PRELIMINARY GEOMORPHIC ASSESSMENT OF THE 32 ROAD WASH-OUT, KLICKITAT RIVER

YAKAMA RESERVATION, WASHINGTON

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Abstract

The east approach of to the east bridge of the 32 Road (a.k.a. Howard Lake Road) across the Klickitat River was washed-out during the winter of 2015-2016. The geomorphic processes involved are complex, extend beyond the immediate vicinity of the road, and have been developing over a twenty year period. Though a roughly 100-year peakflow in December 2015 was the proximal cause for the washout, general aggradation and upstream bar accretion over the prior 10 years set the stage for the washout event.

During that time, aggradation upstream and downstream of the bridge changed flow distribution vectors which increased left-bank forcing and likely reduced hydraulic capacity at the bridge section. Upstream aggradation also increased overbank flow and erosion of the road embankment between the east and west channels. In treating the current washout, there is potential for incorrect treatments to unintentionally exacerbate conditions adverse to road management. With that in mind:

- Channel-spanning treatments should be avoided in the east channel.
- Bank treatments may be appropriate, but should be designed so as not create supplemental resistance that might compound aggradation.
- Sensitivity should be exercised so as not to disrupt downstream reaches (including side channels) nor increase avulsion potential.

The 1999 treatment functioned in some capacity for approximately ten years, though likely contributed to upstream aggradation and made today's hydraulic and geomorphic conditions more challenging to address. Instream treatment beyond about a 20 foot radius from the abutment will likely have an even shorter lifespan than the 1999 treatment without thorough evaluation of site and reach conditions.

Complex channel forms and processes are not a problem in the absence of the bridges and road fill. They are desirable for fish habitat management and help offset losses associated with original construction of the 255 and 32 roads. Funding for potential in-channel treatments would be better applied to broader transportation planning that evaluates maintenance and environmental costs as well as the need for such a concentration of infrastructure. A process is outlined to evaluate if and how the river and road can coexist.

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PURPOSE AND SCOPE

The east approach to the east bridge of the 32 Road (a.k.a. Howard Lake Road) across the Klickitat River was washed-out during the winter of 2015-2016. The purpose of this report is to characterize current conditions and provide a cursory assessment of the hydrologic and geomorphic processes contributing to the washout. A cursory (~1.5 hour) site visit was conducted by the author on June 7, 2016 to inform this report. Unless otherwise noted, photos presented on this report were taken during the site visit. No documents or drawings were received for review. Recommendations for further action are provided.

SITE DESCRIPTION

The 32 Road crosses the Klickitat River and its active floodplain at river-mile (RM) 75.6 within the Closed Area of the Yakama Reservation (Figure 1) in the SW 1/4/ of T10N R13E S9.

Valley Setting

The crossing consists of a valley-wide embankment composed of earthen fill with a crushed aggregate running surface, two bridges (a.k.a. 'Twin Bridges') and several small cross-drain culverts. Each bridge has a single, clear span of approximately 60 feet and an asphalt/BST running surface.

The crossing occurs within a valley segment that has an average width of approximately 1,500 feet with an active, inset valley width ranging from 700-1000 feet. Within the active valley, the Klickitat River exhibits multi-thread channel forms. Secondary channels associated with and/or potentially affected by the crossing range from 3,200 lineal feet (l.f.) upstream (vicinity of Diamond Fork confluence) to 4,800 l.f. downstream (vicinity of Piscoe Creek confluence) measured along the primary channel of the Klickitat River. The 255 Road crosses approximately ½-mile downstream of the 32 Road and also has a cross-valley embankment with two bridge crossings.

Bridge Section (Figure 1, point "1")

The wash-out occurred at the east end of the east bridge which crosses the primary river channel and is oriented more-or-less normal to the channel alignment. The river has undercut the left-bank immediately upstream of the flanked east abutment, and partly eroded fill material of the approach

Figure 1. Location and site map with reference points for Klickitat River at 32 Road (streamflow is from top to bottom).

(Figure 2). The road was impassable to vehicular traffic and traffic barricades were in-place at the time of the site visit.

Figure 2. Close-up photos of east abutment washout (all photos taken 6/7/16).

The east bridge has a deck length of ~65' and traveled way width of 30'. The deck slopes downward from east to west at 1-2%. The span is composed of eight concrete panels, each 4' wide that are cross-bolted (visible in bottom-left photo in Figure 2).

Riprap formerly on the river face of the east abutment was mostly absent (Figure 3). Riprap on the face of the west abutment was largely in-place, but the slope steepens in the downstream direction, has a sheared appearance, and the toe deflects toward the abutment by several feet (Figure 4) resulting in a slope steeper than angle of repose. Riprap size, based on median particle axis, was estimated with a D100 ≈1.5' and D84 ≈1.1'. Alluvial gravels and sands have been deposited at the toe along the upstream half (by length) of the west abutment's riprap.

Flow alignment observed through the section was highly forced, flowing behind, through, and along the face of the left abutment then crossing over to the right side of the channel in fairly short downstream distance (1-2 widths of bridge).

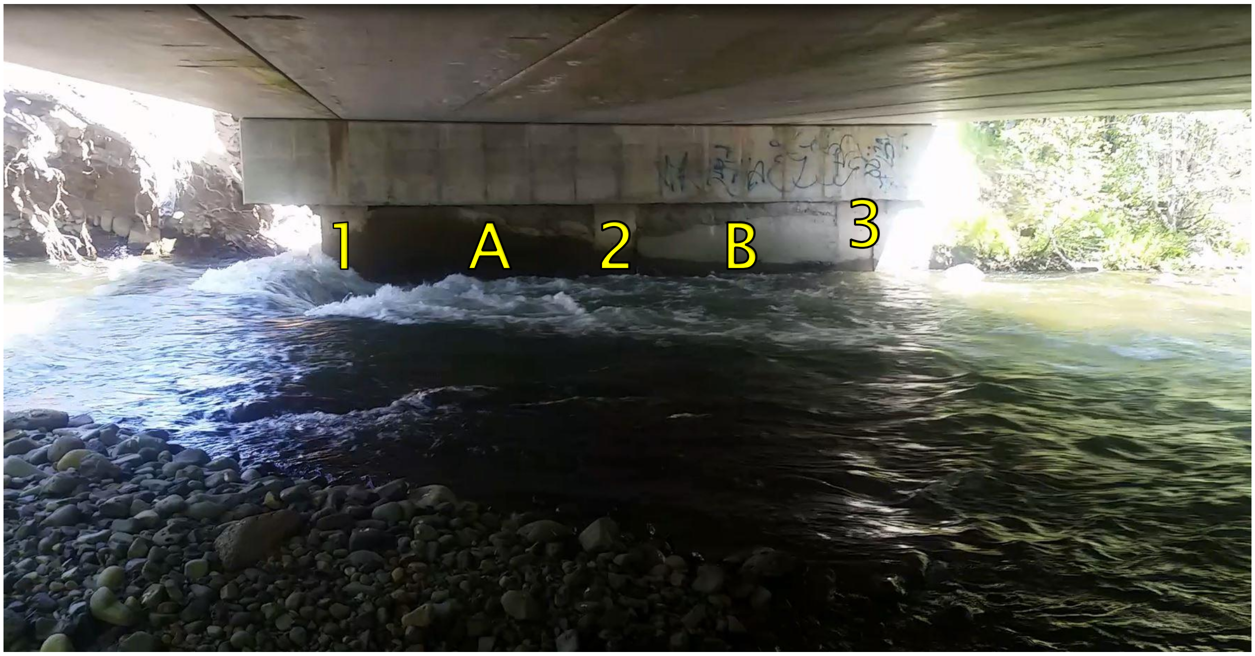

Figure 3. Face of east abutment.


Figure 4. Face of west abutment.

The abutment appears to be composed of three pilings with concrete panels between for grade separation (numbered and lettered, respectively in Figure 3). No warping, cracking, or other visual indicators of differential settling were observed that might suggest structural compromise. However, there is definitely flow from behind the abutment back to the river between the pilings and underneath one or both of the grade separation panels. Panel 'A' (Figure 3) also appears to have differentially shifted vertically.

Immediately Upstream of Bridge

The asymmetrical distribution of erosion and deposition across the bridge section is due to approaching flow vectors resulting from upstream bar accretion (Figure 5). The bar accretion focuses sheer on the left/east half of the active channel and creates a hydraulic shadow along the right-bank.

Figure 5. Downstream view of bar accretion (river-right) associated with asymmetrical flow distribution at bridge section.

Downstream extension of the bar into the bridge section (foreground of Figure 3) has resulted in vertical clearance between top of the cobble/gravel bar and upstream face of the bottom bridge chord measured as 5.5 feet on June 7, 2016 (Figure 6). The wetted channel was unwadeable at the time of visit, but maximum depth of bridge section was estimated to be at least 4-5 feet.

Figure 6. Close-up of bridge section looking downstream at distil end of bar accretion under bridge.

Right-bank Floodplain Upstream of Bridge (Figure 1, point “3” vicinity)

Opposite the eroding bank and adjacent to the previously mentioned bar accretion is a very active floodplain surface (Figure 1, point “3”), significant portions of which show signs of frequent inundation including 1.2-year recurrence and less flows (Figure 7). Signs include extensive fresh woody debris and uncolonized fine sediment deposits. Some fine sediment deposits were still saturated at the time of visit (daily flow at gage = 518 cfs) suggesting inundation within the last day or two and at fairly low magnitudes.

Left-Bank Upstream of Bridge (Figure 1, point “2” vicinity)

Aside from the bridge itself, the most visible feature in the vicinity of the bridge is the left channel margin upstream of the bridge.

This margin is a steep, eroded face that marks the left/east boundary of the active valley bottom and floodplain (Figure 8). The bank is composed of multiple units with at least four major ones, including:

- Upper (top 4-5’ of profile) – poorly sorted, weakly clast-supported (possibly matrix-supported), rounded to sub-angular large gravels to medium boulders, silty matrix
- Upper Middle – thin, variable unit of clast-supported, sub-rounded gravels to large-cobbles with a few boulders

Figure 7. Recent overbank flow (5/9/2016, ~1.2-yr RI) and susbsequent indicators (6/7/2016) on right-bank floodplain upstream of east bridge.

Figure 8. Actively eroding face of left bank approximately 200 l.f. upstream of bridge.

- Lower Middle – variable, sub-angular gravels with some cobbles, possibly matrix-supported
- Toe (lower 2' visible above waterline) – clast-supported sub-rounded gravels up to medium-cobble with cohesive matrix; likely multiple units

Within 50 feet of the bridge there are more varied and generally fluvial or slackwater deposits in the lower-half of the profile including units of coarse channel deposits, open-framework gravels, and laminated fines. These fluvial units are capped by a poorly sorted layer similar to the "upper" unit described above and overly a cohesive unit similar to the "toe" unit described above.

Figure 9. Looking upstream at main (east) channel of Klickitat River from upstream end of eroding bank.

The contact along the active channel extends approximately 200 feet upstream from the bridge. The cohesion of the "toe" unit provides the main resistance along the bank as it is unvegetated and there is a seam of deeper water along the boundary. The seam extends slightly upstream of the contact (Figure 9). However, at the upstream end, it may be due a combination of resistance associated with boulders, vegetation, and flow contraction.

Vicinity of Side-Channel Inlet (Figure 1, vicinity of point "4")

An active side channel bifurcates from the right bank of the main channel approximately 500 l.f. upstream of the bridge. During the site visit, surface flow was observed entering the side-channel and flowing toward the west bridge/channel. This area has signs of mainstem bed aggradation in the area with vegetation providing the most recognizable indicators (Figure 10).

Gaged discharge on the day of the site visit was half of a minimally effective discharge (~1.4-year RI) for the area. For this portion of the Klickitat River, persistent woody riparian vegetation is expected to be rooted outside of the active channel (~1.4-year RI). However, numerous mature cottonwoods were observed with the lowers portions of their trunks in six inches or more of water (e.g. Figure 10, vicinity of "A"). Further, young, vigorous alders (e.g. "B"s) and young, dead firs (e.g. "C"s) were observed growing on the same surface. An older ponderosa pine ("D") occupies a lower cross-sectional position than would be typically expected for initial establishment. Firs are intolerant to inundation and alders are a colonial species and quite well adapted to inundation and fluvial disturbance. Given ages and species involved, the aggradation would seem to be fairly recent (likely within last 10 years). Channel aggradation and side channel development are discussed further in the section titled, "Evaluation of Photographic Time-series".

Figure 10. Signs of aggradation in vicinity of side-channel inlet approximately 500' upstream of bridge.

HYDROLOGY

To understand the current site conditions and provide a foundation for interpreting the photographic time-series presented in the next section of this report, a review of peak discharge data within a magnitude-frequency context is helpful.

Gage Hydrology

The USGS has operated gage 14107000 ("Klickitat River above West Fork near Glenwood, WA") near Castile Falls since 1945. During that period, there a 59 years of record and a hiatus for water-years 1979-1991 (inclusive). The gage is located approximately 9.9 miles downstream of the 32 Road at the "Castile Crossing" bridge at RM 65.7.

A magnitude-frequency analysis was performed on an annual maxima series of 59 records in Aquarius Workstation v3.7.134. Data from the Log-Pearson Type III (LPIII) and Gumbel distributions provided a best fit of the data (Figure 11). Tabular values for standard recurrence intervals are presented in Table 1. Other distributions evaluated were Normal, log-normal, Pearson Type III, gamma, log-gamma, GEV, and Weibull. Only values related to the LPIII distribution are used subsequently because of fit to data and widespread use.

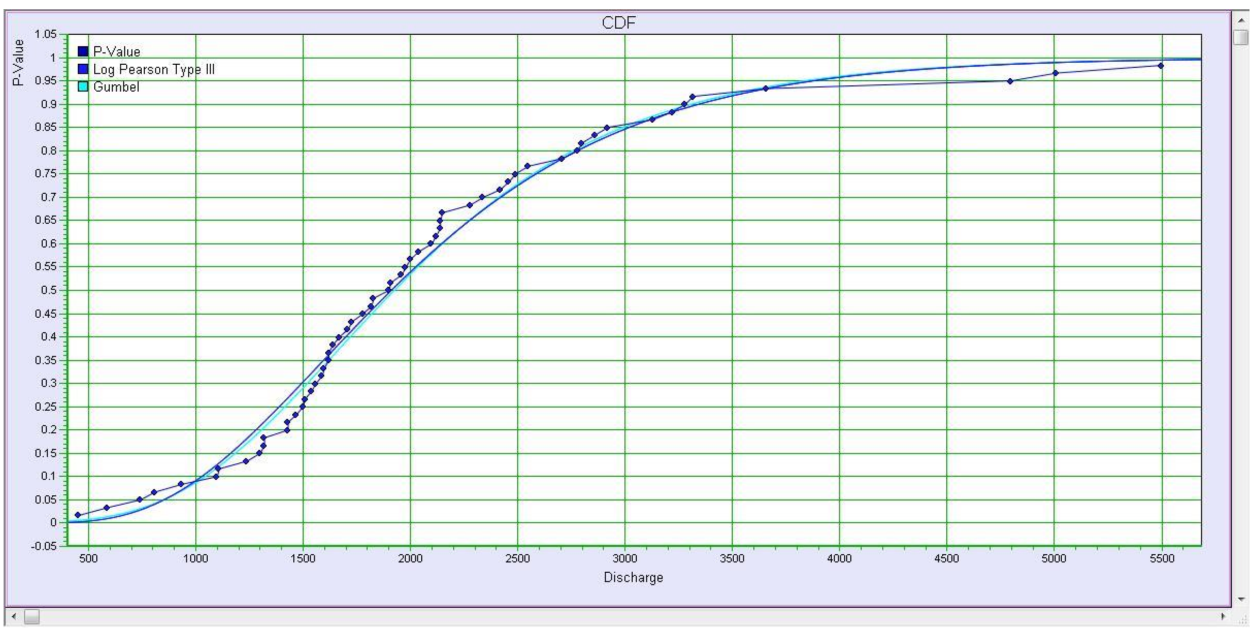

Figure 11. Magnitude-frequency analysis for annual maximum discharge (cfs) for USGS gage 14107000.

The fitted LPIII curve was used to compute discharge values for standard recurrence intervals (Table 1). The magnitude-frequency values were then superimposed onto a scatterplot of recent and historic peak flow events for interpretive context (Figure 12). This affords the opportunity to discuss flow frequency at the ungaged site independent of discharge.

Table 1. Computed discharges (cfs) using three different methods for specified recurrence intervals given 59 annual maxima from USGS gage 14107000.

Return Period (years)	Statistical Distribution		
	Log Pearson Type III	Gumbel	Weibull
1.4	1,460	1,490	1,440
2	1,910	1,920	2,000
5	2,780	2,760	2,920
10	3,340	3,310	3,430
25	4,040	4,010	3,990
50	4,560	4,520	4,350
100	5,050	5,040	4,680
500	6,190	6,220	5,360

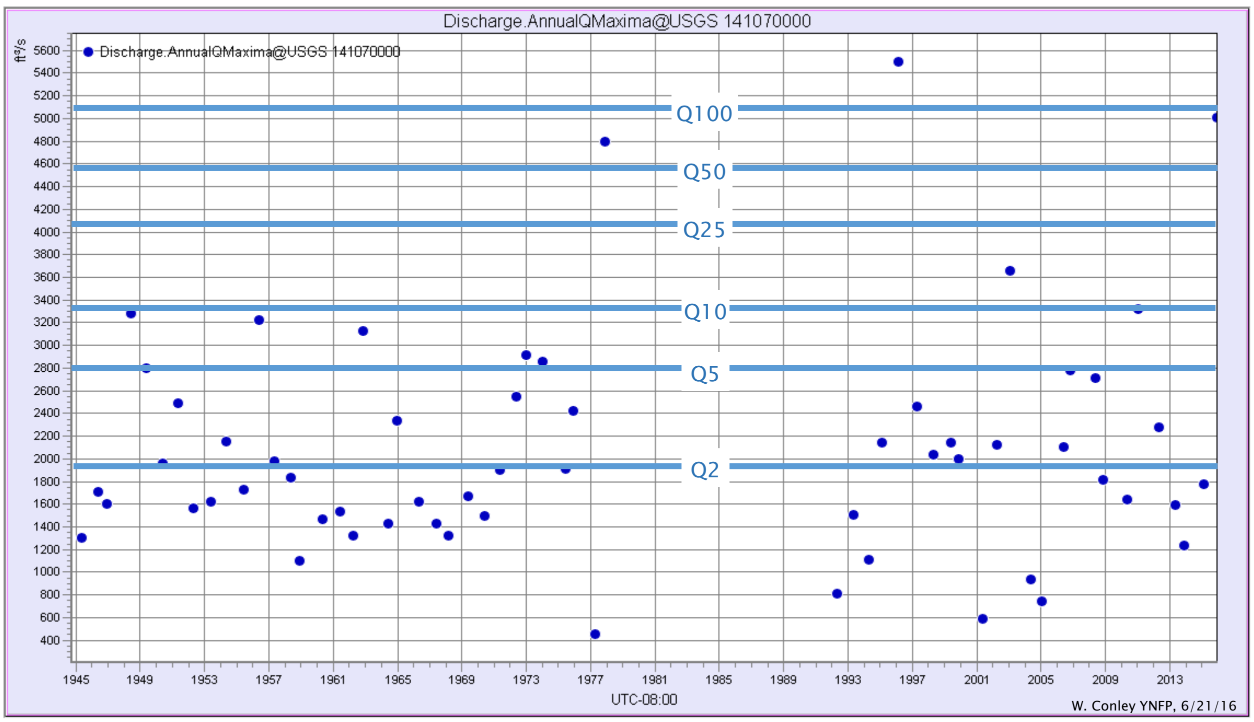

Figure 12. Scatterplot of annual maxima for USGS gage 14107000 from WY 1945 through 2016; annotated, blue horizontal lines indicate computed recurrence intervals.

Peak Site Hydrology

Four named (Piscoe, Huckleberry, McCreedy, and Chaparral creeks) and numerous smaller tributaries discharge to the Klickitat River downstream of the site and upstream of the gage. For design purposes, it is important to know the hydrology at the site in question. Site hydrology was estimated using two methods:

1. Correcting the magnitude-frequency relationship from the gaged site based on drainage area (Thomas et al. 1994)
2. WA State Region 6 regression equations (Sumioka et al. 1999)

The Thomas et al. (1994) method can be used where drainage area of an ungaged site is between 50 and 150 percent of drainage area of a gaged site on the same stream can be computed as:

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^x$$

Drainage area at the gage is 151 square-miles and drainage area at the site is 86 square-miles. The exponent values for the region that includes the Klickitat is 0.75 (Sumioka et al. 1999).

The Region 6 magnitude-frequency equations are derived from empirical data collected at a suite of Washington gages along an 80-mile east-west axis of the Columbia Gorge. The geographic distribution spans the crest of the Cascade Mountains and extends well into the interior Columbia Basin. Thus, gages from semi-arid catchments (10-inch mean annual precipitation (MAP)) are lumped with gages from temperate rainforest (116-inch MAP). This contributes to high standard errors of prediction (63-77%). Consequently, values based on the Region 6 equations are provided only as a check. While the equations approximate the drainage area method (Table 2), it is recommended that hydraulic modeling and design calculations be based on the drainage area method results.

Table 2. Estimated peak instantaneous discharge (cfs) for the Klickitat River at the 32 Road for specified recurrence intervals based on two methods.

Probability Equaled or Exceeded	Recurrence Frequency (years)	Region 6 Equation	Gaged LPIII Distribution Corrected for Drainage Area
0.71	1.4	-	961
0.50	2	1,210	1,250
0.20	5	-	1,820
0.10	10	2,080	2,200
0.04	25	2,590	2,660
0.02	50	3,010	2,990
0.01	100	3,450	3,320
0.002	500	-	4,070

EVALUATION OF PHOTOGRAPHIC TIME-SERIES

A variety of ground-based and aerial imagery from 1996 to present was available and reviewed. Because discharge differs through time, daily discharge at the gage was compiled for each image collection date (Table 3) to assist interpretation.

Table 3. Daily discharge (cfs) at USGS gage 141070000 for dates of imagery presented in this report. Return intervals listed for discharges with 1.0 RI and greater.

Date	Daily Discharge (cfs)	Return Interval as an Annual Maximum (years)
07/15/1996	248^{A}	-
10/26/1999	130^{A}	-
08/25/2004	203^{A}	-
06/23/2006	438^{A}	-
07/06/2007	212^{A}	-
08/16/2007	95^{A}	-
05/21/2008	1,850^{A}	1.9
06/25/2009	353^{A}	-
10/25/2010	125	-
05/16/2011	1,990^{A}	2.2
09/25/2011	116^{A}	-
07/02/2013	338^{A}	-
06/09/2015	169^{A}	-
05/09/2016	1,110^{P}	1.2
06/07/2016	518^{P}	1.0

^{A} = approved data ^{P} = provisional data (subject to revision)

The greatest number of ground-based images were taken from the bridge looking upstream (Figure 13 and Figure 14). The earliest photos are from October 1999 and show construction of a boulder drop-structure. At that time, there also appears to be reshaping of the left bank and installation of several toe logs. The treatment was more-or-less intact and functional through at least August 2004. By May 2007, most of the toe logs were gone. The rock structure remained intact through at least July 2007 with some hydraulic effect persisting until May 2011. By October 2010, the bed upstream had aggraded upstream to the crest of the rock structure.

There are three main observations of interest between the May 2011 and June 2016 photos: reactivation of left-bank erosion, breaching of the left side of the rock structure, and significant bar accretion (lateral and vertical) along the right channel margin. It's worth noting some ebb and flow of bed/bar cutting and accretion along the right channel margin for the 2007-2011 photos.

Figure 13. Looking upstream at east (main) channel of Klickitat River from 32 Road Bridge, clockwise from top-left: 10/26/99, 8/25/04 (top) and 7/6/07, 5/21/08.

Figure 14. Looking upstream at east (main) channel of Klickitat River from 32 Road Bridge, clockwise from top-left: 10/25/10, 5/16/11, and 6/7/16.

Downstream photos of the bridge (Figure 15) are less frequent, but show lateral accretion and downstream extension of the right-bank bar. They also suggest a transition from a plane-bed in 1996 to a skewed cross-sectional shape with thalweg alignment left-of-centerline (also see Figure 5). It seems likely that hydraulic capacity at the bridge has decreased. Also note the bank face has steepened considerably in the 2016 photo.

Figure 15. Looking downstream at bridge across east (main) channel of Klickitat River; counter-clockwise from top: 10/26/99, 5/20/08 (left) and 6/7/16 (right).

Reduced capacity due to depositional effects on local channel form at the bridge are likely compounded by increased backwatering associated with aggradation of the tailwater control (Figure 16). It appears angular boulders were placed at the inlet of a left-bank side channel during the 1999 in-channel treatment (Figure 16, circled upper-left; Figure 1, point “8”). This element seems an unlikely cause for the aggradation, though. Decreased confinement just downstream of the bridge makes flow-expansion a more likely local cause and may be working in concert with a change in local slope where there is some range of discharges where competency (i.e. maximum particle size that can be transported) diminishes compared to upstream. In other words, there is some range of flows where steeper channel slope upstream of the bridge and confinement through the bridge section move larger particles that hydraulic conditions downstream of the bridge cannot.

Figure 16. Looking downstream from bridge; clockwise from top-left: 10/26/99, 10/25/10, and 6/7/16.

Loss of capacity due to bed changes and backwatering within the bridge section are partly offset by the loss of armor on the face of the east abutment (Figure 17). The photo from 2007 shows lower sectional area (and height on face of concrete) occupied by armor than even the west abutment in 2016 (Figure 4).

By 2010, more armor appears to have been removed, though some aggradation is apparent and may have buried/embedded residual armor along the toe.

Figure 17. Looking upstream at east abutment 8/16/07 (left) and 10/25/10 (right).

Accretion of the upstream right-bank bar and general channel aggradation between the rock structure and right-bank side channel are the proximal causes for routine overbank flows, including discharges lower than what would typically be expected (<1.3 or 1.4 RI) for this area. Some overbank flow re-enters the east channel immediately upstream of the bridge and the remainder crosses the floodplain and routed to the west channel (Figure 18). Some smaller portion is transmitted via two different culvert cross-drains through the road embankment.

The previously noted side channel (Figure 1, along points 4-7) does not appear to be present in either the 1996 or 2006 imagery (Figure 19 and Figure 20, respectively). By 2009, a channel is clearly evident crossing the floodplain (Figure 21, vicinity of point "5") and erosion along the road embankment face (point "7") appears to have occurred. The 2011 photo (Figure 22) was taken during base-flow conditions (late-September) and suggests the floodplain channel has developed into a perennial channel. The channel appears better defined in the 2013 and 2015 imagery (Figure 23 and Figure 24, respectively), suggesting continued channel evolution. Lateral bar development is visible in the 2015 photo.

Figure 18. Overbank flow on 5/21/08 (top photos) and 5/16/11 (bottom photos) approximately 1.9- and 2.2-year recurrence events

Figure 19. Aerial photo of active valley in vicinity of 32 Road on 7/15/1996; flow direction is top to bottom.

Figure 20. Aerial photo of active valley in vicinity of 32 Road on 6/23/2006; flow direction is top to bottom.

Figure 21. Aerial photo of active valley in vicinity of 32 Road on 6/25/2009; flow direction is top to bottom.

Figure 22. Aerial photo of active valley in vicinity of 32 Road on 9/25/2011; flow direction is top to bottom.

Figure 23. Aerial photo of active valley in vicinity of 32 Road on 7/2/2013; flow direction is top to bottom.

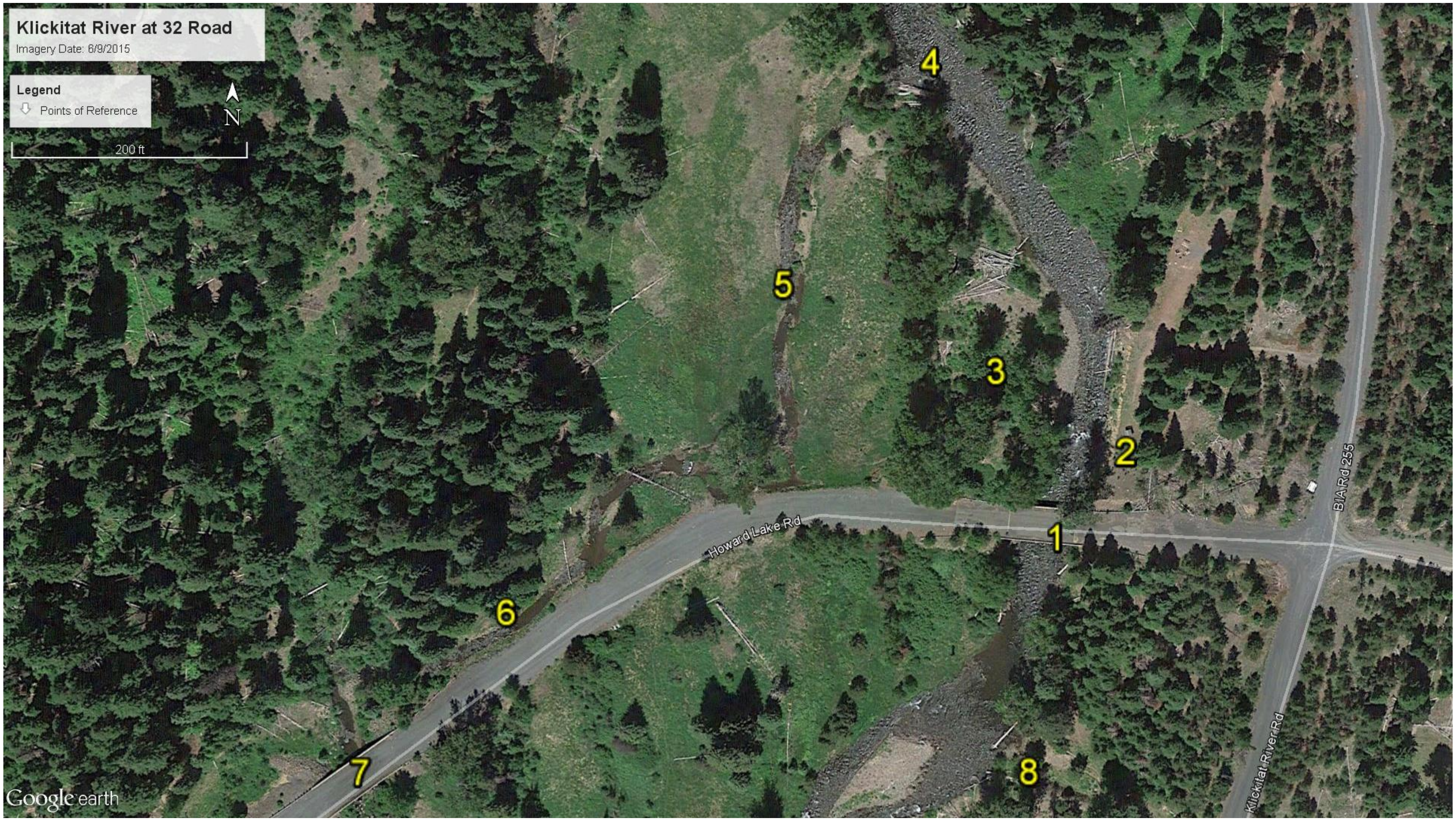

Figure 24. Aerial photo of active valley in vicinity of 32 Road on 6/9/2015; flow direction is top to bottom.

Sediment deposition upstream of the bridge is aggrading the bed and accreting and extending the bar. This increases lateral hydraulic forcing contributing to erosion of the left bank and effectively changes flow approach vectors to the bridge. Overbank flow frequency also seems to be increasing (and flow magnitude for occurrence decreasing). This 'loss' of flow to the channel diminishes sediment transport capacity and positively reinforces recent/current depositional processes. Based on conditions observed at the site visit, these processes can be expected to continue into the foreseeable future.

Discussion

The washout of the east abutment of the main channel bridge of the 32 Road is of a flanking style associated with erosion of the left bank. Left bank erosion is a product of forcing associated with momentum (located on the outside of a meander bend) and is magnified by forcing associated with bar accretion on the opposite bank.

Multiple lines of evidence suggest the bed of the main channel of the Klickitat River is aggrading in vicinity the road. A ground-based photo time series indicates lateral accretion and downstream extension of the right-bank bar immediately upstream of the bridge crossing. Ground and aerial photos suggest aggradation of the tail-water control downstream of the bridge. Aggradation frequently contributes to increased stress on lateral boundaries (e.g. banks).

The left-bank active channel contact extends approximately 200 feet upstream from the bridge. It appears to be part of a much longer topographic feature that continues 4,000 feet upstream to the vicinity of the Diamond Fork confluence and serves as the boundary for the active floodplain for much of that distance. The tread of this feature is approximately 10 feet higher than the active floodplain immediately upstream of the bridge, but rises to approximately 30 vertical feet above the active valley bottom where the Diamond Fork valley enters. The tread has an average downvalley slope of 0.025 ft/ft which is considerably steeper than the active valley bottom (0.015 ft/ft). The sorting, clast angularity, matrix, and organization of the upper bank profile near the bridge appear similar to glacial till, but it lacks the consolidation of basal till. Other tell-tale signs of glacial activity (e.g.

moraines, kettle features, and hummocky terrain) are not evident in the vicinity. Given the slope difference and composition, it does not appear to be a proper alluvial terrace of the Klickitat River. This feature could be the residual surface from an outburst flood, potentially originating from the upper Diamond Fork watershed which is steeper than the mainstem Klickitat and has a greater proportion of watershed area mapped as glacial deposits. This is relevant as it is one of several older (probably Pleistocene-aged) valley fills in the vicinity of the site and several miles upstream. Based on a cursory review of aerial imagery this particular boundary does not appear very active outside the bridge vicinity.

Bed aggradation seems to be increasing the frequency of right-overbank flow (and decreasing flow magnitude required to occur). In the process, this 'loss' of flow to the channel diminishes sediment transport capacity which positively reinforces the current depositional regime contributing to further bar accretion.

While local factors certainly influence aggradation and accretion, the role of processes operating at larger extents (e.g. changes in sediment supply) are unclear. Such evaluation would require specific investigation and is outside the scope of this report.

Peak discharges from the gage record and observations from the photographic record were compiled into a common chronology and presented in Figure 25. The main window where a threshold seems to have been crossed is between November 2007 and May 2010. This period of time is where the initial development of the floodplain channel occurs, left-bank erosion resumes, and the drop structure deteriorates. However, bed aggradation was likely occurring prior to that. The October 1999 in-channel treatment effectively persisted for 8-10 years and functioned during three 1-year, four 2-year, two five-year, and one 15-year events. There does not appear to have been a single, acute flow event causing its demise as there was nothing larger than a 5-year recurrence event in the preceding eight years. A shift in flow distribution and forcing caused by aggradation and bar accretion are the most likely causes. As the

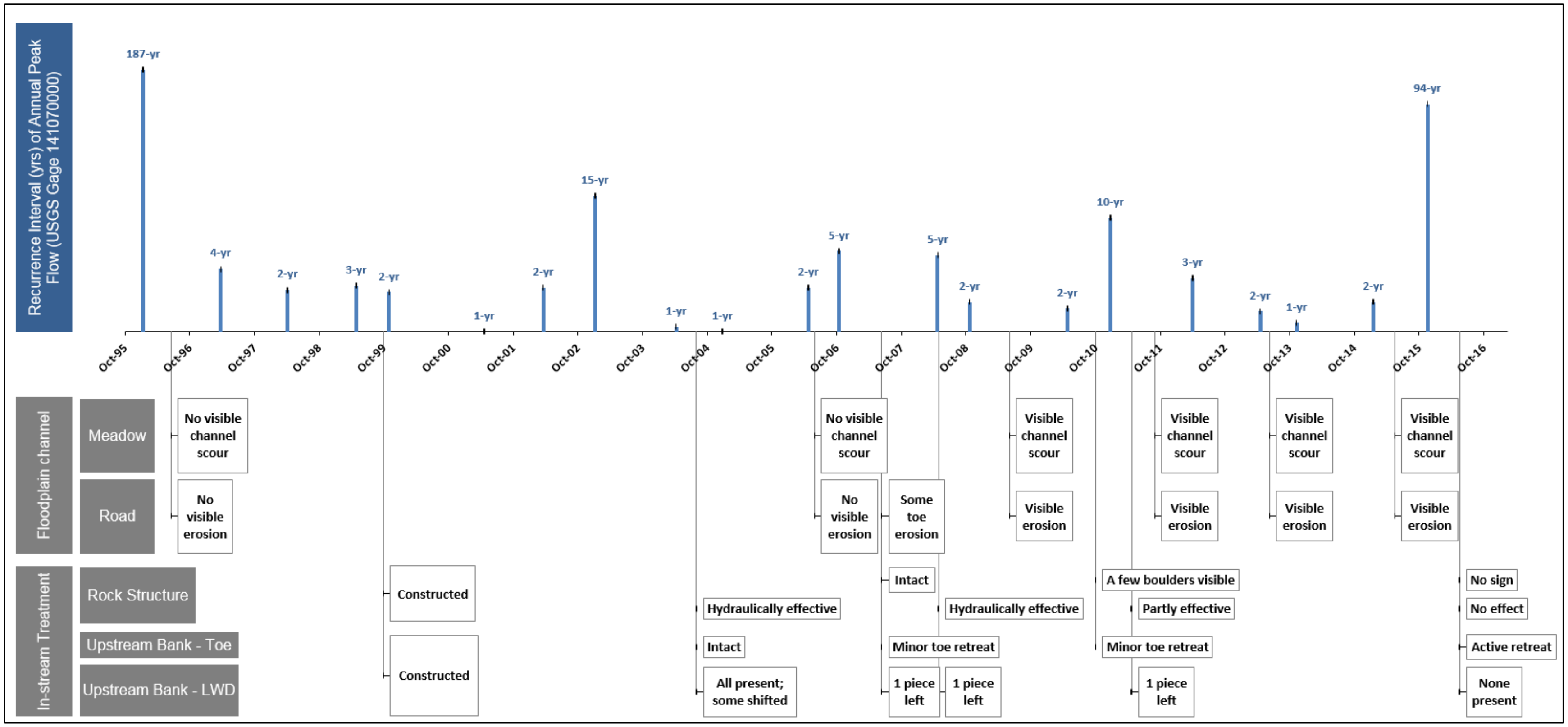

Figure 25. Post-1996 flood peak-flow recurrence annotated with observations from photographic record in the vicinity of the 32 Road crossing.

magnitude and cumulative duration of overbank flow across the floodplain toward the west channel increased, a side-channel has developed in the last ten years (points 4, 5, 6, and 7 in air photo series).

The Klickitat River splits into two major channels (“east/main” and “west”) approximately 3,000 feet upstream of the 32 Road. Both channels exhibit wandering forms. Review of high resolution topography collected in 2011 indicate overbank flow is typically from the east/main channel across the floodplain toward the west channel (Figure 26). Within approximately 2,100 feet upstream of the road crossing, the west channel generally occupies lower positions for most valley cross-sections (Figure 27) which is consistent with flow patterns.

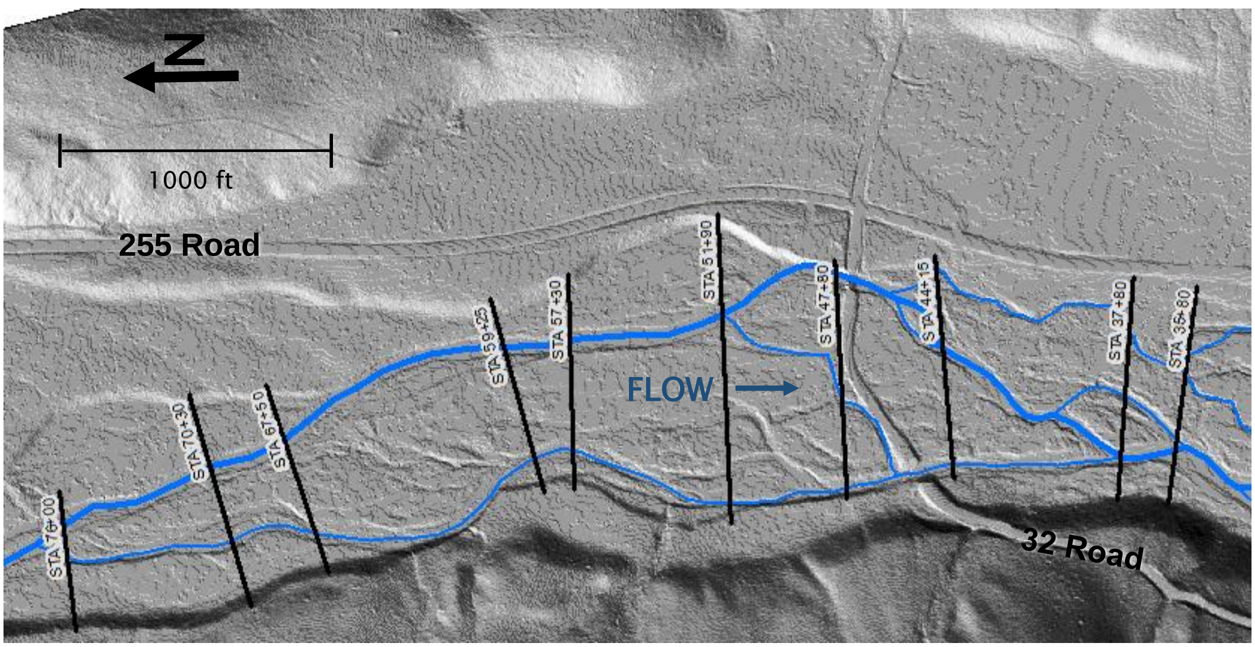

Figure 26. High resolution topography of Klickitat River valley in vicinity of 32 Road derived from LiDAR collected in 2011; stationing in feet along valley centerline from Piscoe Creek confluence; Diamond Fork confluence is at left edge of image; line stationing indicates cross-sections presented in Figure 27.

Review of post-1996 flood aerial imagery indicates increasing vegetation encroachment on the west channel. Visits to the west channel upstream (and within ~1,000 feet) of the bridge in August 2007 and October 2010 under baseflow conditions indicated very low surface flow conditions, with interstitial flow or dry conditions though riffles. The west channel was characterized by a very coarse, poorly organized bed that generally lacked pool development. The low-flow condition was interpreted to be that baseflow in the west channel was

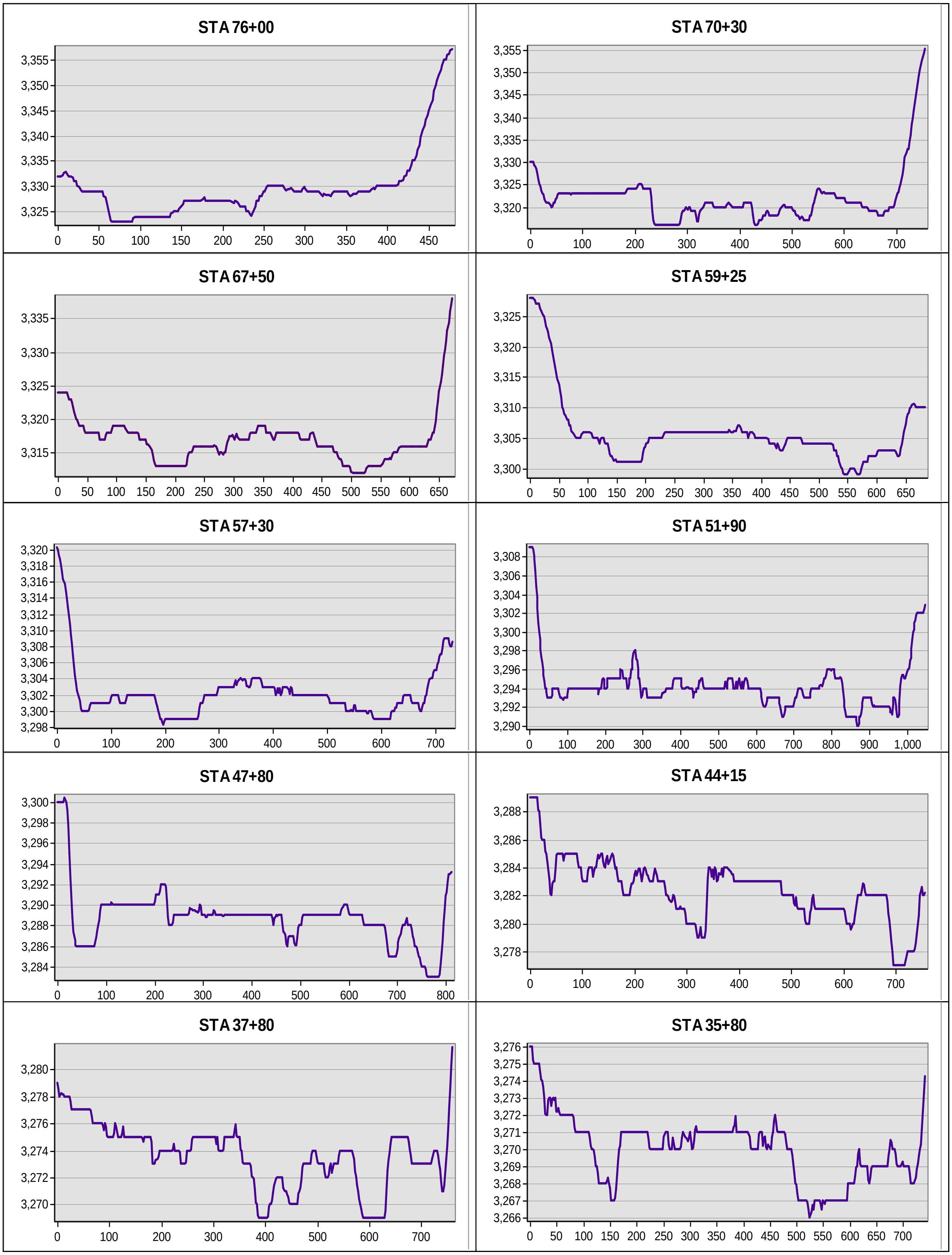

Figure 27. Cross-sections of active valley from bare-earth LiDAR (all views looking down-valley); stationing same as Figure 26.

probably hyporheically-fed. Surface flow in the west channel at the bridge in May 2008 and May 2011 was substantially less than the east channel, though was sufficiently high to suggest surface inflow (other than cross-over flow from the east channel immediately upstream) was occurring. It is inferred that surface inflow to the west channel may be limited by a sediment slug in the vicinity of the inlet.

The combination of the relative vertical position of the west channel invert 4-5 feet lower than the east channel at the road crossing, ongoing aggradation of the east channel, and floodplain channel development, preconditions exist for channel avulsion. If avulsion were to occur, substantial damage or even complete removal of the embankment to the east of the west bridge can be expected. Even in the absence of avulsion, increased pressure on the up-valley embankment face can be expected into the future.

While challenging from a road management perspective, it should be noted that the channel and floodplain patterns observed in vicinity of the 32 Road are desirable from a fisheries habitat management perspective. Historic Klickitat River channel complexity and floodplain connectivity were lost with construction of the 255 and 32 roads. Over the last 12-13 years, the YN Fisheries Program has been actively managing the Klickitat River to mitigate past habitat losses and minimize future damage caused by forest roads in the general area.

Recommendations

The nature and scale of the processes involved are not easily (or inexpensively) addressed. The channel has evolved and is different than that which was treated in 1999. The channel-spanning drop structure constructed in 1999 has almost certainly had a part in that evolution by encouraging aggradation upstream.

There is potential to unintentionally trade one problem for another by applying the incorrect treatment for the current regime. In general:

- Channel-spanning treatments should be avoided in the east channel as they are likely to increase overbank flow, embankment erosion near the west bridge, and avulsion risk.

- Bank treatments may be appropriate, but should be designed so as not create supplemental channel-scale resistance that might compound aggradation.
- Sensitivity should be exercised so as not to disrupt downstream reaches (including side channels) nor increase avulsion potential.

A two-stage process is recommended:

1. Immediate protection of the east abutment
    a. Investigation of scour and structure at left abutment by licensed engineer(s).
    b. Implementation of localized treatment (i.e. within 20' or less) of abutment to protect abutment and facilitate reopening the road to vehicular traffic.
2. Evaluation of the broader geomorphic and hydraulic setting of the road:
    a. Reach assessment (from 255 Road to Diamond Fork confluence)
        i. Review of pre-1996 aerial imagery (include a mile or two upstream of both Diamond Fork and Klickitat River upstream of their confluence within assessment)
        ii. 2D hydraulic model
        iii. Sediment supply & transport
    b. Site Assessment
        i. Review of historic data, design reports, etc.
        ii. Hydraulic conditions at the bridge section
        iii. Evaluation of left-bank resistance/retreat
    c. Alternatives analysis that considers cost:benefit and investigates design options including:
        i. Reposition existing 32 Road bridge (move both abutments east)
        ii. Install new, longer bridge (use right/west existing abutment, construct set-back abutment, 16 or 20' deck width)
        iii. Increase flow-frequency of west channel
        iv. Abandon 32 Road alignment across Klickitat River (could include improvements to McCreedy Creek Road)
            1. 32 Road bridges could be re-purposed
            2. Partner with Fisheries Program to conduct restoration

v. Abandon 255 Road between McCreedy Creek and 80 Road
    1. longer bridges from 255 Road could be moved to 32 Road
    2. 32 Road bridges could be re-purposed
    3. Partner with Fisheries Program to conduct restoration

Site hydraulics should be carefully considered in any design scenario as some (e.g. increasing flow-frequency of west channel and longer bridge span) could compound aggradation already occurring in the vicinity.

Dewatering for any type of treatment should not involve wholesale rerouting of discharge to the east channel as it would also involve dewatering of at least 3,000 feet of fish-bearing side channels. Localized (<20 foot radius to abutment) armoring should be able to be implemented by minor channel excavation of bar sediments, coffering, and seepage pumping. A fishery biologist should be consulted in the planning stages and be on-site to direct salvage of aquatic organisms for any dewatering event.

The last in-stream treatment functioned for roughly a decade and was constructed in a more receptive hydraulic and geomorphic setting. It was also a likely contributor to the aggradation that now makes the 2016 channel and processes more challenging to address. While instream work is often satisfying in the short-term, instream work conducted beyond immediate abutment protection (i.e. within 20 foot radius and approach reconstruction in the absence of thorough evaluation of site and reach conditions will likely have a very short lifespan. Funding for in-channel treatments at this point in time would be better spent if applied to a transportation planning exercise.

Arterial roads in the upper Klickitat are high-standard roads that were constructed in a time (1960s and 1970s) of relatively high road spending. High-standard roads in geologically-active mountain environments are expensive to maintain and also tend to have greater environmental costs. Observed use on both the 32 and upper 255 roads is very low over the last 15+ years. The 255 Road fill between the 32 Road and McCreedy Creek Road intersections displaces old river alignments and isolates the river from side channels and valley margins important for habitat formation. The 32 Road alignment is in a valley segment where the river is continues to re-work a variety of paleo-fills (unconsolidated and weakly consolidated sediments from prehistoric depositional events) that will continue to be problematic in terms of washouts and scour. A multi-disciplinary evaluation is highly encouraged to consider whether the redundancy and high standards of roads in the vicinity 1) continues to be necessary and 2) will have suitable funding for maintenance given ongoing environmental and maintenance costs.

Finally, it's important to remember: the bar accretion, aggradation, overbank flow, terrace erosion, and floodplain channel development are not a problem in the absence of the bridges and road fill. From a fish habitat management perspective, they are desirable processes in this particular valley segment of the Klickitat River. The valley-wide road embankment and the bridges are the problem. The challenge is to figure if and how the two can coexist.

SUMMARY

The geomorphic processes involved with the 32 Road washout are complex, extend beyond the immediate vicinity of the road, and have been developing over a twenty year period. Though a near 100-year peakflow in December 2015 was the proximal cause for the washout, general aggradation, bar accretion, and deterioration of the 1999 treatment upstream of the bridge had been occurring for the previous 10 or more years to set the stage.

Upstream aggradation has caused an increase in overbank flow and erosion of the road embankment between the two bridges. Lateral bar accretion and downstream extension to the bridge section have changed flow distribution vectors which has increased left-bank forcing and likely reduced hydraulic capacity at the bridge section. Aggradation of the tailwater control downstream is likely due to decreased sediment competence associated with a reduction in local channel confinement and gradient. Downstream aggradation may reduce hydraulic capacity at the bridge section and contribute to sediment deposition immediately upstream of the bridge.

In treating the current washout, there is potential to unintentionally exacerbate conditions adverse to road management by applying the incorrect treatment. With that in mind:

- Channel-spanning treatments should be avoided in the east channel as they could increase upstream aggradation and erosive force on road embankment between the bridges.
- Bank treatments may be appropriate, but should be designed so as not create supplemental channel-scale resistance that might compound aggradation.
- Sensitivity should be exercised so as not to disrupt downstream reaches (including side channels) nor increase avulsion potential.

The 1999 treatment functioned in some capacity for approximately ten years. However, it likely contributed to channel aggradation that has increased overbank flow frequency (causing embankment erosion near the west bridge) and made today's hydraulic and geomorphic conditions upstream of the east bridge more challenging to address.

Instream work conducted beyond immediate abutment protection (i.e. within 20 foot radius of the abutment) and approach reconstruction in the absence of thorough evaluation of site and reach conditions will likely have a very short lifespan and could make the situation worse. Funding for in-channel treatments would be better applied to broader transportation planning that evaluates maintenance and environmental costs as well as the need for such a concentration of high-standard infrastructure.

Dewatering for any type of treatment should not involve wholesale rerouting of discharge to the east channel as it would also involve dewatering at least 3,000 feet of fish-bearing side channels. Localized treatment could be implemented with minor channel excavation of bar sediments, coffering, and seepage pumping. A fishery biologist should be consulted in the planning stages and be on-site to direct salvage of aquatic organisms for any dewatering event.

Complex channel and floodplain patterns and processes are not a problem in the absence of the bridges and road fill. From a fish habitat management perspective, they are desirable processes in this particular valley segment of the Klickitat River and help offset losses associated with original construction of the 255 and 32 roads. The valley-wide road embankment and the bridges are the problem. The present challenge is to figure if and how the river and the road can coexist.