



100 PERCENT DESIGN REPORT
PROJECT AREA 14
TUCANNON RIVER

Prepared for

Snake River Salmon Recovery Board
410 B East Main
Dayton, Washington 99328

Prepared by

Anchor QEA, LLC
1605 Cornwall Avenue
Bellingham, Washington 98225

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List of Accompanying Documents

- Construction Drawings (22 sheets)
- Construction Technical Specifications
- Opinion of Probable Construction Costs

List of Acronyms and Abbreviations

%	percent
1-D	one-dimensional
Anchor QEA	Anchor QEA, LLC
BMP	best management practice
CRP	Conceptual Restoration Plan
DBH	diameter at breast height
ELJ	engineered log jam
ESA	Endangered Species Act
HEC-RAS	Hydraulic Engineering Center-River Analysis System
LiDAR	Light Detection and Ranging
LWD	large woody debris
PA	Project Area
RM	river mile
SRSRB	Snake River Salmon Recovery Board
WDFW	Washington Department of Fish and Wildlife

ELJ Structures

BA	Bar Apex
BAb	Bar Apex bank
BAr	Bar Apex racking
BB	Bank Barb
CG	Channel Grade
CS	Channel Spanning

LWD Features

BBp	Bank Barb pile
S	Single
SRb	Sediment Retention boulder
SRp	Sediment Retention pile
TH	Toe Habitat
THb	Toe Habitat boulder

1 INTRODUCTION

Anchor QEA, LLC (Anchor QEA), was retained by the Snake River Salmon Recovery Board (SRSRB) to develop 100 percent (%) designs for restoration within Project Area (PA)-14 of the Tucannon River as delineated in the *Conceptual Restoration Plan* (CRP; Anchor QEA 2011c) from approximately river mile (RM) 39.2 to 37.15. The Tucannon River basin is located in southeast Washington State in Columbia and Garfield counties (Drawing T-01). Enhancing and restoring instream habitat in PA-14 will be accomplished through a variety of treatment actions in the main channel, along the banks, and within the floodplain. This report describes the project areas, as well as the function, design, and construction of restoration treatments that are proposed for implementation. These treatments include construction of large woody debris (LWD) features and engineered log jam (ELJ) structures, removal of infrastructure such as dredge spoils, and riparian plantings. In addition, a gravel augmentation program is proposed to place former dredge spoils back into the river to help treat incision and arrest an existing headcut moving through the reach near the upstream extent of PA-14. A description of the area with respect to existing natural processes and habitat conditions is provided in the 30% design report (Anchor QEA 2011d), along with the specific physical and biological objectives that the proposed restoration features are expected to achieve (Appendix A, Anchor QEA 2011d). The project's contribution to the overall watershed-scale restoration plan is also described in the 30% design report.

1.1 Previously Completed Studies

Previous studies completed in support of restoration within PA-14 are presented below:

- *Tucannon Subbasin Plan* (CCD 2004)
- *Snake River Recovery Plan for SE Washington* (SRSRB 2006)
- *Tucannon River Geomorphic Assessment and Habitat Restoration Study* (Anchor QEA 2011a)
- *Draft Conceptual Restoration Plan, River Miles 20 to 50 Tucannon River Phase II* (Anchor QEA 2011b)
- *Conceptual Restoration Plan, Reaches 6 to 10* (Anchor QEA 2011c)
- 30 Percent Design Report (Anchor QEA 2011d)
- 60 Percent Design Report (Anchor QEA 2012a)

1.2 Construction and Permit Considerations

PA-14 is located entirely on property owned by the Washington Department of Fish and Wildlife (WDFW). Although several access routes will be required to access the length of PA-14, disturbance to existing vegetation will be minimized by observing best management practices (BMPs) during construction. Any trees that are disturbed may be incorporated into the project design to add additional complexity to the proposed LWD features. The gravel augmentation program described in this report and shown on the Drawings will take place only in areas where the initial gravel placement will not fill critical habitat features such as pools and LWD cover. Gravel augmentation programs will be monitored closely and adaptively managed over the course of the project. Additional construction considerations and BMPs are included in the 30% design report for the proposed treatment actions (Anchor QEA 2011d).

2 PROJECT PURPOSE AND OBJECTIVES

The system-wide restoration objective for the Tucannon River is to improve habitat conditions for Endangered Species Act (ESA)-listed species for all life history stages. Improving habitat conditions will lead to an increase in the abundance of listed species returning to the river. Increasing abundance will lead to delisting of the species, which is the overall recovery goal for the system. Previous efforts (CCD 2004; SRSRB 2006) have identified the habitat-limiting factors associated with the decline of ESA-listed populations. A geomorphic assessment synthesized and updated this information and identified ten geomorphic reaches between the river mouth and Panjab Creek (RM 50). Reach-scale restoration actions based on this basin-scale assessment were provided at a preliminary level in the CRP (Anchor QEA 2011c). A summary of this plan for the reaches that included PA-14 can be found in Section 2.1 of the PA-14 60% design report (Anchor QEA 2012a), and a brief description of the project selection process can be found in Section 2.2. The restoration actions described in the CRP (Anchor QEA 2011c) were refined in the 30% and 60% design phases (Anchor QEA 2011d; Anchor QEA 2012a, respectively). The restoration actions have now been further refined in the 100% design. The refinements are based on detailed comments from the SRSRB and WDFW, along with additional information about site conditions, access considerations, and anticipated permit requirements.

3 DESIGN DEVELOPMENT

For discussion purposes, PA-14 was divided into four discrete subareas with similar existing conditions, restoration objectives, and suites of treatment actions (Table 1). For an overview of the proposed conditions in PA-14, see Drawings C-03 and C-04.

Table 1
PA-14 Subareas

Subarea	River Miles ¹	Project Stationing	Length (feet)
1	39.2 to 38.8	108+00 to 88+00	2,000
2	38.8 to 38.45	88+00 to 60+00	2,800
3	38.45 to 37.75	60+00 to 30+00	3,000
4 ²	37.75 to 37.15	30+00 to 0+00	3,000

Notes:

1. RM rounded to nearest 0.05 mile
2. No actions are proposed for Subarea 4 in the 100% design

The proposed restoration actions are described within each subarea, including the physical descriptions, construction details, and expected biological and physical benefits. Design details for LWD features and ELJ structures¹ are shown in Drawings C-10 through C-19. To describe the specific benefits of the design elements, the subareas have been further subdivided into groups of one or more features. However, the proposed design is intended to function collectively throughout the overall project area to achieve a reach-scale geomorphic response and optimum biological benefit in the long term. Therefore, the subareas and feature groups are not independent from one another. However, construction may spread out over a number of years depending on funding.

3.1 Subarea 1, Stations 108+00 to 88+00

Subarea 1 is located between the hatchery bridge near Station 108+00 to just upstream of the outlet of the hatchery outfall channel, Station 88+00. The proposed restoration features within this subarea are summarized in Table 2 and shown in Drawings C-05 and C-06.

Table 2
Summary of Proposed Restoration Actions and Expected Benefits, Subarea 1

Feature Group	Approximate Station	Action(s)	Expected Benefit
A	107+50 to 102+00	Spoil pile removal and gravel bedload augmentation	Works collectively with downstream LWD features and ELJ structures to raise the bed elevation of incised portions of PA-14, contributing to channel complexity and floodplain connectivity.
B	103+50 to 98+50	Placement of three channel S LWD features; construction of one BA ELJ structure and a custom channel spanning jam connecting it to the right bank; placement of five TH LWD features in the left split channel; and intensive riparian planting on the right bank	Address the active headcut by directing the majority of flow into the left-hand split flow channel and add LWD to the left bank to promote disturbance and roughen the channel; roughen the floodplain adjacent to the hatchery levee to minimize avulsion risk. Promote retention of wood and sediment to smooth out the headcut and steepened elevation in the subarea.
C	100+00	Floodplain pilot channel excavation	Excavation of a floodplain pilot channel will immediately increase channel floodplain connectivity and access a long network of flow paths downstream of the excavation location. The increased floodplain connectivity will make large areas available for fish refuge during high flows and promote longer term channel migration through healthy riparian areas.
D	98+50 to 95+50	Construction of three TH LWD features on the left bank, two BBp LWD features on the right bank, and one BAb ELJ structure on the right bank	Provide hydraulic complexity and cover, promote gravel deposition, and encourage channel thalweg development away from the riprap-lined bank upstream of the hatchery outfall.
E	95+50 to 92+00	Construction of one CG and one BA ELJ structure at the heads of existing islands, placement of two channel S LWD, and floodplain pilot channel excavation	Maintain the existing split flow/island configuration and direct flood flows toward the inlet of the floodplain pilot channel. Excavation of a floodplain pilot channel will immediately increase channel floodplain connectivity and access a long network of flow paths downstream of the excavation location. The increased floodplain connectivity will make large areas available for fish refuge during high flows and promote longer term channel migration through healthy riparian areas.

Feature Group	Approximate Station	Action(s)	Expected Benefit
F	90+60 to 89+20	Construction of four TH LWD features along the left bank	Create hydraulic diversity, initiate meander bend development, and promote floodplain connectivity.
G	90+50 to 86+50	Spoil pile removal and in-channel gravel placement during construction; placement of eight S LWD features in the hatchery outfall channel	Spoil pile removal and channel gravel placement is intended to promote increased floodplain connectivity and increase the local channel bed elevation to improve accessibility to the hatchery outfall channel. S LWD features are intended to provide cover and complexity at the downstream end of the existing hatchery outfall channel.

3.2 Subarea 2, Stations 88+00 to 60+00

Subarea 2 is located from Stations 88+00 to 60+00. The proposed restoration features within this subarea are summarized in Table 3 and shown in Drawings C-06 and C-07.

Table 3
Summary of Proposed Restoration Actions and Expected Benefits, Subarea 2

Feature Group	Approximate Station	Action(s)	Expected Benefit
A	88+00 to 84+00	Construction of three TH LWD features, one BAr ELJ structure, and one CS ELJ structure	Improve low-flow connectivity to the existing side channel. Retain mobile LWD and bedload to raise the bed elevation along the valley wall over time.
B	84+00 to 80+50	Placement of one channel S LWD, construction of two SRb LWD features and one CG ELJ structure, and floodplain pilot channel excavation	Add instream complexity and promote floodplain connectivity and evolution of a channel network through the adjacent floodplain. Excavation of a floodplain pilot channel will immediately increase channel floodplain connectivity and split the flow away from the valley wall in an otherwise straight run. The increased floodplain connectivity will make large areas available for fish refuge during high flows and promote longer term channel migration through healthy riparian areas.
C	79+00 to 76+00	Placement of one S LWD in the main channel; construction of two THb LWD features, two SRp LWD features, one BB ELJ	Initiate the reversal of the existing meander bend and promote the development of a point bar on the right bank. Provide hydraulic complexity and cover in the pool at the outlet of the floodplain flow paths at Station 76+50.

Feature Group	Approximate Station	Action(s)	Expected Benefit
		structure, and multiple S LWD features secured to existing trees	
D	67+00 to 63+00	Placement of three channel S LWD; construction of one CG ELJ structure, two SRb and one TH LWD feature	Split high flow to enhance flow into the existing floodplain flow paths that connect to the Blue Lake outfall. Promote point bar development and right bank floodplain connectivity.

3.3 Subarea 3, Stations 60+00 to 29+00

Subarea 3 is located from Stations 60+00 to 29+00. The proposed restoration features within this subarea are summarized in Table 4 and shown in Drawings C-07 through C-09.

Table 4
Summary of Proposed Restoration Actions and Expected Benefits, Subarea 3

Feature Group	Approximate Station	Action(s)	Expected Benefit
A	60+00 to 55+50	Placement of five channel S LWD, construction of one BA ELJ structure, one TH LWD features, one CS ELJ structure, and placement of multiple single LWD that will be incorporated into a natural log jam	Create cover and refuge in the main channel short term, retain wood and sediment to increase floodplain connectivity, and reverse the incised channel condition over time.
B	53+00 to 47+50	Placement of two channel S LWD; construction of three BB ELJ structures and four TH LWD features	Add instream complexity, promote development of more complex channel configuration, and raise the bed elevation over time.
C	47+00 to 41+00	Construction of two CS ELJ structures and two SRp LWD features	Provide diverse hydraulic conditions in the short term. Retain mobile LWD and bedload to raise the bed elevation of the incised channel over time.
D	36+50 to 29+00	Placement of two channel S LWD and construction of three CG ELJ structures	Provide cover and complexity in the short term. Retain mobile LWD and bedload over time to promote floodplain connectivity without impacting the functionality of the bridge just downstream.

3.3.1 Bridge Removal

Removal of the bridge at Station 31+00 is proposed as part of this project (the bridge is located across the former Tucannon Road crossing). This process will involve demolition and removal of two concrete abutments, four cast-in-place piers, and the bridge deck and railings. A portion of the fill on the left bank floodplain leading up to the bridge will also be regraded to more closely match the natural floodplain grade. The bridge opening currently represents a significant channel constriction that likely causes a backwater effect and accelerated velocities during flood flows that may affect fish passage, particularly juveniles. In addition to creating better instream conditions, removing this constriction will allow the presently straight channel to evolve to a more natural configuration over time. See Drawing C-09 for bridge and approach removal extents.

3.4 Subarea 4, Stations 29+00 to 0+00

Subarea 4 stretches from Station 29+00 to the downstream end of the project subarea at Station 0+00. All restoration actions proposed for this subarea in the 60% design were removed from the 100% design at the request of the clients (SRSRB and WDFW). The relative functionality and steady recovery trajectory of this subarea, combined with the desire to limit riparian disturbance, made this subarea less of a focus for restoration when compared to the other subareas.

3.5 Key Modifications to the 60% Design

Anchor QEA refined the 60% design to accommodate comments provided by SRSRB and WDFW, increase habitat and geomorphic benefits, and improve constructability. The following subsections detail design changes made to the LWD features and ELJ structures.

3.5.1 Pilot Channel Excavations

These excavations are new for the 100% design. They were introduced conceptually at 60%, but no specific depths, lengths, or widths were provided. Four pilot channel excavations are proposed within PA-14. The excavations enhance floodplain connectivity and channel complexity with limited riparian impacts by taking advantage of existing floodplain flow paths. The pilot channel excavations are typically only 2 to 3 feet deep, 10 to 15 feet wide at

the bottom, and 100 to 250 feet long. The width of the cut is designed to work with existing topography and may be adjusted in the field to work around large trees. The alignment of the pilot channels may also be modified in the field to work with low spots that may not have been identified by the Light Detection and Ranging (LiDAR). Each pilot channel will improve connectivity to a floodplain flow path at least twice the length of the pilot channel excavation. The relative connectivity of these cuts varies, but the pilot channels will typically be activated at discharges just over the 1-year return period. To provide a rough estimation of the relative amount of flow, each channel cut would capture—during a 5-year return period event—the percent conveyance area for each of the channels presented in Table 5.

Table 5
Pilot Channel Relative Conveyance Areas

Pilot Channel Inlet Main Channel Station (Drawing Cut Letter)	Pilot Channel Inlet Elevation (feet)	Pilot Channel Bottom Width (feet)	5-year Return Period Event Percent Conveyance Area	
			Main Channel	Side Channel
100+00 (B)	2160.0	15	87%	13%
93+00 (C)	2150.0	15	89%	11%
82+00 (D)	2135.5	10	89%	11%
57+50 (E)	2107.5	15	89%	11%

All pilot channels will be active during the 5-year return period event and capture between 10% and 15% of the total flow. The inlet elevations for the pilot channels are designed to activate at discharges just over the 1-year return period event. However, given the uncertainty in the analysis, flow down the pilot channels will likely begin around the 1-year return period event.

Material produced from the pilot channel excavations will be incorporated into many of the ELJ structures, placed in the main channel as a one-time gravel augmentation, or spread out across a wide area in the floodplain. Trees and other woody vegetation cleared from these cuts may be incorporated into the ELJ structures and LWD features or be placed back on the pilot channel finished grade surface to add roughness to the channel and provide habitat and hydraulic complexity.

3.5.2 Single (S) LWD Feature

The specified rootwad log diameter at breast height (DBH) was reduced from 18 inches to 15 inches to accommodate availability from local sources. A number of S LWD features were added in the main channel near other LWD features and ELJ structures to seed PA-14 with additional LWD and increase smaller LWD retainment. These S LWD features will not be buried or connected to existing trees. They will be allowed to shift over time and rack up against the other LWD features and ELJ structures in the project.

3.5.3 Toe Habitat (TH) LWD Feature

The specified rootwad log DBH was reduced from 18 inches to 15 inches to accommodate availability from local sources. The specified rootwad log minimum length was increased from 25 feet to 30 feet to match availability from local sources and to improve long-term LWD retainment. To reduce the overall number of rootwad logs required for the project, the designs allow a log pole to be substituted for the top rootwad log.

3.5.4 Toe Habitat boulder (THb) LWD Feature (Type TH2 LWD at 60%)

The specified rootwad log DBH was reduced from 18 inches to 15 inches to accommodate availability from local sources. The specified rootwad log minimum length was increased from 25 feet to 30 feet to match availability from local sources and to improve long-term LWD retainment. The specified intermediate boulder diameter was reduced from 4 feet to 3.8 feet in relation to the small reduction in buoyancy from the use of smaller diameter, longer rootwad logs. To reduce the overall number of rootwad logs required for the project, the designs allow a log pole to be substituted for the top rootwad log.

3.5.5 Sediment Retention pile (SRp) LWD Feature (Type SR LWD at 60%)

Log piles were substituted for the rootwad log piles to reduce material costs and construction impacts related to excavation. The relative position of the log piles and the rootwad logs was revised to reduce the reliance on rope connections. This was accomplished by placing the rootwad logs between the piles and allowing them to lever against the piles in opposing directions. The distance between the rootwad ends and the nearest rootwad log piles was increased from 8 feet to 9 feet to improve in-channel low-flow habitat benefit and reduce scour potential near the log piles. The specified rootwad log DBH and log pole diameter was

reduced from 18 inches to 15 inches to accommodate availability from local sources. The specified rootwad log minimum length was increased by 5 feet to match availability from local sources and to increase the habitat and geomorphic benefit footprint.

3.5.6 Sediment Retention boulder (SRb) LWD Feature (Type SR2 LWD at 60%)

Revisions to the rootwad log layout and size specifications are similar to the SRp LWD feature for the 100% design. The specified intermediate boulder diameter was reduced from 4 feet to 3 feet in relation to the reduction in buoyancy from the use of smaller diameter rootwad logs.

3.5.7 Bank Barb pile (BBp) LWD Feature

This structure type is new for the 100% design. It is a log pile or tree-supported bank barb feature that is designed to capture additional LWD over time while providing immediate habitat benefit at low to moderate flows. The log pile and rootwad log configuration is similar to the SRp LWD feature in the way the rootwads are threaded between the log piles, allowing them to lever against the piles in opposing directions. Unlike the SRp LWD feature, there is no boxed-in area for sediment retention; rather, the rootwads are oriented to deflect flow away from the bank and back into the center of the channel. This feature is proposed in two locations on the right bank upstream of a riprap-lined bend. Over time, these features should work with the BAb ELJ structure to redirect the main channel away from the riprapped bank toward a mature riparian area.

3.5.8 Bar Apex (BA) ELJ Structure

The specified rootwad log DBH was reduced from 24 inches to 18 inches for layer 1 and from 18 inches to 15 inches for the remaining layers to accommodate availability from local sources. The number of layers was increased from 9 to 11 to compensate for the reduction in individual layer height while maintaining a similar overall structure height. Small refinements in the layer layback rate and rootwad position were made to allow the use of fuller rootwads while improving constructability.

3.5.9 Bar Apex bank (BAb) ELJ Structure

This structure type is new for the 100% design. It is a variation on the BA ELJ structure and is designed specifically to be placed against an existing channel bank. All the rootwad ends protrude from the structure on the upstream and channel sides. This configuration improves the ability to tie the bank side of the structure into the existing bank with more limited disturbance relative to placing rootwads against the existing bank. The alternating use of rootwad logs and log poles in many of the layers will allow long rootwad logs (typically 40 feet) to be cut into one shorter rootwad log and one log pole. This efficient use of materials will reduce the total number of large woody materials needed for the structure. The upstream side of the structure is beveled away from the bank to deflect flow toward the channel center and limit the likelihood of structure flanking. The structure is also longer in the direction of flow compared to the BB ELJ and will help maintain a longer sediment deposition zone in the lee of the structure relative to the BB ELJ. This longer sediment deposition zone is intended to help maintain a more natural-looking bank and a widened riparian zone in front of the existing riprap downstream of the structure location.

3.5.10 Channel Grade (CG) ELJ Structure

The specified rootwad log DBH was reduced from 24 inches to 18 inches for odd-numbered layers and from 18 inches to 15 inches for even-numbered layers to accommodate availability from local sources. The number of layers was increased from 6 to 8 to compensate for the reduction in individual layer height while maintaining a similar overall structure height. To reduce the number of rootwad logs required in the structure, log poles were substituted for rootwad logs in multiple locations. Log poles replaced the interior rootwads on layer 2 and the rootwad logs in layers 4, 5, 7, and 8. These substitutions are not anticipated to have a significant impact on geomorphic or habitat benefits. Small refinements in the layer layback rate and rootwad position were made to allow the use of fuller rootwads while improving constructability. The specified intermediate boulder diameter was reduced from 4.5 feet to 3.5 feet to improve constructability and material sourcing. The total number of boulders required was increased from 30 to 48 to compensate for the reduction in minimum boulder diameter.

3.5.11 Bank Barb (BB) ELJ Structure

The specified rootwad log and log pole diameter was reduced from 18 inches to 15 inches to accommodate availability from local sources. The number of layers was increased from 8 to 10 to compensate for the reduction in individual layer height while maintaining a similar overall structure height. One log pole was substituted for the rootwad log on the downstream side in the even-numbered layers and three log poles were substituted for the rootwad logs in layer 1. These substitutions reduced the number of rootwad logs required in the structure without having a significant impact on geomorphic or habitat benefits. Refinements in the layer layback rate and rootwad position were made to allow the structure to better conform to the existing bank slope and to allow use of fuller rootwads without excessive rootwad interference. The specified minimum length was increased for two of the three logs in each layer by approximately 5 feet to lengthen the structure in the direction of flow and to allow for more flexibility in layer setback rate.

3.5.12 Channel Spanning (CS) ELJ Structure

The specified rootwad log diameter was reduced from 36 inches to 30 inches for the three rootwad logs in layer 1 to reduce the weight of each rootwad log and allow the use of smaller equipment and possibly helicopter placement (with an assumed helicopter lift weight limit of 15,000 pounds). The log pole diameters in layers 1 and 2 were reduced from 24 inches to 18 inches to better match availability from local sources. Four rootwad logs (24-inch DBH) were added to the top of the structure of layer 3 to compensate for the reduction in individual layer height while maintaining a similar overall structure height. These additional rootwad logs will also improve long-term woody debris retention and overall structure effectiveness. The additional rootwad logs as layer 3 did not allow for a revision to the size or number of boulders used to provide initial structure stability. However, it would be possible to replace some or all of the largest diameter boulders with more smaller diameter boulders as long as the total weight of placed boulders remains the same or greater. This potential field modification would allow a helicopter to pick boulders with a larger margin between the helicopter lift capacity and the weight of the boulder.

3.5.13 Bar Apex racking (BAr) ELJ Structure

This structure type is new for the 100% design. It is similar to the multiple LWD placement design found in the PA-24 30% design drawings (Anchor QEA 2012b). The structure uses two rootwad logs and one log pole per layer, spaced approximately 6 feet apart and oriented at approximately a 45-degree angle to the flow. The design of this ELJ allows the orientation of each log to be flexible to work with existing large trees. To improve stability, the ELJ may be backfilled with native material if a borrow source is available nearby. The habitat benefits and geomorphic function is similar to the BA ELJ except that a deep pool is not excavated at the time of construction.

4 HYDRAULIC ANALYSIS

4.1 HEC-RAS Model

A reach-based, one-dimensional (1-D) Hydraulic Engineering Center-River Analysis System (HEC-RAS) hydraulic model (Brunner 2010a, 2010b) was developed for the 60% design by Anchor QEA (2012a) for a portion of PA-14 (Stations 94+50 to 111+00). The results of this HEC-RAS model were again used to support the structure and feature design calculations and scour calculations presented in this report. The model was run for the design hydrology shown in Table 6. The design hydrology provided a thorough understanding of hydraulic conditions over a wide range of discharges.

Table 6
Design Hydrology, PA-14, Tucannon River

Discharge (cfs)	Return Period
245	1-year
664	2-year
1,481	5-year
2,276	10-year
3,627	25-year
4,923	50-year
6,498	100-year

Notes:

1. Hydrology was developed by Anchor QEA as part of the geomorphic assessment and habitat restoration study (Anchor QEA 2011a).

cfs = cubic feet per second

The detailed hydraulic model was only developed for the portion of PA-14 where concerns related to existing infrastructure (WDFW hatchery) are the greatest. All structure and feature design analyses were completed using the hydraulic results of this model.

A description of the HEC-RAS model development can be found in Section 4 of the 60% design report (Anchor QEA 2012a). A proposed conditions model was not developed as part of this design phase. The design analysis for features and structures only requires information on existing conditions hydraulics.

5 DESIGN ANALYSES

The design analyses completed for the proposed features and structures include scour, stability, and pile analyses. Forces considered in these analyses include log buoyancy, 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 holding strength to the actual applied load.

5.1 Scour Analysis

Bed scour at the BB and BAb ELJ structures and the SRp and BBp LWD features placed along existing banks 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 ELJ structures. The equation relates flow conditions (i.e., flow depth and velocity), obstruction dimensions, and Froude number to maximum scour depth below existing grade. Approach velocity, water depth, and Froude number were obtained from the hydraulic output of a HEC-RAS steady-state model completed by Anchor QEA.

Bed scour at the BA and CG ELJ structures was estimated using the simplified Chinese equation (Landers and Mueller 1996) developed for bridge piers in coarse bed rivers. The equation relates flow conditions (i.e., flow depth and velocity), obstruction dimensions, and sediment grain size distribution to maximum scour depth below existing grade. Values for the required hydraulic parameters were obtained from output of the HEC-RAS steady-state model completed by Anchor QEA. Estimates of the of the channel bed grain size distribution were made based on site visit observations. A detailed description of the scour equation referenced above can be found in Sections 5.1.1 and 5.1.2 of the 60% design report (Anchor QEA 2012a). 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 installation depths will be determined based on scour estimates and professional judgment.

5.1.1 Results

The maximum probable scour was estimated for the BA, BAb, CG, and BB ELJ structures over a range of flows up to the 100-year event. The maximum probable scour was estimated for the BBp and SRp features over a range of flows up to the 10-year event. Table 7 presents probable scour depths based on both the results of this analysis and professional judgment.

Table 7
Probable Maximum Scour Depths for Features and Structures

Feature or Structure ¹	Flow Event	Scour Depth (feet)
BA	100-year	8.5
BAb	100-year	7.4
CG	100-year	8.5
BB	100-year	7.4
BBp	10-year	4.0
SRp	10-year	3.5

Notes:

1. Results are reported for the feature or structure location with the highest calculated scour depth (for that feature or structure). A common structure design was used even though scour may be less at other locations.

The probable maximum scour depth for the BA and CG ELJ structures are very similar as their width (b), at the channel grade, is nearly the same. The major difference between these two ELJ structures is how they are designed to handle to scour.

- The BA ELJ structure is emended into the channel bed to a depth just above the probable maximum scour depth. Embedding the structure into the bed reduces the likelihood of scour under the structure would result in differential settling, thereby compromising the stability of the structure.
- The CG ELJ structure is essentially placed at the existing channel grade with only minor excavation for the rootwad mass to allow good ground contact along the length of the logs in the bottom layer. The front of the structure, where maximum scour depth is anticipated, is set forward of the enclosed portion of the structure containing the ballast material. This configuration limits the likelihood that scour would undermine the structure and cause differential settling. Additionally, the enclosed portion of structure is backfilled with large boulders rather than native material. The size of the boulders greatly improves the retention of the ballast required for stability

even if the structure experiences differential settling and distortion. Furthermore, many locations where the CG ELJ structure is proposed have a significantly coarser bed material than what was assumed in the calculations.

Scour was not evaluated at the TH, THb, and SRb features or at the BAr and CS ELJ structures. These structures are designed to be flexible and settle into any scour local to the rootwad logs and boulders. In the case of the BAr structure, the stability is primarily derived from bracing the layers up against existing standing trees rather than ballast placed within the structure. Although the structure is braced against existing standing trees, it is not directly attached to them. This configuration allows the structure to freely settle into any scour pools that may develop over time. The CS structures span the entire channel and flow contraction and acceleration is expected to be primarily in the vertical direction. These hydraulic conditions are more likely to result in material deposition upstream of the structure rather than scour.

The probable maximum scour depth for the BB and BAb ELJ structures is slightly less than the scour for the BA and CG ELJ structures, as its effective length (L_e) into the flow presents less of an obstruction to flow than the wider BA and CG ELJ structures. The embedment depth of the BB and BAb ELJ structures is designed to handle scour in a similar way to the BA ELJ structure. The footer log along the leading edge of the BB structure and the layer 1 rootwad log in the BAb structure is intended to help retain the backfill required for structure stability in the event that scour begins to undercut the structure.

The probable maximum scour depth for the SRp and BBp LWD features is considerably less than the other structures for the following reasons:

- The design discharge is the 10-year flow event
- The features' low profile causes the effective length (L_e) into the flow used in the calculations to be reduced as the structure becomes further submerged at higher discharges
- Similar to the CS ELJ structure, the flow contraction and acceleration is expected to be both horizontal and vertical for discharges overtopping the features

The probable maximum scour depth for the SRp and BBp LWD features is used to determine the unsupported length of the log piles (see Section 5.3).

5.2 Stability of Ballasted Features and Structures

The ballasted features and structures stability analysis evaluates the sum of all the forces acting on the feature or structure to determine the horizontal and vertical factor of safety against displacement. The forces driving and resisting structure displacement are:

- The upward vertical force on the structure from the buoyancy of the submerged wood
- Downward vertical forces from the weight of the un-submerged wood and the ballast material secured to or within the feature or structure
- Driving horizontal forces from drag and differential hydrostatic pressure acting on the structure
- The resisting horizontal force caused by friction between the bottom of the structure and the river bed

The factors of safety presented in Table 8 (for both vertical and horizontal forces) are for features and structures just after construction. Calculations assume that the LWD density is equal to the average green weight of wood and bark for the lowest density species allowed in construction. Over time, much of the wood within the structure can become saturated, thereby increasing the log's density and increasing the overall weight and resisting force of the structure. Calculations also assume the bulk porosity of the backfill material placed as ballast is 0.30. For structures where boulders are used as ballast, the rock mass specific gravity is assumed to be 2.5 to account for variability in rock type density.

Table 8
Gravity Structure Stability Factors of Safety

Feature or Structure	Representative of Moderate Discharge Events		Representative of 100-year Discharge Events		Fully Submerged
	Approach Velocity, V (fps)	Horizontal Factor of Safety ¹	Approach Velocity, V (fps)	Horizontal Factor of Safety ¹	Vertical Factor of Safety ²
BA	9.0	2.2	12.5	1.2	3.4
BAb	9.0	2.0	12.5	1.0	3.0
CG	9.0	2.0	12.5	1.1	6.1
BB	9.0	2.1	12.5	1.1	3.2
CS	7.5	2.0	10.5	1.0	2.9
THb	5.2	2.0	7.2	1.0	3.3
SRb	7.8	2.0	11.0	1.0	3.5

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.

Structure buoyancy calculations were not completed for the pile-supported or tree-braced structures. See Section 5.3 for pile-supported feature stability calculations. See Section 5.4 for an explanation of tree-braced structures and the features' expected stability.

5.3 Pile-supported Feature Stability

Pile stability analyses were completed for the SRp and BBp features. The pile stability analyses examined the size of the feature, the number of log piles, the depth of the log piles, and the hydraulic load applied to the feature. The number of log piles needed for each feature is based on the feature length and width (feature geometry) and the hydraulic load applied to the feature. The hydraulic load is transferred from the above grade rootwad logs to the log piles. Results of the log pile analyses are presented in Table 9.

A resulting factor of safety was determined for the pile-supported features. The factor of safety is the ratio of the structural capacity of the pile system to the design load. The factor of safety increases as the number of piles or the pile diameter increases because the structural capacity of the pile system is increasing as the load remains constant.

Table 9
Pile-supported Feature Design Summary and Resulting Factors of Safety

LWD Feature ¹	SRp	BBp
Design Event	10-year	10-year
Velocity ² , V (fps)	5.6	5.6
Scour Depth (feet)	3.6	4.0
Log Pile Embedment ³ , L (feet)	3.4	4.0
Pile Depth BEGS (feet)	7.0	8.0
Log Pile Diameter ⁴ , B (inches)	12	12
Number of Log Piles, n	4	4
Minimum Pile Bending Stress Capacity ⁵ (psi)	475	475
Factor of Safety Log Pile Overturning	1.1	1.0
Factor of Safety Log Pile Bending Strength	2.7	1.5

Notes:

1. See design plans for additional details regarding LWD feature design and construction.
2. Velocity is determined using the HEC-RAS 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 the mid-point 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

5.3.1 Soil Strength

The soil strength resisting pile overturning was calculated for the sediment retention features. These calculations represent the condition where the soils (substrate) supporting the log piles fail and the log piles overturn before the pile strength is exceeded (Section 5.3.2), resulting in feature 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 features are subject to the highest modeled channel velocity in the vicinity of the feature. Furthermore, calculations assume a homogenous channel substrate.

5.3.2 Pile Bending Strength

The pile bending strength was calculated for the sediment retention features. 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 probable maximum scour depth for determination of the unsupported pile length. The pile bending strength factor of safety was evaluated to exceed the soil strength for each feature.

5.4 Feature Stability Using Existing Trees

A specific stability analysis for LWD features and ELJ structures braced against existing standing trees was not completed. The stability of each LWD and ELJ braced against existing standing trees will depend largely on the size, species, and health of the trees that the hydraulic forces are transferred to, as well as the approach angle of hydraulic forces and the changes in these forces over time. During construction, the engineer will identify trees that can be used to brace LWD features and ELJ structures. The trees will be selected based on their size, species, and health to provide the best possible stability at that location. Bracing features and structures against existing standing trees may increase the risk that the trees could be brought down during a high-flow event. However, this risk will generally be reduced over time as the rootwads making up the feature or structure become more saturated and as the standing trees continue to grow. It is expected that features and structures braced against existing trees will be capable of withstanding moderate discharge events. The hydraulic forces and the potential for channel migration caused by a 100-year event may cause the structures to shift significantly or dislodge entirely.

6 LIMITATIONS

This report was prepared for the SRSRB for use in documenting design analysis for the 100% design phase of the PA-14 geomorphic and habitat improvements. Conditions within the project may change both spatially and with time and as additional scientific and engineering data may become available. Significant changes in project area 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 this area at the time this report was prepared.

Engineered log jams (ELJs) 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 Columbia River Basin and are a vital component of healthy ecological systems. ELJs 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 aquatic 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 ELJs 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 ELJs. Walking on or over the ELJs 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 man-made. 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 Endangered Species Act 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.

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

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SRSRB (Snake River Salmon Recovery Board), 2006. *Snake River Recovery Plan for SE Washington*. Prepared for Washington Governor's Salmon Recovery Office. December 2006.

ACCOMPANYING DOCUMENTS

- Construction Drawings (22 Sheets)
- Construction Technical Specifications
- Opinion of Probable Construction Costs