Salmon Creek Culvert Replacement
Hydraulic Analysis
W. Uncas Road

Prepared for:
Jefferson County Public Works
623 Sheridan Street,
Port Townsend, WA 98368

And

Shearer Design
3613 Phinney Ave N. #B
Seattle, WA 98103

.

Prepared by:
Watershed Science & Engineering
110 Prefontaine Pl S., Suite 508
Seattle, WA 98104

WATERSHED
SCIENCE & ENGINEERING

August 24, 2015

ACKNOWLEDGEMENTS

The following staff of Watershed Science & Engineering participated in this evaluation:

Chris Frei	Lead Investigator, Technical Analysis
Erika Ottenbreit	Technical Analysis
Jeff Johnson	Technical Analysis, QA/QC

We gratefully acknowledge the assistance of the following individuals for providing project information:

David Shearer	Shearer Design
Josh Pruitt	Shearer Design
Eric Kuzma	Jefferson County Department of Public Works
Bob Barnard	Washington Department of Fish and Wildlife
Jim Shedd	Washington Department of Ecology

EXECUTIVE SUMMARY

Jefferson County has determined that the existing Salmon Creek culvert under W. Uncas Road has reached the end of its useful life. Shearer Design has been retained to design a replacement structure and Watershed Science & Engineering (WSE), serving as a sub-consultant to Shearer Design, is responsible for the hydraulic design aspects of the new crossing.

WSE used field observations, topographic survey data, and HEC-RAS modeling to analyze the crossing reach in order to determine a safe, economical, and low maintenance replacement waterway that will satisfy agency permit requirements. Initial alternatives considered in this investigation were based on a review of preliminary design recommendations made by WDFW in a 2009 crossing alternatives report.

Based on WSE's hydraulic investigation and discussion with Shearer Design, we recommend installation of an 80-ft bridge placed on a 30 degree skew with the centerline of the Salmon Creek to improve the crossing alignment. The bridge will be supported on driven pile foundations buried behind 1.75H:1V flow through earthen abutment slopes. Abutment slopes should be lined with a 3-ft thick layer of heavy loose riprap placed on top of a 1-ft thick graded filter or appropriate geotextile filter layer. The riprap is to be keyed in and buried 6 feet beneath the constructed channel thalweg. A "V" shaped low flow channel should be constructed between the abutments using a constructed streambed material mix including a slightly coarsened bed material to reduce the potential for the stream to migrate to the riprap abutment slopes. It is also recommended that a large wood jam be constructed upstream of the crossing on the north bank to help redirect the creek into the bridge waterway and provide additional bank protection and habitat value. The following report details WSE's hydraulic investigation and presents recommended bridge waterway layout drawings, scour and erosion protection placement, and bed material sizing for the replacement crossing.

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1 INTRODUCTION

The following report describes WSE's hydraulic investigation to support the design of a new bridge crossing to replace the existing W. Uncas Road culvert crossing over Salmon Creek in Jefferson County, WA. The purpose of the investigation is to develop a safe, economical, low maintenance waterway that will satisfy agency requirements. The primary permit condition to be addressed by the hydraulic investigation is to demonstrate that the proposed waterway is large enough to safely pass the design event and that it will not adversely impact natural fluvial processes, and therefore aquatic habitat. WSE also determined freeboard required to safely pass debris, and developed scour countermeasures to protect the recommended crossing structure.

1.1 Previous WDFW Investigation

The Washington Department of Fish and Wildlife (WDFW) previously completed a site assessment and design alternatives report in 2009 to support selection of a replacement structure. WDFW ultimately recommended a 30-ft stream simulation culvert or bridge placed on a skewed orientation to improve crossing alignment with the stream channel. The project was not completed because additional right-of-way (ROW) necessary to re-align the crossing could not be negotiated. In 2013, WDFW amended the conceptual plans to include a 24-ft No Slope culvert option that would be built within the existing ROW, but would maintain the alignment of the existing crossing.

1.2 Current Alternatives Analysis

For the current design investigation, the County asked Shearer and WSE to consider all practical replacement alternatives, including the No-Slope Culvert option recommended by WDFW, as well as bridge/culvert alternatives that would require additional ROW and realignment of the stream channel. The County ultimately decided to move forward with design of a bridge option based on comparison of initial alternative cost estimates and ROW discussion with adjacent landowners. The following report details hydraulic design of the preferred bridge crossing.

2 BACKGROUND INFORMATION

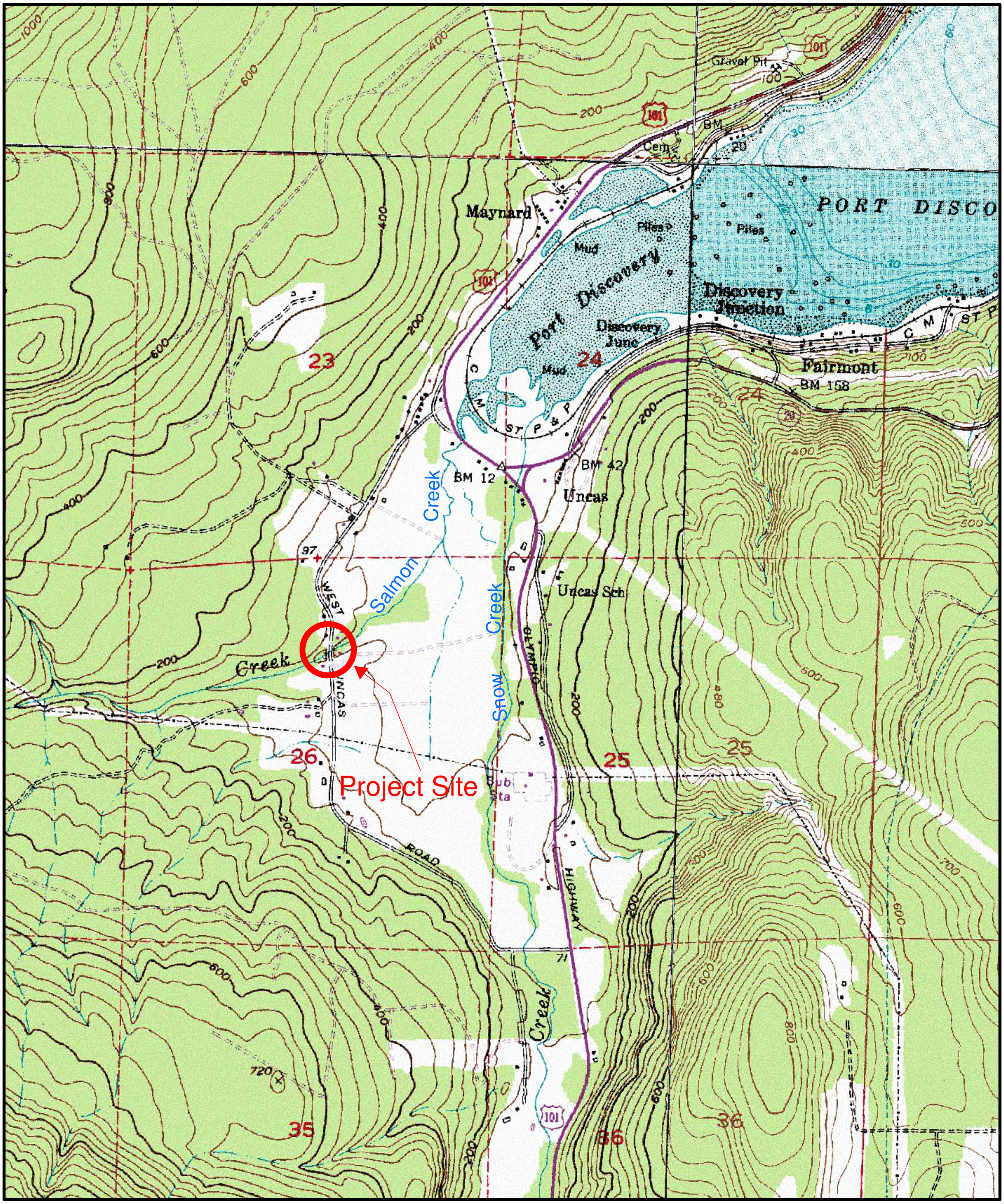
2.1 Crossing and Project Site Description

W. Uncas Road runs along the western edge of the Snow Creek Valley parallel to Highway 101 (See Figure 1). The road crosses Salmon Creek approximately 1.0 mile above the creek confluence with Discovery Bay. The existing 15.5’ by 9.5’ pipe arch culvert crossing is in poor condition, and has started to rust through in a number of areas. Scour at the culvert outlet has resulted in a 1.0 foot drop in water surface that presents a barrier to fish passage.

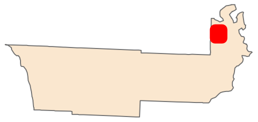
The Salmon Creek channel and estuary downstream of the culvert has been the focus of substantial restoration work to enhance returning runs of the ESA listed Hood Canal Summer Chum and Coho (NOSC, 2011). In recent years, sand bag weirs have been placed at the culvert outlet to improve fish passage conditions during summer spawning runs. The poor condition of the existing culvert and the environmental sensitivity of the setting make this site a high priority for culvert replacement.

2.2 Flood History

This site has no known history of issues with hydraulic capacity, road closure, or overtopping due to flood flows.



Jefferson County, WA



W.Uncas Road Salmon Creek Project Location Map

0 1,300 2,600 Feet

N

Scale: 1:24,000
NAD 1983 StatePlane
Washington North FIPS
4601 Feet

15 Dec 2014

WATERSHED
SCIENCE & ENGINEERING

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Figure 1

2.3 Site Visit/Observations

WSE traveled to the culvert site on August 29th, 2014 to meet with representatives from Jefferson County, Shearer Design, and WDFW, and returned on December 19th, 2014 to collect additional measurements. Significant observations are presented below and photographs from the site visits are included on the pages that follow (Photos 1 through 9).

1 The existing culvert structure is in poor condition. The lower 2 feet show signs of active corrosion, including a number of places where the culvert floor is starting to rust through.

2 The road surface is approximately 20 feet above the stream bed and the culvert is buried under approximately 10 feet of fill, as measured from the road crest to the top of the culvert (See Photo 1).

3 The culvert is located on a slight skew, and the upstream creek channel bends approximately 130 degrees to enter the culvert (Photo 2 and Photo 3). This has encouraged sediment deposition along the inside of the bend, creating a channel bar, and helps maintain the existing channel thalweg location along the north side of the culvert.

4 A scour pool has developed immediately upstream from the crossing along the left (north) bank as a result of the channel bend (Photo 4). Metal wire bank reinforcement is located in this area, presumably to protect the bank from further erosion.

5 The crossing is located where the creek transitions from a confined ravine to the floodplain valley floor. The creek maintains a relatively steep slope of approximately 1.5 percent upstream of the crossing, transitioning to approximately 1.0 percent slope downstream.

6 The creek channel upstream from the crossing is entrenched and shows evidence of past incision. Banks are steep and have been armored in many locations (Photo 5, Photo 8). The channel banks currently appear stable with no evidence of significant lateral erosion.

7 The natural channel has an average channel top width of approximately 24 ft based on a number of representative top widths measurements collected by WSE upstream from the crossing.

8 WSE completed Wolman Pebble counts in order to estimate a surface bed material gradation (Photo 6). Two separate counts were conducted: one at the riffle immediately upstream from the culvert and the other approximately 600-feet upstream. Both counts suggest a mean particle diameter (D_{50}) of approximately 35 mm (1.5 inches, see Figure 2). (Note – Figure 2 contains additional sediment size gradation data which will be discussed later in this report.)

9 Photos 7 and 8 show the condition of the downstream channel and the drop at the culvert outlet. Sandbag weirs shown in Photo 7 are placed seasonally to backwater the culvert and improve fish passage conditions. Current downstream channel conditions are shown in Photo 9.

Photo 1. Viewing downstream through the existing culvert opening (Dec 19, 2014). Culvert alignment focuses flow toward the left (north) edge of the culvert opening.

Photo 2. Viewing upstream from culvert entrance. (Photo courtesy of WDFW)

Photo 3. Viewing downstream toward existing culvert from approximately 100 feet upstream (Sept 19, 2014). The individuals pictured are standing on the gravel bar deposited at the entrance to the culvert. The channel bends approximately 130 degrees around the bar to enter the culvert.

Photo 4. Scour pool at culvert entrance (Dec 19, 2014). Coiled wire along the bank is currently helping to prevent additional erosion.

Photo 5. Viewing upstream from the scour pool at the culvert entrance (Dec 19, 2014). Riprap protection is present on the east channel bank (left of photo).

Photo 6. WSE conducting a Wolman pebble count at a location approximately 600 feet upstream of culvert crossing (Dec 19, 2014).

Photo 7. Viewing downstream through culvert outlet to downstream channel (Sept 2013). Sand bag weirs are installed seasonally as a temporary retrofit to improve fish passage. (Photo courtesy of WDFW)

Photo 8. Viewing upstream toward culvert outlet on December 19, 2014 (sand bag weir shown in Photo 7 have since been removed).


Photo 9. Viewing downstream to downstream channel from near location of Photo 8 (Sept 19, 2014).

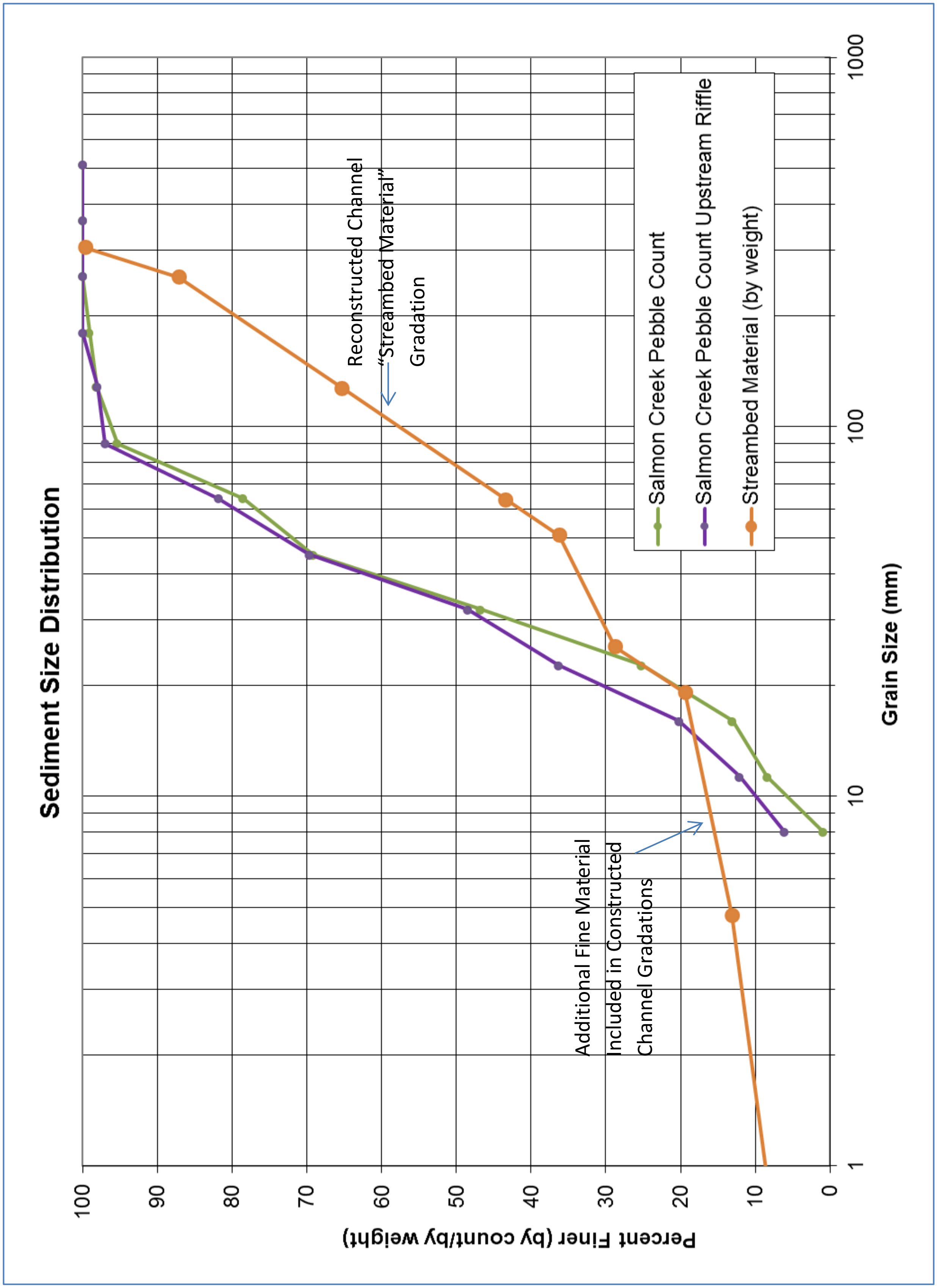


Figure 2. Salmon Creek Sediment Size Distribution Based on Wolman Pebble Count.

3 HYDRAULIC ANALYSIS

3.1 HYDROLOGY

WSE determined peak flow estimates for the current Salmon Creek hydraulic analysis based on historical peak flow data collected by the USGS on neighboring Snow Creek (gage 12050500). The methods of Bulletin 17B were used to compute flow quantiles for Snow Creek based on peak flow values recorded between 1952 and 1973. Flows computed for Snow Creek were then scaled based on relative drainage area to determine corresponding peak flow values for Salmon Creek at West Uncas Road, shown in Table 1. The hydraulic performance of alternative crossing designs were then analyzed using the flow values in Table 1.

Table 1. Computed Flow Frequency Quantiles for Salmon Creek at W. Uncas Road.

Return Interval (Years)	Annual Instantaneous Peak Discharge (cfs)
2	295
10	675
25	900
100	1270
*200	1465
*500	1740

*Flows used for Scour Analysis

The Discovery Bay watershed has been the subject of numerous hydraulic studies and assessments including both the historical USGS gage Snow Creek (described above) as well as Department of Ecology (DOE) and WDFW gaging programs on both Salmon and Snow. DOE gage data were not used in the determination of peak flows because the focus of the gaging was low flows, not peak flows. Flow records from a WDFW Salmon Creek gage could not be found, other than a reference to mean daily flows values in a watershed report (PSRBT 1992). The USGS gage on Snow Creek therefore provided the most complete and appropriate source for the calculation of peak flows for this Salmon Creek culvert replacement analysis. As will be demonstrated below, the proposed waterway will have ample capacity to handle flows up to and exceeding the 100-year flow listed in Table 1.

3.2 HYDRAULIC MODELING

Hydraulic analysis for this project was completed using a steady state HEC-RAS computer model to simulate flow in Salmon Creek through the project reach (USACE, 2010). The model was used to identify the size of the waterway required to safely pass the design discharge, minimize impacts to the stream, and compute the hydraulic variables needed to determine freeboard, assess scour and erosion potential, and to design scour countermeasures. Preliminary modeling was completed for the existing culvert crossing as well as three alternative design options including a WDFW No-Slope culvert, WDFW Stream Simulation culvert, and a single span bridge. The discussion below focuses on the existing conditions model and the proposed 80-ft bridge alternative that was selected by the County for full design.

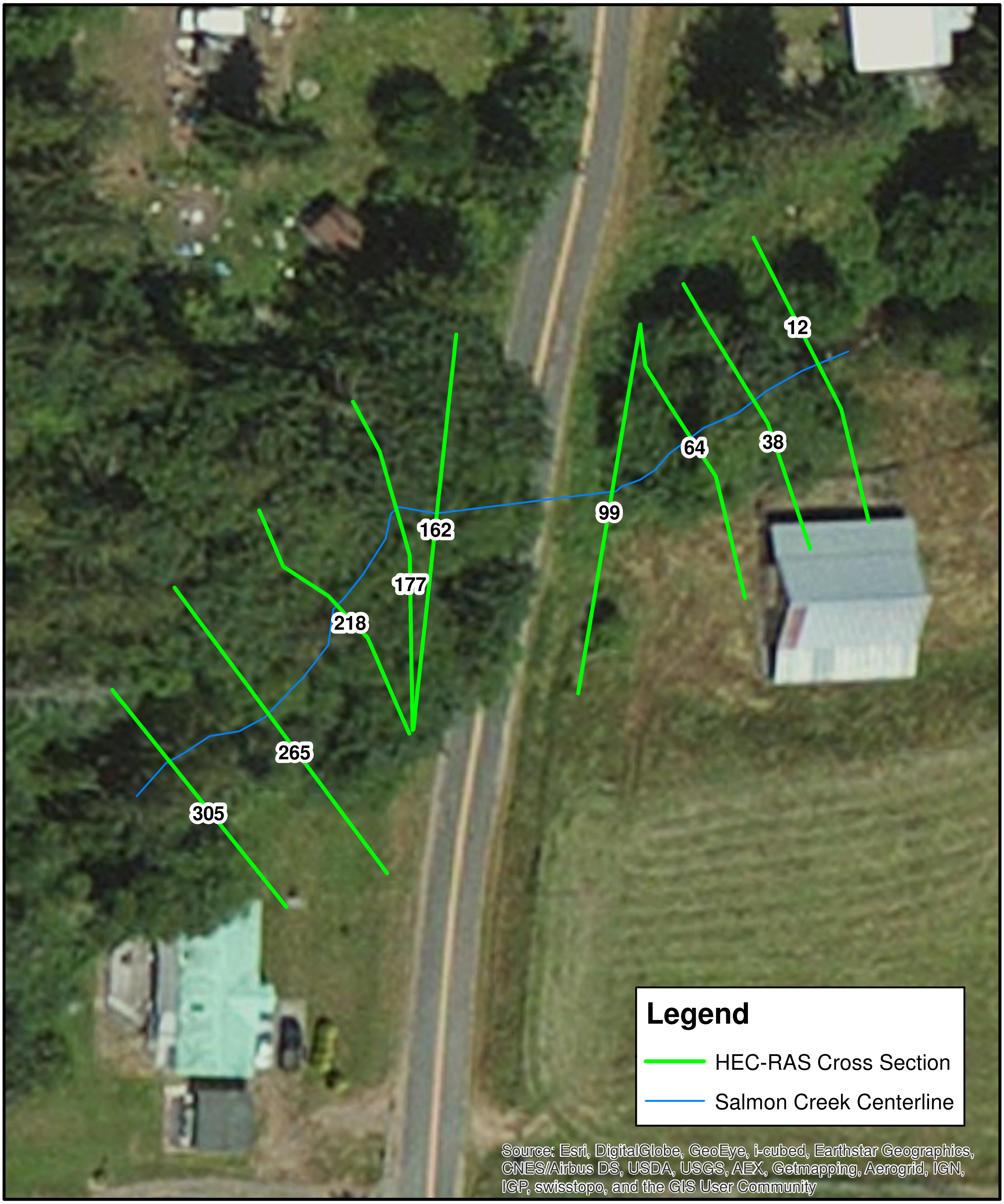
3.2.1 Existing Conditions Model

The "existing condition" model geometry represents conditions that exist today. The geometry is based on topographic survey collected by Van Aller Surveying in October, 2014. Model cross section layout is shown in Figure 3.

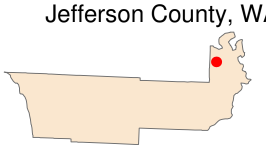
No reliable stage discharge data are available for this reach of Salmon Creek, therefore model variables such as Manning's n roughness values were estimated based on field observations and engineering judgment. Ineffective flow areas were input to represent flow transitions at the culvert crossing, and to block overbank areas that are inaccessible to flow.

3.2.2 Proposed Conditions Model

"Proposed" condition model geometries were then created to represent conditions that would exist following installation of the proposed bridge crossing. Through discussion with Shearer Design, it was determined that an 80-ft bridge span (skewed 30 degrees to the channel) was adequate to allow re-construction of a 30-foot low flow channel between 1.75H:1V sloping abutments. The proposed bridge layout is shown in Figure 4.



Jefferson County, WA



W.Uncas Road Salmon Creek Hydraulic Model Layout

0 30 60 Feet

N

Scale: 1:600
NAD 1983 StatePlane
Washington North FIPS
4601 Feet

22 Jan 2015

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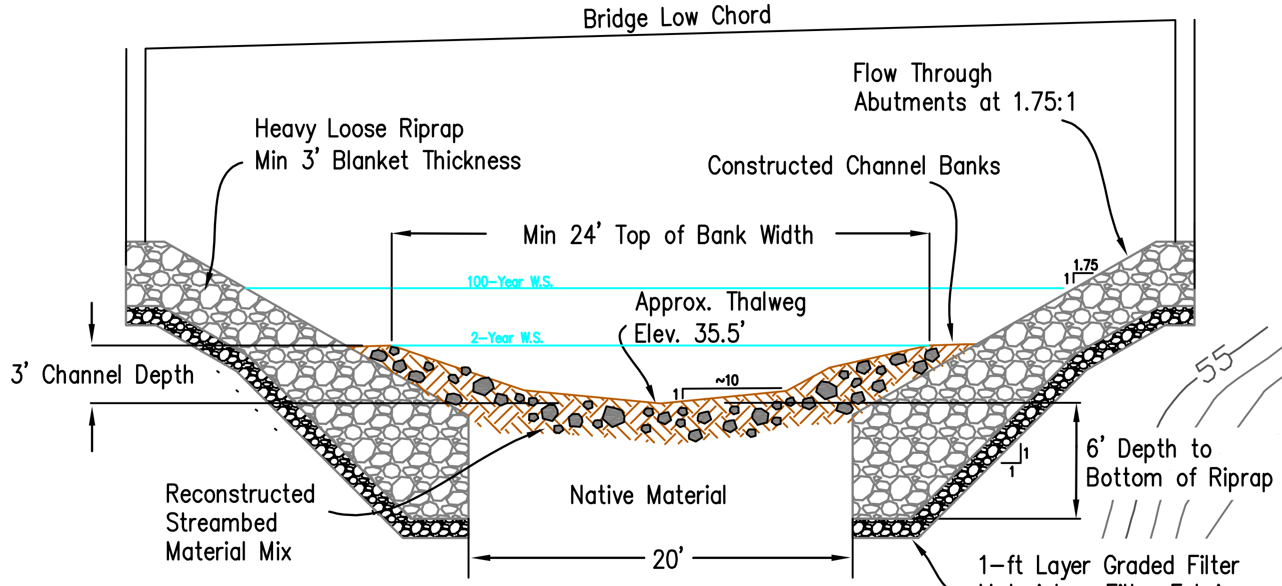
Figure 3

SECTION A-A

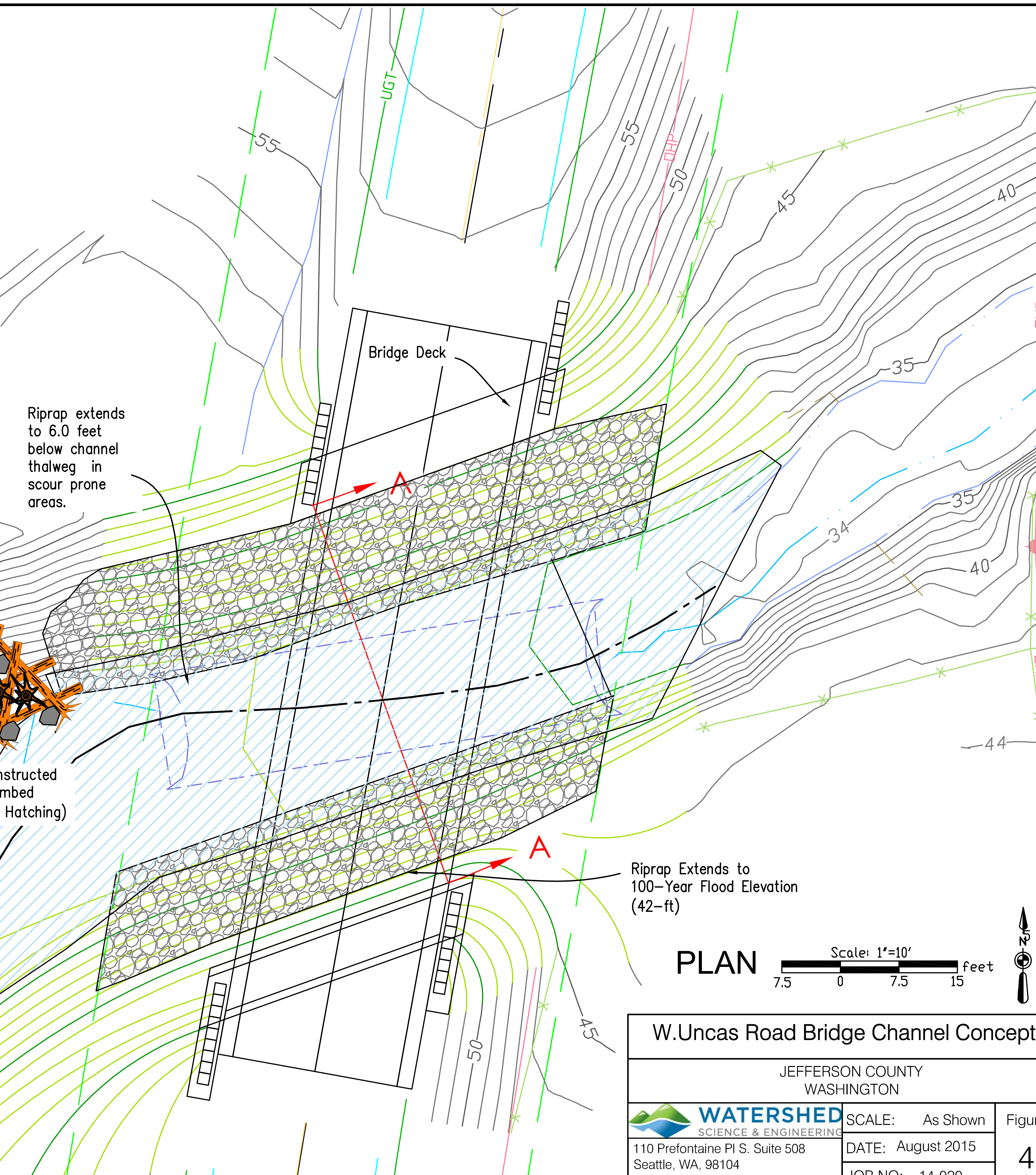
NOT TO SCALE



Thalweg should meander as shown in Plan View, and will not always be located in channel center. Low flow channel sideslopes will vary from 10H:1V.

PRELIMINARY

Concept only – Not for Construction



PLAN

Scale: 1"=10'

7.5 0 7.5 15 feet

N

W.Uncas Road Bridge Channel Concept		
JEFFERSON COUNTY WASHINGTON		
WATERSHED SCIENCE & ENGINEERING 110 Prefontaine Pl S. Suite 508 Seattle, WA, 98104 (206) 521-3000	SCALE: As Shown DATE: August 2015 JOB NO: 14-020	Figure 4

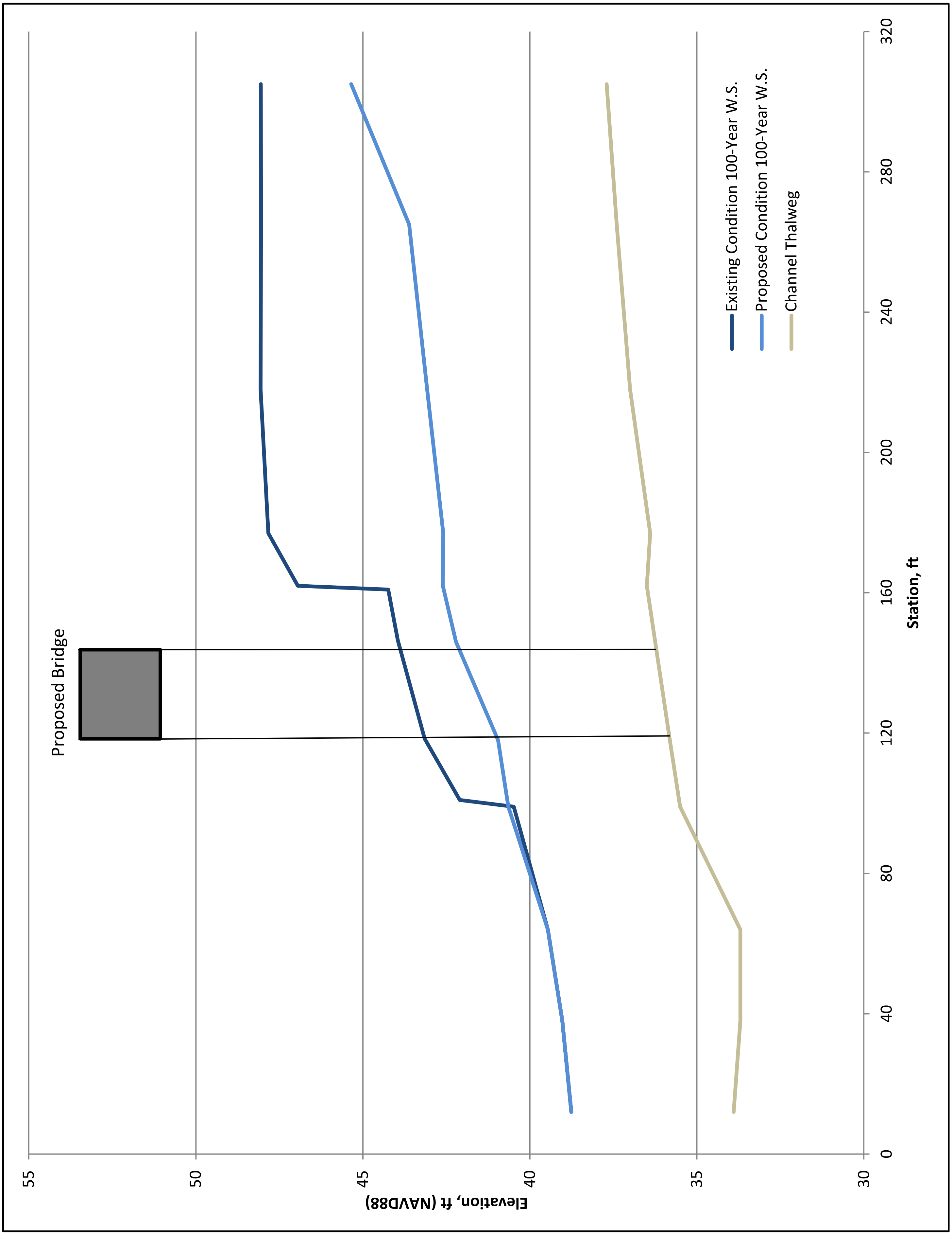


Figure 5. 100 Year Water Surface Profile Comparison

3.3 Hydraulic Results

Both the Existing and Proposed condition models were run for flows listed in Table 1. Results for the 100-year event are presented in Table 2 and the profiles are compared in Figure 5. The existing culvert structure can safely pass the 100-year event without roadway overtopping; however, the crossing constricts flow, resulting in increased water surface elevation and reduced velocities immediately upstream from the crossing, and increased velocities and scour potential downstream.

The proposed bridge crossing will provide significant hydraulic benefit compared to the existing culvert. The bridge will not constrict flow and therefore, velocities and water levels will remain relatively consistent through the reach, greatly reducing the impact the crossing has on the stream and therefore habitat.

Table 2. 100-Year Hydraulic Results

Location	Flow	Water Surface		Velocity	
XS Station (ft)	(cfs)	Existing (ft)	Bridge (ft)	Existing (ft/s)	Bridge (ft/s)
12	1270	38.8	38.8	10.1	10.1
38	1270	39.0	39.0	12.3	12.3
64	1270	39.5	39.5	12.3	12.3
99	1270	40.5	40.6	13.9	10.9
Bridge Location					
177	1270	47.8	42.6	6.0	8.6
218	1270	48.1	43.1	5.4	12.8
265	1270	48.0	43.6	6.2	13.8
305	1270	48.1	45.4	6.3	10.0
12	1270	38.8	38.8	10.1	10.1

3.4 Freeboard

WSDOT recommends that the low chord of a bridge be elevated three feet above the design water surface elevation to ensure that there is adequate room for the safe passage of large woody debris during major floods. To achieve three feet of freeboard, the crossing low chord will need to be set at an elevation of approximately 45 feet (NAVD 88). The proposed bridge has a low chord above 50 feet (NAVD88) and therefore, freeboard exceeds the WSDOT requirement.

4 CHANNEL DESIGN ELEMENTS AND RECONSTRUCTION

4.1 CHANNEL DESIGN

Figures 4 shows the proposed channel layout for the reconstructed bridge channel. Bed material should conform to the gradation detailed in Table 3. Additional fine material has been specified to fill void spaces and prevent interstitial flow. Steambed material used to construct the channel shall be clean, naturally occurring water rounded gravel and cobble material. Angular rock from quarries, ledge rock, talus slopes are not acceptable for this application. Streambed material shall have uniform distribution of size and conform to the following gradation requirements.

Streambed material for the stream channel restoration should be made up of the "Streambed Material" listed in Table 3. The recommended design shown in Figure 4 includes includes filling the scour hole downstream of the culvert to eliminate the drop in bed surface and provide continuity between the reconstructed crossing and the downstream reach. A cross section view of the proposed channel has been included in the channel design figures. An initial "V" shaped low flow channel should be placed at the time the channel is constructed as shown in the cross section elevation view (Figure 4). The low flow channel should be placed to meander as shown in the plan view. Channel sideslopes will be approximately 10H:1V, but will to vary slightly to construct the channel meander while maintaining the longitudinal channel slope. Bed material should extend up to the 2-year flow level, and used to create channel banks. Additional large cobbles have been specified in the streambed mix to help keep the channel thalweg from migrating to either abutment slope. This is particularly important along the left (south) channel bank/abutment within the upstream portion of the crossing where flow will be concentrated due to the upstream channel alignment. Bed material was not specified for placement above the 2-year flood level because that additional material would be inundated infrequently, and would be susceptable to undermining and slumping as the channel adjusts towards one bank or the other.

Table 3. Sediment Grain Size Distribution for Channel Reconstruction

Sieve Size	Design Percent Passing by Weight
	Streambed Material[1]
12-in	99-100
10-in	80
5-in	60
4-in	
3-in	
1.5-in	
0.75-in	20
No 40	5

[1]**Approximately 5 Parts WSDOT 12" Cobbles and 3 Parts WSDOT Streambed Sediment**

4.2 Recommended LWD Jam

A large wood jam upstream of the bridge opening is recommended to help redirect flow into the re-aligned bridge channel and protect the left (south) bank abutment from erosion (see Figure 4).

5 SCOUR AND EROSION

5.1 SCOUR

Scour prediction methods presented in the Federal Highway Administration's HEC-18 manual "Evaluating Scour at Bridges" (2012) were used to estimate scour potential within the proposed waterway for the 200-year and 500-year flood events. The primary threat to the foundations is lateral migration of the channel toward the abutments, which could cause the steep abutment slopes to fail and undermine bridge approaches. To reduce this risk, riprap slope protection described below will need to be installed. The bridge structure will be supported on pile foundations located well beneath the anticipated scour depth and protected by the abutment slope; therefore, failure of the foundations themselves due to undermining is not a concern.

Scour within the bridge waterway can be produced by several different processes, which include longitudinal incision of the stream profile, contraction scour, or local scour. Longitudinal incision currently is not a concern. WSE staff examined the stream channel upstream and downstream from the crossing and determined that the profile is generally stable. Application of the live-bed contraction scour formula recommended in HEC-18 indicates that during the 200-year and 500- year events, the channel bed may scour an average of one foot (see scour calculation spreadsheet in Appendix A). This, however, assumes that flow will be evenly distributed across the bridge waterway and therefore, the entire channel bed will scour an equal amount. Due to the upstream channel alignment, more flow will pass through the left side of the waterway and therefore, scour will be greater along the toe of the left (north) abutment, and sediment will likely continue to deposit along the right (south) abutment. HEC-18 does not provide guidance on how to address this uneven flow distribution issue; however, based upon experience we would recommend that the scour depth estimates above be increased to two to three feet at the toe of the abutment slopes.

Local scour is not a concern for there are no intermediate piers and the abutments will be buried in the channel banks and approach fills.

5.2 BANK PROTECTION RECOMMENDATIONS

Both abutments will need to be protected from lateral erosion and local scour. The recommended approach is to cover the slopes with a 3-foot thick blanket of WSDOT specified heavy-loose rock riprap set on a 1-ft thick graded filter or appropriate geotextile filter fabric (Figure 4). To prevent scour from undermining the slope protection, the toe of the riprap will need to be keyed into and buried below the bed of the stream at all locations (Figure 4). The toe of the riprap protection should extend to or below elevation 30 feet (NAVD 88).

The upstream and downstream ends of the rock riprap revetments should feather into the existing banks so that they do not create abrupt transitions that could initiate scour. It will also be important to minimize disturbance of the unprotected adjacent bank immediately upstream or downstream from the revetment ends. Areas that are disturbed will need to be covered with a coir type blanket that is appropriately anchored to remain secure during winter high flows in the year following construction.

These areas should be seeded and preferably planted with willow stake cuttings or similar to establish bank roughness and a stabilizing root network.

As an added precaution and to improve habitat it is best to keep the thalweg of the channel from shifting laterally to the riprap covered abutment slope. To reduce this likelihood we included additional coarse material in the streambed material mix, as shown in Figure 2, and specified in Table 3.

5.3 Bank Protection Development

The recommended bank protection concept (shown in Figure 4) is the result of an iterative design process considering site constraints, bank stability, constructability, and comments from technical reviewers representing the Salmon Recovery Funding Board (SRFB). The height of abutment walls were maximized at the site by using large cantilevered wingwalls to contain the steep approach fill. Preliminary abutment protection concepts then called for 2H:1V abutment slopes lined with heavy loose riprap extending from the base of the abutment walls down to the anticipated scour depth. This resulted in a buried layer of riprap beneath the bridge waterway that would have limited vertical channel adjustment to approximately 3 feet. Although it is unlikely that the channel would ever incise to the buried riprap layer, an updated concept was designed to improve future channel adjustment potential. In the updated concept, abutment slopes were steepened to 1.75H:1V, and the toe of the riprap was pulled back and bulked up to create a launching toe key. This provided 15 feet between the toe of riprap abutment protection, which was later increased to 20 feet (as shown in figure 4) to provide a spacing as close to the bankfull channel width of 24 feet as possible. A SRFB technical reviewer suggested a 24 foot width could be achieved if the abutment slopes were increased to 1.5H:1V; however, as the engineer responsible for the reliability of the protection we are not comfortable increasing slopes beyond the proposed 1.75H:1V. The standard of practice is to construct revetment slopes at 2H:1V which is the recommendation in most design guidance documents including the Washington State Department of Transportation Hydraulic Manual (WSDOT 2015). Because the proposed revetments must withstand high velocities during major floods, it is our professional opinion that reducing the stability of the revetment by steepening the slope is not a prudent decision for this site. The primary reason to achieve a 24 foot width between abutment protection would be to accommodate possible future channel incision. However, as discussed earlier in this report the channel profile has remained stable for many years and nothing was observed that would indicate that channel incision is likely in the future. In addition, the channel would have to incise nearly 4 feet before the riprap would begin to constrict the channel top width. This updated concept balances function and stability of the riprap protection with freedom for the channel to adjust downward.

5.4 Non Scour Critical Certification

If the bridge and abutment slope protection is constructed as described in this report, it would be "Not Scour Critical" and should be assigned an NBIS Scour Code of "8" which means the bridge foundations are stable for the assessed scour condition. This rating is based upon the following:

1. The bridge is supported on pile foundations that extend well below anticipated scour depth.
2. Embedded rock riprap revetments will protect the sloped channel banks under the bridge. Note -- the "Not Scour Critical" rating does not rely upon this riprap protection. However, the riprap serves to help to keep the stream aligned toward the center of the waterway and will prevent the channel from migrating towards the bridge piles or undermining abutment slopes and approach fill.

5.4.1 Future Maintenance Inspections

Bi-annual and post flood inspections should be conducted to monitor the condition of the stream banks upstream and under the bridge.

6 CONCLUSIONS AND RECOMMENDATIONS

Based on WSE's hydraulic investigation and discussion with Shearer Design, we recommend installation of an 80-ft bridge placed on a 30 degree skew with the centerline of the Salmon Creek to improve the crossing alignment. The bridge will be supported on driven pile foundations buried behind 1.75H:1V flow through earthen abutment slopes. Abutment slopes should be lined with a 3-ft thick layer of heavy loose riprap placed on top of a 1-ft thick graded filter or appropriate geotextile fabric filter. The riprap is to be keyed in and buried 6 feet beneath the constructed channel thalweg. A "V" shaped low flow channel should be constructed between the abutments using a constructed streambed material mix including additional coarse bed material to reduce the potential for the stream to migrate to the riprap abutment slopes. It is also recommended that a large wood jam be constructed upstream of the crossing on the north bank to help redirect the creek into the bridge waterway and provide additional bank protection and habitat value.

7 REFERENCES

NOSC (2011) "Salmon Creek Estuary Restoration and Wood Waste Removal: Monitoring Report". North Olympic Salmon Coalition for the Estuary and Salmon Recovery Program. June 2011.

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WDFW (2009) "Salmon Ck West Uncas Road Culvert Removal and Bridge Design", WDFW Region 6 Habitat Engineering Technical Assistance. February 9, 2009. Updated conceptual plans dated September 16, 2013.

WDFW (2013) "Water Crossing Design Guidelines", Washington Department of Fish and Wildlife, 5th Draft Water Crossing Design Guidelines January 2, 2013.

WSDOT (2015) "Hydraulics Manual" M 23-03.04, Washington State Department of Transportation, January 2015

Scour Calculations -

river: **Salmon Creek** ***by:*** Chris Frei
bridge no.: **W.Uncas Road** ***date:*** 2/3/2015

Scour Summary

Contraction Scour Calculations

Comments:
Laursen's Live-Bed Contraction Scour Formula (FHWA 2012, Page 6.10)

200-yr Q = 1465 cfs

Y1	Yo	Q1	Q2	W1	W2	K1	Y2	Ysc
(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft)		(ft)	(ft)
6.5	6.5	1465	1465	20	24	0.69	5.7	-0.8

500-yr Q = 1740 cfs

Y1	Yo	Q1	Q2	W1	W2	K1	Y2	Ysc
(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft)		(ft)	(ft)
7.5	6	1740	1740	21.5	24	0.69	7.0	1.0

Comments:

1. Y1 is the average flow depth in the upstream channel.
2. Yo is the average flow depth in the contracted section before scour channel.
3. W1 and W2 are the average channel bottom widths of the upstream and bridge cross-sections respectively (see calculations).
4. K1 = 0.59 for mostly contacgt bed material transport, K1= 0.64 for some suspended bed materail transport,
   K1 = 0.69 for Mostly suspended bed material transport