U.S. Department of Transportation
Federal Highway Administration

Memorandum

Western Federal Lands Highway Division
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UPPER HOH RIVER ROAD BANK STABILIZATION DRAFT - HYDRAULICS REPORT

To:	Kirk Loftsgaarden, WFLHD Project Manager
From:	Sven Leon, P.E., WFLHD Hydraulics Engineer
Date:	March 2, 2016
Project:	Upper Hoh River Road Bank Stabilization – WA JEFF 91420(1)

Background

One of the major roads leading into Olympic National Park (Park), Washington, is the Upper Hoh Road located off of US Highway 101 on the far western side of Olympic National Park. The road is the only entryway into the Hoh Rain Forest and the Park Rain Forest Visitor Center. The Upper Hoh Road is approximately 18 miles in length. Jefferson County (County) owns and maintains the portion of the road from the junction with US 101 to the OLYM boundary, approximately 12 miles. The Park owns and maintains the remaining 6 miles.

Management of the road to provide constant safe access to residents, business, and Park visitors, has become increasingly difficult over the past 20 years. Portions of the Upper Hoh Road are located within and adjacent to the Hoh River's channel migration zone. The location combined with the increasing frequency and severity of winter storm events (most recently in 2004, 2006, 2007, and 2009) has resulted in an increasing number of roadway washouts which either completely prevents access or creates unsafe roadway conditions for visitors, Park personnel, and local residents. In some cases the damage resulted in road closures, allowing no access to the Hoh Rain Forest and the Park's Hoh Rain Forest Visitor Center for weeks at a time (and many months in 1996). Response to these storm events and maintenance of the road in its current location has resulted in a continuing outlay of limited maintenance funds to maintain safe access and to mitigate for adverse impacts those actions have on threatened and endangered fish species.

In 1998 the Hoh Tribe requested the U.S. Bureau of Reclamation (BOR) prepare a geomorphic study to better understand the existing and historical channel processes on the Hoh River, and how human activities may have impacted those processes. The study, entitled Geomorphic Assessment of Hoh River in Washington State, published in 2004, identifies areas of risk for further lateral erosion in the historic channel migration zone and provided some general management considerations to deal with these areas of concern. The report recommended more detailed data collection and analysis for developing a management approach at any specific particular location.

In 2009, the Park published a report entitled Olympic National Park, Road Hazards and Solutions Report. This report examined two methods to address roadway locations, vulnerable to damage from severe storm events, within the Park. The two different methods evaluated included a site-specific approach versus a natural systems engineering approach. The report concluded that a natural systems engineering approach would likely provide a more long-term fix while improving the ecological conditions. Six sites along the Upper Hoh River Road within the Park were included in this evaluation.

September 2013 Western Federal Lands Highway Division (WFLHD) completed for the County an Upper Hoh Road Bank Failure Risk Reduction Study. The Study developed a comprehensive road management strategy for mitigating high risk sites along the Upper Hoh Road. WFLHD used the information from the two earlier reports and from site visits for developing the road management strategy. The WFLHD study included the prioritization of sites (regardless of management jurisdictions), development of a range of treatment options for each site, and initial cost estimates for each option including construction, Preliminary Engineering (PE), Construction Engineering (CE), and ROW. Treatment options developed represented a full range of types, costs, and environmental impacts. All treatment options where expected to provide a similar level of road failure risk reduction.

Selection and refinement of treatment options will be completed as part of the current project for two sites, road mile post (MP) 3.7 to 4.1 (MP 4.0 Site) and MP 7.7 to 7.9 (MP 7.8 Site) (Fig. 1). The County selected these sites for the project as having the highest priority for needing bank stabilization.

Two bank stabilization design options were evaluated;

- Stream barbs with mitigation logs.
- Wood buffer with dolosse ballast.

MP 4.0 Site has 2,570 feet of proposed bank stabilization. MP 7.8 Site has 500 feet of proposed bank stabilization. Each design options was evaluated on controlling bank erosion, cost, disrupting existing habitat, reducing flow velocity, preserving stream processes, and minimizing private property impacts. Recommendations, design option descriptions, private property and stream process impact estimates, analytical design basis, and cost estimates are presented.

Recommendations

Based on the hydraulic analysis and cost estimates, installation of wood buffer with dolosse ballast is recommended for both sites. The design approach is the least expensive for effectively controlling bank erosion. The wood buffer can accommodate a greater range of active flow channel migration and flow impingement angles. The minimal channel bed excavation and ability to place the wood and dollose directly into flowing water is least disruptive to environment. The approach does not appear to noticeably increase flooding or bank erosion on private property adjacent to the project sites. It does not appear to negatively affect stream processes. The wood buffer provides the greatest flow velocity reduction and habitat complexity. The approach is most adaptable to changing field conditions. Total estimated construction cost is $4,200,000 for MP 4.0 Site and $690,000 for MP 7.8 Site. Concepts details are presented on Sheet H.14. Preliminary plans and profiles are shown on Sheets R.6 to R.9 and S.3 and S.4.

Design Options

Streambarbs with mitigation logs

The approach involves placing streambarbs along the unstable, eroding banks. The streambarbs deflect river flow away from the bank area, reducing the risk of scour and channel incision undermining the bank. Flow velocities and shear stress along the bank area upstream of each streambarb is reduced, promoting sediment deposition and retention along the bank toe. This encourages riparian vegetation establishment. Deposition upstream of the streambarb and scour along the barb tip creates channel complexity.

Based on review of historical satellite imagery, length of bank typically exposed to impinging flood flow is estimated to be approximately 300 feet. The radius of curvature for the active channel is 500 to 800 feet. To effectively deflect the impinging river flow away from the bank area, the streambarbs would need to be spaced every 150 to 200 feet. The impingement point changes over time. All of the at-risk, unstable bank areas will receive stream barbs. MP 4.0 site has 18 proposed streambarbs and MP 7.8 site has four (Sheets R.2 to R.5 and S.1 and S.2).

Barb orientation and length is critical for achieving desired flow velocity reductions. Each is 90 feet long, angled upstream approximately 30 degrees relative to the bank line, and is made of Class 8 (FP-14) riprap (Sheet H.12). Each has a 10-foot wide crest. To accommodate different channel conditions than currently mapped and future channel migration, barb elevations are not set relative to actual streambed elevations at time of construction. Barb elevations are set relative to the modeled 50-year flood design water surface elevation. The barb crest base (bank end) is set approximately 2 feet lower than the 50-year flood design water surface elevation. The barb tip (stream end) is 10 feet lower than the barb crest base. Crest slope is 9(h):1(v). The barb bottom is set 8 feet below the barb tip for mitigating expected scour. A minimum 8 feet embedment depth below thalweg elevation should be verified at time of construction. Crest slope may be adjusted for achieving minimum embedment depth. Each barb is keyed into a Class 5 riprap revetment key. The key is 4 feet thick with 1.5(h):1(v) slope. Each key is 90 feet long with crest set 4 feet above the barb crest base and the bottom set equal to the streambarb bottom.

The bank, riprap key, stream barbs, and channel area between the streambarbs is covered with streambed material conserved from the barb excavation (Sheet H.13). The conserved stream bed material is placed to cover up approximately one-half the exposed barb height. Willow pole, cedar, and alder plantings are installed in the riprap key and bank areas above the ordinary-high-water limits. Four mitigation logs with root wads are placed at the barb bottom, approximately 20 feet from the barb tip. Each mitigation log is 24 to 36 inches in diameter and at least 20 feet long.

Wood buffer with dolosse ballast (ELJ)

The approach involves placing a wood buffer in a series of engineered-log-jams (ELJ's) along the unstable, eroding banks. The ELJ's deflect river flow away from the bank area, reducing the risk of scour and channel incision undermining the bank. Flow velocities and shear stress along the bank area upstream and between each ELJ is reduced, promoting sediment deposition and retention along the bank toe. This encourages riparian vegetation establishment. The large woody debris, deposition between the ELJ's, and scour along the ELJ streamside face creates channel complexity.

The ELJ's are spaced approximately 30 feet. Each is 75 feet long, 20 feet wide, and aligned along the bank toe. Site MP 4.0 has 25 proposed ELJ's and Site MP 7.8 has four (Sheets R.6 to R.9 and S.3 and S.4). To accommodate different channel conditions than currently mapped and future channel migration, ELJ elevations are not set relative to actual streambed elevations at time of construction. ELJ elevations are set relative to the modeled 50-year flood design water surface elevation. Scour will induce some settlement of the ELJ. The ELJ top is set approximately 3 feet above the 50-year flood design water surface elevation for accommodating expected settlement. To provide adequate mass for bank erosion control, the ELJ bottom is set 18 to 22 feet lower than the top (Sheet H.14).

Each ELJ must be anchored for resisting floating away and being pushed down the river by flood flow. The anchor system must consider additional forces imposed by woody debris carried by the river entangling on the ELJ. The ELJ must be flexible enough to allow settlement when undermined by scour. A typical anchor system can utilize deep piles. Deep piles anchors would need to penetrate the river bottom at least 20 to 30 feet for providing adequate resistance to buoyancy and sliding. The river bed contains cobbles and small boulders. Tree trunk piles would likely splinter before reaching the desired design depth. As wood decays, it losses strength and cannot resist the shear stresses created by a sliding ELJ mass. Driving steel piles for pinning the ELJ structure to the river bottom would be expensive and leave a tangle of steel piles protruding from the river bottom. Deep piles would restrict settlement when undermined with scour. Deep piles are not proposed for anchoring the ELJ's.

To be easy to construct and be successful in controlling bank erosion, each ELJ is constructed of a repeatable sequence of log bundles and logs with root wads (Sheet H.14). Anchoring is provided by chaining the log bundles to precast concrete dolose ballast. Based on expected scour and flood flow velocities and depths, chaining is considered necessary for achieving long-term ELJ stability. Assuming an 8 ton dolose, the log bundle volume cannot exceed 140 ft3. To be cost effective, each log bundle volume must be at least 105 ft3. Each log in the bundle should be 18 to 36 inches in diameter. Each log bundle should be at least 20 feet long. To increase log bundle stability, the dolose should be located towards the middle of the bundle length. Each log with root wad should be 18 to 36 inches in diameter and at least 20 feet long.

Initial placement of the log bundles and logs with root wads should be as shown on Sheet H.14. Orientation is critical for deflecting flow away from bank toe and achieving log jam stability. The log bundles and logs with root wads should be placed in a random manner above the bottom layer. Care must be taken to pack bundles as densely as possible and to place key members along the bank line for effectively controlling bank erosion. Construction with scaled models indicates adequate ELJ length, width, and height can be achieved with 25 log-dolose bundles and 14 logs with root wads. Six shallow log pins are proposed for adding additional slippage resistance and vertical member integration. The log pins are 12 to 18 inches in diameter and at least 30 feet long. They should be embedded into the river bed at least 6 feet with a track hoe-mounted vibratory hammer. Coarse woody debris, even mixture of branches, limbs, trunks, and vegetation, is to be placed between the logs and over the ELJ to a minimum depth of 1 foot.

<u>Private Property and Stream Processes Impacts</u>

HECRAS 5.0 modeling results for the 50-year flood flow velocity and water surface elevations are presented in Figure 6, 7, 8, 10, and 11. Differences between the existing condition and proposed bank stabilization models for the 100-year flood flow velocities and water surface elevations are presented in Figures 9 and 12. Bank erosion occurs when the active flow channel migrates to the valley sides and directs flow at sharp angles against erodible banks. Woody debris and gravel bars affect channel migration and flow impingement angles. Impacts to private property and stream processes for streambarbs with mitigation logs, wood buffer with dolosse ballast, and continued maintenance are discussed below.

Streambarbs with mitigation logs.

Based on the HECRAS 5.0 modeling, streambarbs break up the flow velocity line along the bank by increasing velocity at the barb tip and reducing velocity along the bank (Fig. 6). Flow velocities do not appear to increase above background level for bank areas downstream of the barbs. Refugia habitat is created at the mitigation logs. Channel complexity is created by the bed scour at the barb tips and sediment deposition between the barbs.

At the MP 4.0 site, streambarbs increase the 100-year flood water surface relative to existing modeled flow conditions 0.2 to 0.5 feet near the barbs to less than 0.1 feet across the floodplain (Fig. 9). A rise of 0.1 feet is modeled for the left (looking downstream) bank floodplain area along the base of the valley wall. The barbs increase the 100-year flood flow velocity 1.0 to 3.0 ft/sec near the barbs and less than 0.1 ft/sec across the floodplain (Fig. 9). An increase of 0.4 ft/sec is modeled for a large portion of the left bank floodplain area.

At the MP 7.8 site, streambarbs increase the 100-year flood water surface relative to existing modeled flow conditions less than 0.1 feet near the barbs and across the active channel and floodplain (Fig. 12). The barbs increase the 100-year flood flow velocity 0.1 to 1.0 ft/sec near the barbs and 0 ft/sec across the floodplain (Fig. 12).

Based on the HECRAS modeling, streambarbs are not expected to noticeably increase flooding or bank erosion on private property adjacent to the project sites above current levels. The streambarbs are not likely to restrict sediment and woody debris transport relative to existing conditions. A minor reduction in woody debris recruitment is expected as a result of stabilizing the eroding banks. Higher flow velocities along the barb tips will scour the bed materials. That material will be deposited as gravel bars. Mid-channel and floodplain sediment deposition is not expected to be noticeably different than current trends. Current natural active channel migration and bank erosion levels beyond the existing riprap revetments and proposed bank stabilization is expected to continue.

Installing the streambarbs and riprap keys requires excavating 8 to 15 feet into the channel bed. Work will be within the active river channel and requires temporarily diverting the river flow. Flow defection is assumed accomplished with gravel berms, large sandbags, or water-inflated bladders. Dewatering the work area would be extremely difficult and expensive. Excavation and placing logs, stone, and conserved stream bank fill material is assumed to take place in the water ponded behind the flow diversion structure. Turbidity release is expected to be limited in extent and duration. Access for construction is assumed down a ramp constructed over the existing riprap revetment. The ramp could provide permanent access for maintenance. Upper Hoh Road traffic impacts are expected to be limited to one-lane closures and short-term delays.

Wood buffer with dolosse ballast (ELJ).

Based on the HECRAS 5.0 modeling, the ELJ’s push the high flow velocity line away from the bank, maintaining low velocity along the bank and between the ELJ’s (Fig. 6). Flow velocity increases along the base of the ELJ’s. Flow velocities do not appear to increase above background level for bank areas downstream of the ELJ’s. Refugia habitat and channel complexity is created along the entire length of ELJ.

At the MP 4.0 site, ELJ’s increase the 100-year flood water surface relative to existing modeled flow conditions 0.2 to 0.5 feet near the ELJ’s to less than 0.1 feet across the floodplain (Fig. 9). A rise of 0.2 feet is modeled for the left (looking downstream) bank floodplain area along the base of the valley wall. The ELJ’s increase the 100-year flood flow velocity 1.0 to 3.0 ft/sec near the ELJ’s to less than 0.1 ft/sec across the floodplain (Fig. 9). An increase of 0.5 ft/sec is modeled for a large portion of the left bank floodplain area.

At the MP 7.8 site, ELJ’s increase the 100-year flood water surface relative to existing modeled flow conditions less than 0.1 feet near the ELJ’s and across the active channel and floodplain (Fig. 12). The ELJ’s increase the 100-year flood flow velocity 0.1 to 1.0 ft/sec near the ELJ’s to 0 ft/sec across the floodplain (Fig. 12).

Based on the HECRAS modeling, the ELJ’s are not expected to noticeably increase flooding or bank erosion on private property adjacent to the project sites above current levels. The ELJ’s are not expected to restrict sediment and woody debris transport relative to existing conditions. Woody debris recruitment is expected to increase as a result of logs being washed away during flood flows. Higher flow velocities along the ELJ’s sides will scour the bed materials. That material will be deposited as gravel bars. Mid-channel and floodplain sediment deposition is not expected to be noticeably different than current trends. Current natural active channel migration and bank erosion levels beyond the existing riprap revetments and proposed bank stabilization is expected to continue.

Installing the ELJ's requires excavating 4 to 10 feet into the channel bed in areas where the gravel bar surface needs to be lowered. Excavation work will be within the active river channel and requires temporarily diverting the river flow. Flow defection is assumed accomplished with gravel berms, large sandbags, or water-inflated bladders. Dewatering the work area would be extremely difficult and expensive. Excavation work is assumed to take place in the water ponded behind the flow diversion structure. Placing the wood and dolosse might be done in flowing water without flow diversion. Turbidity release is expected to be limited in extent and duration. Access for construction is assumed down a ramp constructed over the existing riprap revetment. The ramp could provide permanent access for maintenance. Upper Hoh Road traffic impacts are expected to be limited to one-lane closures and short-term delays.

Continued Maintenance.

Continued maintenance assumes that the current extent of riprap revetment is extended in response to emergency washout events. Based on the HECRAS 5.0 modeling, a high, continuous flow velocity line would be maintained near the bank (Fig. 6). Flow velocities appear to increase above background level for bank areas downstream of the placed riprap. Refugia habitat and channel complexity is not created along the revetment.

Based on the HECRAS modeling, a continuous, linear riprap revetment could increase bank erosion on private property immediately downstream. The revetment would not likely restrict sediment and woody debris transport relative to existing conditions. A minor reduction in woody debris recruitment is expected as a result of stabilizing the eroding banks. Higher flow velocities along the revetment will scour the bed materials. That material will be deposited as gravel bars. Mid-channel and floodplain sediment deposition is not expected to be noticeably different than current trends. Current levels of natural aggressive channel migration and bank erosion would be expected to continue.

Continued maintenance would require periodic replacement of material below the ordinary high water mark where there is currently riprap revetment. The Seattle District of the U.S. Army Corps of Engineers (Corps) has indicated that such work is exempt from Section 404 of the Clean Water Act provided that all work occurs within the existing road prism. Consequently, no state water quality permitting would be required.

In the event that one of the areas of concern should fail during a storm event, the roadway failure would release a large amount of sediment into the river. Assuming this sediment release occurs concurrently with the storm event it is unlikely that this would result in a considerable increase over the background condition.

Repair of the road after failure would likely cause considerable environmental impacts. The need to quickly reestablish access would permit no design time typically needed for more habitat-friendly solutions, thus relying on the use of conventional methods including riprap. Also, work would likely need to occur outside of the in-water work window. The need for rapid response to an emergency situation will result in environmental impacts to sensitive habitats that would likely warrant expensive mitigation.

Site Conditions

The river is braided with dramatically shifting active flow channels. Bank erosion is observed at all bank areas not protected by riprap revetments, heavy vegetation, or boulder lag deposits. The bank erosion is caused by mid-channel sediment deposits and woody debris shifting across the braid plain and redirecting flood flows at unstable bank areas. Erosion is severest where flow is directed at sharp angles against an erodible bank. Large woody debris appears to play a significant role in deflecting and redirecting flood flows. Cobbles and small boulders naturally armoring the toe and large trees growing in the stream bank inhibits the bank erosion.

MP 4.0 Site

The site parallels the outside bank of a river bend (Fig. 2). Approximately 3,900 lineal feet of riprap revetment along the apex of the river bend appears to be effectively controlling road embankment erosion. The 2 to 4 feet diameter riprap comprising the revetment is properly graded and placed. Revetments are in two segments. The upstream segment is approximately 1,350 feet long. The downstream segment is approximately 1,150 feet long. Both segments are densely planted with willow and alder and appear stable (Photos 1 and 2). Riprap revetment segments nearly devoid of alder and willows, with 1.5(h):1(v) or steeper finished surface slopes appear less stable. At these steeper sections, riprap has been dislodged from toe and mid slope areas. The damaged revetment segments generally appear at maximum point of stream bank curvature and likely experiences high shear stress when floods occur. No work is proposed for the existing riprap revetments.

Toe erosion and undermining of the stream bank is observed between the existing revetment segments (Photos 3 to 6) and immediately downstream of the downstream revetment segment (Photo 7, Fig. 2). The channel edge is approximately 10 to 20 feet away and 10 to 18 feet below the road pavement edge. Mid-channel sediment deposits and large woody debris jams entrapped next the banks, deflect stream flow towards the stream banks, exacerbating the erosion (Photos 8, 9, and 10). Continued stream bank erosion could undermine the road. Approximately 2,170 feet of bank stabilization is proposed for the location between the existing revetments (Fig. 2). Approximately 400 feet of bank stabilization is proposed for the location immediately downstream of the downstream revetment segment.

The Historic Channel Migration Zone (HCMZ, Geomorphic Assessment of the Hoh River in Washington State, Bureau of Reclamation, July 2004) narrows from 1,600 upstream and downstream to 500 feet at the site. An erosion resistant poorly consolidated alluvium terrace deposit has limited river bend migration to the north and south. The terrace deposit represents the HCMZ right and left (looking downstream) boundaries. The road embankment coincides with the HCMZ right boundary and valley wall.

Upstream the active channel width is 400 to 1,200 feet. Downstream width is 400 to 1,600 feet. At the site the width is 250 to 400 feet. Based on historical satellite imagery, the active channel has not changed significantly in width and location from 1994 to 2013 (Fig. 3). Sand, gravel, and small boulders comprise the stream bed material (Photos 11 and 12). Gradation analysis indicates the bed material ranges from sands to 10-inch cobbles with a D50 of 3 inches.

MP 7.8 Site

The site parallels the outside bank of a river bend (Fig. 4). Approximately 1,300 lineal feet of riprap revetment along the apex of the river bend appears to be effectively controlling road embankment erosion. The 2 to 4 feet diameter riprap comprising the revetment is properly graded and placed. The upstream 800 feet long segment, installed in 2007, has a 1.75(h):1(v) finished surface slope and appears stable (Photo 1). The downstream 500 feet long segment, installed in 2004, has a 1.5(h):1(v) steeper finished surface slope and appears less stable. Some riprap has been dislodged from toe and mid slope areas. The segment is at the maximum point of stream bank curvature and likely experiences high shear stress when floods occur. No work is proposed for the existing riprap revetments.

Toe erosion and undermining of the stream bank is observed immediately upstream and downstream of the existing riprap revetment. At the upstream location, the stream bank toe is approximately 50 feet away and 20 feet below the road surface (Photos 2 and 3). Cobbles and small boulders naturally armoring the toe and large trees growing in the stream bank have inhibited the bank erosion. A mid-channel gravel bar approximately 50 feet away from and paralleling the stream bank deflects stream flow towards the bank, aggravating the bank erosion (Photo 4). Continued stream bank erosion could undermine the road. Approximately 100 feet of bank stabilization is proposed for the upstream location.

At the downstream location, the stream bank toe is approximately 50 feet away and 20 feet below the road surface (Photos 5, 6, and 7). Cobbles and small boulders naturally armoring the toe and large trees growing in the stream bank have inhibited the bank erosion. Currently, the downstream stream bank toe is separated from the active river channel by a gravel bar (Photo 6). The gravel bar is expected to be completely exposed at typically normal annual low flow conditions. Woody debris will likely continue to accumulate on the existing small woody debris jam at the head of the small mid-channel gravel bar. A woody debris jam not completely plugging the 150 feet wide side channel between the small mid-channel gravel bar and stream bank could deflect river flow directly at the stream bank, accelerating the bank erosion and undermining the road. Based on the amount and size of wood available in the river for transport and the width of the side channel, the risk of a woody debris jam building that only partially blocks the side channel is high. With a partial blocking of the side channel, the risk of a catastrophic road embankment failure is high. Approximately 400 feet of bank stabilization is proposed for the downstream location.

An erosion resistant poorly consolidated alluvium terrace deposit has limited river bend migration to the north. The terrace deposit represents the HCMZ right boundary. Width of the HCMZ is approximately 2,500 feet. The road embankment coincides with the HCMZ right boundary. Wetlands between the terrace toe and existing road have been established due to drainage off the hillside. Terrace deposits have also limited active channel migration to the south. Terrace deposits and Tower Creek debris flow and alluvial lag deposits have restricted down-valley migration of the meander bend (Photos 8, 9, and 10).

Upstream the active channel width is 380 to 900 feet. Downstream width is 300 to 700 feet. At the site the width is 300 to 500 feet. Based on historical satellite imagery, the active channel upstream and at the site has not changed significantly in width and location from 1994 to 2013 (Fig. 5). Between 1994 and 2009 the active river channels for the next downstream meander bend flowed along the north bank. Down valley meander bend translation combined with sediment deposition, woody debris accumulation in the active channel, and large flooding in 2004 and 2007 forced a complete avulsion to the south bank. Sand, gravel, and small boulders comprise the stream bed material (Photos 11 and 12). Gradation analysis indicates the bed material ranges from sands to 12 inches with a D50 of 7 inches.

<u>Analysis</u>

Analysis completed by WFLHD includes streambed gradation, hydrologic, two-dimensional hydraulic modeling, scour, stream barb design, and ELJ design.

Streambed Gradation

Gradations were estimated for two gravel-bar sites and one bank site at the MP 4.0 site (Fig. 2, Photo 11). At the MP 7.8 site gradations were estimated for two gravel-bar sites (Fig. 4, Photo 11). The gradations were determined by photographing the bed or bank material with two markers spaced 3 feet apart for scale. The scaled-photographs were then processed with the Hydraulic Toolbox, version 4.2, sediment gradation analysis tool. Resulting gradations are plotted in Figure 13.

Hydrology

The Hoh River drains the western slope of the Olympic Mountains. The river originates on the slopes surrounding Mount Olympus and adjacent mountain peaks at an elevation of 7,800 feet (NAVD88) and flows approximately 41 miles through relatively-wide, moderately high-relief, glacial valleys before discharging to the Pacific Ocean. Elevations at the MP 4.0 and MP 7.8 project sites are 245 and 300 feet, respectively. MP 4.0 site is at river mile post 20 to 20.4. MP 7.8 site is at river mile post 24.6 to 24.9.

MP 4.0 site drainage area, including Willoughby Creek, was determined using USGS StreamStats, version 3.0 to be approximately 223.0. MP 7.8 site drainage area, including Tower Creek, was determined using USGS StreamStats to be approximately 210.0 mi^2. Approximately 70 percent of the watershed is heavily timbered and 20 percent is exposed bedrock. Four small glaciers, White, Blue, Hoh, and Hubert, are found in the higher elevations and occupy approximately 7 mi^2 (3 percent) of the drainage area. Only small lakes are present. Mean annual precipitation reported by USGS StreamStats is 168 inches. The watershed lies mostly within the Olympic National Park and Olympic National Forest. Development is sparse, primarily light rural residential. No diversions for irrigation occur upstream.

The USGS maintains a stream gage station (12041200) on Hoh River, near the State Highway 101 Bridge, river mile 15.4. The gage has 54 years of record, beginning in 1961. Hydrology for the gage station is presented in Magnitude and Frequency of Floods in Washington: U.S. Geological Survey Water-Resources Investigations Report 97-4277 (Sumioka, S.S., Kresch, D.L., and Kasnick, K.D., 1998). Annual peak stream flow for the gage station is presented in Figure 14. The gage station has not experienced floods greater than the 50-year event. Largest floods of record occurred in 2004 (62,100 cfs) and 2007 (60,700 cfs). Both were approximately equal to the 25-year flood event.

Peak flood discharges were estimated with the weighting equation in USGS WRIR 97-4277 for ungagged sites on gaged streams. Peak discharges for the ungaged sites were estimated using USGS StreamStats regression equations. The regression equation estimates were then improved by weighting with the weighted estimates for the USGS 12041200 gage station (Table 2, USGS WRIR 97-4277). Peak discharge estimates are presented in Table 1.

Maritime weather dominates. Storms and moderate to heavy precipitation occurs year round. Storms are more frequent and precipitation is heavier September through January. September through November have the heaviest recorded rainfall. Snow occurs frequently during winter months, but melts after a few days. Lowest flows occur in February, March, April, July, and August. Winter season snowfall ranges from 10 to 30 inches in the lower elevations and between 250 to 500 inches in the higher mountains. In the lower elevations, snow melts rather quickly and depths seldom exceed 6 to 15 inches. In midwinter, the snowline is between 1,500 and 3,000 feet above sea level. The higher ridges are covered with snow from November until June.

Hydraulic Modeling

Water surface elevations and flow velocities were estimated using the Hydrologic Engineering Center River Analysis System HEC-RAS 5.0 (beta Aug. 2015), a computer program that performs two-dimensional unsteady steady flow calculations. Two–dimensional flow models provide a more thorough understanding of how the design options effect water surface elevations and flow velocities.

WFLHD developed HEC-RAS 5.0 flow models for the existing conditions and proposed design options. LIDAR terrain data was obtained from Puget Sound LIDAR Consortium. The LIDAR mapping was surveyed April 14 and 21, 2012. The LIDAR data does not have topography of the channel bed beneath the water surface and cannot be used directly to accurately model flow conditions. WFLHD surveyed topography and cross sections of the river channel at both bank stabilization sites. Terrain data was developed for the existing condition models by merging the LIDAR terrain data with the surveyed river cross sections and ground topography data. To represent worst case flow conditions, the active flow channel was aligned along the revetment toe. Stream barbs were added to the existing conditions terrain data for the stream barb hydraulic models. Each streambarb was placed dimensionally correct in the models at design location and elevation. Each wood buffer was placed in the models at design location and elevation. To represent the wood buffers, each unit was defined as three abutting cubes 25 feet long, 20 feet wide, and 20 feet high. Each cube side was vertical with 2 feet by 2 feet crenulations.

Meshes with 5 feet by 5 feet grid spacing encompassing the flow areas were generated for each model. Floodplains and areas with higher flow roughness were delineated on the meshes from aerial imagery. Floods occurring 2004 and 2006 approximately equaled the 25-year event. Existing condition models for both sites were calibrated by adjusting the Manning's Roughness Coefficients until the 25-year flood flow water surfaces approximately equaled observed high water marks and debris limits. Manning's Roughness Coefficient of 0.045 was selected for the main channel 2D flow areas. Manning's Roughness Coefficient of 0.09 was selected for the floodplain areas. Normal flow depth with 0.01 feet/feet friction slope was set for the downstream boundary condition. A 3-hour duration, 1-minute interval hydrograph was used for the upstream boundary condition. The calibrated models were run for the 50 and 100-year and flood flows. 2D break lines were added along the center of each stream barb. The break lines use 1-foot minimum grid spacing. Each model uses a 4 second computation interval.

Predicted 50-year flood flow velocities are presented in Figures 7 and 10. Predicted 50-year flood water surface elevations are presented in Figures 8 and 11. The 50-year flood flow velocities and water surface elevations were used for designing the bank stabilization features and evaluating potential effect on stream processes. Differences between the existing condition and proposed bank stabilization models for the 100-year flood flow velocities and water surface elevations are presented in Figures 9 and 12. The 100-year flood flow velocity and water surface elevation differences help identify potential private property flooding, private property bank erosion, and natural stream processes impacts.

Scour

Total scour for the stream barbs design option is a combination of contraction scour and barb scour. Total scour for wood buffer design option is a combination of contraction scour and bend scour. Long term degradation is not expected to occur. Contraction scour was estimated using Hydraulic Engineering Circular, Evaluating Scour at Bridges (HEC 18), 5th Edition, April 2012. Scour near the stream barbs was estimated using WA-RD 581.1 (WADOT, Papanicolaou, Feb. 2004). Bend scour was estimated using the National Engineering Handbook, Technical Supplement 14B, August 2007. Water depths and flow velocities for the scour analysis were obtained from the two-dimensional modeling. Bed grain sizes were obtained from the grain-size analysis of the channel bed materials. Table 2 summarizes the scour analysis. Scour analysis is attached.

Stream Barb Design

The stream barbs were designed using the sliding and overturning analysis from NRCS, Engineering Technical Note 23, Design of Stream barbs, version 2.0 (OR210-2005-2, May 3, 2005). Water depths and flow velocities for the design were obtained from the two-dimensional modeling. An active channel width of 330 feet and radius of 400 feet were estimated from satellite imagery. A vertical velocity correction factor of 1.3 was selected assuming a high impingement angle and flow contracted or deflected around debris and mid-channel sediment deposits. A stability factor of 1.3 was used for angular rock. Unit weight of stone was assumed to be 165 pounds per cubic foot (lbs/ft3). Fluid drag coefficient was assumed to be 0.5. Friction factor was assumed to be 0.8. Average 50-year flood flow velocity over the stream barb of 12 ft/sec was obtained the HECRAS 5.0 models. Class 8 riprap was found to have adequate sliding and moment factor of safeties. The barb bottom was set to approximately the total scour depth. To minimize excavation depth, some undermining from scour and displacement of barb stone is expected. Riprap for the stream barb key was sized using the approach from USACE EM 1110-2-1601, June, 1994. Average flow velocity along the stream barb key was assumed to be 10 ft/sec. A factor of safety of 1.3 was used for the riprap key resulting in Class 5 riprap. Sizing analysis is attached.

Wood Buffer Design (ELJ)

A wood buoyancy and sliding analysis (Design Guidelines for Reintroducing Wood in Australian Streams, Abbe/Brooks, 2006) was completed for the ELJ's. The analysis assumes single log-dolose bundles. Water depths and flow velocities for the design were obtained from the two-dimensional modeling. The analysis uses an average 50-year flood flow velocity along the ELJ sides of 12 ft/sec. Active channel width of 330 feet and radius of 400 feet were estimated from satellite imagery. A vertical velocity correction factor of 1.3 was selected for representing high flow impingement angles and flow contracted or deflected around debris and mid-channel sediment deposits. Analysis was completed for 18, 24, and 36-inch average log diameters. Unit weight of concrete was assumed to be 150 lbs/ft3. Each dolose weighs 8 tons. Fluid drag coefficient was assumed to be 1.2. Friction angle was assumed to be 70 degrees. The design assumes the log mass will settle into scour holes as scour occurs. ELJ heights were set to accommodate the design water depth plus displacement from scour.

Floodplain and Flood-rise Limitations

Executive Order 11988, Floodplain Management, established federal policies for protecting floodplains and floodways. The intention of the associated regulations is to avoid, to the extent practical, adverse impacts to floodplains; minimize the impact of floods to human safety, health, and welfare; and avoid supporting land use development that is incompatible with the natural and beneficial floodplain values. When avoidance is not possible, the policies require appropriate consideration of methods to minimize adverse impacts.

The sites are located within Zone A identified on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) 5300690600B and 5300690625B. Zone A is an area of 100-year flood not determined. Jefferson County is the local floodplain administrator. Both federal and local regulations require increases in the 100-year water surface elevation for Zone A to be less than one foot. Based on the HECRAS 5.0 modeling, the 100-year flood-rise is predicted to be less than 0.1 feet across the floodplain for both sites and both bank stabilization design approaches.

Cost Estimates

Construction cost estimates were completed for the two alternatives (Table 3). Assumed stabilization length is 2,570 feet for Site MP 4.0 and 500 feet for Site MP 7.8. Material excavated from the channel is assumed placed as road fill over the regraded bank area. The estimates assume logs with root wads cost $1,100 and logs without root wads cost $600 each. The estimates assume riprap will be obtained from a commercial pit near Port Angelis, WA. Estimated riprap cost is $110 per cubic yard placed. The larger stone needed for the streambarbs is estimated to cost $170 per cubic yard placed. Flow diversion is assumed accomplished using channel bed material berms. The berm material would then be pulled back over the placed riprap. The costs presented include 7 percent mobilization and 15 percent contingency.

attachments: Tables 1, 2, 3, and 4
Figures 1 to 14
MP 4.0 Site Photographs 1 to 12
MP 7.8 Site Photographs 1 to 12
Sheets H.12 to H.14
Sheets R.2 to R. 9
Sheets S.1 to S.4
Calculations

Table 1. Peak Discharges (ft3/sec)

Estimate Method	Drainage Area (mi2)	Annual Precip	Recurrence Intervals (years) 2	10	25	50	100
MP 4.0 - Streamstats	223	168	29,600	46,500	54,700	61,700	69,400
MP 7.8 - Streamstats	210	170	28,400	44,700	52,500	59,300	66,700
USGS 12041200	PEAKFQ		32,660	52,390	61,460	67,890	74,060
USGS 12041200	Tab. 2		32,200	51,100	59,700	65,700	71,400
weighted Tab.2			32,000	51,000	59,600	65,700	71,200
MP 4.0 - Design	223		**28,492**	**45,409**	**53,066**	**58,497**	**63,394**
MP 7.8 - Design	210		**26,960**	**42,968**	**50,213**	**55,352**	**59,986**

Notes:

1. USGS - USGS Regression Equations, “Magnitude and Frequency of Floods in Washington”, WRIR 97-4277, 1998.

Table 2. Scour

Scour Type		Location / Stabilization Type: MP 4.0 - 50-year - Stream Barbs	MP 4.0 - 50-year - Wood Buffer	MP 7.8 - 50-year - Stream Barbs	MP 7.8 - 50-year - Wood Buffer
Clear Water Contraction	Feet	0.0	0.0	0.0	0.0
Bend	Feet		8.6		11.1
Barb	Feet	11.2		15.0	
Bend + Contraction	Feet		8.6		11.1
Barb + Contraction	Feet	11.2		15.0	

Notes:

1. Contraction scour - HEC 18, 5th ED. 4/2012.
2. Barb Scour - Papanicolaou (2004) - WSDOT WA-RD 581.1
3. Bend Scour - Maynord (1996) - 210-VI-NEH, Aug. 2007.

Table 3. Cost Estimates

Site: **C1 - CMP 3.8 to 4.2 - Bank Stabilization**

Wood Buffer with Dolose

Stabilization Length **2570** feet

Item			Unit	Quantity	Unit Cost	Total Cost
Mobilization	7%	of construction cost	LS	1	$ 238,700	**$ 238,700**
Remove Existing Revetment			LF	-	$ 200	**$ -**
Flow Diversion			LS	1	$ 40,000	**$ 40,000**
Wood Buffer						
Exc./Place Conserved SBM			CY	5,000	$ 20	**$ 100,000**
18" dia. X 20' Logs w/out rootwads			EA	1,875	$ 600	**$ 1,125,000**
18" dia. X 20' Logs w/ rootwads			EA	350	$ 1,100	**$ 385,000**
Log piles 18" dia. X 30' Logs			EA	150	$ 1,100	**$ 165,000**
Chain, 1/2" HDG Grade 30			FT	20,000	$ 15	**$ 300,000**
Dolos			EA	625	$ 2,000	**$ 1,250,000**
Coarse Woody Debris			CY	2,250	$ 20	**$ 45,000**
Per ELJ Unit						
ELJ Width	75	feet				
ELJ Unit No.	25					
Exc./Place Conserved SBM	200	CY				
18" dia. X 20' Logs w/out rootwads	75	No.				
18" dia. X 20' Logs w/ rootwads	14	No.				
Log piles 18" dia. X 30' Logs w/out	6	No.				
Chain, 1/2" HDG Grade 30	800	feet				
Dolos	25	No.				
Coarse Woody Debris	90	CY				
Cost per ELJ Unit	**$ 134,800**					
Total Construction Cost without Contingencies						**$ 3,648,700**
Contingency	15%	of construction cost				**$ 547,305**
Total Construction Cost						**$ 4,196,005**
CE and PE	30%	of construction cost				**$ 1,258,802**
ROW						**$ -**
TOTAL Capital Cost		Cost/Foot	**$ 2,122**			**$ 5,454,807**
Annualized Capital Cost		Discount rate, i	0.07125			**$ 401,512**
		Service life, n	50	years		
		CFR	**0.0736071**			

Streambarbs with Mitigation Logs

Stabilization Length **2570** feet

Item			Unit	Quantity	Unit Cost	Total Cost
Mobilization	7%	of construction cost	LS	1	$ 248,623	**$ 248,623**
Remove Existing Revetment			LF	-	$ 200	**$ -**
Flow Diversion			LS	1	$ 100,000	**$ 100,000**
Streambarbs, Class 8			EA	18	$ 171,772	**$ 3,091,893**

	W ft	T ft	L ft	Vol cy	Unit Cost	Total Cost	
Key	74	4	39	428	110	$ 47,031	Class 5
Barb	24	10	70	622	170	$ 105,778	Class 8
Ex	40	8	80	948	20	$ 18,963	
						$ 171,772	

Item			Unit	Quantity	Unit Cost	Total Cost
Mitigation Logs, 18" dia., 20 ft long w/ rootwads			EA	72	$ 1,100	**$ 79,200**
Dolos			EA			**$ -**
Chain, 1/2" HDG Grade 30			LF			**$ -**
Pole Plantings/tree plantings			EA	3,000	$ 30	**$ 90,000**
Place Conserved SBM			CY	17,067	$ 10	**$ 170,667**
Final Grading			LS	1	$ 20,000	**$ 20,000**
Total Construction Cost without Contingencies						**$ 3,800,383**
Contingency	15%	of construction cost				**$ 570,057**
Total Construction Cost						**$ 4,370,441**
CE and PE	30%	of construction cost				**$ 1,311,132**
ROW						**$ -**
TOTAL Capital Cost		Cost/Foot	**$ 2,211**			**$ 5,681,573**
Annualized Capital Cost		Discount rate, i	0.07125			**$ 418,204**
		Service life, n	50	years		
		CFR	**0.0736071**			

Table 4. Cost Estimates

Site: **MP 7.8 - Bank Stabilization**

Wood Buffer with Dolose

Stabilization Length **500** feet

Item			Unit	Quantity	Unit Cost	Total Cost
Mobilization	7%	of construction cost	LS	1	$ 39,144	**$ 39,144**
Remove Existing Revetment			LF			**$ -**
Flow Diversion			LS	1	$ 20,000	**$ 20,000**
Wood Buffer						
Exc./Place Conserved SBM			CY	800	$ 20	**$ 16,000**
18" dia. X 20' Logs w/out rootwads			EA	300	$ 600	**$ 180,000**
18" dia. X 20' Logs w/ rootwads			EA	56	$ 1,100	**$ 61,600**
Log piles 18" dia. X 30' Logs			EA	24	$ 1,100	**$ 26,400**
Chain, 1/2" HDG Grade 30			FT	3,200	$ 15	**$ 48,000**
Dolos			EA	100	$ 2,000	**$ 200,000**
Coarse Woody Debris			CY	360	$ 20	**$ 7,200**
Per ELJ Unit						
ELJ Width		75	feet			
ELJ Unit No.		4				
Exc./Place Conserved SBM		200	CY			
18" dia. X 20' Logs w/out rootwads		75	No.			
18" dia. X 20' Logs w/ rootwads		14	No.			
Log piles 18" dia. X 30' Logs w/out		6	No.			
Chain, 1/2" HDG Grade 30		800	feet			
Dolos		25	No.			
Coarse Woody Debris		90	CY			
Cost per ELJ Unit		**$ 134,800**				
Total Construction Cost without Contingencies						**$ 598,344**
Contingency	15%	of construction cost				**$ 89,752**
Total Construction Cost						**$ 688,096**
CE and PE	30%	of construction cost				**$ 206,429**
ROW						**$ -**
TOTAL Capital Cost			Cost/Foot	**$ 1,789**		**$ 894,524**
Annualized Capital Cost		Discount rate, i		0.07125		**$ 65,843**
		Service life, n		50	years	
		CFR		**0.0736071**		

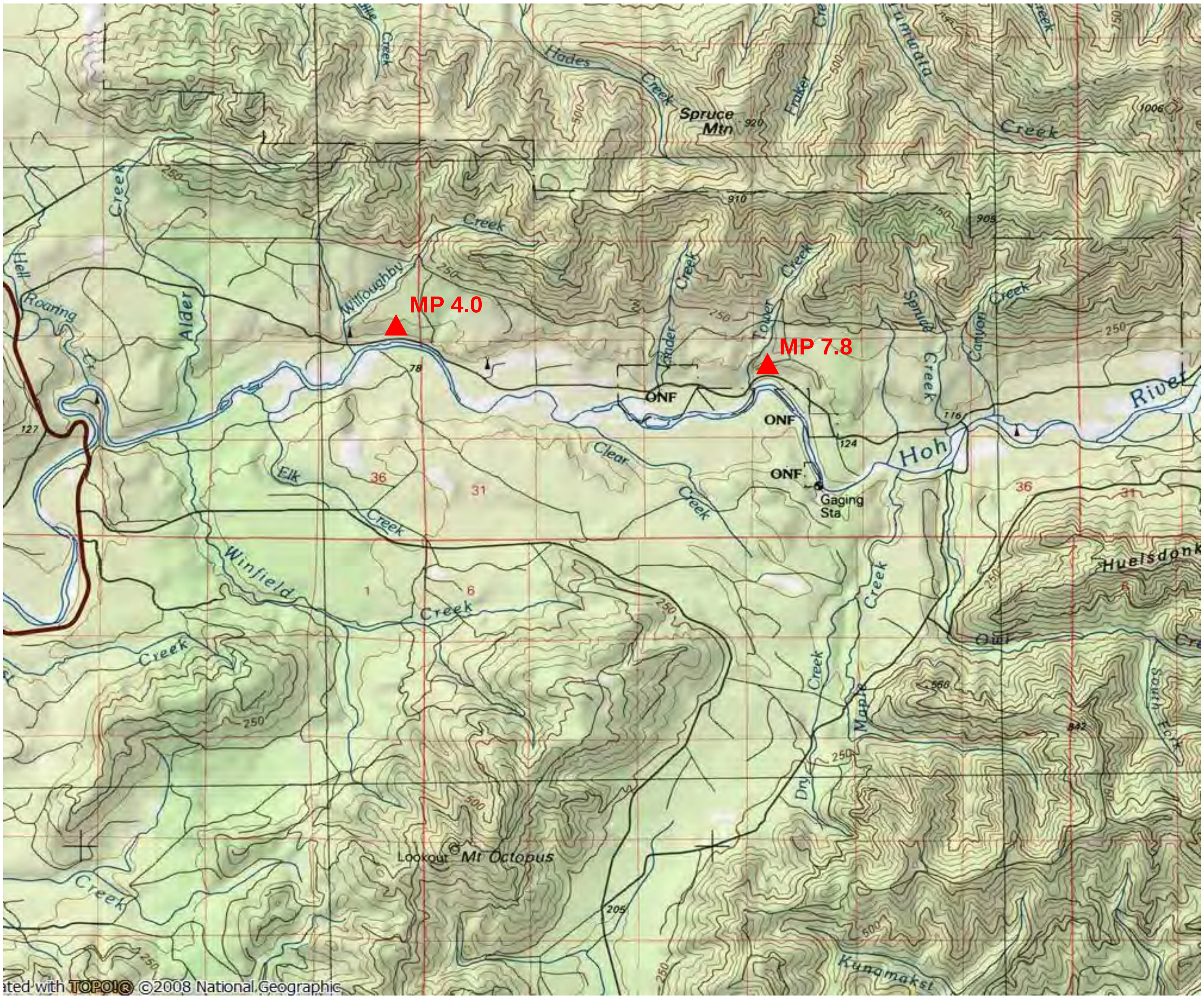
Streambarbs with Mitigation Logs

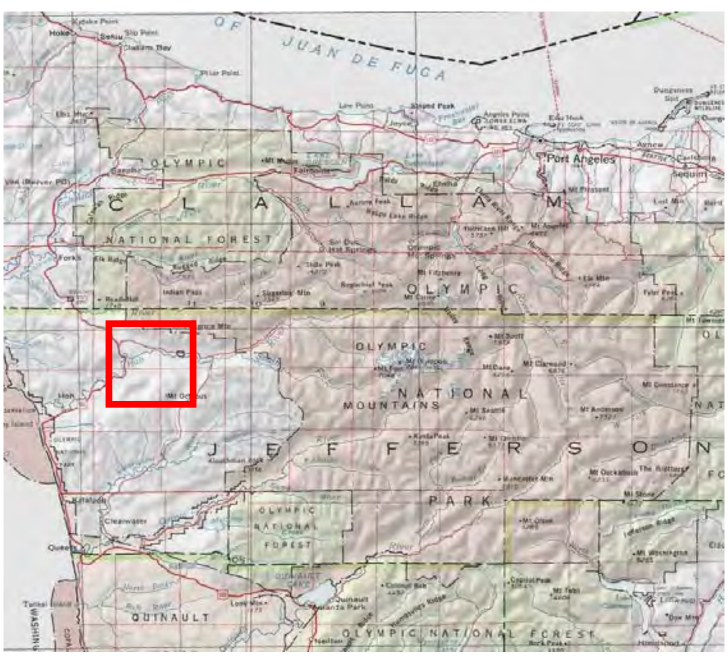
Stabilization Length **500** feet

Item			Unit	Quantity	Unit Cost	Total Cost
Mobilization	7%	of construction cost	LS	1	$ 57,443	**$ 57,443**
Remove Existing Revetment			LF			**$ -**
Flow Diversion			LS	1	$ 50,000	**$ 50,000**
Streambarbs, Class 8			EA	4	$ 171,772	**$ 687,087**

	W ft	T ft	L ft	Vol cy	Unit Cost	Total Cost	
Key	74	4	39	428	110	$ 47,031	Class 5
Barb	24	10	70	622	170	$ 105,778	Class 8
Ex	40	8	80	948	20	$ 18,963	
						$ 171,772	

Item			Unit	Quantity	Unit Cost	Total Cost
Mitigation Logs, 18" dia., 20 ft long w/ rootwads			EA	16	$ 1,100	**$ 17,600**
Dolos			EA			**$ -**
Chain, 1/2" HDG Grade 30			LF			**$ -**
Pole Plantings/tree plantings			EA	600	$ 30	**$ 18,000**
Place Conserved SBM			CY	3,793	$ 10	**$ 37,926**
Final Grading			LS	1	$ 10,000	**$ 10,000**
Total Construction Cost without Contingencies						**$ 878,056**
Contingency	15%	of construction cost				**$ 131,708**
Total Construction Cost						**$ 1,009,765**
CE and PE	30%	of construction cost				**$ 302,929**
ROW						**$ -**
TOTAL Capital Cost			Cost/Foot	**$ 2,625**		**$ 1,312,694**
Annualized Capital Cost		Discount rate, i		0.07125		**$ 96,624**
		Service life, n		50	years	
		CFR		**0.0736071**		





Map printed from National Geographic TOPO

▲ Project Site Location

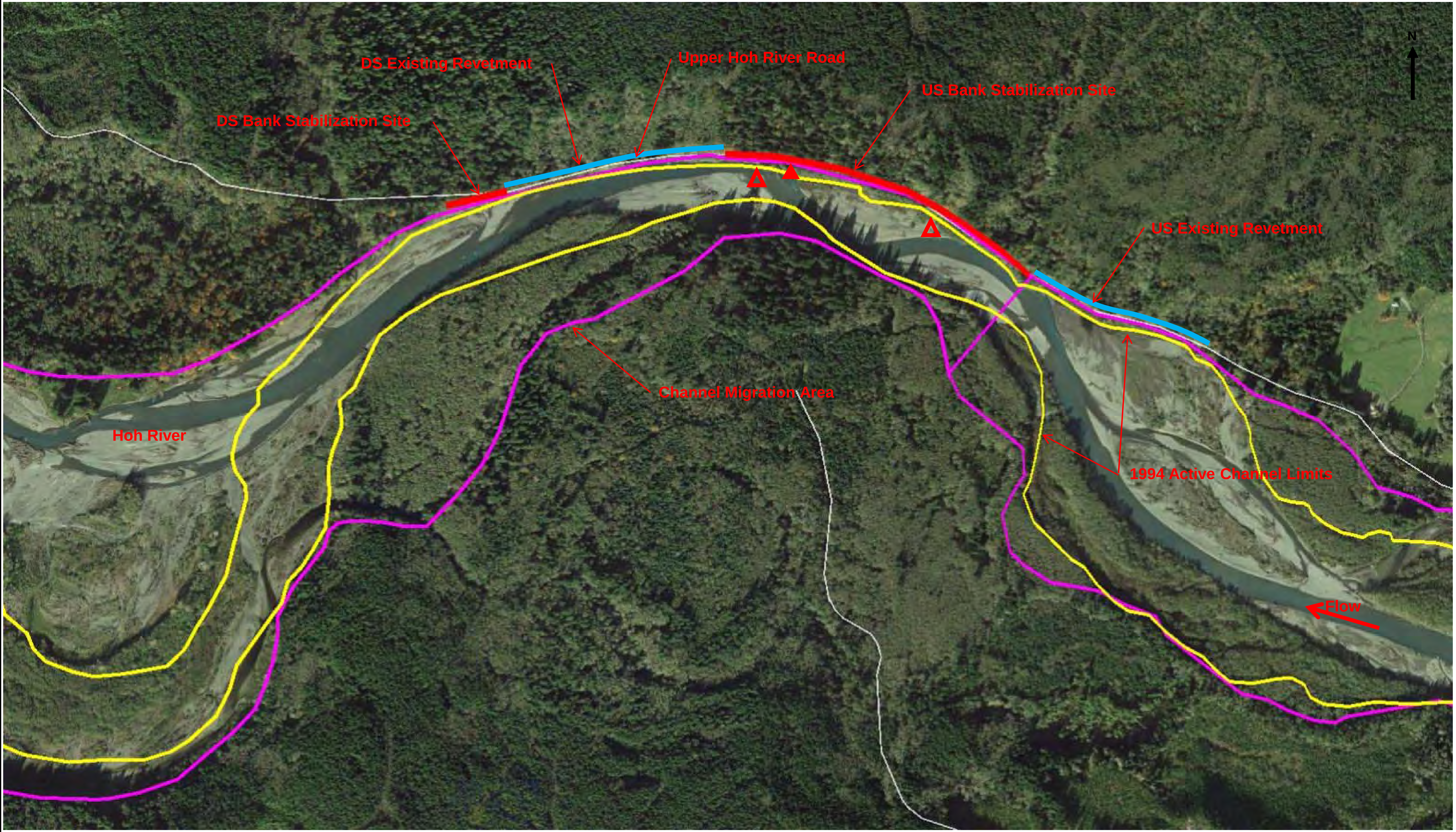
□ Project Area Location

0 1 mile

N

FIGURE 1

UPPER HOH RIVER BANK STABILIZATION



Bank material gradation location

Channel sediment gradation location

Image from Google Earth Pro, 2013.

0 600 Feet

FIGURE 2

MP 4.0 BANK STABILIZATION STUDY AREA

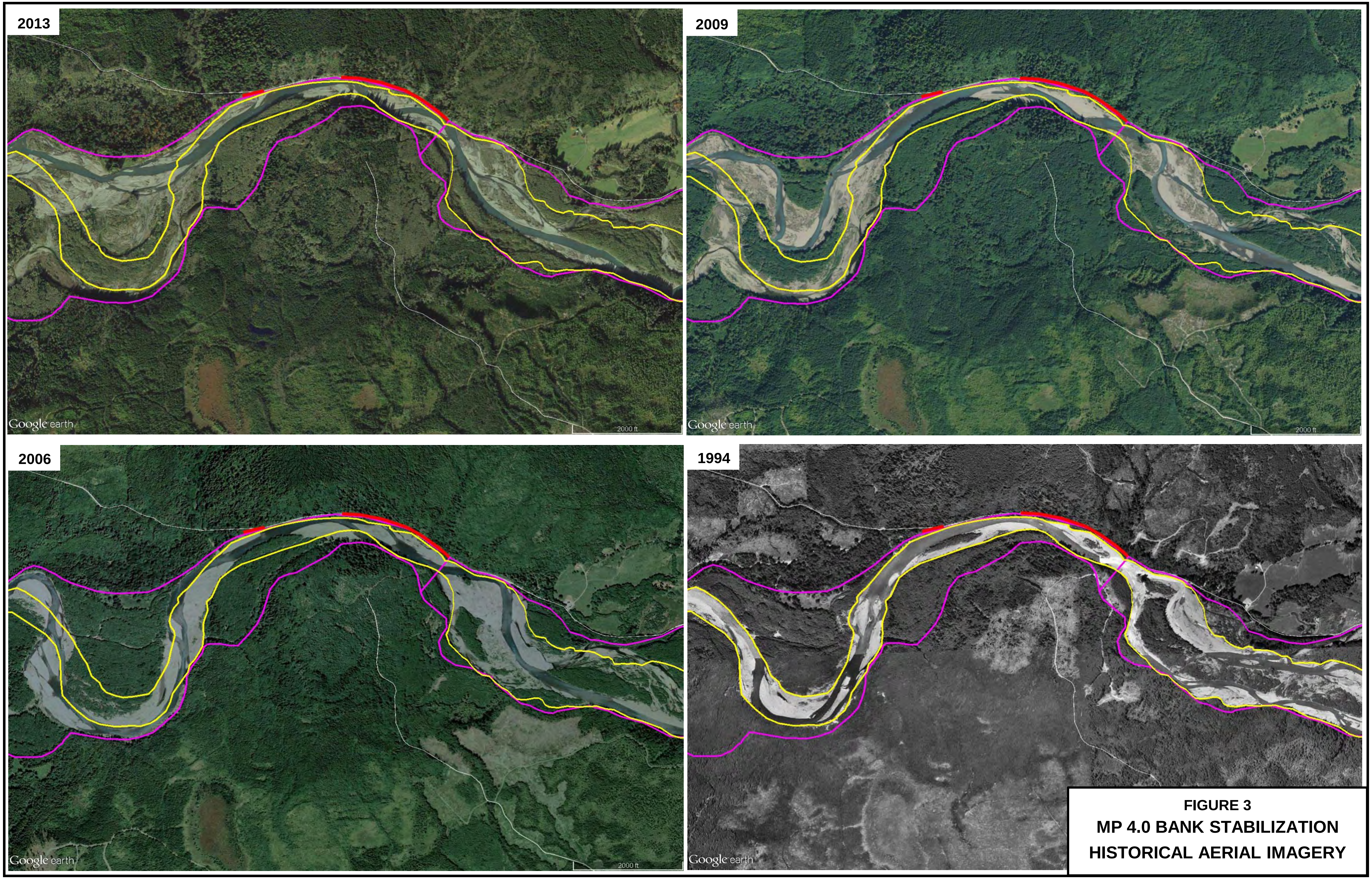
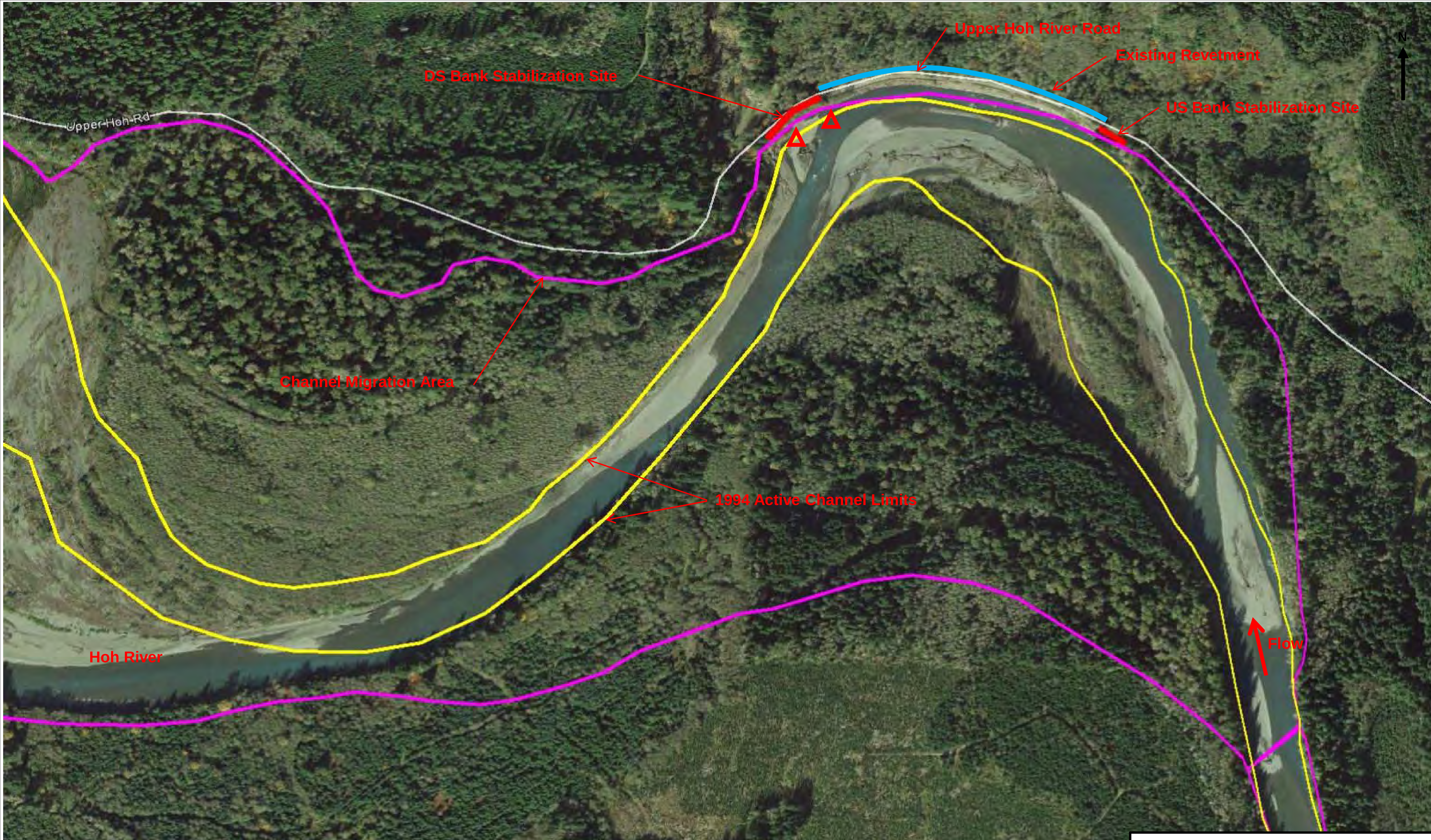


FIGURE 3
MP 4.0 BANK STABILIZATION
HISTORICAL AERIAL IMAGERY



Channel sediment gradation location

0 600 Feet

Image from Google Earth Pro, 2013.

FIGURE 4

MP 7.8 BANK STABILIZATION STUDY AREA

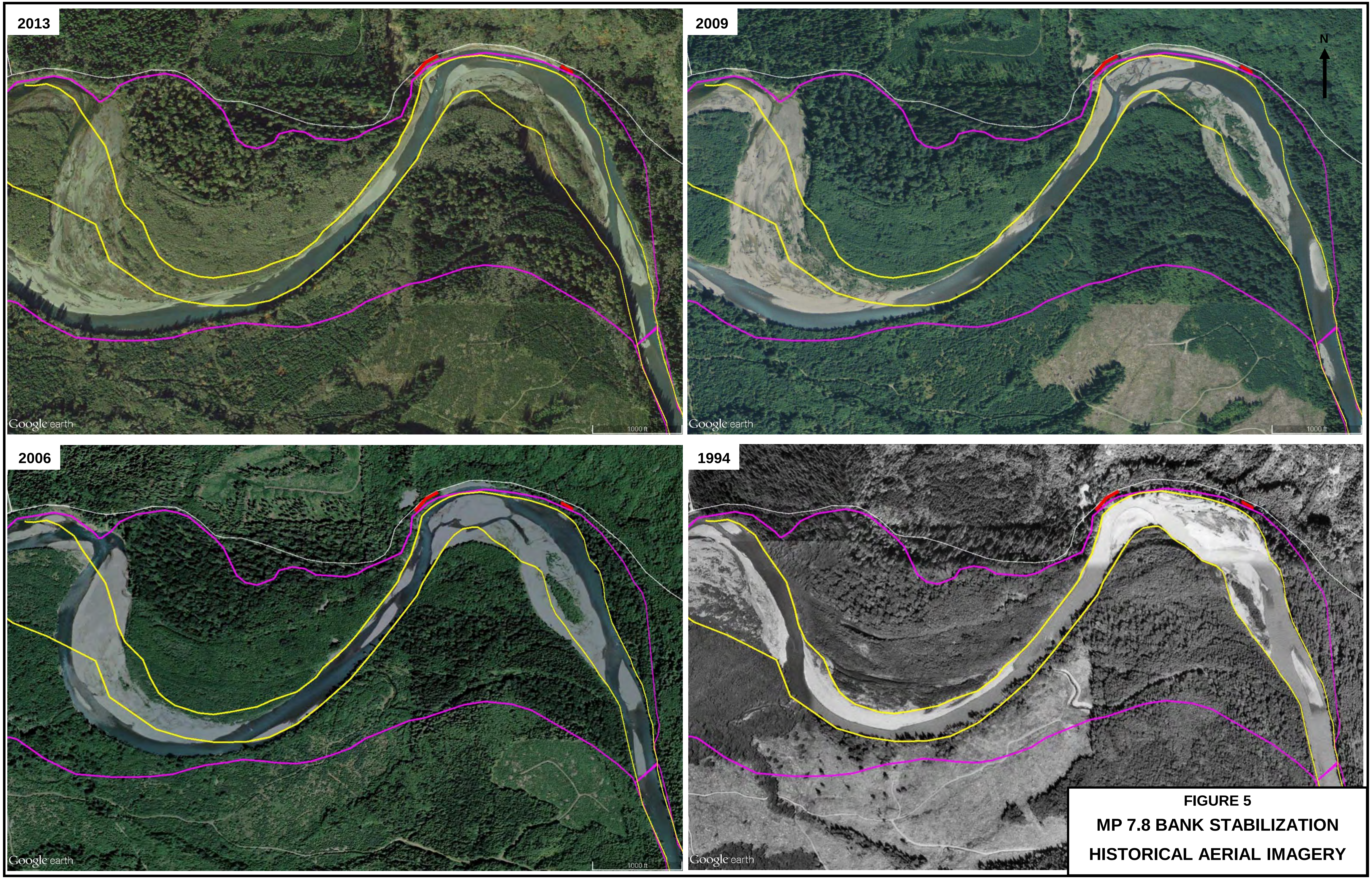


FIGURE 5

MP 7.8 BANK STABILIZATION

HISTORICAL AERIAL IMAGERY

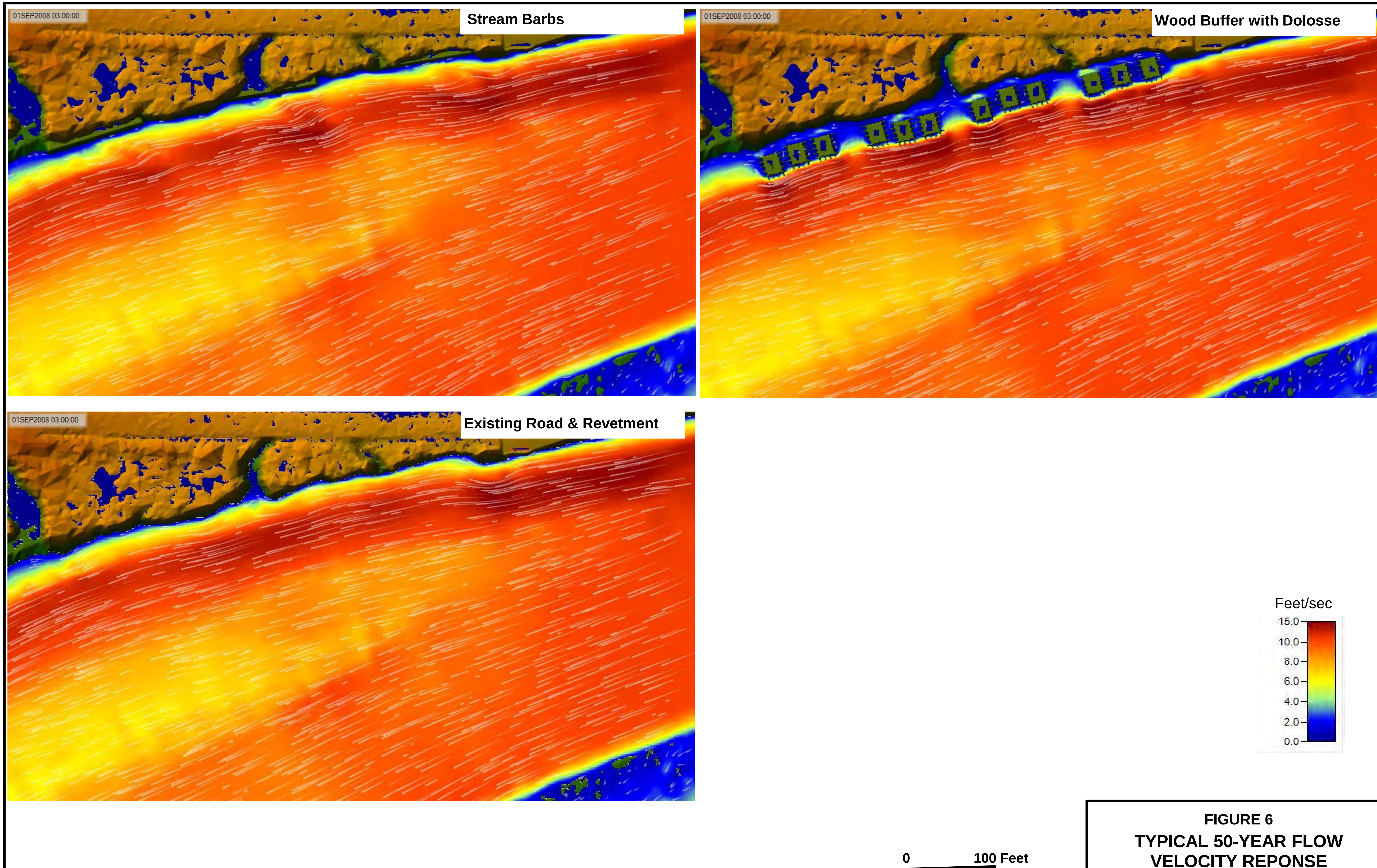
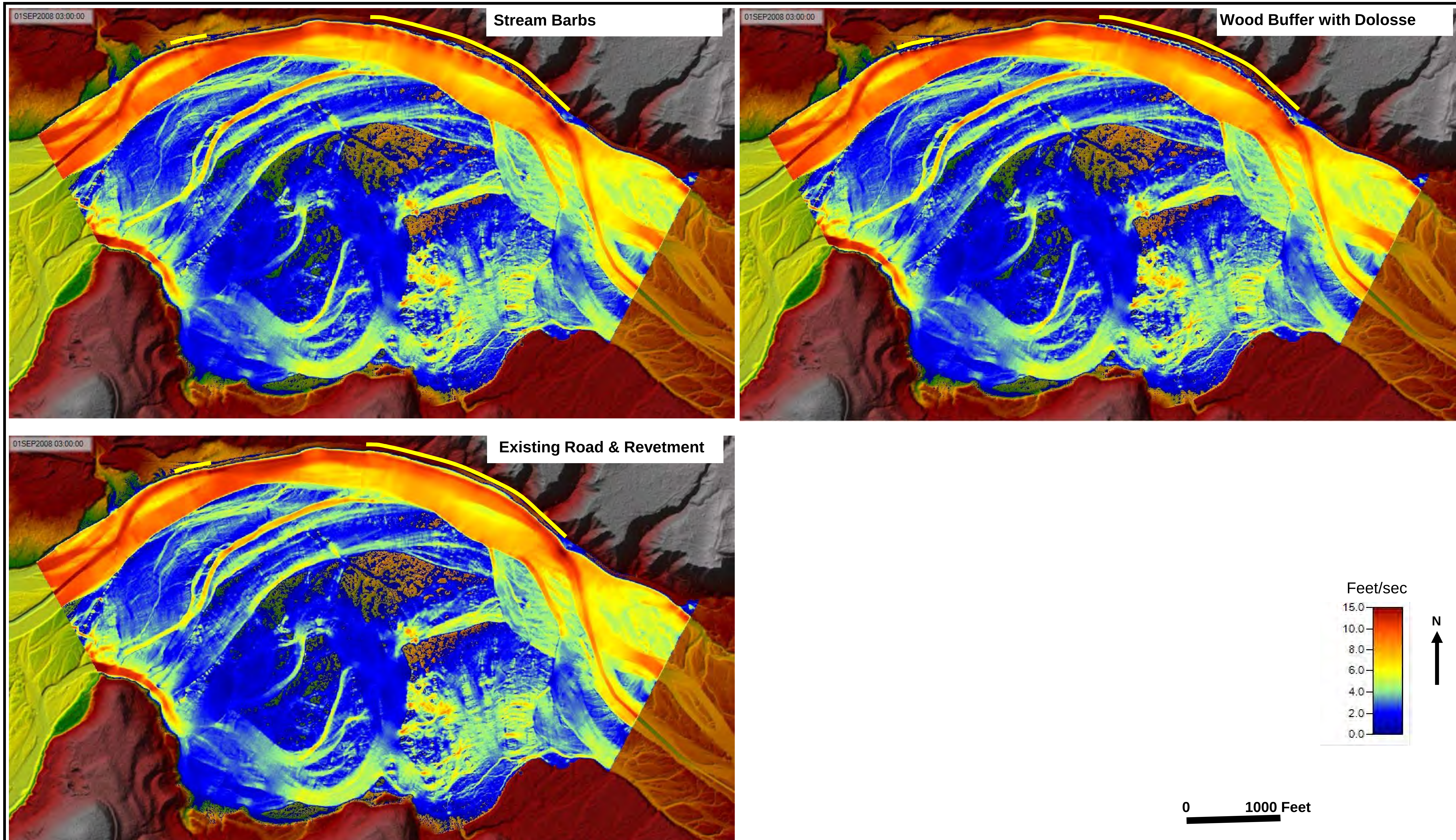


FIGURE 6

TYPICAL 50-YEAR FLOW VELOCITY REPONSE

Terrain from Puget Sound LIDAR Consortium, 2012.

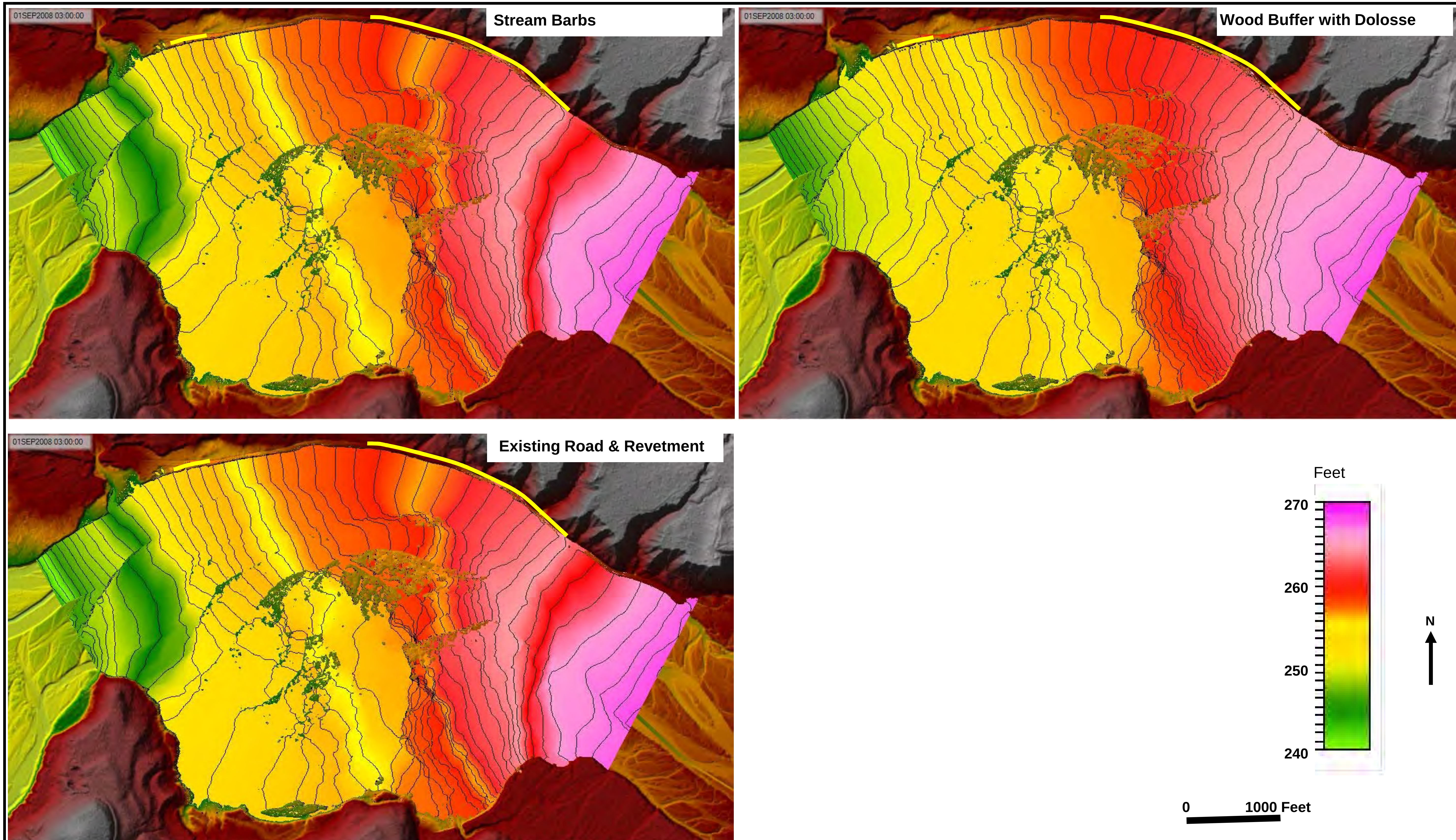


Proposed Bank Stabilization

Terrain from Puget Sound LIDAR Consortium, 2012.

FIGURE 7

MP 4.0 BANK STABILIZATION
2-D 50-YR FLOW VELOCITIES

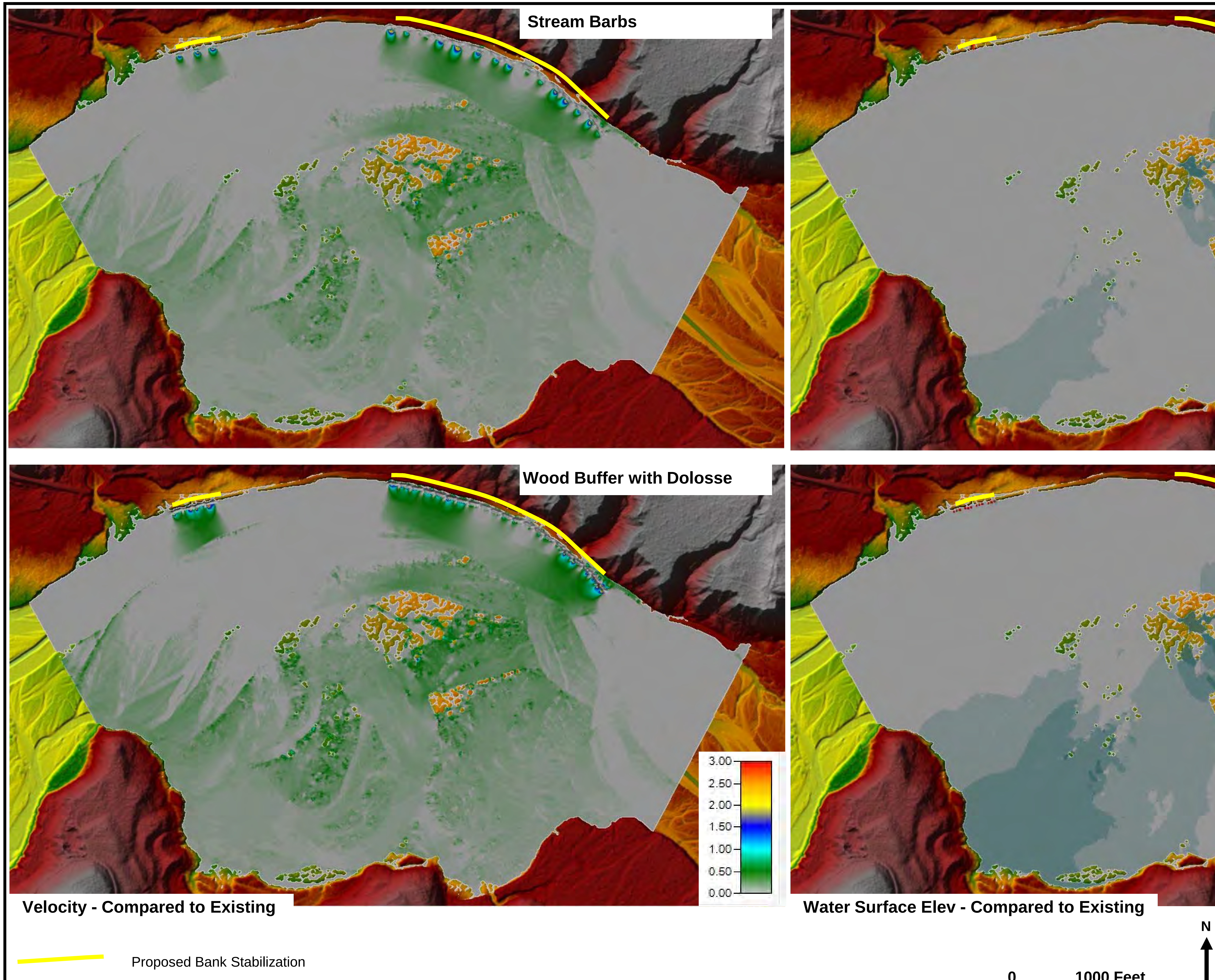


Proposed Bank Stabilization

Contour interval 0.5 feet.
Terrain from Puget Sound LIDAR Consortium, 2012.

FIGURE 8

MP 4.0 BANK STABILIZATION
50-YR WATER SURFACE ELEV.

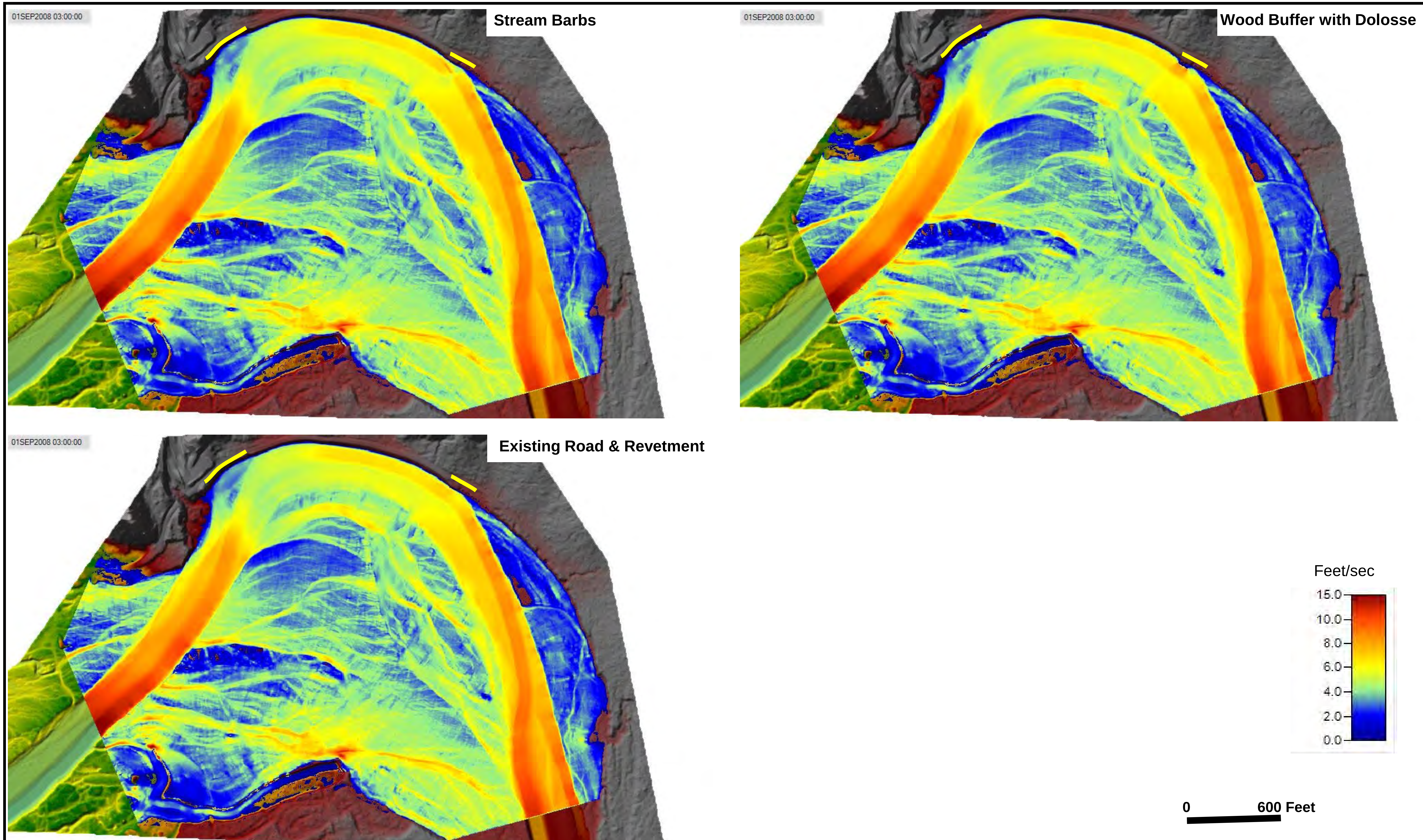


Terrain from Puget Sound LIDAR Consortium, 2012.

FIGURE 9

MP 4.0 BANK STABILIZATION

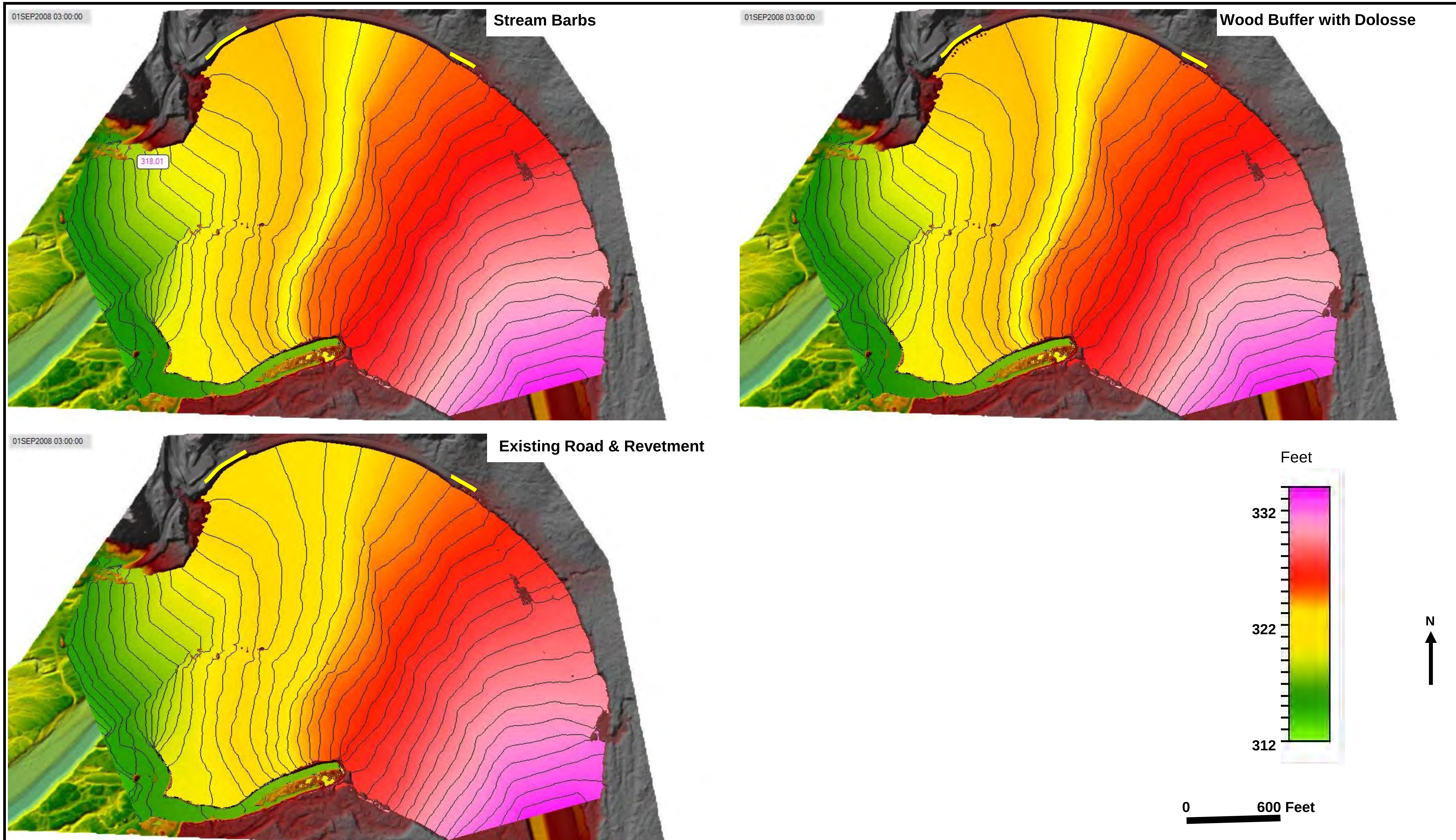
100-YR DIFFERENCE



Proposed Bank Stabilization

Terrain from Puget Sound LIDAR Consortium, 2012.

FIGURE 10
MP 7.8 BANK STABILIZATION
2-D 50-YR FLOW VELOCITIY



Proposed Bank Stabilization

Contour interval 0.5 feet.
Terrain from Puget Sound LIDAR Consortium, 2012.

FIGURE 11
MP 7.8 BANK STABILIZATION
50-YR WATER SURFACE ELEV.

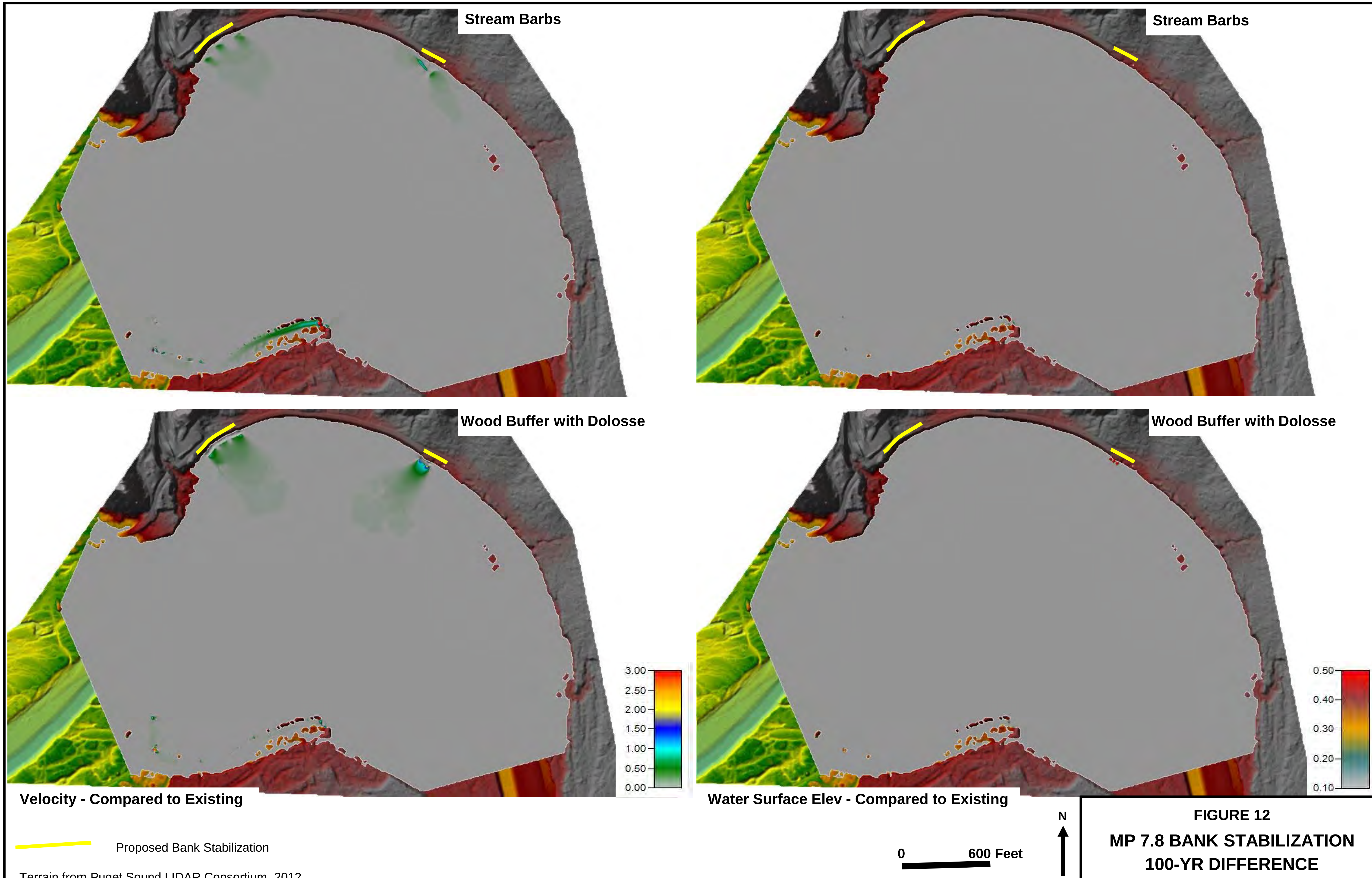


FIGURE 12
MP 7.8 BANK STABILIZATION
100-YR DIFFERENCE

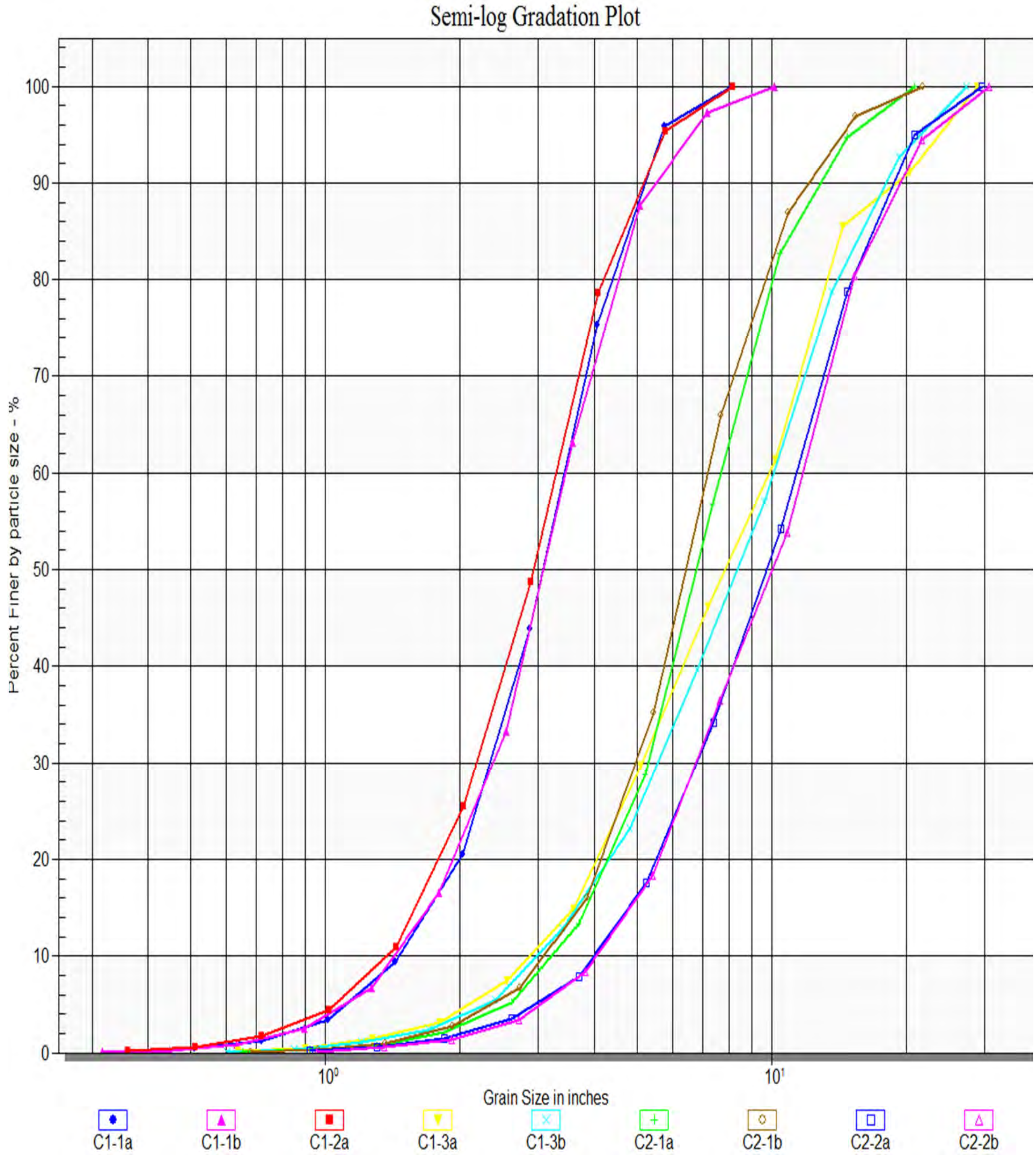
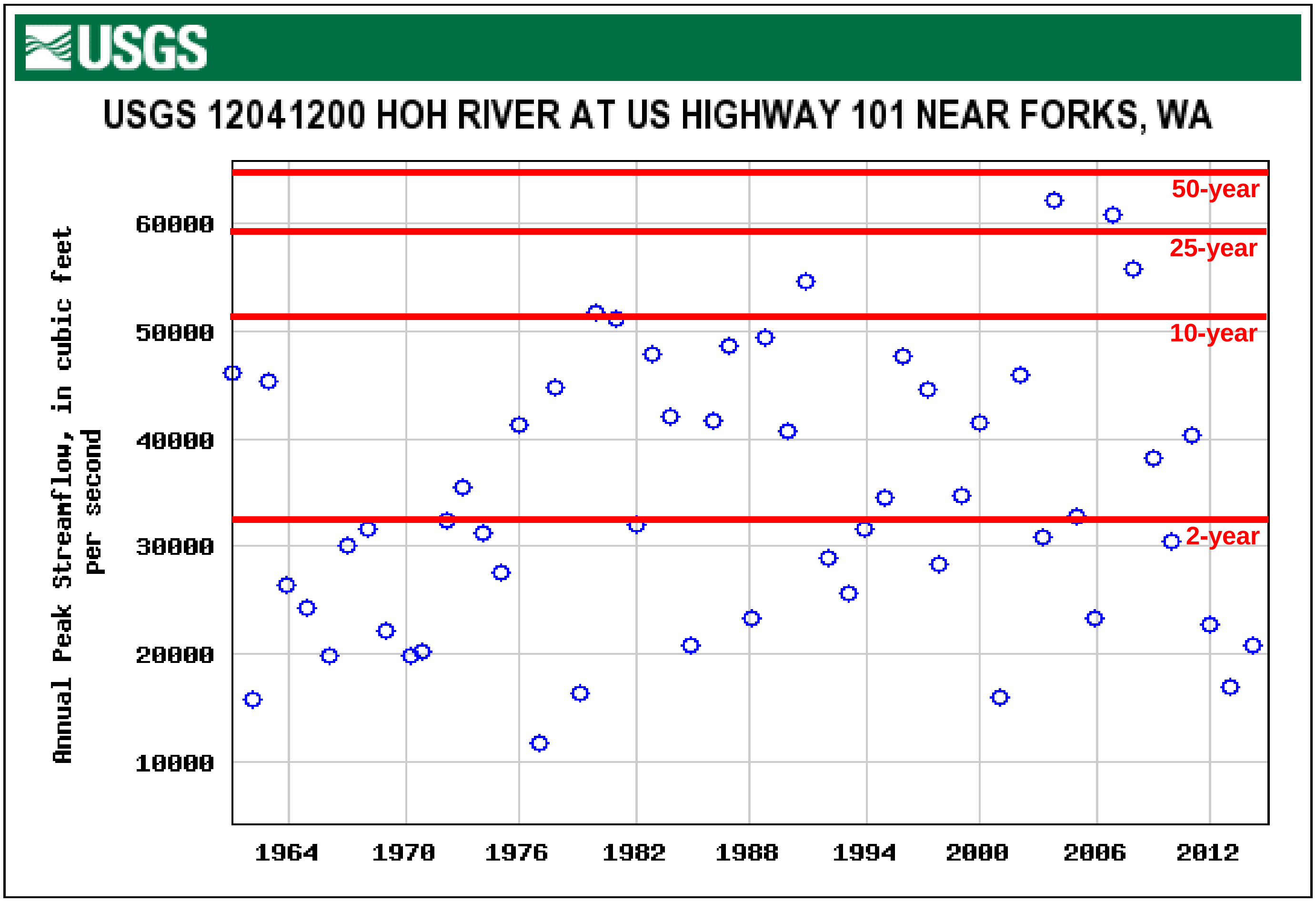


FIGURE 13

HOH RIVER GRADATION ANALYSIS

From Hydraulic Toolbox, version 4.2.



Peak discharges for flood frequencies from Table 2 weighted, USGS Report 97-4277, 1998.

From USGS Washington Surface Water Data Website.

FIGURE 14

HOH RIVER PEAK FLOOD FLOWS

DRAWINGS

Concept Details

MP 4.0 Site - Plan and Profiles

MP 7.8 Site - Plan and Profiles

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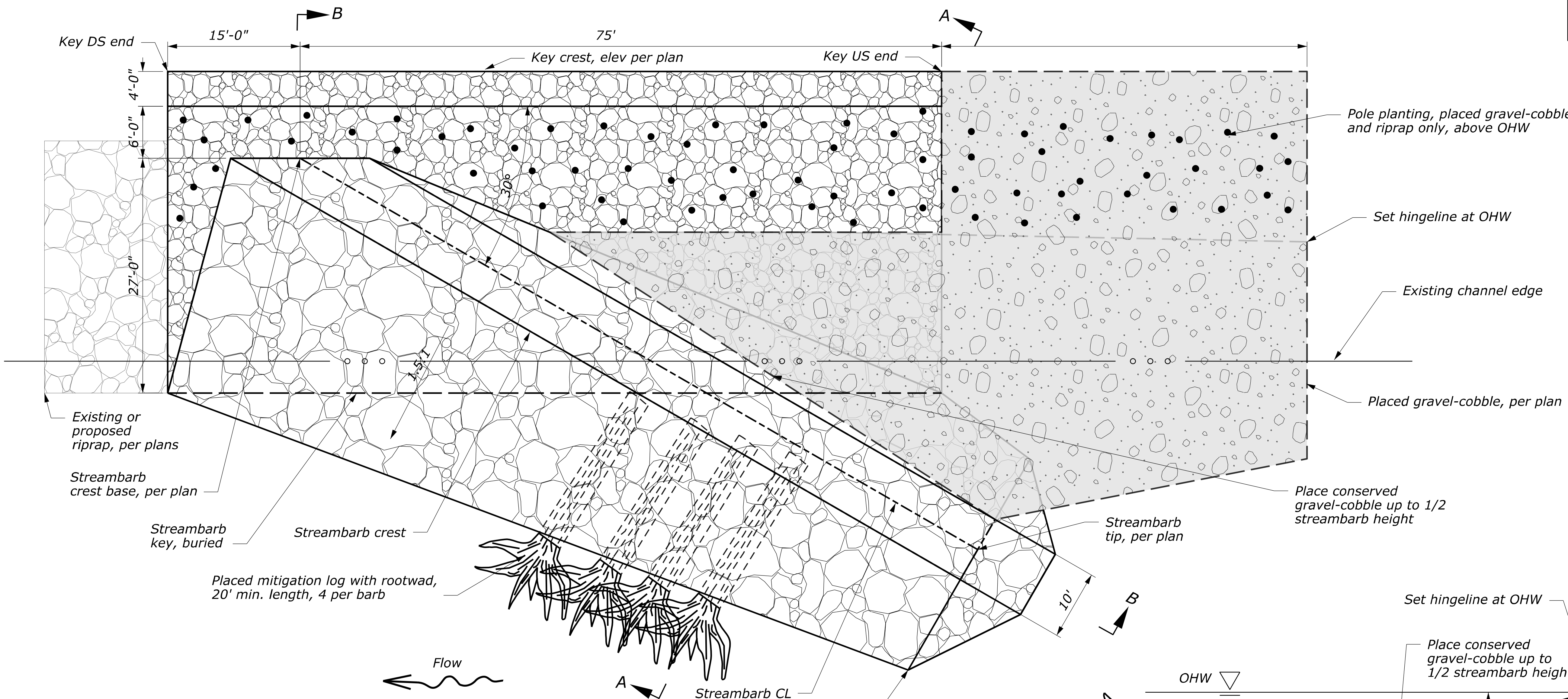
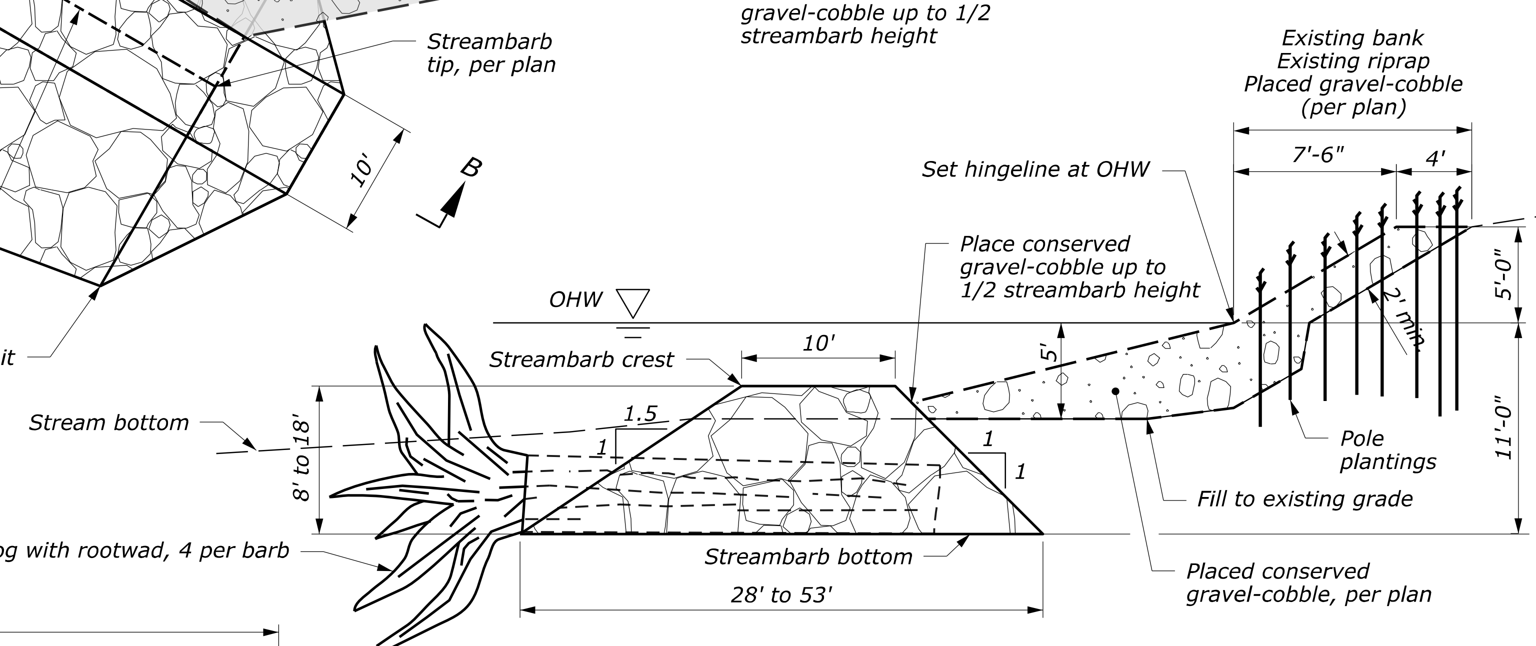
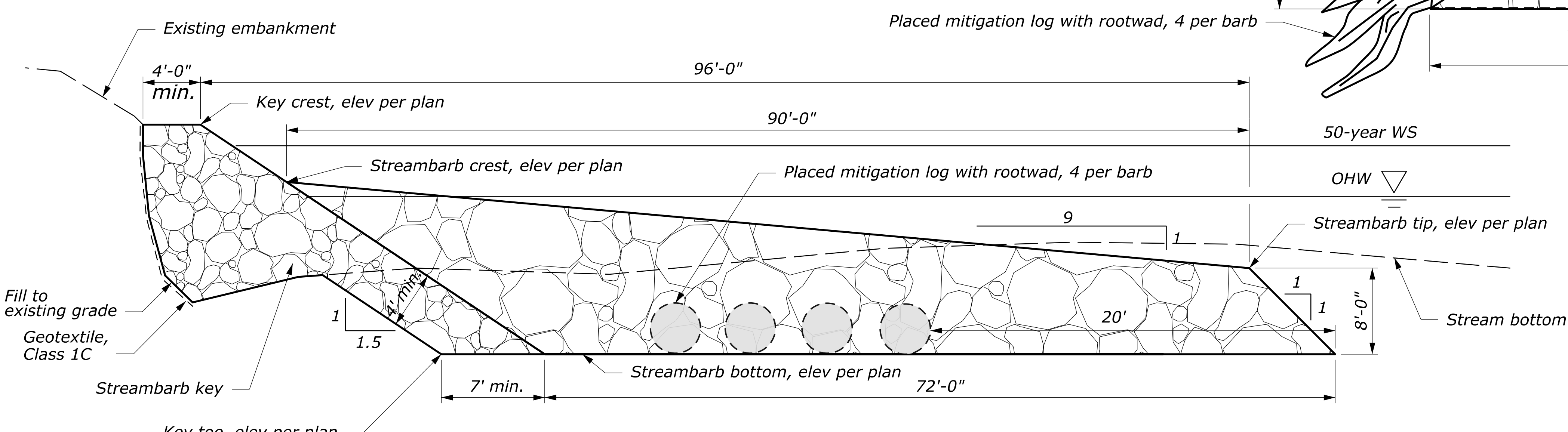


PLAN



SECTION A



SECTION B

NOTES:

1. Streambarb Class 8 riprap.
2. Streambarb key Class 5 riprap.
3. If needed, placed conserved gravel footprint can be increased.

NO SCALE

STREAMBARBS TYPICAL DETAILS

--/---- Checked by: --/----

Designed by:

c:\myfiles\pw_production\d02032886\H.12 - v5-Typical_streambarb_BS_Sur_ft2D.dgn [US_Sur_ft2D]

7 December 2015 2:51 PM

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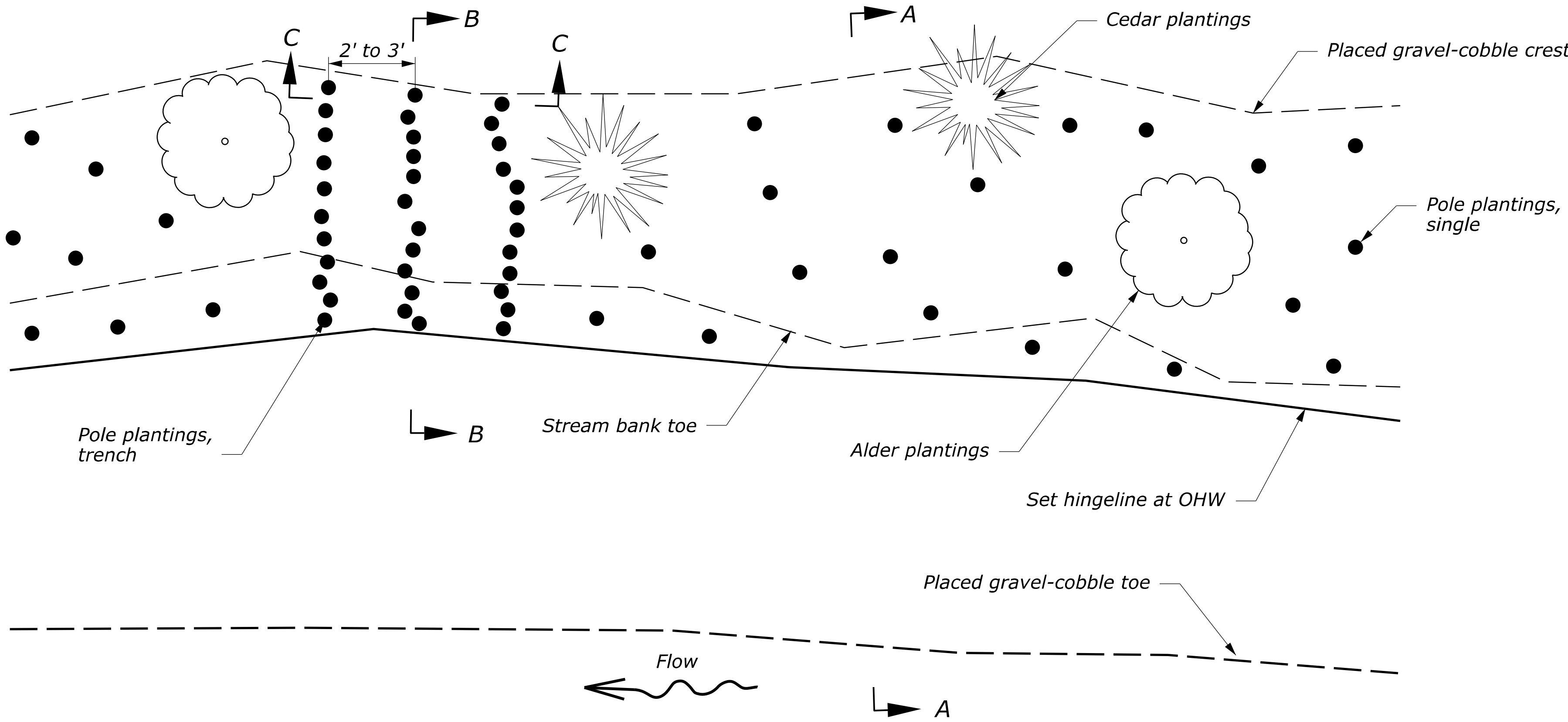

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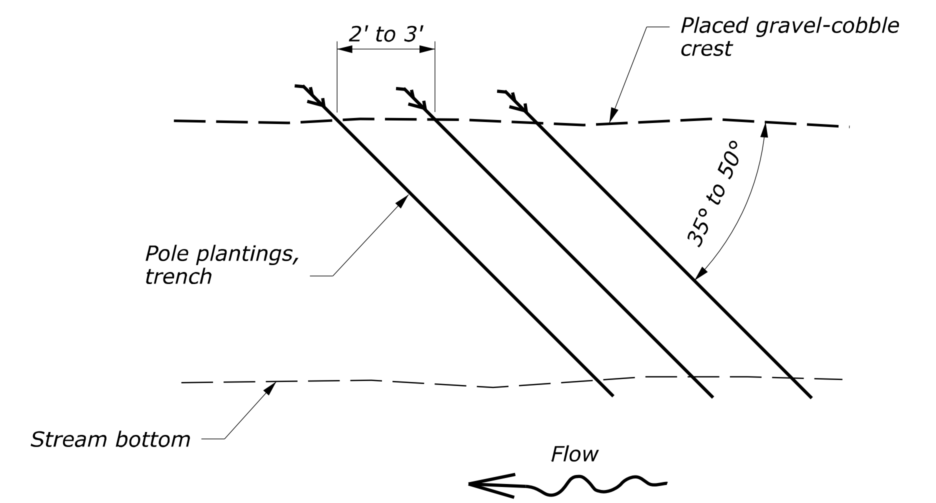

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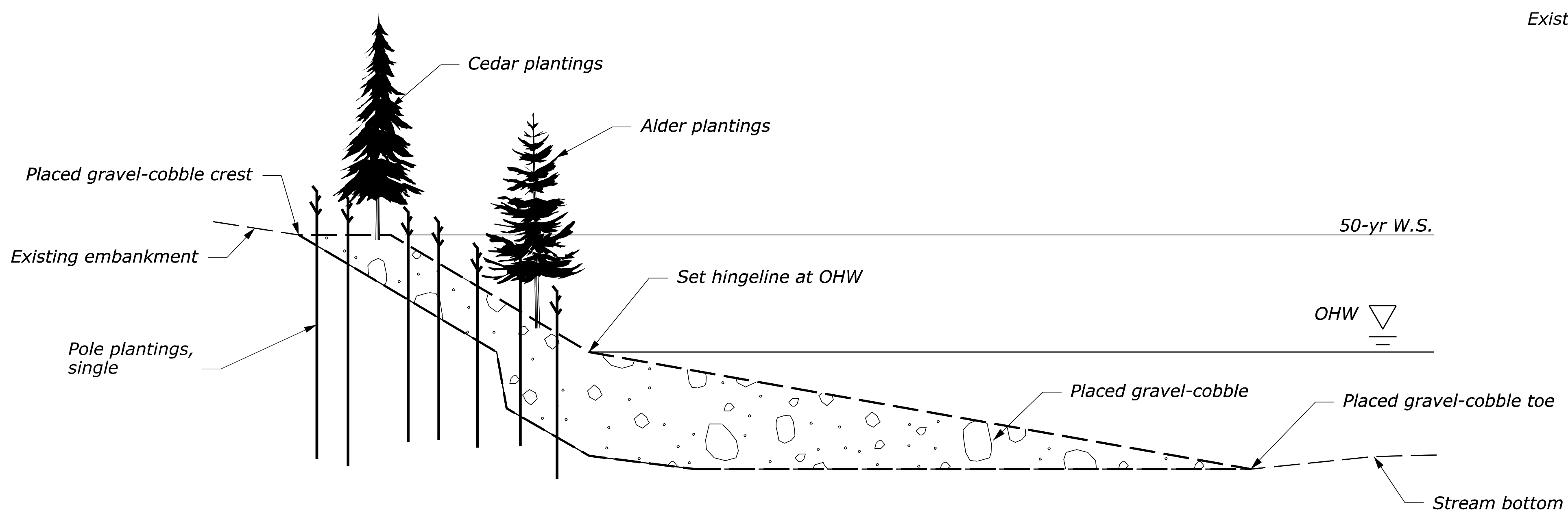
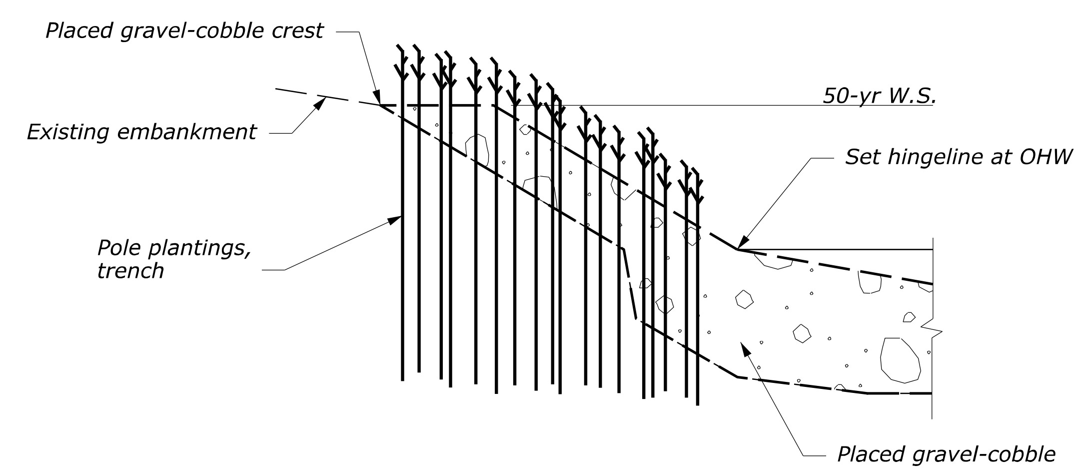


SECTION A



SECTION B

NO SCALE

GRAVEL-COBBLE BANK STABILIZATION TYPICAL DETAILS

7 December 2015 3:51 PM
c:\myfiles\pw_production\d0203286\H.13 - v5-Typical_bank_stabilization_logs_BS_Sur_ft2D.dgn [US_Sur_ft2D]
Designed by: --/----
Checked by: --/----

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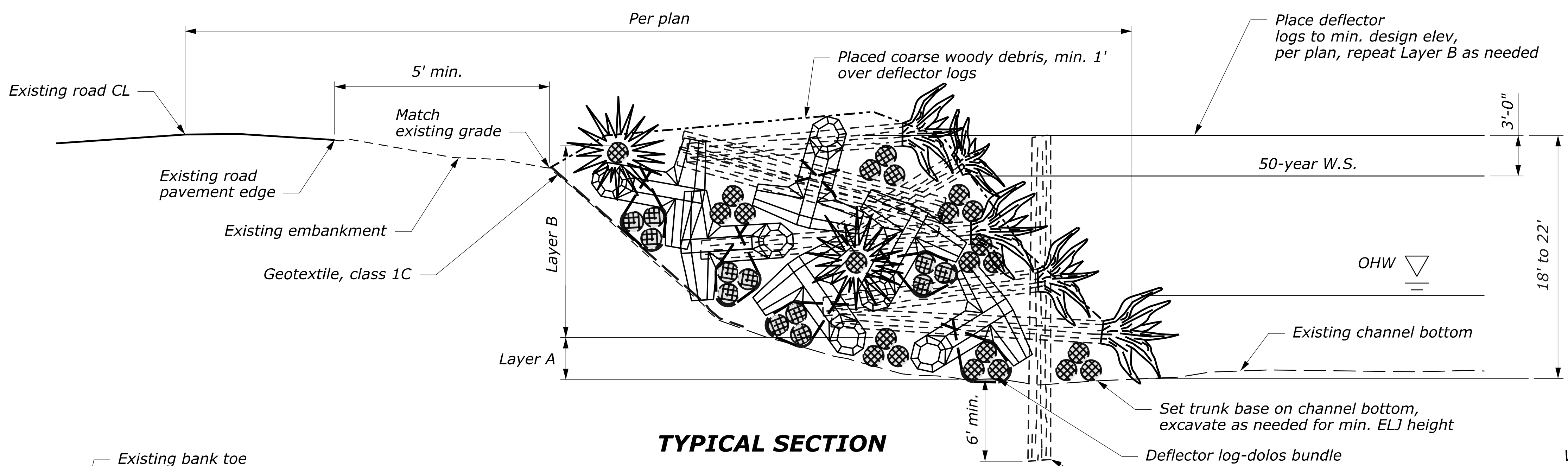
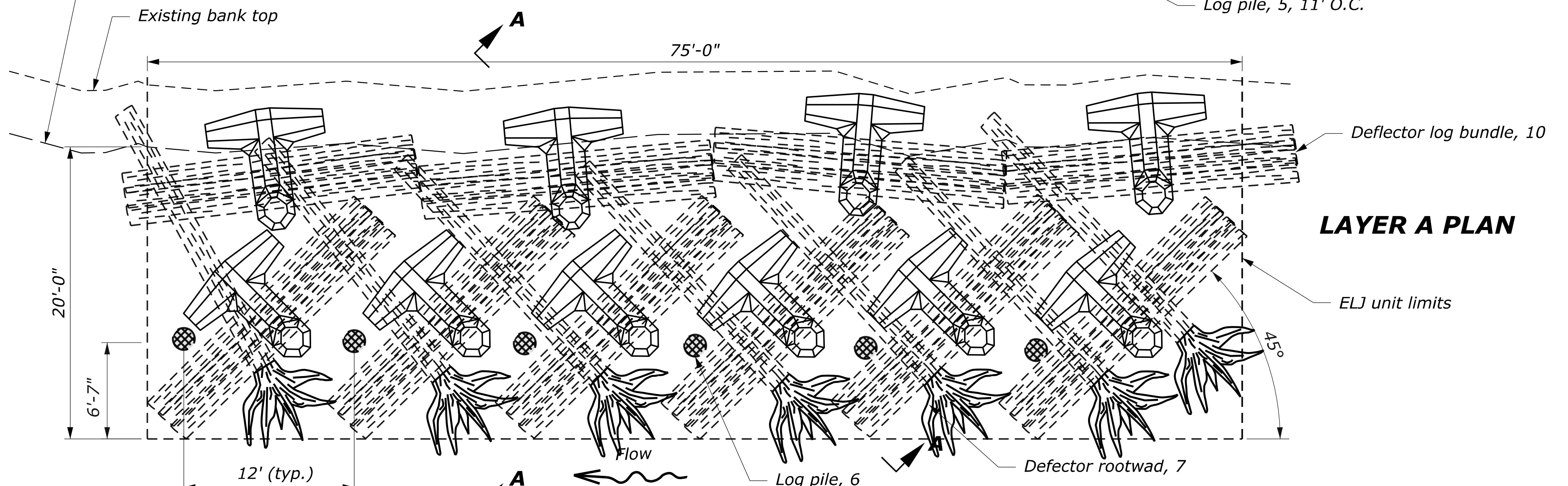
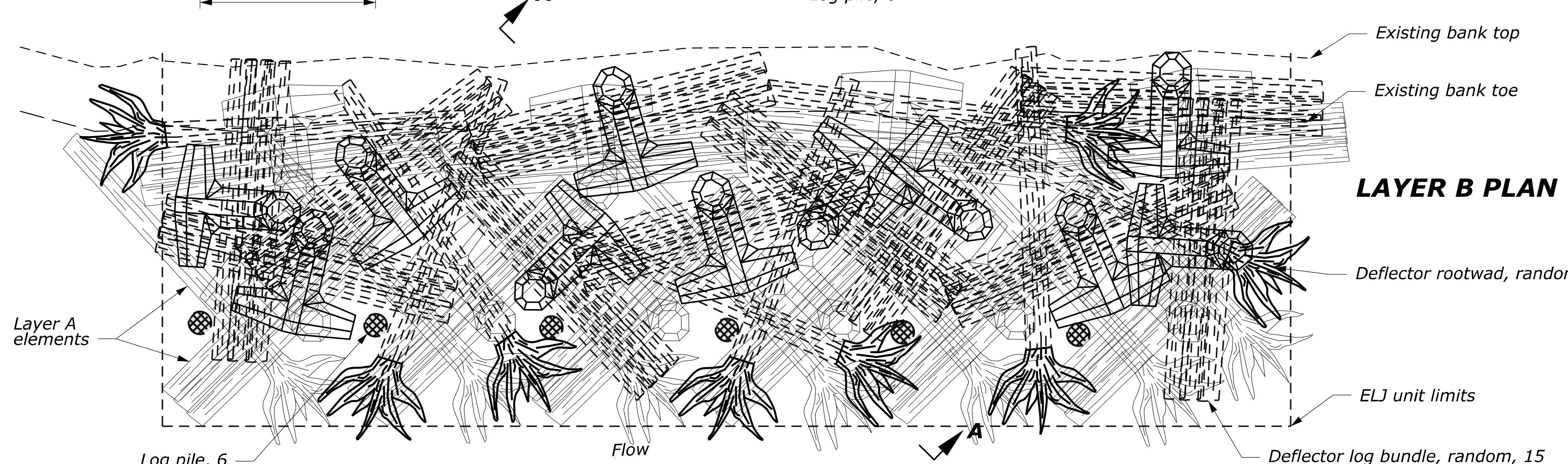


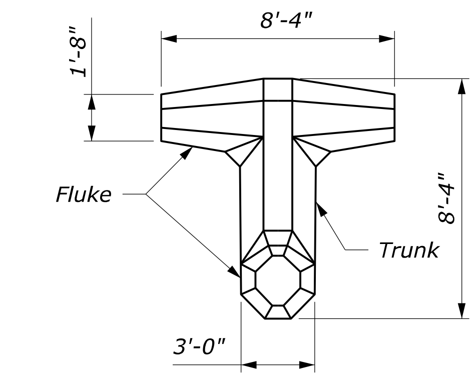
TYPICAL SECTION



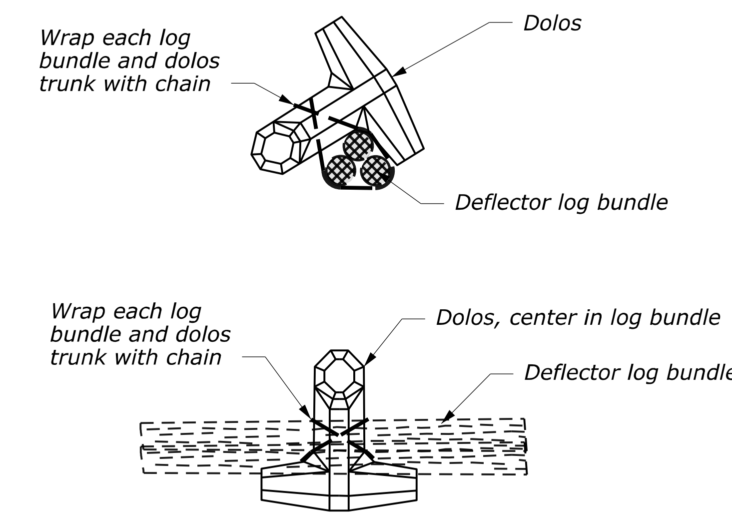
LAYER A PLAN



LAYER B PLAN



DOLOS DETAIL



TYPICAL DEFLECTOR LOG-DOLOS BUNDLE DETAIL

Notes:

1. Deflector log; 20-foot min. trunk, 18 to 36-inch diameter without attached rootwad.
2. Deflector rootwad; 20-foot min. trunk, 18 to 36-inch diameter with attached rootwad.
3. Deflector log bundle; 105 to 140 ft3 total log volume, 16,000 lbs dolos weight.
4. Log pile; 30-foot min. trunk, 12-inch to 18-inch diameter without attached rootwad, 6 per log jam unit.
5. Coarse woody debris; even mixture of branches, limbs, trunks, vegetation, 1-inch to 8-inch diameter, tightly pack into void space between fill logs and deflector logs.
6. Layer B; 15 randomly placed deflector log-dolos bundles and 6 defector rootwads.

NO SCALE

BANK STABILIZATION WOOD BUFFER w/ DOLOSSE DETAILS

Designed by: --/----
Checked by: --/----
c:\myfiles\pw_production\d0203286\H.14 - v6uni-jumble_Typical_dolosse_BS_Sur_ft2D.dgn [US_Sur_ft2D]
2 December 2015 4:34 PM

STATE	PROJECT	SHEET NUMBER
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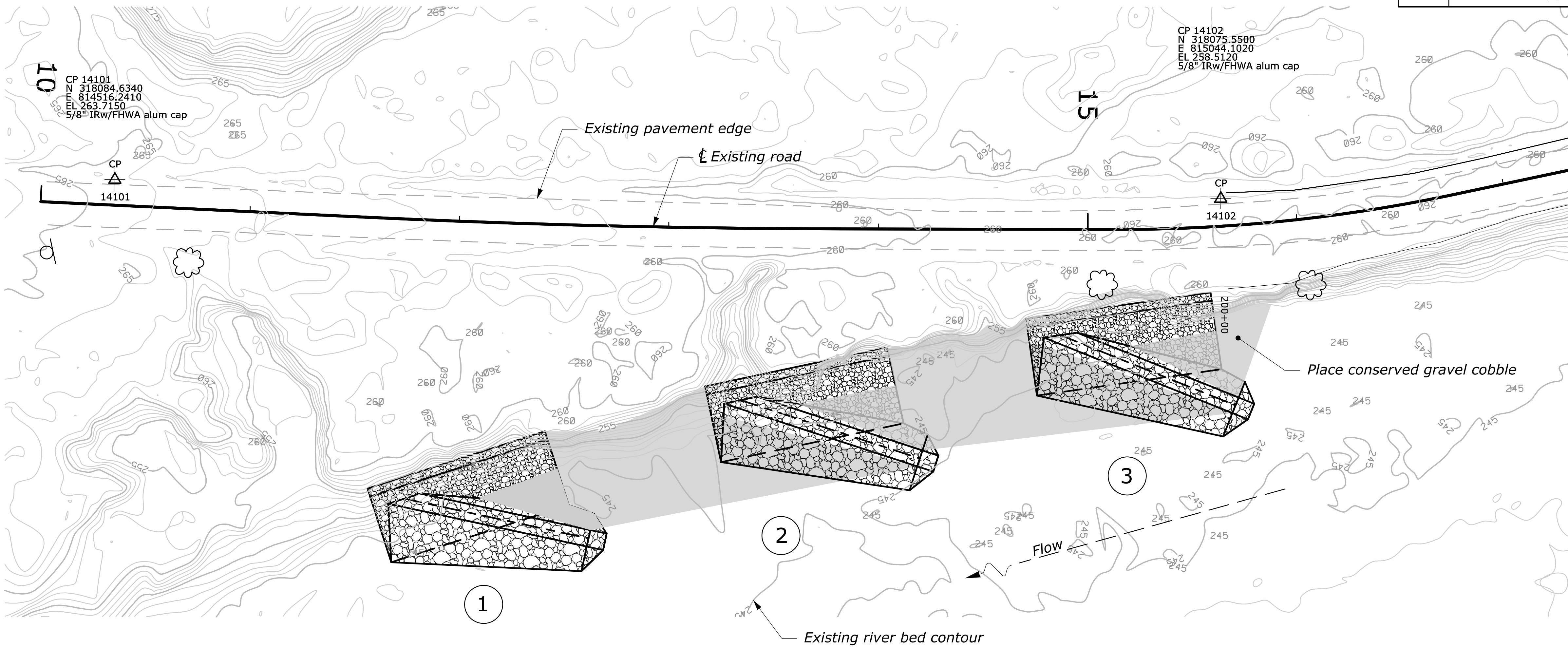

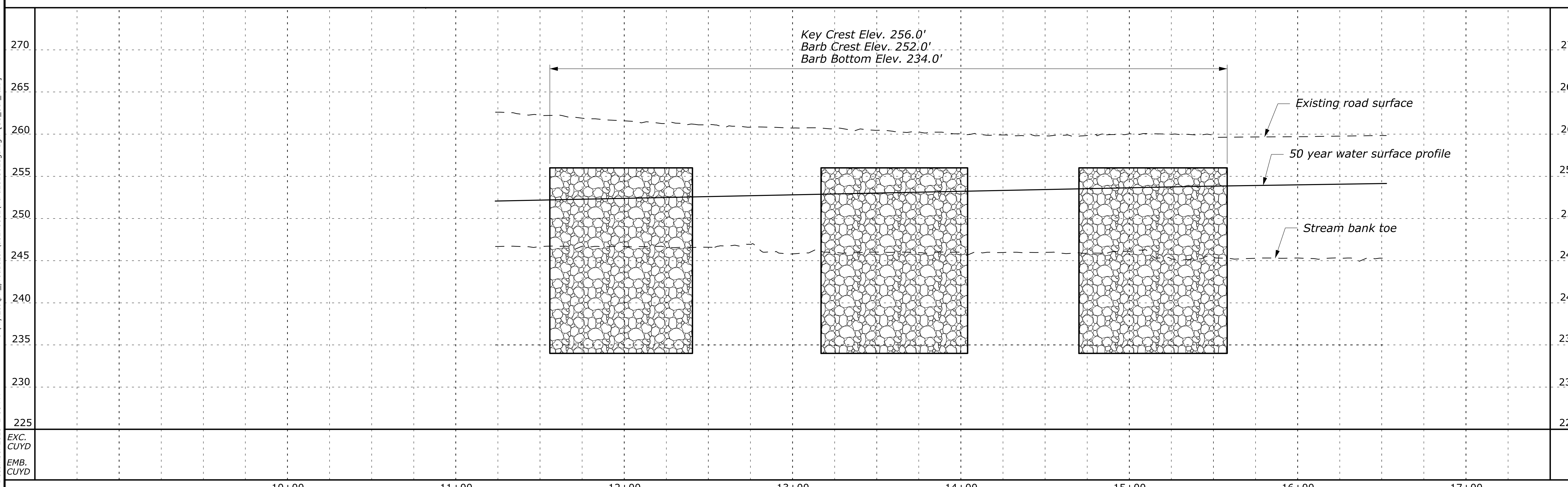

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3 December 2015 2:08 PM

STATE	PROJECT	SHEET NUMBER
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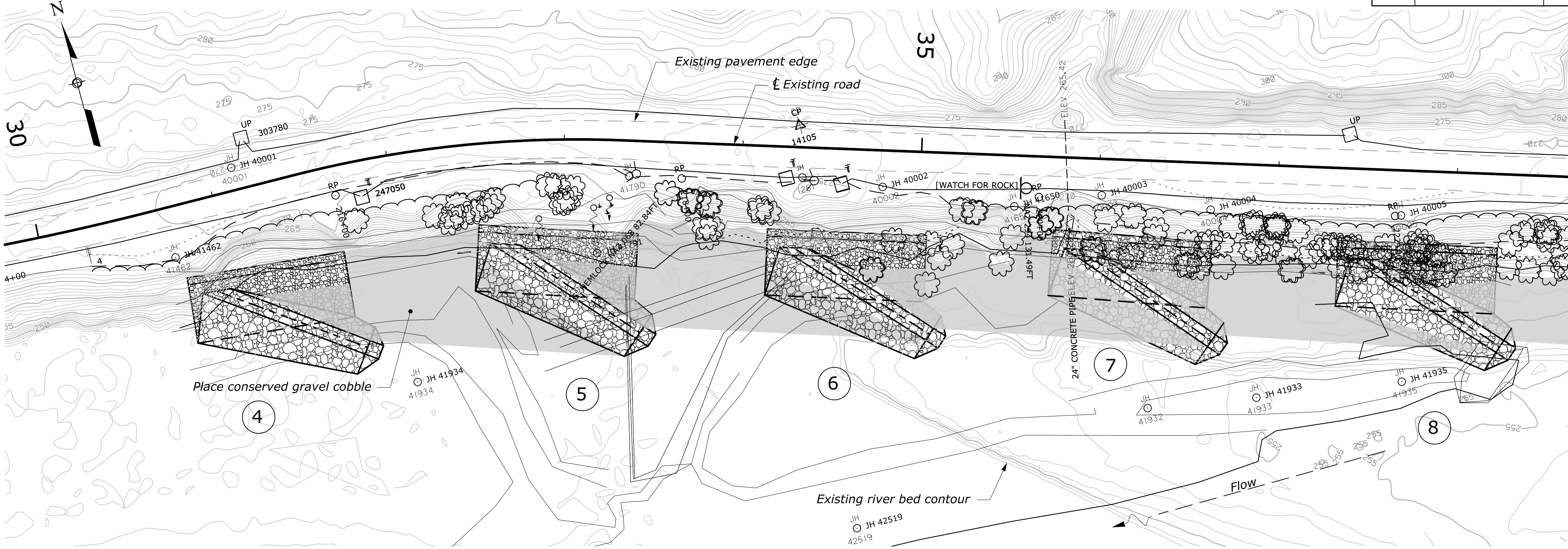

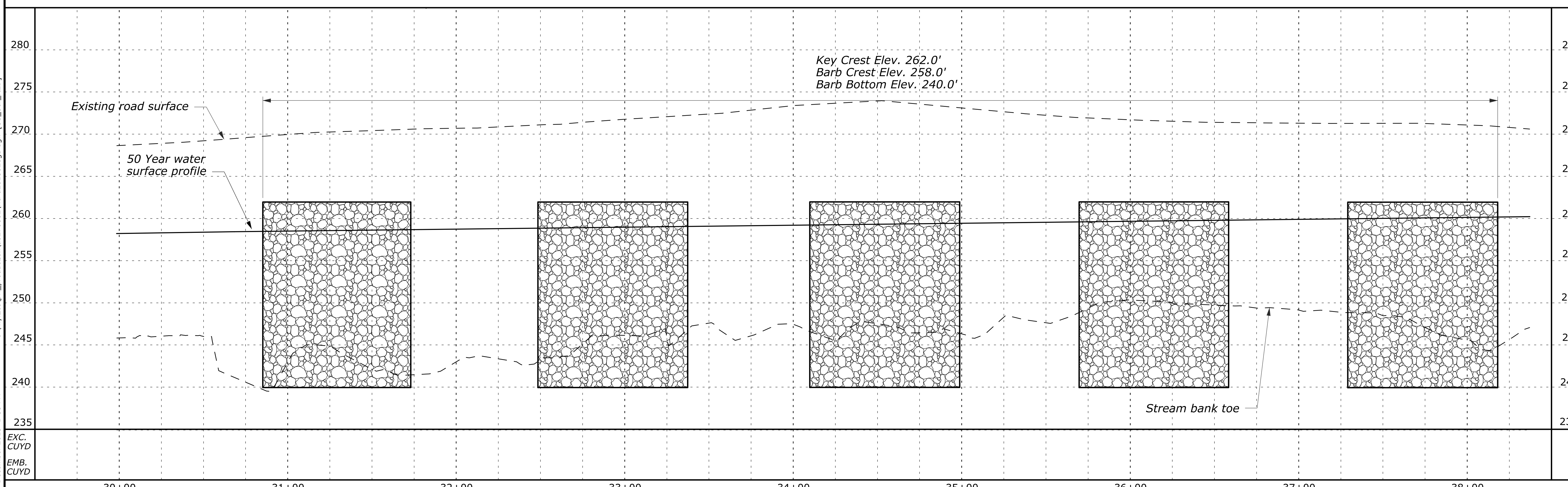

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Checked by:
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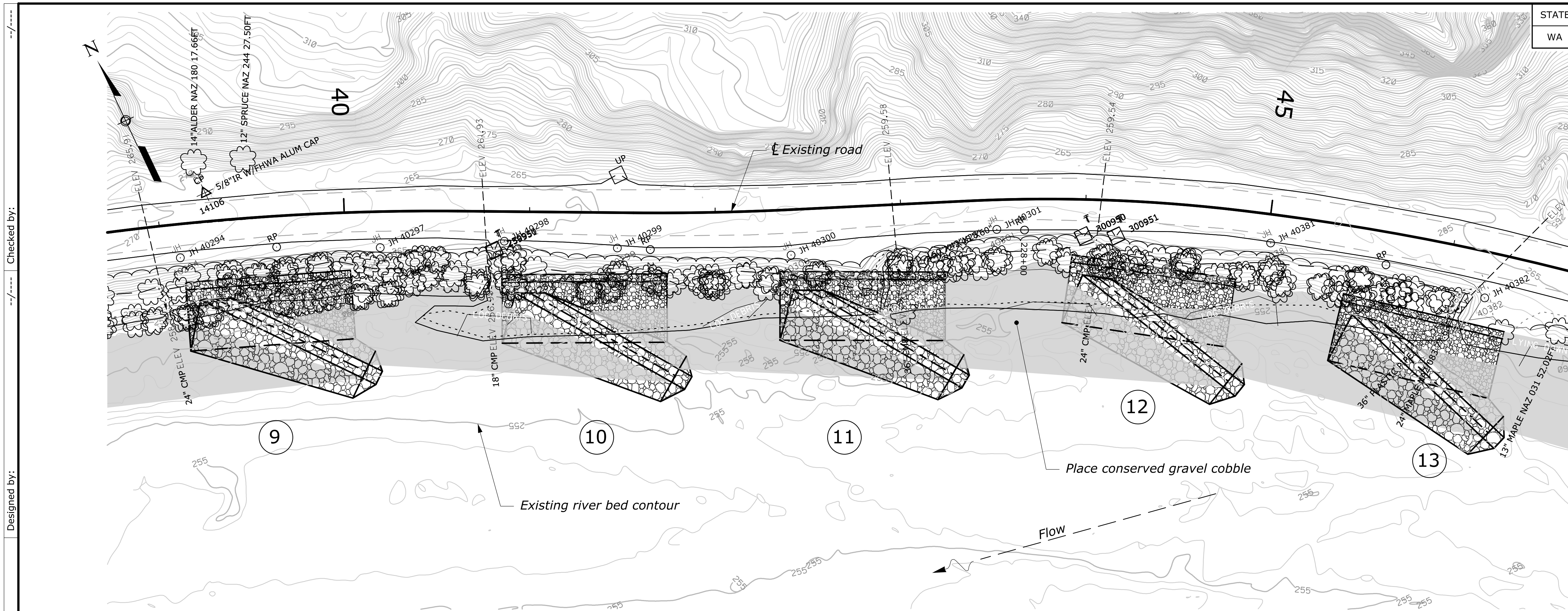
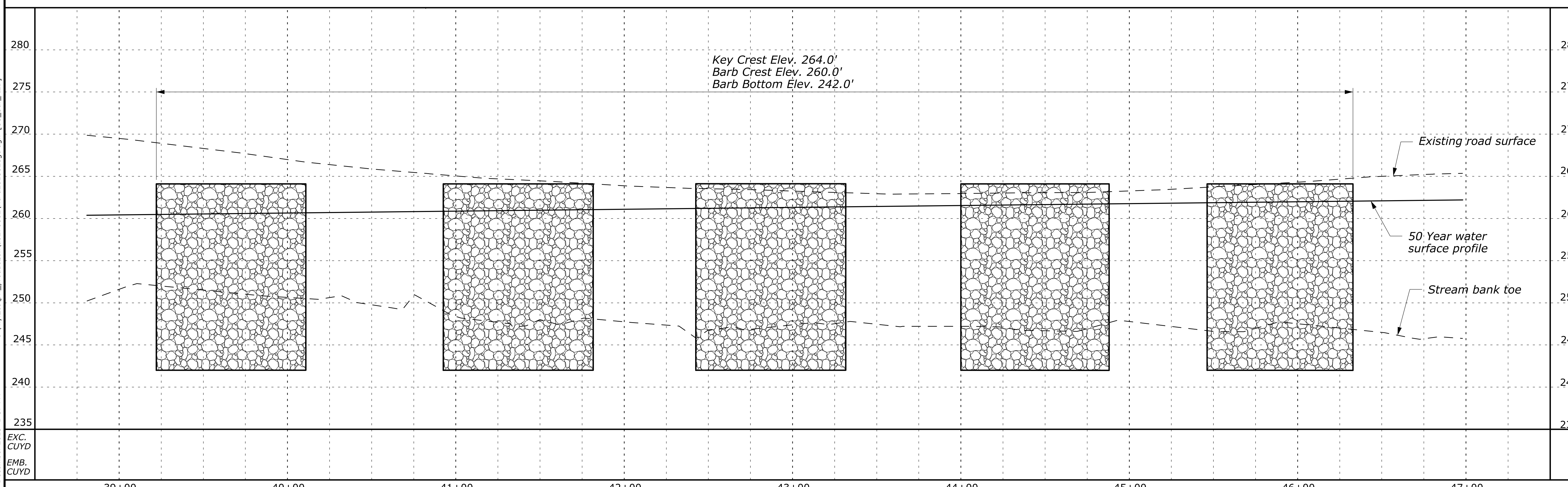
3 December 2015 1:55 PM

STATE	PROJECT	SHEET NUMBER
WA	JEFF 91420(1)	R.4





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3 December 2015 1:57 PM

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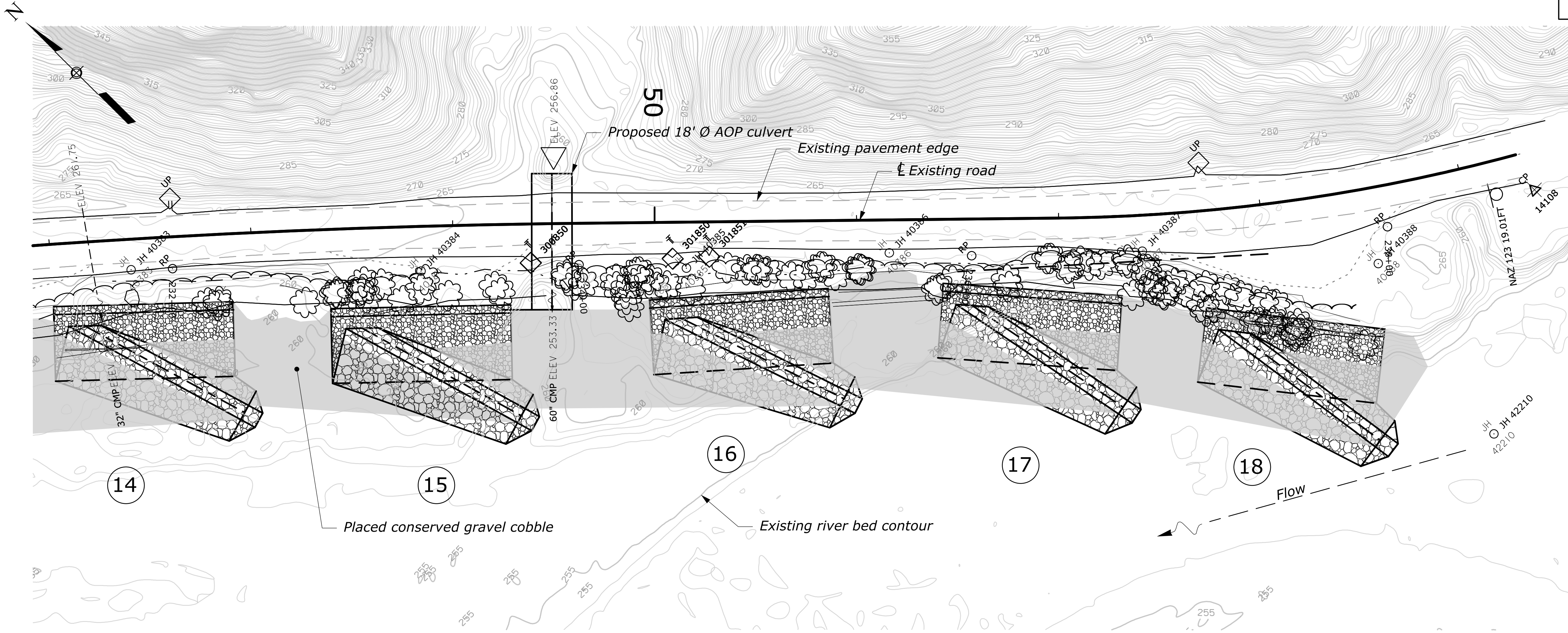

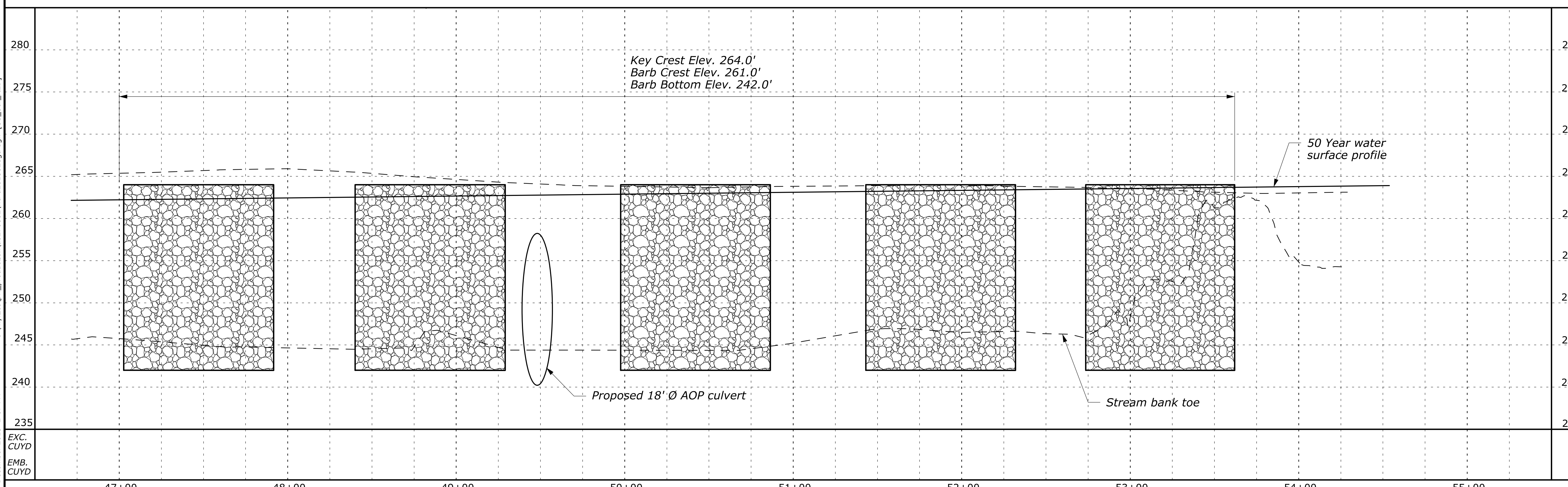

Designed by:
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Checked by:
--/----

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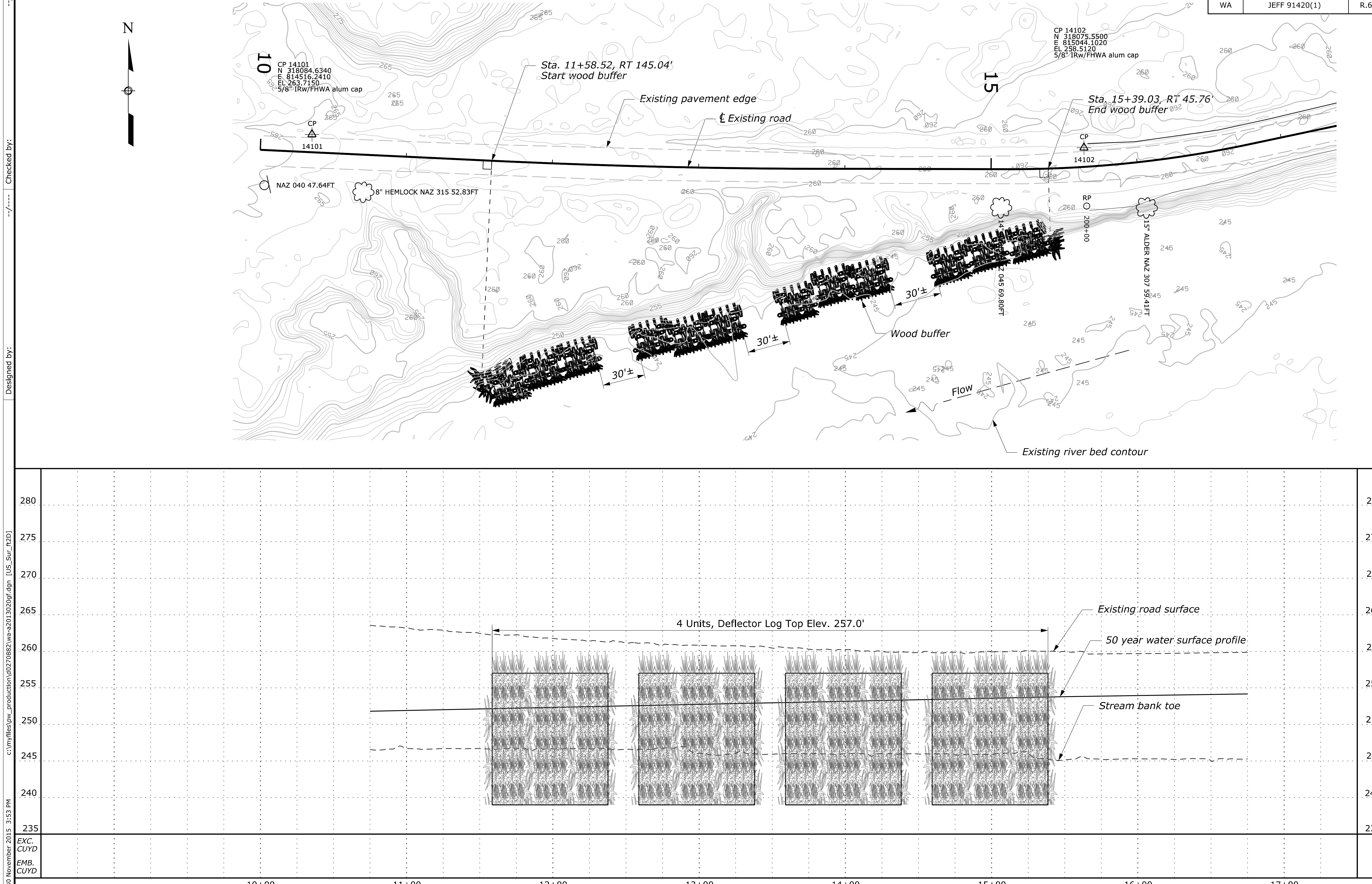
3 December 2015 2:07 PM

STATE	PROJECT	SHEET NUMBER
WA	JEFF 91420(1)	R.6



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Checked by:
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Designed by:
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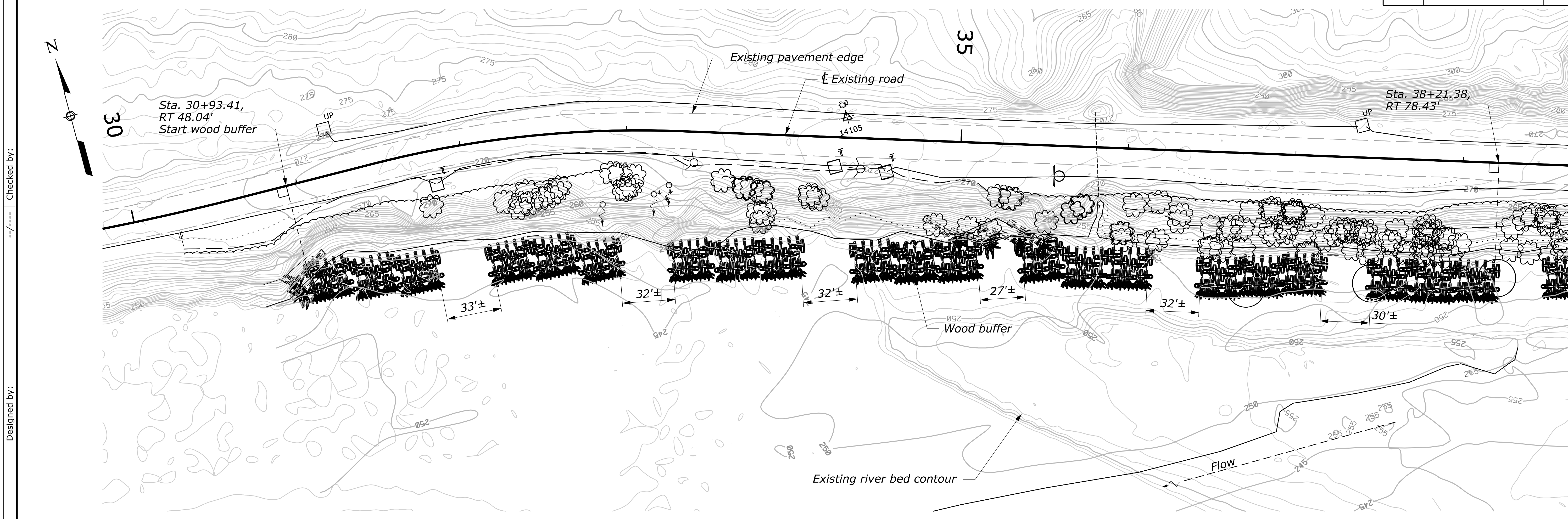
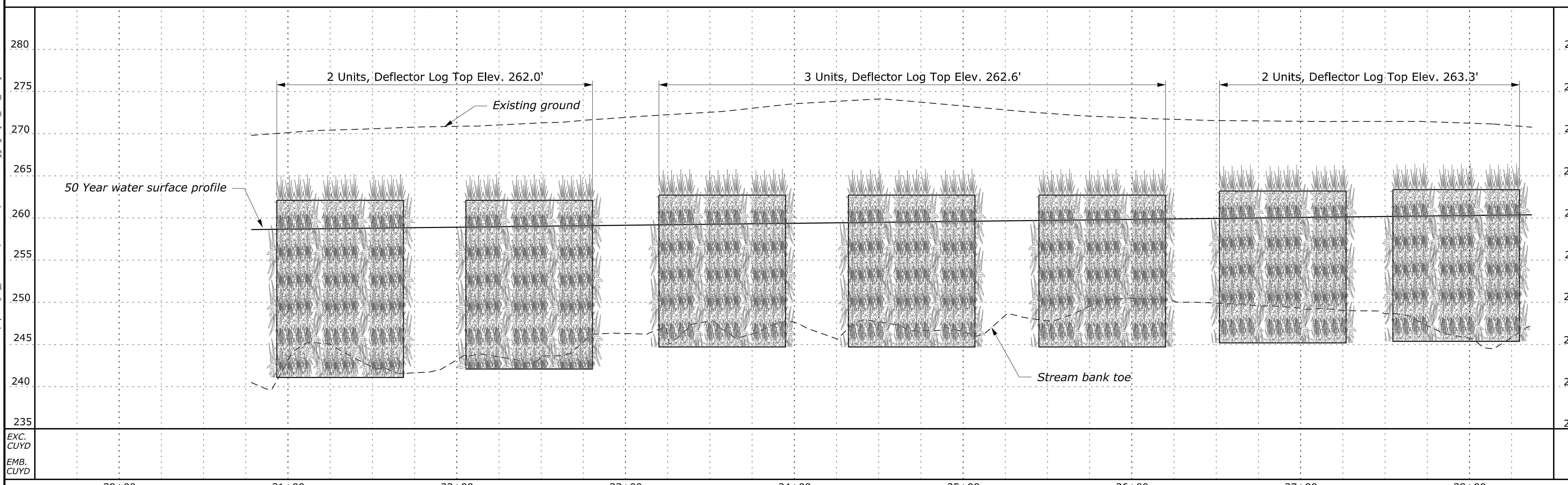
30 November 2015 3:53 PM

STATE	PROJECT	SHEET NUMBER
WA	JEFF 91420(1)	R.7





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30 November 2015 12:45 PM

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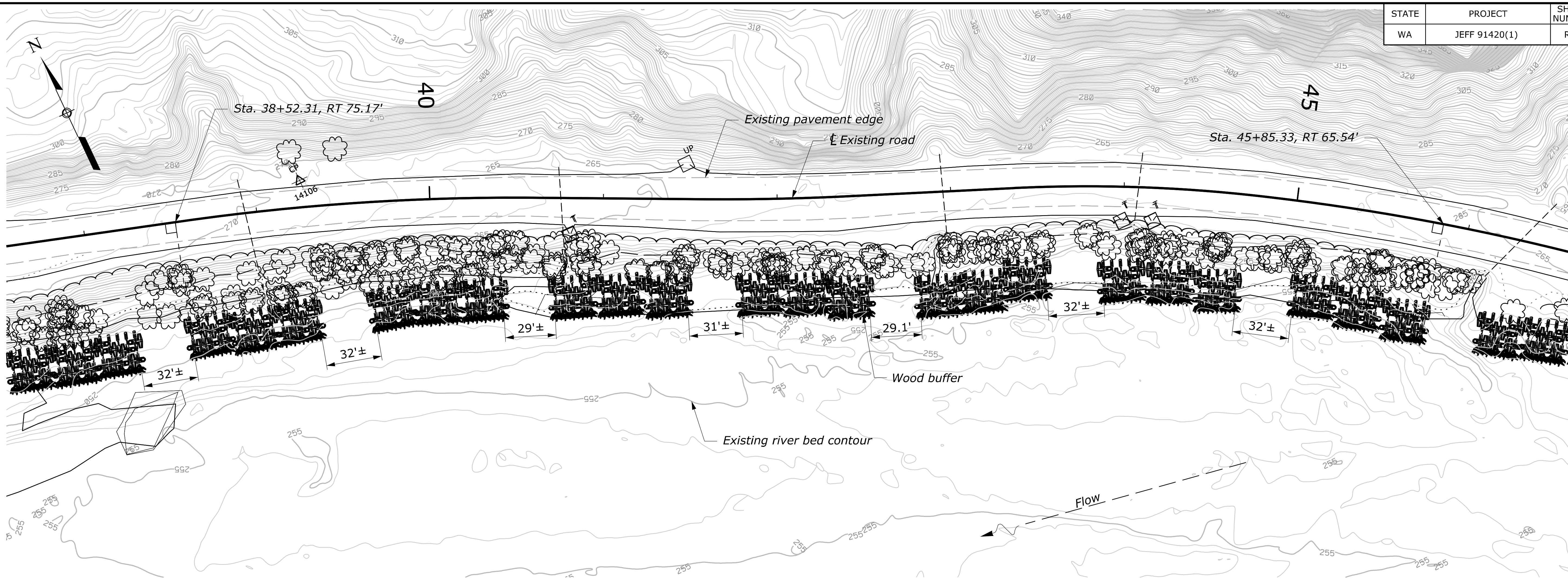

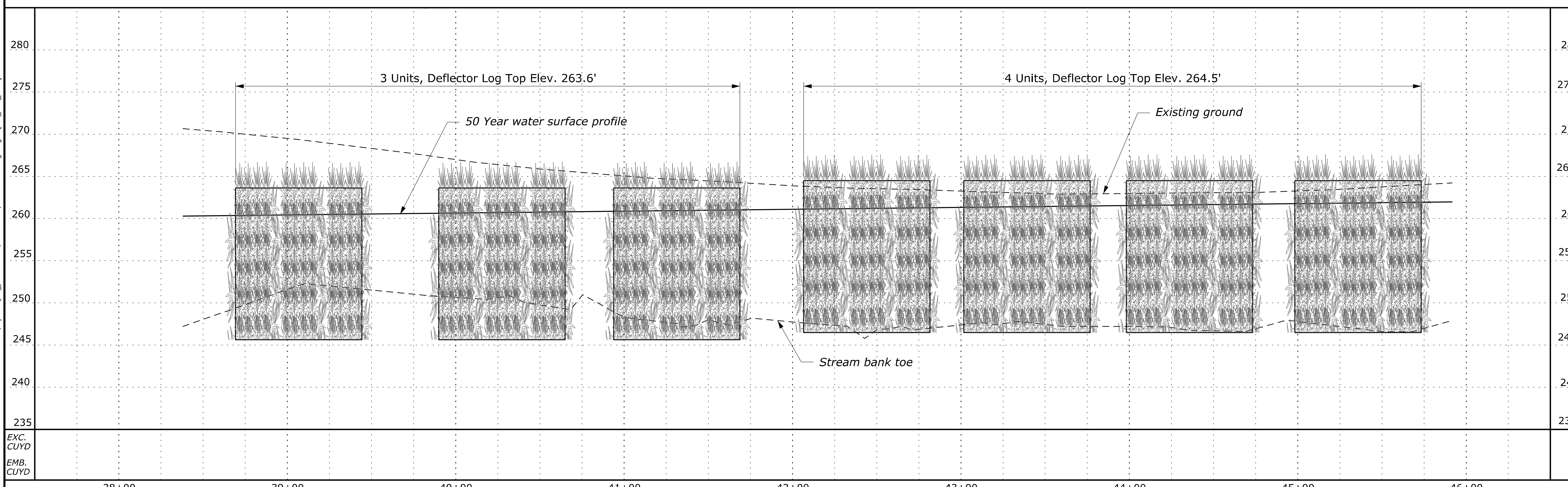

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30 November 2015 3:52 PM

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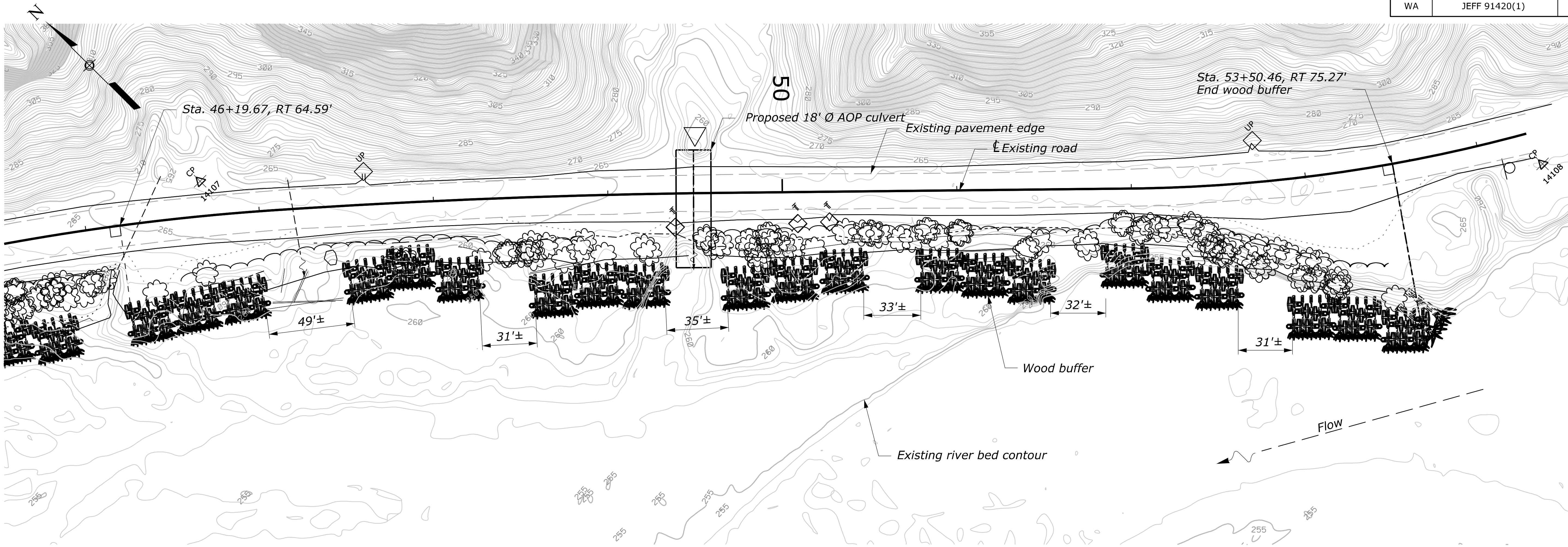

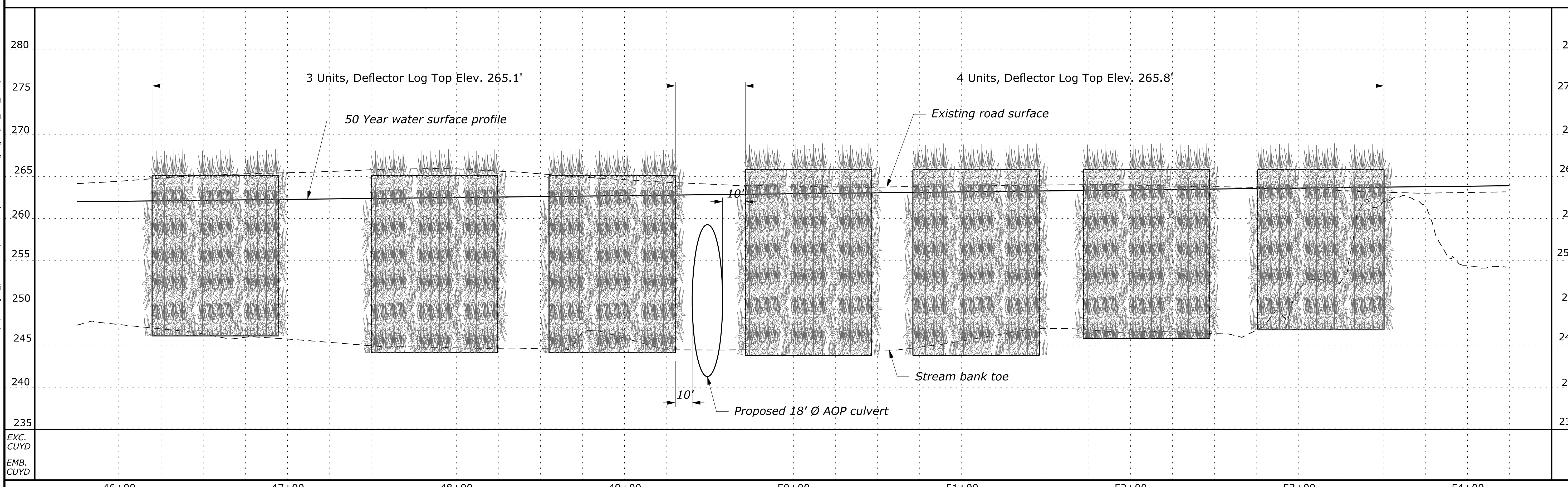

Checked by:

Designed by:

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30 November 2015 3:52 PM

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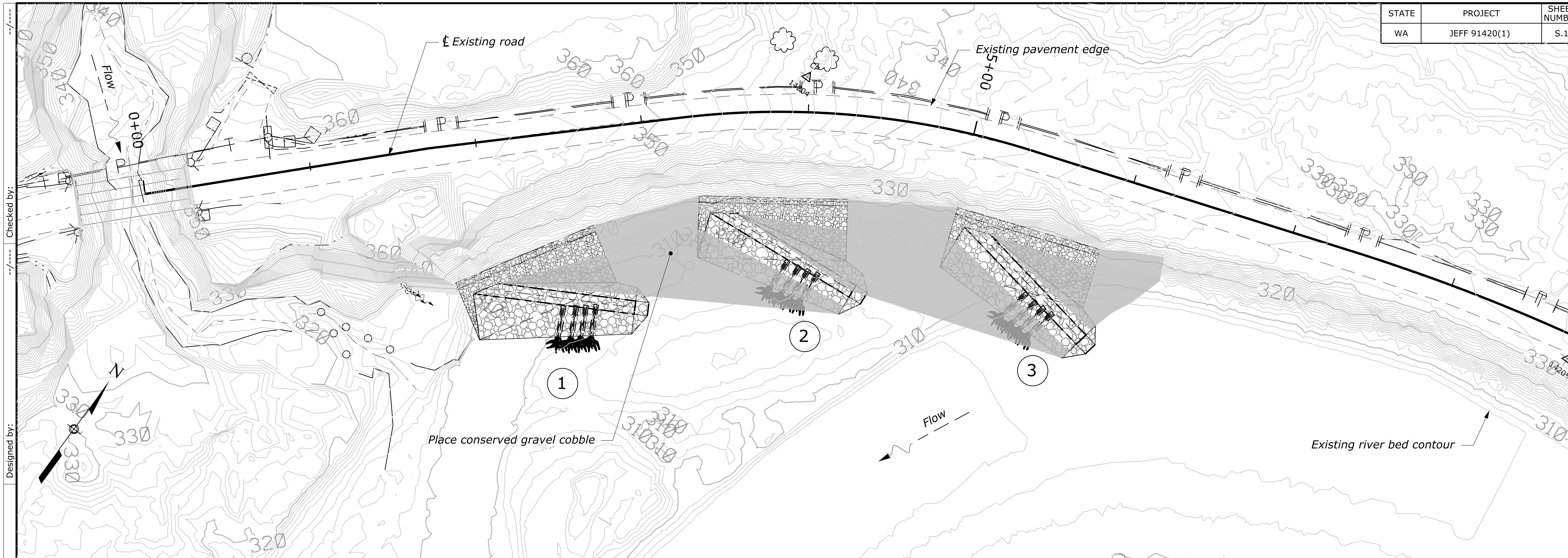

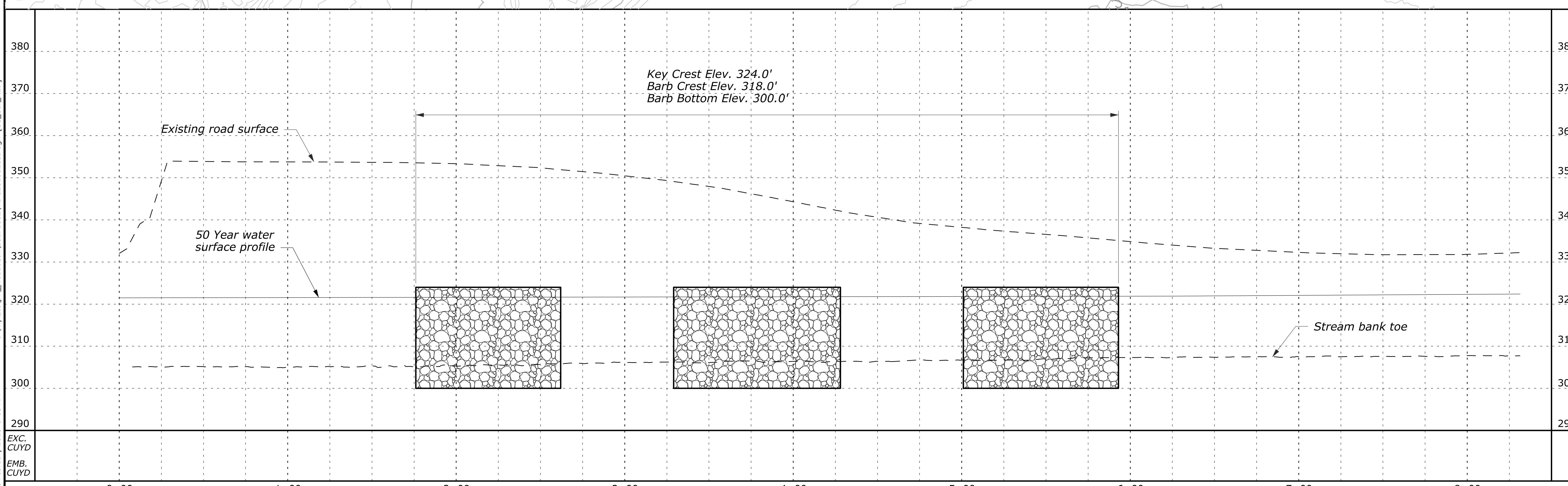

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18 February 2016 9:05 AM

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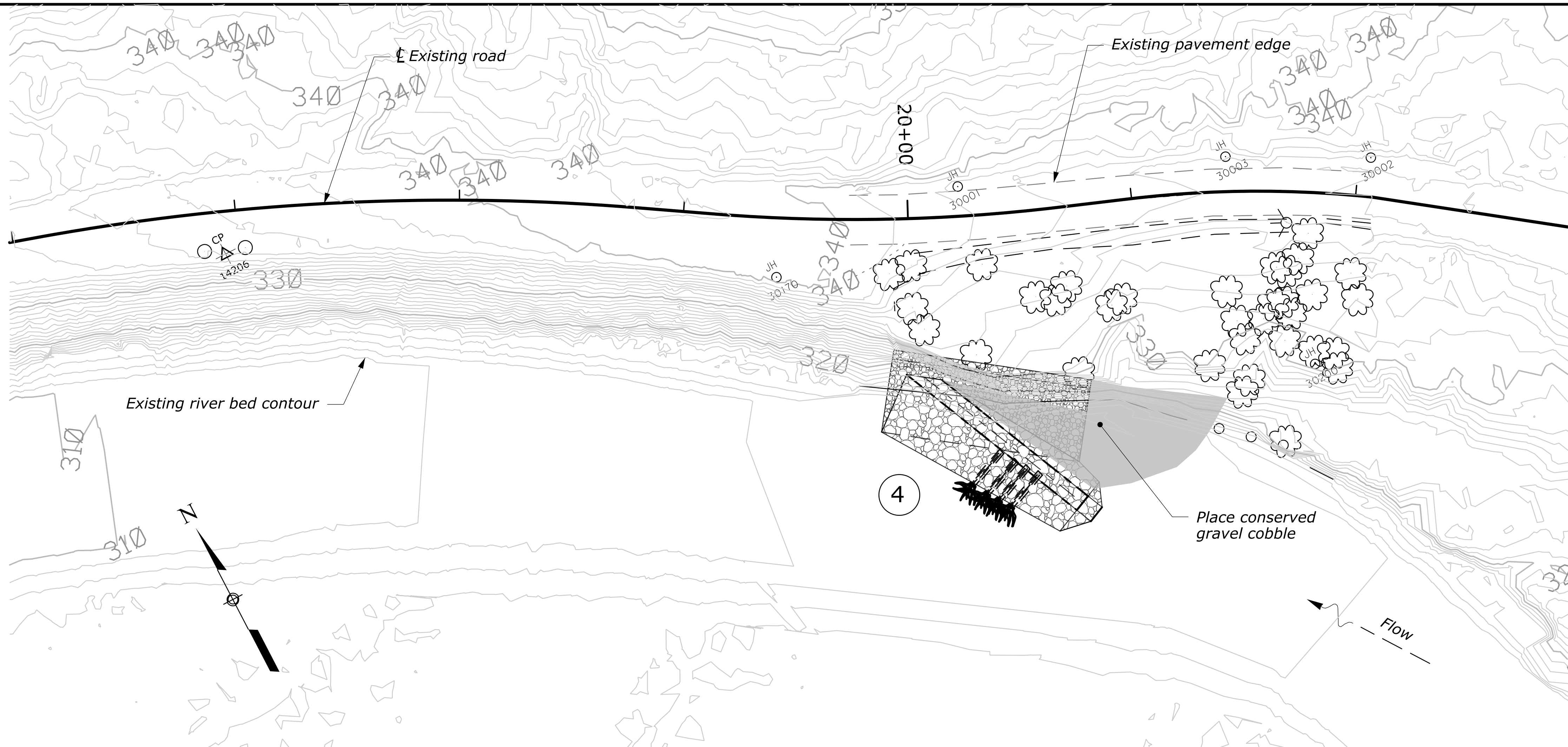

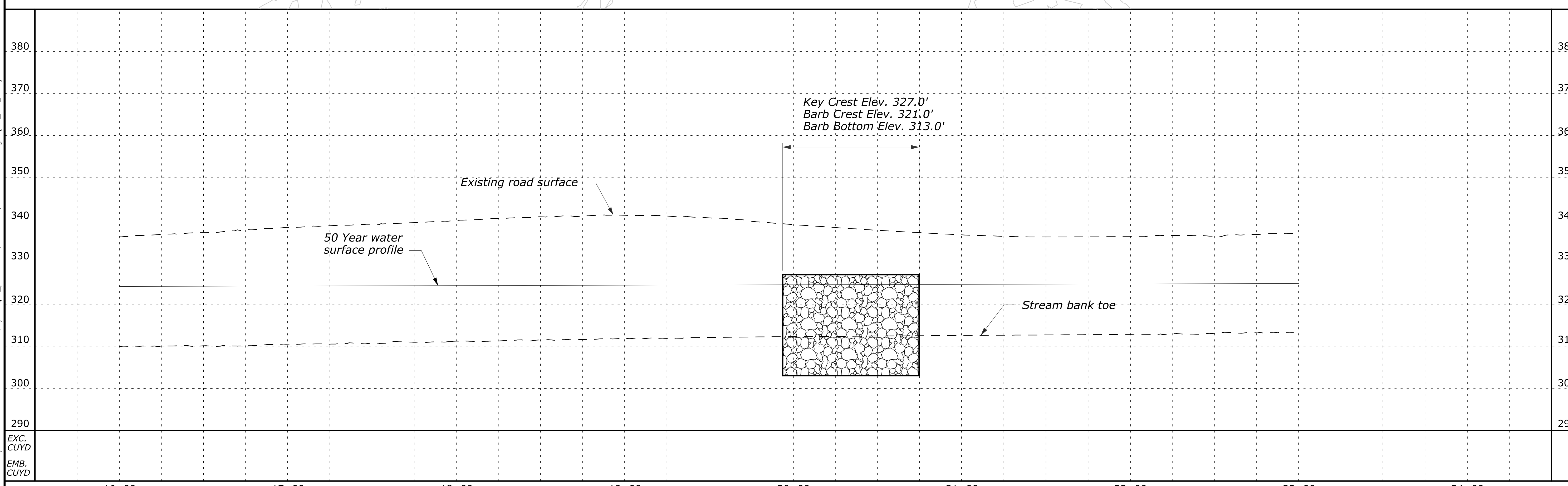

Designed by:

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Checked by:

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18 February 2016 9:05 AM

STATE	PROJECT	SHEET NUMBER
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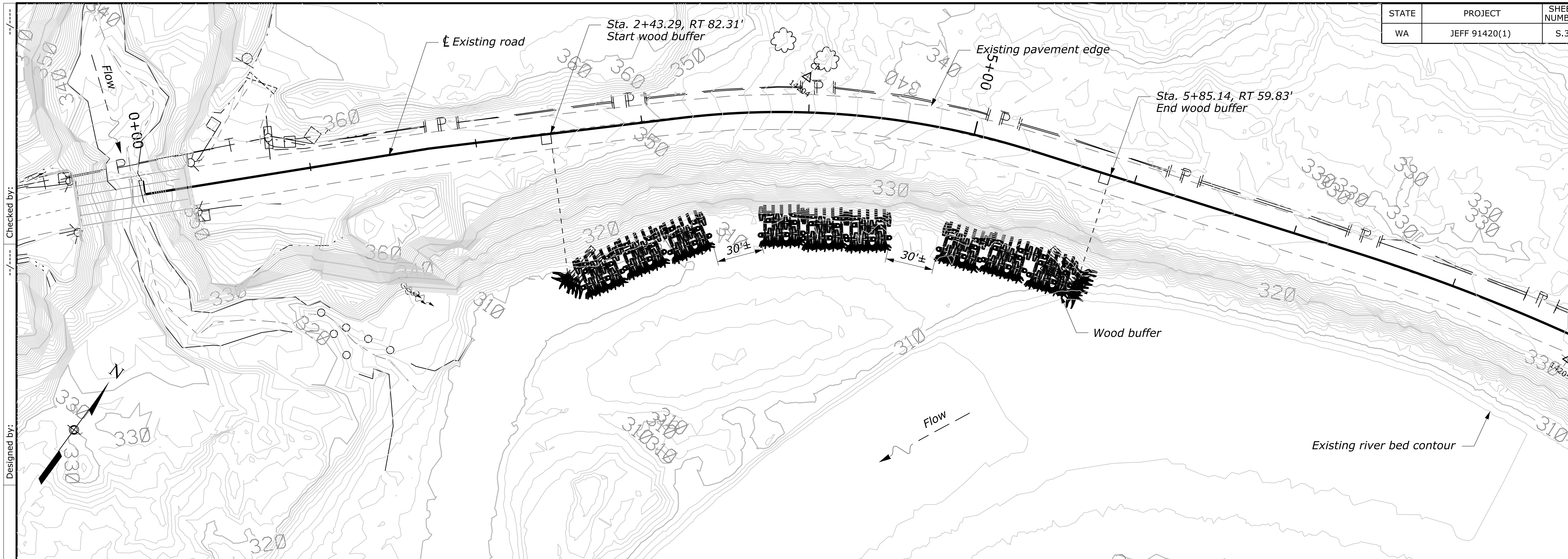

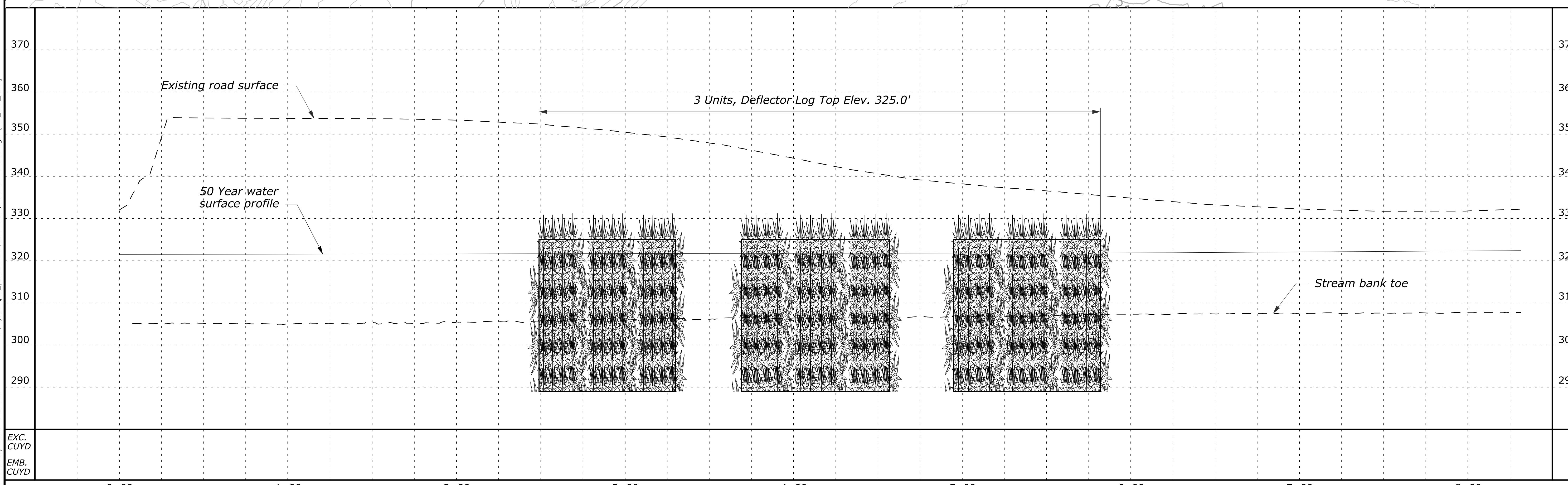

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Checked by:

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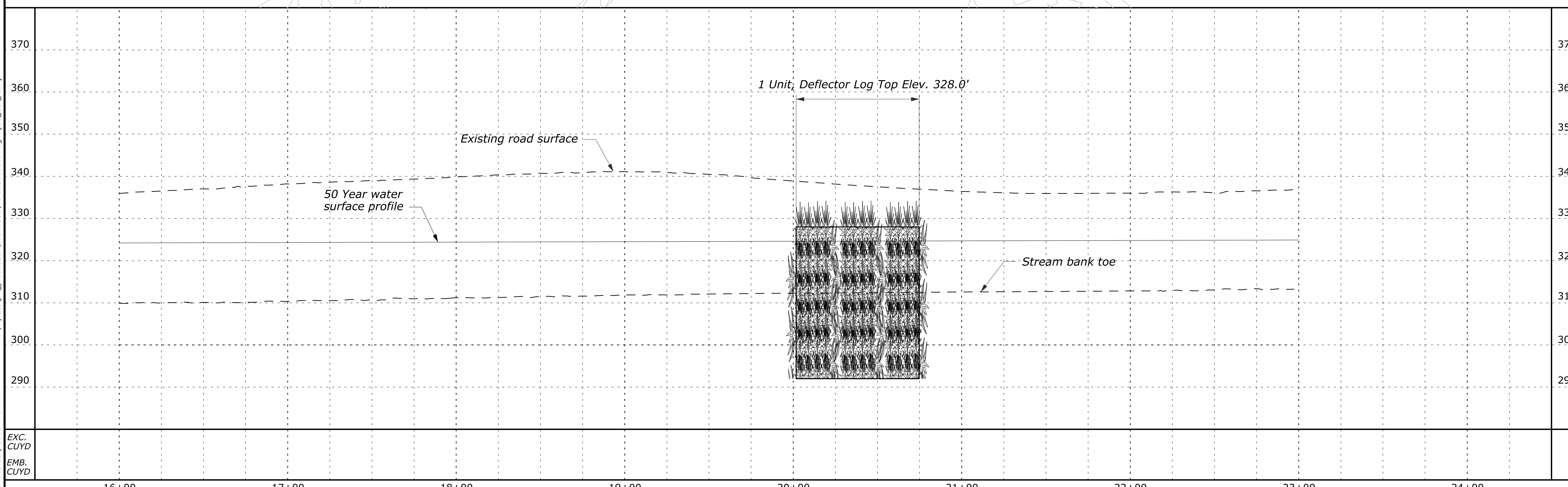
17 February 2016 4:05 PM

STATE	PROJECT	SHEET NUMBER
WA	JEFF 91420(1)	S.4



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Checked by:
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Designed by:

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17 February 2016 4:04 PM

CALCULATIONS

Peak Discharge Estimates

Scour

Stream Barb Sizing

Riprap Sizing

ELJ Sizing

FLOOD DISCHARGE ESTIMATES
UNGAGED WASHINGTON SITES

Project: Hoh River Bank Stabilization Study - WA JEFF 91420(1) **File:** reg-spec2014
Desc: Major Drainage Peak Flow **By:** S. Leon

Region: 1 **Date:** 12/10/2015

Exceed Prob.	Coefficients a	b	c	Error
0.50	0.350	0.923	1.240	32.00%
0.10	0.502	0.921	1.260	33.00%
0.04	0.590	0.921	1.260	34.00%
0.02	0.666	0.921	1.260	36.00%
0.01	0.745	0.922	1.260	37.00%

Equation: Q = a(A)^b(P)^c
Source: Magnitude and Frequency of Floods in Washington, 1998. USGS Report 97-4277

Culvert Type	HW/D	K	M	a
CMP Projecting	1.0	0.5	0.667	2.827

Station	Drain. Area (sq mi)	Mean Annual Precip (in)	Forest Cover (%)	Estimated Discharge (Q) Exceedance Probability 0.50 (cfs)	0.10 (cfs)	0.04 (cfs)	0.02 (cfs)	0.01 (cfs)	0.02 Design (cfs)	Min. Culvert Dia (ft)
Maximum	1294	201								
Minimum	0.15	45								
				0	0	0	0	0	0	0.0
				0	0	0	0	0	0	0.0
MP 4.0 - Streamstats	223.00	168		29,600	46,500	54,700	61,700	69,400		
MP 7.8 - Streamstats	210.00	170		28,400	44,700	52,500	59,300	66,700		
USGS 12041200	PEAKFQ			32,660	52,390	61,460	67,890	74,060		
USGS 12041200		Tab. 2		32,200	51,100	59,700	65,700	71,400		
-weighted	253.00	Tab. 2		32,000	51,000	59,600	65,700	71,200		
MP 4.0	223.00	0.88		28,492	45,409	53,066	58,497	63,394		
MP 7.8	210.00	0.83		26,960	42,968	50,213	55,352	59,986		
	x =	0.92								

Notes:

a = ((HW/D)/K)^(1/M)

K = Constant from Table 9, HDS-5

M = Constant from Table 9, HDS-5

D = [Q/(0.7844x(1/K^1/M))]^.4 from HDS-5, equation 27. Assumes HW/D < 1.2 ,unsubmerged.

StreamStats Version 3.0

Basin Characteristics Ungaged Site Report

Date: Tues Feb 23, 2016 9:31:37 AM GMT-8
Study Area: Washington
NAD 1983 Latitude: 47.8203 (47 49 13)
NAD 1983 Longitude: -124.1974 (-124 11 51)

Label	Value	Units	Definition
DRNAREA	223.08	square miles	Area that drains to a point on a stream
RELIEF	7660	feet	Maximum - minimum elevation
ELEVMAX	7900	feet	Maximum basin elevation
MINBELEV	244	feet	Minimum basin elevation
ELEV	2670	feet	Mean Basin Elevation
CANOPY_PCT	69.5	percent	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267
PRECIP	168	inches	Mean Annual Precipitation
SLOP30_30M	79.9	percent	Percent area with slopes greater than 30 percent from 30-meter DEM.
BSLDEM30M	52.5	percent	Mean basin slope computed from 30 m DEM
NFSL30	22.8	percent	North-Facing Slopes Greater Than 30 Percent

StreamStats Version 3.0

Flow Statistics Ungaged Site Report

Date: Tues Feb 23, 2016 9:33:32 AM GMT-8
Study Area: Washington
NAD 1983 Latitude: 47.8203 (47 49 13)
NAD 1983 Longitude: -124.1974 (-124 11 51)
Drainage Area: 223.08 mi2

Peak-Flow Basin Characteristics			
100% Region 1 (222 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	223	0.15	1294
Mean Annual Precipitation (inches)	168	45	201
1% Region 2 (1.24 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	223	0.08	3020
Mean Annual Precipitation (inches)	168	23	170

Peak-Flow Statistics Area-Averaged						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max
PK2	29600	cfs	32	1		
PK10	46500	cfs	33	2		
PK25	54700	cfs	34	3		
PK50	61700	cfs	36	3		
PK100	69400	cfs	37	4		
PK500	86800	cfs				

Peak-Flow Statistics Region_1						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max
PK2	29600	cfs	32	1		
PK10	46500	cfs	33	2		
PK25	54700	cfs	34	3		
PK50	61700	cfs	36	3		
PK100	69400	cfs	37	4		
PK500	86800	cfs				

Peak-Flow Statistics Region_2						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max

PK2	23700	cfs	56	1		
PK10	43900	cfs	53	1		
PK25	54600	cfs	53	2		
PK50	65200	cfs	53	2		
PK100	73700	cfs	54	3		
PK500	98600	cfs				

http://pubs.er.usgs.gov/usgspubs/wri/wri974277# (http://pubs.er.usgs.gov/usgspubs/wri/wri974277#)
Sumioka_ S.S._ Kresch_ D.L._ and Kasnick_ K.D._ 1998_ Magnitude and Frequency of Floods in Washington: U.S. Geological Survey Water-Resources Investigations Report 97-4277_ 91 p.

StreamStats Version 3.0

Basin Characteristics Ungaged Site Report

Date: Tues Feb 23, 2016 9:39:25 AM GMT-8
Study Area: Washington
NAD 1983 Latitude: 47.8145 (47 48 52)
NAD 1983 Longitude: -124.1187 (-124 07 08)

Label	Value	Units	Definition
DRNAREA	210.11	square miles	Area that drains to a point on a stream
RELIEF	undefined	feet	Maximum - minimum elevation
ELEVMAX	undefined	feet	Maximum basin elevation
MINBELEV	undefined	feet	Minimum basin elevation
ELEV	2790	feet	Mean Basin Elevation
CANOPY_PCT	69.4	percent	Percentage of drainage area covered by canopy as described in OK SIR 2009_5267
PRECIP	170	inches	Mean Annual Precipitation
SLOP30_30M	undefined	percent	Percent area with slopes greater than 30 percent from 30-meter DEM.
BSLDEM30M	undefined	percent	Mean basin slope computed from 30 m DEM
NFSL30	undefined	percent	North-Facing Slopes Greater Than 30 Percent

StreamStats Version 3.0

Flow Statistics Ungaged Site Report

Date: Tues Feb 23, 2016 9:40:18 AM GMT-8
Study Area: Washington
NAD 1983 Latitude: 47.8145 (47 48 52)
NAD 1983 Longitude: -124.1187 (-124 07 08)
Drainage Area: 210.11 mi2

Peak-Flow Basin Characteristics			
99% Region 1 (209 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	210	0.15	1294
Mean Annual Precipitation (inches)	170	45	201
1% Region 2 (1.24 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	210	0.08	3020
Mean Annual Precipitation (inches)	170	23	170

Peak-Flow Statistics Area-Averaged						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max
PK2	28400	cfs	32	1		
PK10	44700	cfs	33	2		
PK25	52500	cfs	34	3		
PK50	59300	cfs	36	3		
PK100	66700	cfs	37	4		
PK500	83400	cfs				

Peak-Flow Statistics Region_1						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max
PK2	28400	cfs	32	1		
PK10	44700	cfs	33	2		
PK25	52500	cfs	34	3		
PK50	59300	cfs	36	3		
PK100	66700	cfs	37	4		
PK500	83300	cfs				

Peak-Flow Statistics Region_2						
Statistic	Value	Unit	Prediction Error (percent)	Equivalent years of record	90-Percent Prediction Interval	
					Min	Max

PK2	22900	cfs	56	1		
PK10	42500	cfs	53	1		
PK25	52900	cfs	53	2		
PK50	63100	cfs	53	2		
PK100	71400	cfs	54	3		
PK500	95500	cfs				

http://pubs.er.usgs.gov/usgspubs/wri/wri974277# (http://pubs.er.usgs.gov/usgspubs/wri/wri974277#)
Sumioka_ S.S._ Kresch_ D.L._ and Kasnick_ K.D._ 1998_ Magnitude and Frequency of Floods in Washington: U.S. Geological Survey Water-Resources Investigations Report 97-4277_ 91 p.

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.002.000
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    02/24/2015 08:07

                          --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\MyFiles\Projects\Upper Hoh River -
Phase 2\Calculations\PEAK.TXT
                         specifications - C:\MyFiles\Projects\Upper Hoh River -
Phase 2\Calculations\PKFQWPSF.TMP
                      Output file(s):
                         main - C:\MyFiles\Projects\Upper Hoh River - Phase
2\Calculations\PEAK.PRT

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.001.001
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    02/24/2015 08:07

         Station - 12041200  HOH RIVER AT US HIGHWAY 101 NEAR FORKS, WA


                       I N P U T   D A T A   S U M M A R Y

                 Number of peaks in record            =       54
                 Peaks not used in analysis           =        0
                 Systematic peaks in analysis         =       54
                 Historic peaks in analysis           =        0
                 Beginning Year                       =     1961
                 Ending Year                          =     2014
                 Historical Period Length             =        0
                 Generalized skew                     =    0.140
                      Standard error                  =    0.550
                      Mean Square error               =    0.303
                 Skew option                          =   WEIGHTED
                 Gage base discharge                  =      0.0
                 User supplied high outlier threshold =   --
                 User supplied PILF (LO) criterion    =   --
                 Plotting position parameter          =     0.00
                 Type of analysis                       BULL.17B
                 PILF (LO) Test Method                      GBT
                 Perception Thresholds             =   Not Applicable
                 Interval Data                     =   Not Applicable


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********

    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                    0.0
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.           10742.3
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.      95993.7
```

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
SYSTEMATIC RECORD	0.104	0.270	144.000	54

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 02/24/2015 08:07

Station - 12041200 HOH RIVER AT US HIGHWAY 101 NEAR FORKS, WA

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	4.5067	0.1700	-0.423
BULL.17B ESTIMATE	0.0	1.0000	4.5067	0.1700	-0.258

BULL.17B ESTIMATE OF MSE OF AT-SITE SKEW 0.1247

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	<-- FOR BULLETIN 17B ESTIMATES --> VARIANCE OF EST.	95% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	10660.	10040.	----	8467.0	12670.0
0.9900	12000.	11470.	----	9731.0	14060.0
0.9500	16410.	16150.	----	14000.0	18580.0
0.9000	19260.	19170.	----	16820.0	21470.0
0.8000	23240.	23350.	----	20780.0	25550.0
0.6667	27520.	27780.	----	24990.0	30060.0
0.5000	32660.	33010.	----	29900.0	35710.0
0.4292	34990.	35340.	----	32060.0	38370.0
0.2000	44820.	44880.	----	40730.0	50180.0
0.1000	52390.	51920.	----	47080.0	59810.0
0.0400	61460.	60000.	----	54420.0	71810.0
0.0200	67890.	65490.	----	59500.0	80550.0
0.0100	74060.	70590.	----	64290.0	89120.0
0.0050	80030.	75370.	----	68870.0	97560.0
0.0020	87700.	81280.	----	74670.0	108600.0

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 02/24/2015 08:07

Station - 12041200 HOH RIVER AT US HIGHWAY 101 NEAR FORKS, WA

I N P U T   D A T A   L I S T I N G

WATER YEAR	PEAK VALUE	PEAKFQ CODES	REMARKS
1961	46000.0		
1962	15900.0		
1963	45400.0		
1964	26500.0		
1965	24300.0		
1966	19900.0		
1967	30100.0		
1968	31700.0		
1969	22200.0		
1970	19800.0		
1971	20200.0		
1972	32400.0		
1973	35400.0		
1974	31200.0		
1975	27600.0		
1976	41200.0		
1977	11700.0		
1978	44800.0		
1979	16500.0		
1980	51600.0		
1981	51100.0		
1982	32100.0		
1983	47900.0		
1984	42000.0		
1985	20900.0		
1986	41700.0		
1987	48600.0		
1988	23400.0		
1989	49300.0		
1990	40600.0		
1991	54500.0		
1992	29000.0		
1993	25700.0		
1994	31700.0		
1995	34600.0		
1996	47600.0		
1997	44500.0		
1998	28400.0		
1999	34800.0		
2000	41400.0		
2001	16100.0		
2002	45900.0		
2003	30900.0		
2004	62100.0		
2005	32700.0		
2006	23300.0		
2007	60700.0		
2008	55700.0		
2009	38200.0		
2010	30400.0		
2011	40300.0		
2012	22800.0		
2013	17000.0		
2014	20900.0		

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- \- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- \- Minus-flagged water year -- Historic peak used in computation

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Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 02/24/2015 08:07

Station - 12041200 HOH RIVER AT US HIGHWAY 101 NEAR FORKS, WA

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	B17B ESTIMATE
2004	62100.0	0.0182	0.0182
2007	60700.0	0.0364	0.0364
2008	55700.0	0.0545	0.0545
1991	54500.0	0.0727	0.0727
1980	51600.0	0.0909	0.0909
1981	51100.0	0.1091	0.1091
1989	49300.0	0.1273	0.1273
1987	48600.0	0.1455	0.1455
1983	47900.0	0.1636	0.1636
1996	47600.0	0.1818	0.1818
1961	46000.0	0.2000	0.2000
2002	45900.0	0.2182	0.2182
1963	45400.0	0.2364	0.2364
1978	44800.0	0.2545	0.2545
1997	44500.0	0.2727	0.2727
1984	42000.0	0.2909	0.2909
1986	41700.0	0.3091	0.3091
2000	41400.0	0.3273	0.3273
1976	41200.0	0.3455	0.3455
1990	40600.0	0.3636	0.3636
2011	40300.0	0.3818	0.3818
2009	38200.0	0.4000	0.4000
1973	35400.0	0.4182	0.4182
1999	34800.0	0.4364	0.4364
1995	34600.0	0.4545	0.4545
2005	32700.0	0.4727	0.4727
1972	32400.0	0.4909	0.4909
1982	32100.0	0.5091	0.5091
1968	31700.0	0.5273	0.5273
1994	31700.0	0.5455	0.5455
1974	31200.0	0.5636	0.5636

2003	30900.0	0.5818	0.5818
2010	30400.0	0.6000	0.6000
1967	30100.0	0.6182	0.6182
1992	29000.0	0.6364	0.6364
1998	28400.0	0.6545	0.6545
1975	27600.0	0.6727	0.6727
1964	26500.0	0.6909	0.6909
1993	25700.0	0.7091	0.7091
1965	24300.0	0.7273	0.7273
1988	23400.0	0.7455	0.7455
2006	23300.0	0.7636	0.7636
2012	22800.0	0.7818	0.7818
1969	22200.0	0.8000	0.8000
1985	20900.0	0.8182	0.8182
2014	20900.0	0.8364	0.8364
1971	20200.0	0.8545	0.8545
1966	19900.0	0.8727	0.8727
1970	19800.0	0.8909	0.8909
2013	17000.0	0.9091	0.9091
1979	16500.0	0.9273	0.9273
2001	16100.0	0.9455	0.9455
1962	15900.0	0.9636	0.9636
1977	11700.0	0.9818	0.9818

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End PeakFQ analysis.
Stations processed : 1
Number of errors : 0
Stations skipped : 0
Station years : 54

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4, or *.)
(2, 4, and * records are ignored.)

For the station below, the following records were ignored:

FINISHED PROCESSING STATION: 12041200 USGS HOH RIVER AT US HIGHWAY 101 N

For the station below, the following records were ignored:

FINISHED PROCESSING STATION:

SCOUR ESTIMATE

Project:	**Hoh River Bank Stabilization Study - WA JEFF 91420(1)**	File:	**scour18-5.xls**
Desc:	**MP 4.0 and 7.8 Bank Stabilization**	Date:	**12/23/2015**
Units:	**ENG**	By:	**S. Leon**

		Location Description			
		MP 4.0/50-year/Stream Barbs	MP 4.0/50-year/Wood Buffer	MP 7.8/50-year/Stream Barbs	MP 7.8/50-year/Wood Buffer
CONSTANTS					
UNITS	SI or ENG	ENG	ENG	ENG	ENG
g	ACCELERATION OF GRAVITY, 9.81 m/s2, 32.2 ft/s2	32.20	32.20	32.20	32.20
Du	D UNIT CONVERSION, 0.001 SI, 0.00328 English	0.00328	0.00328	0.00328	0.00328
LIVE-BED OR CLEAR-WATER DETERMINATION					
y	AVERAGE FLOW DEPTH, m, ft	15.0	15.0	15.0	15.0
D50	DIAMETER 50% FINER BED PARTICLES, mm	76	76	178	178
V	AVERAGE VELOCITY, m/s, ft/s	10.0	10.0	8.0	8.0
Ku	UNIT COEFFICIENT, 6.19 SI, 11.17 English	11.170	11.170	11.170	11.170
Vc (6.1)	CRITICAL VELOCITY, m/s, ft/s	11.05	11.05	14.67	14.67
LB / CW	LIVE BED or CLEAR WATER	CW	CW	CW	CW
LIVE-BED CONTRACTION SCOUR					
y1	AVERAGE U/S DEPTH, MAIN CHANNEL, m, ft	15.0	15.0	12.0	12.0
y0	AVERAGE CONTRACTED DEPTH BEFORE SCOUR, m, ft	18.0	18.0	15.0	15.0
Q1	FLOW IN UPSTREAM CHANNEL, m3/s, ft3/S	58497.0	58497.0	55352.0	55352.0
Q2	FLOW IN CONTRACTED CHANNEL, m3/s, ft3/S	58497.0	58497.0	55352.0	55352.0
W1	WIDTH OF THE UPSTREAM CHANNEL, m, ft	450.0	450.0	280.0	280.0
W2	WIDTH OF THE CONTRACTED SECTION, m, ft	330.0	330.0	280.0	280.0
S1	ENERGY SLOPE OF MAIN CHANNEL, m/m, ft/ft	0.010	0.010	0.010	0.010
w (Fig 6.8)	D50 FALL VELOCITY, m/s	0.500	0.500	0.500	0.500
	UNIT COEFFICIENT, 1.0 SI, 3.28 English	3.28	3.28	3.28	3.28
	D50 FALL VELOCITY, m/s, ft/s	1.640	1.640	1.640	1.640
k1 (p6.10)	TRANSPORT COEFFICIENT	0.64	0.64	0.64	0.64
	BED MATERIAL TRANSPORT MODE	BL/SL	BL/SL	BL/SL	BL/SL
V*	SHEAR VELOCITY, m/s, ft/s	2.20	2.20	1.97	1.97
y2 (6.2)	AVERAGE DEPTH, CONTRACTED SECTION, m, ft	18.29	18.29	12.00	12.00
yS (6.3)	AVERAGE SCOUR DEPTH, m, ft	0.29	0.29	0.00	0.00
As	AVERAGE SCOUR AREA, m2, ft2	96.88	96.88	0.00	0.00

SCOUR ESTIMATE

Project: **Hoh River Bank Stabilization Study - WA JEFF 91420(1)** File: **scour18-5.xls**
Desc: **MP 4.0 and 7.8 Bank Stabilization** Date: **12/23/2015**
Units: **ENG** By: **S. Leon**

		Location Description			
		MP 4.0/50-year/Stream Barbs	MP 4.0/50-year/Wood Buffer	MP 7.8/50-year/Stream Barbs	MP 7.8/50-year/Wood Buffer
CLEAR-WATER CONTRACTION SCOUR					
y0	AVERAGE CONTRACTED DEPTH BEFORE SCOUR, m, ft	18.0	18.0	15.0	15.0
D50	MEDIAN DIAMETER BED MATERIAL, mm	76	76	178	178
Q	DISCHARGE THROUGH THE BRIDGE, m3/s, ft3/s	58497.0	58497.0	55352.0	55352.0
W	BOTTOM WIDTH OF THE CONTRACTED SECTION, m, ft	330.0	330.0	280.0	280.0
Ku	UNIT COEFFICIENT, 0.025 SI, 0.0077 English	0.0077	0.0077	0.0077	0.0077
Dm	DIA. SMALLEST NONTRANSPORT PARTICLE, m, ft	0.3116	0.3116	0.7298	0.7298
y2 (6.4)	AVERAGE DEPTH, CONTRACTED SECTION, m, ft	14.67	14.67	12.63	12.63
yS (6.5)	AVERAGE SCOUR DEPTH, m, ft	0.00	0.00	0.00	0.00
As	AVERAGE SCOUR AREA, m2, ft2	0.00	0.00	0.00	0.00
BEND SCOUR					
WS	WATER SURFACE ELEVATION, ft	267.0	267.0	325.0	325.0
Fs	FACTOR OF SAFETY, 1.0 to 1.1	1.0	1.0	1.0	1.0
Rc	BEND RADIUS OF CURVATURE, ft	400.0	400.0	400.0	400.0
Wi	CHANNEL WIDTH AT BEND INFLECTION POINT, ft	330.0	330.0	280.0	280.0
yc	MEAN WATER DEPTH UPSTREAM OF BEND, ft	12.0	12.0	12.0	12.0
Rc/Wi	BETWEEN 1.5 AND 10	1.21	1.21	1.43	1.43
Wi/yc	BETWEEN 20 AND 125	27.50	27.50	23.33	23.33
Ymax	MAXIMUM WATER DEPTH IN BEND, ft	23.63	23.63	23.08	23.08
SElev	SCOUR ELEVATION, ft	243.4	243.4	301.9	301.9
	Maynord (1996) - 210-VI-NEH, Aug. 2007.				
BARB SCOUR					
H	WATER DEPTH UPSTREAM OF BARB, ft	15.0		15.0	
d16	PARTICLE SIZE GRADATION - 16% FINER, ft	0.15		0.33	
d50	PARTICLE SIZE GRADATION - 50% FINER, ft	0.25		0.60	
d84	PARTICLE SIZE GRADATION - 84% FINER, ft	0.40		0.80	
g	GRAVITATIONAL ACCELERATION, ft/sec	32.2		32.2	
L	AVERAGE BARB LENGTH, ft	90.0		90.0	
V	AVERAGE FLOW VELOCITY OVER BARB, ft/sec	12.0		12.0	
segma g	d84/d16	1.6		1.6	
Q	DISCHARGE OVER BARB, ft3/s	8100.0		8100.0	
dsm	MAXIMUM SCOUR SEPTH, ft	11.2		15.0	
	Papanicolaou (2004) - WSDOT WA-RD 581.1				

SCOUR ESTIMATE

Project:	Hoh River Bank Stabilization Study - WA JEFF 91420(1)	File:	scour18-5.xls
Desc:	MP 4.0 and 7.8 Bank Stabilization	Date:	12/23/2015
Units:	ENG	By:	S. Leon

	Location Description			
	MP 4.0/50-year/Stream Barbs	MP 4.0/50-year/Wood Buffer	MP 7.8/50-year/Stream Barbs	MP 7.8/50-year/Wood Buffer
SCOUR SUMMARY				
Base Elevation	252.0	252.0	313.0	313.0
DEPTH				
Live Bed Contraction	0.3	0.3	0.0	0.0
Clear Water Contraction	0.0	0.0	0.0	0.0
Bend		8.6		11.1
Barb	11.2		15.0	
Bend + Contraction		8.6		11.1
Barb + Contraction	11.5		15.0	0.0
ELEVATION				
Live Bed Contraction	251.7	251.7	313.0	313.0
Clear Water Contraction	252.0	252.0	313.0	313.0
Bend		243.4		301.9
Barb	240.8		298.0	
Bend + Contraction		243.4		301.9
Barb + Contraction	240.5		298.0	

Note:

S. Leon 12/23/15

HEC 18, 5th ED. 4/2012 (EQUATIONS SHOWN IN PARENTHESIS)

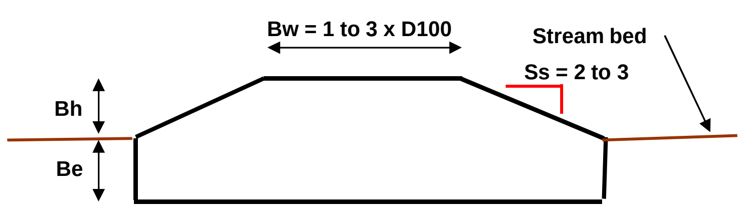
STREAM BARB STABILITY / DESIGN

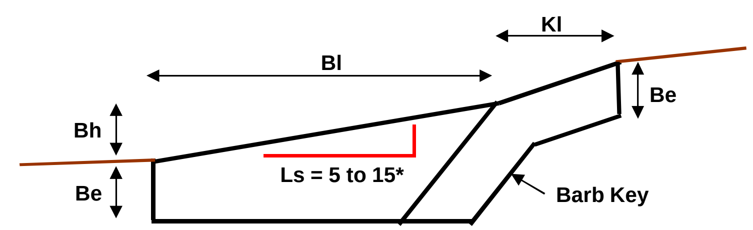
Project: **Hoh River Bank Stabilization Study - WA JEFF 91420(1)**　　File: streambarb3.xls

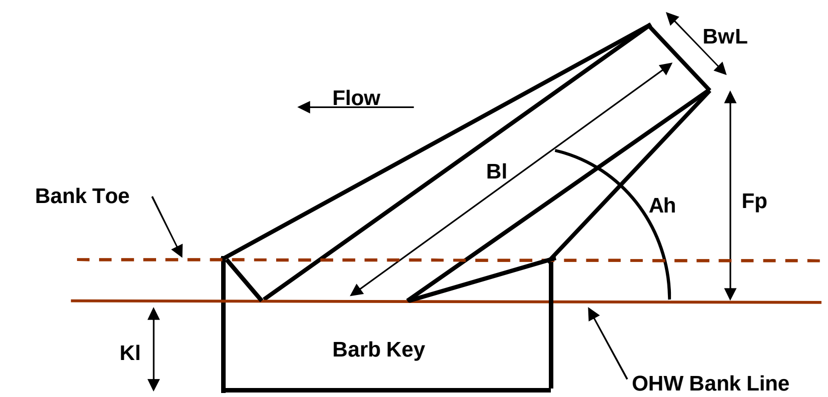
Desc: **MP 4.0 and 7.8 Bank Stabilization**　　Date: 12/14/2015　　By: S. Leon

Gw 62.4 lbs/ft3　　Gs 165 lbs/ft3　　g 32.2 ft/s2

	Hydraulic Data							Design															Barb Stone Sizing						Stone Stability (D15)								
																													Sliding								Moment
																													Fluid Drag (Fd)				Friction (Ff)			FSs	
Location	Q (cfs)	Event (yr)	V (fps)	BCW (ft)	OHW (ft)	Rc (ft)	Rc/BCW	Ah (deg)	Bh (ft)	Ls (h:1v)	Ss (h:1v)	Kl (ft)	D100/ D15	D100 (in)	Bw (ft)	Be (ft)	Bl (ft)	Fp (ft)	Fp/BCW (.33 max)	Vol Barb (cy)	Vol Key (cy)	Key Class (cy)	Cs	Cv	C	D (in)	W (lbs)	Gradation	Cd	A (sf)	Fd (lbs)	f	W' (lbs)	FL (lbs)	Ff (lbs)		FSm
															2																						
Site		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6		27	5	2	90	45.0	0.14	475	186	5	1.00	1.30	0.88	27	1028	8	0.5	4.1	286	0.8	639	243	317	1.1	3.3
		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6		32	5	3	90	45.0	0.14	520	222	5	1.00	1.30	0.88	32	1638	8	0.5	5.6	390	0.8	1019	331	550	1.4	4.0
D100 check		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6		64	11	5	90	45.0	0.14	884	516	5	1.00	1.30	0.88	64	13106	8	0.5	22.3	1559	0.8	8150	1325	5460	3.5	8.7
D85 check		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6			10.0	8.0	90	45.0	0.14	1083	880		1.00	1.30	0.88	45	4495	8	0.5	10.9	764	0.8	2795	649	1717	2.2	5.9
D50 check		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6											1.00	1.30	0.88	32	1638	8	0.5	5.6	390	0.8	1019	331	550	1.4	4.0
D15 check		50	12.0	330	8	400	1.2	30	10	9.0	1.5	6											1.00	1.30	0.88	24	655	8	0.5	3.0	212	0.8	408	180	182	0.9	2.8







Gradation (FHWA-FP-14)				
% Passing		Gradation Type		
STONE (in)	D85/D	8		
100	0.70	64	0	0
85	1.00	45	0	0
50	1.40	32	0	0
15	1.90	24		
D85/D15		1.9		

Assume: Stone is angular blocky shape, long/short axis <2.5, and 1.5< D85/D15 <2.5.

Notes: Method from NRCS, Engineering technical note no. 23, Design of stream barbs, version 2.0, April, 2005.

Q	Design discharge
Event	Design discharge flood event
V	Average channel flow velocity
BCW	Bankfull channel width
OHW	Oridinary high water depth
Rc	Channel curve radius
Rc/BCW	Tortuosity
Ah	Horizontal angle of barb relative to tangent line of the bank.
	Ah maximum = 30 except when Rc/W < 3 Ah maximum 25
KL	Length key extends into stream bank.
D100/D15	Ratio D100 to D15
D100	Maximum stone diameter
Fp/BCW	Ratio of Fp to BCW, .33 maximum.
Vol	Stone volume per barb

Cs	Shape factor (1 for angular, 1.25 for rounded)
Cv	Velocity factor (1 for straight uncontracted flow, 1.25 for skewed contracted flow)
C	Isabash constant (0.88 for high turbulence, 1.2 for low)
D15	Cs*Cv*(V/(C [2g (Gs-Gw)/Gw)]^.5))^2 , S<2% (From EM 1110-2-1601)
W15	Weight of D15
Gradation	Gradation type, See table this sheet.
Cd	Fluid drag coefficient, 0.3 to 0.5 typical, 2.0 for partially submerged rocks.
A	Rock area exposed to hydraulic force
Fd	Fluid drag
f	Friction factor, 0.8 typically
W'	Submerged weight of stone
FL	0.85 x Fd (Chepil, 1958)
Ff	Force due to friction
FSs	Sliding factor of safety, 1.5 minimum.
FSm	Moment factor of safety, 1.5 minimum.

RIPRAP DESIGN - USACE

Project: **Hoh River Bank Stabilization Study - WA JEFF 91420(1)** File: **riprap2015**

Desc: **MP 4.0 and 7.8 Bank Stabilization** By: **S. Leon** Date: **12/12/15**

CHANNEL, REVETMENT, AND ABUTMENT

Location			Design Input																				Riprap																					
		Riprap	Flow			Riprap						Coefficients											Weight							Cubic Dimension					Quantity /ft					Total Quantity		Cost	
Slope	Desc	Class	Vavg (f/s)	D (ft)	Tdes (ft)	D100/ 85	50	30	15	Sb (h:1v)	Phi (deg)	Vh	SF	Cs	R (ft)	W (ft)	R/W	Cv	Vdes (ft/s)	Ct	Gs (lb/ft3)	W15 (lbs)	W30 (lbs)	W50 (lbs)	W85 (lbs)	W100 (lbs)	C85/ C15	K1	D15 (in)	D30 (in)	D50 (in)	D85 (in)	D100 (in)	Toe (cy)	Slope (cy)	Total (cy)	Geo (sy)	<OHW (cy)	Riprap (cy)	<OHW (cy)	$/ft	Total
			50-yr			1.4	1.9	2.2	2.7				0.1																													
1.5:1		4	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.50	41	1.0	1.1	0.3	400	330	1.2	1.3	13.0	1.0	165	62	110	178	444	1,219	1.9	0.5	11	13	15	21	29	0.0	5.0	5.0	5.0	0.8	451	451	$ 550	$ 49,500
		4	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.50	41	1.0	1.2	0.3	400	330	1.2	1.3	13.0	1.0	165	76	137	217	543	1,489	1.9	0.5	11	14	16	22	31	0.0	5.0	5.0	5.0	0.8	451	451	$ 550	$ 49,500
	DESIGN	5	10.0	15.0	4.0	1.4	1.9	2.2	2.7	1.50	41	1.0	1.3	0.3	400	330	1.2	1.3	13.0	1.0	165	91	169	262	655	1,797	1.9	0.5	12	15	17	24	33	0.0	6.7	6.7	5.0	1.1	601	451	$ 730	$ 65,700
		5	10.0	15.0	4.0	1.4	1.9	2.2	2.7	1.50	41	1.0	1.4	0.3	400	330	1.2	1.3	13.0	1.0	165	109	205	313	781	2,144	1.9	0.5	13	16	18	25	35	0.0	6.7	6.7	5.0	1.1	601	451	$ 730	$ 65,700
		6	10.0	15.0	5.0	1.4	1.9	2.2	2.7	1.50	41	1.0	1.5	0.3	400	330	1.2	1.3	13.0	1.0	165	129	246	369	923	2,532	1.9	0.5	14	17	19	26	37	0.0	8.3	8.3	5.0	1.3	751	451	$ 920	$ 82,800
1.75:1		3	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.75	41	1.0	1.1	0.3	400	330	1.2	1.3	13.0	1.0	165	27	50	78	194	532	1.9	0.7	8	10	12	16	22	0.0	5.6	5.6	5.6	0.9	504	504	$ 620	$ 55,800
		3	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.75	41	1.0	1.2	0.3	400	330	1.2	1.3	13.0	1.0	165	35	67	101	252	691	1.9	0.7	9	11	13	17	24	0.0	5.6	5.6	5.6	0.9	504	504	$ 620	$ 55,800
		4	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.75	41	1.0	1.3	0.3	400	330	1.2	1.3	13.0	1.0	165	45	86	128	320	879	1.9	0.7	10	12	14	19	26	0.0	5.6	5.6	5.6	0.9	504	504	$ 620	$ 55,800
		4	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.75	41	1.0	1.4	0.3	400	330	1.2	1.3	13.0	1.0	165	45	86	128	320	879	1.9	0.7	10	12	14	19	26	0.0	5.6	5.6	5.6	0.9	504	504	$ 620	$ 55,800
		4	10.0	15.0	3.0	1.4	1.9	2.2	2.7	1.75	41	1.0	1.5	0.3	400	330	1.2	1.3	13.0	1.0	165	62	110	178	444	1,219	1.9	0.7	11	13	15	21	29	0.0	5.6	5.6	5.6	0.9	504	504	$ 620	$ 55,800
2.0:1		2	10.0	15.0	2.0	1.4	1.9	2.2	2.7	2.00	41	1.0	1.1	0.3	400	330	1.2	1.3	13.0	1.0	165	20	36	58	146	400	1.9	0.7	7	9	11	14	20	0.0	4.1	4.1	6.2	0.7	373	559	$ 460	$ 41,400
		2	10.0	15.0	2.0	1.4	1.9	2.2	2.7	2.00	41	1.0	1.2	0.3	400	330	1.2	1.3	13.0	1.0	165	20	36	58	146	400	1.9	0.7	7	9	11	14	20	0.0	4.1	4.1	6.2	0.7	373	559	$ 460	$ 41,400
		2	10.0	15.0	2.0	1.4	1.9	2.2	2.7	2.00	41	1.0	1.3	0.3	400	330	1.2	1.3	13.0	1.0	165	27	50	78	194	532	1.9	0.7	8	10	12	16	22	0.0	4.1	4.1	6.2	0.7	373	559	$ 460	$ 41,400
		2	10.0	15.0	2.0	1.4	1.9	2.2	2.7	2.00	41	1.0	1.4	0.3	400	330	1.2	1.3	13.0	1.0	165	35	67	101	252	691	1.9	0.7	9	11	13	17	24	0.0	4.1	4.1	6.2	0.7	373	559	$ 460	$ 41,400
		2	10.0	15.0	2.0	1.4	1.9	2.2	2.7	2.00	41	1.0	1.5	0.3	400	330	1.2	1.3	13.0	1.0	165	45	86	128	320	879	1.9	0.7	10	12	14	19	26	0.0	4.1	4.1	6.2	0.7	373	559	$ 460	$ 41,400

DESIGN: Class 5, 1.5(h):1(v), 4 feet thick.

Notes:

Approach from Army Corps of Engineers EM 1110-2-1601, Change 1, Jun 30, 1994, Chapter 3.

Vavg	Local depth-averaged velocity.
D	Local depth of flow.
Tdes	Design riprap layer thickness. Largest of 2 **x D50 or** 1.2 **x D100**
Sb	Bank sideslope (0 = Channel bottom analysis).
Phi	Riprap angle of repose.
Vh	Horizontal velocity correction facor (1.0 min).
SF	Safety factor 1.3 **minimum**
R	Radius of curvature
W	Width of stream
Cs	Stability (0.30 for angular rock, 0.38 for round rock).
Cv	Vertical velocity distribution (1.0 straight, 1.3 typical bend, 1.5 sharp bend)
Ct	Thickness (0.5 for 2xTdes, 0.9 for 1.5xTdes)
Gs	Unit weight of stone (155 lbs/ft3 min).
Gw	Unit weight of water. 62 lbs/ft3
g	Gravitational constant. 32 ft/s2
K1	Side slope correction = (1-(sin2Sb/sin2Phi))^0.5 (eq. 3-4)
D30	Sf*Cs*Cv*Ct*D*(((Gw/(Gs-Gw))^0.5)*((Vavg*Vh)/((K1*g*D)^0.5)))^2.5 (eq. 3-3)
D15	D100 / D100/15
D50	D100 / D100/50
D85	D100 / D100/85
D100	D100/30 * D30
C85/C15	Uniformity ratio (1.7 to 5.2)

Riprap Class	Cost ($/cy)
2	$110
3	$110
4	$110
5	$110
6	$110
7	$110
8	$110
9	$110
10	$110

Riprap Class	5	
Design Water Surface Elevation	267.0	feet
Freeboard	2.0	feet
Revetment Crest Elevation	269.0	feet
Total Scour Elevation	244.0	feet
Key Toe Top below Scour Elev	0.0	feet
Key Toe Thickness	0.0	feet
Key Toe Top Elevation	244.0	feet
Revetment Bottom Elevation	244.0	feet
Revetment Height	25.0	feet
Key Toe Width	0	x Tdes
Revetment Length	90.0	feet
Ordinary-High-Water Elevation	265.0	feet

Riprap Layout Notes

Riprap costs assumes commercial source near Port Angeles, WA.

ENGINEERED LOG JAM DESIGN

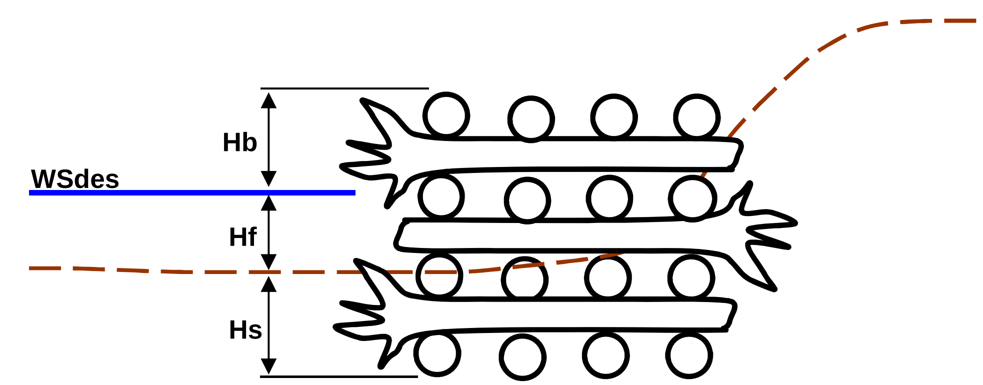
Project: Hoh River Bank Stabilization Study - WA JEFF 91420(1) File: ELJ-1

Desc: ELJ Alternative - Single bundle analysis By: S. Leon Date: 11/10/2015

Avg. Log Dia (in)	Root Area Fact.	Cross Logs: LC (ft)	Cross Logs: Max. No. Per Row	Cross Logs: Des. No. Per Row	Cross Logs: Volume Each (ft3)	Cross Logs: Weight Each (lbs)	Longitudinal Logs: LL (ft)	Longitudinal Logs: Max. No. Per Row	Longitudinal Logs: Des. No. Per Row	Longitudinal Logs: Volume Each (ft3)	Longitudinal Logs: Weight Each (lbs)	Design Quantities: Riprap Mass (ton)	Design Quantities: Log Avg. Dia. (in)	Longitudinal Logs: No.	Longitudinal Logs: Length (ft)	Longitudinal Logs: Spacing (ft)	Cross Logs: No.	Cross Logs: Length (ft)	Cross Logs: Spacing (ft)	Constants Density: Wood (lbs/ft3)	Constants Density: Water (lbs/ft3)	Constants Density: Rock (lbs/ft3)
18	2	20	7	4	35	1,060	20	7	0	35	1,060	0	18	0	20	0.0	4	20	4.7	30	62.4	150
24	2	20	5	2	63	1,885	20	5	0	63	1,885	0	24	0	20	0.0	2	20	16.0	30	62.4	150
36	2	20	3	1	141	4,241	20	3	0	141	4,241	0	36	0	20	0.0	1	20	#DIV/0!	30	62.4	150

Design: WSdes Elev. (ft)	Flood Event (yr)	Hf (ft)	Hs (ft)	Riprap Class	Riprap Void S (%)	Below Design Water Surface: No. Layers Total	No. Layers Long.	No. Layers Cross	Log Volume (ft3)	ELJ Volume (ft3)	Rock Volume (ft3)	Rock Weight (lbs)	End Area (ft2)	Above Design Water Surface: No. Layers Total	No. Layers Long.	No. Layers Cross	Hb (ft)	Log Volume (ft3)	ELJ Volume (ft3)	Rock Volume (ft3)	Log Weight (lbs)	Rock Weight (lbs)
263	50	3	0	3	0.0%	2	0	1	141	1,200	0	0	60	0	0	0	0	0	0	0	0	0
263	50	3	0	3	0.0%	2	0	1	126	1,600	0	0	60	0	0	0	0	0	0	0	0	0
263	50	3	0	3	0.0%	1	0	1	141	1,200	0	0	60	0	0	0	0	0	0	0	0	0

Total Log Weight (lbs)	Buoyancy Safety Factor: Wrb (lbs)	Fb (lbs)	FSb	Sliding Safety Factor: Vavg (ft/s)	VC	Vdes (ft/s)	Cd	Fd (lbs)	Friction Angle (deg)	Ffs (lbs)	FSs	Dolos Ballast: No.	Volume (ft3)	Sub. Weight (lbs)
4,241	13,585	8,822	1.5	12	1.3	16	1.2	16,978	70	13,088	0.8	1	107	9,344
3,770	13,114	7,841	1.7	12	1.3	16	1.2	16,978	70	14,486	0.9	1	107	9,344
4,241	13,585	8,822	1.5	12	1.3	16	1.2	16,978	70	13,088	0.8	1	107	9,344



Notes: (Approach from Design Guidelines for the Reintroduction of Wood into Australian Streams, Abbe/Brooks, 2006)

Gravity 32.2 ft/sec-2

Hf Design flow depth

Hs Depth below predicted scour

Average Log Dia. (End dia. + Base dia. Above root) / 2

Root Factor Root area / Trunk Area

LC Cross Log Length - without rootwad

LL Longitudinal Log Length - without rootwad

Riprap Void S Riprap Void Space - Set to 100% for no riprap

Log Volume Volume of trunk based on log length and average log dia. - excluding rootwad.

Riprap Volume (ELJ Volume - Log Volume) x (1 - Riprap Void S)

Riprap Mass Riprap Volume x Rock Density

Wrb Weight Resisting Buoyancy = Total Log Weight + Rock Weight Above WSdes + Rock Weight Below Wsdes

Fb (mass) Buoyant Force (mass) = Log Volume Submerged x Water Density

FSb Wrb / Fb, 2 minimum

Vavg Average Channel Velocity -

Vc Velocity Correction Factor -

Vdes Design Velocity -

Cd Drag Coefficient, 1.2 (Shields/Knight, 2000)

Fd (mass) Drag = (0.5 x Vdes^2 x Submerged End Area x Water Density x Cd) / g

Friction Angle Rock / Streambed Interface

Ffs (mass) Force Resisting Drag = (Wrb - Fb) x tan(Friction Angle)

FSs Ffs/Fd, 2.0 minimum