MEMORANDUM

TO: Lawrence Dillin, P.E., Chelan County
FROM: Craig Cooper, L.G.
Adam Miller, P.E.
DATE: April 15, 2015
SUBJECT: Preliminary Clear Creek Culvert Replacement, Chelan County Chiwawa Loop Road Phase 3, G&O #14081.01

Chelan County has requested that preliminary design considerations for replacement culvert types be provided for their review in anticipation of the 30% design submittal. This Memorandum provides a summary of existing site conditions, design criteria guidance available from WDFW (2013), and recommendations for suitable culvert replacement options. This Memorandum is accompanied by sketches of our preliminary recommended design (plan and profile), and a manufacturer's informational brochure.

Existing Conditions

Descriptions of the project area are based on County channel and topographic survey, a geomorphic field reconnaissance, and data obtained from available publications, culvert replacement projects upstream on USDA Forest Service land, and from the USGS. The following table displays a summary of conditions pertinent to the design of the replacement culvert.

Drainage Area at culvert[a]	3.79 mi^2
Mean Annual Precipitation[a]	38.3 inches
2-YR Peak Flow[a]	40 cfs (rounded)
100-YR Peak Flow[a]	143 cfs (rounded
Energy Slope Upstream of Culvert[b]	0.014
Energy Slope Downstream of Culvert[b]	0.008
Slope through existing culvert	0.057
Channel bankfull width upstream of culvert[b]	10.18 feet[c]
Channel bankfull width downstream of culvert[b]	10.66 feet[c]
Floodplain Utilization Ratio (FUR) upstream[f]	3.21
Floodplain Utilization Ratio (FUR) downstream[f]	3.75
Approximate elevation of grade-supported bearing[d] (at downstream invert)	EL 2006
Approximate elevation of grade-supported bearing[e] (at upstream invert)	EL 2007.27
Approximate slope of grade-supported bearing between existing culvert inverts	0.033

a. USGS Washington StreamStats (http://water.usgs.gov/osw/streamstats/Washington.html)

b. Average of bankfull elevations, from Chelan County survey. Note that these slopes also reasonably approximate the channel slopes within the length of survey.
c. Per WDFW (2013) Appendix C guidelines: width calculations ignore artificial channel constriction near the culvert inverts
d. Aspect Consulting (2014) draft geotechnical report
e. G&O, Inc. geomorphic reconnaissance Dec 12, 2014; from depths estimated with steel probe approximately 10 feet, 28 feet, and 75 feet upstream of the upstream culvert invert
f. FUR calculated from survey as Wfp/Wbf, where Wfp = floodprone area width and Wbf = bankfull width. Wfp is the available width of flood flow projected laterally from the elevation of twice the maximum channel bankfull depth.

County survey extended approximately 145 feet upstream of the existing culvert invert, and approximately 100 feet downstream of the culvert outfall. The upstream channel bed exhibits a slight convex profile, in whole or in part due to a relatively deep (up to 1.5 feet) and loose accumulation of sandy substrate overlaying firm gravel / cobble substrate. Depths of the loose substrate overlaying the firm gravel / cobble substrate were estimated by steel probe during the geomorphic reconnaissance. The channel upstream of the surveyed area narrows to approximately 6 feet width, and the channel slope increases above 2 percent. An approximately 4 foot high rock weir is located approximately 220 feet upstream; this weir impounds water for diversion to the Thousand Trails water treatment facility. A relatively broad valley bottom upstream of the weir may attenuate flood flow, and trap larger bedload and woody debris. Downstream of the weir the channel is relatively debris-limited, although small limbs and leaves can be recruited to the channel. Channel meander migration potential is low upstream of the existing culvert as the overbank floodplain is constrained by upland valley slopes. In addition, robust shrub species, vine maple, and alder provide rooting strength that limits erodibility of the channel banks. The same vegetation on the floodplain, along with evergreen tree species, rock, and organic debris, provide roughness on the floodplain that also minimizes the channel migration potential.

The Chiwawa Loop Road surface is approximately 4 feet higher than the invert to the 2-foot diameter culvert, with a cover of about 2 feet of road fill and paving. Clear Creek's channel bed is level to the upstream invert. With an existing culvert slope of 5.7 percent, the downstream culvert outfall is approximately 2.16 feet lower than the upstream invert. The creek outfalls to a broad pool approximately 20 feet in length; hydraulic control is provided by large rock and a stand of alder. Fine sand deposition also occurs in the downstream channel, but probed depths were less than 0.5 feet over firm alluvial substrate.

Design Approach and Criteria

We understand that the upstream water diversion is planned for removal, which may result in a greater potential for woody debris loading than presently exists.

Pertinent design of water crossings for fish passage are currently referenced to WAC 220-110-070 and to guidance provided in WDFW (2013) Water Crossing Design Guidelines. Critical to the crossing of Clear Creek are the channel's elevation difference between the existing culvert invert and outfall, the elevation of the road surface, and the floodplain utilization ratio (FUR) (see table of existing conditions, above). Per WDFW (2013) channels having a FUR value greater than 3 are recommended to be crossed with a bridge. Candidate crossing structures considered in this case include bottomless arch and 3-sided and 4-sided box culverts (concrete and aluminum).

Stream Simulation is the culvert design option chosen for the Clear Creek culvert replacement, with reference to guidance provided in WDFW 2013. Hydraulic analysis was modeled using WinXSPRO Version 3.0 (http://www.stream.fs.fed.us/publications/winxspro.html). Stream Simulation is the culvert design option preferred by permitting agencies and tribal nations in general in Washington State.

Modeling of flow hydraulics of a 3-sided or 4-sided concrete box culvert provided the basis for comparing the suitability of different structures based on the structure's geometries and available flow area through the structure. Below are the modeling results for a box culvert compared to a bottomless aluminum box. A pipe arch has less area than an aluminum box and would require a larger structure and raising the roadway so it was not modeled.

Variable	Concrete Box[a]	Aluminum Box
Minimum road cover (H20, HS-20 loading) (ft)	0.83	2
Span (ft)	15	25.42
Rise (ft)	8	10.2
Flow area (ft^2)	76	48.2
Channel bed to crown maximum height (ft)	5.6	3.8
100-year design discharge stage to crown height (ft)	3.3	1.7
Manufacturer estimated cost	$126,500	$44,000[b]

a. Concrete 3-sided (bottomless) or 4-sided bridge
b. Cost estimate does not include precast footings, headwalls, or wingwalls. Cost is delivered FOB. Contractor to provide labor for assembly and set.

Recommendation

A 3-sided or 4-sided concrete box culvert is better suited to the Clear Creek culvert replacement. The concrete box meets WDFW guidelines and provides a greater flow area than the other options reviewed in a shorter span. Additionally, the concrete box does not require cover over the structure which would necessitate additional raising of the proposed roadway grade. The advantages of the concrete box over a bottomless arch or an aluminum box culvert are shown in more detail below:

- For given span and rise, the box culvert has greater cross-sectional area and therefore greater flow capacity (a bottomless arch has less flow capacity than an aluminum box, so was not included in the comparison)
- The box culvert has greater capacity to pass larger woody debris, and exceeds WDFW and federal transportation guidelines in providing more than 3 feet of clearance between the 100-year flow stage and the crown.
- Minimum road cover over the aluminum structure is 2 feet; the box culvert cover is 10 inches thick and does not require additional cover. Both structures evaluated are rated for appropriate traffic ratings by the manufacturers.
- A box culvert is generally preferred by contractors for comparative ease of site preparation, installation, backfill and compaction, and labor costs.
- With its span and rise the aluminum box requires a significantly greater footprint and depth of excavation.

The 3-sided or 4-sided concrete box culvert will both work for the Clear Creek culvert replacement, however, we recommend the use of the 4-sided box culvert. The 4-sided box culvert will be easier to construct in this situation. It is easier to set the base of the 4-sided culvert on the proper grade than it will be to set the 3-sided culvert on the pre-cast footings. This will result in a shorter construction time with a shorter period of stream bypass and roadway shutdown. Additionally, the 4-sided box culvert will allow placement of the streambed gravel materials from the surface which will result in a better, consistent streambed material within the culvert. The invert elevations of the culvert are below the stream scour depths so there is not worry about scouring under the base slab.

The preference for a 4-sided concrete box culvert was confirmed at the permitting agency kickoff meeting on March 19th, 2015 which was attended by members of Chelan County, WSDOT, Ecology, WDFW, National Marine Fisheries, US Fish and Wildlife, and others.

Stream Simulation suitability guidelines for channels having slopes less than 4% were used for meeting culvert design criteria. Design criteria and results are presented below.

Construction Considerations
We recommend that the 40-foot box culvert be centered on the new roadway alignment. This will allow room on both sides of the new roadway for guardrail or traffic barriers. It is likely that the roadway will need to be shut down during the construction. We estimate that the installation of the box culvert may take up to a week to complete. Additionally, stream bypass may be required during the construction.

Design Slope
- Slope of channel bed through the culvert (based on survey for design and on upstream equilibrium slope) = 1.4 %
- Slope of culvert and slope of channel bed inside culvert = 1.4%
- [Criterion: slope ratio = slope of culvert bed/slope of channel upstream $\leq$ 1.25]

Design Flow Velocity
- 2-year peak flow less than 4 feet per second for fish passage (modeled average flow velocity = 3.4 ft/sec). Note that employment of the Stream Simulation design option assumes acceptable flow velocities for juvenile fish migration.

Culvert Dimensions
- Bed width inside culvert = 15 ft.
  [Criterion: 1.2 x bankfull width, + 2 ft. Generally, Stream Simulation design option is applied to channels having bankfull widths less than 15 feet]
- Length ~ 40 ft.
  [Criterion: culvert length to span ratio less than 10]
- Rise (vertical open dimension) 8 ft
  Rise is maximized to accommodate the 100-year design flood stage and passage of wood debris. Guidance for bridge clearance is that the crown be 3 feet or more above the 100-year flood water surface. Clearance is 3.2 feet.
- Countersink: 30%
  [Criterion: the channel bed fill inside the culvert should result in a countersunk depth of 30% to 50%.]

Sediment Sizing for Stability and Scour
Proposed sizing of channel bed material within the culvert was guided by requirements to preserve stability against excessive scour at the 100-year design discharge. A first approximation of size was made using Equation 6.4 (*in* WDFW 2013):

$$D_{30} = [(1.95)*(S^{0.555})*(1.25*q)^{0.67}] \div g^{0.33}\text{, and } D_{84} = 1.5*D_{30} \qquad \text{Equation 6.4}$$

Results provided a D_{84} particle size of 0.46 feet. A bed material gradation was derived using guidelines provided in WDFW 2013 (Equations 3.6, 3.7, 3.8).

Channel/Culvert Section located approximately between County ROW	Slope (ft/ft)	Width (ft)	D_{84} (ft)	Specification D_{84} (in)	D_{100} (in)	D_{50} (in)	D_{16} (in)
	0.014	15	0.46	5.5	13.8	2.2	0.7

The D50 sediment size was applied to equations for estimation of general scour in a straight reach for the 100-year design discharge (Lacey and Blench regime equations *in* USDA NRCS 2007):

$$z_t = KQ^aW^bD_{50}^c$$

where: z_t = maximum scour depth at the cross section or reach (ft)
K = coefficients
Q_d = design discharge (cfs)
W = flow width at Q (ft)
D_{50} = median size of bed material (mm)
a, b, c = exponents

Calculated maximum depths of scour were 0.3 feet and 1.5 feet, with an average of 0.9 ft. This calculated maximum scour depth of 1.5 feet is in close agreement with depths estimated using a steel probe during the geomorphic reconnaissance. The design depth of bed fill in the open bottom culvert is 2.4 feet from the top of the culvert footings, nearly 1 foot deeper than the maximum calculated depth of scour.

REFERENCES

Barnard, R.J., J. Johnson, P. Broods, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. Water Crossing Design Guidelines, Washington Department of Fish and Wildlife, Olympia, Washington, Published by Washington State Aquatic Habitat Guidelines. http://wdfw.wa.gov/hab/ahg/culverts.htm

USDA NRCS. 2007. Handboods Title 210-Engineering, National Engineering Handbook, Technical Supplement 14B Scour Calculations http://directives.sc.gov.usda.gov/viewersFS.aspz?hid=21433