Effects of Elwha River Dam Removals on the US 101 Bridge

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Introduction

Northwest Hydraulic Consultants (NHC), working for the Washington State Department of Transportation (WSDOT), collaborated with the United States Bureau of Reclamation (USBR) and United States Geological Survey (USGS) with assessing the effects of the removal of the Elwha River Dams on the existing and proposed US 101 Elwha River Bridges (Figure 1). The effects to-date, along with the estimated effects to occur in the future, were used to assess the vulnerability of the existing US 101 Bridge and aid in the design of the proposed bridge.

Background

The US 101 Elwha River Bridge was constructed in 1926 and consists of a three-span concrete arch structure with two in-water intermediate piers, Piers 6 and 7 (Figure 2). The bridge was originally constructed between two dams, which were removed between 2011 and 2012, namely the former Elwha Dam (located downstream) and the Glines Canyon Dam (located upstream). Both dams had influences on the Elwha River reach from above Glines Canyon Dam, through the US 101 crossing and downstream to the Strait of Juan de Fuca. The Elwha Dam was built first, with construction completed in 1913, followed by the Glines Canyon Dam in 1927. The Elwha and Glines Canyon Dams influenced the hydraulics through the US 101 crossing and thus impacted sediment transport through the US 101 Bridge reach. Due to the influence of the Elwha Dam (Lake Aldwell), sediment was deposited at the US 101 crossing from the time of construction in 1913 until 1926 when the US 101 Bridge was constructed. As such, the US 101 Bridge had never seen a free-flowing river and was most likely founded on sediment deposited due to the Elwha Dam construction (although as-builts indicated the bridge foundations were founded on bedrock). In October 2016, the WSDOT Geotechnical Office conducted a subsurface investigation to determine types and thicknesses of soil/rock below the in-water piers (Allen 2016). The geotechnical borings assisted in determining that the US 101 in-water intermediate piers were founded on lake sediment deposits. Pier 6 has approximately 4 to 8 feet of sand/gravel (lake deposit), underlain by approximately 6 to 11 feet of cobbles/boulders (pre-dam river alluvium) below the foundation seal. Basalt was observed approximately 11 to 20 feet below the foundation seal. Pier 7 has approximately 3 to 4 feet of sand/gravel (lake deposit) below the foundation seal, until basalt was observed. Based on this assessment, and changes post dam removal, the US 101 Elwha River Bridge was rated scour critical and an emergency was declared to protect the bridge from scour.
Figure 1. Vicinity Map

Figure 2. Existing Bridge Layout
Watershed Assessment

Watershed and Landcover

At the US 101 Bridge (project site), the Elwha River drains approximately 293 square miles from the central portion of the northern slope of the Olympic Mountains. The contributing basin ranges in elevation from about 190 feet to 7,300 feet (Figure 3). The basin is essentially undeveloped as it lies mostly within the boundaries of the Olympic National Park and a Federally protected Wilderness Area upstream from Lake Mills. More than 70% of the basin’s area is covered by lowland and sub-alpine forest landcover. The remaining area is mostly above the elevation of 4,500 feet and is dominated by alpine landcover including meadows, perennial snow cover, and bare rock and talus. Only Lake Mills and Lake Aldwell interrupted sediment connectivity between the alpine peaks and the valley bottom.

Figure 3. Overview of Elwha River Basin Topography
Peak Flow Analysis

The USGS operates a streamflow gage on the Elwha River that is located approximately 0.9 river miles upstream of the US 101 crossing (Elwha River at McDonald Bridge near Port Angeles, WA, USGS Gage 12045500). This gage has operated from 1898 to present and thus includes over 100 years of peak flow data. The USGS 12045500 gage was utilized to develop estimates of peak flows at the US 101 crossing as it has essentially the same basin characteristics, and nearly the same drainage area, as the US 101 crossing. Little River is the only named tributary entering the Elwha River, between the stream gage and the US 101 crossing.

To determine peak flows at the US 101 crossing, data from the USGS 12045500 gage was evaluated utilizing the methods provided by the USGS's *Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington* (Mastin et al., 2016). The USGS PeakFQ statistical software was used to conduct a flow frequency analysis on the gage data (Veilleux et al., 2014).

Peak flow estimates were then scaled following USGS guidelines (Mastin et al., 2016) to obtain flows at the US 101 Bridge crossing. Flows were analyzed utilizing both the weighted and unweighted flood frequency analysis. In general, the weighted flow values provide benefit for sites with smaller records of data; however, the USGS gage #12045500 has over 100 years of recorded data and thus provides an adequate record for analysis. Flows calculated from the unweighted gage analysis was therefore determined to be the most accurate to assess hydraulic and scour conditions at the bridge. Table 1 depicts the peak flows utilized for the project site.

<table>
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<tr>
<th>Mean Recurrence Interval (MRI)</th>
<th>Gage Analysis from USGS Gage #12045500</th>
<th>Gage Analysis from USGS Gage #12045500 at the US 101 Crossing</th>
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Geomorphology

The project site is located on the Middle Reach of the Elwha River, which lies between the historic locations of Lake Mills and Lake Aldwell. This reach is highly dynamic and continues to respond to changed geomorphic controls from the removal of the Elwha Dam in 2012 and the removal of the Glines Canyon Dam in 2014 (with the Lake Mills being drained in 2012). The Elwha Dam impounded Lake Aldwell just downstream of the project location since 1913 and the Glines Canyon Dam impounded Lake Mills upstream of the project location since 1927. Substantial work has been completed which aimed to predict the expected channel responses prior to removal of
the dams and actual responses post removal. Key publications documenting channel geomorphology impacts include East et al. (2015), Magirl et al. (2015), and Warrick et al. (2015). This work summarizes channel changes between the Elwha Dam removal in 2012 and in the Spring of 2013, which occurred during relatively modest flows following the dam removals. This however does not include details of response to larger flood flows in water years 2015, 2016, or 2018 (Figure 4). A report, recently produced by a U.S. Department of the Interior (DOI) technical team, analyzed sediment management and channel response along the Elwha River (DOI, 2018). This report includes the more recent large flood flows, specifically investigating sediment transport from 2011 through 2017.

The US 101 Bridge spans the location where the Elwha River formed the Lake Aldwell delta. Removal of the Elwha Dam, therefore, lowered the geomorphic base level for the channel at the bridge location, leading to incision and channel profile steepening (East et al., 2015), possibly leading to the scour that threatened the existing structures’ foundations (Figure 5).

Removal of the Glines Canyon Dam upstream, in contrast, released a large and relatively coarse sediment pulse into the river channel. Between October 2012 and September 2013, roughly 9.1 metric tons (Mt) of the 23 Mt (plus or minus 6 Mt) of stored sediment had eroded from reservoir deposits in Lake Mills, increasing sediment transport rates through the Middle Reach by a factor of more than 100, compared to the incoming load (Warrick et al., 2015). This resulted in about 5 feet of channel aggradation in alluvial portions of the middle reach not affected by incision into the Lake Aldwell delta (East et al., 2015). A substantial fining of the bed material was caused by the transport of smaller sediment stored behind the Glines Canyon Dam. This resulted in an
increase in bed material transport rates in the Middle Reach as the bed shifted from a range of small boulders to pebble sized sediment to cobble to medium sand sized sediment.

Aggressive channel migration and substantial channel widening are occurring through the project reach, as the channel is responding to perturbations in its base level and sediment supply due to removal of the upstream and downstream dams. Figures 6 and 7 show erosion patterns through the project reach, following removal of the dam near the US 101 Bridge, in plan and cross section, respectively.

Cross Section 1 (XS 1), shown in Figure 6, is located approximately 400 feet upstream of the US 101 Bridge. As can be seen in Figures 6 and 7, the main channel has incised by several feet and has, in general, moved to the east. Significant erosion occurred during the months of November and December, 2014 just upstream of the bridge (shown with yellow and orange polygons in Figure 6 and the groundlines between Station ~175 and ~350 in Figure 7). The groundline between stations ~175 and ~350 dropped upwards of 8 feet, when the channel meander translated upwards of 350 feet in the downstream and westerly direction.

Cross Section 2 (XS 2), shown in Figure 6, is located approximately 1,350 feet downstream of the US 101 Bridge. As can be seen in Figures 6 and 7, the main channel has incised by a couple of feet, however has more dominantly moved to the west. Significant erosion has progressively occurred from Water Year (WY) 2013 to WY 2018 (blue and red polygons in Figure 6 and grey line to green line in Figure 7). Overall, the river’s left bank has migrated from approximately station 900 to station 250 (650 feet) between WY 2013 and WY 2017, for an average rate of 130 feet/year. Notably, there was no indication of changes at the left bank between WY 2013 and WY 2014.
Cross Section 3 (XS 3), shown in Figure 6, is located approximately 3,300 feet downstream of the US 101 Bridge. As can be seen in Figures 6 and 7, the main channel has incised by a couple feet, however more evident is the widening and movement to the west. Significant erosion has progressively occurred from WY 2013 to WY 2018 (blue and red polygons in Figure 6 and grey line to green line in Figure 7). Overall, the river’s left bank has migrated from approximately station 1025 to station 400 (625 feet) between WY 2013 and WY 2017, for an average rate of approximately 125 feet/year. Notably, there was no indication of changes at the left bank between WY 2016 and WY 2017.

These rates suggest migration on the order of hundreds to a thousand feet are possible, even during relatively low to moderate flood flows that occurred during this period (Figure 4). It is expected that the channel will continue to be highly dynamic in both vertical and horizontal dimensions until oversupply of bed material from upstream ceases and a new equilibrium profile is established through the historic extent of Lake Aldwell.

Figure 6. Active Channel Positions Following Removal of the Elwha Dam. Channels are Stacked with the Most Recent on the Bottom to Highlight Meander Growth Patterns
Figure 7. Cross Sections at Locations Shown in Figure 6
Figure 8 shows photos taken from a remote camera looking towards the left bank of cross section 3 (XS3), shown in Figures 6 and 7, during the November 2014 flow event (Figure 4). The red polygon highlighted in yellow is depicting erosion that happened between November 27th and December 15th, 2014.

![Figure 8. Photos Taken November 27th, 2014 (Left) and December 12th, 2014 (Right)](image)

**Long-term Aggradation/Degradation of the River Bed:** Channel response has been highly dynamic at the US 101 Bridge crossing due to the interplay of changing bed material sediment supply from the removal of Glines Canyon Dam and base level control at the Elwha Dam. As describe above, this has caused substantial bed elevation volatility at the US 101 Bridge, but the overall trend has been degradational following the Elwha Dam removal. This suggests the dominant controlling factor at the bridge has been both erosion and downcutting, following the removal of the Elwha Dam. It is expected that the channel will continue to degrade, but the presence of bedrock near the surface should limit long-term degradation.

The DOI technical team (which included the USGS, National Park Service and Bureau of Reclamation (Reclamation)) recently analyzed sediment management along the Elwha River (DOI, 2018). Their report indicates that portions of the Elwha Dam foundation, which are still exposed, may influence channel responses upstream (DOI, 2018). Figure 9 depicts this portion of the remaining Elwha dam and caisson compared to historic and more recent water surface and groundline data. Once these exposed portions are removed, the channel will likely experience additional degradation which will likely extend upstream to the US 101 Bridge and contribute to the expected eventual exposure of bedrock near the proposed bridge.

The DOI technical team believes it is unlikely that the bedrock would become exposed during all flow durations at the US 101 Bridge, rather it may become exposed during large floods which may mobilize larger material covering the bedrock.

It is possible that the bed material pulse from the removal of the Glines Canyon Dam may drive some future aggradation at the project site, but bridge sounding data (Figure 10) do not suggest this impact has, to date, overwhelmed the degradational response from the removal of the two dams.
Figure 9. Longitudinal Profile at Elwha Dam (Figure 72 from DOI, 2018)

Figure 10. Plot of Bridge Sounding Data
**Hydraulic Analysis**

The hydraulic analyses of the existing and proposed US 101 Elwha River Bridge crossings were performed utilizing SRH-2D (U.S. Bureau of Reclamation, 2016), a two-dimensional, depth-averaged hydraulic model. The SRH-2D model allowed for a detailed understanding of the hydraulics through the existing and proposed bridge crossing near the abutments, piers, and along the banks to be utilized for the scour analysis.

**Proposed Conditions**

Figure 11 depicts the water surface elevations (WSE) determined by the 2D model for the 100-year peak flow on the Elwha River under proposed conditions. The model results indicate that the proposed bridge crossing reduces the 100-year backwater condition that is caused by the existing bridge. Figure 12 shows an average reduction in WSE of 0.8 feet along the cross section labeled XS1, in Figure 11, located at the upstream face of the existing bridge. Throughout the right side of the channel, the localized reduction in WSE is approximately 3 to 4 feet (Figure 12).

![Figure 11. Proposed Conditions Water Surface Elevations Near Proposed US 101 Crossing at 100-year flood](image-url)
Figure 12. Water Surface Elevations Comparison at Upstream Face of Existing Bridge

Figure 13 depicts velocity magnitudes and vectors for the proposed conditions during the 100-year event. The blue and smaller arrows show areas of low velocity, whereas the red and longer arrows show areas of high velocities.
Figure 14 provides velocity values for existing and proposed conditions plotted along cross section XS2 from Figure 13, to illustrate the velocity shadows caused by the wakes of the existing Piers 6 and 7. The proposed conditions velocity magnitude values are typically lower than the existing conditions throughout most of the channel, except where there are large dips where the existing Pier 6 (~Station 130) and Pier 7 (~Station 260) had significant effects on the velocity distribution. The averaged velocity magnitude for both existing (10 feet/sec) and proposed conditions (9.4 feet/sec) are also displayed on this figure as pink and red lines, respectively. The proposed conditions average velocity magnitude is also lower than the existing conditions value, likely due to providing a larger bridge span and minimizing widths of in-water piers. Consequently, the proposed conditions velocity distribution is more natural, therefore, the proposed bridge will better allow for the natural movement of water, wood, and sediment.

**Conclusion**

Practitioners should assess hydrology, hydraulics, and geomorphology (e.g. potential channel responses) when designing bridges and other infrastructure, especially in highly dynamic fluvial systems. The existing US 101 Bridge was constructed on lake sediment deposits, which likely became mobilized following the removal of the Elwha River Dam. Impacts from depositional deltas may extend well upstream from the normal reservoir water surface elevations. Consequently, dam removals can result in channel incision through the entire length of the reservoir delta, including the river channel upstream of the delta. Any infrastructure built after reservoir sedimentation may be threatened by the channel incision, resulting from dam removal, and therefore should be evaluated when designing new infrastructure and when analyzing existing infrastructure. These considerations will allow for more sustainable structures to be designed and maintained.
References


