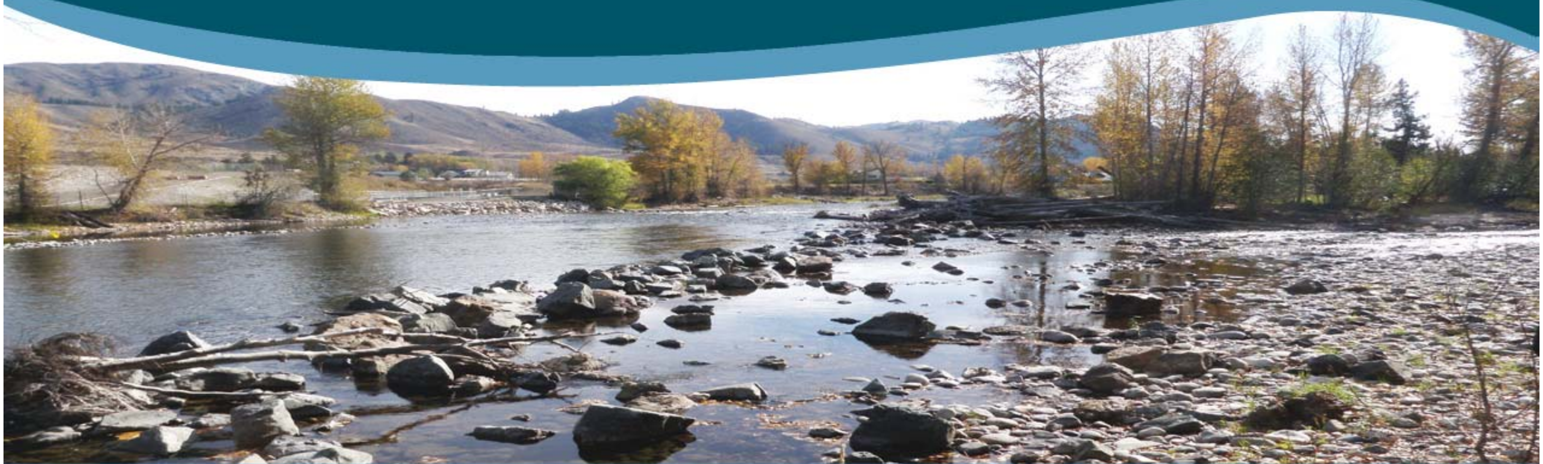
REPORT



100 PERCENT BASIS OF DESIGN REPORT
WDFW HABITAT IMPROVEMENT PROJECT

Prepared for

U.S. Bureau of Reclamation

1150 N. Curtis Road, Suite 100

Boise, Idaho 83706

Prepared by

Anchor QEA, LLC

1605 Cornwall Avenue

Bellingham, Washington 98225

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LIST OF ACRONYMS AND ABBREVIATIONS

%	percent
BEGS	below existing ground surface
BFE	base flood elevation
BODR	Basis of Design Report
d_1	upstream hydraulic depth
d_s	scour depth
ELJ	engineered log jams
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
HEC-RAS	Hydraulic Engineering Center–River Analysis System
L_e	effective length into flow
LWD	large woody debris
MSRF	Methow Salmon Recovery Foundation
MVID	Methow Valley Irrigation District
Reclamation	U.S. Bureau of Reclamation
RM	river mile
WDFW	Washington Department of Fish and Wildlife

ELJ Structures

Type A	Bar Apex ELJ, one location
Type Ac	Custom Bar Apex ELJ, one location
Type B	Bank Barb ELJ , 12 locations
Type BD	Bar Development ELJ, three locations
Type As	Small Bar Apex ELJ, three locations

LWD Features

Type V	Sediment Retention LWD, two locations

1 INTRODUCTION

The following Basis of Design Report (BODR) documents engineering and supporting calculations for the Washington Department of Fish and Wildlife (WDFW) Habitat Improvement Project 100% Design Drawings (Drawings) and Specifications. The Bureau of Reclamation (Reclamation) proposes to design and construct (with project partners) a salmonid habitat improvement project in the upper part of the middle reach of the Methow River (and side channel) near Twisp, Washington, in summer 2013. The following report builds upon the previous 30, 60 and 90 percent design Drawings and design reports completed by Anchor QEA (Anchor QEA 2011b, Anchor 2012a, and Anchor QEA 2012b).

The goal of the 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 2011b):

- Increase hydraulic and habitat complexity in the main channel and side channel
- Increase right bank floodplain connectivity upstream of the side channel by removing an existing levee and promote the development of a low-lying floodplain through the use of large woody debris (LWD) structures
- Improve structural complexity and cover through the side channel by promoting natural processes through the installation of a series of engineered log jams (ELJs)
- Increase habitat complexity in the main channel with LWD structures that will influence hydraulics resulting in high-flow refuge and sediment sorting and temporary storage
- Protect and improve the quantity and function of riparian vegetation by improving natural rates of bank erosion, 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 100% design addresses these habitat goals with the construction of LWD and ELJ structures throughout the side channel and main channel. ELJs and LWDs are proposed to improve habitat conditions. Six distinct types of structure designs were developed to achieve the habitat goals of this project (ELJ types A, Ac, As, B, and BD, and LWD type V).

1.1 Project Setting

The WDFW Habitat Improvement area extends from river mile (RM) 46.75 to RM 45.50 of the main channel and includes an approximately 1,700-foot-long river side channel and the right bank floodplain east of Old Twisp Highway. The floodplain contains relict flow paths originating behind an existing levee. A majority of the floodplain area is inundated during 25-year and greater flood events; the entire area was inundated during the flood of 1948, which can be seen in aerial photos.

The upstream portion of the floodplain is a densely vegetated forest adjacent to a small open pasture. A majority of the floodplain is separated from the main channel by a rock levee. South and west of the levee and east of the Old Twisp Highway, the floodplain is primarily an open area vegetated with native and invasive grass and forb plant species with an occasional tree or shrub. A majority of this area is former pasture that is currently unoccupied and is owned by Washington Department of Fish and Wildlife. Several shallow flow paths sculpted out during the 1948 flood cross-cut the pasture, sloping towards the wetland complex west of the Old Twisp Highway. East of the open pasture, the floodplain is sparsely to moderately vegetated with mixed pine and deciduous trees.

The wetland complex will be connected to the river; this project is discussed in the Design Drawings and 100% BODR completed for the WDFW Culvert Improvement Project (Anchor QEA 2013).

1.2 Previous Studies

Previous studies completed in support of the WDFW Habitat Improvement Project are presented below:

- *The Methow Subbasin Geomorphic Assessment* (Reclamation 2008)
- *The Middle Methow Reach Assessment* (Reclamation 2010)
- *Conceptual Project Alternatives Assessment* (Anchor QEA 2010)
- *Alternatives Evaluation Report* (Anchor QEA 2011a)
- *30 Percent Design Report Upper Middle Methow Reach WDFW Floodplain* (Anchor QEA 2011b)
- *60 Percent Basis of Design Report WDFW River Project* (Anchor QEA 2012a)

- *Final 90 Percent Basis of Design Report WDFW Habitat Improvement Project* (Anchor QEA 2012b)

The 30% design report includes a detailed discussion of the project goals and objectives, detailed project area description, design development, hydrologic and hydraulic analysis, and a description of the proposed construction activities.

Modifications Based on 30% Design Review

For the 60% design (and subsequent project designs), the culvert improvement project was separated into a separate BODR. This BODR proposes creating channels through the right bank floodplain. The channel network would allow some floodwaters to pass under Old Twisp Highway through a bottomless culvert and would also connect the wetland complex on the west side of the highway to the Methow River through a second bottomless culvert.

The 30% design included 5 Type BD structures adjacent to the proposed levee removal. Based on additional analysis and the Methow Salmon Recovery Foundation's (MSRF) desire to reduce the construction footprint and limit imported fill materials, the number of these structures was reduced to three, the elevation of each structure was reduced, and the extent to which each structure protruded into the river was reduced. The 30% design included several Type W structures that were changed in configuration to better achieve objectives; these were renamed Type Z structures and included in the 60% and 90% design phases.

During the 30% design review process, MSRF and Reclamation expressed a dislike for some of the logjam structures placed along the river banks and asked for structures that did not include rock backfill and included more void space within the structure. Anchor QEA designed the Type Bp structures and included them in the 60% and 90% designs in an effort to satisfy this request. These structures relied on log piles embedded into the river bed below the expected scour depth for stability, rather than on native backfill placed within the structures.

Modifications Based on 60% Design Review

During review of the 60% design and Reclamation's 2-D model output, the mid-channel bar apex jam (Type A) was removed from the design because of safety concerns and the uncertain benefits associated with changes the structure would cause to flows in the main channel (basically model results were inconclusive). Interpretation of model output suggested that some refinement of structure locations in the lower side channel would be beneficial for meeting objectives. These modifications are discussed in detail in later sections of this report.

Type B structures, located along the left bank of the main channel, were revised to reduce risks to river users during higher recreational flows where rafts may be in the river. The upstream side of the structure was redesigned to remove rootwads and include "bumper" logs that would help rafters shunt the structures should they come in contact with the structures. One such Type B structure was constructed in 2012 as part of the RM 46 project. The Type B structures presented in the 100% design include rootwad logs on the upstream side and do not include "bumper" logs. See Section 3.3 for more information on changes made to the 90% designs.

Type L and Type Z structures were redesigned to a 10-year design flow based on MSRF's desire for these structures to "fail safe." The intent is for the structures to break apart and be transported downstream as individual logs should the structure fail rather than travel downstream as a combination of wood and cable. All cable fastening was replaced with manila rope. One Type L structure was constructed in 2012 as part of the RM 46 project. The Type V structures presented in the 100% design replace the Type Z structures shown in the 60% design. See Section 3.3 for more information on changes made to the 90 percent designs.

A rock sill was introduced into the design based on a strong desire for such a feature by Reclamation. This sill will be placed into the bed of the river near the upstream extent of the side channel using the existing rock materials that are present across the head of the channel.

2 DESIGN ASSUMPTIONS AND CONSIDERATIONS

2.1 Depth to Bedrock

There is a bedrock outcrop downstream of the project limits on the right bank near river Station 234+00. However, bedrock has not been observed in the main channel or side channel within the project limits. Bedrock conditions are not expected to constrain the construction and function of the ELJs. Depth to bedrock was not determined at any of the proposed structure locations throughout the subreach. The 100% design assumes that subsurface conditions are adequate for structure construction per the Drawings. Structure embedment depths are not expected to reach bedrock throughout the project site.

2.2 Hydraulic Modeling

A 1-D Hydraulic Engineering Center–River Analysis System (HEC-RAS) model was used to support the 100% design development and design analysis calculations. A summary of the modeling analysis is included in the 30% design report (Anchor QEA 2011b). Reclamation has completed a preliminary 2-D model of the proposed condition with the structures from the 90% design in place. 2-D modeling results are included in a separate report prepared by Reclamation (Reclamation 2012).

2.3 No-rise Floodway Policy

Placement of ELJs in the floodway (including the channel) can cause localized water surface elevation rise. This is created by the backwater effect that the structure creates when placed in the active flow of the channel. Generally, a no-rise floodway 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 no-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 that the action does not cause a rise in the BFE. FEMA does make 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 in order to ensure fish 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 be impacted by the rise.

2.5 River Safety Evaluation

Anchor QEA and MSRF completed a River Safety Evaluation as part of the 2012 project work products (Anchor QEA 2012c). This evaluation addressed the potential hazard of wood placement in the Methow River main channel and side channel. This information was presented in a memorandum and included information about sight distances, expected instream velocities, reaction times, and expected boater usage. Results of the Reclamation 2-D model were used to support this assessment.

2.6 Signage

Based on the results of the River Safety Evaluation, appropriate signage will be placed at the project site and in the vicinity of the project site as necessary. Signage placement and content will be the responsibility of MSRF.

3 ENGINEERED LOG JAM AND LARGE WOODY DEBRIS STRUCTURE DESIGN

The WDFW Habitat Improvement Project is planned to add 22 structures in the main channel and side channel and more than 800 pieces of large wood in the main channel and side channel. 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% design report describes in detail the function and benefits of the proposed ELJ and LWD structure types (Anchor QEA 2011b).

The project includes the following structure types (see accompanying document: WDFW Habitat Improvement Project, Bid Set Drawings, Proposed Conditions Plan [Sheets 6 to 8]):

- **Type A Structure**: One Type A structure will be placed at the head of the forested island. 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 structure will consist of 11 rootwad log layers and one log pole layer. The structure will be approximately 50 feet long by 36 feet wide at the base. The top elevation of this structure will be above the existing grade of the forested island and is designed to be overtopped only during discharges greater than the 100-year flood event. The Type A design flow is the 100-year event.
- **Type Ac Structure**: One Type Ac structure will be placed on the right bank at the entrance of the side channel. This structure is a slight modification of the Type A structure. All the rootwads that are placed perpendicular to flow will protrude on the side of the structure exposed to flow. The front of the structure is also staggered slightly downstream to minimize the potential for erosion on the bank side of the structure. The structure will consist of nine rootwad log layers. The structure will be approximately 50 feet long by 36 feet wide at the base (with approximately 1/3 of the structure width recessed into the bank). The top elevation of this structure will closely match the existing grade of the forested island and may be overtopped during the 100-year flood event. The Type Ac design flow is the 100-year event.
- **Type As Structures**: Three Type As structures will be placed in the side channel to the left of the existing thalweg. The side channel Type As structures will consist of nine rootwad log layers and one log pole layer. The structure will be approximately 45 feet long by 24 feet wide at the base. The top elevation of these structures will closely match the elevation of the adjacent floodplain and will be overtopped during a 100-year flood event. The Type As design flow is the 100-year event.

- **Type B Structures**: Twelve Type B structures will be placed in the side channel along the left and right banks. 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). The Type B structures are gravity structures that consist of 10 rootwad log layers and a footer log and are approximately 16.5 feet in height. After the first four layers, every other layer is setback from the previous layer by approximately 6 feet, creating benches and a slope similar to the existing bank. The structure will extend an average of 17 feet into the channel. The top elevation of these structures will closely match the existing grade of the forested island and will be overtopped during a 100-year flood event. The Type B design flow is the 100-year event.
- **Type BD Structures**: Three Type BD structures will be placed along the right bank along the extent of main levee removal (approximately 1,000 feet). These structures will extend approximately 55 feet into the channel from the toe of the bank to the end of the rootwad logs exposed above the existing bed elevation. The top of the structures will decrease in height outward from the bank. The first six layers will be backfilled with large rock sourced from the levee removal. Native gravels and residual levee material will be used as backfill above layer 6. The top of the structures will be capped with log poles and logging slash to provide increased roughness and improve backfill retention during overtopping. The area in the lee of these structures will be backfilled with native rounded river gravel and cobble material sourced from the levee removal. The backfill will extend approximately 120 feet downstream of each structure in a triangular shaped wedge (see Sheet 6). The length of this backfill will vary slightly depending on if the optional levee removal bid item is activated. Type BD structures will be overtopped during a 2-year flood event. The Type BD structural stability design flow is the 100-year event. Structural stability is initially contingent on the large rock backfill in the lower layers of the structure in case overtopping occurs before vegetation is fully established. However, we anticipate that, over time, riparian vegetation growth and gravel bar deposition will take over as the stabilizing mechanism for these structures.
- **Type V Structures:** Two Type V structures will be placed along the right bank of the side channel. These structures are intended to help deepen and narrow the thalweg through the side channel, as well as help develop a vegetated gravel bar in 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 buried rootwad logs (12-inch diameter) that will be embedded to a minimum depth of 7.5 feet below the existing ground surface. The structures are approximately 18 feet long by 35 feet wide. These structures will be overtopped during a 2-year flood event. The Type V design flow is the 10-year event.

3.1 Levee Removal

In addition to installing ELJ and LWD structures, approximately 92% (by length) of the existing right bank levee will be removed to allow for reconnection of the right bank floodplain. The portion of the levee between main channel Stations 270+60 and 261+60 will be removed, approximately 900 linear feet. The east-west portion of the levee that directs water back into the main channel may also be removed, approximately 200 linear feet. This portion of the levee is listed as an optional bid item as an agreement with that adjacent land owner is uncertain at the time of bid advertisement. A short length of levee just upstream of the entrance to the side channel, between main channel Stations 261+60 and 260+60, will be left in place, approximately 100 linear feet, to protect existing mature vegetation. However, as part of the project's adaptive management strategy, the area should be monitored for signs of excessive erosion, especially following large floods. If excessive erosion is observed, mitigating actions that are consistent with the project objectives should be taken.

3.2 Related Project

Details of the WDFW Culvert Improvement Project are in a separate set of Design Drawings and a 100% BODR (Anchor QEA 2013).

3.3 Key Modifications to the 90% Design

Anchor QEA modified the 90% design to accommodate comments provided by Reclamation and MSRF. The following design changes were made:

- Type A Structure: The length of the rootwad logs specified for use in the odd numbered layers 3 through 11 was decreased from 45 feet to 40 feet to take advantage of on-hand owner-supplied materials while maintaining the structure's function. The typical spacing of the rootwad logs in the even numbered layers was decreased from 6 feet to 5 feet to improve backfill retention and accommodate the decreased rootwad log length in the odd numbered layers. An upper limit for the use of large rock backfill was defined to improve plant rooting success in the upper layers and limit the long term visibility of large rock in the river. No large rock backfill will be allowed above the top of layer 4. The planting layers and locations were more clearly defined to improve planting success and reduce uncertainty in construction coordination efforts between the planting crews and the general contractor. The location and extent of logging slash and native material backfill was also more clearly defined to reduce uncertainty during construction.

- **Type As Structure**: The rootwad log diameter and length in layers 1 and 3 was increased from 1.5 feet DBH by 35 feet long to 2 feet DBH by 40 feet long. This increase in rootwad log size was made to take advantage of on-hand owner-supplied materials while maintaining the structure's function. To compensate for the increased height of layers 1 and 3, the layer 10 rootwad logs were removed from the design and replaced with two log poles to finish the structure. Layer 11 was removed from the structure.
- **Type Ac Structure**: Several layers of the structure were reconfigured to take advantage of on-hand owner-supplied materials while maintaining or improving the structure's function. These changes include:
  - Rootwad log size in layer 2 was increased from 1.5 feet DBH by 25 feet long to 2 feet DBH by 30 feet long
  - Rootwad log size in layer 3 was increased from 2 feet DBH by 40 to 45 feet long to 2.5 feet DBH by 45 feet long
  - Rootwad log size in layer 4 was increased from 1.5 feet DBH by 25 feet long to 2 feet DBH by 30 feet long.
  - Rootwad log size in layer 6 was increased from 1.5 feet DBH by 25 feet long to 2 feet DBH by 40 feet long. The number of rootwad logs in layer 6 was also reduced from 6 to 5 to accommodate the larger diameter rootwad masses. The increased length of the rootwad logs will improve the tie-in to the bank.
  - Two of the rootwad logs in layer 7 were decreased in length from 45 feet to 40 feet. The number of rootwad logs in layer 7 was increased from 3 to 4 to improve the tie-in to the bank.
  - The number of rootwad logs in layer 9 was reduced from 4 to 3, all with a length of 40 feet

  - To compensate for the increased height from the larger diameter rootwad logs in layers 2, 3, 4, and 6, layers 10 and 11 were removed from the top of the structure.

An upper limit for the use of large rock backfill was defined to improve plant rooting success in the upper layers and limit the long term visibility of large rock in the river. No large rock backfill will be allowed above the bottom of layer 4. The planting layers and locations were more clearly defined to improve planting success and reduce uncertainty in construction coordination efforts between the planting crews and the general contractor. The location and extent of logging slash and native material backfill was also more clearly defined to reduce uncertainty during construction.

- **Type B Structures**: A total of 11 Type B structures replaced the Type Bp structures shown in the 90% design. The B structures will deliver the same geomorphic and habitat benefits while providing additional planting areas within the structure. The "bumper" logs were removed from the structures and the six log poles on the upstream side of the structure were replaced with rootwad logs. These changes were made to improve habitat benefit and mobile wood retention in the side channel where boater entrapment concerns are more limited. An upper limit for the use of large rock backfill was defined for structure B-1 to improve plant rooting success in the upper layers and limit the long term visibility of large rock in the river. No large rock backfill will be allowed above the top of layer 4 in structure B-1. All other Type B structures will use only native cobble, gravel, and sand material for backfill. The excavation of a pool extending up from near the base of the structure was added to all the structures to provide immediate pool and cover habitat in the side channel. The planting layers and locations were more clearly defined to improve planting success and reduce uncertainty in construction coordination efforts between the planting crews and the general contractor. The location and extent of logging slash and native material backfill was also more clearly defined to reduce uncertainty during construction. To improve tie-in to the bank the layer set back distance may be customized for each structure.
- **Type Bp Structures**: All Type Bp structures where replaced with Type B structures. The B structures will deliver the same geomorphic and habitat benefits while providing additional planting areas within the structure.
- **Type BD Structures**: The restriction to allow only cottonwood tree species was removed to improve material availability and eliminate any chance that a riparian area would be damaged to acquire cottonwood trees. The allowable tree species are now the same as the other structures. The backfill configuration for within the

structure was modified to improve backfill retention during high flows, especially those flows overtopping the structure. The backfill configuration was modified to specify the placement of large rock below the top of layer 6 and placement of native gravels and residual levee materials above layer 6. To further improve the retention of backfill, additional log poles were added in layers 6 and 8. These log poles will provide a protective cover with gaps between the logs of approximately 12 to 18 inches. Logging slash will also be pinned down under these additional logs poles before they are secured in place and the following layers placed. The location and extent of logging slash, large rock, and native/levee residual material backfill was also more clearly defined on the Drawings to reduce uncertainty during construction.

- **Type V Structures:** The Type V structures replace the two Type Z structures shown in the 90% designs on the right side of the side channel at approximately Stations 7+60 and 6+80. These structures provide similar geomorphic, riparian, and habitat benefits compared the Type Z structures. The configuration of the rootwad logs in the structures is intended to provide a more natural look and improve flexibility during construction. Each structure uses three rootwads logs secured to four buried rootwad logs to form a V shape. The area within the V will be filled with native material and planted. A small pool will be excavated around the rootwad ends to provide immediate in channel habitat benefit.
- **Levee Removal:** The upstream most perpendicular portion of the proposed levee removal is identified as an optional bid item to handle uncertainty related to landowner willingness. The optional bid item will be activated if an agreement can be reached with the landowner on the upstream side of the levee. Removal of this portion of the levee would produce approximately 580 cubic yards of material. If the optional bid item is activated, this additional material will be incorporated into the interior of the Type BD structures or placed in the lee of the structures. Material removed that is generally classified as large rock will be placed as backfill in the lower layers of the structure. Material removed that is generally classified native rounded cobbles and gravels may be placed within the structures or in the lee depending on material needs during construction. To improve the accuracy of levee removal, grading the alignments of the grade breaks in the typically levee removal section will be provided to the contractor for use.

4 HYDRAULIC ANALYSIS

4.1 HEC-RAS Model

A 1-D HEC–RAS model was developed by Anchor QEA for the Upper Middle Methow reach. HEC–RAS modeling overview is presented in Appendix A of the 30% design report (Anchor QEA 2011b). The results of this HEC–RAS model were used to support the structure design calculations and scour calculations presented below (see Section 5 and Section 6, respectively).

4.2 Reclamation Model

Reclamation developed a 2-D model of the proposed project condition with structure placements within the WDFW Habitat Improvement Project. The 2-D model results are included in a separate modeling report for the WDFW Habitat Improvement Project produced by Reclamation (Reclamation 2012). The 2-D model results shown in the report support the design decisions that are based on the HEC-RAS 1-D model. In addition, 2-D model results were used to confirm the effects of the proposed BD structures and levee removal.

5 DESIGN ANALYSES

The design analyses completed for the proposed structures include scour, stability, buried rootwad stability analyses, and river user safety (Anchor QEA 2012c). 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 and to 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 ultimate strength to the actual applied load.

5.1 Scour Analysis

Bed scour with the proposed structures (except the Type A and Type As bar apex structures) was evaluated using an equation originally presented by Lui 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 and Type As) structures was determined using the simplified Chinese equation developed for bridge piers in coarse bed rivers (see Section 5.1.2).

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 buried rootwad depths were determined based on scour estimates and professional judgment.

5.1.1 Scour Equation (Liu et al. 1961)

The Lui et al. (1961) scour equation was developed from laboratory tests in a flume and ELJ prototype measurements and was subsequently verified during 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 evaluate scour for the Type A bar 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.

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

Maximum probable scour was estimated for each of the Type A, Type Ac, Type As, Type BD, Type B, and Type V structures. Scour was estimated for the design event for each of these structures. Design analysis scour depths based on both the results of this analysis and professional judgment are presented in Table 1.

Table 1
Design Scour Depths for Structures at Specified Design Flows

Structure Type – Location	Design Event	Design Scour (feet)
Type A[1] – Island Apex	100-year	13.7
Type Ac – At side channel entrance	100-year	11.9
Type As[1,2] – Side Channel	100-year	9.0
Type BD – Main Channel[3]	2-year	11.7
Type B	100-year	10.1
Type V	10-year	3.7

1. Scour results for Type A and As structures were calculated using the simplified Chinese equation.
2. Results are reported for the Type As structure with highest scour calculation results in the side channel. Located at approximately Station 8+00 in the side channel.
3. Results are reported for the structure with the highest scour calculation result in the main channel. Located at approximately Station 270+00 in the main channel.

The Type BD structure blocks a smaller percentage of the total cross-sectional area when looking at a 100-year event. The structure blocks the largest percentage of the cross-sectional area for the 2-year event. During the 2-year event, flow is forced around the tip of the structure, which would produce the most scour at that location. For events beyond the 2-year flow, the structure does not behave as an abutment since the structure is overtopped, and the flow is not concentrated at the tip of the structure. Therefore, for higher flow events, additional scour is not expected at the tip of the structure. For this reason, the 2-year flow was chosen for the scour depth calculation for the Type BD structure.

The calculated maximum scour depths at the structures ranged from 3.7 feet (Type V structure) to 13.7 feet (Type A Structure). The structures with the largest calculated estimated scour are the Type A and Type Ac (at the side channel entrance) and the most upstream Type BD structure in the main channel. These structures have the deepest scour because they are the larger structures that extend into the channel the farthest (have a long effective length, L_e) and are subject to the greatest hydraulic depths (d_1). They are also at cross-sections where higher Froude numbers are estimated by the hydraulic model, resulting in deeper estimated scour.

5.2 Gravity Structure Stability

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

Calculations assume that the logs have a specific gravity of 0.608 and a porosity of the ballast material placed on the logs of 25%. Over time, much of the wood within the structure can become saturated, thereby increasing each log's specific gravity and decreasing the overall buoyant 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 ELJs that rely on gravity for stability (Type A, As, Ac, BD, and B). Structure buoyancy calculations were not completed for the structures secured to buried rootwad logs. See Section 5.3 for buried rootwad log stability calculations.

Table 2
Gravity Structure Stability Factors of Safety

Structure ID	Horizontal Factor of Safety[1]	Vertical Factor of Safety[2]
Type A	1.6	3.0
Type As[3]	1.4	1.9
Type Ac	1.6	2.6
Type BD[3]	1.2	2.4
Side channel Type B[3]	1.6	4.6

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.
3. For structure types with multiple locations, the horizontal factor of safety is reported for the location with the highest approach velocity at the design discharge event.

5.3 Buried Rootwad Log Supported Structure Stability

A buried rootwad log stability analysis was completed for the Type V structures. The buried rootwad log stability analyses examined the size of the structure, the number of buried rootwad logs, the depth of the burial, and the hydraulic load applied to the structure. The number of buried rootwad logs needed for each structure is determined by the structure length and width (structure geometry) and the hydraulic load applied to the structure. The hydraulic load is transferred from the rootwad logs above grade to the buried rootwad logs. Results of the buried rootwad log analysis are presented in Table 3.

A resulting factor of safety was determined for the structure. The factor of safety is the ratio of the structural capacity of the buried rootwad logs to the design load. The contribution of the rootwad mass to the stability of the buried log was not included in the analysis as there is a great deal of uncertainty regarding the size and shape of the rootwad mass. However, a larger fuller rootwad mass will generally increase the stability of the buried rootwad log.

Table 3

Buried Rootwad Log Supported Structure Design Summary and Resulting Factors of Safety

Structure Type and Location[1]	Structure Type V (side channel Station 7+50)
Design Event	10-year
Velocity[2], V (fps)	6.8
Scour Depth (feet)	3.7
Effective Embedment Depth[3], L (feet)	3.8
Embedment Depth BEGS (feet)	7.5
Log Diameter[4], B (inches)	12
Number of Logs, n	4
Min. Log Bending Stress Cap.[5] (psi)	475
F.S. Log Overturning	1.4
F.S. Log Strength	2.5

Notes:
1. See design Drawings 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. The selected structure locations have the highest approach velocity at the design discharge event.
3. Effective embedment is the depth below the design analysis scour depth (see Section 5.1).
4. Log diameter is measured at breast height to be consistent with the design specifications.
5. Specified minimum bending stress is the starting design value before strength reduction factors are applied per timber design methods.

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

5.3.1 Soil Strength

The soil strength to resist buried rootwad log overturning was calculated for the Type V structures. These calculations represent the condition where the soils (substrate) supporting the buried rootwad fails and the rootwad logs overturn before the log strength is exceeded (Section 5.3.2). 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 embedment depth. The analysis also assumes that 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 diameter, buried rootwad log quantity, substrate characteristics, and varying velocities across the channel.

5.3.2 Log Bending Strength

The log bending strength was calculated for the Type V structures. These calculations represent the condition where the log yield and break in bending under the applied load. These calculations assess each log 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 length. The log bending strength factor of safety was evaluated to exceed to the soil strength for each structure type. Log bending strength sensitivity analysis included varying the diameter and bending stress capacity of the logs.

6 LIMITATIONS

This report was prepared for Reclamation for use in documenting design analysis for the 100% design phase of the WDFW Habitat Improvement project. Conditions within the project site may change both spatially and with time and as additional scientific and engineering 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.

7 REFERENCES

Anchor QEA, 2010. *Conceptual Projects Alternatives Assessment: M2 Reach Project Concept Formulation*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). November 2010.

Anchor QEA, 2011a. *Alternatives Evaluation Report; Upper Middle Methow Reach*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). September 2011.

Anchor QEA, 2011b. *30 Percent Design Report, Upper Middle Methow Reach, WDFW Floodplain*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). December 2011.

Anchor QEA, 2012a. *60 Percent Basis of Design Report WDFW River Project*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). February 2012.

Anchor QEA, 2012b. *Final 90 Percent Basis of Design Report WDFW Habitat Improvement Project*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). June 2012.

Anchor QEA, 2012c. Middle Methow River Safety Memorandum. Prepared for the Methow Salmon Recovery Foundation (Twisp, Washington). June 2012.

Anchor QEA, 2013. 100 *Percent Basis of Design Report WDFW Culvert Improvement Project*. Prepared for the U.S. Bureau of Reclamation Pacific Northwest Region (Boise, Idaho). March 2013.

Drury, T., 1999. *Stability and pool scour of engineered log jam structures in the North Fork Stillaguamish River, Washington*. M.S. Thesis University of Washington.

Liu, M.K., F.M. Chang, and M.M. Skinner, 1961. *Effect of Bridge Construction on Scour and Backwater*, Dept. of Civil Engineering, Colorado State University, Report No. CER60-HKL22. February 1961.

Reclamation, 2008. *Methow Subbasin Geomorphic Assessment, Okanogan County, Washington*. U.S. Bureau of Reclamation Technical Service Center. Denver, Colorado. February 2008

Reclamation, 2010. *Middle Methow Reach Assessment, Methow River, Okanagan County, Washington*. U.S. Department of the Interior. U.S. Bureau of Reclamation Pacific Northwest Region. Boise, Idaho. August 2010.

Reclamation, 2012. *2D Modeling of Restoration Alternatives for WDFW Project Area Methow River*. Technical Report No. SRH-2012-21. U.S. Bureau of Reclamation Technical Service Center. Denver, Colorado. July 2012.

ACCOMPANYING DOCUMENTS

- Construction Drawings (21 Sheets)
- Construction Technical Specifications
- Opinion of Probable Construction Costs