effective length (L_e) of the ELJ protruding into the flow divided by the upstream hydraulic depth (d_1) is less than 25.

$$d_s = 1.1 \cdot \frac{L_e}{d_1}^{0.4} \cdot Fr^{0.33} \cdot d_1$$

where:

d_s = Scour Depth (predicted)

L_e = Length (effective)

d_1 = Upstream Hydraulic Depth

Fr = Froude Number (dimensionless number), where

$$Fr = \frac{V}{\sqrt{g \cdot d}}$$

V = Flow velocity

g = gravitational acceleration

d = flow depth

5.1.2 Simplified Chinese Equation (Landers and Mueller 1996)

The simplified Chinese pier-scour equation was used to estimate scour for the Type A apex structure. This equation is applicable to coarse-bed rivers and is based on laboratory and field data from China (Landers and Mueller 1996, as cited in Chase and Holnbeck 2004). The equation accommodates clear-water scour and live-bed scour.

$$y_s = 0.95 \cdot K_s \cdot b^{0.6} \cdot y_o^{0.15} \cdot D_{50}^{-0.07} \left(\frac{V_o - V_{ic}}{V_c - V_{ic}} \right)^c \text{ for live-bed scour } (V_o > V_c)$$

where:

y_s = depth of scour below bed, feet

K_s = Pier shape coefficient

b = pier width, feet

y_o = existing depth in channel before contraction scour, feet

V_o = approach velocity upstream of the pier, feet/second

$$c = \left(\frac{V_C}{V_o}\right)^{8.20 + 2.23 \cdot \log D_{50}}$$

D_{50} = median particle size, feet

V_c = critical velocity (incipient motion) for the D_{50}-sized particle, feet/second

$$V_c = 3.28\left(\frac{y_0}{D_{50}}\right)^{0.14} \cdot \left[8.85 \cdot D_{50} + 6.05 \cdot 10^{-7}\left(\frac{10 + 0.3048 \cdot y_o}{(0.3048 \cdot D_{50})^{0.72}}\right)\right]^{0.5}$$

V_{ic} = Approach velocity corresponding to critical velocity at the pier, feet/second

$$V_{ic} = 0.645\left(\frac{D_{50}}{a}\right)^{0.053} V_c$$

5.1.3 Results

The maximum probable scour was estimated for each of the Type A, Type As, Type Bp, Type L, Type Z, and Live Crib structures for the 5-, 10-, 25-, 50-, and 100-year events. Design analysis scour depths based on both the results of this analysis and professional judgment are presented in Table 1.

Table 1

Design Analysis Scour Depths for Structures at Specified Design Flows

Structure[1]	Design Flow Event	Design Analysis Scour (feet)
Type A[2]	100-year	11.0
Type As	100-year	8.7
Type Bp	100-year	9.2
Type L	10-year	7.0
Type Z	10-year	3.0
Live Crib	100-year	12.0

Notes:

1. Results are reported for the structure location with the highest calculated scour depth (for that structure type). A common structure design was used even though scour may be less at other locations.
2. Type A structure scour result was calculated using the simplified Chinese equation (Landers and Mueller 1996).

The design analysis scour depths at the structures ranged from 3 feet (Type Z) to 12 feet (Live Crib). The two structures with the deepest estimated scour are the Live Crib (side channel) and the apex structure at the head of Whitefish Island (Type A). These structures have the deepest scour because they are large structures that extend farthest into the channel (have a long effective length, L_e) and are subject to the greatest hydraulic depths (d_1). At cross-sections where higher Froude numbers are estimated by the hydraulic model, deeper scour is estimated.

5.2 Gravity Structure Stability

The gravity structure stability analysis evaluates the sum of all the forces acting on the structure (i.e., the vertical and horizontal forces): the *upward* vertical force on the structure caused by the submerged logs (unsaturated), and a *downward* vertical force caused by the weight of the overlying logs, ballast material, and gravity. The horizontal forces include the drag, friction, and hydrostatic forces acting on the structure.

Calculations assume that the logs are unsaturated and a void ratio of the ballast material placed on the logs of 25 percent. Over time, much of the wood within the structure can become saturated, thereby increasing each log's specific gravity and increasing the overall weight-resisting force of the structure.

The factor of safety (for both vertical and horizontal forces) for proposed ELJ logs in the unsaturated state (at time of construction) is presented in Table 2. Results are presented for the structures that rely on gravity for stability (Type A, Type As, Type S, and Live Crib). Structure buoyancy calculations were not completed for the pile-supported structures. See Section 5.3 for pile stability calculations.

Table 2

Gravity Structure Stability Factors of Safety

Structure ID	Horizontal Factor of Safety[1]	Vertical Factor of Safety[2]
Type A	2.2	3.5
Type As	2.4	3.8
Live Crib	7.0	10.8
Type S	3.4	2.4

Notes:

1. Horizontal factor of safety is the friction force divided by the drag force.
2. Vertical factor of safety is the downward vertical force of the ballast and logs divided by the upward vertical force of the submerged wood logs.

5.3 Pile-supported Structure Stability

Pile stability analyses were completed for Structure Types B, L, and Z. The pile stability analyses examined the size of the structure, the number of log piles, the depth of the log piles, and the hydraulic load applied to the structure. The number of log piles needed for each structure is dictated based on the structure length and width (structure geometry) and the hydraulic load applied to the structure. The hydraulic load is transferred from the rootwad logs to the log piles. Results of the log pile analyses are presented in Table 3.

A resulting factor of safety was determined each of these log pile-based structures. The factor of safety is the ratio of the structural capacity of the log pile system to the design load. The factor of safety increases as the number of log piles or log pile diameters increase because the structural capacity of the log pile system is increasing as the load remains constant.

5.3.1 Soil Strength

The soil strength resisting pile overturning was calculated for Types Bp, L, and Z. These calculations represent the condition where the soils (substrate) supporting the log piles fails and the log piles overturn before the pile strength is exceeded (Section 5.3.1.1) resulting in structure deformation. The soil strength is calculated using published methods for estimating ultimate lateral soil resistance to timber piles in cohesion-less soils. The soil strength calculations assume the design maximum scour depth for effective pile embedment depth and also assume the structures are subject to the highest modeled channel velocity in the vicinity of the structure. Furthermore, calculations assume a homogenous channel substrate.

Soil strength sensitivity analysis included varying embedment lengths, log pile diameter, log pile quantity, substrate characteristics, and varying velocities across the channel.

5.3.2 Pile Bending Strength

The pile bending strength was calculated for Types Bp, L, and Z. These calculations represent the condition where the log piles yield and break in bending under the applied load. These calculations assess each log pile as a cantilevered beam subject to the hydraulic loads of the design flow event. The calculations assume the estimated maximum scour depth for determination of the unsupported pile length. Pile strength calculations confirmed that the selected pile diameter and minimum bending stress capacity would provide a factor of safety that meets or exceeds standard structural design practices. Additionally the pile bending strength factor of safety was evaluated to exceed to the soil strength for each structure type. Pile bending strength sensitivity analysis included varying the diameter and bending stress capacity of the log piles.

Table 3

Pile-supported Structure Design Summary and Resulting Factors of Safety

Structure Type and Location[1]	Type Bp (side chl. Sta. 15+11)	Type L (side chl. Sta. 9+30)	Type Z (side chl. Sta. 15+11)
Design Event	100-year	10-year	10-year
Velocity[2], V (fps)	8.7	4.9	6.9
Scour Depth (ft)	9.2	7.0	3.0
Log Pile Embedment[3], L (feet)	8.4	7.0	4.0
Pile Depth BEGS (ft)	17.6	14.0	7.0
Log Pile Diameter[4], B (inches)	20	12	12
Number of Log Piles, n	7	4	4
Min. Pile Bending Stress Cap.[5] (psi)	1700	1700	475
F.S. Log Pile Overturning	2.0	2.0	1.7
F.S. Log Pile Bending Strength	3.0	2.1	2.7

Notes:
1. See design plans for additional details regarding structure type design and construction.
2. Velocity is selected from the HEC-RAS proposed conditions hydraulic model for the indicated design event.
3. Log pile embedment is the depth below the design analysis scour depth (see Section 5.1).
4. Log pile diameter is measured at a distance equal to three times the pile diameter from the butt end of the log pile. Diameter does not include bark.
5. Specified minimum bending stress is the starting design value before strength reduction factors are applied per timber pile design methods.

BEGS = below existing ground surface, fps = feet per second, psi = pounds per square inch

6 LIMITATIONS

This report was prepared for Reclamation for use in documenting design analysis for the 90 percent design phase of the Whitefish Island Habitat Improvement Project. Conditions within the project site may change both spatially and with time and as additional scientific data may become available. Significant changes in site conditions or the available information may require reassessment of both existing and proposed project conditions. Within the limitations of scope, schedule, and budget, our services have been executed in accordance with generally accepted scientific and engineering practices in the area at the time this report was prepared.

Engineered log jams and other large wood structures are designed and intended to emulate the large, natural wood accumulations historically found in forested river systems. These accumulations have long been a part of most forested rivers in the Pacific Northwest and are a vital component of healthy ecological systems. Engineered log jams are intended to modify the hydraulic function of river systems and to create improved habitat for aquatic species. Localized scour pools are expected to form adjacent to and beneath portions of the log jam structures after several flood events. These scour pools are desirable as key components of riverine habitat improvement.

Rivers are dynamic systems and experience major seasonal changes in flow. Flood events will result in localized scour and deposition of bed sediment near the log jams. Cyclic periods of accumulation and depletion of logs on, and adjacent to, log jam structures are expected during conditions of high flow as part of natural river dynamics.

Like their natural counterparts, constructed log jams can pose unique risks to property and to persons who access the river or stream. Log jam structures may be partially or completely destroyed in extreme floods, carrying the logs downstream for accumulation in other areas. This potential downstream accumulation of logs could cause changes in channel position or unintended damage to improved and unimproved property on or near the river.

During periods of low to moderate flow, the river's flow may converge on the deep-water areas adjacent to and beneath the ELJs. The changes in flow patterns and the flow convergence near engineered log jams can pose significant risks for people using the river for general recreation, boating, rafting, fishing, swimming, wading, or other purposes. Bodily injury or death could result from people being trapped within or under the log jams. Walking on or over the log jams also involves risk of falling and injury.

These risks are similar to those posed by natural log jams. However, the structures contemplated by this design and report will be manmade. This may create unique risks for the owner, designer, and builder of this project. Accordingly, we specifically recommend that permanent warning signs be posted and maintained along all publicly accessible areas of the river containing ELJs. These signs, at a minimum, should warn river users of the presence and potential hazards associated with natural and artificial log jams in the river.

The following key points should be noted:

1. The ELJ structures are a response to the ESA and are designed to improve fish habitat as a matter of public policy.
2. All structures in the river, including ELJs, represent a potential hazard to boaters and swimmers.
3. Because some **known** risk is inherent in building an ELJ, the design of such structures does not represent engineering negligence. If the risks were **not** known, considered, and communicated to interested parties, then potential negligence could be an issue.

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APPENDIX A
WHITEFISH ISLAND HABITAT IMPROVEMENT PROJECT, BID SET DRAWINGS