SR 104 MP 16.55 Machias Creek (990710): Preliminary Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013, (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), WSDOT is proposing a project to provide fish passage at the State Route (SR) 104 crossing of Machias Creek at milepost (MP) 16.55 within WSDOT's Olympic Region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 990710); and has an estimated 3,481 linear feet of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing and stream simulation is the most suitable methodology for fish passage design due to the size of Machias Creek and the confined system around the project crossing (Section 4).

The crossing is located in Kitsap County, one-half mile west of Port Gamble, Washington, in WRIA 15. The highway runs in a west–east direction at this location and is about 1,000 feet upstream of the confluence with Hood Canal. Machias Creek generally flows from south to north beginning in Port Gamble Heritage Park one mile upstream of the SR 104 crossing (see Figure 1 for vicinity).

The proposed project will replace the existing three-foot diameter and 141-foot-long round concrete culvert with a structure designed to accommodate a minimum hydraulic width of 14 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard, et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022). Structure type is not being recommended by Headquarters Hydraulics and will be determined by others at future design phases.

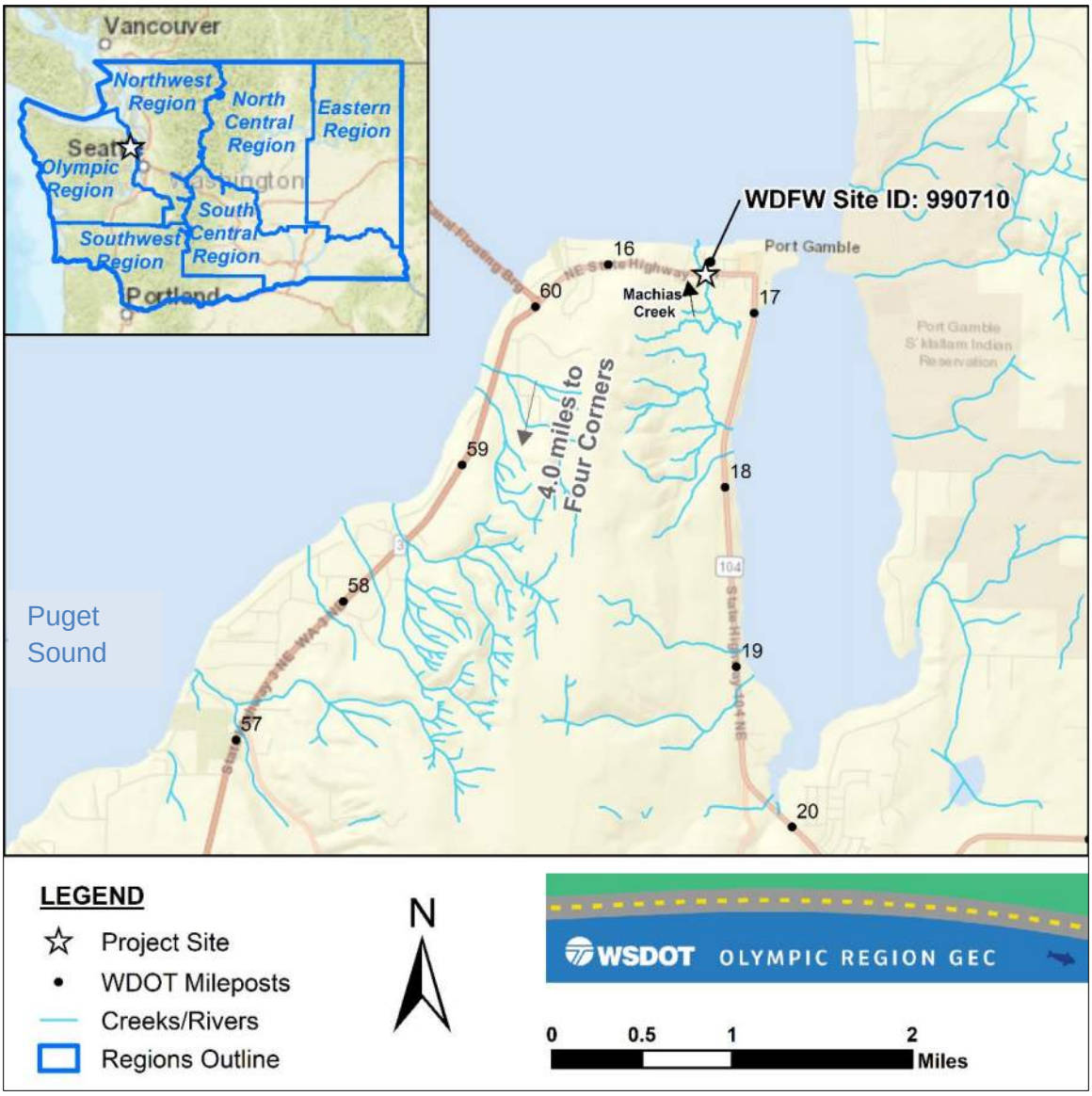

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), Washington Department of Fish and Wildlife (WDFW), and past records like observations and fish passage evaluation.

2.1 Site Description

Crossing 990710 is in Kitsap County in Water Resources Inventory Area (WRIA) 15 on SR 104 at milepost 16.55. It is a barrier to fish migration due to the slope of the undersized culvert which restricts access to an estimated 3,481 linear feet of habitat for salmonid species. The site is not known to flood or a Chronic Environmental Deficiency (CED). WSDOT Area 2 Maintenance was contacted, and the maintenance representative indicated that there was no record of large woody material (LWM) or sediment blockage or removal at this crossing.

2.2 Watershed and Land Cover

The drainage area contributing to crossing 990710 on SR 104 is 167 acres on the north end of Port Gamble Heritage Park (Figure 2). The major stream within the watershed is Machias Creek draining to crossing 990710. The mainstem starts as a small channel on an open field collecting the drainage from the surrounding hills (Figure 2). It flows west to east into a forested valley, converges with a tributary from the east and passes through a flat wooded wetland (see land cover in Figure 3). The channel turns to flow south to north for the lower half of the basin. The channel is flowing north for the crossing SR 104, and flows north approximately another ¼ mile before flowing into Hood Canal. The watershed was delineated using Kitsap County OPSW 2018 LiDAR (DNR 2018). Watershed elevations range from 360 feet, North American Vertical Datum of 1988 (NAVD88) in the Port Gamble Forest Heritage Park to 55 feet near SR 104. In the existing conditions, the creek crosses SR 104 in a 3-foot-diameter round concrete pipe. The invert elevation of the existing culvert inlet is 24.34 feet and the invert elevation of the outlet is 21.19 feet. WSDOT survey crews provided the structure elevations as part of the survey received for this project (Section 2.6.1).

The land cover for the watershed is summarized in Table 1. The prevailing land use in the watershed is forest. The watershed consists of approximately 55.3 percent forest, 27.2 percent pasture cover, and 17.5 percent developed area, based on estimates from National Land Cover Database (NLCD 2019). The 17.5 percent developed area is further broken down into three classes based on the intensity of development: “medium-intensity,” “low-intensity,” and “open-space” (Figure 3). The medium-intensity developed area comprises 1.3 percent of the total basin. Assuming the medium-intensity developed area is all impervious, the impervious area in this watershed is low enough to qualify for hydrology analysis through regression equation (Section 3).

Three other WDFW identified fish barriers (ID: 930873, 930874 and 930875) are found in the watershed draining to the project site. These barriers are located within private properties, hence are not within the scope of this project.

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Forest	55.3
Pasture	27.2
Developed	17.5

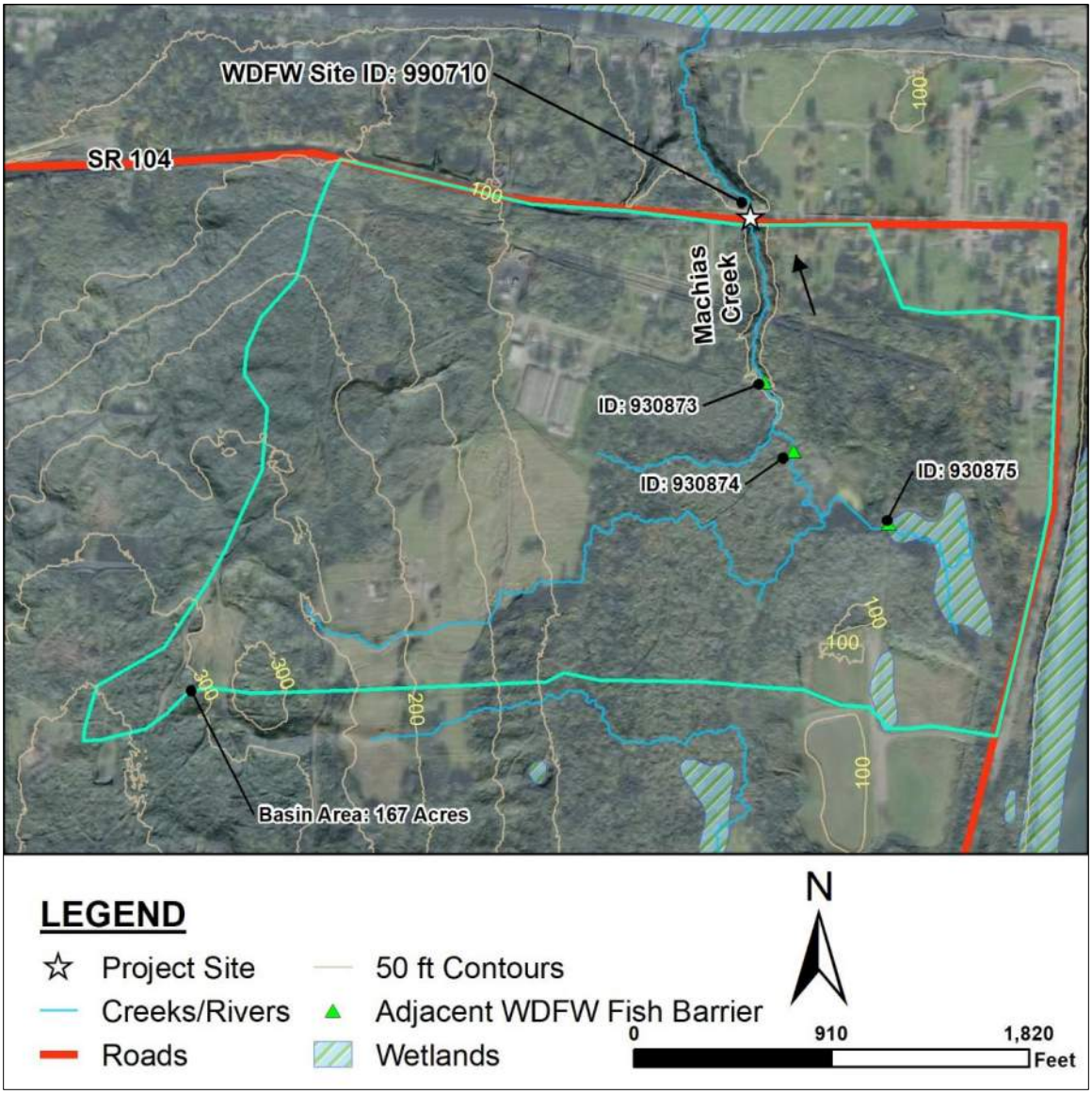

Figure 2: Watershed map.

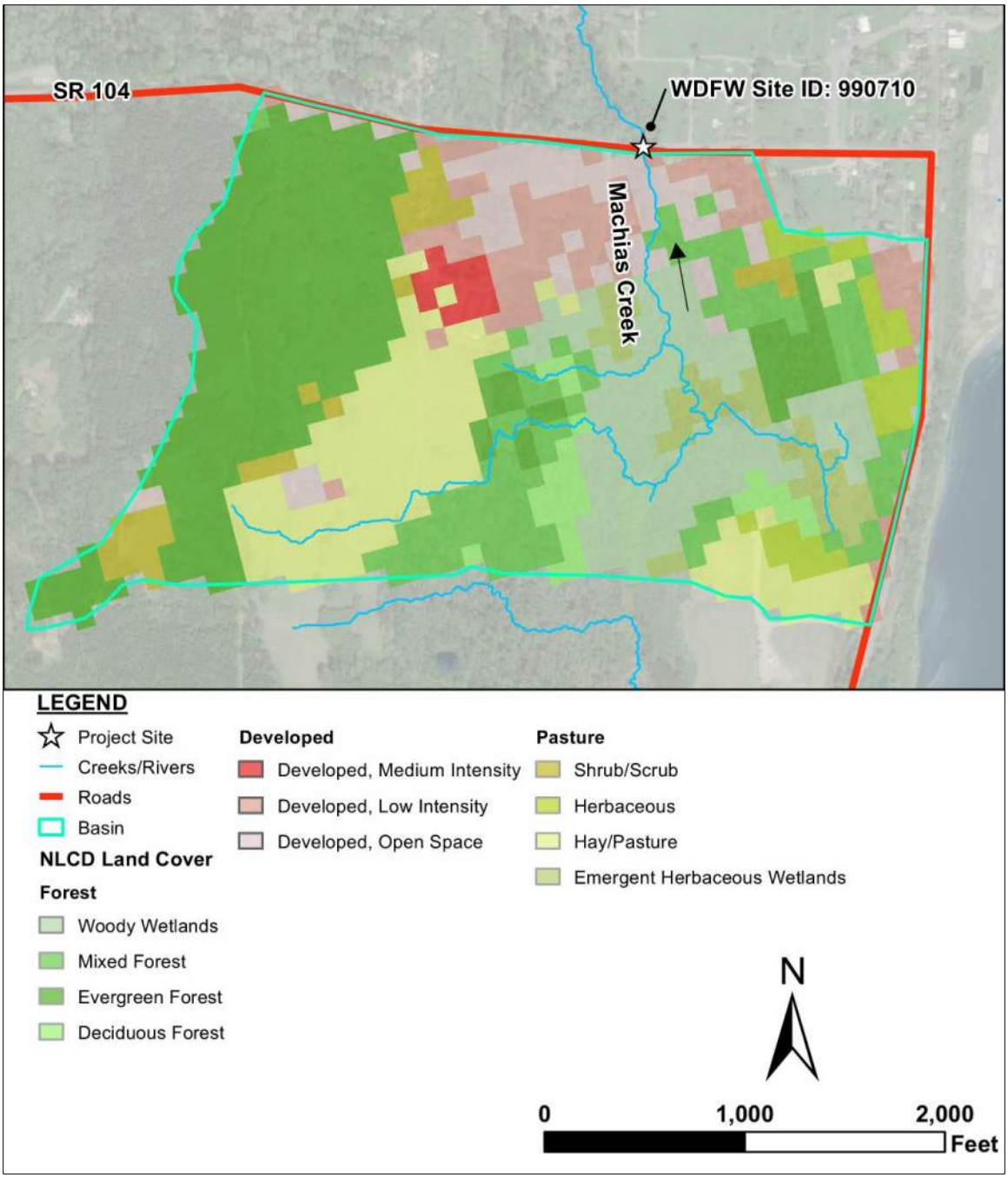

Figure 3: Land cover map (NLCD 2019).

2.3 Geology and Soils

The project site is located within the Puget Lowland, a low-lying area between the Cascade Range to the east and the Olympic Mountains to the west. The geology of the Puget Lowland reflects multiple periods of glacial advance and recession occurring throughout the Pleistocene epoch. Geology within the project crossing vicinity was obtained from Department of Natural Resources (DNR) geologic mapping (Figure 4) (DNR 2016). The 1:100,000 scale geologic mapping shows that geologic Pleistocene continental glacial till (Qgt), advance continental

glacial outwash (Qga), continental sedimentary deposits or rocks (Qc) and artificial landfill (Qf) are found within the project vicinity.

Qgt (Pleistocene continental glacial till) underlies the north side of Port Gamble peninsula within the project vicinity (DNR 2016). The till deposits are found on hills, ridges, slopes, and valley sides, either as the topmost unit or beneath younger outwash deposits. Till consists of a non-sorted mixture of mud, sand, pebbles, cobbles, and boulders. The till deposit is generally compact and often is referred to as hardpan, which has high resistance to surface erosion and landslide. When till it is not compacted into a hardpan it is often very silty, and Qgt is likely the source of most of the fines observed in the channel. The Port Gamble peninsula consists of a till-underlying terrace with drift and outwash deposit near the shoreline (Figure 4). The entire watershed draining to the project crossing is within the terrace. The underlying till layer lowers the risk of drastic degradation within the project crossing.

Older quaternary sedimentary deposits (Qc) are found at the north shoreline of the Port Gamble peninsula and the downstream reach of Machias Creek. It is originated from the Pleistocene glaciation. Artificial landfill (Qf) is found at the northeast corner of the Port Gamble peninsula. Qga is advance continental glacier outwash. The advance outwash is a thick section of mostly clean, gray, pebbly sand with increasing amounts of gravel higher in the section. The outwashes are mapped within the steeper river valleys on the peninsula.

Figure 4: Geologic map

The soils in the project vicinity are predominantly sandy to gravelly loam on varying slopes. Most of the soil are classified within hydrologic soil group A to C within the watershed. Mckenna gravelly loam (32) has the lowest the infiltration rate as it is where the wetland is located in Figure 2 and Figure 3. Dystric Xerorthents (10) are mapped underneath the reach within the project vicinity. It is classified within hydrologic soil group A with high infiltration rate (NRCS n.d.). The depth to water table is up to 80 inches in this type of soil.

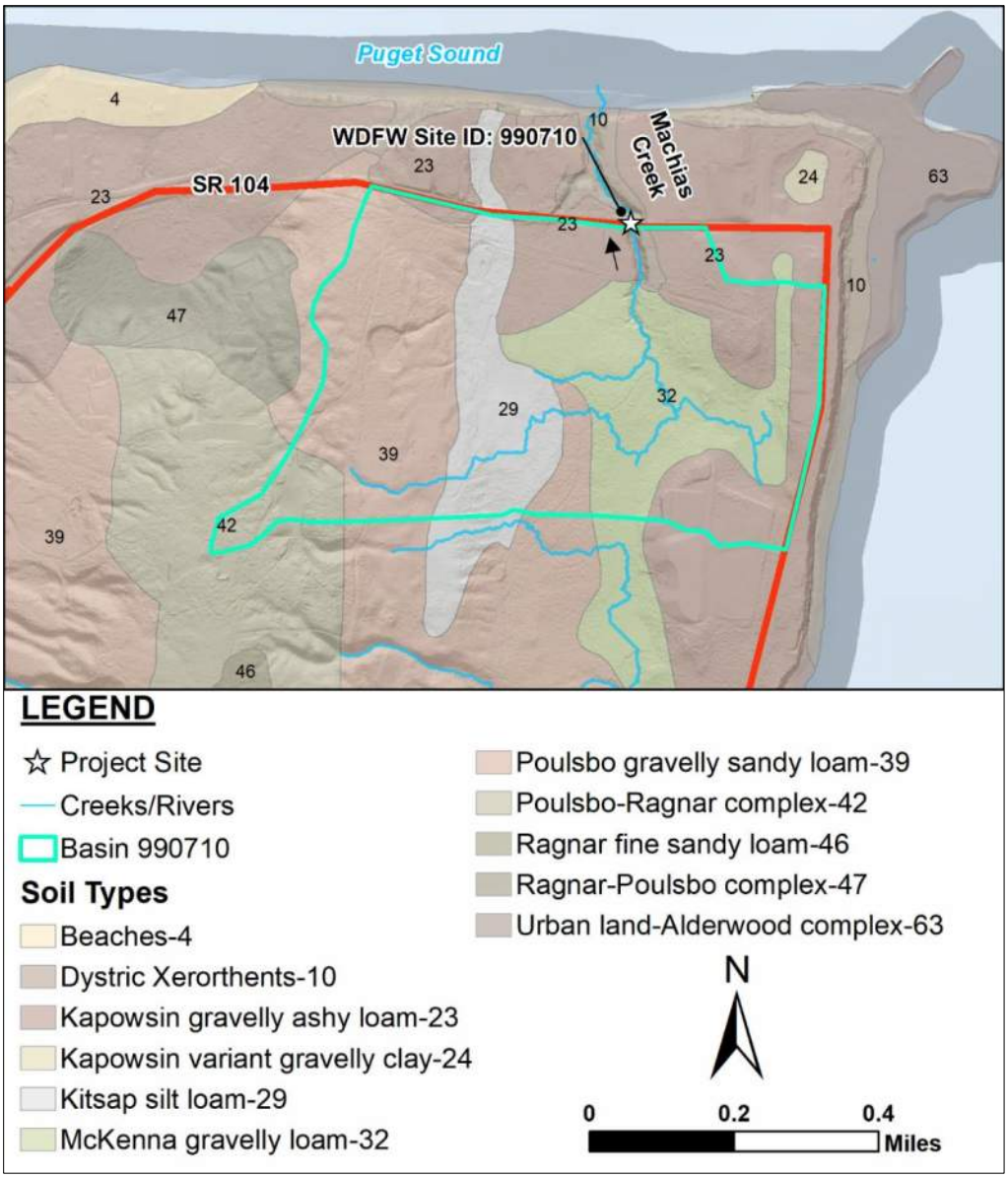

Figure 5: Soils map

2.4 Fish Presence in the Project Area

WDFW fish barrier site assessments (WDFW 2019) and Statewide Integrated Fish Distribution data (SWIFD) (NWIFC 2022) were the primary resources used to identify fish species found or potentially found in Machias Creek. WDFW barrier inventory crews surveyed crossing 990710 in 2009. The barrier inventory identified five species as being potentially present in the site: Coho (*Oncorhynchus kisutch*), Chum (*O. keta*), steelhead (*O. mykiss*), Cutthroat Trout (*O. clarkii*), resident trout (*O. spp.*). The Statewide Integrated Fish Distribution (SWIFD) database documents Coho in Machias Creek downstream of the crossing and as presumed present upstream of the crossing. SWIFD maps resident coastal cutthroat fish presence as presumed in Machias Creek downstream of the crossing (Table 2).

The Hood Canal Chum Summer-Run evolutionary significant unit, which was listed as threatened in 1999 (NOAA 1999), potentially may use Machias Creek. The Puget Sound Steelhead distinct population segment, which was listed as threatened in 2007 (NOAA 2008), is also present in Machias Creek.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Cutthroat	Presumed	SWIFD	Not listed
Coho	Documented	SWIFD	Not listed
Resident Trout	Presumed	Barrier Inventory	Not listed
Chum	Presumed	Barrier Inventory	Threatened
Steelhead	Presumed	Barrier Inventory	Threatened

2.5 Wildlife Connectivity

Wildlife Connectivity will only be included in the FHD if Wildlife connectivity is included as part of the project.

2.6 Site Assessment

The immediate project vicinity is forested within the ravine of Machias Creek. The ravine is approximately 30- to 40-foot wide in the bottom and 25 feet lower than SR 104 corridor. The surrounding property uses include retail, single-family residential, undeveloped land and forest land (Figure 6). The property on the east side of the ravine is owned by Port Gamble Environmental Associates and OPG Port Gamble LLC (Figure 6), which consists of mostly open lawn area, some parking lots, a drive-through coffee stand and a few single-family residential houses. The upstream reach of Machias Creek is within the lot of Port Gamble Environmental Associates LLC. The downstream reach flows through two undeveloped private properties and outlets to Hood Canal through a single-family residential lot.

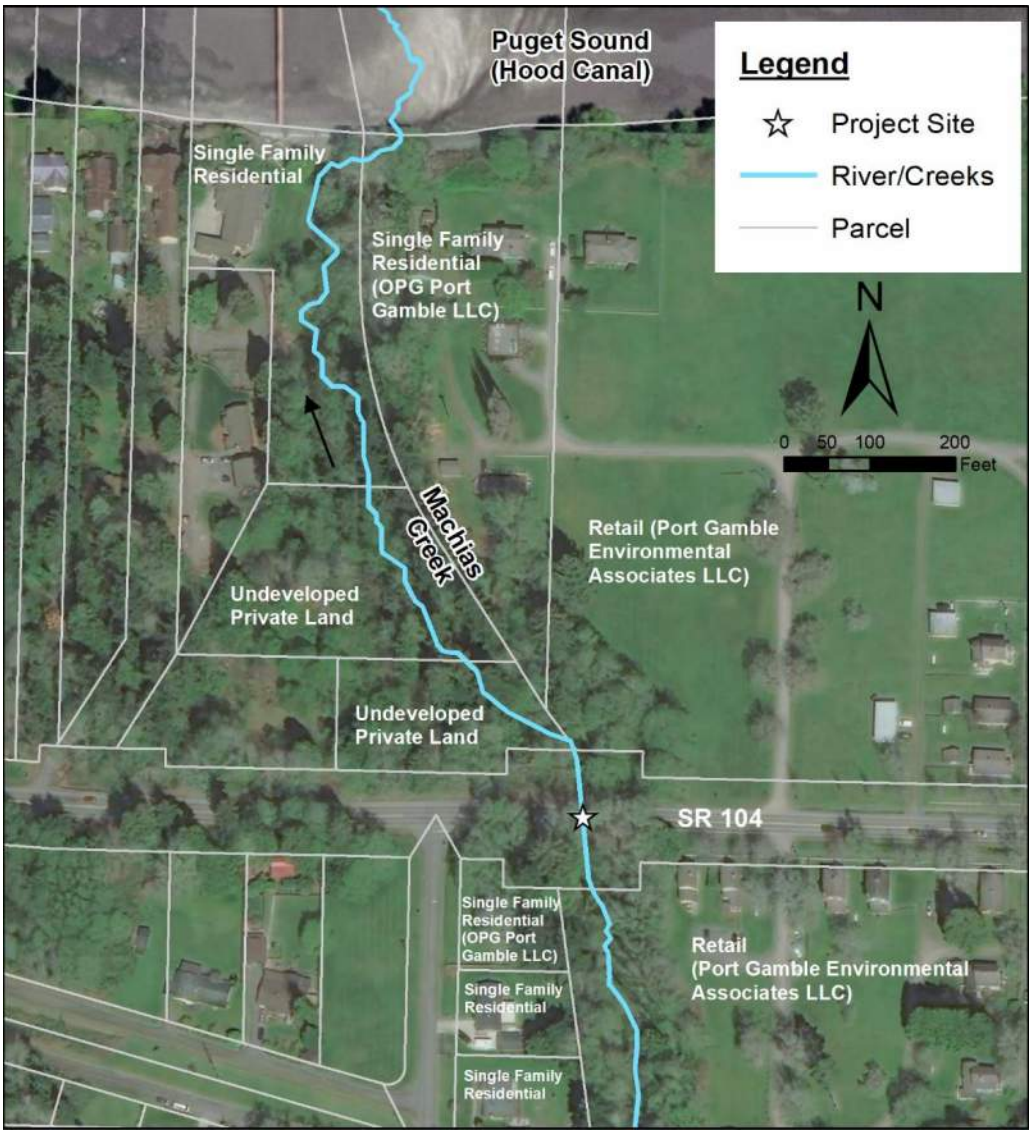

Figure 6: Property uses map around SR 104 Machias Creek Crossing

2.6.1 Data Collection

The survey data was delivered by the WSDOT survey team on August 31, 2021. The survey extent covers 300 feet of Machias Creek upstream and downstream of the crossing with SR 104. A site visit was conducted by PACE Engineers (PACE) on December 2, 2021. The reference reach for SR 104 and Machias Creek is identified 120 to 160 feet upstream of the existing culvert inlet. Three bankfull width (BFW) measurements were taken in the reference reach by PACE on December 2, 2021. They are marked as BFW #1 to BFW #3 in Figure 7. Three Wolman pebble counts were performed at the project site, two in the upstream reach and one in the downstream reach (Figure 7). The sediments for this stream are mostly fine to small gravel and the occasional cobble. More discussion of the sediment is in Section 2.7.3.

A concurrence meeting was held on February 2, 2022, with the co-managers including WSDOT, WDFW, Snoqualmie Tribe and Port Gamble S'Klallam Tribe. During the meeting, BFW#4 was taken ten feet downstream of BFW #1, and three BFW measurements were taken exactly at the

same locations PACE measured. Those measurements are called out as BFW #5 to BFW #7 in Table 3 and Table 4. BFW # 8 and #9 were taken within the downstream reach. Further discussion of the BFW is in Section 2.7.2. The field report for the December 2021 site visit and the concurrence meeting can be found in Appendix B.

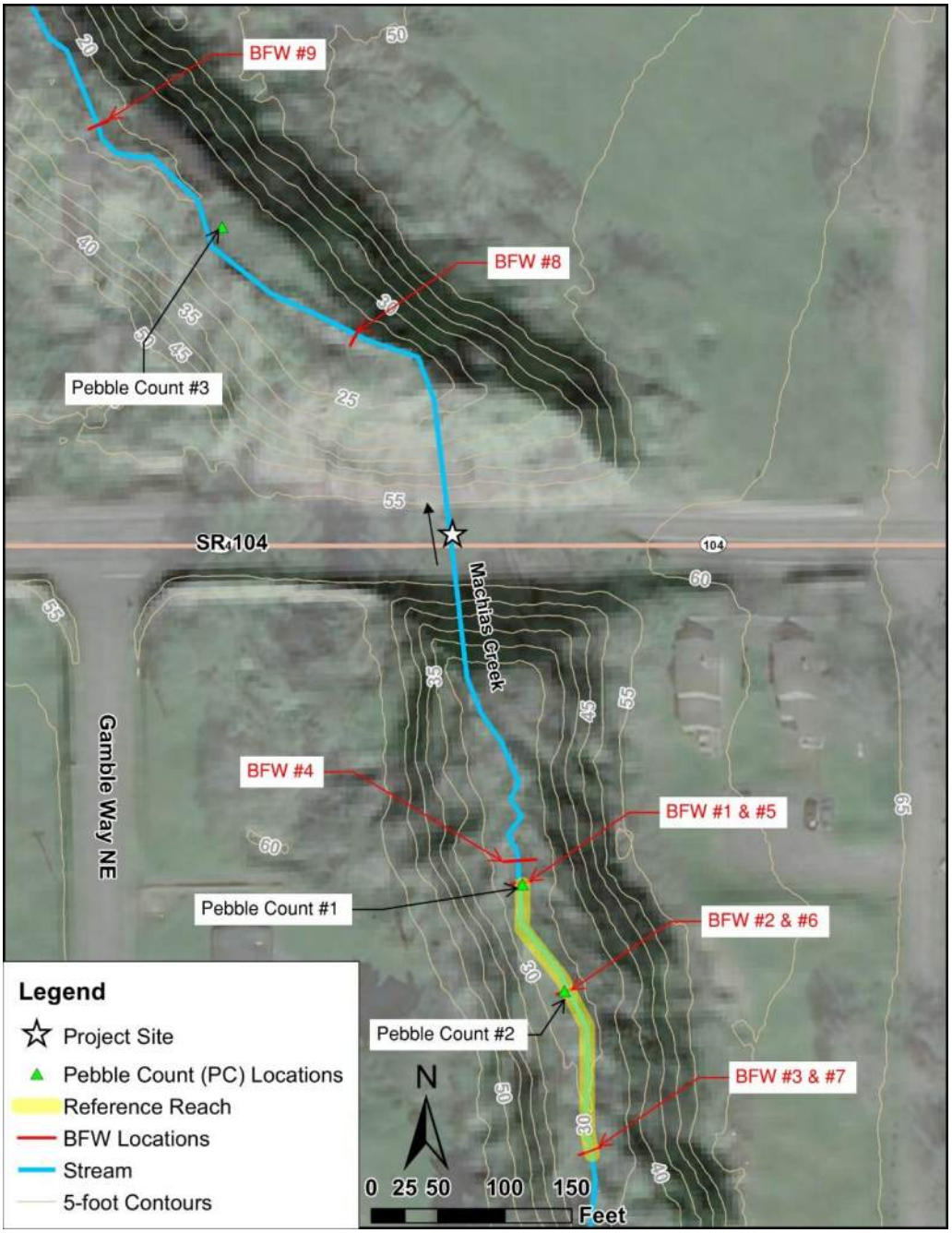

Figure 7: Reference reach, bankfull width (BFW), and pebble count (PC) locations

2.6.2 Existing Conditions

The existing crossing of SR 104 and Machias Creek is a 141-foot-long, three-foot-diameter concrete culvert. The surveyed culvert inverts show that the existing crossing has a 2.2 percent slope. The banks are steep with signs of erosion (Figure 8(a)). The inside of the culvert is clear of debris and sediment (Figure 8(b)), indicating that the culvert has sufficient capacity to transport sediment and organic debris. No sign of maintenance was observed. The existing culvert alignment is approximately perpendicular to SR 104. The inlet location is assumed to be artificially relocated to the edge of the ravine during road construction for shorter crossing. The culvert outlet is overhung with vegetation and the invert is below grade. There is a small pool immediately downstream of the culvert (Figure 9). The topographic survey (Appendix D HY01) shows the outlet of the culvert against the right toe of the ravine. The proposed alignment will be skewed from the existing culvert to prevent erosion on the right bank. As-built is not available for the project site. Existing sewer line under SR 104 is shown in the survey data. Potential relocation should be considered during construction.

Figure 8: (a) The existing culvert Inlet of 990710 crossing and (b) the view inside the culvert looking downstream

Figure 9: Existing outlet of crossing 990710 partially embedded

The first 80 feet of the upstream reach has steep banks approximately 2.5-foot high on both sides forming a U-shape channel dominated by a glide-pool morphology (Figure 11 and Figure 12). Undercut banks and scour pools were frequently observed in this section of the channel Figure 12. Upstream of the U-shape channel, a sequence of forced plunge pools and short glide riffle morphologies are formed by channel-spanning buried logs. A 2-foot-deep plunge pool formed underneath of a large log and is approximately 110 feet upstream of the existing culvert inlet (Figure 10 and Figure 13). The main log and rootwad have accumulated other smaller woody debris to form a log jam. Upstream of the log jam, the vertical banks of the channel lowered to 1 foot high and the gradient becomes milder. The main channel is approximately 5 feet wide here, with floodplain overbanks on two sides extending approximately 15 to 20 feet to meet the valley wall (Figure 14). Small areas of sediment accumulation and scour in the channel bed were formed by woody material approximately every 20 to 30 feet and created the observed forced glide riffle morphology (Figure 14). The upstream reach has an average channel gradient of 1.74 percent (Figure 10).

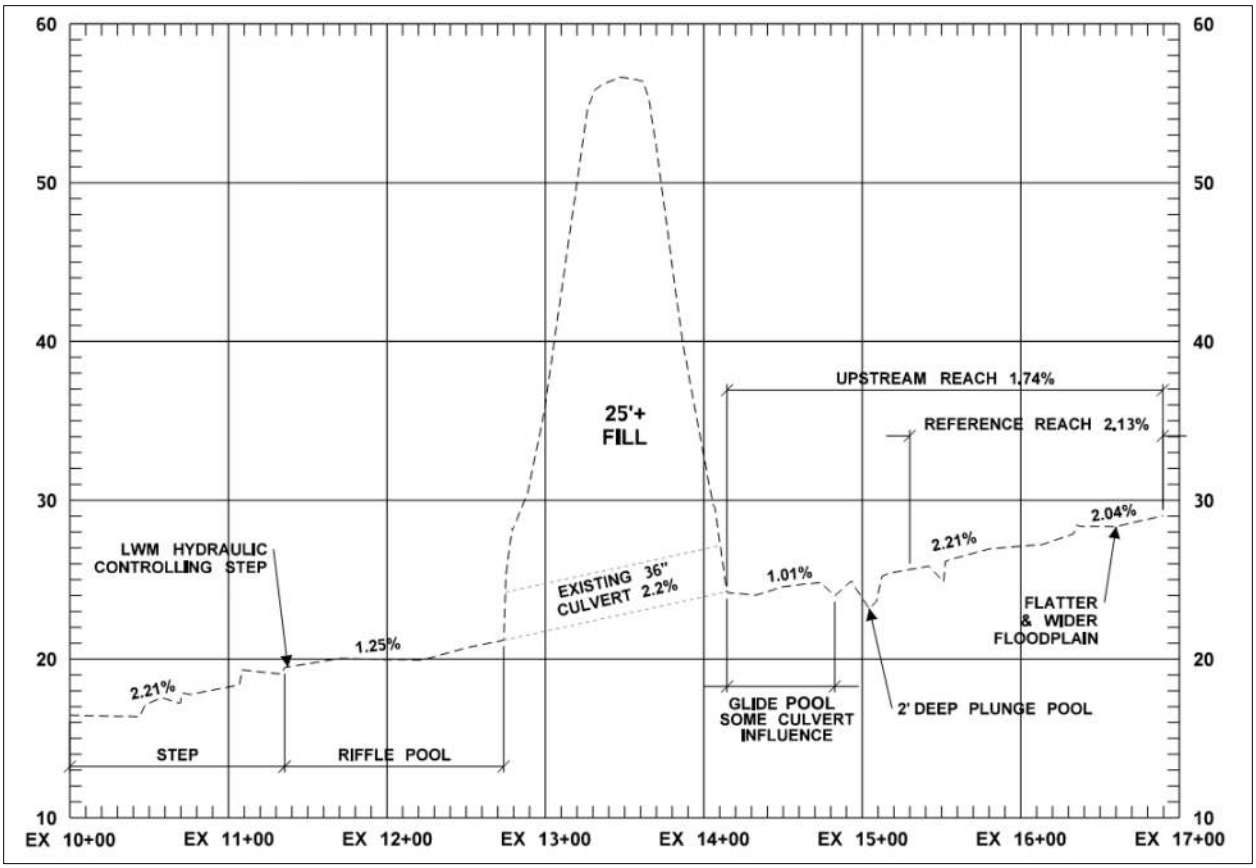

Figure 10: Survey channel profile

Figure 11: Vertical banks and U-shape channel upstream of the existing culvert inlet; looking upstream

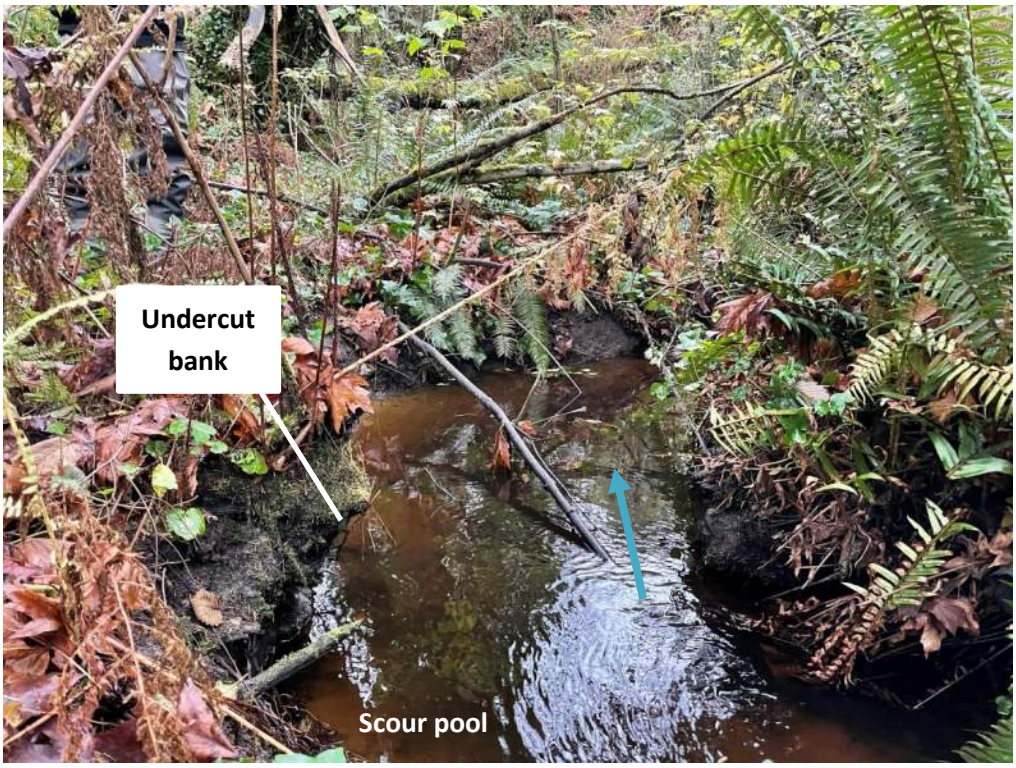

Figure 12: Undercut banks and scour pool in the first 100 feet of the upstream reach, looking downstream

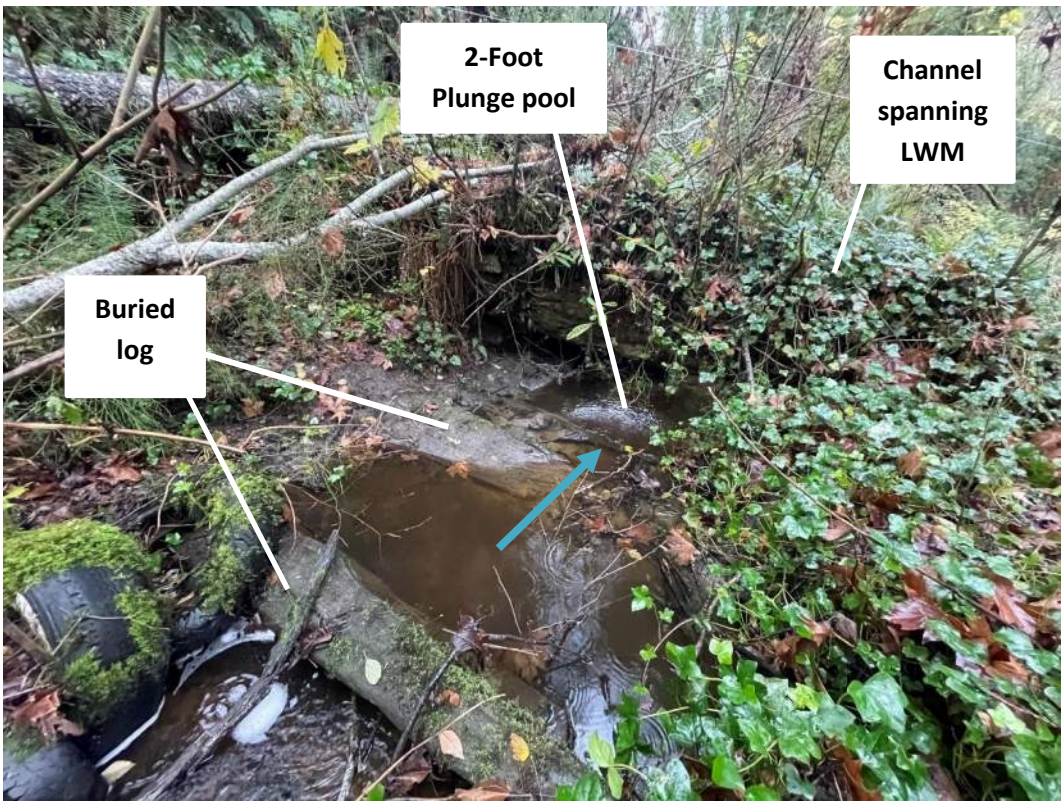

Figure 13: Plunge pool formed by water flowing over a buried natural LWM and 2-foot-deep pool under channel-spanning LWM; looking downstream

Figure 14. Wider floodplain upstream of a log jam and the 2-foot-deep plunge pool looking upstream

The channel immediately downstream of the culvert outlet has a riffle-pool morphology for approximately 120 feet. This section of the channel has an average gradient of 1.25 percent. There are scour pools forced by wood in the channel and clear riffles in between the pools (Figure 15) and occasionally small steps less than 1 foot formed by buried woody debris. Most pool-riffles have short sequences, approximately 10 to 20 feet between the riffles. This section of the channel is hydraulically controlled by a 1-foot step created by a buried LWM (Figure 16). The step formed a shallow pool extending upstream for approximately 80 feet and created a milder channel gradient upstream of the step (Figure 10).

Downstream of the hydraulic-controlling step, the channel developed more steps and plunge pools created by buried logs with up to 2-foot elevation drops. The channel has approximately 1-foot-high banks with clear floodplain benches out for approximately 20 to 40 feet on both sides of the channel. Signs of active scour on the left bank were observed 200 feet downstream of the crossing (Figure 17). The average channel gradient in this section is 2.21 percent (Figure 10).

Habitat is negatively affected as fish have limited access to the upstream reach due to the undersized and steeply sloped concrete culvert. See Section 2.6.3 for more discussion on the fish habitat. Throughout the upstream reach evidence of dumping was present with tires and large metal objects found in the channel. There is no local constraint or infrastructure found in the immediate vicinity.

Figure 15: Riffle-pool morphology in the first 100 feet channel downstream of the culvert outlet; looking downstream

Figure 16: LWM hydraulic controlling step; looking upstream

Figure 17: Scour observed in the downstream reach; looking downstream

2.6.3 Fish Habitat Character and Quality

Overall, the project site has several forced scour pools which are suitable salmonid rearing habitat, but the streambed is largely composed of fine sediment limiting the available spawning habitat. The channel is a single thread glide-pool channel, with LWM forcing pools. Coho juveniles are particularly attracted to low velocity rearing habitat and would benefit from these pools. There are occasional small habitat units that could be described as riffles, with faster water and coarser gravels. But these are limited throughout the project site, and generally the pools are separated by non-turbulent shallow glide features. Machias Creek empties out into Puget Sound but there is no tidal influence in the project vicinity.

Flow upstream of the crossing was slow, with the dominant sediment being silt/clay and unsuitable for spawning. There are pockets of gravel, and it is possible there could be some successful spawning activity, especially for smaller resident trout. There were several pools that have the potential to be used as velocity refuge with vegetation overhanging that could serve as protection from predators. These pools were generally 0.5 to 1 foot deep and would serve as excellent juvenile rearing habitat, likely for both over-summer and overwinter rearing. Approximately 100 feet upstream of the crossing there is a two-foot-deep plunge pool which offer the best rearing habitat seen in the surveyed reach (Figure 13). On the day it was observed it would make nice low velocity rearing habitat for coho or steelhead juveniles. If it stays deep and cold over the summer, it would be the ideal over-summer habitat for coho and steelhead parr. Some of the pools were large enough adult anadromous spawners could hold in them as they rest while migrating upstream or digging a redd. During large flood events there

may be limited floodplain habitat available which would offer additional slow velocity refuge habitat. Coho would be particularly attracted to any off channel ponded areas.

On the downstream side of the crossing there is more gravel present in the streambed and it is likely there could be successful spawning activity in the gravel pockets. There were several places where steps caused by wooden material blockage were forming backwaters, potentially providing velocity refuges (Figure 16). These steps likely pool water throughout the summer and would offer over-summer rearing opportunities. There is ample cover and overhanging vegetation offering cover, shade and foraging opportunities. In several places LWM spanned over the channel offering cover and additional foraging opportunities. It is unlikely any of the spanning wood or steps create full migration barriers, although it is possible at low summer flows fish may have difficulty passing the steps taller than one foot (Figure 14).

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

The vegetation in the upstream reach is primarily shrubs and ivy in the vicinity of the stream, with trees, western red cedar (*Thuja plicata*), big leaf maple (*Acer macrophyllum*) growing higher up the valley slopes. The shrubs are salmonberry (*Rubus spectabilis*), sword fern (*Polystichum munitum*), spreading wood fern (*Dryopteris expansa*) with English ivy (*Hedera helix*) making up the rest of the coverage. Surrounding the channel are salmonberry and the withered fronds of the annual spreading wood ferns. These are close enough to the stream to cover it and provide both habitat for invertebrates as well as cover from predators for fish. On the east slope of the valley English ivy is dominate, with many of the trees covered up to near their canopy. It is also covering most of the LWM found on that side of the stream. While English ivy is still present on the west slope, sword ferns are more established and the trees are not covered nearly as extensively. Downstream of the culvert many of the same species are present. There is less of a difference between the east and west slopes and, while on the road embankment there is a large amount of ivy, the rest of the downstream reach is salmonberry, sword fern and a ground covering (Fringe Cup, *Tellima grandiflora*).

Several pieces of LWM were observed in the upstream reach. The gradient and quantity of channel-spanning logs resulted in consistent steps of buried wood. There were indications that older pieces of LWM have decayed and eventually broken apart, releasing the sediment trapped behind the log. However, during the site visit all of the LWM surveyed appeared solid and none was noted as soft or decaying. Several 8-inch-diameter logs span the glide-pool channel from top of bank to top of bank in the first 100 feet of the upstream reach (Figure 11). Steps formed by channel-spanning LWM were observed in this section of the reach. There is a key piece spanning the channel overbanks 110 feet upstream of the crossing near BFW #1 location (Figure 13). There were no green leaves on this piece of LWM and it did not appear old or decaying. Smaller woody debris has accumulated under the spanning logs and created higher roughness in the channel. Two 8-inch-diameter deciduous logs lie parallel to the channel on the floodplain. Some LWMs have trunks partially buried in the bench (Figure 18). Scour pools were observed along the toe logs. More channel-spanning key pieces were observed farther upstream within the reference reach (Figure 14 and Figure 18). The low clearance below the channel-spanning log in Figure 13 allows the LWM to be engaged with higher flow events. The WDFW Inventory reported a large beaver pond approximately 1,000 feet upstream of the crossing (WDFW, 2021). The beaver pond is visible in Esri basemap data, but was not

assessed during the site visit. The land cover data also maps the area of beaver pond as woody wetlands (NLCD 2019).

Figure 18: LWM within reference reach on the floodplain and spanning the channel; looking upstream

Figure 19: (a) Open canopy 200 feet downstream of the crossing with (b) smaller logs spanning the channel and steps formed by half-buried LWM; both looking upstream

Figure 20: Existing LWM forcing flow in the downstream reach; looking upstream

Abundant LWM supply provided by dense canopy was observed in the downstream reach. There were approximately 2 to 3 key pieces every 100 linear feet of the channel. There were two 2-foot-diameter key pieces across the banks near the culvert outlet at a 45-degree angle. Smaller LWM and vegetation caught on the key piece partially engage with the flow and provide shading to create quality habitat. Approximately 100 feet downstream of the outlet, a sequence of key pieces span from bank to bank. One has a rootwad on one bank shading the main channel, while the trunk of another key piece lying on the opposite overbank (Figure 16). The canopy opens up approximately 200 feet downstream of the culvert outlet, and smaller logs were observed in this section of channel (Figure 19 (a)). Several 8-inch-diameter logs cross the floodplain from the bank slope to bank toe (Figure 19 (b)). Small steps formed by buried in-channel wood were frequently observed, approximately every 15 feet (Figure 19 (b)). At the time of the site visit the LWM within Machias Creek was actively engaged with the flow. Figure 20 shows evidence of high flows beginning to scour the bank as a new flow path forms around the channel-spanning wood.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross-sections of the channel, and stability of the channel both vertically and laterally of Machias Creek.

2.7.1 Reference Reach Selection

A reference reach was selected for Machias Creek from 110 feet to 260 feet upstream of the existing culvert (Figure 7). The reference reach starts upstream of the 2-foot-deep plunge pool underneath a channel-spanning key log (Figure 13), and ends at another channel-spanning key log 140 feet further upstream shown in Figure 22. During the concurrence meeting on February 2, 2022, the co-managers walked the entire length of the reference reach and agreed that the reach is outside the influence of the existing culvert (Figure 23). The habitat features created by abundant amount of LWM make this reach an appropriate location for crossing design reference. See more description of the channel in the next section.

Figure 21: Reference reach and BFW #2 location; Looking upstream

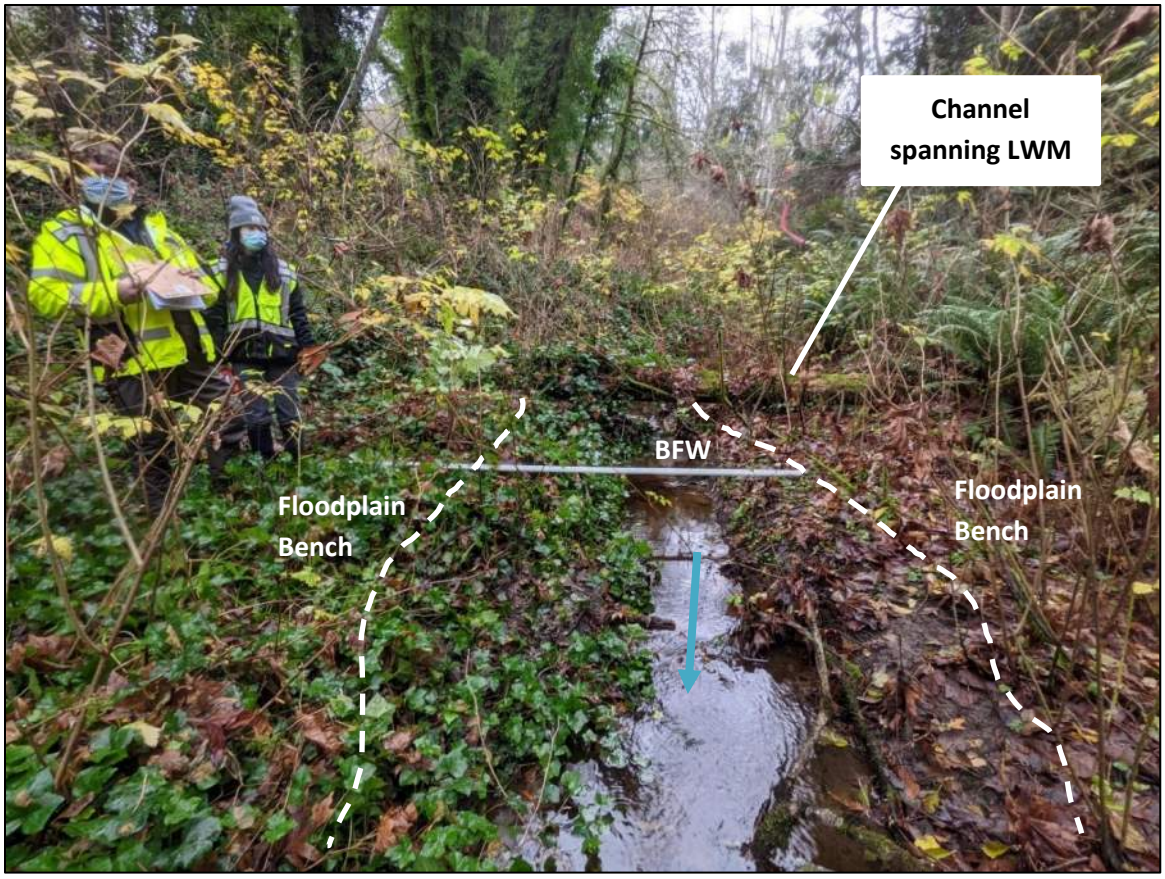

Figure 22: Reference reach and BFW #3 location, looking upstream

Figure 23: Concurrence group taking a bankfull measurement in the upstream end of the reference reach (near BFW #3) looking downstream

2.7.2 Channel Geometry

The stream within the reference reach has a mild channel gradient of approximately 2.13 percent, similar to the crossing slope and the downstream channel gradient. It has a single-thread low-flow main channel. The channel bankfull width ranges from 5.3 to 9 feet (Table 3). The banks are incised, approximately 1 to 1.6 feet high on slopes steeper than 1H:1V (Figure 24). See BFW locations in Figure 7. The design bank slope will be 2H:1V for constructability. The floodplain was measured 32 feet wide within the reference reach. A sequence of shallow plunge pools downstream of spanning logs were observed throughout the reach every 20 to 30 feet (Figure 25). The channel turns slightly wider in the middle of the plunge pool and narrows upstream of the next channel-spanning log (Figure 25). The bedform is riffle-pool with steps where log spans the channel.

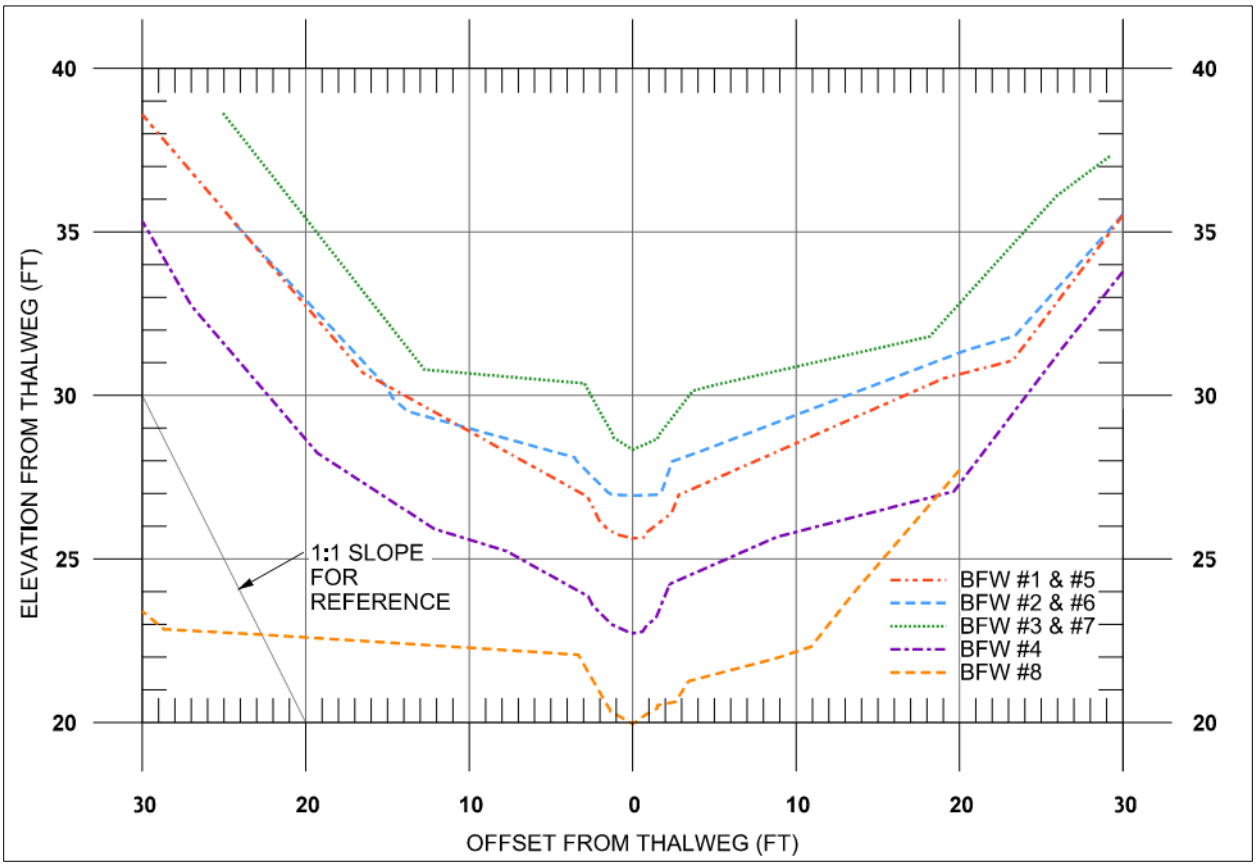

Figure 24: Existing cross-section examples.

Figure 25: BFW #1 location; Shallow plunge pool and channel-spanning log; looking upstream

During the December 2021 site visit, those BFW locations were flagged for future reference. The BFW measurements were taken between the channel-spanning logs to avoid the hydraulic impacts from these channel-spanning LWM (Figure 22). During the February 2022 concurrence meeting, additional BFW measurements were taken by the co-managers at similar locations (Table 3). The BFW values from the February 2022, concurrence meeting were slightly larger than the early site visit in December 2021. The upstream and downstream reaches have the same flow and similar channel geometry. The width to depth ratio at the BFW locations are all lower than 10, indicating the confinement of Machias Creek.

There is a discrepancy in the concurred BFW. The co-managers documented a concurred BFW of 7.5 feet, while the design team documented to average all the measured BFW during both December 2021 and February 2022 visits and results in a design average of 6.7 feet. The discrepancy can be a miscommunication of which BFW measurements to include, or simply a calculation mistake when averaging BFWs in the field. Regardless of how the discrepancy originated, the concurred BFW of 7.5 was used as the starting point to size minimum hydraulic width. The proposed 14-foot width is greater than the steam simulation equation result regardless of the additional 0.8 feet of concurred BFW discrepancy.

The average BFW of 6.7 feet is used for channel geometry design as it is closer to the 2-year flow width modeled in the reference reach. The design iteration shows that using the concurred BFW of 7.5 feet will result in a main channel that is too wide to provide floodplain connectivity even during high-flow events. See more discussion about channel geometry in Section 4.1.1.

Table 3: Bankfull width (BFW) measurements

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert)	Concurrence notes
1	5.3	Yes	125 feet upstream	Taken by PACE on 12/02/2021 Co-manager concurred on 02/02/2022
2	5.4	Yes	165 feet upstream	Taken by PACE on 12/02/2021 Co-manager concurred on 02/02/2022
3	8.5	Yes	256 feet upstream	Taken by PACE on 12/02/2021 Co-manager concurred on 02/02/2022
4	5.5	Yes	115 feet upstream	Co-manager added on 02/02/2022
5	7.5	Yes	125 feet upstream	Co-manager added on 02/02/2022
6	7.5	Yes	165 feet upstream	Co-manager added on 02/02/2022
7	9.0	Yes	256 feet upstream	Co-manager added on 02/02/2022
8	5.5	Yes	70 feet downstream	Co-manager added on 02/02/2022
9	6.5	Yes	350 feet downstream	Co-manager added on 02/02/2022
Design average	**6.7**			Used for channel geometry design
Concurred BFW	**7.5**			Used for sizing MHO

BFW measurements may be used to inform design elements such as crossing hydraulic opening size, main channel width and LWM quantity and size for the proposed channel conditions when appropriate. The average bankfull width of 6.7 feet (Table 3) will be applied in the stream simulation design and used to calculate the minimum hydraulic opening (MHO) for the proposed crossing.

The width to depth ratio, defined as BFW divided by bankfull depth, is approximately 6 in the reference reach. A ratio of 6 is on the lower end for natural stream channels and indicates that the channel is confined to a narrow single thread. The LWM in the channel creates localized scour and plunge pools, while also aggregating sediment and organic debris. This creates a state of dynamic equilibrium, where the channel aggrades and scours within a set range. Scour and aggradation do not appear to be chronic in one direction or the other (discussed more in Section 2.7.4). Those field observations, the surveyed channel gradients and width to depth ratio show that Machias Creek adjacent to the project crossing is at Stage VI Quasi-Equilibrium of the channel evolution model (Simon and Rinaldi 2006).

2.7.2.1 Floodplain Utilization Ratio

The WCDG (Barnard, et al. 2013) present the floodplain utilization ratio (FUR) as a method to determine whether a channel is confined or unconfined. The FUR is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. The simulated 100-year flow width was used as FPW for this project. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel (Barnard, et al. 2013).

The FUR was calculated for Machias Creek both upstream and downstream of the crossing where the channel is outside the impact of the existing culvert. No sign of incision or backwater caused by the existing culvert is observed at those locations during the site visit and in the existing-conditions model. The existing-conditions model was used to calculate FUR. The FUR

was calculated as the simulated 100-year flood width divided by the BFW taken by the co-managers in both the reference reach and downstream reach along the existing stream alignment from survey basemap (Table 3). The existing alignment stations are labeled EX in Figure 26. In the upstream reference reach the FURs are all less than 3.0 indicating Machias Creek is a confined system. The maximum FUR in the reference reach is 2.5 at EX 15+20. FUR analysis is done in the downstream reach at BFW #8 (EX 12+08). The downstream reach has lower floodplain overbanks (Figure 19), resulting in FURs larger than the upstream reach. The backwatering caused by the existing LWM steps is another factor contributing to higher FUR in the downstream reach. See discussion of backwater in Section 5.2. FUR was not calculated at BFW #9 location as it was taken outside the limit of the hydraulic model extent.

Table 4: FUR determination

Station	FPW (ft)	FUR	Confined/ unconfined	Included in average FUR determination
EX 15+20 (Reference Reach BFW #4)	13.9	2.5	Confined	Yes
EX 15+30 (Reference Reach BFW #5)	12.4	1.7	Confined	Yes
EX 15+80 (Reference Reach BFW #6)	10.3	1.4	Confined	Yes
EX 16+60 (Reference Reach BFW #7)	11.8	1.3	Confined	Yes
EX 12+08 (Downstream Reach BFW #8)	15.5	2.8	Confined	No
Average	**N/A**	**1.7**	Confined	N/A

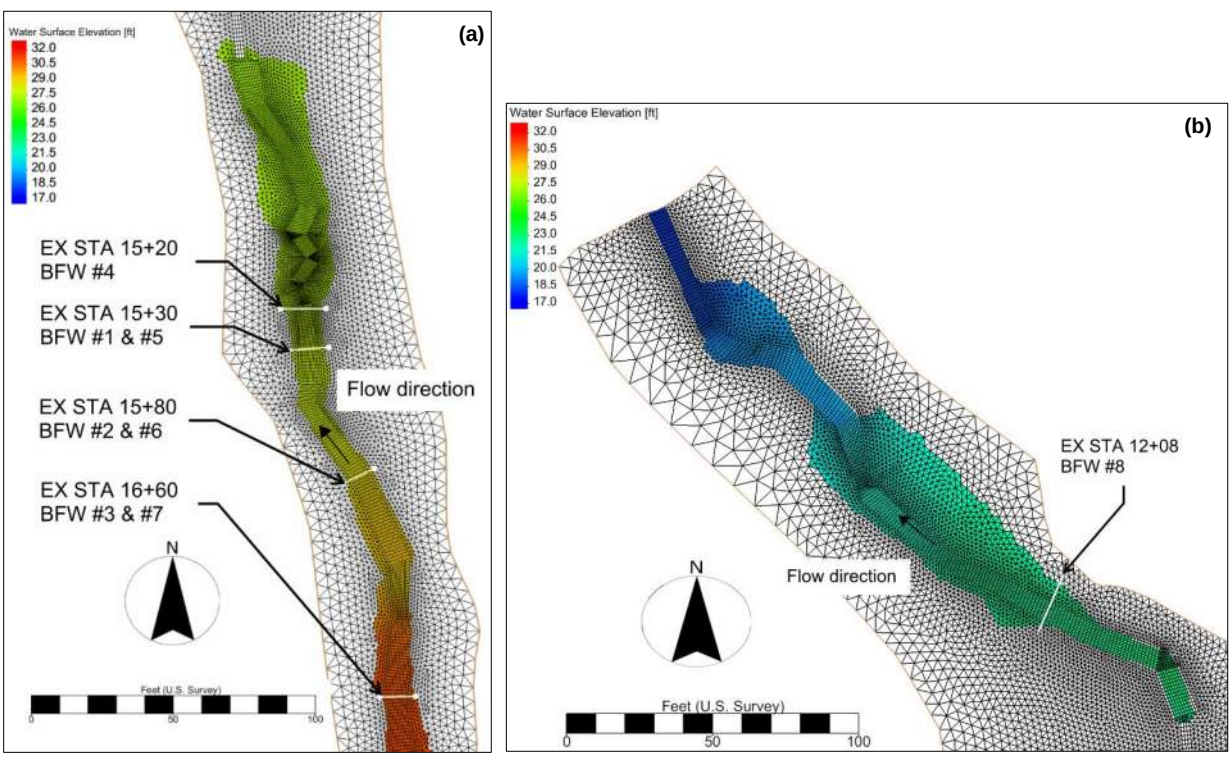

Figure 26: (a) Upstream and (b) downstream FUR locations

2.7.3 Sediment

A total of three Wolman PCs were collected during the assessment: two upstream and one downstream of the project crossing (Figure 7). The streambed sediment in the reference reach consists of fine sand, medium size gravels and occasionally cobbles (Figure 27 (a)). No subsurface sample was taken. There is no armoring layer observed at the project site. Silt was observed at PC #1 location (Figure 27 (b)). Sediment becomes finer in the upstream end of the reference reach at PC #2 with 50 percent sand (Figure 29 and Figure 30 (a)), however larger cobbles were also present. The largest materials found in the reference reach were cobbles between 7 and 10 inches in diameter. In the downstream reach, PC #3 was sampled in a zigzag pattern through a riffle pool to catalog particles in different water depth (Figure 15). The sediment was mainly fine sand and some medium size gravels (Figure 30 (b)). All the PCs are performed outside the influence of the existing culvert and were included in the average for design.

Figure 27: Sand, cobbles and silt observed at PC #1 location

Figure 28: Sample of medium size gravels within the reference reach

Figure 29: 5 to 7-inch cobble found at PC #2 location

Table 5: Sediment properties near the project crossing

Particle size	PC #1 diameter (in)	PC #2 diameter (in)	PC #3 diameter (in)	Average diameter for design (in)
Included in average?	**Yes**	**Yes**	**Yes**	**N/A**
D_{16}	0.1	0.1	0.1	0.1
D_{50}	0.2	0.2	0.3	0.2
D_{84}	0.6	1.0	0.6	0.7
D_{95}	1.1	3.9	0.8	1.9
D_{100}*	1.8	7.1	0.9	3.3
* D100 represents the largest sediment sampled.				

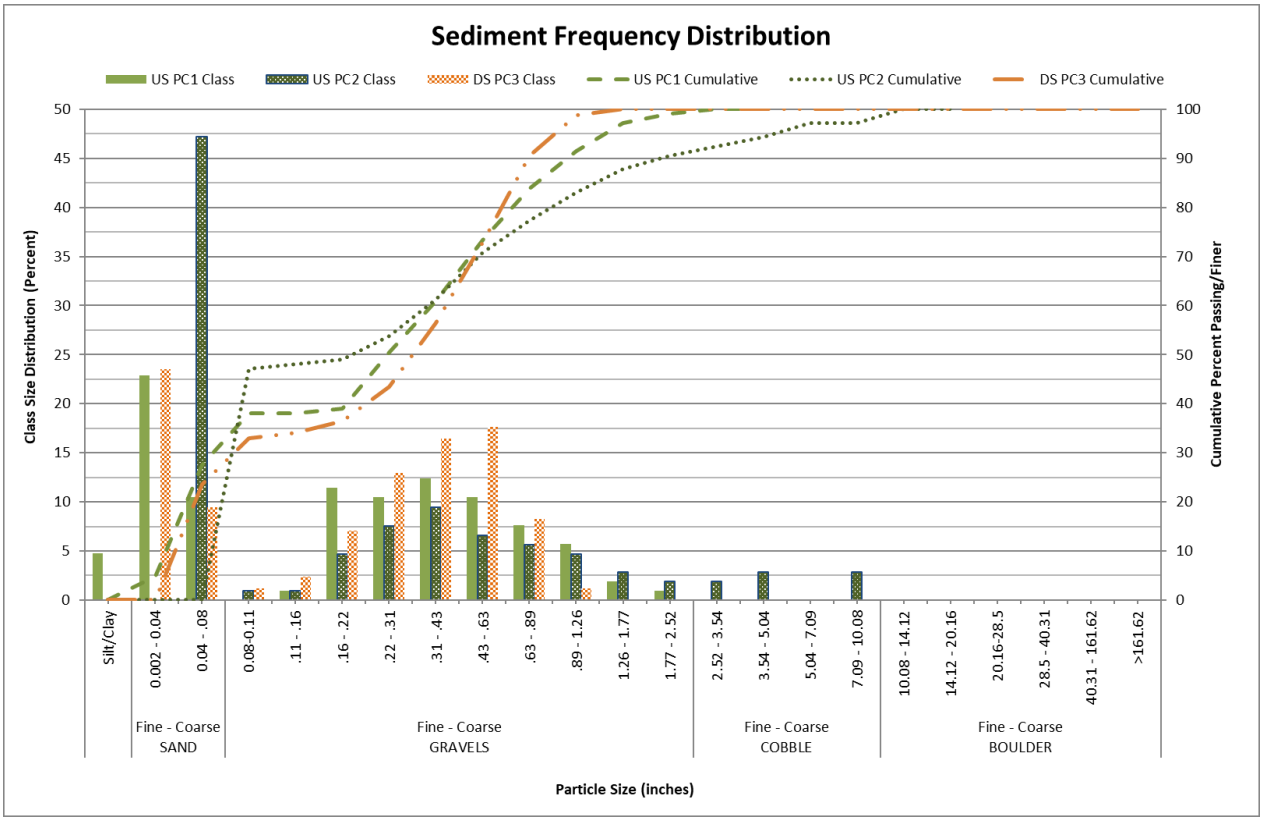

Figure 30: Sediment size distributions in upstream reach and downstream reach

2.7.4 Vertical Channel Stability

A watershed-scale LiDAR profile is presented in Figure 31 using Kitsap County OPSW 2018, LiDAR (DNR 2018). The surveyed thalweg topography profile with the existing culvert elevation through the SR 104 roadway prism is in Figure 31 for comparison. The survey topography matches the LiDAR elevation. The profile shows that the headwaters of Machias Creek have a slope of 11.6 percent. In the forested mid watershed, the slope is approximately 2 percent before flowing into a flat woody wetland (Figure 3). The creek comes out of the wetland with a 3.6 percent gradient and crosses an abandoned logging road (WDFW barrier ID 930873) approximately 2000 feet upstream of the project crossing. Crossing 930873 is an existing grade control within the system creating a 3.6 percent channel gradient upstream of it. Machias Creek follows a steady channel gradient of 1.7 percent coming out of crossing 930873, both upstream and downstream of the SR 104 crossing, before draining into the Hood Canal. If crossing 930873 is removed, sediment transport through the project crossing is expected to increase in step with increased supply. Some sediment may deposit in the upstream reach where the slope is lower and be retained by the LWM in the channel.

The consistent channel gradient around the project crossing indicates that the channel is in a state of quasi-equilibrium as described in Section 2.7.2. When new wood and sediment accumulate in the channel, the tributary adjusts its planform and scours the bank in response (Figure 17). The vertical profile has reached a stable state and there is no evidence of chronic

aggradation or degradation within the surveyed reach. No degradation or aggradation is expected for the project crossing.

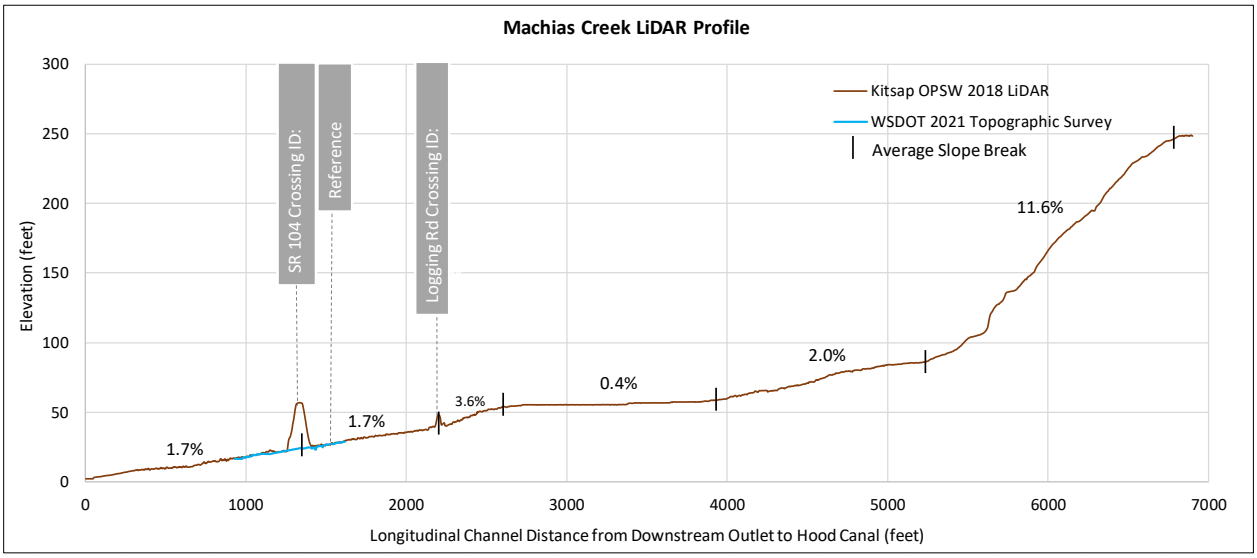

Figure 31: Watershed-scale longitudinal profile

2.7.5 Channel Migration

The floodplain of Machias Creek is approximately 30 to 40 feet wide within a ravine 25 feet lower than the elevation of the properties around the project crossing. Localized scour around the LWM was observed in the system. As described in Section 2.7.4, the erosion and debris accumulation in the channel have reached a state of dynamic equilibrium. Localized bank erosion may result in adjustments to the channel planform confined within the bottom of the ravine. There is low risk of channel migration at a scale that would be impactful to the project. LWM in Machias Creek forces the flow (Figure 20) and creates main channel sinuosity with 5 to 8 feet of amplitude measured from the survey basemap, covering approximately half of the ravine (Appendix D). The floodplain is expected to be partially inundated during 100-year flow, but side channels are not expected to form on the floodplain. Other than the crossing there is no infrastructure in the ravine bottom near the project site that would be at risk.

3 Hydrology and Peak Flow Estimates

Chapter 2 of the WSDOT Hydraulics Manual provides guidance for the selection of the most appropriate method of hydrologic analysis (WSDOT 2022). Methodologies recommended for ungauged basins are USGS Regional Regression Equations, Gauge Basin Transfer with Regional USGS equations, and Continuous Simulation Hydrologic Model approach.

The project site is located half mile to the west of Port Gamble on SR 104. With a LiDAR analysis (DNR 2018), the watershed contributing to the project site was delineated, coming out to an area of 167 acres (0.26 square miles). Using StreamStats, a mean annual precipitation PRISM 1981-2010 value of 32.8 inches was collected. (USGS 2016)

Regional Regression Equations provide the best available science for this project site. The watershed in this area is mostly undeveloped with 1.3 percent of the area considered impervious (shown as medium-intensity developed area in Figure 3), which is less than the 5 percent maximum allowable to use the Regional Regression Equation. However, the PRISM mean annual precipitation of the basin, 32.8 inches, is outside of established values. When applying regression equations for region 3, the accepted range of values for annual precipitation are 33.29 to 168 inches, as this is the range the equations are calibrated to (Mastin, et al. 2016). The minimum value of 33.29 inches produces estimates that are very close to those calculated using the estimate of 32.8 inches, as seen below in Table 6. Since the change is very minimal, regression equations with the mean annual precipitation of 32.8 inches were used. Due to the small size of the basin, impervious area is less than 5 percent of the basin and the lack of suitable stream gauges, USGS Regression was considered appropriate for peak flow estimation.

Table 6: Peak Flow Differences in Precipitation Values

Mean Recurrence interval (yrs)	Regression with 32.8 in (cfs)	Regression with 33.29 in (cfs)
2	3.9	4.0
100	13.8	14.1
500	18.2	18.6

The Regional Regression Equations from the Flood Q Tools excel spreadsheet provide an estimate of the flood discharge for an ungagged site (Mastin, et al. 2016). The spreadsheet gives a range of values for a 90 percent confidence level that the true runoff falls within this range. While usually the average value of these flows is used for peak flow estimates, the upper end of the flow at the 90 percent confidence level is used as peak flow for this project (Table 7). When the SRH-2D existing model was ran using the average flow, the 100-year flow did not overtop the main channel banks and the 2-year channel depth was less than a half-foot. Based on field observations, the bankfull depth in the channel was higher than one foot (Section 2.7.2) and it appeared that the 100-year flow would overtop the main channel at some locations. These are indicators that the estimated peak flows are too low. By using the upper flow values of the 90 percent confidence level as peak flows, 2-year flow depth in the reference reach was greater than one foot and the 100-year flow overtopped the channel at some locations. The

upper limit of the 90 percent confidence level more closely matches the field conditions observed; therefore, these are the peak values used for Machias Creek at SR 104 crossing.

Basin transfer of gauge data was considered for this crossing. At just 0.26 square miles it is a very small basin, one that has no monitored basins within 50 percent of its size on the Kitsap peninsula. USGS stream gauges and Kitsap Public Utility District stream gauges (Kitsap Public Utility District 2021) have been looked in to but none that are of the correct size basin or geomorphology (i.e., not high up in the mountains) have been found. The gauge with the most complete data and comparable size was the Anderson Creek gauge, a stream that drains into Sinclair Inlet, south of Bremerton and west of Port Orchard with data collected just south of SR 16. This gauge has a basin that is 1.9 square miles, more than double our small basin and is outside of the allowable size limits. Also, this gauge is in an area with a mean annual precipitation PRISM 1981-2010 value of 52.8 inches. (As mentioned above crossing 990710 has a mean annual precipitation of 32.8 inches.) Given that Anderson Creek gauge is not within the allowable size range and has a very different annual precipitation value makes it very unlikely that the basin transfer method will give workable results. The Flood Q Ratio tool spreadsheet was used to calculate the flows with the data from the Anderson Creek gauge. The results shown in Table 7 are significantly lower than the results from the regional regression equation. Basin gauged transfer method is not appropriate for the project site.

WSDOT recognizes climate resilience as a component of the integrity of its structures, and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 32.0 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 44.1 percent, yielding a projected 2080 100-year flow of 46.1 cfs. (WDFW 2022)

Table 7: Peak flows for Machias Creek at SR 104

Mean recurrence interval (years)	Weighted basin gauge transfer from Anderson Creek(cfs)	USGS regression equation average (Region 3) (cfs)	USGS regression equation 90% Upper Limit (Region 3) (cfs)*
2	0.2	3.9	**7.9**
10	0.9	8.1	**17.1**
25	1.4	10.3	**22.7**
50	1.9	12.0	**27.3**
100	2.4	13.8	**32.0**
500	3.7	18.2	**46.0**
Projected 2080 100	3.46	19.9	**46.1**

Note: Values in bold are used in the design.

4 Water Crossing Design

This section describes the water crossing design developed for SR 104 MP 16.55 Machias Creek, including channel design, MHO, and streambed design.

4.1 Channel Design

This section describes the channel design developed for Machias Creek at SR 104 MP 16.55. The design proposes a two-stage channel consisting of a primary bankfull channel with overbank floodplain benches on each side. Both planform and cross-sectional variability will be created with channel complexity features described in Section 4.3.2. The proposed design consists of a constant channel gradient within the restored channel area, with an assumption that small-scale scouring will develop around channel forcing features over time.

4.1.1 Channel Planform and Shape

The proposed future conditions channel planform and cross-section shape were informed by the reference reach using stream simulation method, with some bank height modifications to promote floodplain bench interaction. The proposed channel geometry is a two-stage channel which targets the design average BFW of 6.7 feet as the top of bank width. The proposed channel has a 3-foot-wide channel bottom, with 0.8-foot of vertical rise on 2H:1V bank slope, creating a 6.2-foot-wide main channel, similar to the design average BFW of 6.7 feet. The main channel connects to 20H:1V floodplain benches on each side continuing out until it reaches the MHO of 14 feet described in Section 4.2. In the daylighted section of the channel restoration, the edge of the MHO ties into the existing surface with a 2H:1V slope. Figure 32 shows the proposed channel geometry and an existing channel section in the reference reach plotted at BFW #3. Some steeper banks will be created in conjunction with large wood material and other channel complexity features described in Section 4.3.2.

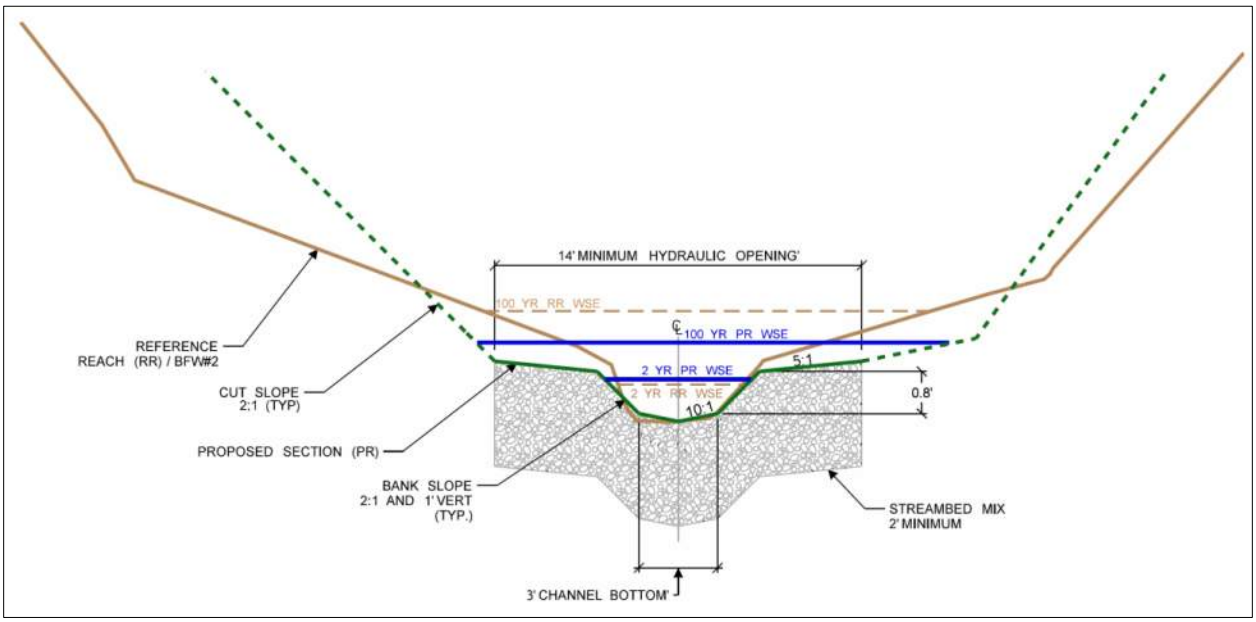

Figure 32: Design cross-section

Initially, 1-foot-high banks were proposed within the main channel as an attempt to match bank height measurements taken in the reference reach. The resulting channel shape was wider than observed BFW due to bank slope constraints, which are restricted to 2H:1V slopes as construction limitations of non-cohesive alluvial sediment. As noted in Section 2.7.2 the observed banks were nearly all vertical. Hydraulic model results for this initial channel geometry with 1-foot-high banks indicated the 2-year flow completely confined well below the top of the banks with little to no overbank floodplains interaction even at higher flows. After examining the initial hydraulic model results and adjusting the hydrology to the upper limit of justifiable flow values (Section 3), the design team decided to lower the height of banks to 0.8 feet to improve floodplain connectivity in the proposed section.

The resulting proposed channel geometry has a slightly shallower bankfull channel than the existing stream. The difference in bank height is on the order of a few inches and the proposed section does not reflect the variation in channel shape resulting from complexity features described in section 4.3.2. The proposed channel shape is a balance between matching the existing channel as best as possible given the limitations of constructable slope and promoting natural fluvial processes. The design is intended to reestablish flow connection to the overbank area within the project area. The slightly lower bank height from existing banks was an intentional design decision to improve floodplain connection at higher flows.

The modeled 2-year flow width within the proposed section is 5.1 feet, slightly smaller than the design average BFW (Table 3), but well within the range of BFW measurements taken in the December site visit. The 100-year flow engages the proposed overbank benches as it does in the reference reach. Figure 33 shows the comparison of the proposed section with all the BFW measurement locations including those taken downstream of the crossing.

Channel complexity features such as large wood and habitat boulders will create planform variability in the both the bankfull channel and thalweg by forcing meanders within the proposed 14-foot-wide channel MHO. A low-flow channel will be directed by the engineer in the field during construction connecting channel complexity features together to ensure the project does not create low-flow stranding. To capture the effect of channel complexity features in the hydraulic model and conceptually convey the expected planform variability, sinuosity was added to the bankfull width channel within the crossing structure. The length of the forced bankfull channel meanders is 12 feet based on the frequency of LWM forcings observed in the downstream reach (Figure 19 (b)). See the detail of meander bar design in Section 4.3.2.

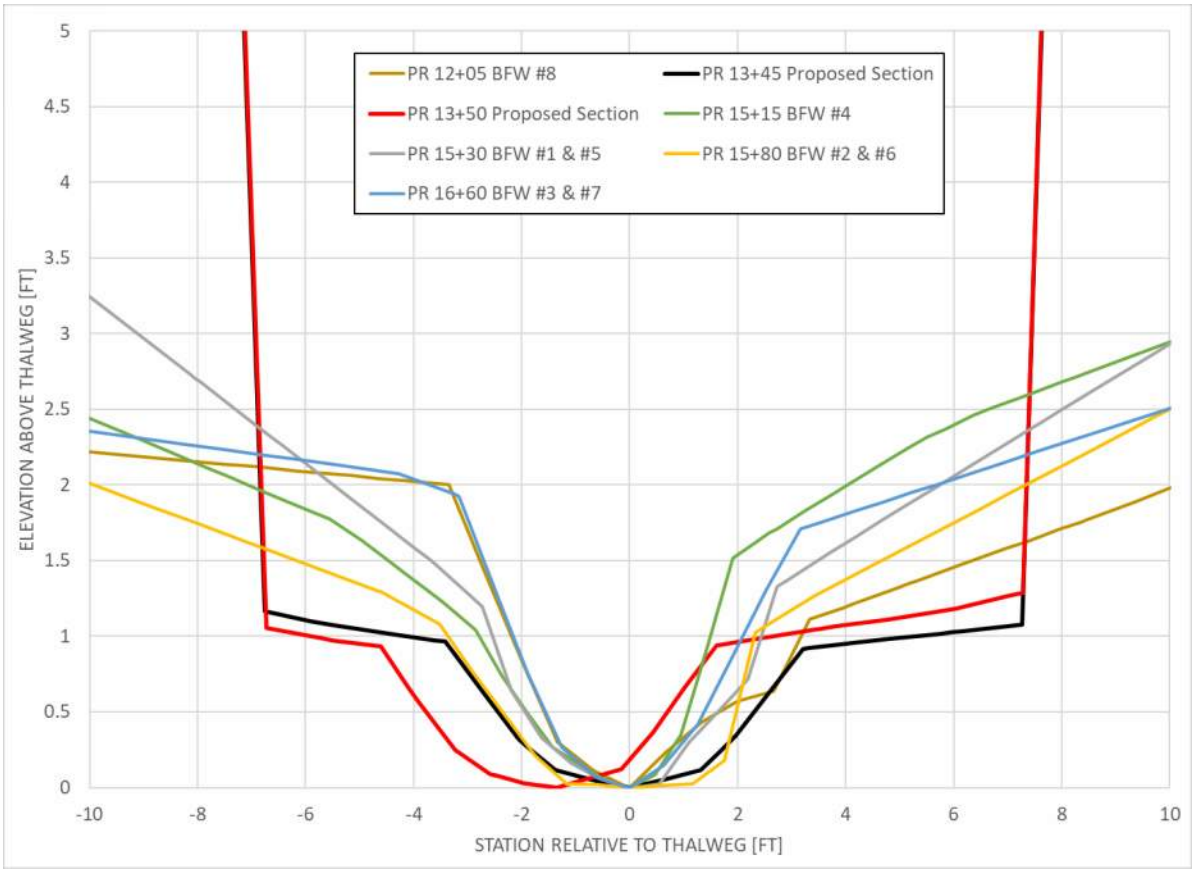

Figure 33: Proposed cross section superimposed with existing survey cross-sections; cross-sections are facing downstream

4.1.2 Channel Alignment

The proposed alignment for Machias Creek on crossing 990710 runs south to north across SR 104. The total proposed length of regrade is 211 feet with a crossing length of approximately 74 feet depending on the final structure type and configuration. The proposed channel alignment can be seen in the preliminary design sheets (Appendix D). The design team suspects the existing culvert was placed perpendicular to the road to minimize its length, which forced the stream to the western edge of the ravine upstream and the eastern edge of the ravine downstream. The proposed wider crossing structure is required to be centered away from the edges of the ravine to avoid major grading impacting on the sides of the ravine. The proposed channel crossing was angled to the northwest to align with the natural ravine (Figure 34). The co-managers agreed in the concurrence meeting that the proposed alignment should be skewed slightly to reestablish the channel closer to the center of the ravine, while maintaining as short a structure length as possible. At the upstream end, the proposed channel restoration ties into the existing channel 35 feet upstream of the existing culvert inlet to remove the aggraded material at the existing culvert entrance and to align the proposed channel with the proposed skewed crossing. The regrade limits also avoid disturbing the natural LWM further upstream. On the downstream side of the crossing the proposed channel ties in 40 feet downstream of the existing culvert outlet to allow the channel to naturally curve back to the existing alignment at a mild 70-foot radius. This realignment of the stream centerline toward the center of the ravine will alleviate the ravine slope scour observed at the existing culvert outlet.

Planform variability was added to the bankfull channel within the crossing structure to reflect the sinuosity created by meander bars (Section 4.3.2). The cross-sections within the reference reach for model results extraction are at the same locations in the existing and proposed-conditions models, although the stations are different in the proposed and existing alignments (Figure 34).

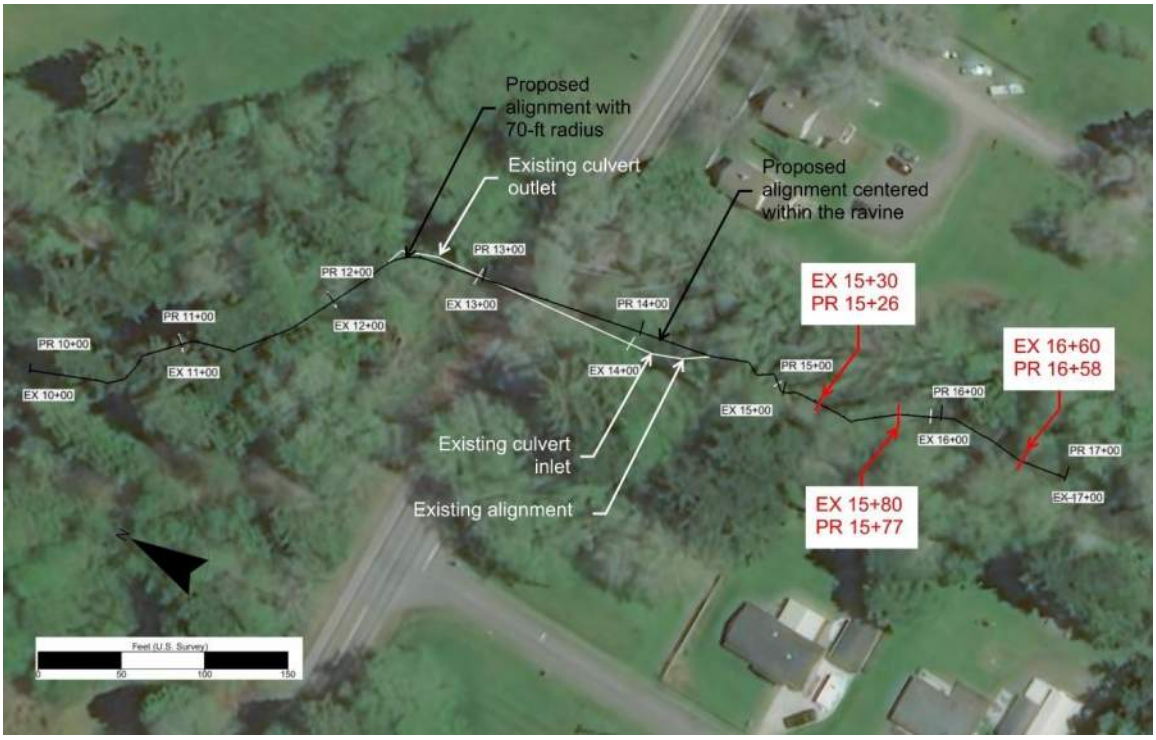

Figure 34. Proposed channel alignment compared to the existing alignment

4.1.3 Channel Gradient

The proposed gradient is 2 percent for the entire length of the restored channel. The slope ratio compared to the reference reach (2.1% gradient) is 1 (Figure 10). The proposed channel gradient is slightly steeper than the stream section immediately upstream of the proposed tie-in which has a slope of approximately 1 percent. The milder 1 percent reach is fairly short and the stream quickly returns to a 2 percent slope after a forced LWM step. Over the longer scale the stream's gradient is on average 1.7-percent throughout the upstream and downstream reach for a couple thousands of feet (Figure 31). The potential for regrading in the milder 1 percent reach is minor and would dissipate quickly upstream. In addition, glacial till underlies the entire Machias Creek project area providing abundance supply of till to the channel (Figure 4). In area impacted by the existing culvert near the crossing inlet, exposed hardpan till was observed on the bank. This is an indicator that till is near the surface in most of the project vicinity. The presence of till will prevent rapid degradation in the adjacent channel reaches. The proposed slope is identical to the reference reach slope and nearly matches the overall watershed-scale stream slope. Long-term degradation and aggradation are not expected in the project crossing as the proposed slope is consistent with the existing upstream and downstream reaches (Section 2.7.4). Minor fluctuations in slope will likely develop due to debris build up and shifts in

the large wood, these natural transient fluctuations do not pose a risk to the structure or the stream's function.

4.2 Minimum Hydraulic Opening

The MHO is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 35 for an illustration of the MHO, hydraulic width, freeboard, and maintenance clearance terminology.

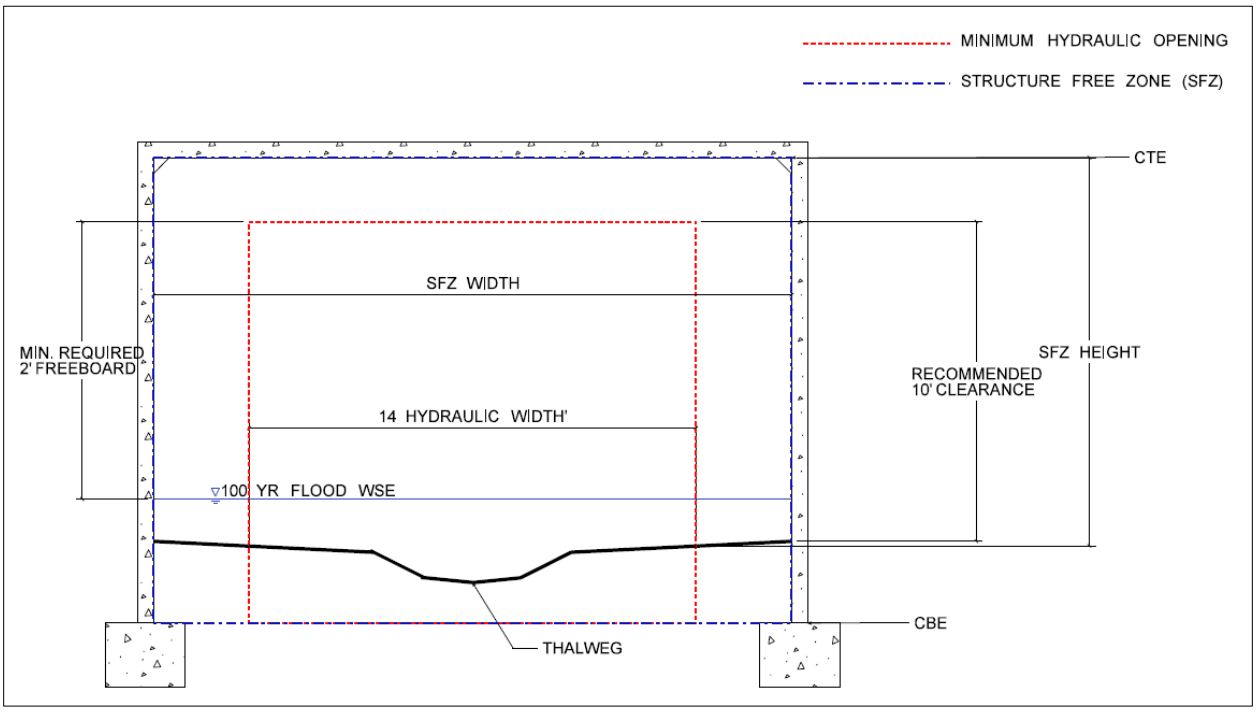

Figure 35: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard, et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the channel has BFW less than 15 feet, moderate confinement, little or no channel movement anticipated, and moderate vertical instability. Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing as the designed average BFW is smaller than 15 feet (Section 2.7.2) and the FUR calculated in Section 2.7.2.1 shows that Machias Creek is a moderately confined stream at the project site. In addition, the slope ratio of the proposed channel and the reference reach is less than 1.25 (Section 4.1.3) with an overall uniform channel gradient upstream and downstream of the project crossing. These stream characteristics indicate a system with vertical stability and marginal risk of channel migration (Section 2.7.4, 2.7.5, and 4.1.1). The length of the proposed crossing is 74 feet (Section 4.1.2). The existing roadway elevation is 25 feet above the channel thalweg, providing sufficient vertical

space for clearance, freeboard, and future climate induced flood increases. There is no risk for aggradation and degradation as described in Section 7.2.

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 11 feet was determined to be the minimum starting point. This is based on the concurred BFW of 7.5 feet times 1.2 plus two equals 11.0 feet. Due to observed LWM-induced channel forcings, and the habitat complexity features proposed within the crossing, an additional 3 feet of width was applied as a factor of safety, increasing the hydraulic width to 14 feet. The factor of safety will provide space for forcing features through the crossing and account for the planform variability created by the meander bars described in Section 4.3.2. The bankfull channel velocity through the existing crossing is 3.4 feet per second during a 100-year event, which is similar to the average velocity of 3.6 feet per second within the reference reach (Table 8). The proposed-conditions model results in Section 5.4 show that the 14-foot hydraulic width creates similar conditions in the crossing compared to the reference reach of Machias Creek, which is the goal of the stream simulation design. As discussed in Section 2.7.5, the risk of lateral migration for Machias Creek is limited by the steep ravine walls and relatively entrenched channel at the project crossing. The proposed 74-foot-long crossing is a little over five times the 14-foot-wide hydraulic width and, as such, is not sufficiently long to warrant increasing the hydraulic width.

Based on the factors described above, a minimum hydraulic width of 14 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was evaluated. Table 8 compares the velocities of the 100-year and projected 2080 100-year events. No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results see Section 5.4.

Table 8: Velocity comparison for 14-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Reference reach BFW #1 (PR 15+26)	3.4	3.7
Reference reach BFW #2 (PR 15+77)	4.4	4.6
Reference Reach BFW #3 (PR 16+58)	3.2	3.7
Upstream of structure (PR 14+20)	3.6	3.9
Through structure (PR 13+45)	3.4	3.9
Downstream of structure (PR 12+60)	2.8	3.0

4.2.3 Vertical Clearance

The factors that influence recommended vertical clearance under a structure are freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 9.

The minimum required freeboard at the project location, based on BFW, is 2 feet above the 100-year water surface elevation (WSE) (Barnard, et al. 2013), (WSDOT 2022).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.2 feet for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or LWM. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features described in Section 4.3.2 do not require maintenance with machinery and a minimum clearance of 6 feet would be sufficient for human accessed maintenance and monitoring. However, the existing SR 104 road is over 25 feet higher than the streambed and channel complexity features would benefit from machinery access. Although it is not a hydraulic requirement, 10 feet of clearance is recommended for equipment access. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

Table 9: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	PR STA 13+02	PR STA 13+76
Thalweg elevation (ft)	21.6	23.2
Highest streambed ground elevation within hydraulic width (ft)	22.8	24.3
100-year WSE (ft)	23.1	24.4
2080 100-year WSE (ft)	23.4	24.6
Required freeboard (ft)	2	2
Recommended maintenance clearance (ft)	10	10
Required minimum low chord, 100-year WSE + freeboard (ft)	25.5	26.2
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	25.7	26.7
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	33.4	33.9
Required minimum low chord (ft)	**25.7**	**26.7**
Recommended minimum low chord (ft)	**33.4**	**33.9**

4.2.3.1 Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage nor removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

The potential for LWM transport within the project reach in the proposed conditions is considered low due to the lack of stream power. Observed LWM at the site largely appeared to

lie where it fell. As noted in Section 2.7.2, the existing channel has steep vertical banks and pieces spanning the banks were not in contact with flow. Large wood pieces that were in contact with the flow forced the stream to move rather than being transported themselves. The transport of small wood and debris appears common. The land cover in the steeper headwaters of the watershed is mostly pasture (Figure 3), and the watershed area does not contain logging activity (Section 2.2). The potential for significant urban growth within the watershed is low. No restoration activity other than this project is known within the watershed. The more heavily forested areas are primary in the flatter gradient sections of Machias Creek (Figure 3 and Figure 31), where stream power is low. The dominant channel substrate observed adjacent to the project crossing is fine sediment (Section 2.7.3). The pebble count data and percent of fines indicate that Machias Creek is not sediment supply limited. The crossing appears to have reached a quasi-equilibrium stage (Simon and Rinaldi 2006). There is no upstream infrastructure that might interrupt natural sediment transport. Erosion of fine-grained bank sediments was observed in several locations. Even though sediment is available, the channel is moderately entrenched and there are no signs of anastomosing or sediment build up. Localized aggradation is possible upstream of channel-spanning features, although it is more likely the stream would respond by migrating horizontally rather than vertically. Long-term aggradation is not anticipated for the project site (Section 7.2).

4.2.4 Hydraulic Length

A minimum hydraulic width of 14 feet is recommended up to a maximum hydraulic length of 140 feet. If the hydraulic length is increased beyond 140 feet, the hydraulic width and vertical clearance will need to be reevaluated.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 104 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for Machias Creek at SR 104 MP 16.55.

4.3.1 Bed Material

WCDG (Barnard, et al. 2013) suggests new crossings must be either filled with a material that replicates adjacent channels or be left empty to fill over time. The WSDOT Hydraulics Manual and the Washington Administrative Code (WAC) dictates allowable sediment sizes in a fish-bearing streams. The design criteria used to define sediment as similar to an adjacent channel is the proposed sediment having a D_{50} within 20 percent of the value in the reference reach as defined by a pebble count data (WSDOT 2022). In addition, the Hydraulics Manual recommends two approaches for determining sediment stability for designed channels: the Modified Critical Shear Stress approach for systems with slopes less than 4 percent and streams with a D_{84}

between the range of 10 and 250 millimeters (0.4 to 9.8 inches); and the Bathurst Unit-Discharge Bed Design approach for systems with slopes greater than 4 percent (WSDOT 2022). The Modified Critical Shear Stress approach is appropriate for the design of this crossing because the proposed crossing gradient is 2 percent, and the observed D_{84} from pebble count is 1 inch.

The main design constraint for the proposed Machias Creek reconstructed channel is the very fine nature of the existing sediment observed in the system. WSDOT Streambed Sediment (WSDOT Standard Specification 9-03.11(1)) is the smallest material typically specified in reconstructed highway crossing channels to avoid completely structureless channels when vegetation, the main source of channel stability, is absent (WSDOT 2023). The proposed mix for streambed material contains 70 percent of WSDOT Streambed Sediment (WSDOT Standard Specification 9-03.11(1)) and 30 percent of WSDOT Streambed Sand. The WSDOT Streambed Sand is a ½-inch-minus material containing as much as 67 percent by weight passing the No. 8 sieve, which is granules and sand, and it lowers the D_{50} of the proposed streambed material to the same size with the pebble count results of 0.2 inches gravel and small cobbles were observed in riffle sections and underlying the thin covering of finer material (Figure 28 and Figure 29).There are no upstream constraints on natural sediment transport in Machias Creek and the proposed crossing should experience the same natural supply of fine sediment from the watershed as the existing channel (Section 2.3). A comparison of average sediment sizes observed in the reference reach and proposed sediment sizes is provided in Table 10.

The mobility of the proposed streambed mix is examined using the Modified Critical Shear Stress approach. The average and maximum shear stress SRH-2D model results for the 2- and 100-year within the proposed crossing were used as input for the Modified Critical Shear Stress Method. The bed mobility analysis results show the proposed streambed material is completely mobile during both 2-year and 100-year events (Appendix C) despite being the same size with the existing pebble count sediment data. This result highlights the large effect vegetation likely plays in the existing channel stability as vegetation is not accounted for in the Modified Critical Shear Stress analysis.

To add bed structure within the proposed crossing where vegetation growth will be minimal and add flow variability to mitigate for the likelihood of a planebed channel forming if the banks where to erode, meander bar complexity features are proposed within the crossing structure (Section 4.3.2). A meander bar consists of immobile sediment-and-boulders mix embedded at the head of the bar into the streambed with small woody materials, and finer mix fill in the tail of the bar that will be mobile during higher flow events. These complexity features are intended to have completely immobile head during 100-year flow and create flow deflection which will increase channel complexity and sediment retention within the crossing structure where LWM is not allowed.

A mix of WSDOT Streambed aggregates, including 30 percent Streambed Sediment (WSDOT Standard Specification 9-03.11(1)), 40 percent 12-inch Cobbles (WSDOT Standard Specification 9-03.11(2)) and 30 percent of 12- to 18- inch Streambed Boulder (WSDOT Standard Specification 9-03.11(3)) is proposed for the head of the meander bar sediment (WSDOT 2023). No motion of meander bar head gradation is shown either 2-year and 100-year events using the Critical Shear Stress Method (Appendix C). Another mix of 30 percent

Streambed Sediment (WSDOT Standard Specification 9-03.11(1)), 70 percent 4-inch Cobbles (WSDOT Standard Specification 9-03.11(2)) is proposed for the tail of the meander bar (WSDOT 2023). Under the 100-year average shear stress, the sediment smaller than D_{60} will be mobile in the meander bar tails. All of the sediment for meander bar tails are immobile under 2-year flow except at locates where localized high shear stress are observed. The proposed meander bars are intended to be overtopped during 10-year flow events. The conceptual layout of the meander bar is shown in Section 4.3.2.1.

Table 10: Comparison of observed and proposed streambed material

Sediment size	Observed diameter for design (in)	Proposed diameter (in)	Meander bar tail diameter (in)	Meander bar head diameter (in)
D_{16}	0.1	0.01	0.6	0.7
D_{50}	0.2	0.2	1.6	5.4
D_{84}	0.7	1.8	2.9	14.8
D_{95}	1.7	2.3	3.6	17.0
D_{100}	3.3	2.5	4.0	18.0

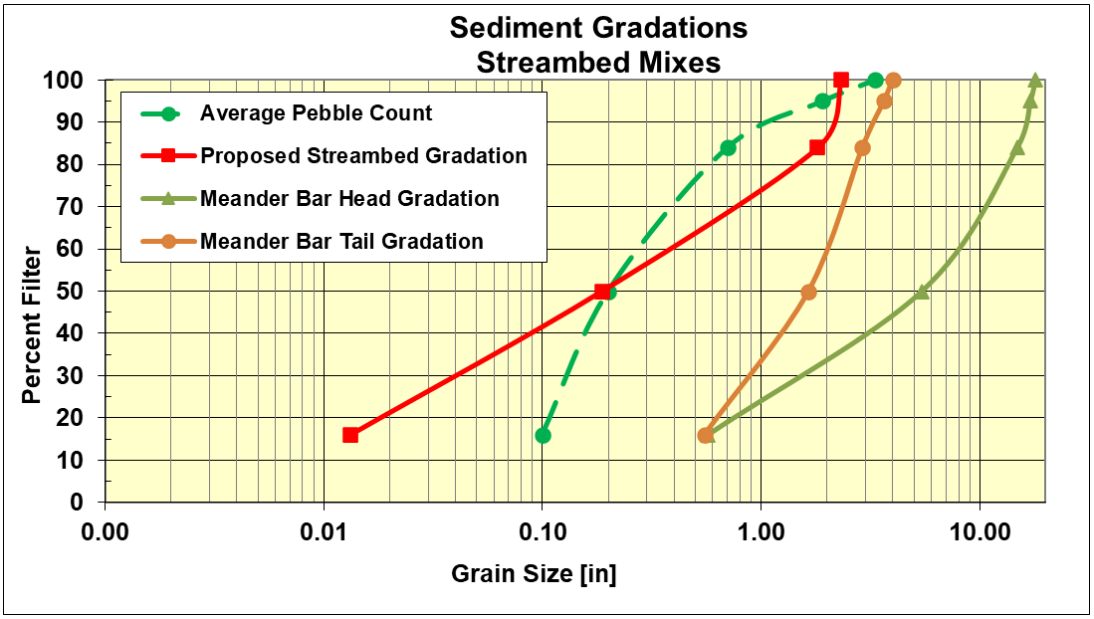

Figure 36. Existing and proposes streambed gradation comparisons

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Machias Creek at SR 104 MP 16.55.

4.3.2.1 Design Concept

LWM will be placed at specific locations to develop channel complexity throughout the regraded channel. No woody material is proposed inside the crossing structure; hence, meander bars are proposed to increase channel complexity. Meander bars within the crossing structures create a channel with riffles, resting pools, and velocity refuge for rearing juveniles. Meander bars also force the thalweg to migrate laterally throughout the crossing, increasing channel complexity

through the crossing and disrupting the formation of shallow plane bed flow. Near proposed complexity features the channel is expected to develop local variability such as scour pools and riffles. Their purpose as complexity features is to create planform variability, prevent entrainment along the structure wall and prevent a planebed morphology from forming within the structure. Note that the design is not based on geomorphic meander bars. Rather they are intended to function similar to LWM outside of the crossing, providing bed complexity within the bankfull channel.

The proposed meander bars within the crossing alternate sides of the stream centerline every 10 feet, forcing the thalweg to meander with a wavelength of 24 feet, approximately four times the design BFW. Each meander bar is 16 linear feet long at the wall of the crossing structure with a rounded wedge shape that extends toward the crossing centerline (Figure 37). The meander bars extend 6 feet from the structure walls toward the centerline, which is approximately one-third of the MHO. The 6-foot projection of the bar forces sinuosity in the channel by deflecting flow, while providing greater than the 6.2-foot-wide main channel width between each bar and the opposite structure wall. The forced meander will create velocity breaks and a longer flowpath as water is forced around each bar during low flow events. The meander bars will be submerged during events larger than 10-year flow. The meander bars consist of streambed sediment, 12-inch cobbles and one-man streambed boulders as described in Section 4.3.1. The meander bar tail mix has a D_{50} of 1.6 inches which not only helps encourage lateral complexity in the low-flow channel but also provides additional substrate which may be utilized for spawning. The sediment and cobbles in the meander bar gradation mix seal the gaps between boulders, reducing permeability and increasing stability of meander bars to ensure will deflect flow and create the desired meandering flow path. The size, position, and material composition of the proposed meander bars will be finalized in the FHD.

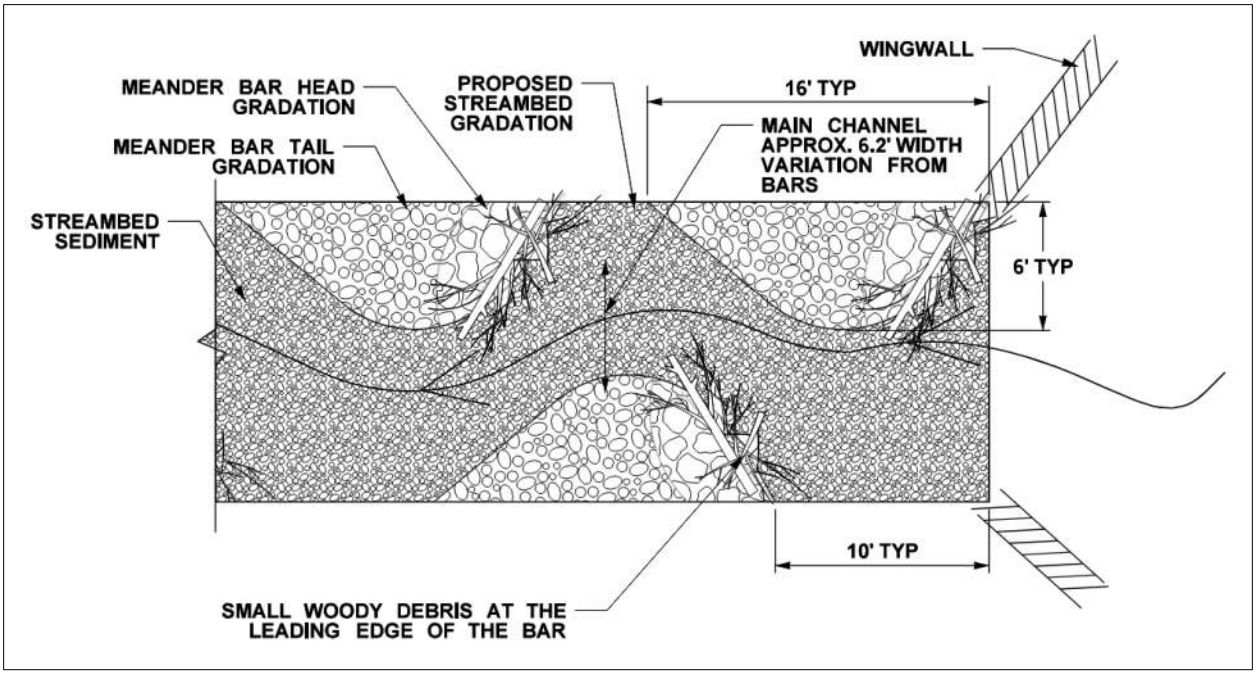

Figure 37. Meander bar conceptual layout

The function of the LWM is to enhance habitat in the proposed channel by forming scour pools, providing cover, adding organic material and a source of food, contributing to hydraulic diversity, and encouraging gravel deposition. WSDOT has provided guidance and analysis tools for LWM quantities consistent with *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forested Basins of Washington State* (Fox and Bolton 2007). There are three metrics representing the LWM quantities observed by Fox and Bolton, density of key pieces, total wood pieces and total wood volume. The percentile targets are determined by habitat zone and bankfull width class. Machias Creek is in the Western Washington habitat zone and has a design average BFW of 6.7 feet (Table 3). The metric targets for the project site are listed below:

- 0.0335 key piece per foot of stream, each key piece must meet minimum volume of 1.31 cubic yards excluding the rootwad
- 0.1158 total wood pieces of LWM per foot of stream
- 0.3948 cubic feet of total wood volume per foot of stream

Table 11. LWM log metrics (Fox and Bolton 2007)

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	8	38	39.1
75% Targets	7	24	83.3
50% Targets	4	19	42.9

The key piece density requirement and total number of LWM pieces in the Fox and Bolton (2007) metrics described above were used as the targets for the proposed LWM design. The minimums required for each metric are based on the total stream reconstruction length of 211 feet. The regrade length for determining quantities includes 74 feet totally covered by the crossing structures where LWM will not be placed. The target numbers for LWM are shown in Table 11. See Appendix F for details on the calculations.

The proposed design surpasses the 75th percentile targets for number of key pieces and total number of LWM pieces. The proposed LWM layout maximizes the regraded channel area outside the crossing structures. While it is not able to meet the 75th percentile target for total LWM volume due to the relatively small size of the stream, it does meet the 50th percentile target. Machias Creek around the project site has a design average BFW of 6.7 feet. Key logs longer than 25 feet will hardly interact with the stream.

The design proposes eight key pieces (labeled as Type 1 log in Figure 38) that each meet the minimum volume of 1.31 cubic yards. The proposed key pieces are 2 feet in diameter at midpoint and 25 feet long. In addition to the eight key pieces, the design includes 30 non-key pieces. Of the non-key pieces, seven are 1.5 feet in diameter at midpoint and 20 feet long with rootwad (labeled as Type 2 log in Figure 38). The rest of the non-key pieces are smaller, 1 foot in diameter at midpoint and 10 feet long with rootwad, to provide smaller woody debris in the channel (labeled as Type 3 log in Figure 38). The LWM layout design proposes a total of 41 LWM pieces and a total wood volume of 43.1 cubic yards. See the proposed LWM layout in Figure 38. Note, that while the layout descriptions below are guidelines for installation, some variation in installation orientation around this description as shown in the layout figure is

encouraged to create habitat diversity. Some smaller pieces are proposed to partially intrude in the entrance and the exit of the structure. The risk of wood rotation is considered during the design of layout and will be reevaluated in later stage of design.

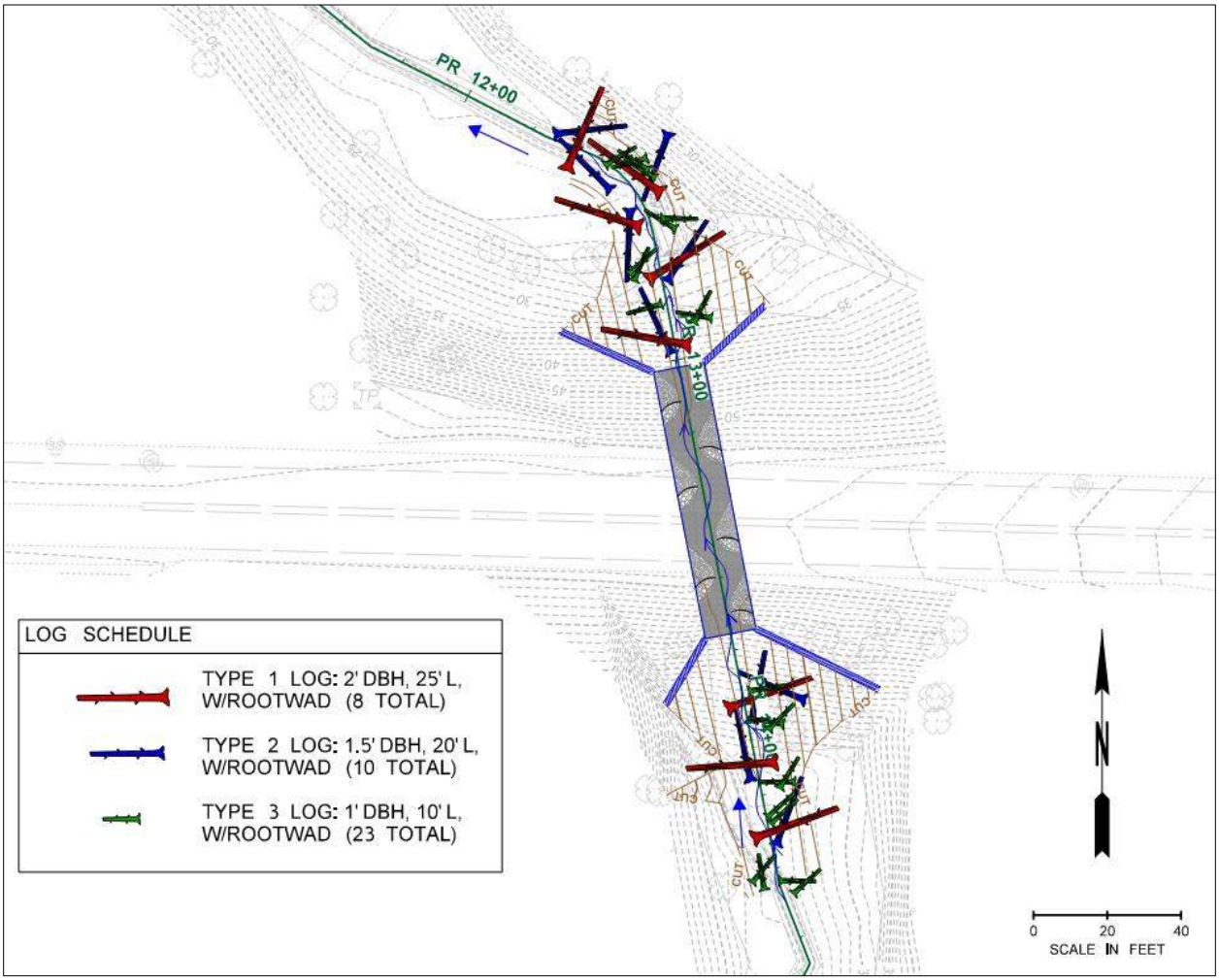

Figure 38: Conceptual layout of habitat complexity

Type 2 log is designed to interact with the central channel flows to reduce velocities and create localized habitat (Figure 38 and Figure 39). Most of these logs are placed with the rootwad facing upstream within the channel. Scour holes will form underneath the trunk and around the rootwad, creating pools for salmonid use. Where appropriate, the space between the trunk and the top of bank will be back filled with streambed materials, resulting in steeper banks along the trunk.

Type 1 key log will have its rootwad partially buried in the overbank and the trunk side laid on top of the Type 2 toe log (Figure 39). This structure creates a shaded area under the key log for salmonid to avoid predators. The key logs weigh the Type 2 logs down resulting in a self-ballasting system to avoid downstream movement. The rootwad of Type 1 key log will be placed on the opposite side of the bank from the toe log to provide more vertical clearance allowing the water to flow underneath while engaging with high-flow events, while the rootwad of the Type 2 logs will be partially buried into the bank so that it interacts with the channel centerline but does

not fully block the channel at low flows (Figure 39). This structure mimics the channel-spanning log observed in the reference reach (Figure 22) and will not create a fish barrier. One of the Type 1 key piece is placed at the outside bend of the channel alignment with 70-foot radius (Section 4.1.2) to provide bank protection in addition to habitat and hydraulic diversity (PR 12+50 in Figure 38).

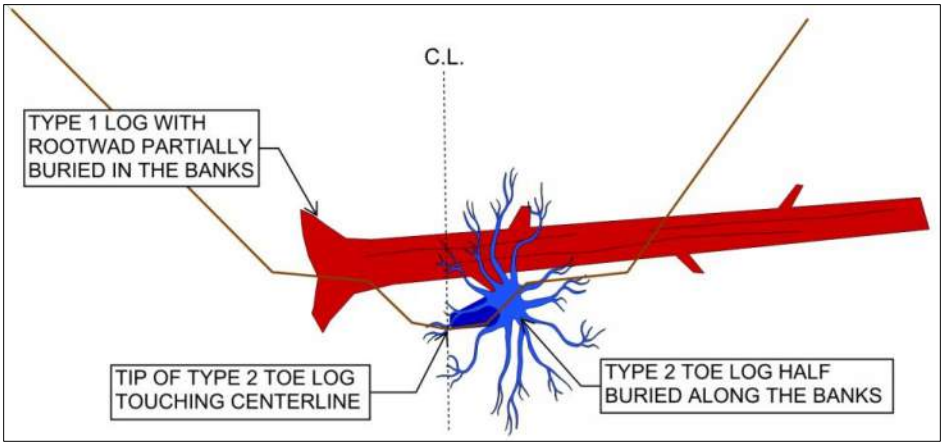

Figure 39. Channel-spanning LWM structure section

Type 3 logs are half buried in the stream bed to force a sinuous thalweg (Figure 38). During effective flows, when sediment in the system is mobile, the half-buried Type 3 logs will aggrade material in the velocity shadow downstream of areas where they project into the flow. This will encourage formation of step-pools as observed in the downstream reach (Figure 16 and Figure 19(b)). Some Type 3 logs are proposed as non-buried pieces placed on top of the half-buried Type 3 logs and toe log structures as smaller woody debris naturally recruited over time and will eventually decompose and fall into the channel. Decomposing woody debris will increase nutrient loads in the system which may translate to an increase in benthic macro-invertebrates and enhanced juvenile foraging opportunities.

The conceptual layout in Figure 38 is feasible for either a bridge or a buried structure. Type 3 logs that are stacked on other LWM structures are designed to be mobile during events larger than 2-year flow. Type 1, Type 2 and the half-buried Type 3 logs will be immobile in any conditions. Where the rootwads contact the bed, scour pools may form under and around it. The scour holes can be used as velocity refuge and cover, which are associated with resting habitat and the potential to connect with hyporheic flow. Preformed scour pools are not recommended at this stage of design. Construction of the low-flow channel will be directed by the engineer in the field. There is no risk of fish stranding with the design during summer flow conditions. At the FHD level, this section will include documentation of stability calculations and a full plan, specification and cost estimate package. Anchoring is not anticipated until stability calculations are completed that indicate otherwise.

This section describes the landscape restoration recommendations for the riparian areas associated with the new channel design in consideration of the proposed alignment, streambank gradient, LWM placement, site design considerations to meet WSDOT's Roadside Manual and other permit requirements.

The conceptual layout of the restoration plan is shown in Figure 40. Based on the existing conditions as described in Section 2.6.2, the banks adjacent to the existing crossing are steep with signs of erosion while the stream itself has a relatively low gradient (between approximately 1 to 2% on average). The riparian area adjacent to the stream contains a mix of native and invasive vegetation. The primary restoration considerations at this crossing are slope stabilization and invasive species treatment.

The riparian area upstream of the crossing is composed primarily of a mature canopy with native understory. Areas with unavoidable vegetation impacts are proposed to be restored with a diverse mix of native trees and shrubs to preserve the native composition of this reach and inhibit the spread of invasive species into newly restored areas with disturbed soils. The area downstream of the crossing has a similar vegetative composition but includes a higher percent cover of invasive English ivy (Hedera helix), which is prevalent across the road embankment. This reach is proposed to receive additional site preparation and weed control treatment prior to plant installation. To provide slope stabilization in restoration areas both upstream and downstream, a combination of live stakes and/or other bioengineering measures (such as coir-logs) along the meander bars and floodplain slopes are proposed.

Other typical restoration design considerations:

- The conceptual restoration plan assumes a box culvert structure under the highway crossing. No restoration plantings will be installed inside the culvert. If the box culvert option is replaced by a bridge in final design, a shadow analysis is recommended to determine the additional planting area suitable to extend the streambank and forest/shrub upland planting limits. In areas with limited sunlight and rainwater, apply wood chip mulch to minimize exposed soil material.
- Regulatory wetland features are not delineated or included in the current conceptual restoration plan. Impacts to wetland and wetland buffer will need to be addressed in the final restoration plan.
- Tree impacts within WSDOT right-of-way and critical areas will be a determining factor on final restoration footprint, planting compositions, and invasive removal requirements.

Typical planting zones are identified to meet the restoration goals:

- Forest/Shrub Upland Mix – A diverse mix of native evergreen and deciduous trees, shrubs, and groundcovers. Select trees and shrubs species to meet standard roadway, overhead utilities, or other design offsets, and to balance the vegetation composition of existing canopy or understory.

- Streambank Mix – Combination of live stakes, live fascine, brush mattress, or inclusion of compost sock, generally 10 feet to 15 feet from the streambank (or between 2-year and 100-year water surface elevations).

- Pollinator/Roadside Restoration Seed Mix – Promotes pollinators and provides erosion control benefits with species acclimated to exposed conditions and low fertile soils. This is generally applied to the first 10 feet from the edge of pavement or to the extent that matches the landscape characteristics (e.g., roadside swale area) for maintenance

purposes. This zone will transition to the upland mix, which includes native trees, shrubs, and groundcovers.

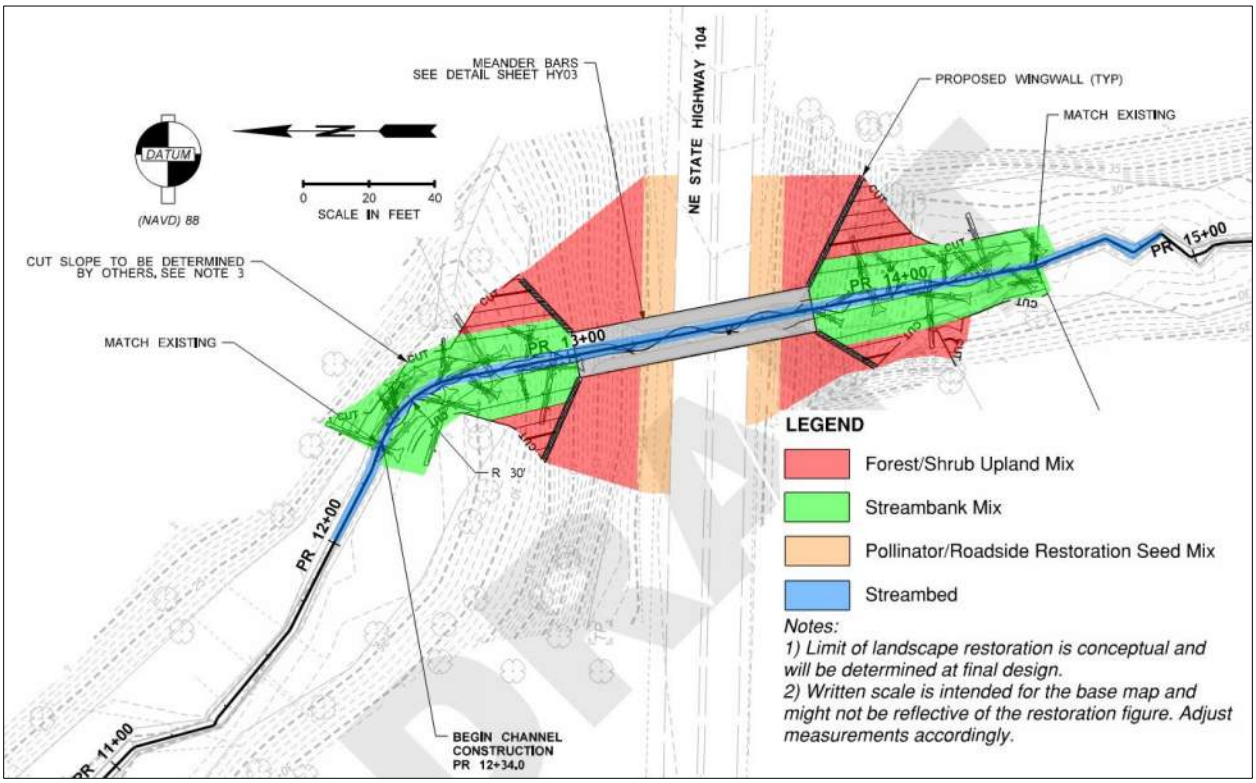

Figure 40. Conceptual layout of restoration

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 104 Machias Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3.0 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using Surface-water Modeling System (SMS) Version 13.1.15 (Aquaveo 2021).

Two scenarios were analyzed for determining hydraulic parameters for Machias Creek with the SRH-2D models: (1) existing conditions with the 3-foot diameter round concrete culvert and (2) proposed conditions with a 14-foot-wide MHO.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT survey team on August 31st, 2021. Proposed channel geometry was developed from the proposed grading surface created by Entitlement and Engineering Solutions, Inc (EES). All survey information is referenced to the NAVD88 vertical datum. LiDAR is not used for hydraulic modeling.

5.1.2 Model Extent and Computational Mesh

The model extent is approximately 300 feet upstream and downstream of the existing SR 104 culvert (Figure 41). The upstream and downstream limits of the model are far enough from the regraded channel to not create hydraulic effects at the crossing. Likewise, the boundary conditions (development of which is described in Section 5.1.4) at the upstream and downstream ends of the mesh are at a sufficient distance from the crossing to ensure they will not influence the modeling results at the project crossing. The model extent covers the floodplain of Machias Creek adjacent to the project crossing. No LiDAR data was used to extend the model domain.

The hydraulic model's computational mesh was developed so that important features (channels, roads, etc.) are captured with enough detail that all flows can be modeled accurately. Breaklines from the survey data were drawn along these important features to ensure that the mesh represents elevations accurately. The mesh is represented by a network of triangles and quadrilaterals that make up the computational cells (elements) of the model, where the modeling results are computed. Quadrilateral elements are defined in channels, culverts, ditches, and roadway surfaces. Triangular elements are defined in areas where flow may spread in several directions (outlets, floodplains, overbank areas). Nodes comprise the corners of each element. Each node in the mesh has an elevation associated with it, defined from the topographic survey surface. The elevations of nodes around the culvert inlet and outlet were

modified to match the surveyed culvert invert elevations to ensure model stability in the existing conditions.

Mesh nodes are spaced along the stream channel at approximately 1 to 1.5-foot intervals so that a minimum of 10 elements span the channel. The mesh developed for the existing-conditions hydraulic model has an area of 49,861 square feet and contains 30,206 elements (Figure 41). The mesh developed for the proposed-conditions hydraulic model has the existing culvert area replaced with the proposed channel using quadrilateral elements (Figure 42) with 31,024 elements covering the same area with the existing-conditions model. The proposed-conditions surface, which include a sinuous main channel in the crossing, is built into the mesh (Figure 42, Figure 41 and Section 4.3.2).

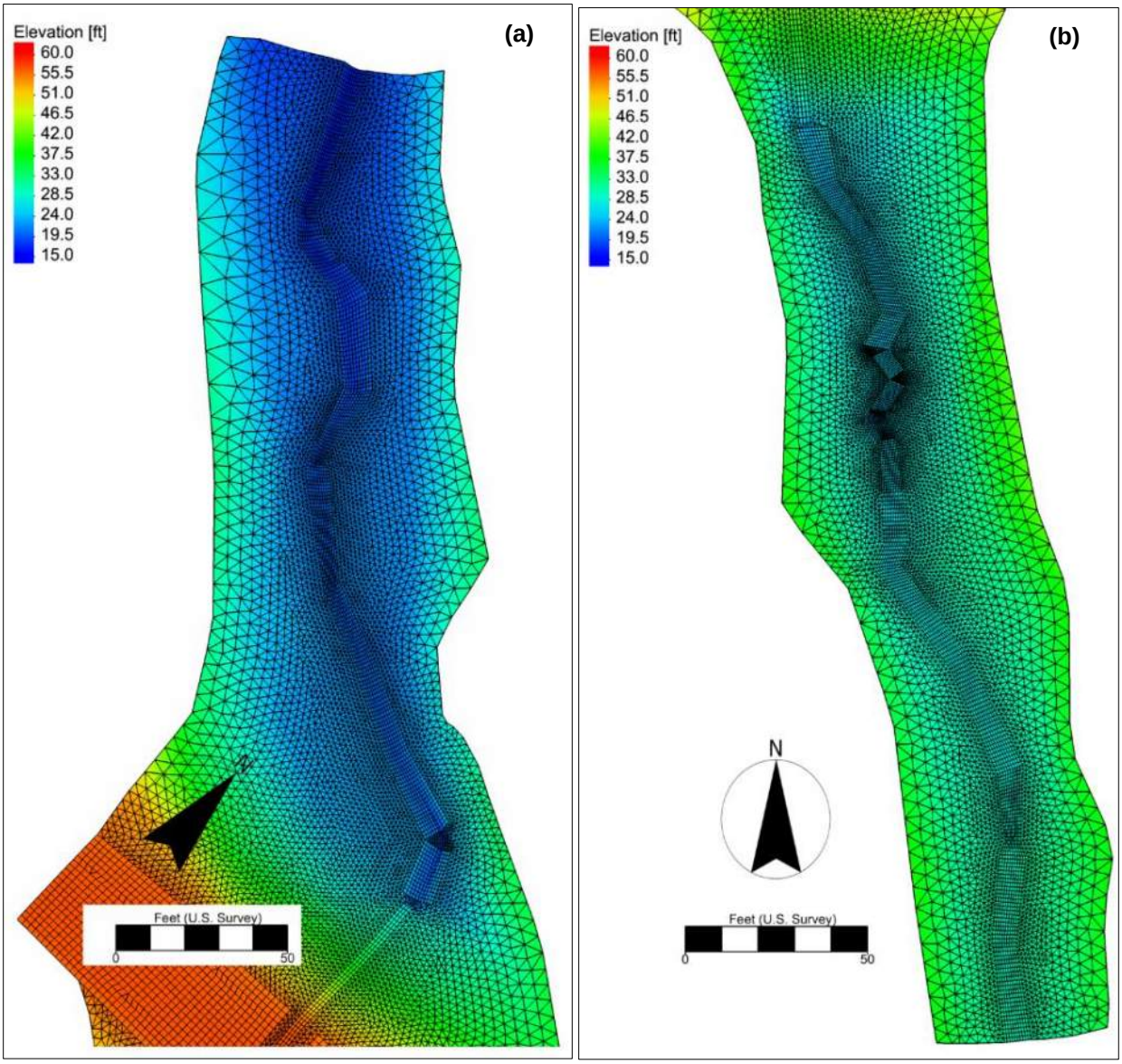

Figure 41: Existing-conditions computational mesh with underlying terrain. (a) Downstream (b) Upstream

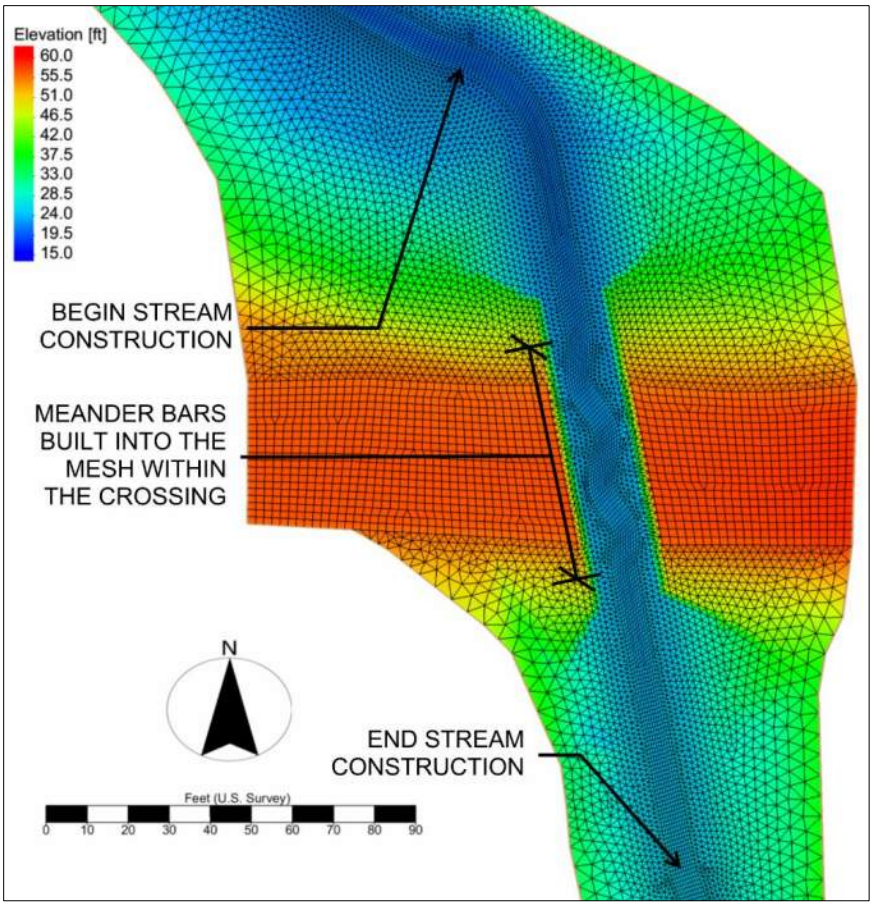

Figure 42: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

For the existing-conditions model, three materials are used to describe the roughness within the model domain: Forest, Road, and Main Channel (Table 12). A Manning's n value of 0.047 was assigned to the existing main channel, using an average roughness value from the quantitative methods, tabular estimates and semi-quantitative estimates (Arcement and Schneider 1989) provided in the US Forest Service's Stream Channel Flow Resistance Coefficient Computation Tool (the spreadsheet tool) (Yochum 2018), and can be reviewed in Appendix E. The spreadsheet tool requires hydraulic radius and mean flow depth as inputs. It is an iterative process performed by extracting these two values from the 100-year existing-conditions model results at a reference reach cross-section, calculating the estimated roughness in the spreadsheet tool and then re-running the model until the roughness value converged. The roughness value converged at 0.047 in the existing channel (Figure 43). The roughness value for forest is suggested by Hydraulics Manual for floodplain with a heavy stand of timber with little undergrowth and no interaction with the branches (WSDOT 2022). The maximum value of 0.12 in this category was chosen as there is heavy undergrowth of English ivy covering the floodplain besides the stand of trees. This Forest floodplain value is used throughout the extent of the modeling as the downstream reach also has significant undergrowth of shrubs in the floodplains. The Manning's n value of the road is chosen from Open Channel Hydraulic for

rough asphalt (Chow 1959). The roughness value for road is assigned in case SR 104 is overtopped.

The spreadsheet tool (Yochum 2018) is also used to estimate roughness values in the proposed-conditions model. The proposed section has a 6.2-foot-wide main channel (Section 4.1.1). The Regraded Channel region in Figure 44 covers the 6.2-foot main channel within the regrading limit outside the proposed crossing structure. Due to the LWM proposed within the Regraded Channel, the tabular estimate, effect of obstruction and variation in cross-section are assigned higher numbers in the spreadsheet tool (Yochum 2018), resulting in an overall average Manning's n value of 0.057, which is greater than the existing main channel (Appendix E). The proposed overbanks will be covered by English ivy and brush the same as the existing conditions, and Mannings value of 0.12 in the Forest region was applied. In the proposed crossing, the degree of irregularity and the amount of vegetation are set to be zero due to the lack of daylight and LWM. Although the meander bars are built into the mesh topography to simulate the effect of obstruction (Section 5.1.2), the proposed two-man and one-man boulders embedded (Section 4.3.2) contribute to additional effect of obstructions and some degree of cross-section variation. The spreadsheet tool (Yochum 2018) yielded a lower Mannings value of 0.047 for the proposed crossing (Appendix E). The rest of the areas in the proposed-conditions model area assigned the same values to the existing-conditions model.

Table 12: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Forest	0.12
Road	0.012
Main Channel	0.047
Regraded Channel	0.057
Regraded Channel Floodplain	0.12
Proposed Crossing (with Meander bars)	0.047

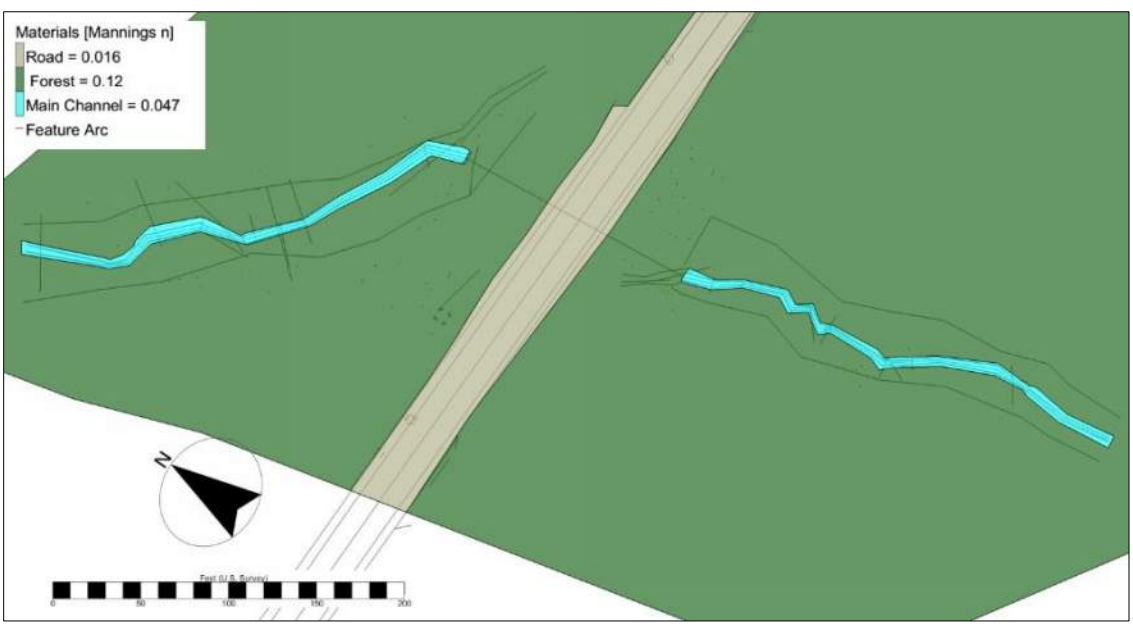

Figure 43: Spatial distribution of existing-conditions roughness values in SRH-2D model

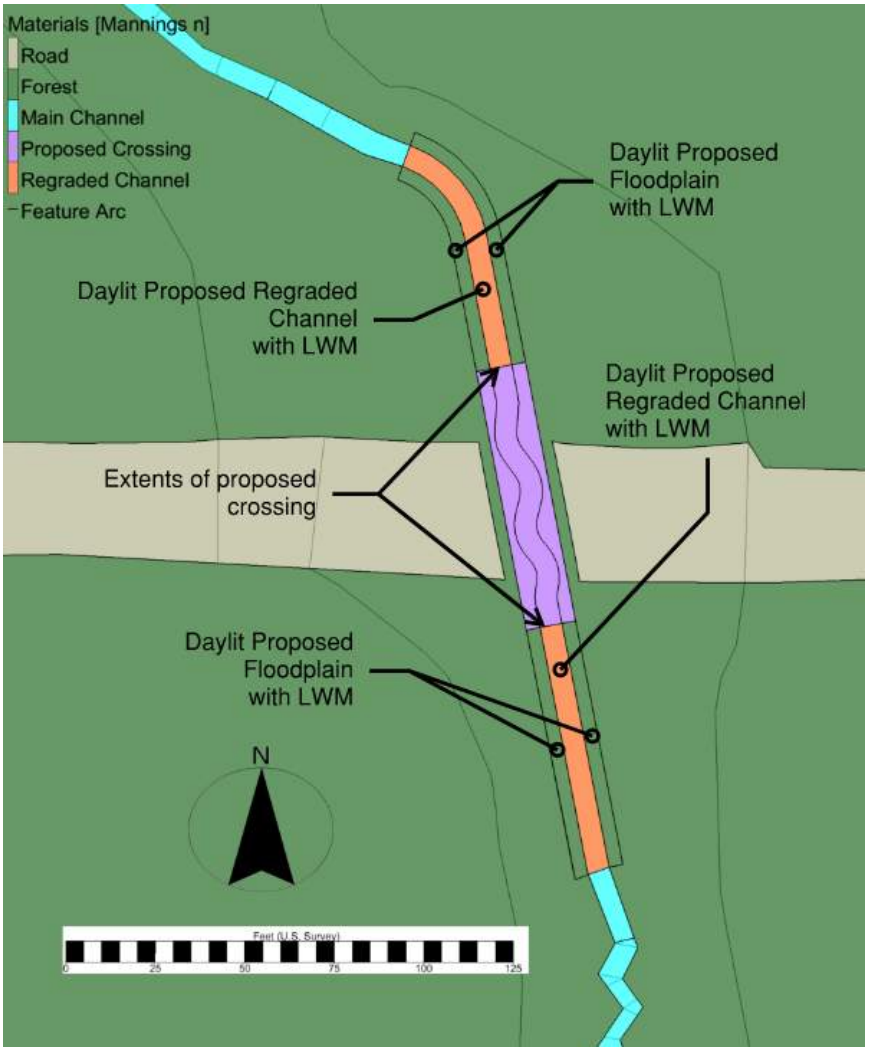

Figure 44: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

Both the existing and proposed-conditions model are simulated using a steady flow regime. The model inflow boundary condition is a subcritical inflow at the upstream end of the model extent with a time series in order to run all the peak flows in one simulation (Figure 45). The time series is separated into half hour increments with a different flow regime for each half hour. Half hour increments were chosen as this is sufficient for the model results to converge. The flows used are summarized in the hydrologic analyses in Section 3: 2-year flow 7.9 cfs, 100-year flow 32.0 cfs, 500-year flow 46.1 cfs. The proposed model uses the same peak flows for both the 500-year flow and the 2080 projected 100-year flow as they are only different by 0.1 cfs so the difference in results is negligible. The distribution setting at the inlet is conveyance and the sediment discharge type is capacity.

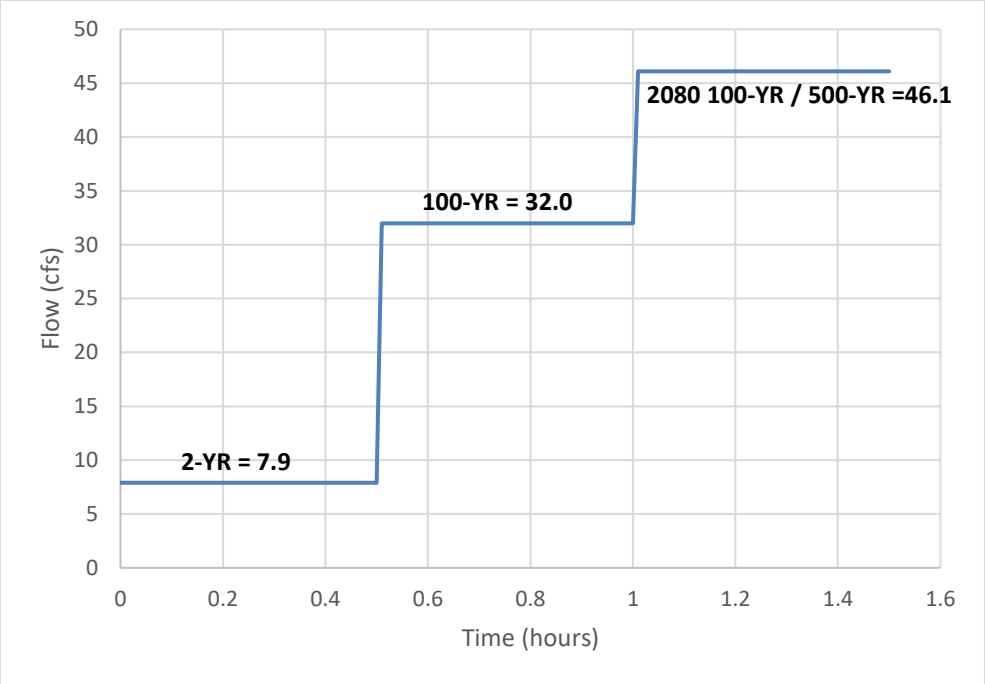

Figure 45. Inflow boundary condition time series

The exit boundary condition is a subcritical outflow using a rating curve calculated through normal depth equation. The slope value is 0.0221 measured from the bathymetry data at the model outlet. The Manning's n value is 0.047 defined for Main Channel in Figure 43. The flow is set from 0 to 46.1 cfs. The curve can be found in Figure 46. This boundary condition was used in both the existing and the proposed-conditions models.

The existing 3-foot diameter culvert is simulated using HY-8 extension (Aquaveo 2019) through boundary conditions in SMS (Aquaveo 2021) in the existing-conditions model. The input parameters can be found in Figure 47. This information is from the survey data delivered by WSDOT survey team in August 2021. The Manning's n value of the crossing is provided by HY-8 using concrete pipe as input. The locations of the boundary conditions in the existing and proposed-conditions model are shown in Figure 48 and Figure 49.

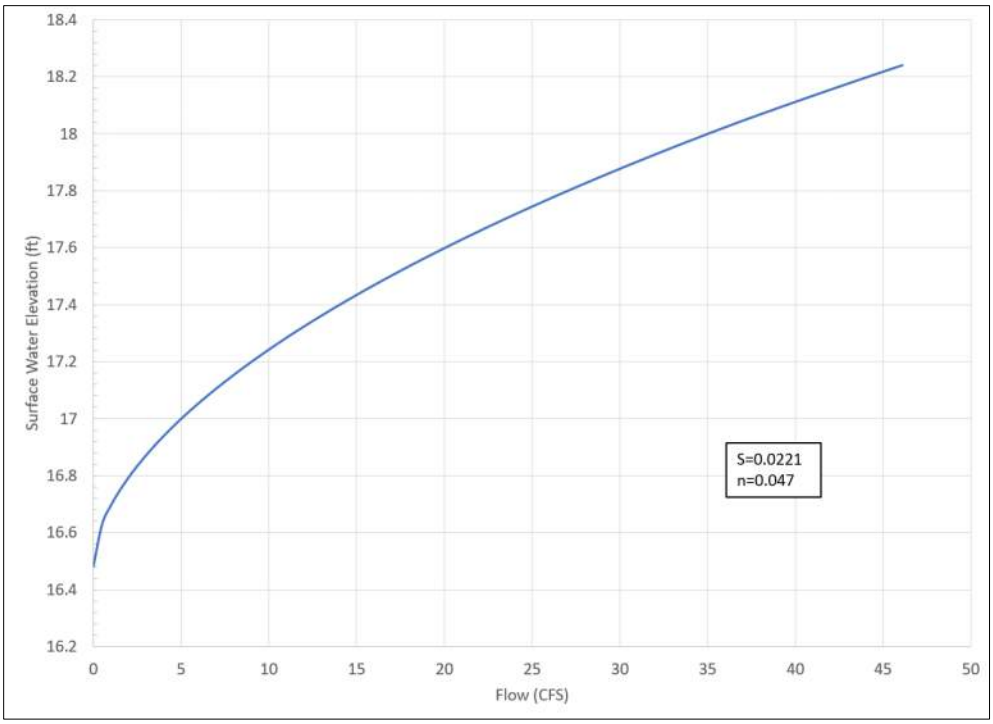

Figure 46: Downstream outflow boundary condition normal depth rating curve

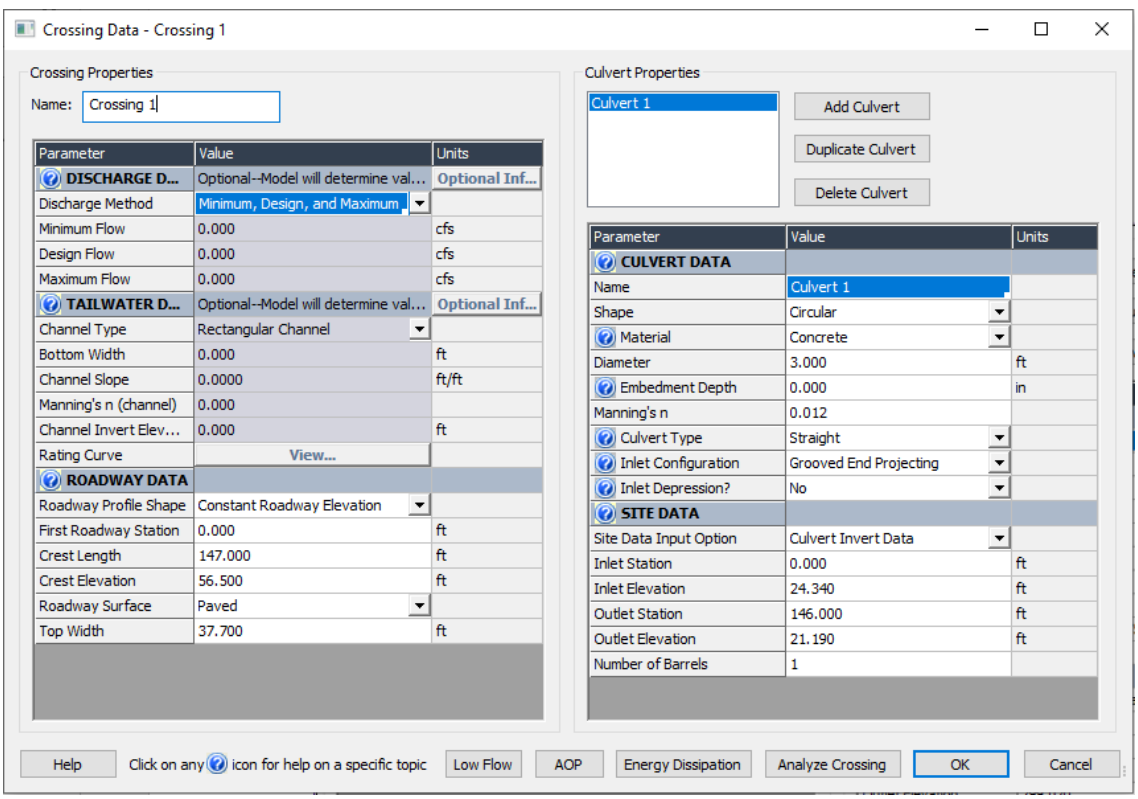

Figure 47: HY-8 culvert parameters

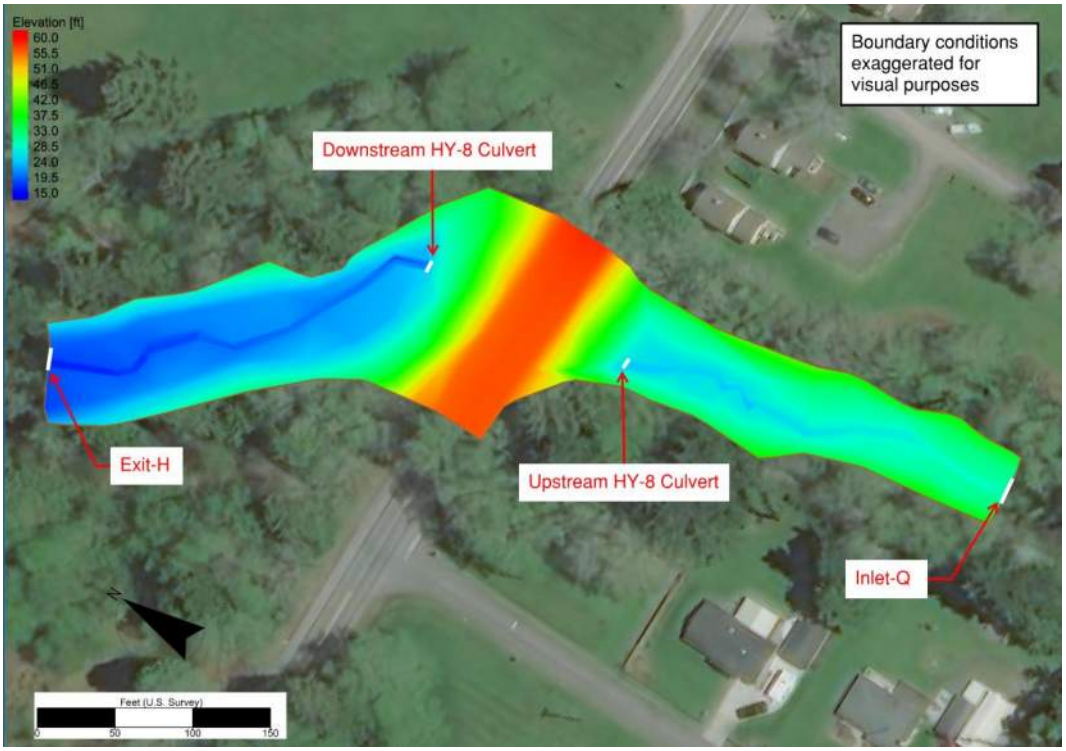

Figure 48: Existing-conditions boundary conditions

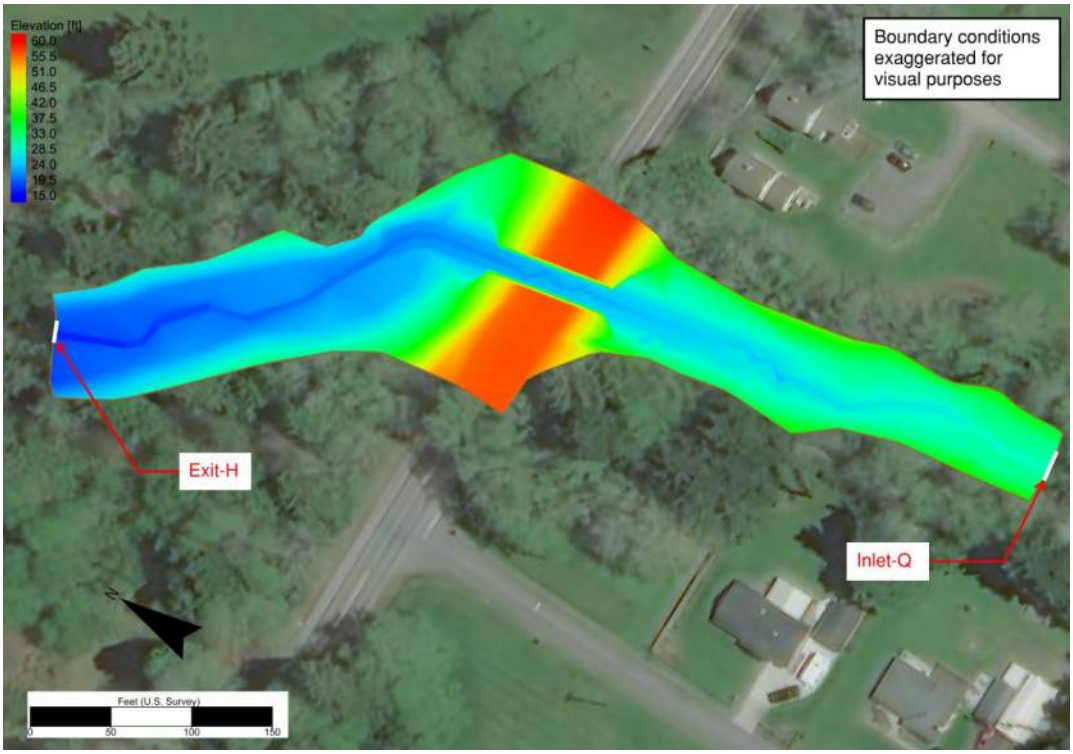

Figure 49: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

The model controls for the existing and proposed conditions are close to default. The time starts with dry initial condition with 1.5 hours of end time. In order to increase stability in the existing conditions, the timestep was decreased from 1 second to 0.5 seconds. The output frequency of the model results is set to every 5 minutes. The existing-conditions model has minor instability in the vicinity around the culvert during 2-year event. This minimally impacts the model results at the cross-sections where the values are reported (See Appendix I). The proposed-conditions model was ran with the same model controls except using 1-second timestep. Both models reach stable steady-state results within half hour for each flow event. See Appendix I for monitor line plots.

Both models were checked using the PACE QC checklist. This checklist covers mesh quality, boundary condition and material coverage inputs and examined model results with high shear stress and Froude numbers. Meshes of both conditions have been adjusted in order to meet these guidelines.

5.1.6 Model Assumptions and Limitations

The complexity of small-scale hydraulics which form around LWM and meander bars are not accurately simulated in the 2-dimensional (2D) model. These micro-scale hydraulics are beyond the scope of the PHD investigation and require different software packages with greater computational demand and level of effort to develop. In the 2-D model areas with LWM and meander bars are assigned higher roughness values, resulting in higher shear stresses and lower velocities. In reality, the complex physical processes are generating eddies, creating scour holes and partitioning shear stress within the water column to reduce velocity and sediment mobility. The SRH-2D models built for this PHD reports do not simulate these physical processes.

The second limitation of the model is the shape of the meander bar. The proposed meander bars are built into the mesh through InRoads template using curves with 24-foot wavelength. Although the meander bar has a tear-drop shape as shown in Figure 37, the geometry of the bars are simplified in the model as symmetrical curves. High shear stresses are observed at the upstream faces of the bars (Appendix H). Two-man boulders are proposed at those locations to prevent erosion using conservative engineering approach. However, as mentioned in the first limitation, the high shear and velocity will be lowered as scour holes form at those spots.

HY-8 is not able to model partial embedment through the culvert. The embedment in the existing culvert is not modeled in HY-8 as it does not have consistent depth from inlet to outlet. Figure 8(a) shows the inlet of the culvert is not embedded. This limitation does not impact the existing model results extracted from the selected cross-sections.

5.2 Existing Conditions

The 2-, 100-, and 500-year peak flow events were simulated in the existing-conditions model. Inundation and flow characteristics were extracted from the model at selected cross-section locations shown in Figure 50 with the results shown in Table 13. Two cross-sections were drawn upstream and downstream of the existing crossing to observe the hydraulic impact of SR 104 construction in the existing conditions. The rest of the cross-sections are at the BFW

locations and the widest 100-year flow location in the downstream reach. Appendix H contains additional cross-sectional plots as well as plan view figures of hydraulic model results. WSE profiles along the thalweg can be seen in the stream profile in Figure 51. Backwatering caused by the existing crossing is observed in 100-year WSE for approximately 100 feet until the downstream end of reference reach (Figure 51), resulting in slower velocity at EX 14+20 (Table 13). The natural LWM steps and log jams in the downstream reach also result in backwatering as observed in the field (Figure 51). Higher shear stress and Froude numbers are shown at EX 11+10 and EX 16+20 where natural steps formed by LWM were observed in the field, while wider flow widths were observed upstream of those locations (Figure 53).

Figure 52 shows the modeled flows at an upstream reference reach cross-section. Machias Creek is a small, confined channel and flow during the 2-year event is mostly contained within the top of banks (Figure 52). The 2-year flow width in the reference reach is 5.1 feet wide, which is 20 percent smaller than the design average BFW of 6.7 feet. Due to the conservative peak flow estimate for this project, this indicates that the BFW measurements are larger than 2-year flow width as discussed in Section 4.1.1.

Table 14 reports average velocity values for the main channel, left overbank (LOB), and right overbank (ROB) during the 100-year flow event at the selected cross-sections (Figure 53). The main channel is defined as the top of banks from the survey base map. Higher velocity is observed at EX 15+80 because the main channel is narrower in this section of stream. Velocities on the LOB and ROB are relatively low, below 1 foot per second, while the main channel velocities all stay around 3.3 feet per second. The 100-year model results have some overbank flows especially in the downstream reach at EX 11+63 (Figure 53). Some 500-year velocities are lower than the 100-year ones as more water inundate the overbanks.

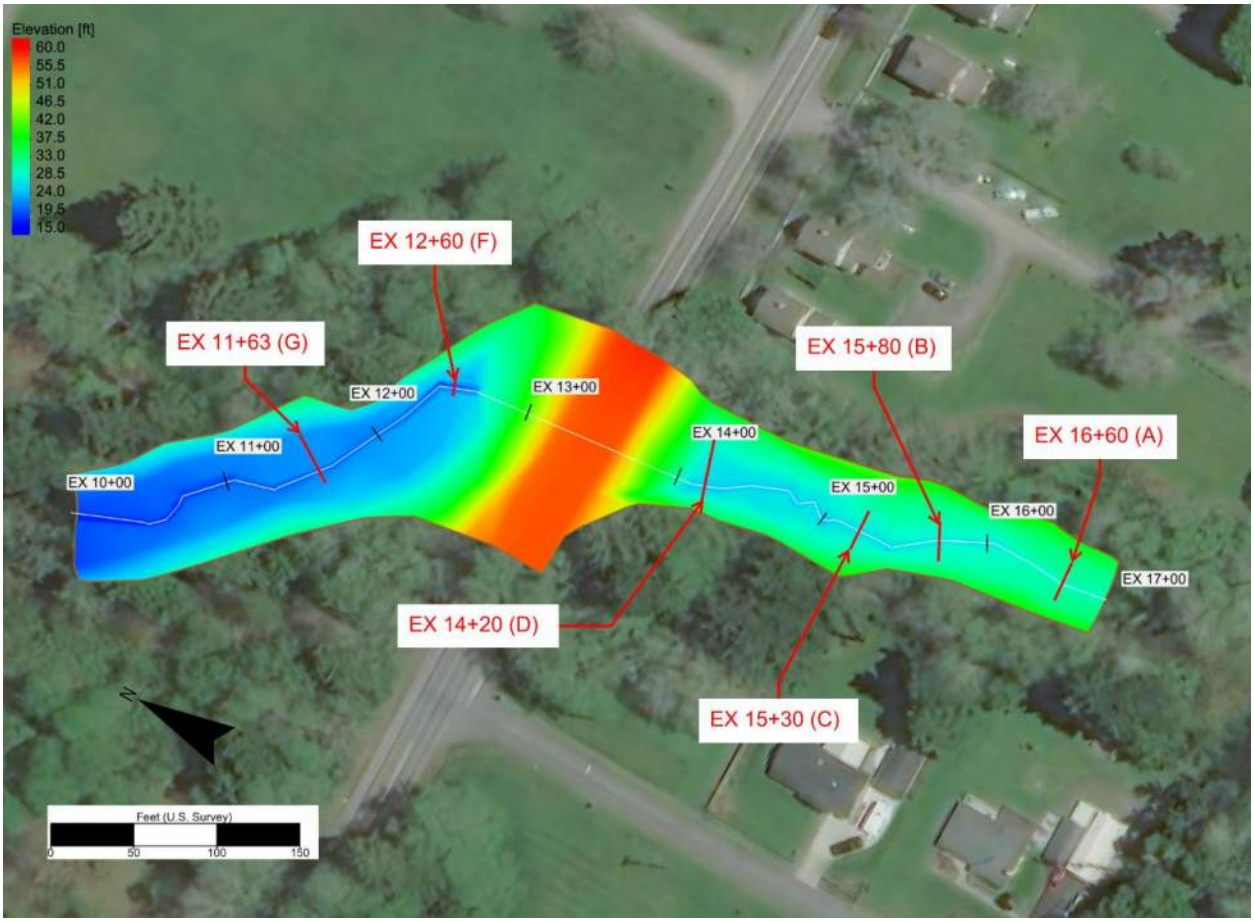

Figure 50: Locations of cross-sections used for results reporting

Table 13: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS EX 11+63 (G)	20.7	21.6	21.9
	DS EX 12+60 (F)	21.5	22.5	22.9
	Structure (E)	NA	NA	NA
	US EX 14+20 (D)	25.6	27.1	28.0
	US EX 15+30 (C)	26.6	27.7	28.2
	US EX 15+80 (B)	27.6	28.3	28.7
	US EX 16+60 (A)	29.7	30.6	30.9
Max depth (ft)	DS EX 11+63 (G)	0.9	1.8	2.1
	DS EX 12+60 (F)	2.8	3.9	4.3
	Structure (E)	NA	NA	NA
	US EX 14+20 (D)	1.4	3.0	3.8
	US EX 15+30 (C)	1.0	2.0	2.6
	US EX 15+80 (B)	0.7	1.4	1.8
	US EX 16+60 (A)	1.3	2.1	2.4
Average velocity (ft/s)	DS EX 11+63 (G)	2.7	3.2	2.7
	DS EX 12+60 (F)	1.1	2.3	2.7
	Structure (E)	NA	NA	NA

Hydraulic parameter	Cross section	2-year	100-year	500-year
	US EX 14+20 (D)	1.0	1.6	1.5
	US EX 15+30 (C)	2.3	3.1	2.9
	US EX 15+80 (B)	2.7	4.4	4.4
	US EX 16+60 (A)	1.7	3.2	3.7
Average shear (lb/sf)	DS EX 11+63 (G)	0.6	1.0	1.0
	DS EX 12+60 (F)	0.1	0.4	0.5
	Structure (E)	NA	NA	NA
	US EX 14+20 (D)	0.1	0.1	0.1
	US EX 15+30 (C)	0.4	0.6	0.5
	US EX 15+80 (B)	0.7	1.3	1.2
	US EX 16+60 (A)	0.2	0.6	0.8
Main channel extents were defined by the surveyed top of bank lines.				

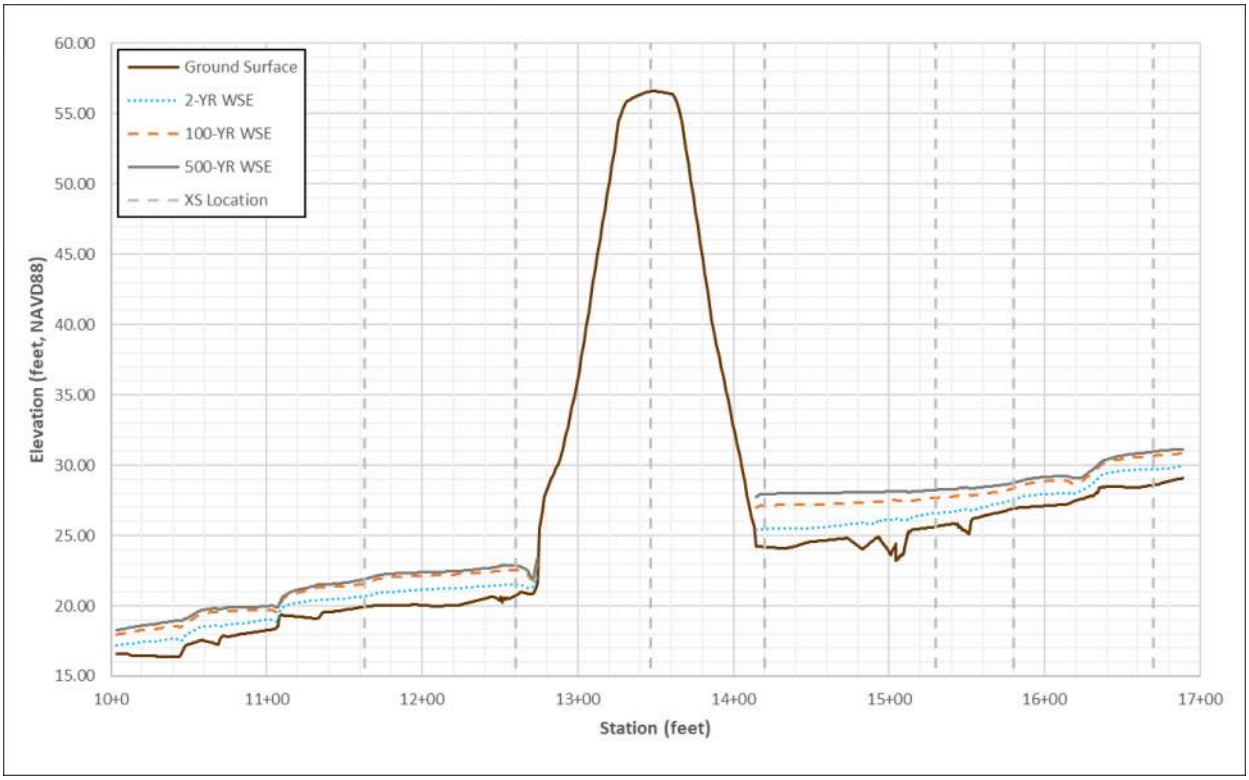

Figure 51: Existing-conditions water surface profiles

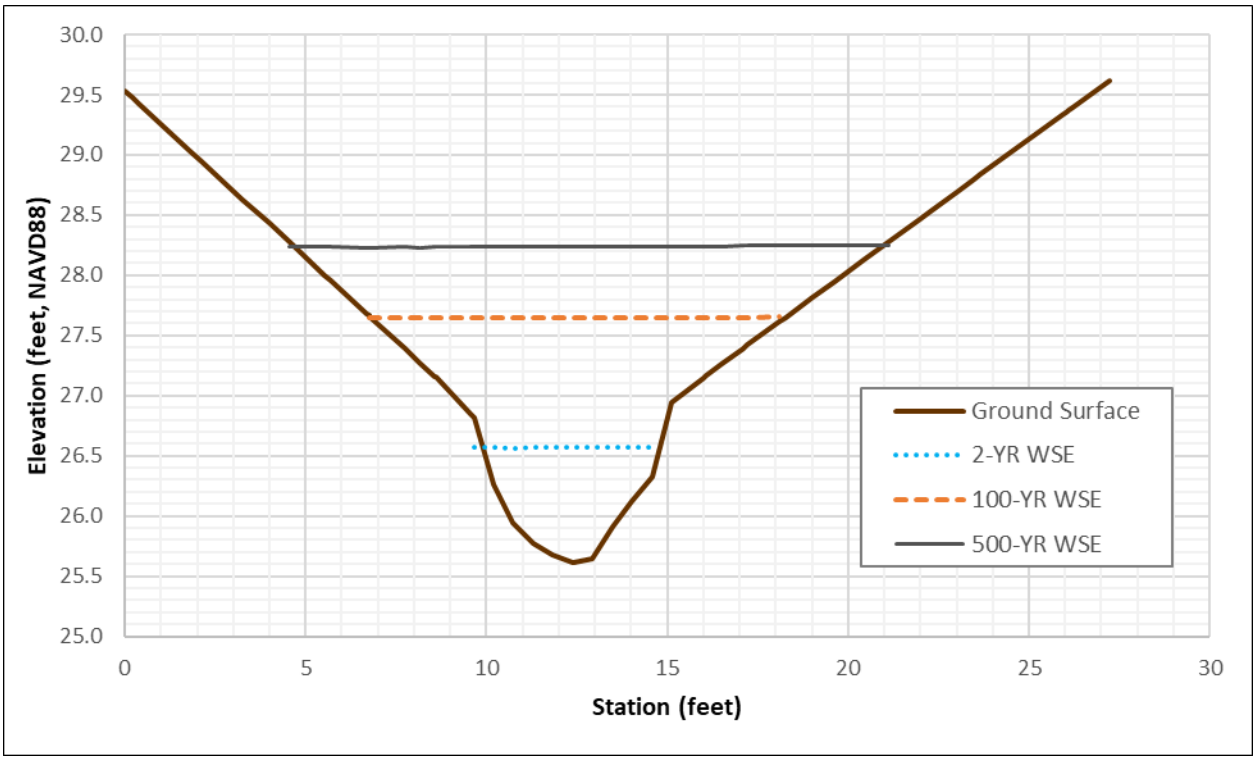

Figure 52: Typical upstream existing channel cross section EX STA 15+30

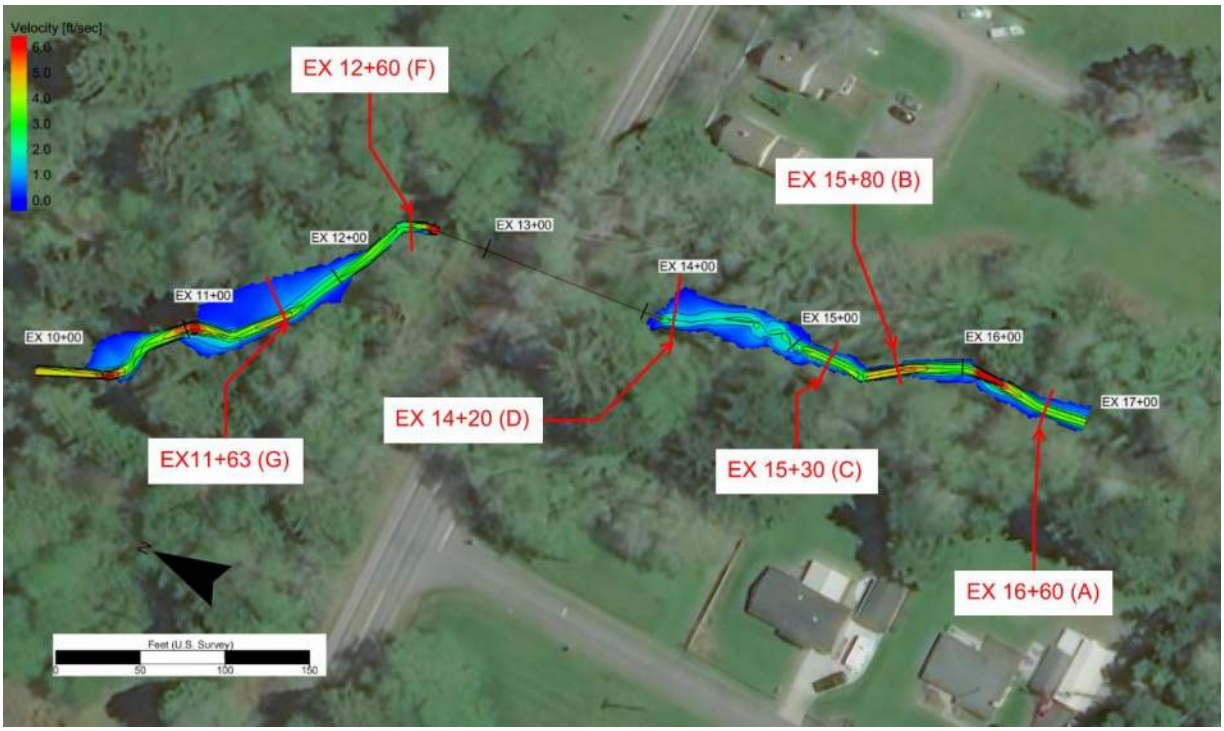

Figure 53: Existing-conditions 100-year velocity map with cross-section locations

Table 14: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS EX 11+63	0.7	3.2	0.6
DS EX 12+60	N/A	2.3	N/A
Structure	NA	NA	NA
US EX 14+20	0.7	1.6	0.4
US EX 15+30	1.0	3.2	0.9
US EX 15+80	0.9	4.4	1.1
US EX 16+60	0.5	3.2	0.8
Right overbank (ROB)/left overbank (LOB) locations were defined by the surveyed top of bank lines.			

5.3 Natural Conditions

A natural conditions model was not required as the system is confined.

5.4 Proposed Conditions: 14-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width. See Section 4.2.2 for a description of how the minimum hydraulic width was determined. The proposed-conditions SRH-2D model results were used to evaluate the hydraulic conditions within the proposed crossing that has a 14-foot-wide hydraulic width for the 2-, 100-, 2080 100-, and 500-year peak flood events for Machias Creek at the project site. Inundation extents and results extracted at selected cross-section locations are discussed in the following paragraphs. Appendix H contains additional cross-sectional plots as well as plan view figures of hydraulic modeling results.

The proposed-conditions model results extracted from the selected cross-sections A through J are shown in Table 15. The locations of the cross-sections along the proposed alignment are shown in Figure 54, with a comparison to the existing alignment. The cross-sections outside the crossing are located at the same place as they are in the existing-conditions model, while reported using the proposed alignment station (PR). Model results show no roadway overtopping in the proposed conditions. The backwatering caused by the SR 104 crossing in the existing condition is eliminated in the proposed conditions, while there is still backwatering caused by the LWM steps in the downstream reach (Figure 55). No flow contraction is observed in the model results at the entrance or exit of the proposed crossing.

Figure 55 shows the proposed WSE steadily follows the proposed grading and maintains a 100- year flow depth of approximately 1.4 to 2 feet. The flow depth is slightly lower in the crossing compared to the depth outside the crossing due to the lower roughness (Figure 44). The 100-year model results within the structure show a flow width of 14 feet through the crossing (Figure 56). The 2-year flow width within the crossing is 5 feet, which is identical with the 2-year flow width measured within the reference reach. As illustrated in Figure 56, the

2-year flow is fully contained within the main channel, while the 100-year flow overtops the proposed overbanks with approximately half feet of depth.

The velocity at the exit of the structure (PR 13+02) is slightly slower with higher water depth. It is a result of local backwater from the reverse slope from PR 11+80 to PR 12+00 in the existing channel as shown in Figure 55. The velocity at the entrance of the structure (PR 13+77) is slightly higher due to the lower roughness value. The downstream floodplain is inundated during event larger than 100-year flow as the existing conditions. No extremely high shear nor velocity is observed in the proposed-conditions model.

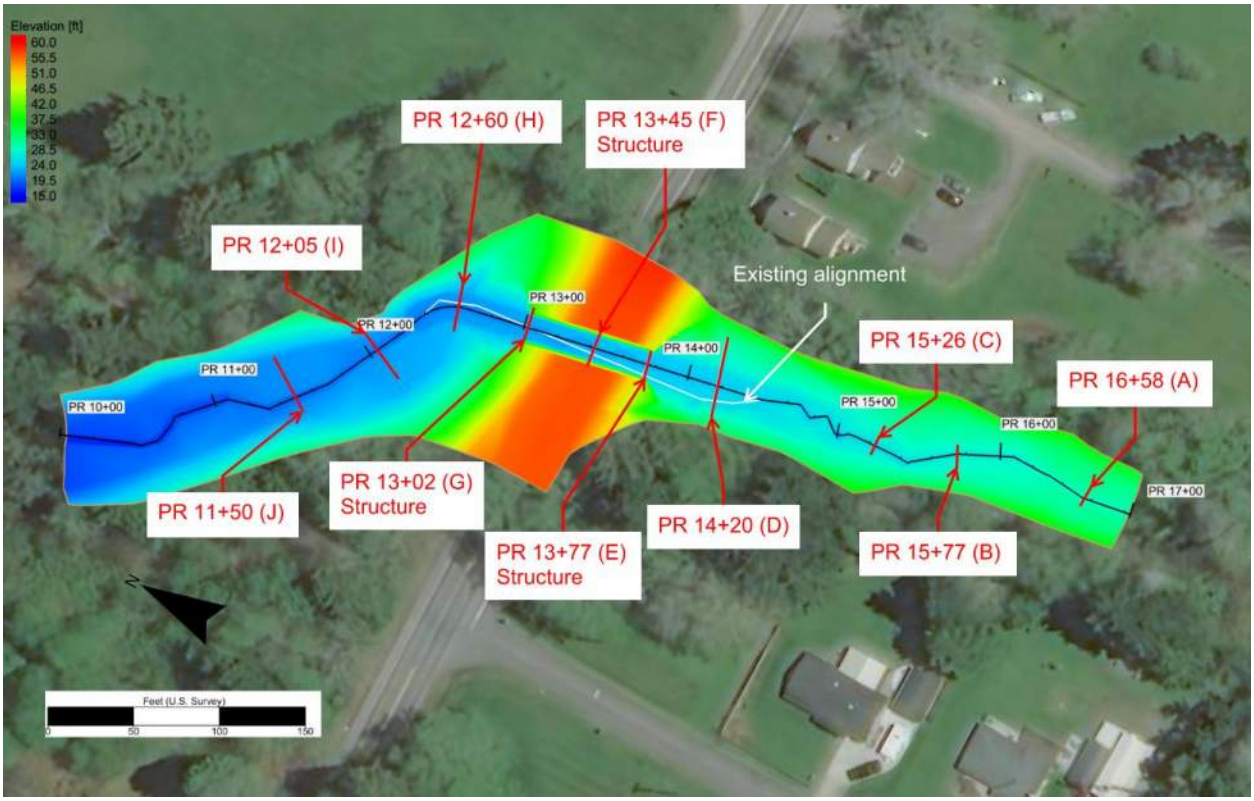

Figure 54: Locations of cross-sections on proposed alignment used for results reporting

Table 15: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS PR 11+50 (J)	20.5	21.4	21.6	21.6
	DS PR 12+05 (I)	21.2	22.1	22.4	22.4
	DS PR 12+60 (H)	21.6	22.5	22.9	22.9
	Structure PR 13+02 (G)	22.4	23.2	23.4	23.4
	Structure PR 13+45 (F)	23.2	23.9	24.1	24.1
	Structure PR 13+77 (E)	23.9	24.5	24.7	24.7
	US PR 14+20 (D)	24.8	25.5	25.8	25.8
	US PR 15+26 (C)	26.6	27.6	27.9	27.9
	US PR 15+77 (B)	27.6	28.3	28.7	28.7
	US PR 16+58 (A)	29.7	30.5	30.8	30.8
Max depth (ft)	DS PR 11+50 (J)	0.9	1.7	2.0	2.0

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
	DS PR 12+05 (I)	1.2	2.1	2.4	2.4
	DS PR 12+60 (H)	0.8	1.7	2.1	2.1
	Structure PR 13+02 (G)	0.8	1.5	1.8	1.8
	Structure PR 13+45 (F)	0.7	1.4	1.6	1.6
	Structure PR 13+77 (E)	0.7	1.3	1.5	1.5
	US PR 14+20 (D)	0.8	1.5	1.8	1.8
	US PR 15+26 (C)	1.0	1.9	2.3	2.3
	US PR 15+77 (B)	0.7	1.4	1.8	1.8
	US PR 16+58 (A)	1.3	2.1	2.4	2.4
Average velocity (ft/s)	DS PR 11+50 (J)	2.2	3.7	4.0	4.0
	DS PR 12+05 (I)	1.6	2.7	3.1	3.1
	DS PR 12+60 (H)	2.1	2.8	3.0	3.0
	Structure PR 13+02 (G)	2.5	3.4	3.6	3.6
	Structure PR 13+45 (F)	2.3	3.4	3.9	3.9
	Structure PR 13+77 (E)	2.6	4.2	4.7	4.7
	US PR 14+20 (D)	2.1	3.6	3.9	3.9
	US PR 15+26 (C)	2.3	3.4	3.7	3.7
	US PR 15+77 (B)	2.7	4.4	4.6	4.6
	US PR 16+58 (A)	1.7	3.2	3.7	3.7
Average shear (lb/sf)	DS PR 11+50 (J)	0.4	0.8	1.0	1.0
	DS PR 12+05 (I)	0.3	0.5	0.7	0.7
	DS PR 12+60 (H)	0.6	0.7	0.7	0.7
	Structure PR 13+02 (G)	0.6	0.9	1.0	1.0
	Structure PR 13+45 (F)	0.5	0.7	0.9	0.9
	Structure PR 13+77 (E)	0.6	1.2	1.4	1.4
	US PR 14+20 (D)	0.6	1.2	1.3	1.3
	US PR 15+26 (C)	0.4	0.7	0.8	0.8
	US PR 15+77 (B)	0.7	1.3	1.3	1.3
	US PR 16+58 (A)	0.2	0.6	0.8	0.8

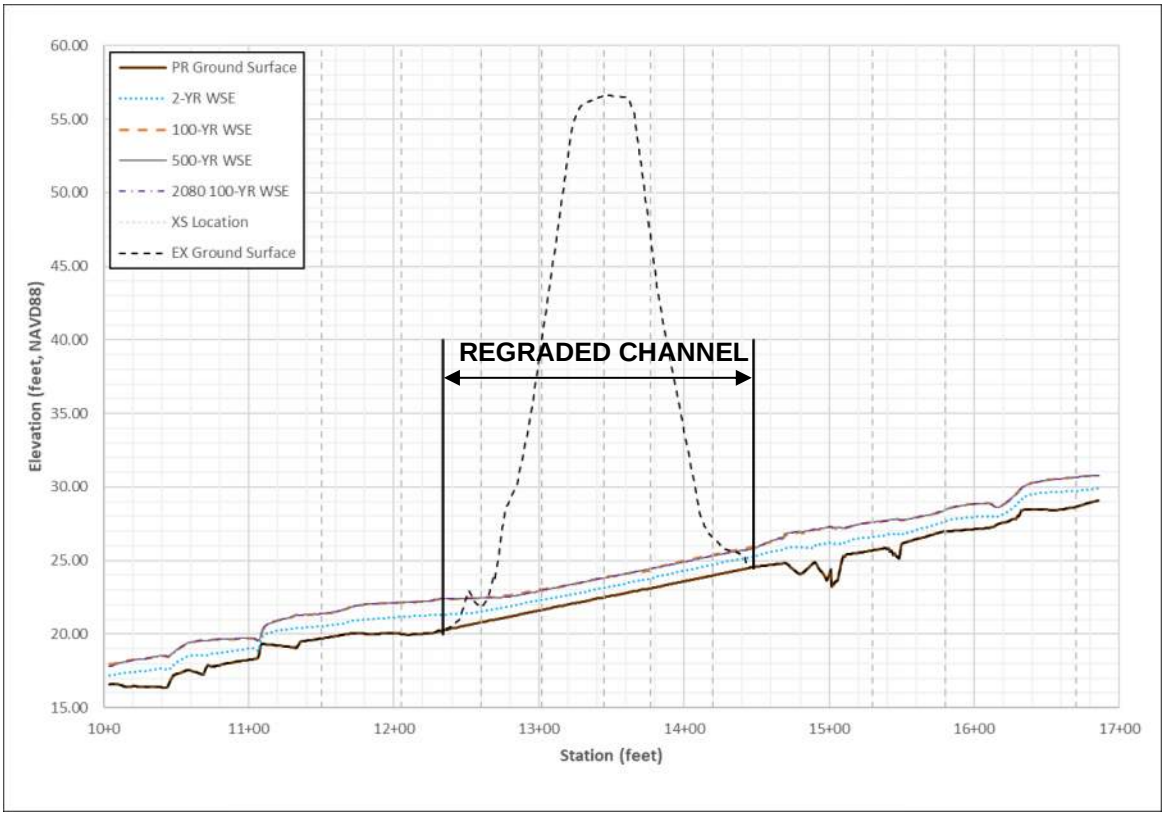

Figure 55: Proposed-conditions water surface profiles

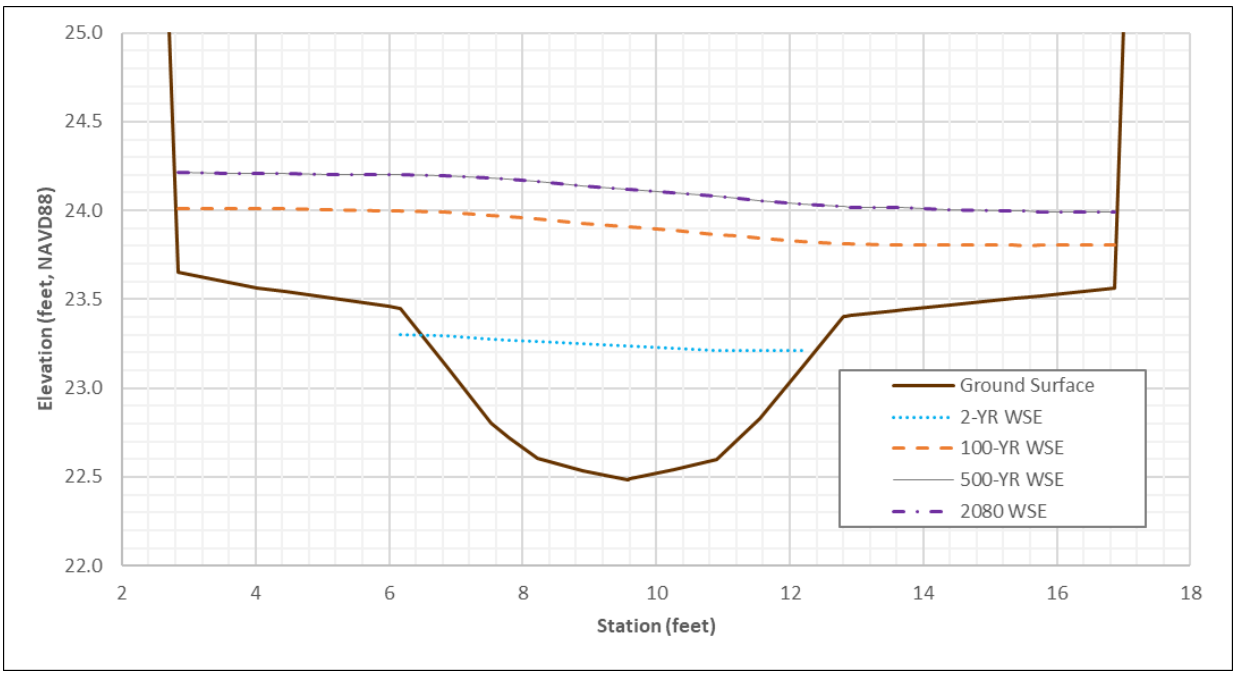

Figure 56: Typical section through proposed structure PR 13+45

Table 16 reports average velocity values for the main channel, LOB, and ROB during the 100-year flow event at the selected cross-section locations shown in Figure 54. A plan view of the 100-earl velocity results is shown in Figure 57. In both cases, the surveyed top-of-bank lines

were used to identify the LOB and ROB in the existing channel, while the 6.2-foot-wide main channel in the structure follows the sinuosity created by meander bars. In comparison to the 100-year flow event, the 2080 projected 100-year flow event yielded nearly identical inundation extents and increases in main channel velocity by approximately 0.3 ft/sec at most cross-section locations. More flow and higher velocities are observed on the overbanks. The velocities through the structure have similar values to the reference reach velocities. Overall, the main channel velocities in the downstream cross-sections are slightly lower as there is more floodplain inundation and backwatering caused by LWM steps in the downstream reach.

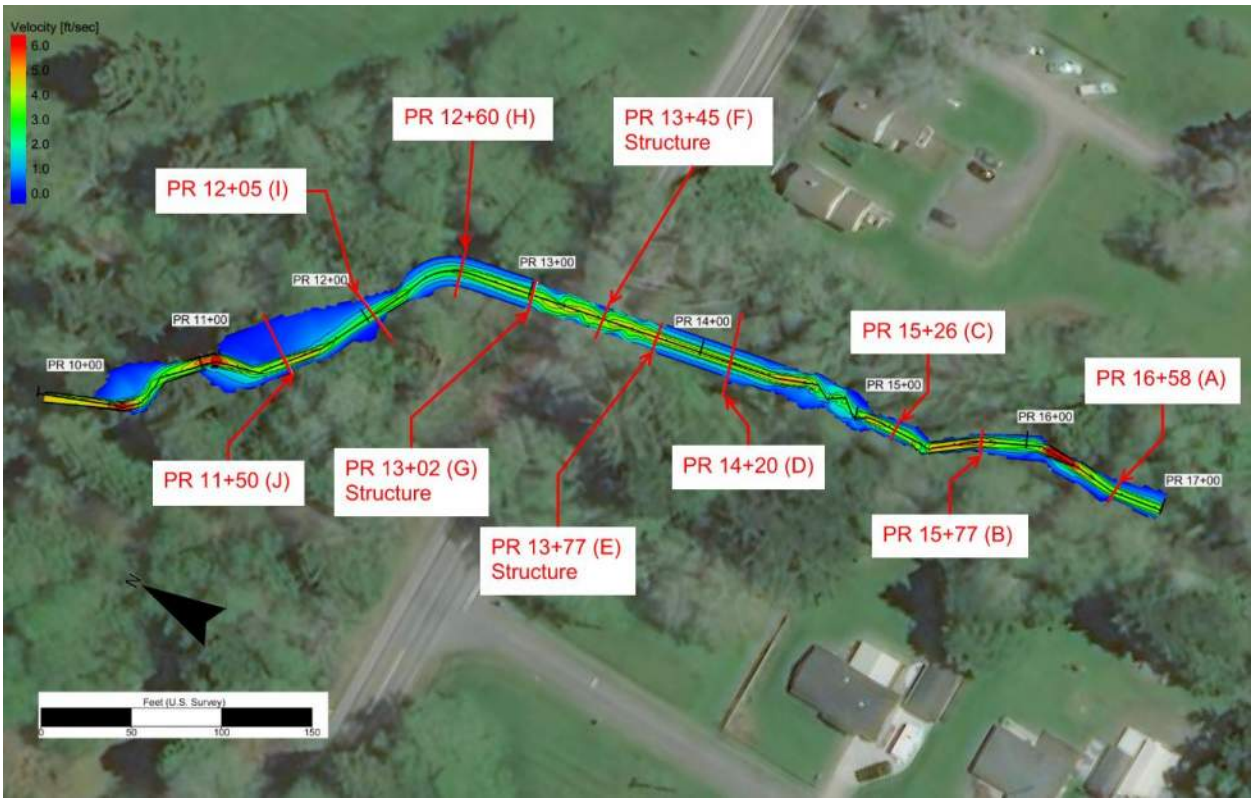

Figure 57: Proposed-conditions 100-year velocity map

Table 16: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS PR 11+50 (J)	1.1	3.7	0.3	1.1	4.0	0.7
DS PR 12+05 (I)	0.3	2.7	0.7	0.3	3.1	1.0
DS PR 12+60 (H)	1.0	2.8	0.8	1.2	3.0	0.9
Structure PR 13+02 (G)	1.3	3.4	1.6	2.1	3.6	1.9
Structure PR 13+45 (F)	2.3	3.4	1.2	2.7	3.9	2.2
Structure PR 13+77 (E)	1.6	4.2	1.7	2.2	4.7	2.3
US PR 14+20 (D)	0.9	3.6	1.0	1.1	3.9	1.3
US PR 15+26 (C)	1.0	3.4	0.9	1.6	3.7	1.6
US PR 15+77 (B)	0.9	4.4	1.1	1.7	4.6	1.6
US PR 16+58 (A)	0.4	3.2	0.8	1.0	3.7	1.3
Right overbank (ROB)/left overbank (LOB) locations were defined by the surveyed top of bank lines						

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA); see Appendix A for FIRMette. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

In the existing-conditions iteration, the existing 3-foot culvert causes backwatering at the 100- year flow event for about 100 feet (Figure 58). With the proposed crossing in place the model shows a drop of about 1.7 ft in WSE immediately upstream of the crossing. The WSEs of the two scenarios meet where the backwater ends, about 100 feet upstream of the crossing at the downstream end of the reference reach. Downstream of the crossing the two surface elevations converge within 20 feet of the crossing with no change occurring after the regraded portion of the proposed surface.

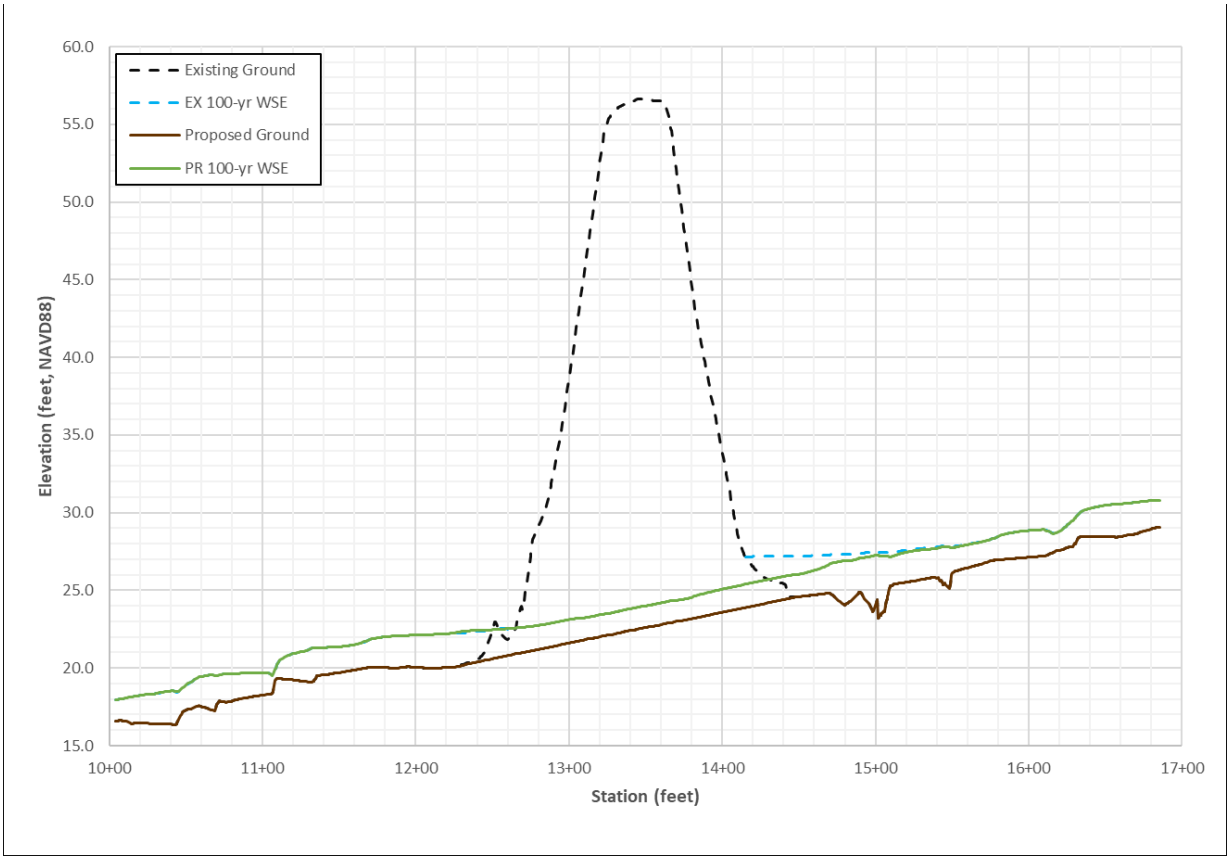

Figure 58: Existing- and proposed-conditions 100-year water surface profile comparison

The change in WSE between existing and proposed conditions at the 100-year flood event is shown in Figure 59. Negative numbers (represented by shades of blue colors) show where the future conditions water depth is lower than the existing condition water depths, while positive numbers (represented by yellow to red colors) indicate the opposite. The purple fill in Figure 59 shows newly dried area around the culvert inlet as the proposed crossing reduces the

inundation caused by the backwater condition. The dark red fill in Figure 59 shows the newly inundated area created by the proposed regrading. There is no infrastructure within the limit of newly inundated area. No risk is posted to properties or infrastructure in the proposed conditions. A flood risk assessment will be developed during later stages of the design.

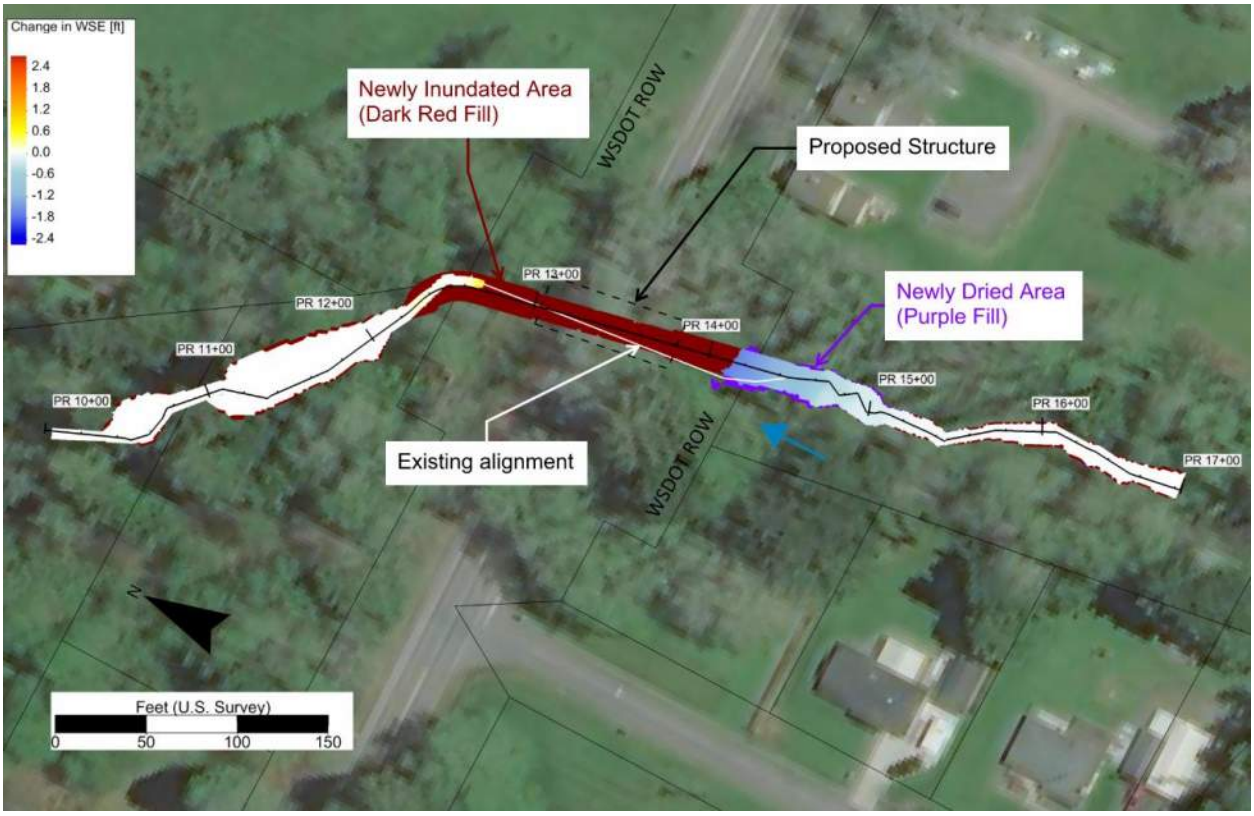

Figure 59: 100-year WSE change from existing to proposed conditions

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation, and evaluation of preliminary total scour are based on available data, including but not limited to LiDAR profile, survey thalweg elevation, and a draft geotechnical scoping package including results from a bore sample. This evaluation is to be considered preliminary and is not to be taken as a final recommendation.

Using the results of the hydraulic analysis (Section 5.4), based on the recommended MHO (14 feet), and considering the potential for lateral channel migration, preliminary calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson, et al. 2012). Scour analysis was completed for 2-year, 10-year, 25-year, 50-year, 100-year, and 500-year events. Coincidentally, at this particular site the 2080 projected 100-year flow (46 cfs) is the same value as the 500-year flow and, therefore, was not simulated separately. Based on the total scour results, the scour design flood and the scour check flood both are the 2080 projected 100-year flow (46.1 cfs), as it shows the deepest scour depth of 0.2 feet. Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections.

7.1 Lateral Migration

In most cases at the PHD stage, the risk of lateral migration leading up to or within the structure is assumed to be possible unless detailed geotechnical data is available to support the assessment that lateral migration will be intrinsically limited over the life of the proposed structure. The draft geotechnical scoping package states the cohesionless sediment at the project site has high to very high HEC-18 erodibility index value. However, no large-scale meander amplitude of Machias Creek is observed in the LiDAR data (Figure 4) (DNR 2018). With the proposed stream design, Machias Creek is not expected to move vertically, and any lateral movement is physically limited to within the 30-foot plus deep ravine as described in Section 2.7.4 and 7.2.

The lateral migration of Machias Creek is not dependent on the crossing infrastructure structure type selected. It is either a buried structure or a full-span bridge. The dynamic physical process of channel meandering capabilities in Machias Creek is primarily caused by naturally forcing LWM features in the system. The proposed Type 1 and Type 2 LWM are designed to be immobile at all examined peak flows and thus should encourage natural channel forcing while promoting long-term channel stability. The model results of velocities and shear stress within the proposed crossing are relatively low, as the estimated stream power is relatively low for Machias Creek. No severe scour or bank erosion is expected for this project, although there will

be localized scour around the proposed habitat features. Scour countermeasures are not required but could be necessary depending on the structure type and foundation location/depth. This will be reevaluated in later stages of design.

7.2 Long-term Degradation of the Channel Bed

Long-term degradation for Machias Creek at the project crossing was estimated based on field observation, watershed assessment, LiDAR profile (DNR 2018), and survey topography. A draft geotechnical scoping package includes results from a bore sample. The boring data shows fine-grained glacial deposits that are soft to hard sandy silt at the channel elevation under the project crossing. No erosion-resistant material was observed in the boring data. There is no active degradation, nickpoint, or potential headcut observed in the existing condition. The channel gradient ranges between 1.5 to 2 percent from the downstream to the upstream reach. Potential degradation was quantified by estimating an equilibrium slope, applying this slope to the proposed stream profile, and graphically measuring the amount of degradation. A reach average gradient through the SR 104 crossing is estimated to be 2 percent based on LiDAR and the survey profile. The regraded channel is proposed with the same gradient. The base level of control occurs at the top of the hydraulic-controlling LWM step downstream of the crossing (Figure 60). Projecting the 2-percent slope from the base level control point upstream to the project crossing results in the slope overlapping with the proposed channel gradient (Figure 60). The estimated long-term degradation at the project crossing is 0.0 feet. The equilibrium slope extended downstream of the LWM step creates the same channel gradient; hence, the base level control will not change if the LWM were to fully degrade.

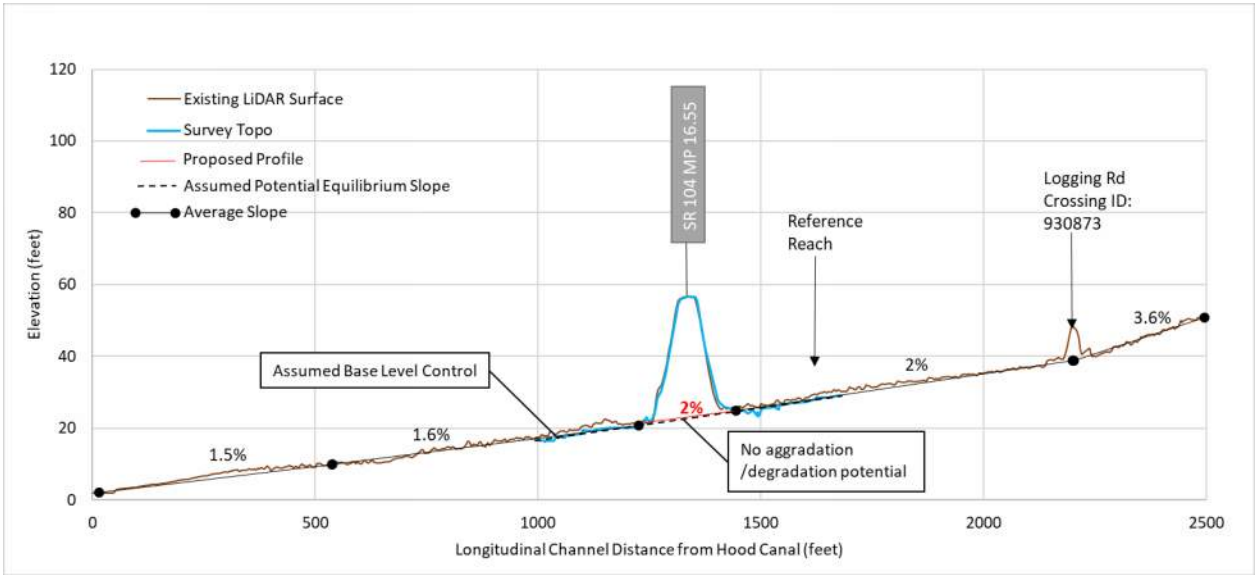

Figure 60: Potential long-term degradation at the proposed structure

7.3 Contraction Scour

The contraction scour for the project crossing was estimated following the methodology outlined in Chapter 6 of HEC-18 (Arneson, et al. 2012). This estimation used the Bridge Scour Analysis tool in Hydraulic Toolbox™ for calculation (FHWA 2018). Contraction scour can be classified as live-bed or clear-water scour.

The 2-year, 10-year, 25-year, 50-year, 100-year, and 500-year proposed-conditions model results with the 14-foot MHO in Section 5.4 were used for the analysis. Critical velocity analysis indicates that the proposed crossing will be under live-bed conditions through all the simulated events in Hydraulic Toolbox.

A Critical Velocity Index (CVI) coverage was developed in SMS to examine areas of clear-water and live-bed conditions across the entire model mesh domain. Live-bed conditions prevail in the bankfull channel area during all the simulated flows. The width of the live-bed channel area varied due to the flow variability from the meander bars built into the mesh. For the 2-year and 10-year flows, bank arcs in the bridge scour coverages were drawn near the edges of estimated live-bed limits. The proposed floodplain benches will be completely inundated during flows higher than the 10-year event. In those scenarios, drawing the bank arcs along the proposed bank lines of the 6.2-foot-wide main channel produced higher scour depth. Hence, this is the approach taken for analyzing scour depth for the events higher than the 10-year flow. Note that the scour depth changes as the location of the contraction arc changes. The contraction arcs were drawn at the face of the structure where the highest scour depth was found. The clear-water and live-bed scour calculation option was chosen in Hydraulic Toolbox. All the simulated events show contraction scour depths rounded up to 0.1 foot. See Appendix K for detailed contraction scour calculations.

7.4 Local Scour

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. Assuming the most conservative scenario wherein vertical walls are constructed at the immediate edge of the 14-foot-wide MHO, the 500-year flow will engage the vertical walls for a half-foot of depth on the floodplain benches. The calculation was done using the Abutment Scour tool in Hydraulic Toolbox.

The abutment scour of the proposed crossing has live-bed conditions for all the simulated events. Maximum flow depth at the thalweg was extracted manually from the SRH-2D® model for each event as input as the flow depth prior to scour in Hydraulic Toolbox. This approach ensures the scour depth is calculated relative to the thalweg elevation and the potential for lateral stream migration is accounted for. The 2080 projected 100-year flow produces the deepest abutment scour of 0.2 feet under live-bed conditions. Therefore, 2080 projected 100-year flow is both scour design flood and scour check flood (Appendix K). Note that abutment scour equations estimate 0.1 feet of scour at 100-year flow. This assessment is specific to the 14-foot MHO that is currently proposed for the crossing. It should be reevaluated when a structure type and structure-free zone are recommended for this crossing in later stages of the design process (Section 4.2.6).

7.4.3 Bend Scour

Bend scour was not quantified at this crossing given the lack of anticipated bends in the vicinity of the crossing.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed Machias Creek SR 104 crossing as shown in the plans dated September 15, 2022, are provided in Table 17. The total scour of the project crossing is evaluated up to the 500-year flow. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 17. These preliminary recommendations could change as the design progresses and should be reevaluated during later stages of design.

Table 17: Scour analysis summary

Calculated scour components and total scour for SR 104 Machias Creek		
	Scour design flood (2080 projected 100-year)	**Scour check flood (2080 projected 100-year)**
Long-term degradation (ft)[1]	0	0
Contraction scour (ft)	0.1	0.1
Local scour (ft)[2]	0.2	0.2
Total depth of scour (ft)[3,4]	**0.2**	**0.2**

1. Reflects the largest end of the range of long-term degradation estimated to be present in the worst-case scenario; long-term degradation should be refined in the FHD phase.
2. Abutment scour.
3. Contraction scour is not included because the local scour method outlined in NCHRP 24-20 includes contraction scour in its estimate, so the two are not additive.
4. Total depths of scour are assumed to be relative to and extending below the thalweg elevation.

8 Scour Countermeasures

The estimated total scour is 0.2 feet during the scour design flood and the scour check flood. The minimum 2-foot thickness of the proposed streambed sediment is thicker than the estimated total scour. Countermeasures are not recommended for the project crossing at the current stage of design. Assuming all structure foundations including any abutment walls, wing walls, and retaining walls, extend below the total scour elevation, then scour countermeasures are not necessary for the project crossing. If non-structure wall foundations do not extend below the elevation associated with the total depth of scour, then the need for scour countermeasures will be reevaluated in a later stage of design once walls and their corresponding foundation design are determined. The extent of potential scour countermeasures is assumed to follow the conceptual wingwalls shown in sheet HY02 of Appendix D. The conceptual wingwalls do not extend outside the SR 104 right-of-way in the preliminary design.

The likelihood of scour countermeasures increases if LWM is placed in the structure (not currently proposed). Elements of a water crossing that may need a scour countermeasure include, but are not limited to, walls and the roadway embankment. Structural foundations cannot rely on scour countermeasure for the integrity of the structure. If scour countermeasures are deemed necessary, they will not encroach within the minimum hydraulic width unless there has been additional coordination and acceptance from WDFW and the Tribes.

9 Summary

Table 18 presents a summary of the results of this PHD Report.

Table 18: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	3,481 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	6.7 ft	2.7.2 Channel Geometry
	Concurrence BFW	6.7 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	12.1 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	1.7 (US)	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100-yr flow	32.0 cfs	3 Hydrology and Peak Flow Estimates
	2080 100-yr flow	46.1 cfs	3 Hydrology and Peak Flow Estimates
	2080 100-yr used for design	No	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	2.2%	2.6.2 Existing Conditions
	Reference reach	2.1%	2.7.1 Reference Reach Selection
	Proposed	2.0%	4.1.3 Channel Gradient
Hydraulic width	Existing	3 ft	2.6.2 Existing Conditions
	Proposed	14 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	2.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100-yr or 2080 100-yr	100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Recommended 10 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	141 ft	2.6.2 Existing Conditions
	Proposed	74 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type	To be decided in FHD	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	Yes	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	6	4.3.2 Channel Complexity
	Boulder clusters	No	4.3.2 Channel Complexity
	Coarse bands	No	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	No	8 Scour Countermeasures
Channel degradation	Potential?	No	7.2 Long-term Degradation of the Channel Bed
	Allowed?	No	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning's Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment

Appendix K: Scour Calculations (will be included in FHD)

Appendix L: Floodplain Analysis (will be included in FHD)

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

122°35'43"W 47°51'27"N

122°35'5"W 47°51'3"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS

- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD

- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS

- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES

- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES

- B 20.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS

- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 1/18/2022 at 9:45 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: Y-12554 Task AC
	Project Name: SR104 MP16.55 Unnamed Tributary to Hood Canal 990710	Date: 2021.12.02
	Project Office: Olympic Region	Time of Arrival: 7:45 am
	Stream Name: Unnamed tributary	Time of Departure: 11:00 am
WDFW ID Number: 990710	Tributary to: Hood Canal	Weather: Overcast with occasional rain, ~45° F
State Route/MP: SR104 MP16.55	Township/Range/Section/ ¼ Section: T27N R2E S6	Prepared By: H. Moen, T. Wang
County: Kitsap	Purpose of Site Visit: Identify reference reach and collect BFW measurements	WRIA: 15

Meeting Location:
Walmart at 21200 Olhava Way NW, Poulsbo, WA 98370 parking lot

Attendance List:

Name	Organization	Role
Shane Sheldon	PACE	Lead Engineer
Tasha Wang	PACE	Project Engineer
Colin Nicol	PACE	Environmental Scientist
Henry Moen	PACE	E.I.T.

Hood Canal Unnamed Tributary – State Route (SR) 104 Crossing Site ID: 990710 (Crossing 990710) has been identified as a fish passage barrier by Washington Department of Fish and Wildlife (WDFW). PACE Engineers (PACE) is working with the Washington State Department of Transportation (WSDOT) to complete a preliminary design for a fish-passable crossing. The following Hydraulics Field Report documents the geomorphic, biological, and hydraulic field assessment of Crossing 990710 conducted by PACE. The reaches both upstream and downstream of the crossing can be accessed directly from SR 104 by parking approximately a quarter mile east of the crossing, in a public parking lot in Port Gamble.

General Site Description

Crossing 990710 is located along SR 104 at mile marker 16.55 in Kitsap County, Washington. This crossing carries run-off from the Port Gamble Heritage Forest through an unnamed tributary to Hood Canal. The WDFW Level A Culvert Assessment report, conducted in December 2009, states that the crossing is a 3-foot round plain cement concrete (PCC) culvert with a length of 69.60 m. (228.4 ft.) and a slope of 6.17%. The inlet opening is at the toe of the road fill with steep banks (approximately 50% slope) on two sides without wingwalls or aprons (Photo 1). The outlet the culvert is inset below grade and there is a small pool immediately downstream of the culvert (Photo 2). Woody material and organic debris had accumulated at the culvert outlet. The slope of the crossing was not verified during the site visit; however, the culvert size was measured to be 3 feet.

Bankfull Width:

Bankfull width (BFW) measurements were taken in three different places in the reference reach (Table 1). A longitudinal profile created from the ground survey data is provided to cross-reference stationing within the project site (Figure 1). BFW, bankfull depth (BFD), and the height of the banks (taken from bank toe to bank top) were also measured at each BFW location (Figure 1). The first BFW measurement (BFW #1) was taken approximately 125 feet upstream of the crossing inlet (EX STA 15+30) at the downstream end of the reference reach (Photo 3). BFW #1 is approximately 10 feet downstream of a channel spanning key log which has accumulated smaller woody material and created a scour pool. There was some exposed silty soil on the steep right bank, but overall the banks in this reach were heavily vegetated and appeared stable. The second BFW measurement (BFW #2) was taken another 50 feet upstream at EX STA 15+80. BFW #2 was intentionally located upstream of the hydraulic influence of the channel spanning key log. At BFW #2 the banks are slightly higher, but the BFW is similar to BFW #1 (Figure 1 and Photo 4). The third BFW (BFW #3) measurement location was at EX STA 16+70, or 266 feet upstream of the crossing (Photo 5). BFW #3 was the widest measurement as the banks were not as steep and there was a wider floodplain at this location (Figure 1 and Photo 5).

Table 1. Bankfull width measurements

Approximate Distance from Crossing (ft)	EX STA	Bankfull Width (ft)	Source/Date
125 (upstream)	15+30	5.3	PACE (December 2021)
165 (upstream)	15+80	5.4	PACE (December 2021)
256 (upstream)	16+60	8.5	PACE (December 2021)
Upstream Average		**6.4**	

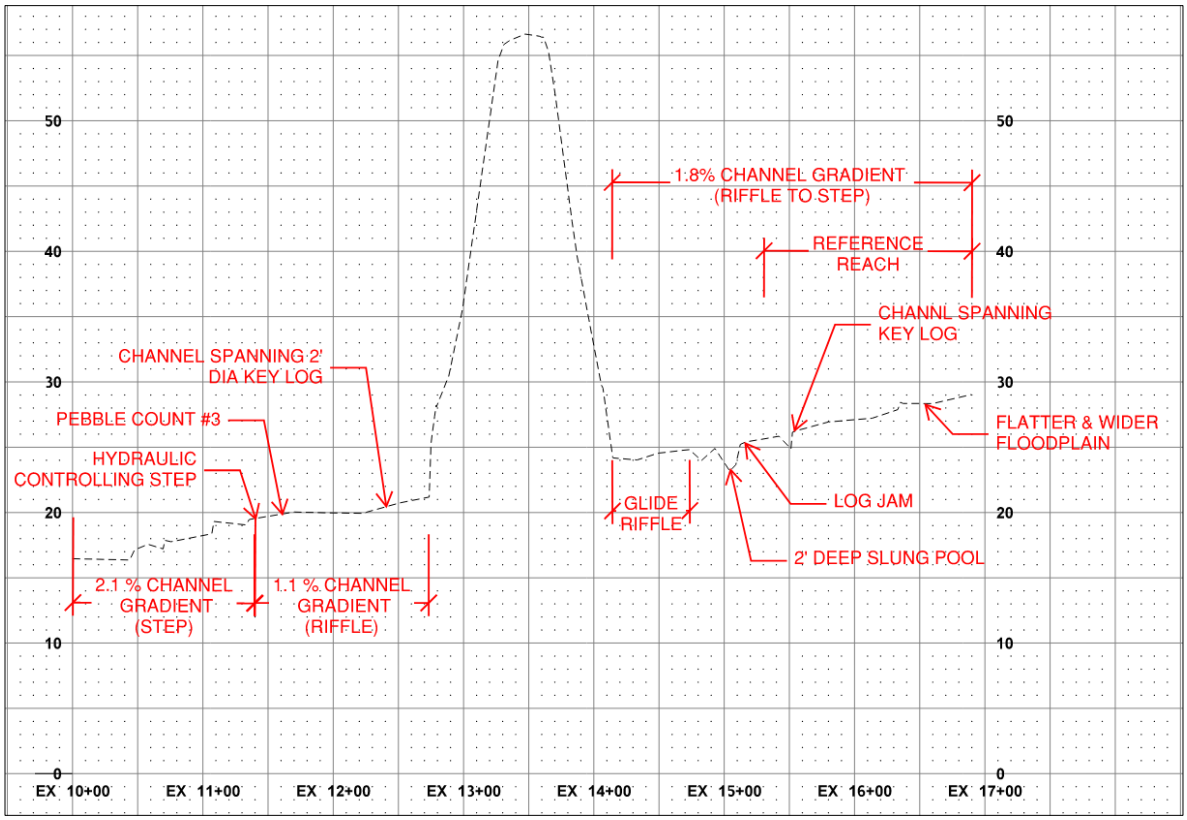


Figure 1. Survey channel profile of crossing 990710

Reference Reach:

The reference reach (RR) is located upstream of the crossing starting at EX STA 15+30, approximately 125 feet upstream of the crossing. Between the crossing and the downstream end of the reference reach the channel is heavily vegetated and there is LWM in the channel. The RR ends at EX STA 16+70 where the channel gradient is milder and a wider floodplain was observed. This site was chosen because it had minimal interference from the crossing or adjacent properties and best represented the natural conditions of the stream. The riparian corridor is densely vegetated with ferns, salmonberry, and English Ivy, predominantly on the east side of the valley. The banks rise steeply for about a foot-and-a-half before reaching a floodplain that slopes gently upward to the toe of the valley walls. On the day of the site visit the flow in the RR was typically slow or pooled. The channel substrate was predominantly sands or fines, with occasional stretches of gravel in small riffles and pool tailouts. There were several places in the stream where large woody material (LWM) spanned the stream, and it was often interacting with the stream directly. In several places the stream was forced to meander around LWM, creating planform and vertical complexity in the channel.

Data Collection:

The entire attendance list participated in the collection of data. Data was collected both upstream, from the inlet until roughly 270 feet upstream of the inlet, and downstream until about 220 feet from the outlet. Data collected included:

- General site observations
- Bankfull width measurements
- Other channel geometry measurements (Bank height, channel width, water depth, etc.)
- Pebble counts

Observations:

Geomorphology

Upstream Conditions

LWM and other organic debris has accumulated near the culvert inlet creating small scour pockets (Photo 1). The first 100 feet of the upstream reach has steep banks approximately 2.5 feet high on two sides forming a U-shaped channel dominated by a glide pool morphology (Figure 1). Upstream of the first 100 feet a sequence of forced scour pools and short riffle/glide morphologies are formed by channel spanning logs and woody debris. A 2-foot-deep plunge pool formed downstream of a large log and rootwad at EX STA 15+10. The main log and rootwad have accumulated other smaller woody debris to form a wood jam. The vertical banks lowered to 1 foot high upstream of the log jam. The main channel is approximately 5 feet wide here, with floodplain benches on two sides extending approximately 20-30 feet to meet the valley wall. Small areas of sediment accumulation and scour in the channel bed were formed by woody material approximately every 20 to 30 feet and created the observed forced pool glide morphology. The upstream reach has an average channel gradient of 1.8% (Figure 1).

Downstream Conditions

The downstream reach has a riffle pool morphology, with scour pools and plunge pools forced by wood in the channel and clear riffles in between the pools. The forcing wood tended to be smaller than on the upstream side and formed clear steps (Figure 1). The reach immediately downstream of the crossing to approximately 120 feet downstream has an average gradient of 1.1%. Riffles were observed between the forced pools and occasional small (generally less than 1 foot) steps formed by woody debris. Most pool-riffle sequences were short (10-20 feet between riffles), but one small log at EX STA 11+40 created a 1-foot step in the water surface and formed a shallow pool which extended upstream for approximately 100 feet (Figure 1 and Photo 9). From 120 feet downstream of the crossing to 280 feet downstream more steps and plunge pools created by buried logs were observed with up to 2-foot elevation drops. The average channel gradient in this section is 2.1% (Figure 1). In general, the banks appear to be stable and do not show signs of chronic degradation or aggradation. In one location (EX STA 10+70) flow is beginning to scour the bank and flow around the spanning wood (Photo 11). The floodplain is 40-80 feet wide and it is likely the channel is in a state of quasi-equilibrium as new wood accumulates and the channel adjusts its planform and vertical profile in response.

Aquatic Habitat Type and Location

Upstream Conditions

In the WDFW Level I Barrier Assessment the potential species identified for this tributary are chum, coho, steelhead, sea run cutthroat, and resident trout. Overall, the flow upstream was slow, with the dominant sediment being silt/clay and unsuitable for spawning. There are pockets of gravels and it is possible there could be some successful spawning activity, especially for smaller resident trout. There were several pools that have the potential to be used as velocity refuge with vegetation overhanging that could serve as protection from predators. These pools would serve as excellent juvenile rearing habitat likely for both over-summer and overwinter rearing. Some of the pools were large enough adult anadromous spawners could hold in them as they rest while migrating upstream or digging a redd. During large flood events it is likely there is good connection between the channel and the floodplain, which would offer additional slow velocity refuge habitat.

Downstream Conditions

On the downstream side there is more gravel present in the streambed and it is likely spawning activity could result in successful egg incubation. There were several places where steps caused by wooden material blockage were forming backwaters, potentially providing velocity refuges. These steps likely pool water throughout the summer and would offer over-summer rearing opportunities. There is ample cover and overhanging vegetation offering cover and foraging opportunities. There were several places where LWM spanned over the channel offering cover and foraging opportunities. It is unlikely any of the spanning wood or steps create full migration barriers, although it is possible at low summer flows that fish may have difficulty passing the taller steps.

LWM Location and Quantity

Upstream Conditions

The quantity of LWM in the upstream reach is high. The channel gradient and stream power of the riffle pool system create a lot of half-buried LWM in the toe and the channel bed. There is one key piece resting on top of the culvert inlet and shading the right overbank (Photo 1). Several 8-inch-diameter logs span the glide-pool channel from top of bank to top of bank in the first 100 feet of the upstream reach (Photo 6). Steps formed by LWM embedded in the channel bottom were observed in this section of the reach. Toe logs buried at the edge of the main channel were observed around 100 feet upstream of the crossing (Photo 2). There is a key piece spanning the channel overbanks 125 feet upstream of the crossing near BFW #1 location (Photo 3). Smaller woody debris has accumulated under the spanning logs and created higher roughness in the channel. Two 18-inch-diameter deciduous logs lie parallel to the channel on the floodplain with trunks partially buried in the top of banks. Scour pools were observed along the toe logs. More channel spanning key pieces were observed farther upstream within the reference reach (Photo 8). The low clearance below the channel spanning log in Photo 8 allows the LWM to be engaged with higher flow events.

Downstream Conditions

Abundant LWM supply provided by dense canopy was observed in the downstream reach. There were approximately 2 to 3 key pieces every 100 linear feet of the channel. There were two 2-foot-diameter key pieces across the banks near the culvert outlet at a 45-degree angle. Smaller LWM and vegetation caught on the key piece partially engage with the flow and provide shading to create quality habitat. Approximately 100 feet downstream of the outlet, a sequence of key pieces span from bank to bank. One has a rootwad on one bank shading the main channel with the trunk lying on the opposite bench (Photo 9). The canopy opens up approximately 200 feet downstream of the culvert outlet, and smaller logs were observed in this section of channel. Several 8-inch-diameter logs cross the floodplain from the bank slope to bank toe (Photo 10). Small steps formed by buried in-channel wood were frequently observed, approximately every 15 feet (Photo 10).

Vegetation

Upstream Conditions

In the upstream reach the valley is covered in salmonberry (*Rubus spectabilis*), sword fern (*Polystichum munitum*), spreading wood fern (*Dryopteris expansa*), red cedar (*Thuja plicata*), large leaf maple (*Acer macrophyllum*), and English ivy (*Hedera helix*). Surrounding the channel are salmonberry and the withered fronds of the annual spreading wood ferns. On the east slope of the valley English ivy is dominant, with many of the trees covered up to near their canopy. English ivy is also covering most of the LWM found on that side of the stream. While English ivy is still present on the west slope, sword ferns are more established and the trees are not covered nearly as extensively.

Downstream Conditions

Downstream of the culvert many of the same species are present. There is less of a difference between the east and west slopes and, while on the road embankment there is a large amount of ivy, the rest of the downstream reach is salmonberry, sword fern and a ground covering (Fringe Cup, *Tellima grandiflora*).

Pebble Counts:

There were three pebble counts taken in association with this crossing: 2 upstream and 1 downstream. The majority of the streambed was silt/clay. The cumulative percentage passing curves in Figure 2 and Figure 3 show plateau at 2 mm sediment. In riffles, where the velocity of the stream is higher, there was gravel present up to 2 inches (Photo 12). The first pebble count was taken at EX STA 15+30 (BFW #1 location). It is downstream of a channel spanning key log, where velocity slows in the scour pool and smaller sediments deposit at this location. 50 percent of the sediment sampled here falls under the categories of sand and silt (Photo 13). The second pebble count was taken on a riffle at EX STA 15+80 (BFW #2 location). Pebble count 2 contained the largest material including 5.5-inch cobbles (Photo 14). The final pebble count was taken at approximately EX STA 11+60, or 100 feet downstream of the crossing downstream of a riffle. The sediment is mostly silt and fine sand in the downstream reach, with some gravel up to 1-inch observed.

Table 2. Results of the pebble counts

Locations	Upstream		Downstream
Pebble Count	PC1	PC2	PC3
Diameter Percentile	(in)	(in)	(in)
D_{95}	1.6	5.5	1.0
D_{84}	0.9	1.4	0.7
D_{50}	0.3	0.2	0.2
D_{16}	0.1	0.1	0.1

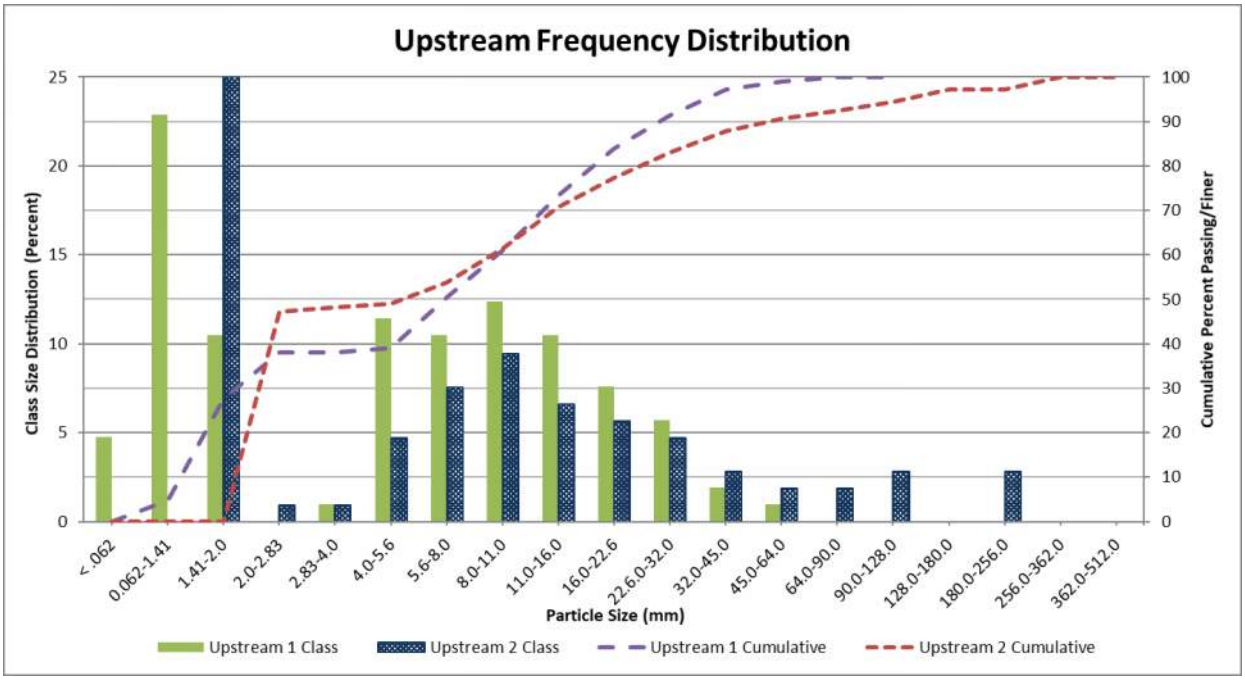


Figure 2. Upstream pebble count gradation

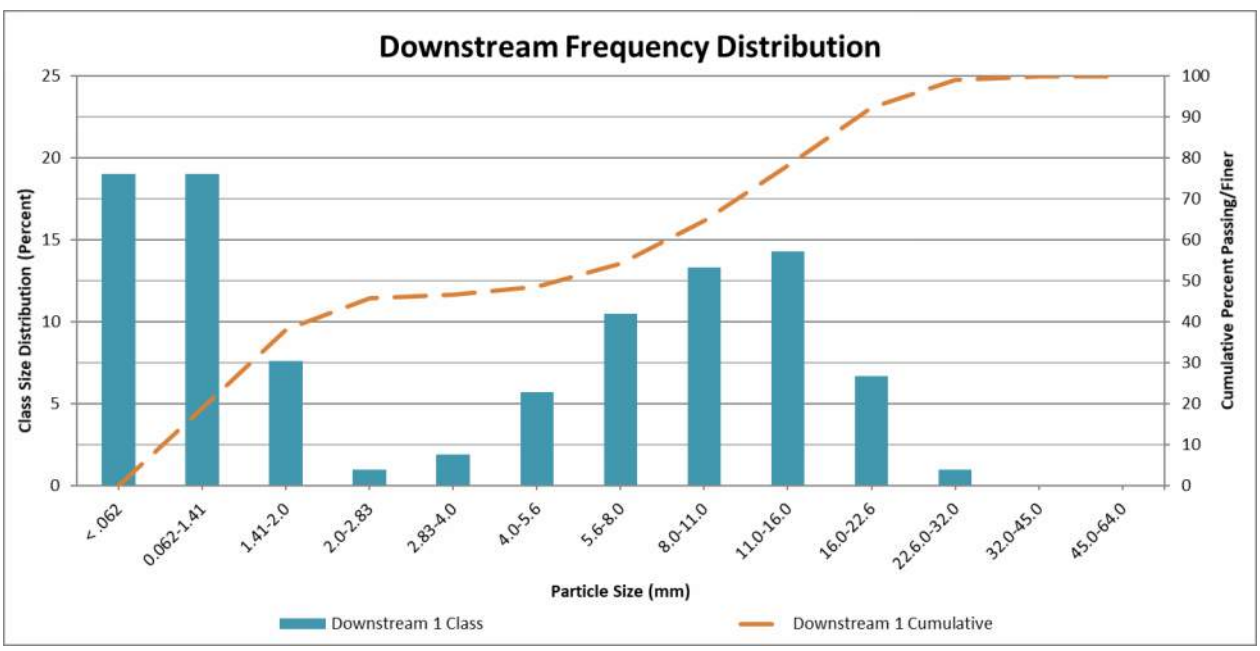


Figure 3. Downstream pebble count gradation

Photos:

Photo 1. Existing 36" culvert inlet with sleep slopes on two sides; key piece resting on the culvert and shading the right overbank

Photo 2. Existing 36" culvert outlet embedded and covered by LWM

Photo 3. BFW #1 measurement 125 feet upstream of the culvert inlet

Photo 4. BFW #2 measurement 165 feet upstream of the culvert inlet

Photo 5. BFW #3 measurement 266 feet upstream of the culvert inlet

Photo 6. Vertical banks in the upstream reach; channel spanning woody materials

Photo 7. Toe logs buried at the edge of main channel within the upstream reach

Photo 8. Channel spanning key piece and buried logs

Photo 9. Step formed by buried LWM hydraulically controlling the downstream reach at STA 11+40

Photo 10. Buried log steps frequently observed in the downstream reach with 2.1% channel gradient

Photo 11. Evidence of high flows beginning to scour the bank as a new flow path forms around the channel spanning wood

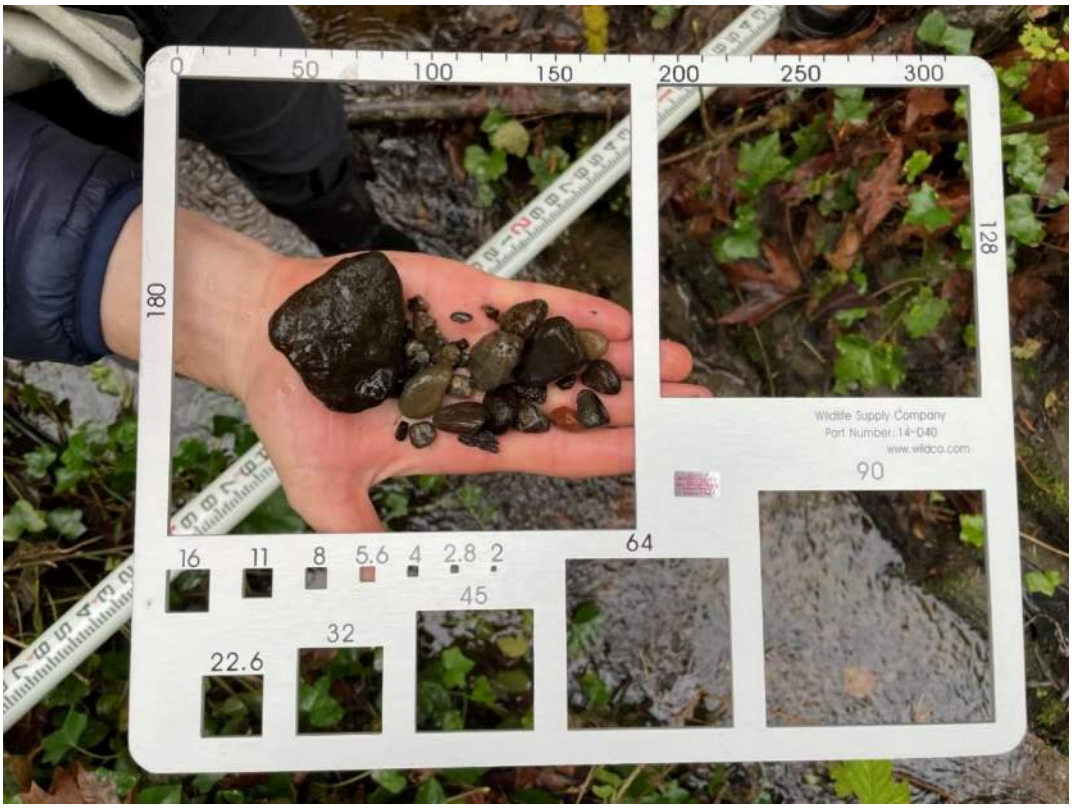


Photo 12. Gravels observed at Pebble count 1 (BFW #1) location

Photo 13. Silt /clay sampled at pebble count 1 (BFW #1) location

Photo 14. Larger cobbles observed at pebble count 2 (BFW #2 location)

Photo 15. Pebble count 3 taken 100 feet downstream of the crossing close to a riffle

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☒ If no, then stop here.*
	Yes ☐ If yes, then fill out the proceeding section for each sample.

Concurrence Meeting	Date: February 2nd, 2022	Time of Arrival: 8 AM
Prepared By: C Nicol, T Wang, S Sheldon	Weather: Partly cloudy	Time of Departure: 10:30 AM

Attendance List:

Name	Organization	Role
Kate Fauver	WSDOT	Transportation Planner
Alison O'Sullivan	Suquamish Tribe	Biologist
Damon Romero	WSDOT	Biologist
Dave Molenaar	WSDOT	Habitat Biologist
Heather Pittman	WSDOT	State Hydraulic Engineer
Amber Martens	WDFW	Biologist
Shawn Stanley	WDFW	Habitat Engineer
Marla Powers	Port Gamble S'Klallam Tribe	Environmental Planner
Hunter Henderson	WSDOT	Transportation Specialist
Colin Nicol	PACE	Environmental Scientist
Shane Sheldon	PACE	Engineer

Bankfull Width:

- Recent flows were at or above a 2-year event, so the group looked for high-water marks from recent events and felt confident in their measurements of bankfull width
- On the upstream side of the crossing the concurrence group took four bankfull width measurements: 5.5 ft, 7.5 ft, 7.5 ft, 9.0 ft. These measurements were taken in approximately the same locations as the three Site Visit 2 measurements
- On the downstream side of the crossing the concurrence group took two bankfull width measurements: 5.5 ft and 6.5 ft

Approximate Distance from Crossing (ft)	EX STA	Bankfull Width (ft)	Used in average	Source/Date
125 (upstream)	15+30	5.3	Y	PACE (December 2021)
165 (upstream)	15+80	5.4	Y	PACE (December 2021)
256 (upstream)	16+60	8.5	Y	PACE (December 2021)
115 (upstream)	15+20	5.5	Y	Concurrence site visit (February 2022)
125 (upstream)	15+30	7.5	Y	Concurrence site visit (February 2022)
165 (upstream)	15+80	7.5	Y	Concurrence site visit (February 2022)
256 (upstream)	16+60	9.0	Y	Concurrence site visit (February 2022)
70 (downstream)	12+00	5.5	Y	Concurrence site visit (February 2022)
350 (downstream)	09+50	6.5	Y	Concurrence site visit (February 2022)
Average		**6.7**		

Reference Reach:

- The group walked the entire length of the reference reach

- General agreement the reference reach was outside of the influence of the culvert
- General agreement the reference reach was suitable for the crossing design

Observations:

- Alison noted the creek is locally known as Machias Creek
- Damon noted the stream bank material is very fine and nearly vertical, which is not something we can construct
    - The design will have to have 2:1 slopes for constructability, and these slope may widen and become more vertical over time
    - Consider low flow depth, beware of over widening
- PACE pointed out the proposed alignment will likely need to be skewed from the existing alignment
    - Group agreed that would be a good decision
- Alison notes there is possibly a sewer line near the stream which may be a concern for construction and/or change hydrology

Photos:

Any relevant photographs placed here with descriptions.

Photo 16. Concurrence group taking a bankfull width measurement and inspecting the streambed sediment in the middle of the reference reach

Photo 17. Concurrence group taking a bankfull measurement in the upstream end of the reference reach

Fish Passage Project Site Visit - Determining Project Complexity

PROJECT NAME:	Unnamed Tributary (UNT) to Hood Canal
WDFW SITE ID:	990710
STATE ROUTE/MILEPOST:	SR 104/ MP 16.55
SITE VISIT DATE:	12/02/2021
ATTENDEES:	Shane Sheldon (PE, PACE), Colin Nicol (Environmental Scientist, PACE), Tasha Wang (PE, PACE), Henry Moen (EIT, PACE)
ANTICIPATED LEVEL OF PROJECT COMPLEXITY - Low/Medium/High (*additional considerations or red flags may trigger the need for new discussions*):	Low. The proposed channel will maintain the existing channel alignment. The slope ratio comparing the reference reach to the project crossing is close to 1. The channel is confined within a 30- to 40-foot-wide valley. Stream simulation design is achievable with floodplain connectivity. Based on the reasons above, the complexity of this project is low.
IN WATER WORK WINDOW	August 1 – August 15

The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects.

Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. If there are items that need follow-up, mark those and provide a brief description in the column labeled, “Is follow-up needed on this item?” The assigned level of complexity determines the appropriate agreed upon review from WDFW (see review parameters here (*final full doc goes here*)). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Fish Passage Project Site Visit - Determining Project Complexity

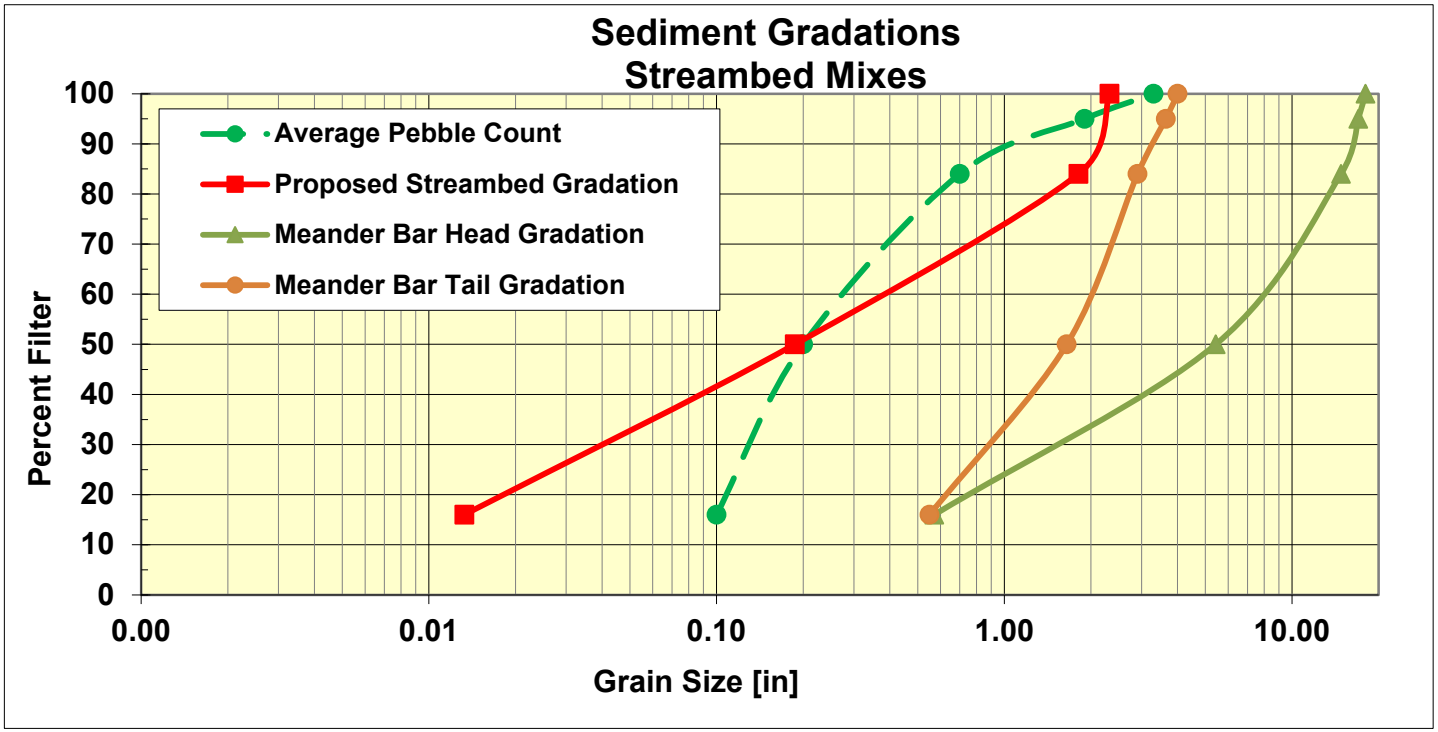
Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Stream grading	X			Limited channel regrade outside of crossing
Risk of degradation/aggradation	X			No signs of excess sediment, fine material in streambed and banks may be mobile
Channel realignment		X		The existing outlet was forced to the far-left side of the ravine to allow the culvert to be installed perpendicular to the road. The new wider structure will be skewed to the road to the road alignment.
Expected stream movement	X			Banks are composed of fine material and some bank erosion may occur with minimal risk
Gradient	X			Slope of the stream throughout the project area is ~2%
Potential for backwater impacts	X			None anticipated
Meeting requirements for freeboard	X			High roadway prism
Stream size, and Bankfull Width	X			BFW 5-8 ft
Slope ratio	X			The slope is consistent at ~2%
Sediment supply	X			No signs of excess sediment
Meeting stream simulation	X			Current crossing 228 ft, which may make the 10x length threshold difficult to meet
Channel confinement		X		The channel is confined within a 30- to 40-foot-wide valley. The main channel has some lateral movement around LWM. The confinement of the channel will need to be finalized using hydraulic model through FUR analysis.
Geotech or seismic considerations	X			None anticipated
Tidal influence	X			No
Alluvial fan	X			No
Fill depth above barrier	X			No complications anticipated
Presence of other nearby barriers	X			None
Presence of nearby infrastructure	X			No nearby infrastructure at risk
Need for bank protection	X			Banks may be somewhat mobile, but a dynamic planform is not a risk to the design

Fish Passage Project Site Visit - Determining Project Complexity

Project Elements (anticipated)	Low Complexity	Medium Complexity	High Complexity	Is follow up needed on this item?
Floodplain utilization ratio		X		Need to be analyzed using 2-D hydraulic model.
Other:	N/A			

Appendix C: Streambed Material Sizing Calculations

Figure 1. Comparison of existing and proposed gradation



Summary - Streambed Material Design (Critical Shear)

Project:	SR 104 MP 16.55 Machias Creek
By:	Tasha Wang

Streambed Design Gradation: Critical Shear					
	D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.21	0.19	0.15	0.02	0.00
in	2.50	2.3	1.8	0.19	0.01
mm	64	59	46	4.8	0.3

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed			Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	Fine	Sand	Sediment	4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914											100	100.0
32.0	813											50	100.0
28.0	711										100		100.0
23.0	584										50		100.0
18.0	457									100			100.0
15.0	381									50			100.0
12.0	305								100				100.0
10.0	254							100	80				100.0
8.0	203						100	80	68				100.0
6.0	152					100	80	68	57				100.0
5.0	127					80	68	57	45				100.0
4.0	102				100	71	57	45	39				100.0
3.0	76.2				80	63	45	38	34				100.0
2.5	63.5			100	65	54	37	32	28				100.0
2.0	51			80	50	45	29	25	22				86.0
1.5	38.1			73	35	32	21	18	16				80.8
1.0	25.4			65	20	18	13	12	11				75.5
0.75	19.1		100	55	8	8	8	8	8				68.5
0.50	12.7		95	50	5	5	5	5	5				63.5
0.38	9.5		90	40									55.0
No. 4 =	4.75	100	85	35									50.0
No. 8 =	2.36	70	50	30									36.0
No. 10 =	2.00	46	32	27									28.5
No. 40 =	0.425	26	26	16									19.0
No. 200 =	0.0750	20	7	7									7.0
% per category			30	70									--> 100%
% Cobble & Sediment		0.0	30.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Proposed Streambed Gradation	in	mm
D16	0.013	0.34
D50	0.2	4.75
D84	1.8	45.96
D95	2.3	58.96
D100	2.5	63.50

Average Pebble Count	in	mm	20%
D16	0.10	2.54	
D50	0.20	5.08	**0.24**
D84	0.70	17.78	
D95	1.90	48.26	
D100	3.30	83.82	

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:	Project Applicable
D_{84} must be between 0.40 in and 10 in	Yes
uniform bed material (Di < 20-30 times D50)	Yes
Slopes less than 5%	Yes
Sand/gravel streams with high relative submergence	Yes

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.044	Dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

* All the shear stress were taken within the crossing, not within the regraded channel.

	Flow 2-YR Max.	2-YR Ave.	100-YR Max.	100--YR Ave.
Average Modeled Shear Stress (lb/ft^2)	0.73	0.46	1.48	0.72
τ_{ci}		Structure		
0.34	Motion	Motion	Motion	Motion
0.33	Motion	Motion	Motion	Motion
0.32	Motion	Motion	Motion	Motion
0.30	Motion	Motion	Motion	Motion
0.28	Motion	Motion	Motion	Motion
0.26	Motion	Motion	Motion	Motion
0.25	Motion	Motion	Motion	Motion
0.23	Motion	Motion	Motion	Motion
0.22	Motion	Motion	Motion	Motion
0.20	Motion	Motion	Motion	Motion
0.19	Motion	Motion	Motion	Motion
0.18	Motion	Motion	Motion	Motion
0.16	Motion	Motion	Motion	Motion
0.15	Motion	Motion	Motion	Motion
0.14	Motion	Motion	Motion	Motion
0.13	Motion	Motion	Motion	Motion
0.12	Motion	Motion	Motion	Motion
0.11	Motion	Motion	Motion	Motion
0.09	Motion	Motion	Motion	Motion
0.09	Motion	Motion	Motion	Motion
0.19	Motion	Motion	Motion	Motion
0.15	Motion	Motion	Motion	Motion
0.14	Motion	Motion	Motion	Motion
0.09	Motion	Motion	Motion	Motion
0.05	Motion	Motion	Motion	Motion

D50 (ft)		in	mm
0.0156	D16	0.013	0.34
	D50	0.19	4.75
	D84	1.81	45.96
	D95	2.32	58.96
	D100	2.50	63.50

Summary - Meander Bar Head Material Design

Project:	SR 104 MP 16.55 Machias Creek
By:	Tasha Wang

Meander Bar Gradation

Design:

	D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	1.50	1.42	1.23	0.45	0.05
in	18.00	17.00	14.8	5.43	0.57
mm	457	432	376	137.9	14.5

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed: Fine	Streambed: Sand	Streambed: Sediment	Streambed Cobbles: 4"	6"	8"	10"	12"	Streambed Boulders: 12"-18"	18"-28"	28"-36"	D_{size}
	36.0	914											100	100.0
	32.0	813											50	100.0
	28.0	711										100		100.0
	23.0	584										50		100.0
	18.0	457									100			100.0
	15.0	381									50			85.0
	12.0	305								100				70.0
	10.0	254							100	80				62.0
	8.0	203						100	80	68				57.3
	6.0	152					100	80	68	57				52.7
	5.0	127					80	68	57	45				48.0
4	4.0	102				100	71	57	45	39				45.7
3	3.0	76				80	63	45	38	34				43.4
2.5	2.5	63.5			100	65	54	37	32	28				41.1
2	2.0	51			80	50	45	29	25	22				32.9
1.5	1.5	38.1			73	35	32	21	18	16				28.3
1	1.0	25.4			65	20	18	13	12	11				23.8
0.8	0.75	19.1		100	55	5	5	5	5	5				18.5
	0.50	12.7		95	50									15.0
	0.38	9.7		90	40									12.0
0.2	No. 4 =	4.75	100	85	35									10.5
	No. 8 =	2.36	70	50	30									9.0
	No. 10 =	2.00	46	32	27									8.1
0	No. 40 =	0.425	26	26	16									4.8
0	No. 200 =	0.0750	20	7	7									2.1
	% per category		0	0	30	0	0	0	0	40	30	0	0	--> 100%
	% Cobble & Sediment		0.0	0.0	30.0	0.0	0.0	0.0	0.0	40.0	30.0	0.0	0.0	70.0%

Meander Bar Head Gradation	in	mm	Average Pebble Count	in	mm	20%
D16	0.6	14.51	D16	0.10	2.54	
D50	5.4	137.89	D50	0.20	5.08	**0.24**
D84	14.8	375.92	D84	0.70	17.78	
D95	17.0	431.80	***D95***	1.90	48.26	
D100	18.0	457.20	D100	3.30	83.82	

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:	Project Applicable
D_{84} must be between 0.40 in and 10 in	Yes
uniform bed material (Di < 20-30 times D50)	Yes
Slopes less than 5%	Yes
Sand/gravel streams with high relative submergence	Yes

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	Dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

* All the shear stress were taken within the crossing, not within the regraded channel.

Flow	2-YR Max.	2-YR Ave.	100-YR Max.	100--YR Ave.
Average Modeled Shear Stress (lb/ft^2)	0.73	0.46	1.48	0.72
τ_{ci}				
4.09	No Motion	No Motion	No Motion	No Motion
3.95	No Motion	No Motion	No Motion	No Motion
3.80	No Motion	No Motion	No Motion	No Motion
3.58	No Motion	No Motion	No Motion	No Motion
3.33	No Motion	No Motion	No Motion	No Motion
3.15	No Motion	No Motion	No Motion	No Motion
2.94	No Motion	No Motion	No Motion	No Motion
2.79	No Motion	No Motion	No Motion	No Motion
2.61	No Motion	No Motion	No Motion	No Motion
2.39	No Motion	No Motion	No Motion	No Motion
2.26	No Motion	No Motion	No Motion	No Motion
2.12	No Motion	No Motion	No Motion	No Motion
1.94	No Motion	No Motion	No Motion	No Motion
1.84	No Motion	No Motion	No Motion	No Motion
1.72	No Motion	No Motion	No Motion	No Motion
1.58	No Motion	No Motion	No Motion	No Motion
1.40	No Motion	No Motion	Motion	No Motion
1.28	No Motion	No Motion	Motion	No Motion
1.13	No Motion	No Motion	Motion	No Motion
1.05	No Motion	No Motion	Motion	No Motion
0.84	No Motion	No Motion	Motion	No Motion
0.68	Motion	No Motion	Motion	Motion
0.65	Motion	No Motion	Motion	Motion
0.41	Motion	Motion	Motion	Motion
0.24	Motion	Motion	Motion	Motion

D50 (ft)		in	mm
0.45	D16	0.57	14.51
	D50	5.43	137.89
	D84	14.80	375.92
	D95	17.00	431.80
	D100	18.00	457.20

Summary - Meander Bar Tail Material Design

Project:	SR 104 MP 16.55 Machias Creek
By:	Tasha Wang

Meander Bar Gradation					
Design:					
	D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.33	0.30	0.24	0.14	0.05
in	4.00	3.64	2.9	1.65	0.55
mm	102	93	74	41.8	14.0

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	Rock Size [mm]	Streambed: Fine	Streambed: Sand	Streambed: Sediment	Streambed Cobbles: 4"	6"	8"	10"	12"	Streambed Boulders: 12"-18"	18"-28"	28"-36"	D_{size}
	36.0	914											100	100.0
	32.0	813											50	100.0
	28.0	711										100		100.0
	23.0	584										50		100.0
	18.0	457									100			100.0
	15.0	381									50			100.0
	12.0	305								100				100.0
	10.0	254							100	80				100.0
	8.0	203						100	80	68				100.0
	6.0	152					100	80	68	57				100.0
	5.0	127					80	68	57	45				100.0
4	4.0	102				100	71	57	45	39				100.0
3	3.0	76				80	63	45	38	34				86.0
2.5	2.5	63.5			100	65	54	37	32	28				75.5
2	2.0	51			80	50	45	29	25	22				59.0
1.5	1.5	38.1			73	35	32	21	18	16				46.3
1	1.0	25.4			65	20	18	13	12	11				33.5
0.8	0.75	19.1		100	55	5	5	5	5	5				20.0
	0.50	12.7		95	50									15.0
	0.38	9.7		90	40									12.0
0.2	No. 4 =	4.75	100	85	35									10.5
	No. 8 =	2.36	70	50	30									9.0
	No. 10 =	2.00	46	32	27									8.1
0	No. 40 =	0.425	26	26	16									4.8
0	No. 200 =	0.0750	20	7	7									2.1
	% per category		0	0	30	70	0	0	0	0	0	0	0	--> 100%
	% Cobble & Sediment				30.0	70.0								100.0%

Meander Bar Tail Gradation	in	mm		Average Pebble Count	in	mm	20%
D16	0.6	13.97		D16	0.10	2.54	
D50	1.6	41.84		D50	0.20	5.08	0.24
D84	2.9	73.78		D84	0.70	17.78	
D95	3.6	92.53		*D95*	1.90	48.26	
D100	4.0	101.60		D100	3.30	83.82	

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organizms at Road-Stream Crossings

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:	Project Applicable
D_{84} must be between 0.40 in and 10 in	Yes
uniform bed material (Di < 20-30 times D50)	Yes
Slopes less than 5%	Yes
Sand/gravel streams with high relative submergence	Yes

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	Dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

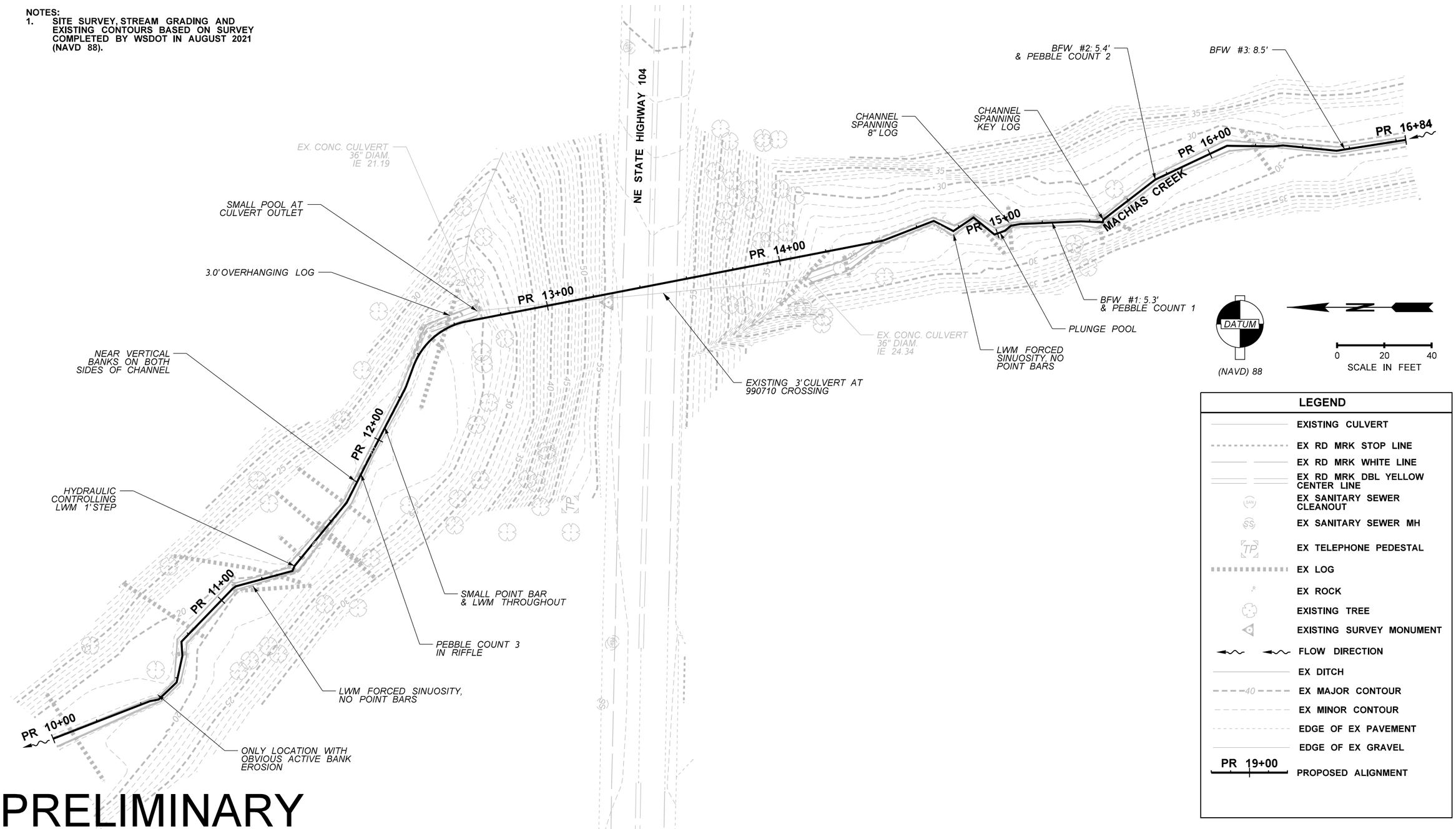
* All the shear stress were taken within the crossing, not within the regraded channel.

	Flow	2-YR Max.	2-YR Ave.	100-YR Max.	100--YR Ave.
	Average Modeled Shear Stress (lb/ft^2)	0.73	0.46	1.48	0.72
τ_{ci}					
1.78		No Motion	No Motion	No Motion	No Motion
1.71		No Motion	No Motion	No Motion	No Motion
1.65		No Motion	No Motion	No Motion	No Motion
1.55		No Motion	No Motion	No Motion	No Motion
1.44		No Motion	No Motion	Motion	No Motion
1.37		No Motion	No Motion	Motion	No Motion
1.28		No Motion	No Motion	Motion	No Motion
1.21		No Motion	No Motion	Motion	No Motion
1.13		No Motion	No Motion	Motion	No Motion
1.04		No Motion	No Motion	Motion	No Motion
0.98		No Motion	No Motion	Motion	No Motion
0.92		No Motion	No Motion	Motion	No Motion
0.84		No Motion	No Motion	Motion	No Motion
0.80		No Motion	No Motion	Motion	No Motion
0.75		No Motion	No Motion	Motion	No Motion
0.68		Motion	No Motion	Motion	Motion
0.61		Motion	No Motion	Motion	Motion
0.56		Motion	No Motion	Motion	Motion
0.49		Motion	No Motion	Motion	Motion
0.45		Motion	Motion	Motion	Motion
0.37		Motion	Motion	Motion	Motion
0.30		Motion	Motion	Motion	Motion
0.28		Motion	Motion	Motion	Motion
0.18		Motion	Motion	Motion	Motion
0.11		Motion	Motion	Motion	Motion

D50 (ft)		in	mm
0.1373	D16	0.55	13.97
	D50	1.65	41.84
	D84	2.90	73.78
	D95	3.64	92.53
	D100	4.00	101.60

Appendix D: Stream Plan Sheets, Profile, Details

NOTES:
1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN AUGUST 2021 (NAVD 88).



LEGEND

- EXISTING CULVERT
- EX RD MRK STOP LINE
- EX RD MRK WHITE LINE
- EX RD MRK DBL YELLOW CENTER LINE
- EX SANITARY SEWER CLEANOUT
- EX SANITARY SEWER MH
- EX TELEPHONE PEDESTAL
- EX LOG
- EX ROCK
- EXISTING TREE
- EXISTING SURVEY MONUMENT
- FLOW DIRECTION
- EX DITCH
- EX MAJOR CONTOUR
- EX MINOR CONTOUR
- EDGE OF EX PAVEMENT
- EDGE OF EX GRAVEL
- PR 19+00 PROPOSED ALIGNMENT

PRELIMINARY

NOT FOR CONSTRUCTION

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DESIGNED BY	T WANG				CONTRACT NO.		LOCATION NO.
ENTERED BY	R VANDYKE						
CHECKED BY							
PROJ. ENGR.							
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 104
MACHIAS CREEK
FISH BARRIER REMOVAL DESIGN

EXISTING STREAM PLAN

PLAN REF NO HY01

SHEET 1 OF 3 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR104_MP16-55_UnnamedtoHoodCanal_990710_CAD_Sheets\990710_EX_HY_001.dgn

NOTES:

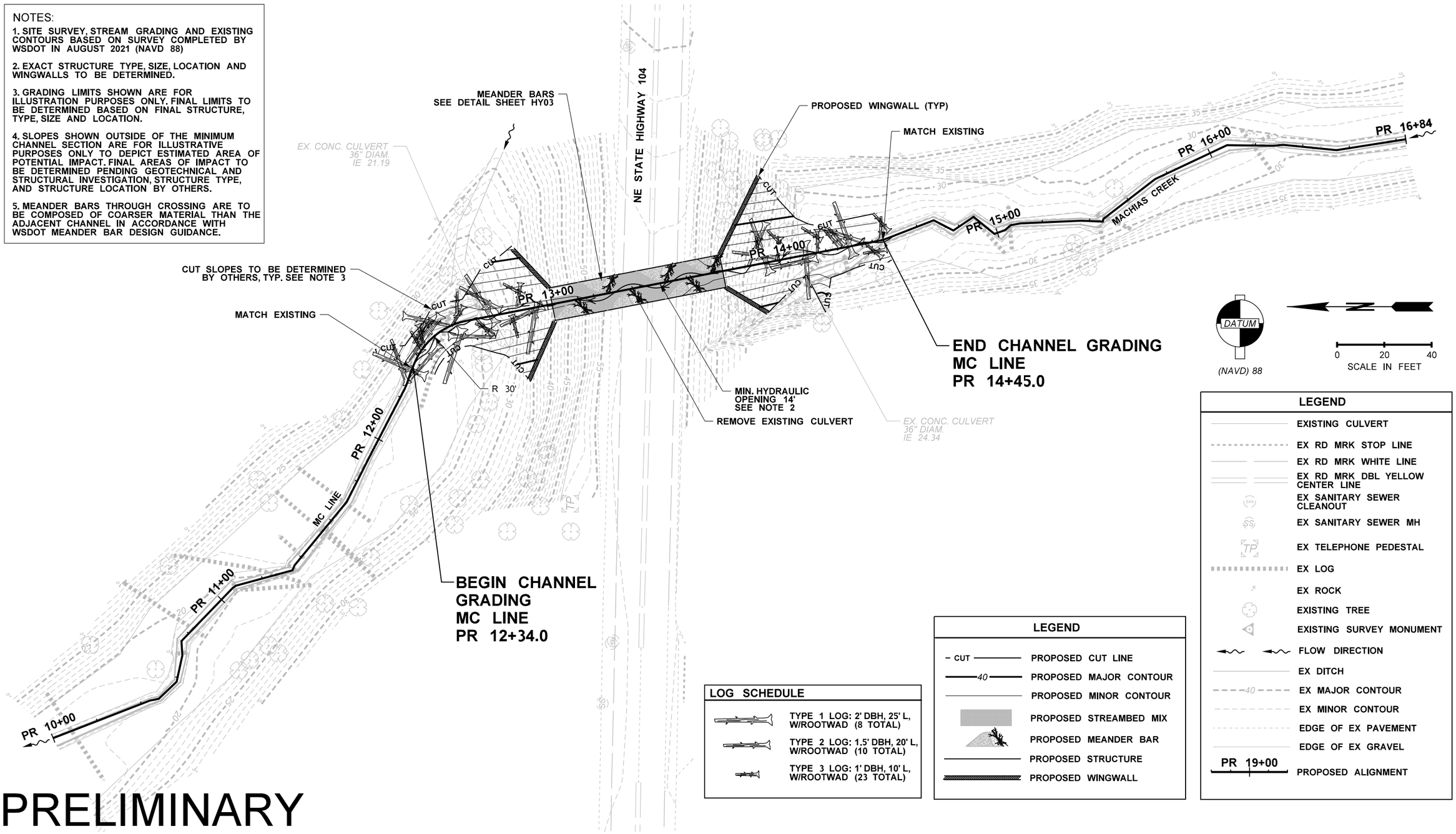
1. SITE SURVEY, STREAM GRADING AND EXISTING CONTOURS BASED ON SURVEY COMPLETED BY WSDOT IN AUGUST 2021 (NAVD 88)

2. EXACT STRUCTURE TYPE, SIZE, LOCATION AND WINGWALLS TO BE DETERMINED.

3. GRADING LIMITS SHOWN ARE FOR ILLUSTRATION PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE, TYPE, SIZE AND LOCATION.

4. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION BY OTHERS.

5. MEANDER BARS THROUGH CROSSING ARE TO BE COMPOSED OF COARSER MATERIAL THAN THE ADJACENT CHANNEL IN ACCORDANCE WITH WSDOT MEANDER BAR DESIGN GUIDANCE.



LEGEND

- EXISTING CULVERT
- EX RD MRK STOP LINE
- EX RD MRK WHITE LINE
- EX RD MRK DBL YELLOW CENTER LINE
- EX SANITARY SEWER CLEANOUT
- EX SANITARY SEWER MH
- EX TELEPHONE PEDESTAL
- EX LOG
- EX ROCK
- EXISTING TREE
- EXISTING SURVEY MONUMENT
- FLOW DIRECTION
- EX DITCH
- EX MAJOR CONTOUR
- EX MINOR CONTOUR
- EDGE OF EX PAVEMENT
- EDGE OF EX GRAVEL
- PR 19+00 PROPOSED ALIGNMENT

LEGEND

- CUT PROPOSED CUT LINE
- 40 PROPOSED MAJOR CONTOUR
- PROPOSED MINOR CONTOUR
- PROPOSED STREAMBED MIX
- PROPOSED MEANDER BAR
- PROPOSED STRUCTURE
- PROPOSED WINGWALL

LOG SCHEDULE

- TYPE 1 LOG: 2' DBH, 25' L, W/ROOTWAD (8 TOTAL)
- TYPE 2 LOG: 1.5' DBH, 20' L, W/ROOTWAD (10 TOTAL)
- TYPE 3 LOG: 1' DBH, 10' L, W/ROOTWAD (23 TOTAL)

PRELIMINARY

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DESIGNED BY	T WANG
ENTERED BY	R VANDYKE
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 104
MACHIAS CREEK
FISH BARRIER REMOVAL DESIGN

STREAM RESTORATION PLAN

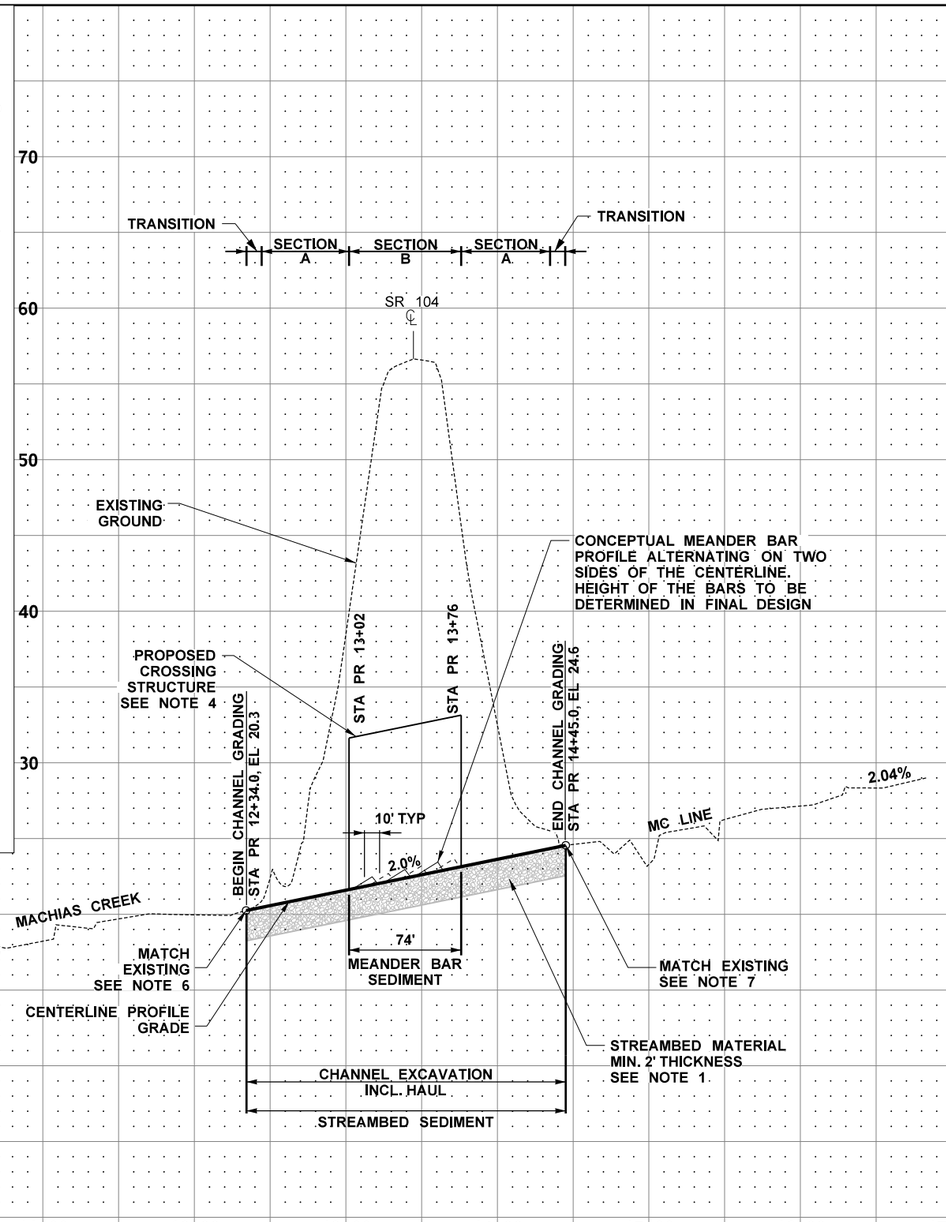
PLAN REF NO HY02

SHEET 2 OF 3 SHEETS

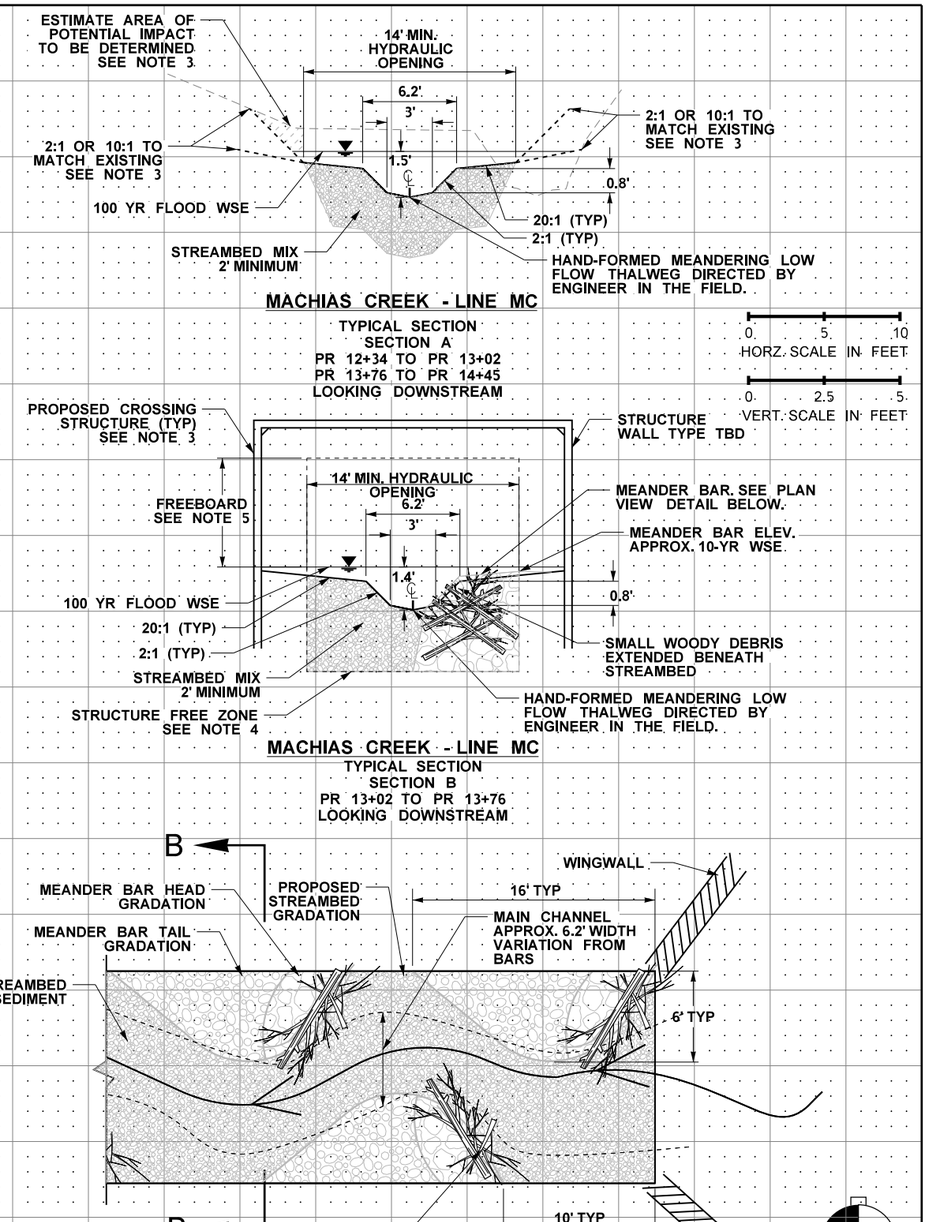
pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR104_MP16-55_UnnamedtoHoodCanal_990710_CAD_Sheets\990710_PS_HY_002.dgn

NOTES:

1. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. MEANDER BARS WILL BE INSTALLED TO THE STRUCTURE FREE DEPTH.
3. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
4. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED. MUST BE OUTSIDE OF STRUCTURE FREE ZONE.
5. THE REQUIRED FREEBOARD FOR THE SR 104 CROSSING IS 2 FEET FROM 100YR WSE. 10 FEET OF CLEARANCE FROM THE HIGHEST STREAMBED GROUND IS RECOMMENDED.
6. FROM PR 12+34 TO PR 12+44, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
7. FROM PR 14+35 TO PR 14+45, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
8. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.



MC LINE PROFILE



MEANDER BAR DETAIL

PRELIMINARY

NOT FOR CONSTRUCTION

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CHECKED BY						
PROJ. ENGR.						
REGIONAL ADM.		REVISION	DATE	BY		

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 104
MACHIAS CREEK
FISH BARRIER REMOVAL DESIGN

STREAM RESTORATION PROFILE

PLAN REF. NO. HY03

SHEET 3 OF 3 SHEETS

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR104_MP16-55_UnnamedtoHoodCanal_990710_CAD_Sheets\990710_PR_HY_003.dgn

Appendix E: Manning's Calculations

Proposed Regraded Channel

Quasi-Qualitative Value from
Arcement and Schneider 1989

This page is extracted from *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Floodplain* (Arcement and Schneider 1989)

Table 2. Adjustment values for factors that affect the roughness of a channel

[Modified from Aldridge and Garrett, 1973, table 2]

Channel conditions		*n* value adjustment[1]	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest channel attainable in a given bed material.
	Minor	0.001–0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006–0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slopes.
	Severe	0.011–0.020	Badly sloughed or scalloped banks of natural streams; badly eroded or sloughed sides of canals or drainage channels; unshaped, jagged, and irregular surfaces of channels in rock.
Variation in channel cross section (n_2)	Gradual	0.000	Size and shape of channel cross sections change gradually.
	Alternating occasionally	0.001–0.005	Large and small cross sections alternate occasionally, or the main flow occasionally shifts from side to side owing to changes in cross-sectional shape.
	Alternating frequently	0.010–0.015	Large and small cross sections alternate frequently, or the main flow frequently shifts from side to side owing to changes in cross-sectional shape.
Effect of obstruction (n_3)	Negligible	0.000–0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.015	Obstructions occupy less than 15 percent of the cross-sectional area, and the spacing between obstructions is such that the sphere of influence around one obstruction does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp-edged angular objects.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross section.
	Severe	0.040–0.050	Obstructions occupy more than 50 percent of the cross-sectional area, or the space between obstructions is small enough to cause turbulence across most of the cross section.
Amount of vegetation (n_4)	Small	0.002–0.010	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.010–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season, growing along the banks, and no significant vegetation is evident along the channel bottoms where the hydraulic radius exceeds 2 ft.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation; 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft; bushy willows about 1 year old intergrown with some weeds along side slopes (all vegetation in full foliage), and no significant vegetation exists along channel bottoms where the hydraulic radius is greater than 2 ft.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; bushy willow trees about 1 year old intergrown with weeds along side slopes (all vegetation in full foliage), or dense cattails growing along channel bottom; trees intergrown with weeds and brush (all vegetation in full foliage).
Degree of meandering[2] (m)	Minor	1.00	Ratio of the channel length to valley length is 1.0 to 1.2.
	Appreciable	1.15	Ratio of the channel length to valley length is 1.2 to 1.5.
	Severe	1.30	Ratio of the channel length to valley length is greater than 1.5.

[1] Adjustments for degree of irregularity, variations in cross section, effect of obstructions, and vegetation are added to the base *n* value (table 1) before multiplying by the adjustment for meander.

[2] Adjustment values apply to flow confined in the channel and do not apply where downvalley flow crosses meanders.

Hydraulics Manual

March, 2022
Appendix 4A

Table 4A-2 Manning's Roughness Coefficients for Stream Channels

Existing conditions channel

Stream Channels	Manning's n
Minor streams (surface width at flood stage less than 100 feet):	
1. Fairly regular section:	
a. Some grass and weeds, little or no brush	0.030-0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035-0.05
c. Some weeds, light brush on banks	0.035-0.05
d. Some weeds, heavy brush on banks	0.05-0.07 0.048
e. Some weeds, dense willows on banks	0.06-0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by 0.01–0.02	
2. Irregular sections, with pools, slight channel meander; increase values given in 1a–e above 0.01–0.02	
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage:	
a. Bottom of gravel, cobbles, and few boulders	0.04-0.05
b. Bottom of cobbles, with large boulders	0.05-0.07
Floodplains (adjacent to natural streams):	
1. Pasture, no brush:	
a. Short grass	0.030-0.035
b. High grass	0.035-0.05
2. Cultivated areas:	
a. No crop	0.03-0.04
b. Mature row crops	0.035-0.045
c. Mature field crops	0.04-0.05
3. Heavy weeds, scattered brush	0.05-0.07
4. Light brush and trees:	
a. Winter	0.05-0.06
b. Summer	0.06-0.08
5. Medium to dense brush:	
a. Winter	0.07-0.11
b. Summer	0.10-0.16
6. Dense willows, summer, not bent over by current	0.15-0.20
7. Cleared land with tree stumps, 100 to 150 per acre:	
a. No sprouts	0.04-0.05
b. With heavy growth of sprouts	0.06-0.08
8. Heavy stand of timber, a few down trees, little undergrowth:	
a. Flood depth below branches	0.10-0.12
b. Flood depth reaches branches	0.12-0.16

Tabular estimates for the proposed regraded channel and the proposed crossing

Major streams (surface width at flood stage more than 100 feet): Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of n may be somewhat reduced. Follow recommendation in publication cited if possible. The value of n for larger streams of most regular sections, with no boulders or brush, may be in the range of 0.028–0.033.

Value for forested floodplain

DRAFT

Appendix F: Large Woody Material Calculations

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***SR 104 MP 16.55***		**Key piece volume**	***1.310***	*yd3*
Stream name	*Machias Creek*		**Key piece/ft**	***0.0335***	*per ft stream*
length of regrade[a]	*211*	*ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*
Bankfull width	*6.7*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.0224
LFrw	1.5
Hdbh	4.5

Log type	*Diam at midpoint **	*Length [d]*	*Volume/log [d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume*	DBH based on mid point diameter	Droot collar	L/2-Lrw
	ft	**ft**	**yd3**				**yd3**			
1	2.00	*25*	2.91	**yes**	yes	8	23.27	2.11	2.21	9.5
2	1.50	*20*	1.31	**yes**	no	7	9.16	1.57	1.67	7.75
3	1.00	*10*	0.29	**yes**	no	23	6.69	0.98	1.08	3.5
4			0.00	**no**			0.00		0.00	0
5			0.00	**no**			0.00		0.00	0
6			0.00				0.00		0.00	0
7			0.00				0.00		0.00	0
8			0.00				0.00		0.00	0
9			0.00				0.00		0.00	0
10			0.00				0.00		0.00	0

	No. of key pieces	**Total No. of LWM pieces**	**Total LWM volume (yd^3)**
Design	8	38	39.1
75% Targets	**7**	**24**	**83.3**
50% Targets	**4**	**19**	**42.9**
	surplus	surplus	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla (generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine (generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine (mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d]includes rootwad if present

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name: 990710

Stream Name: Unnamed Trib to Hood Canal

Drainage Area: 0 ac

Projected mean percent change in bankfull flow:

2040s: 12.4%

2080s: 14.5%

Projected mean percent change in bankfull width:

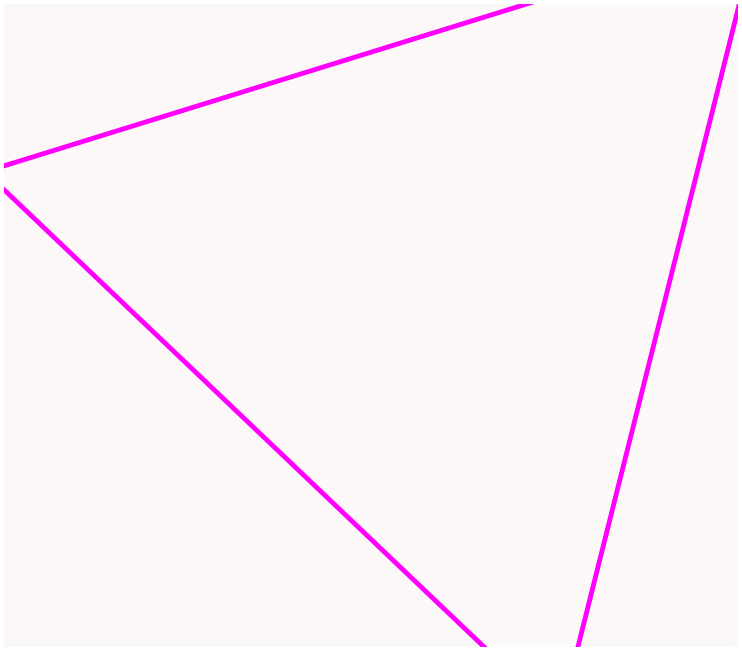
2040s: 6%

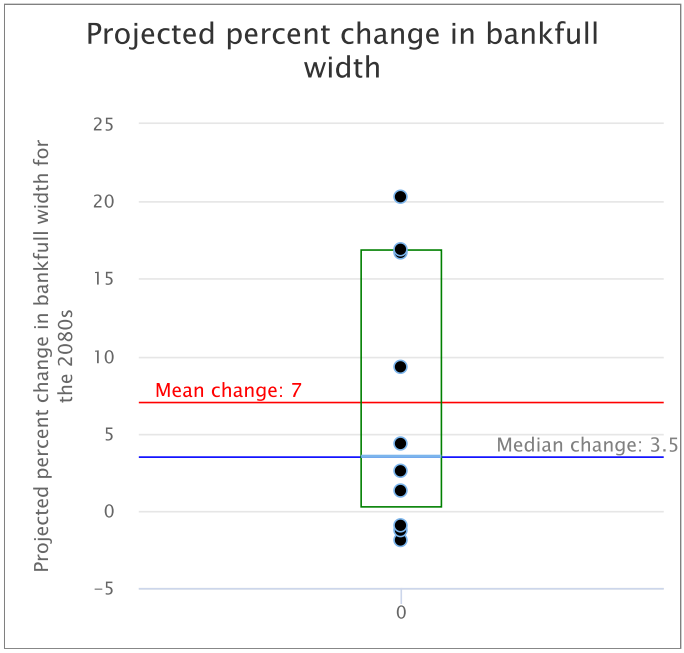
2080s: 7%

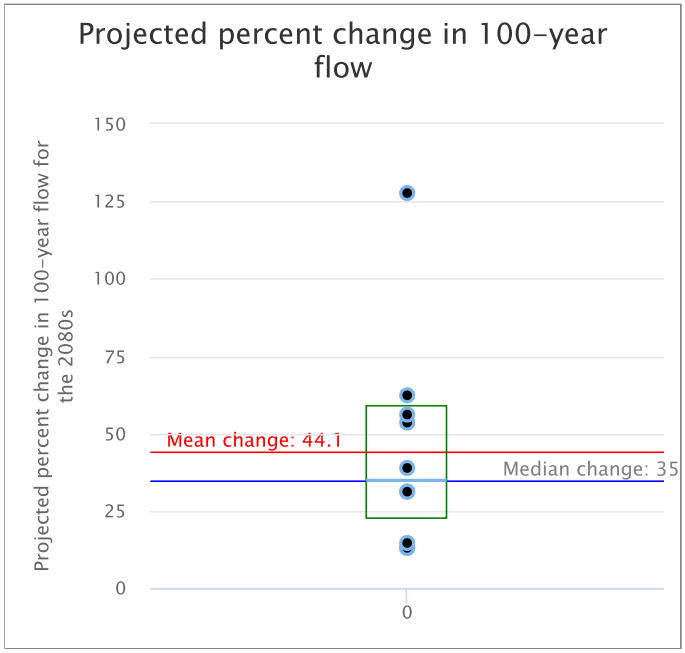
Projected mean percent change in 100-year flood:

2040s: 28.1%

2080s: 44.1%







Black dots are projections from 10 separate models

The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

Appendix H: SRH-2D Model Results

Figure 1. Existing Condition Channel Profile

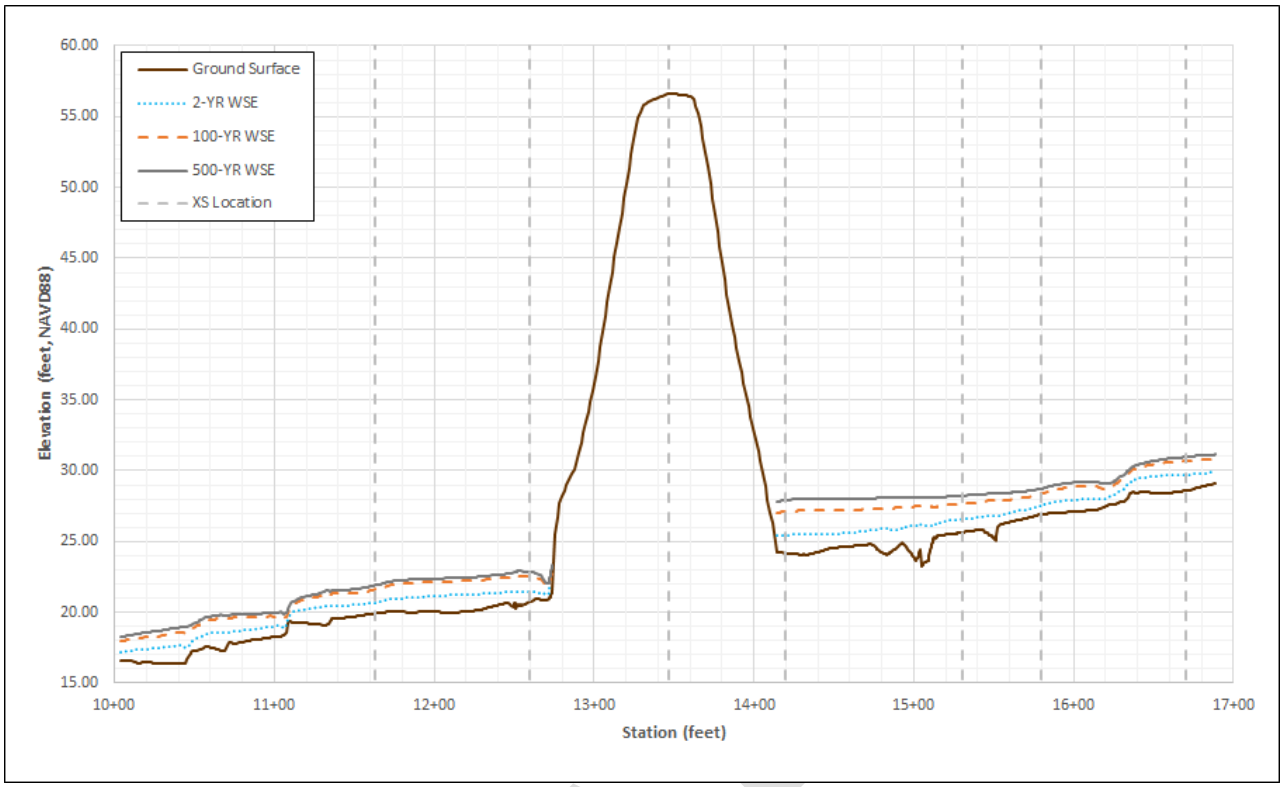


Figure 2. Proposed Condition Channel Profile

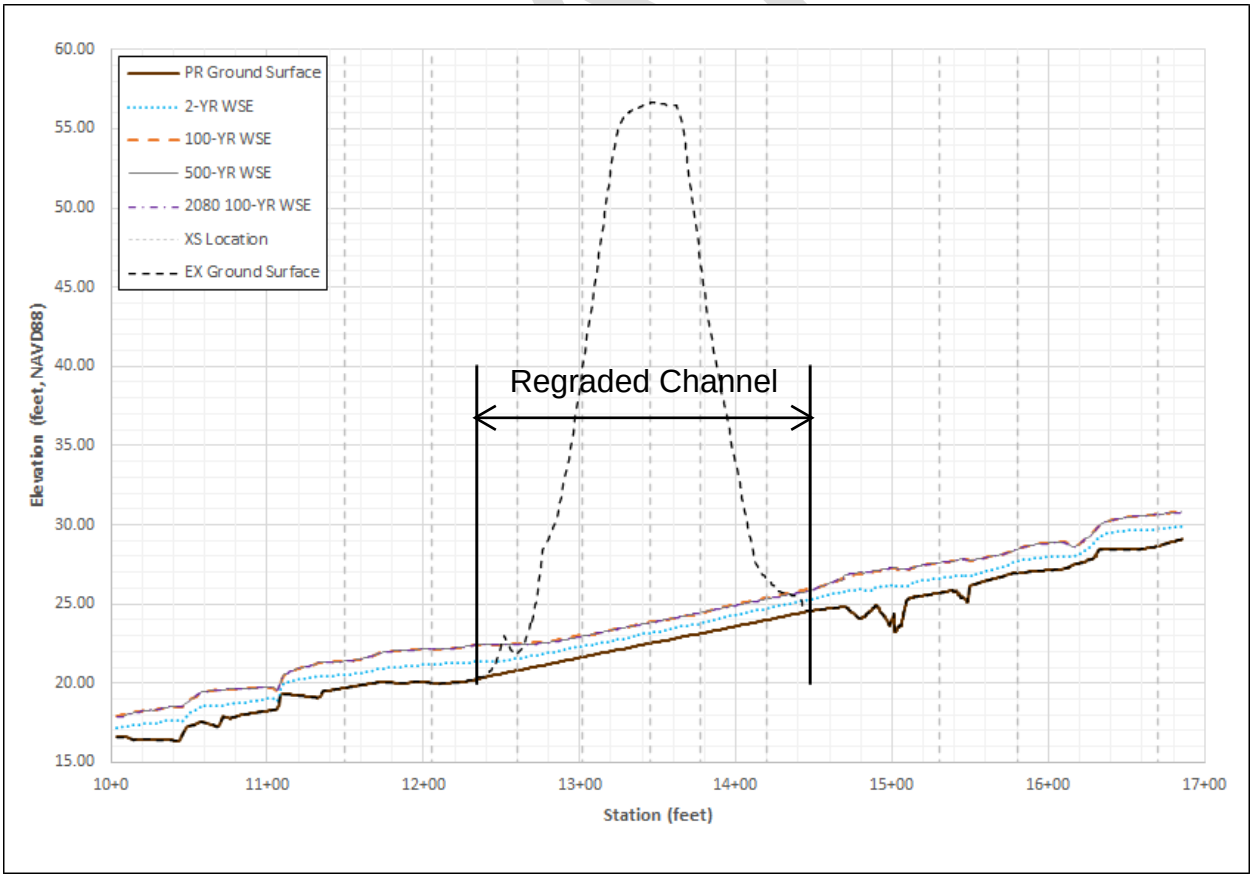


Figure 3. Existing Condition EX 11+63 Downstream

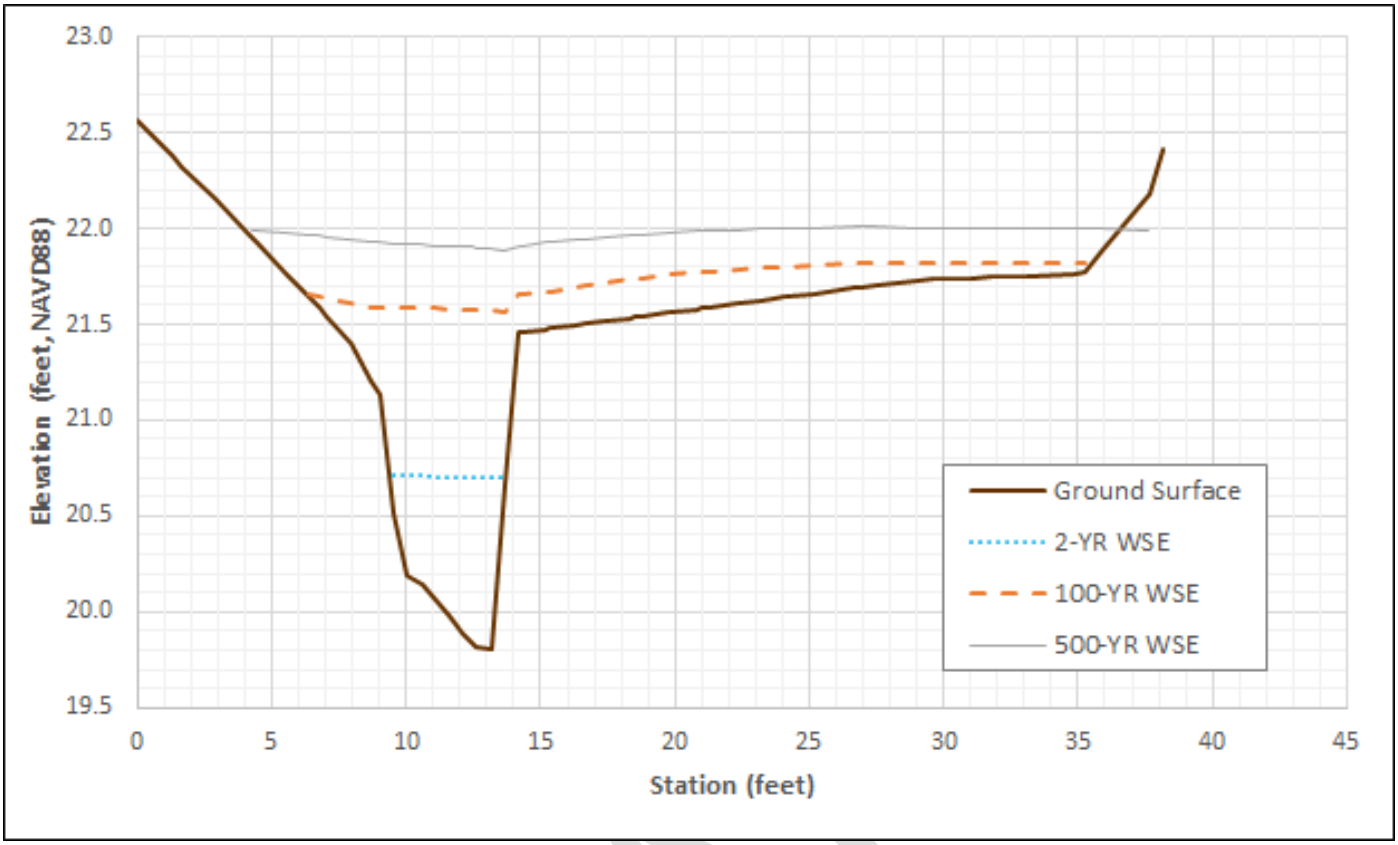


Figure 4. Existing Condition EX 12+60 Downstream

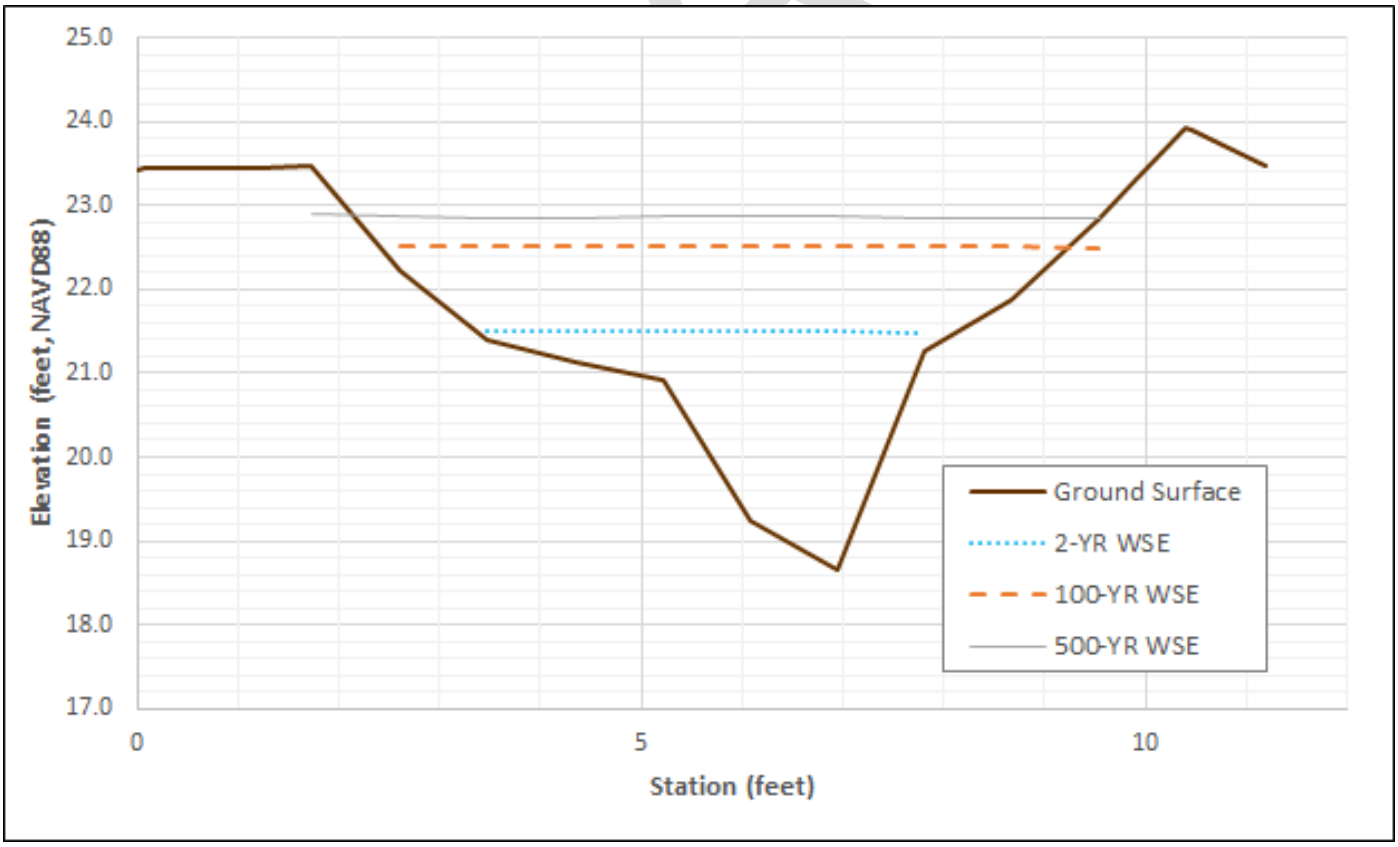


Figure 5. Existing Condition EX 14+20 Upstream

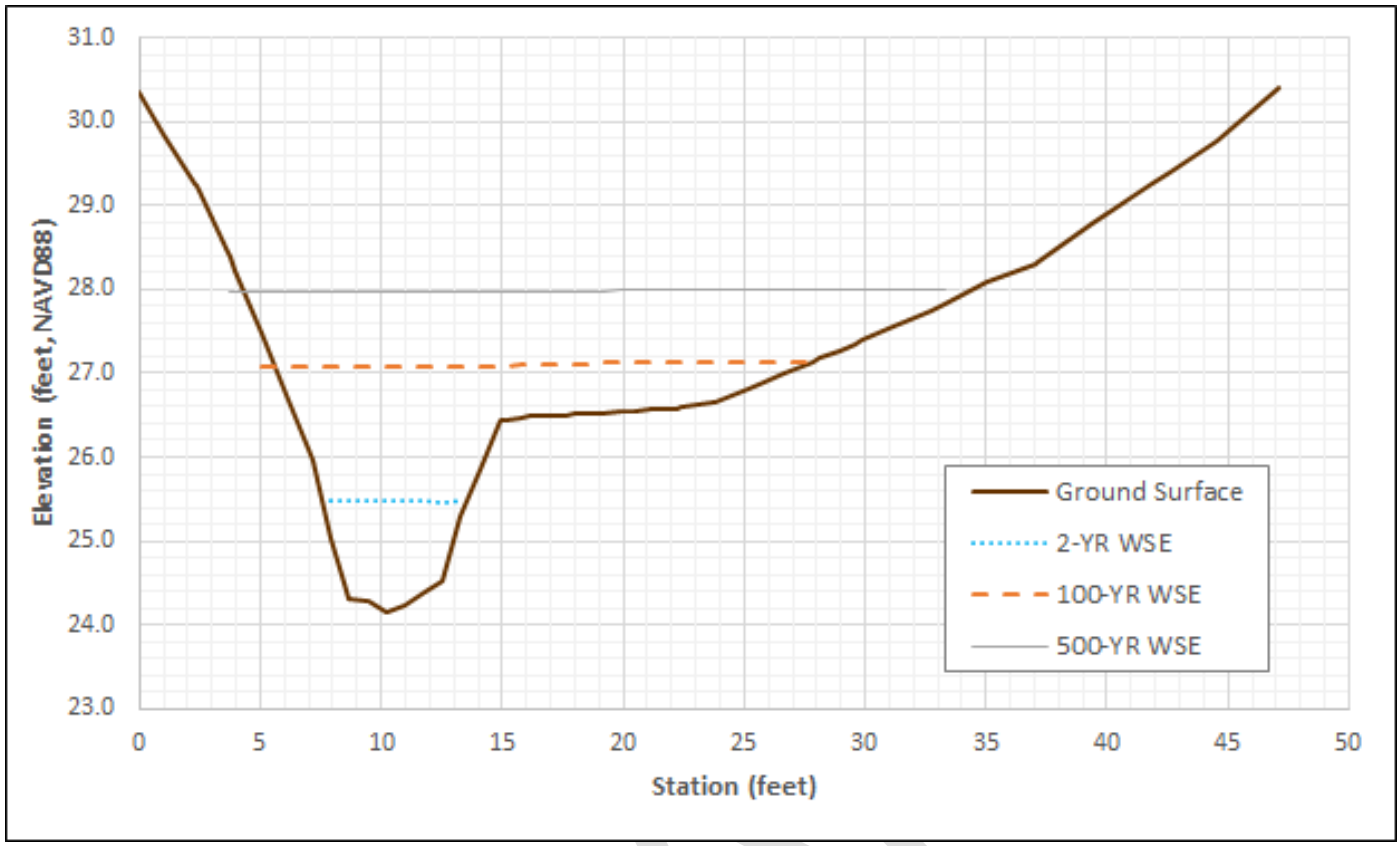


Figure 6. Existing Condition EX 15+30 Reference Reach

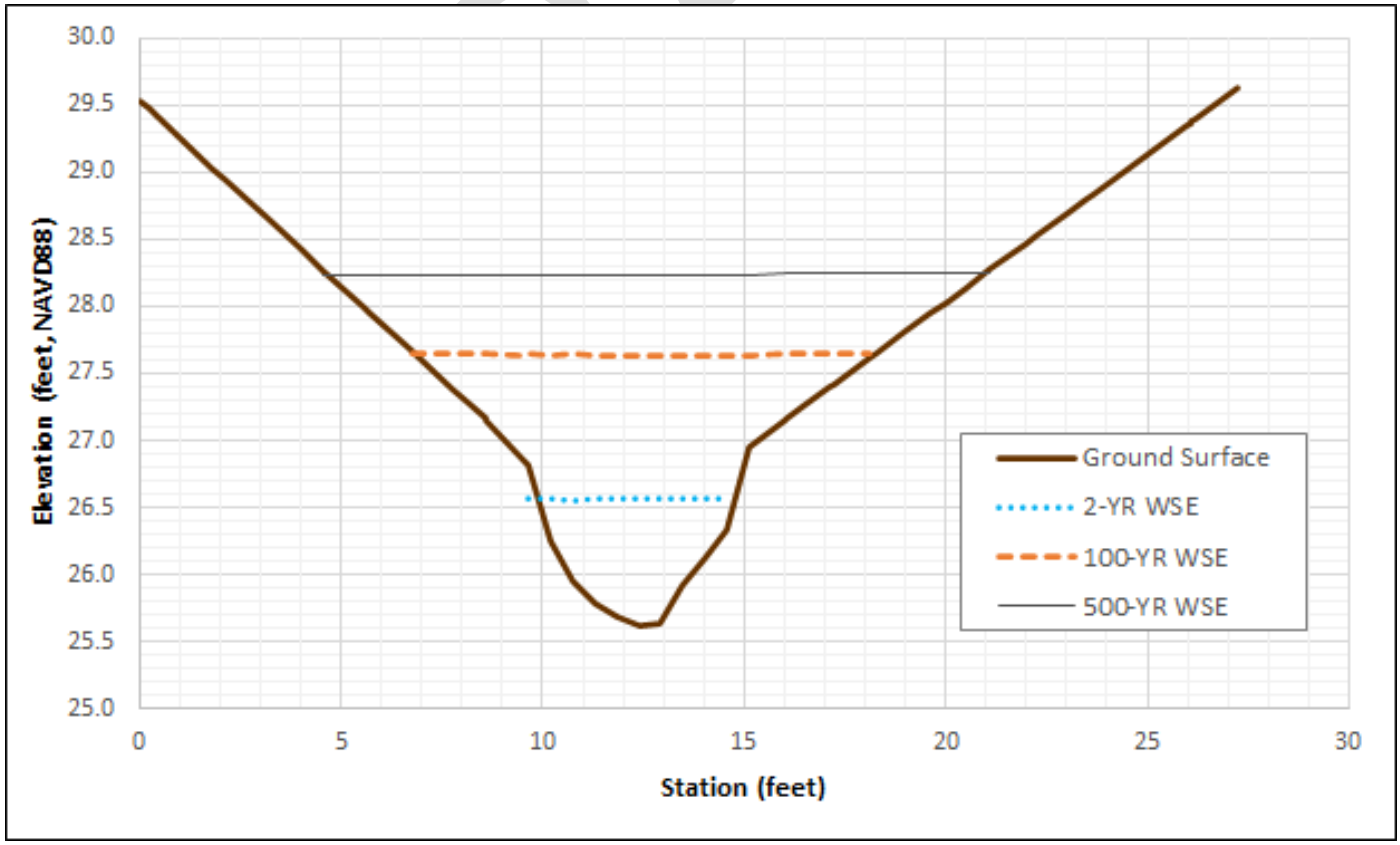


Figure 7. Existing Condition EX 15+80 Reference Reach

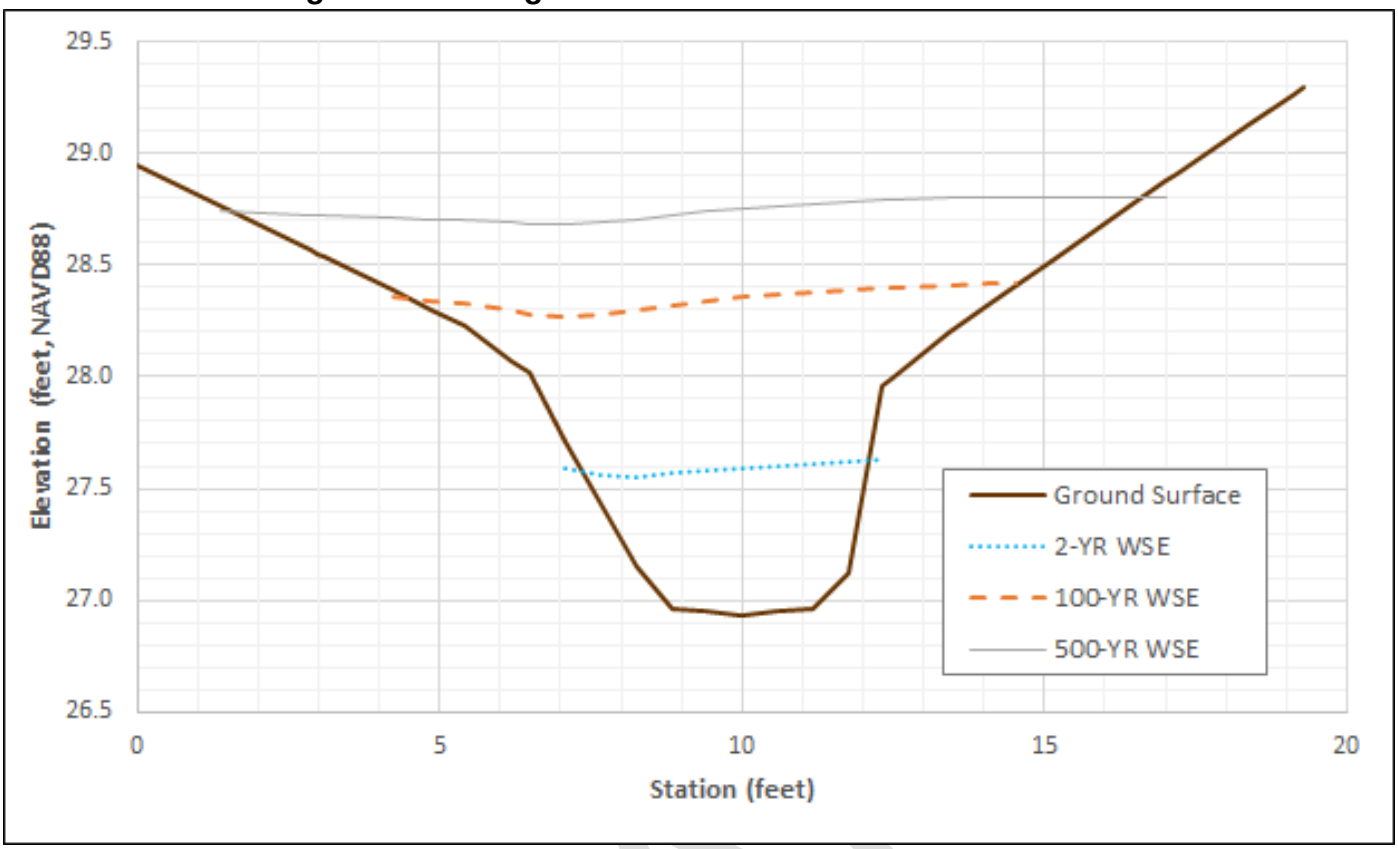


Figure 8. Existing Condition EX 16+60 Reference Reach

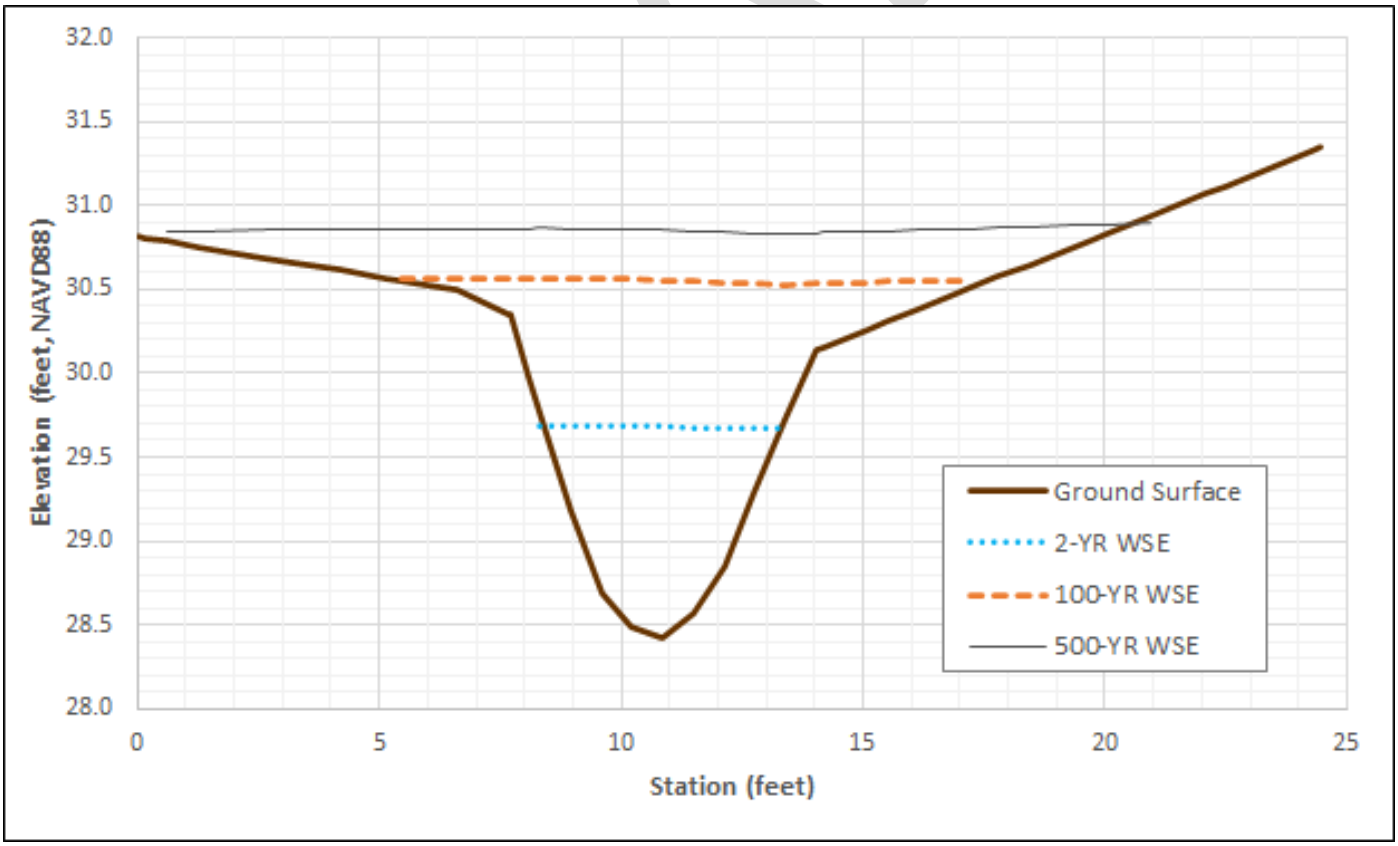


Figure 9. Proposed Conditions PR 11+50 Downstream

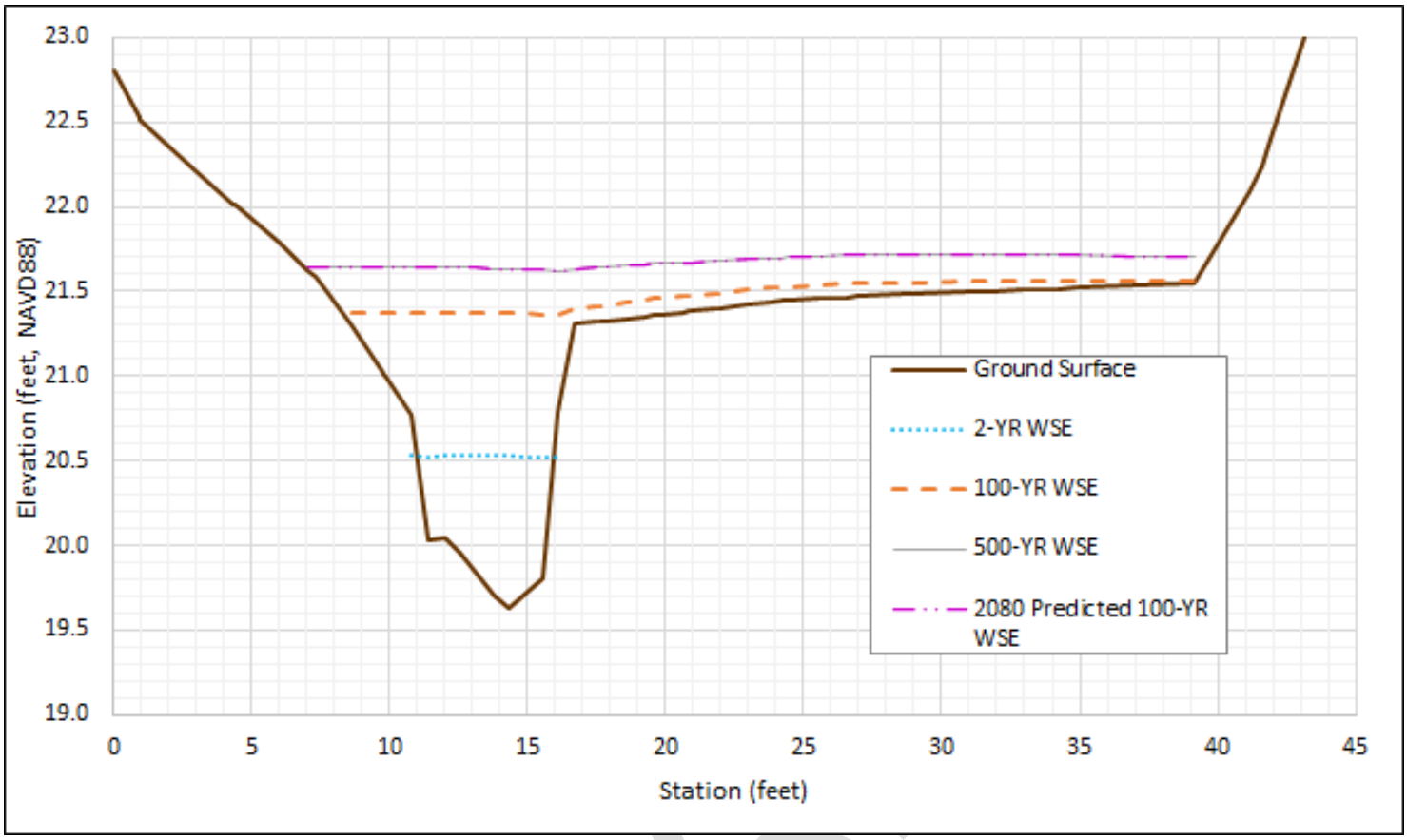


Figure 10. Proposed Conditions PR 12+05 Downstream

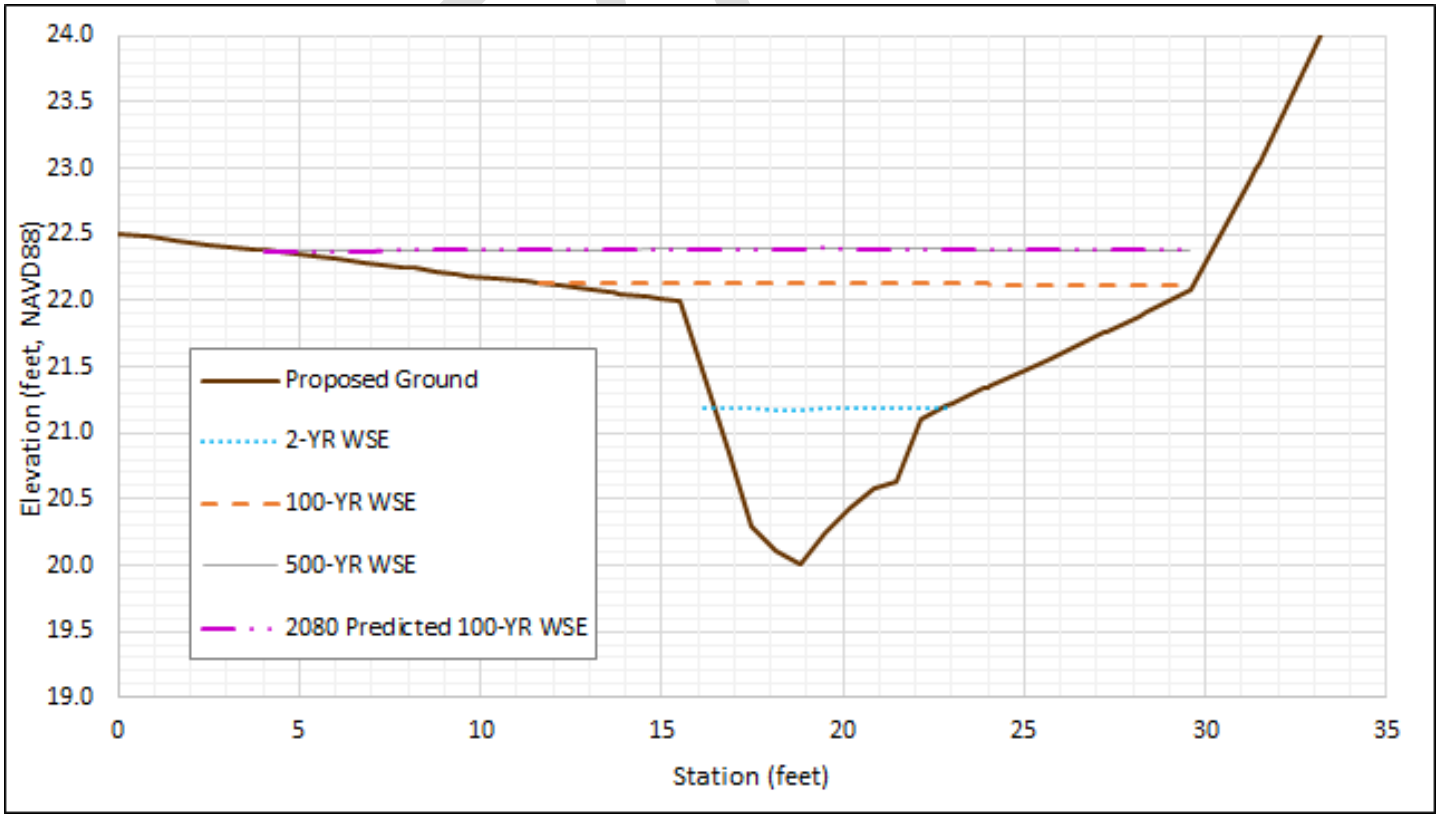


Figure 11. Proposed Conditions PR 12+60 Downstream

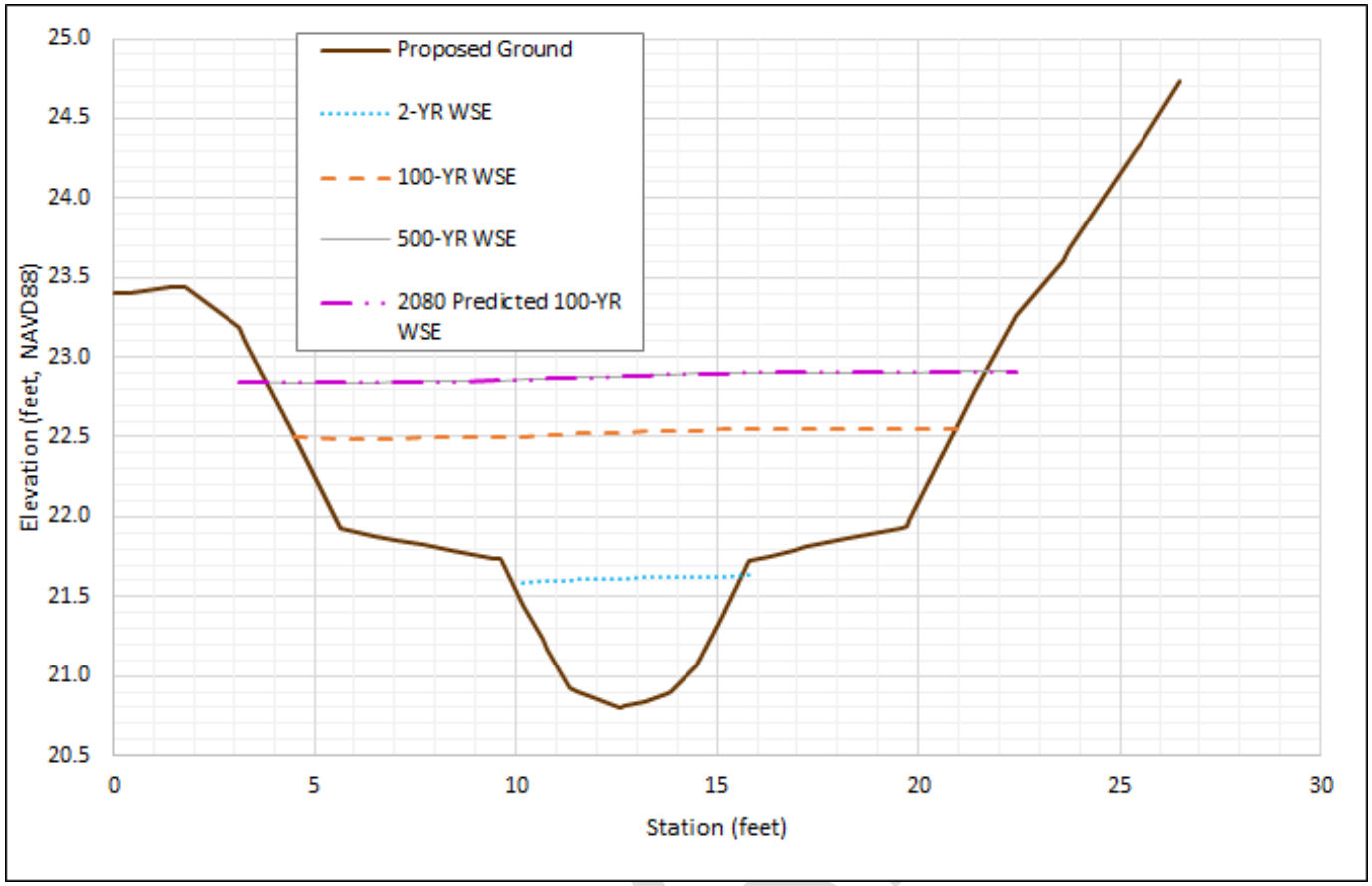


Figure 12. Proposed Conditions PR 13+02 Structure

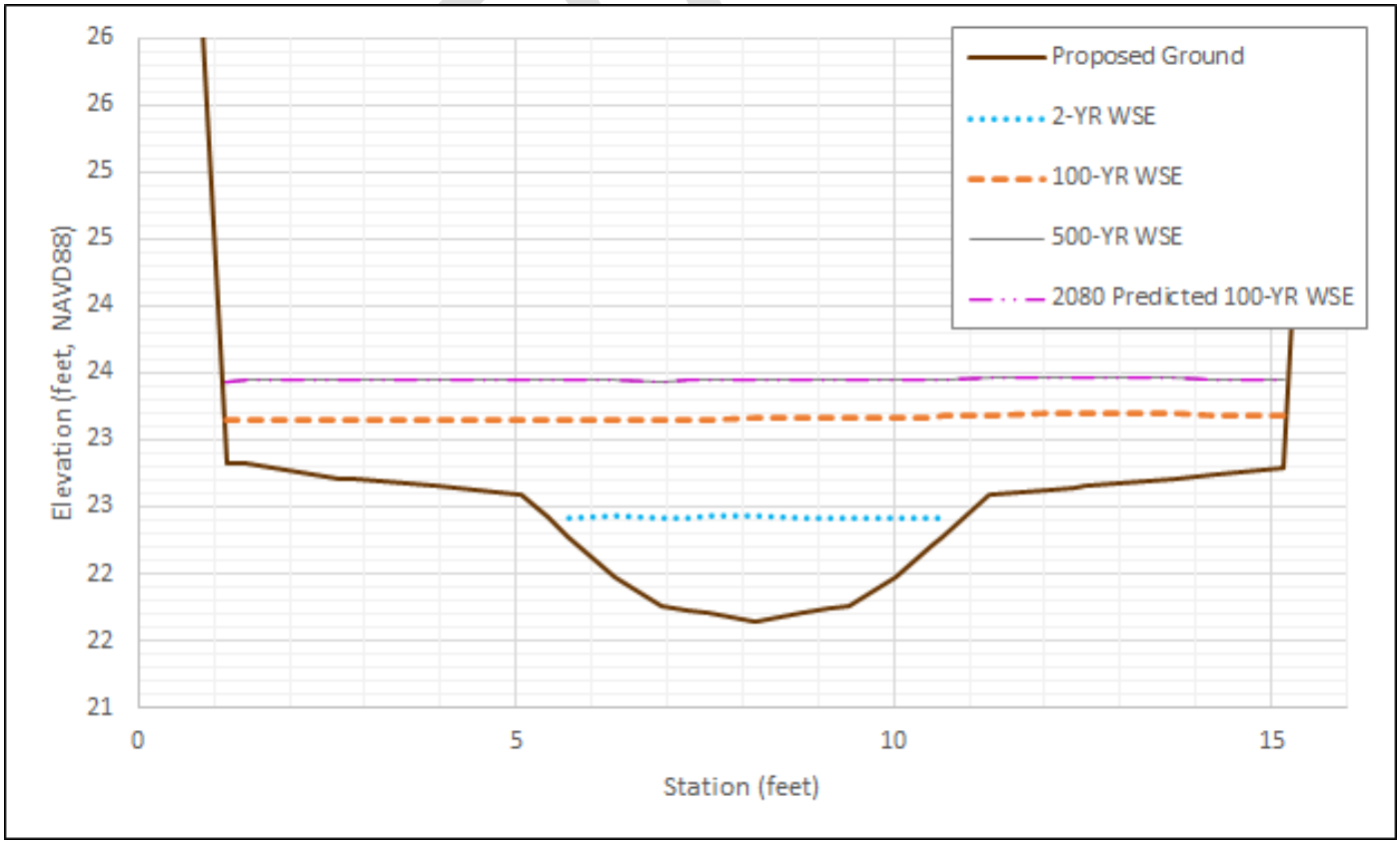


Figure 13. Proposed Conditions PR 13+45 Structure

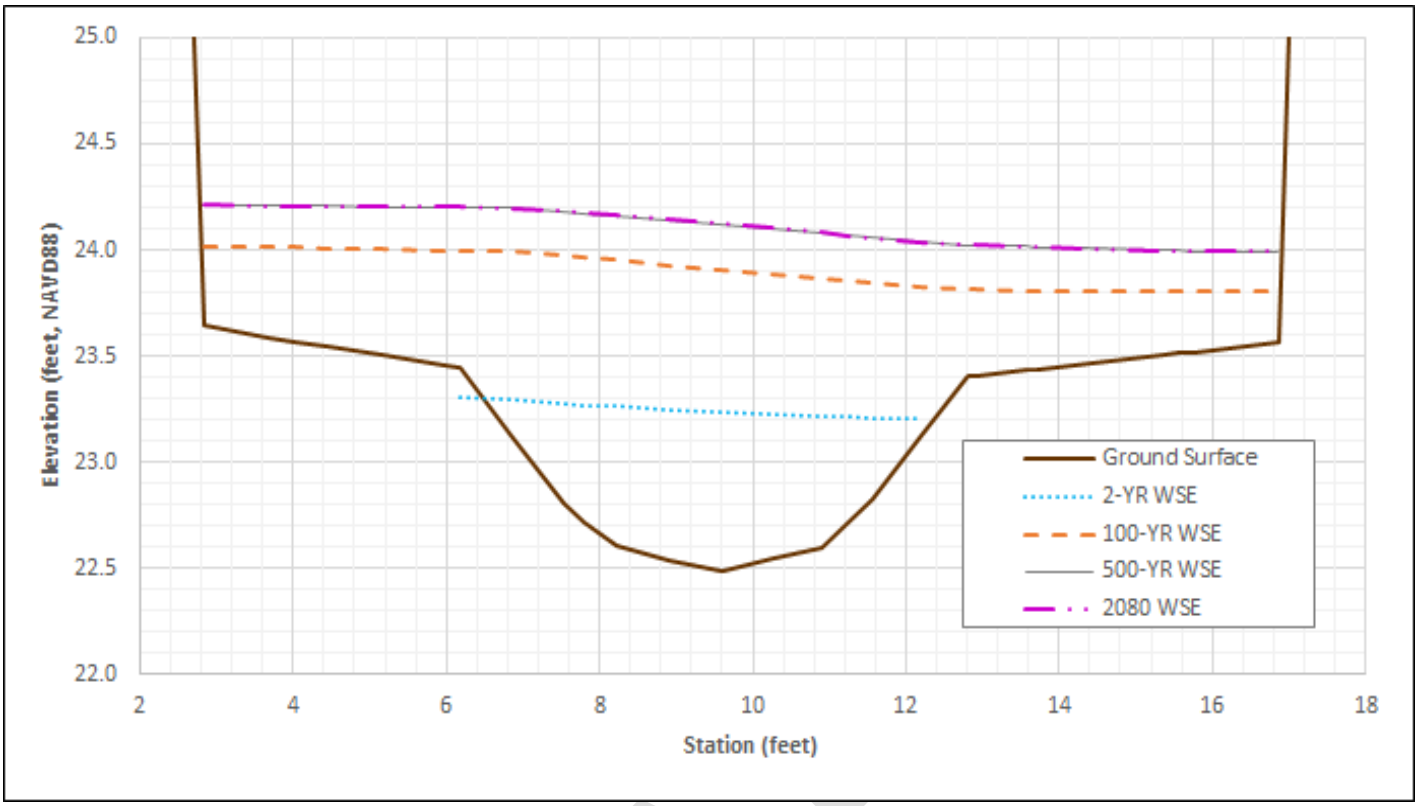


Figure 14. Proposed Conditions PR 13+77 Structure

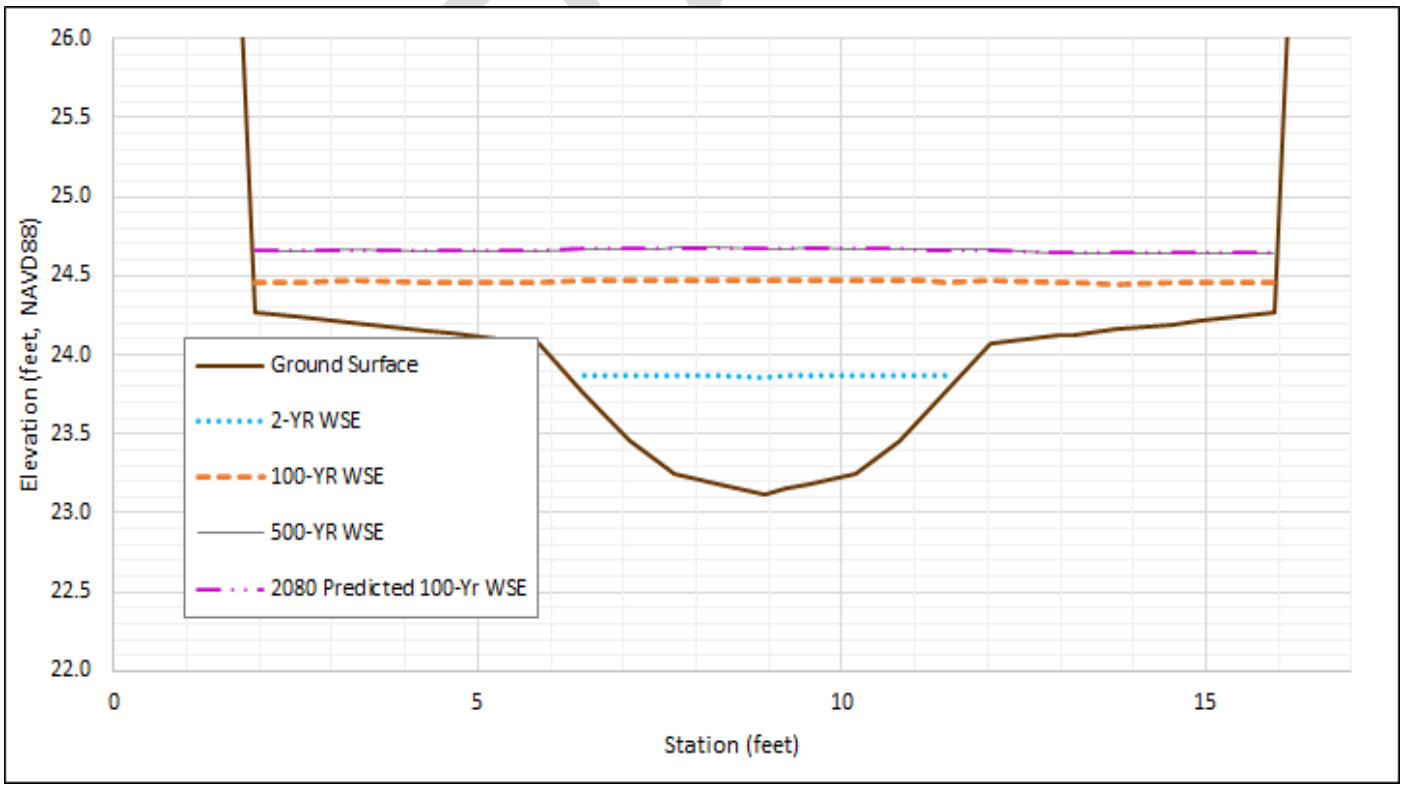


Figure 15. Proposed Conditions PR 14+20 Upstream

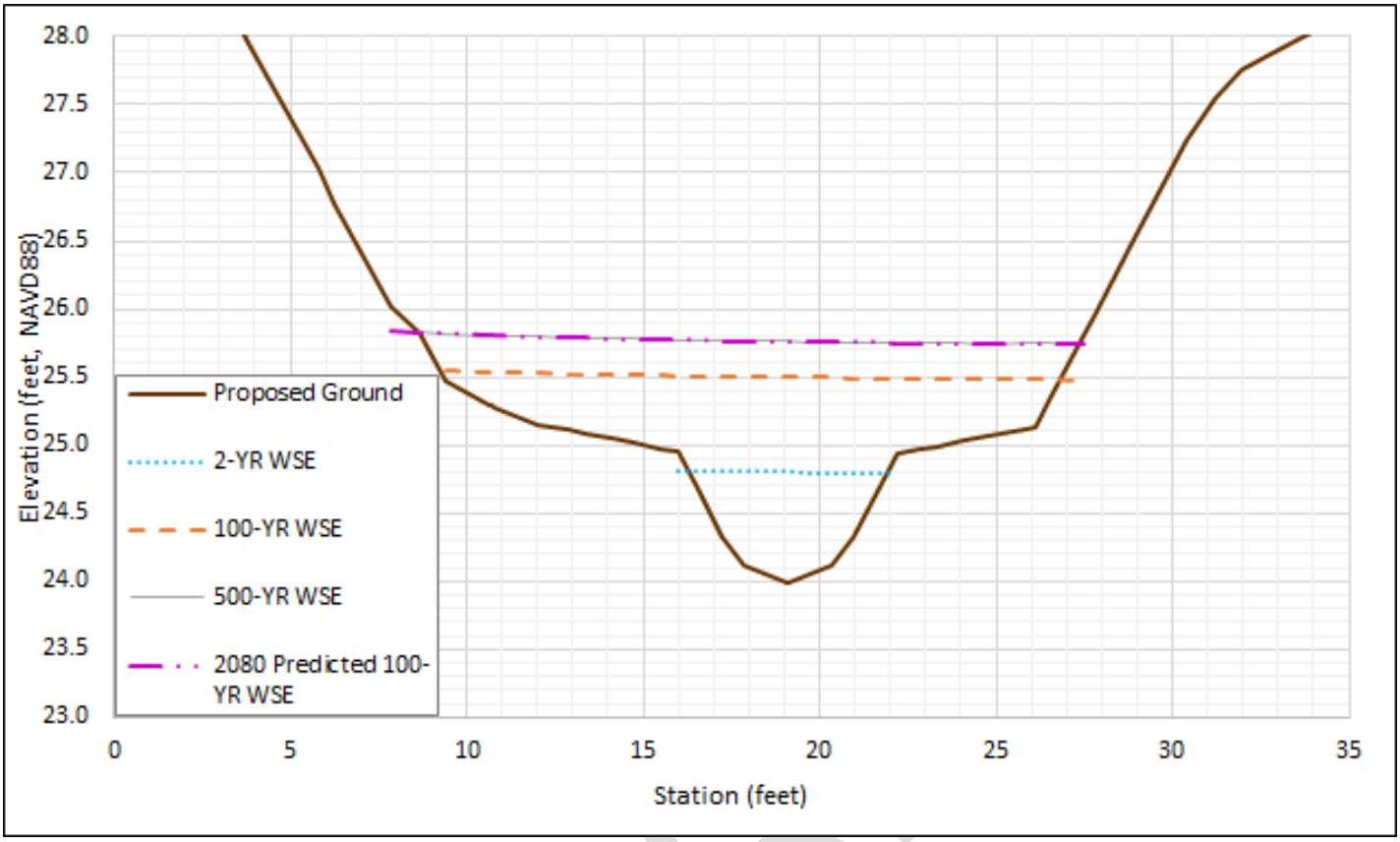


Figure 16. Proposed Conditions PR 15+26 Reference Reach

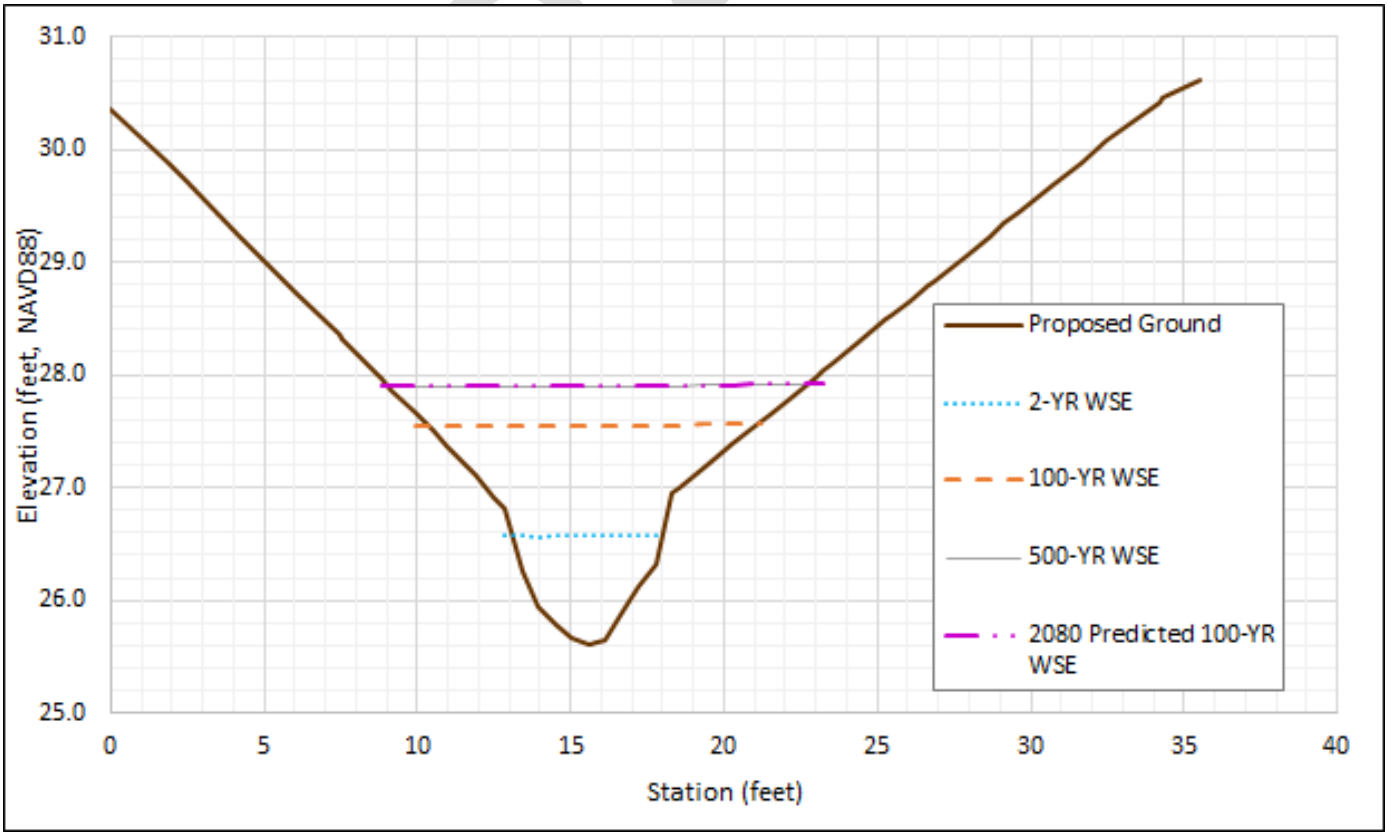


Figure 17. Proposed Conditions PR 15+77 Reference Reach

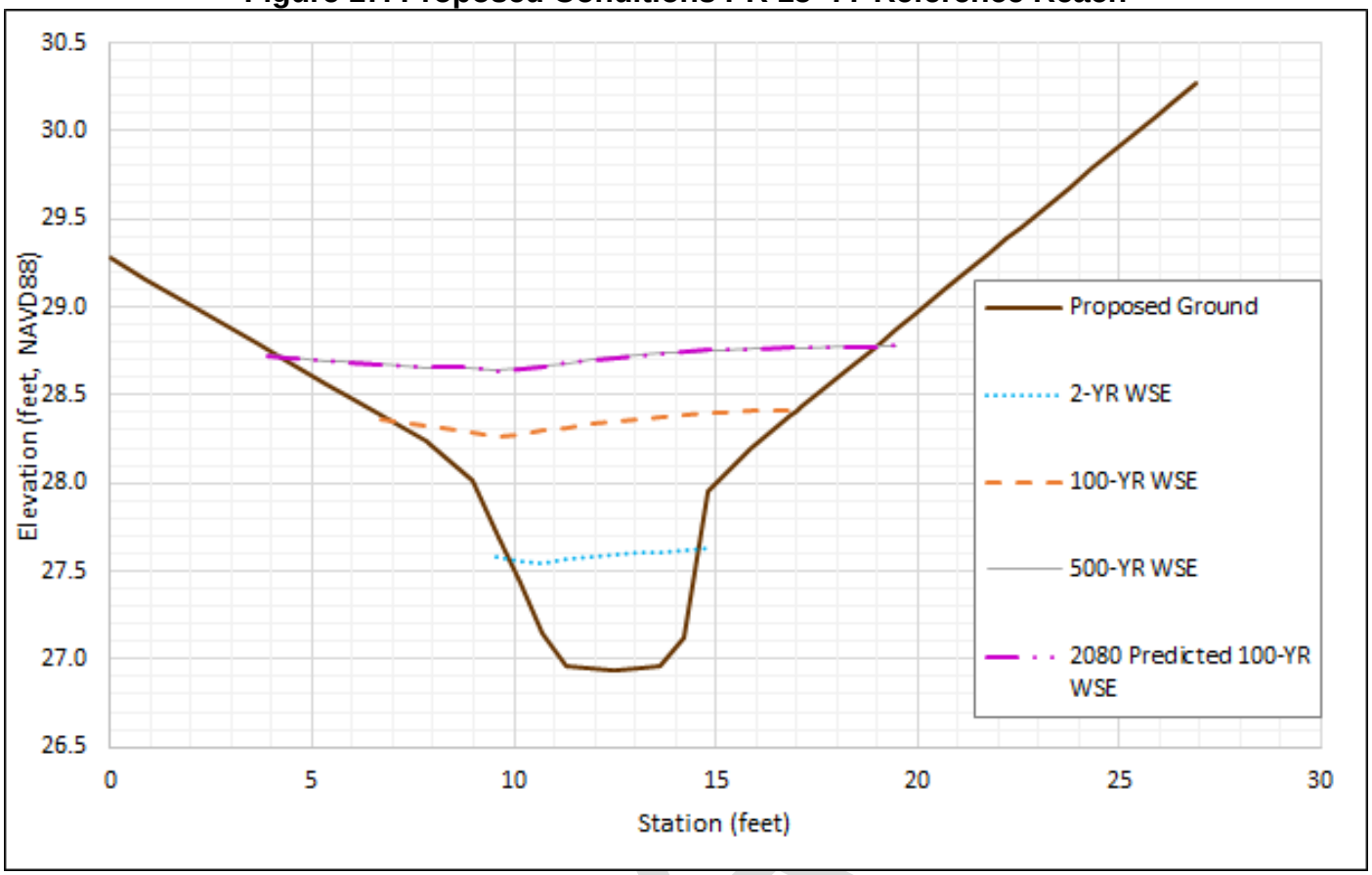
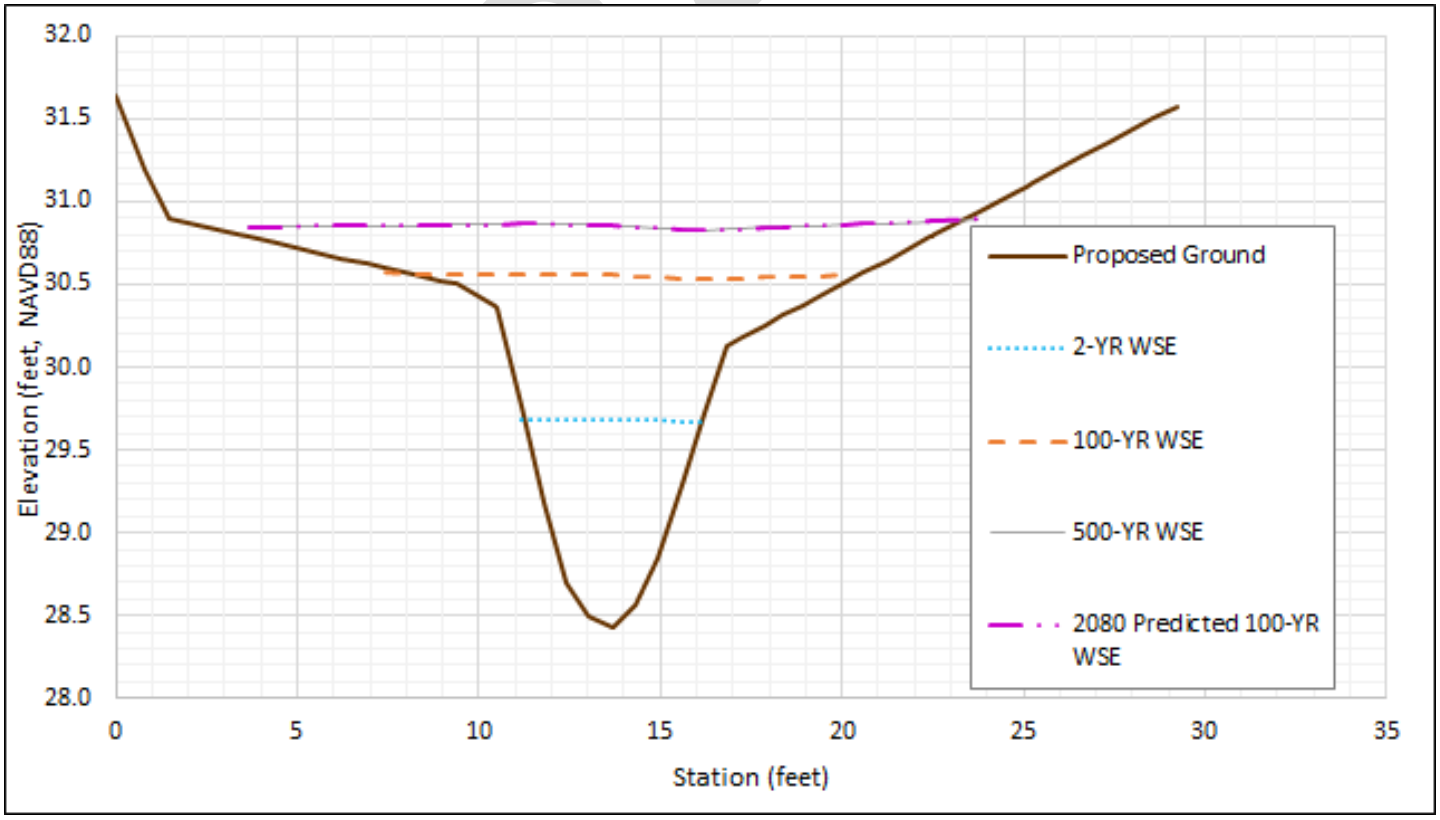
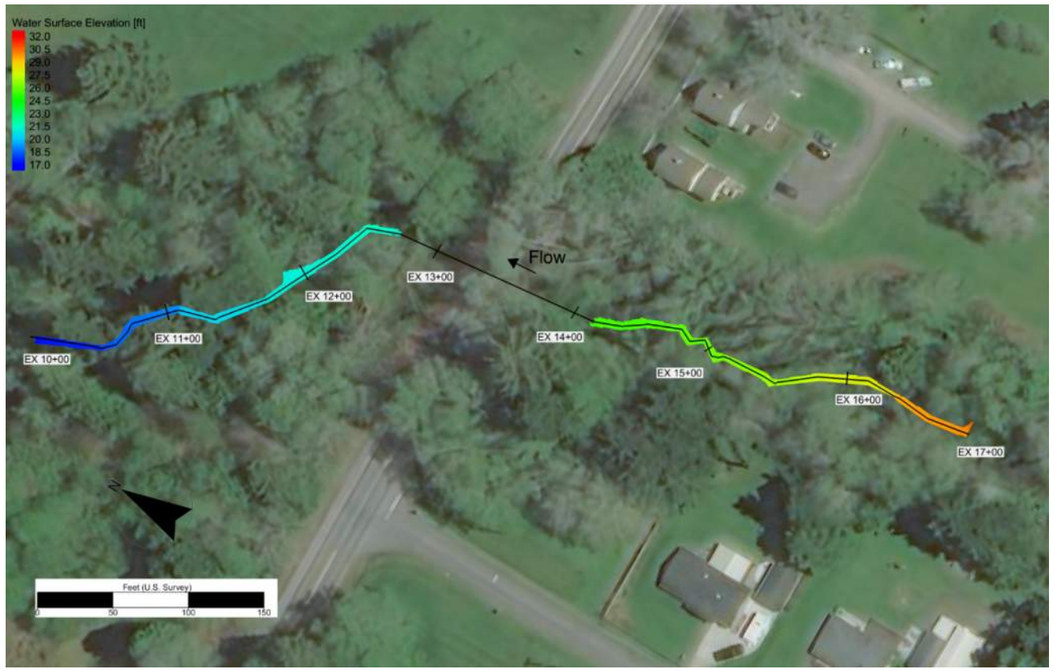
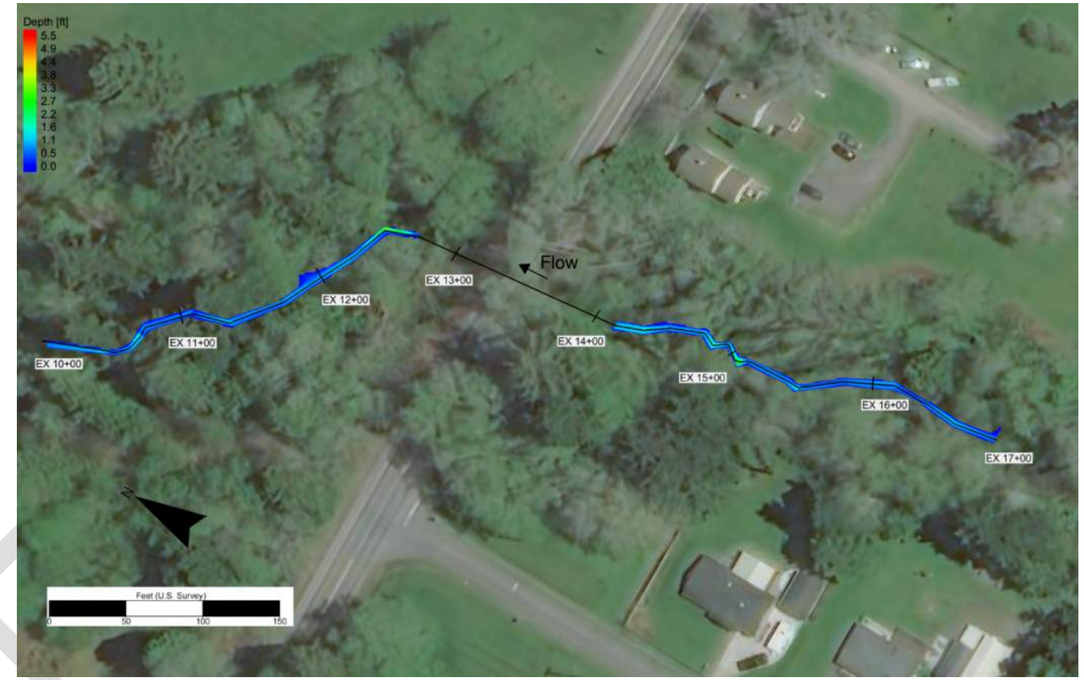


Figure 18. Proposed Conditions PR 16+58 Reference Reach

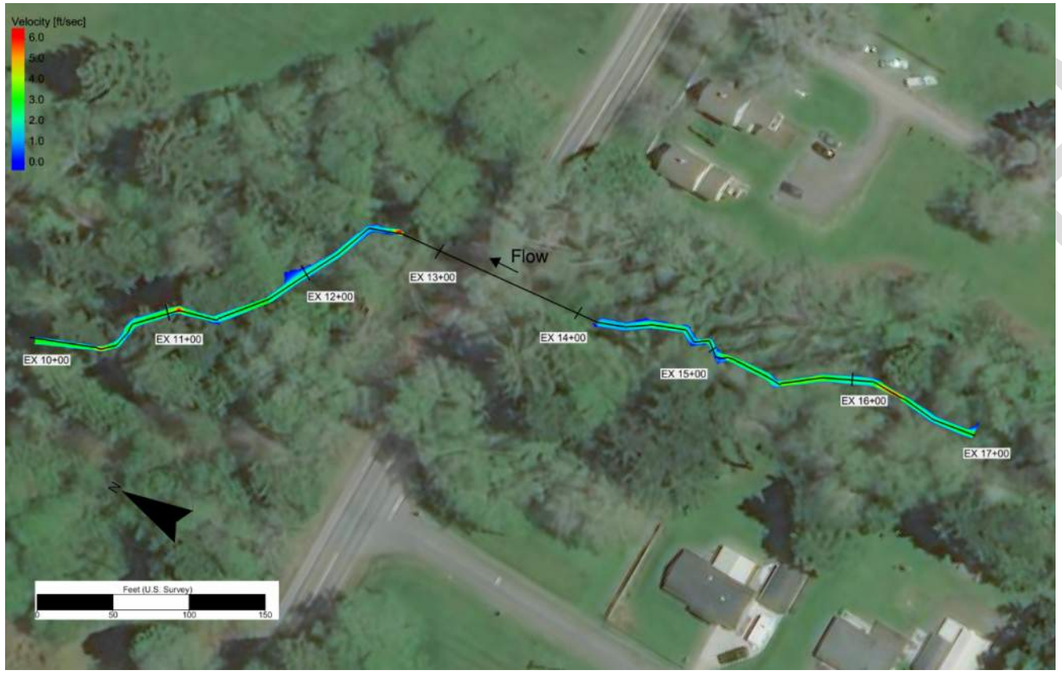




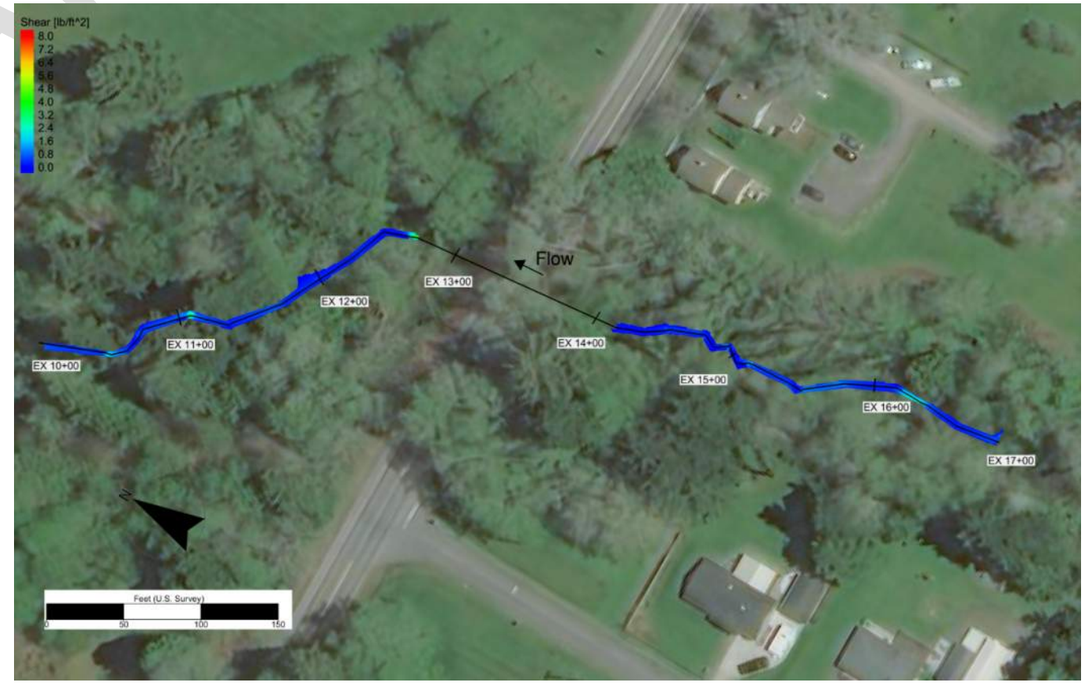
WATER SURFACE ELEVATION



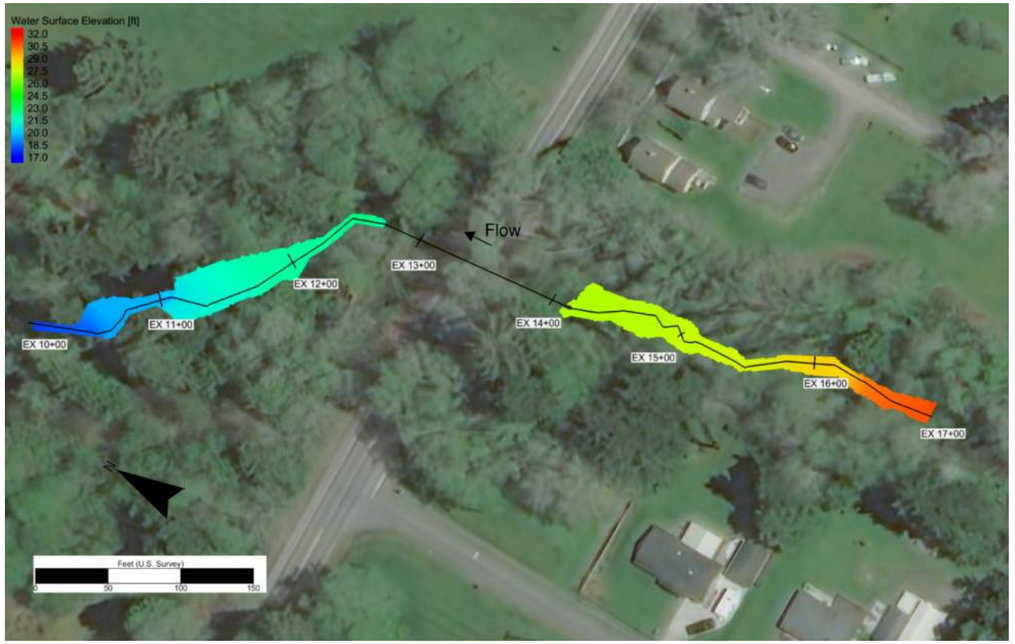
DEPTH



VELOCITY



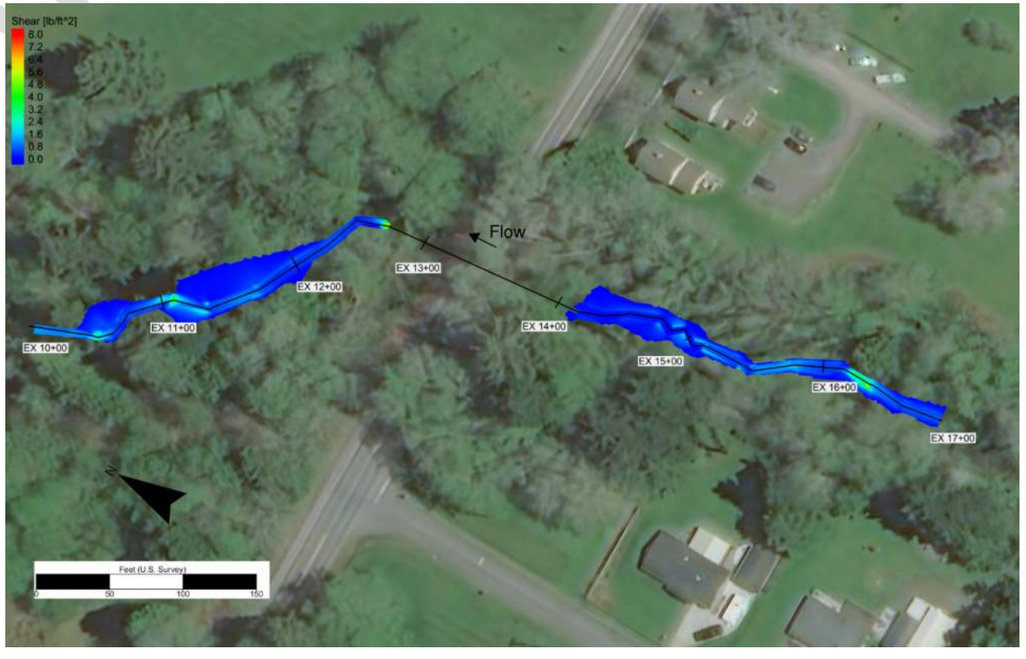
SHEAR



WATER SURFACE ELEVATION

DEPTH

VELOCITY



SHEAR

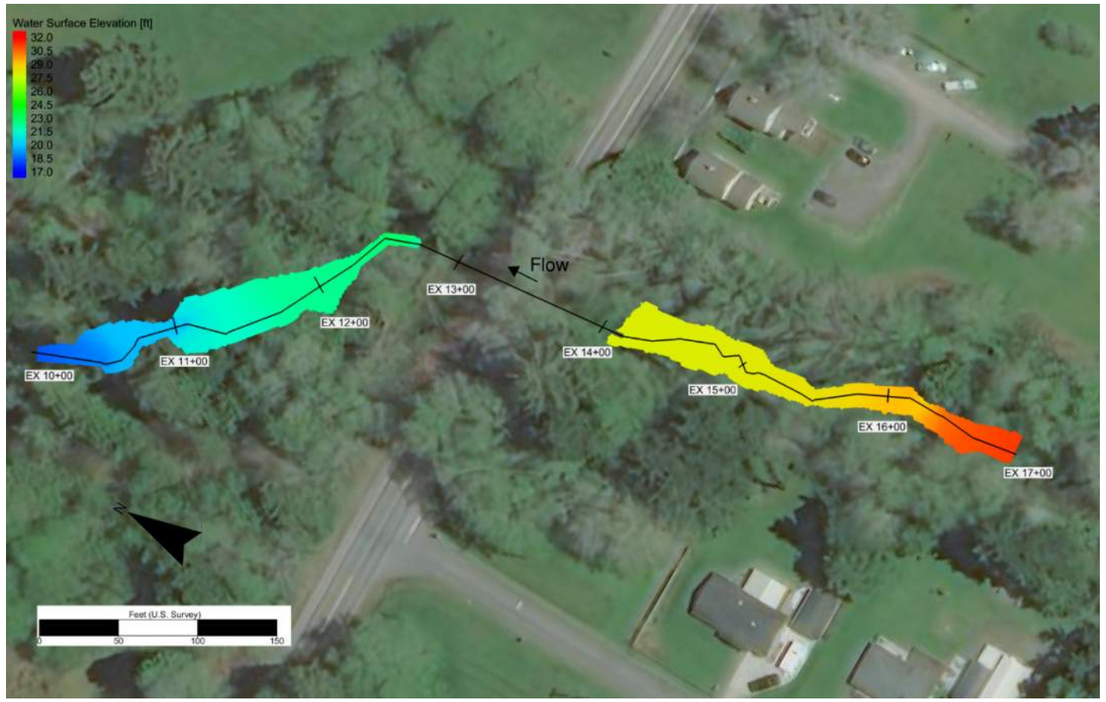
DRAFT

WSDOT OLYMPIC REGION GEC

EXISTING CONDITION 100-YEAR EVENT

SR 104 MP 16.55 Machias Creek to Hood Canal WDFW: 990710

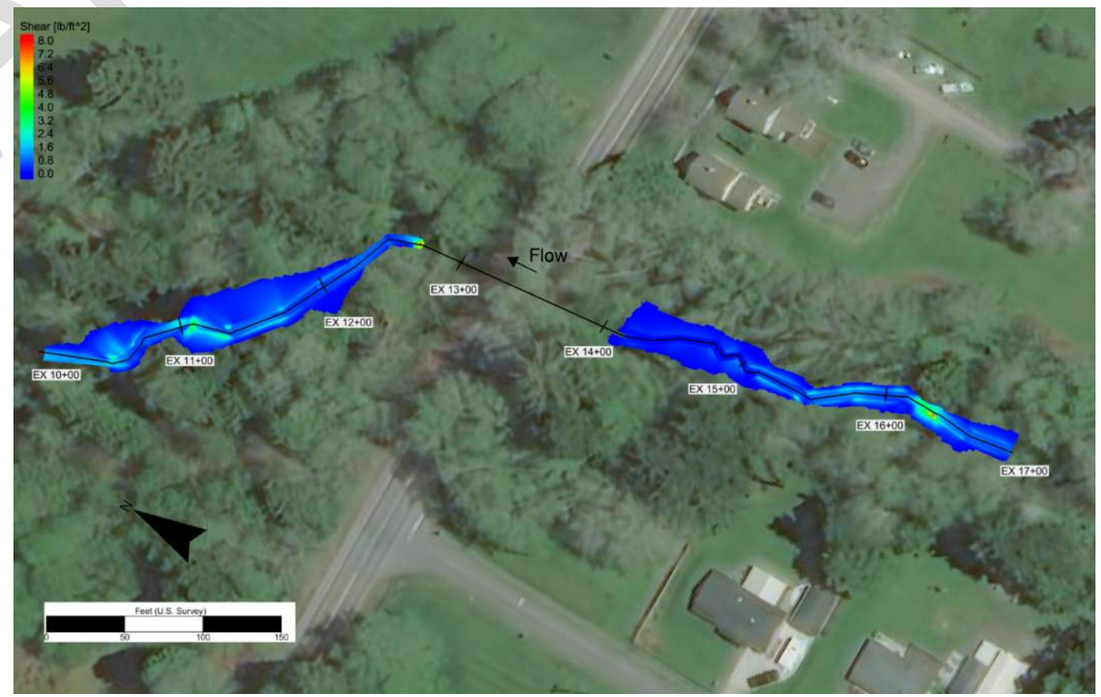
PRELIMINARY HYDRAULIC DESIGN



WATER SURFACE ELEVATION

DEPTH

VELOCITY



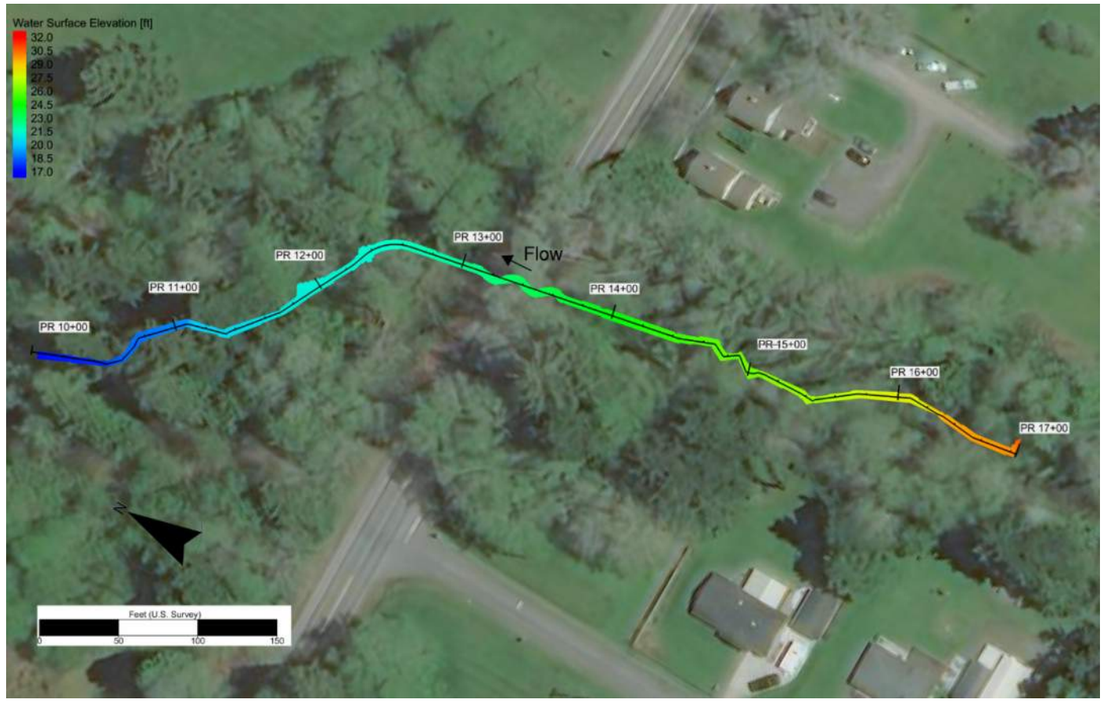
SHEAR

WSDOT OLYMPIC REGION GEC

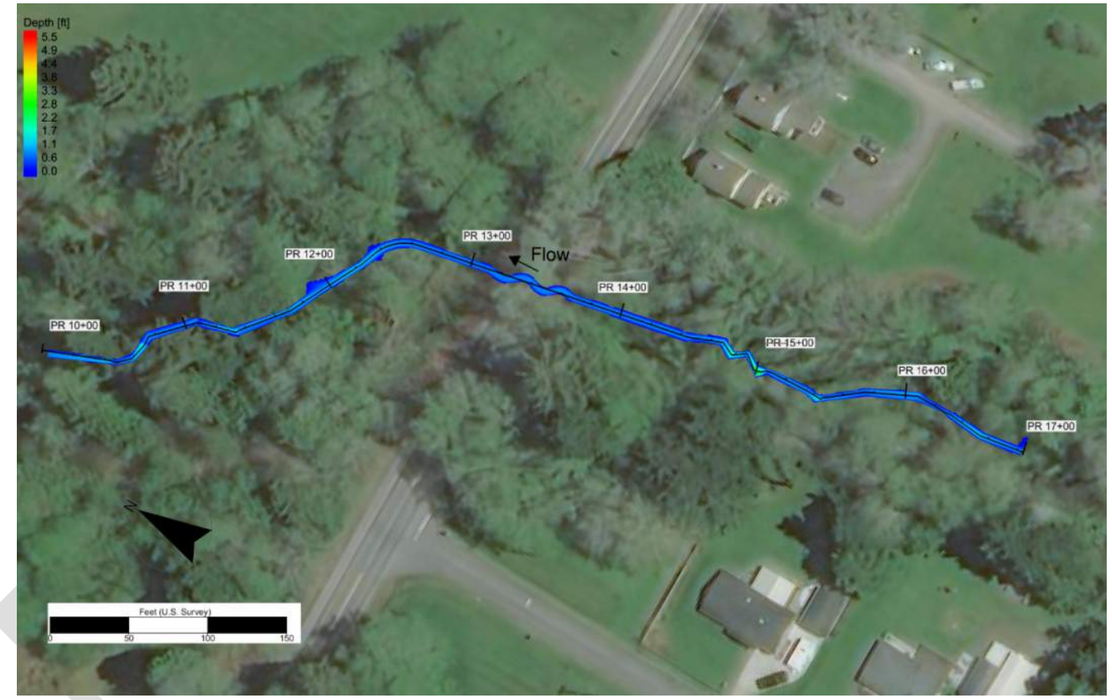
EXISTING CONDITION 500-YEAR EVENT

SR 104 MP 16.55 Machias Creek to Hood Canal WDFW: 990710

PRELIMINARY HYDRAULIC DESIGN



WATER SURFACE ELEVATION



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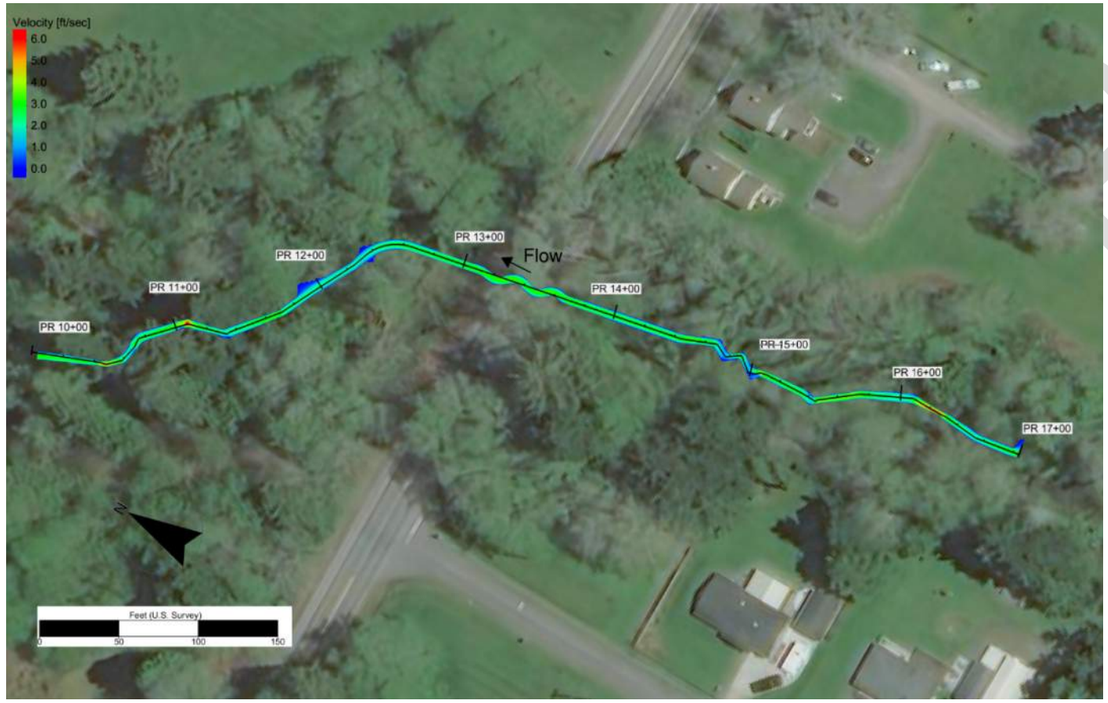

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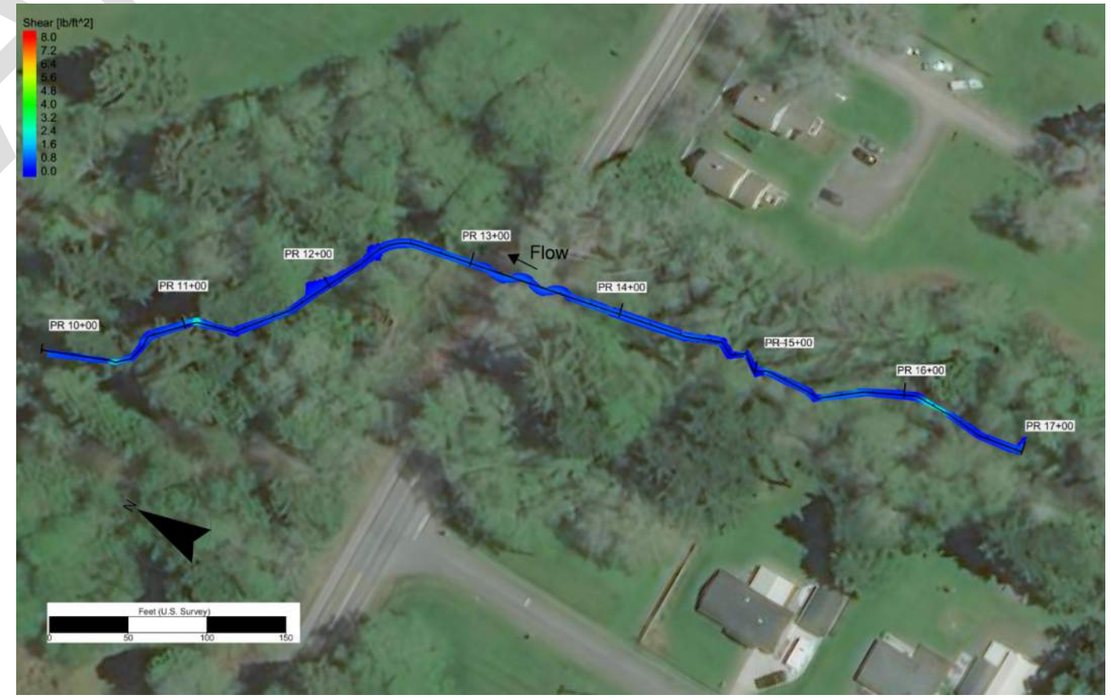


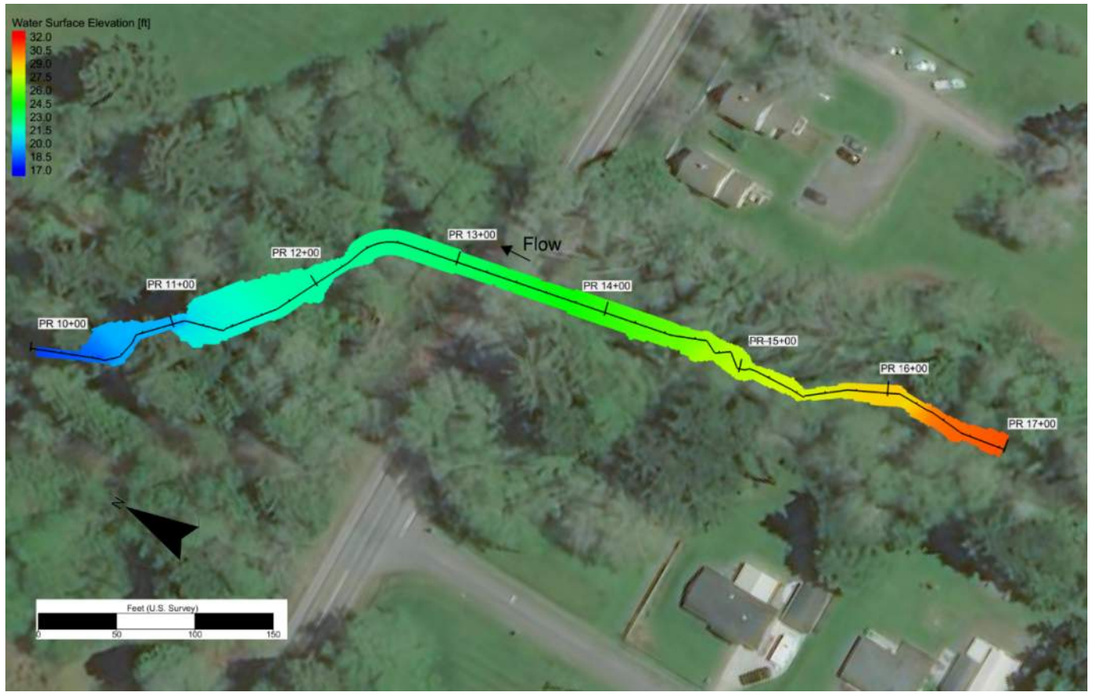
SHEAR

WSDOT OLYMPIC REGION GEC

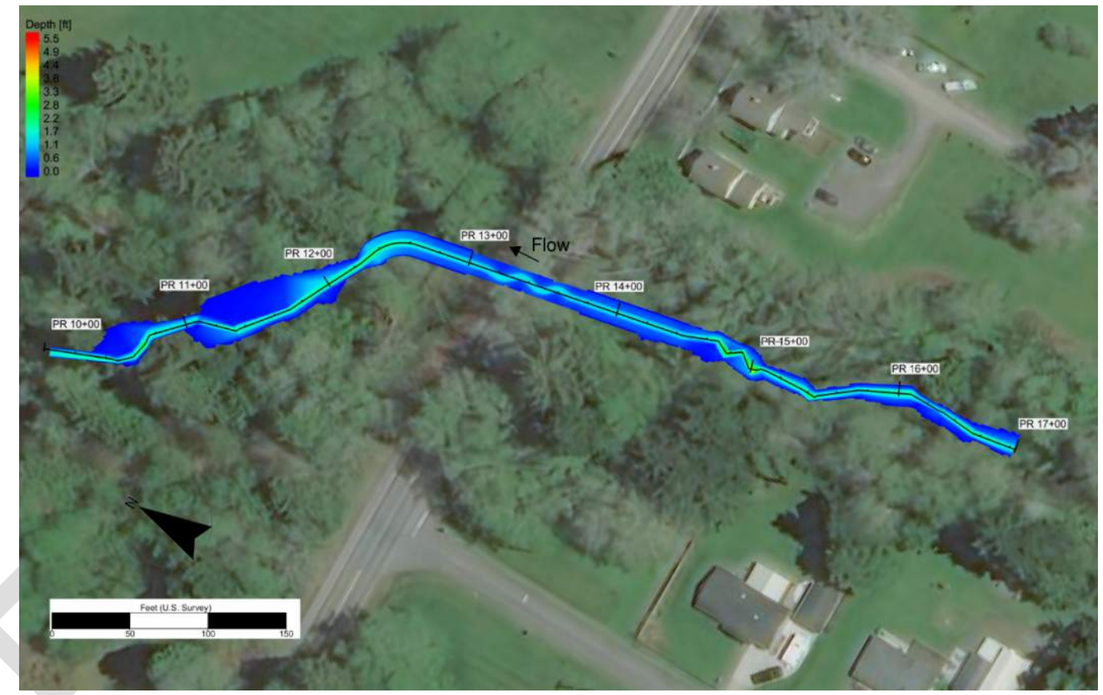
PROPOSED CONDITION 2-YEAR EVENT

SR 104 MP 16.55 Machias Creek to Hood Canal WDFW: 990710

PRELIMINARY HYDRAULIC DESIGN



WATER SURFACE ELEVATION



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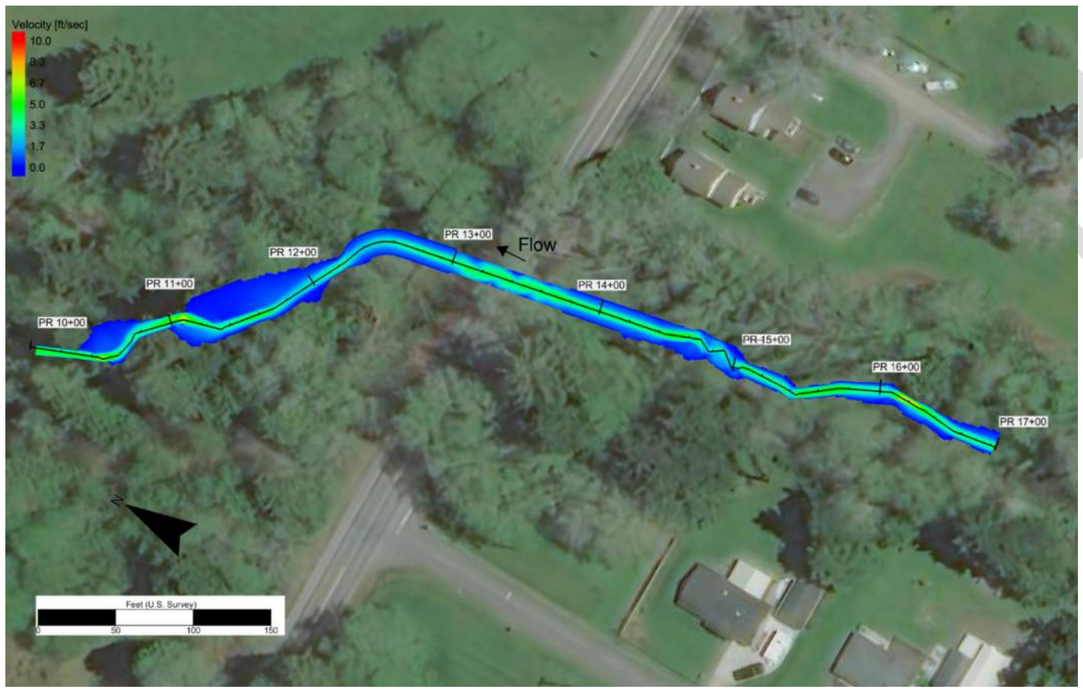

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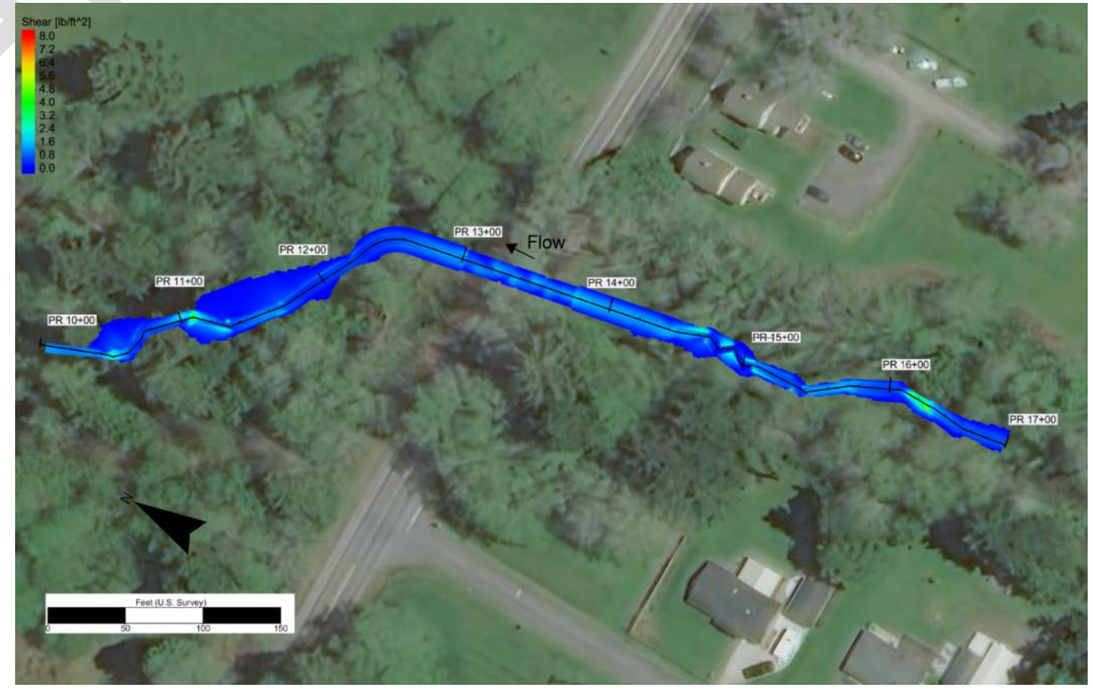

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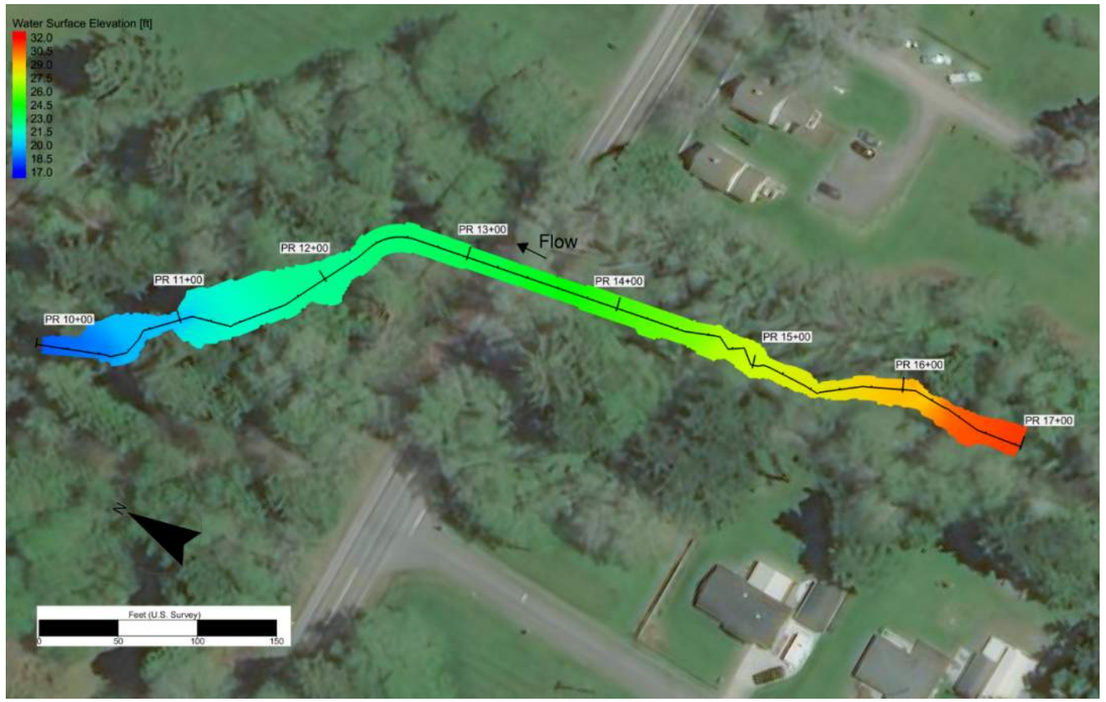
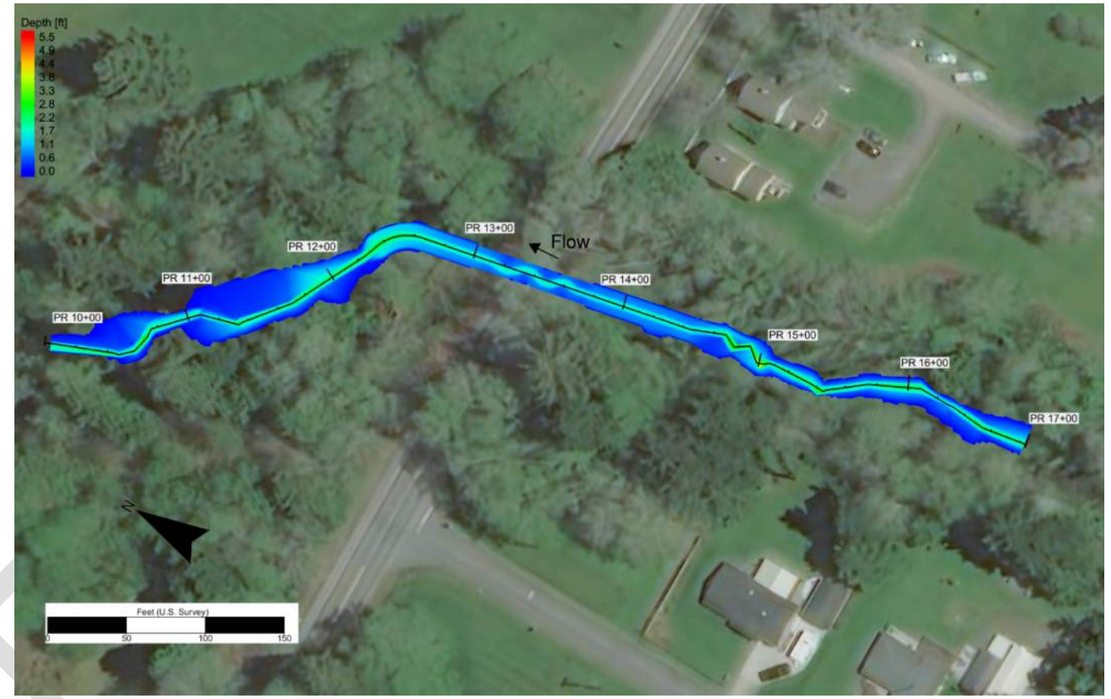


WATER SURFACE ELEVATION



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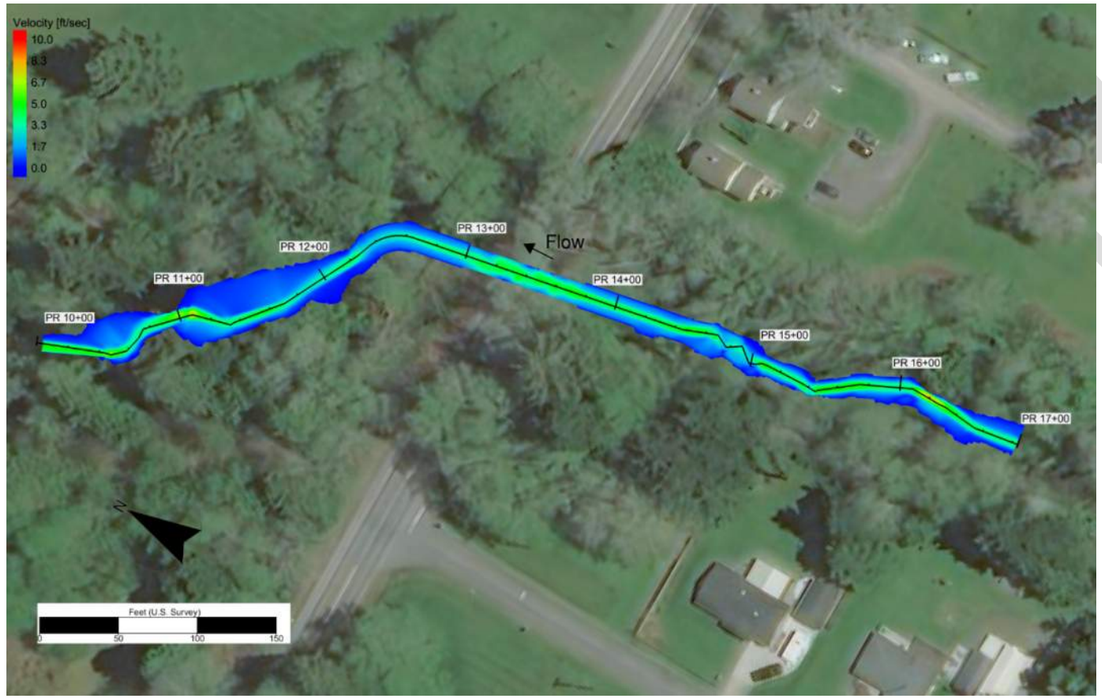

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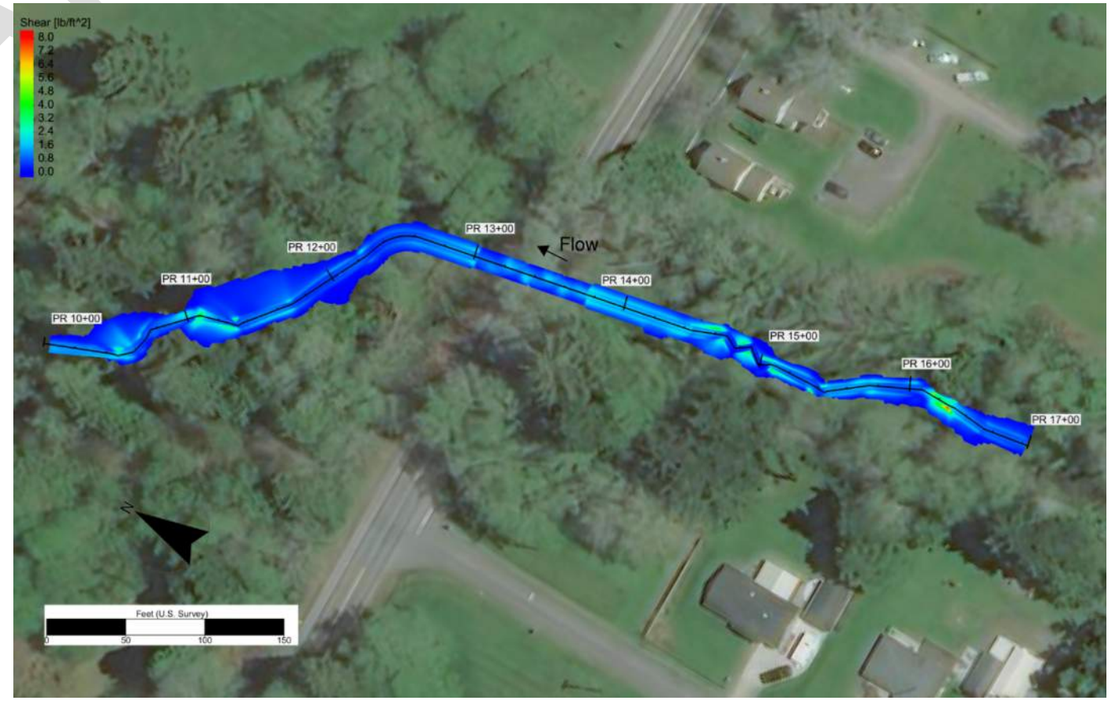


SHEAR

WSDOT OLYMPIC REGION GEC

PROPOSED CONDITION 2080 100-YEAR and 500-YEAR EVENT

SR 104 MP 16.55 Machias Creek to Hood Canal WDFW: 990710

PRELIMINARY HYDRAULIC DESIGN

Appendix I: SRH-2D Model Stability and Continuity

Figure 1. Existing Condition Monitor Location

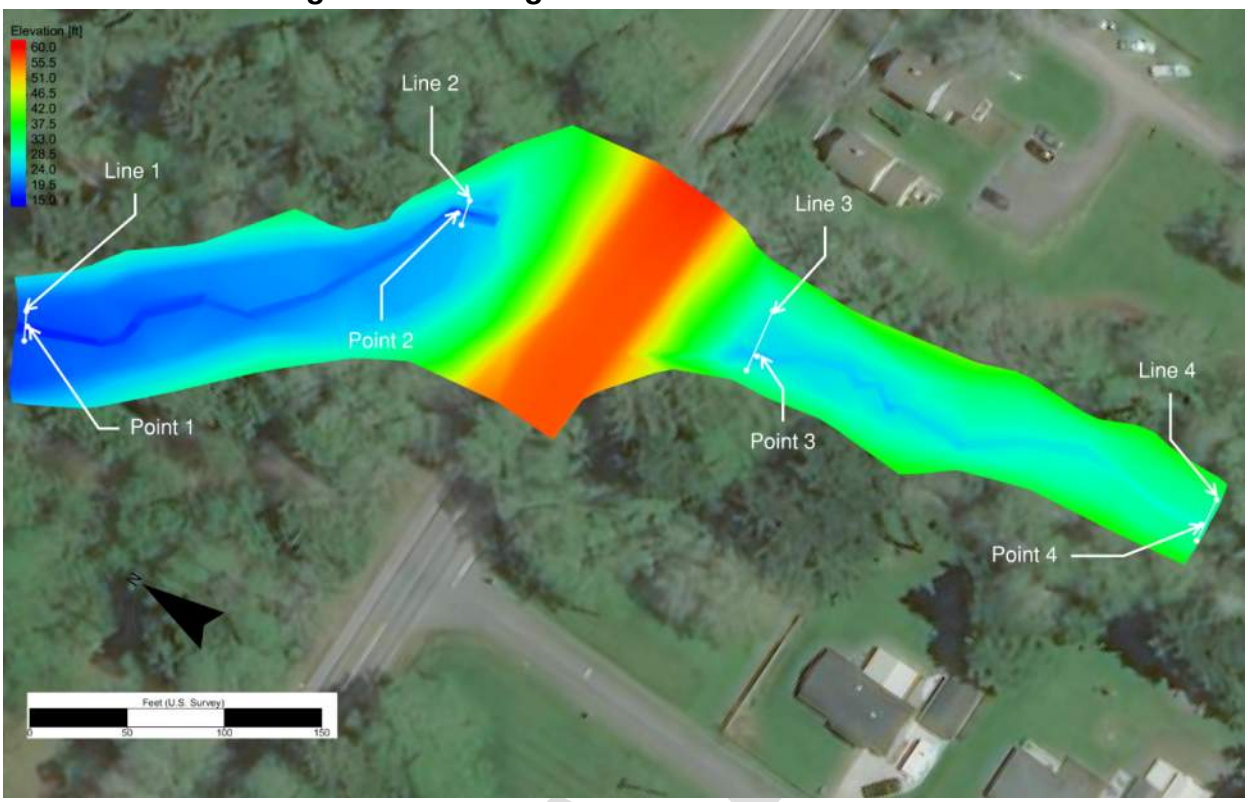


Figure 2. Proposed Condition Monitor Location

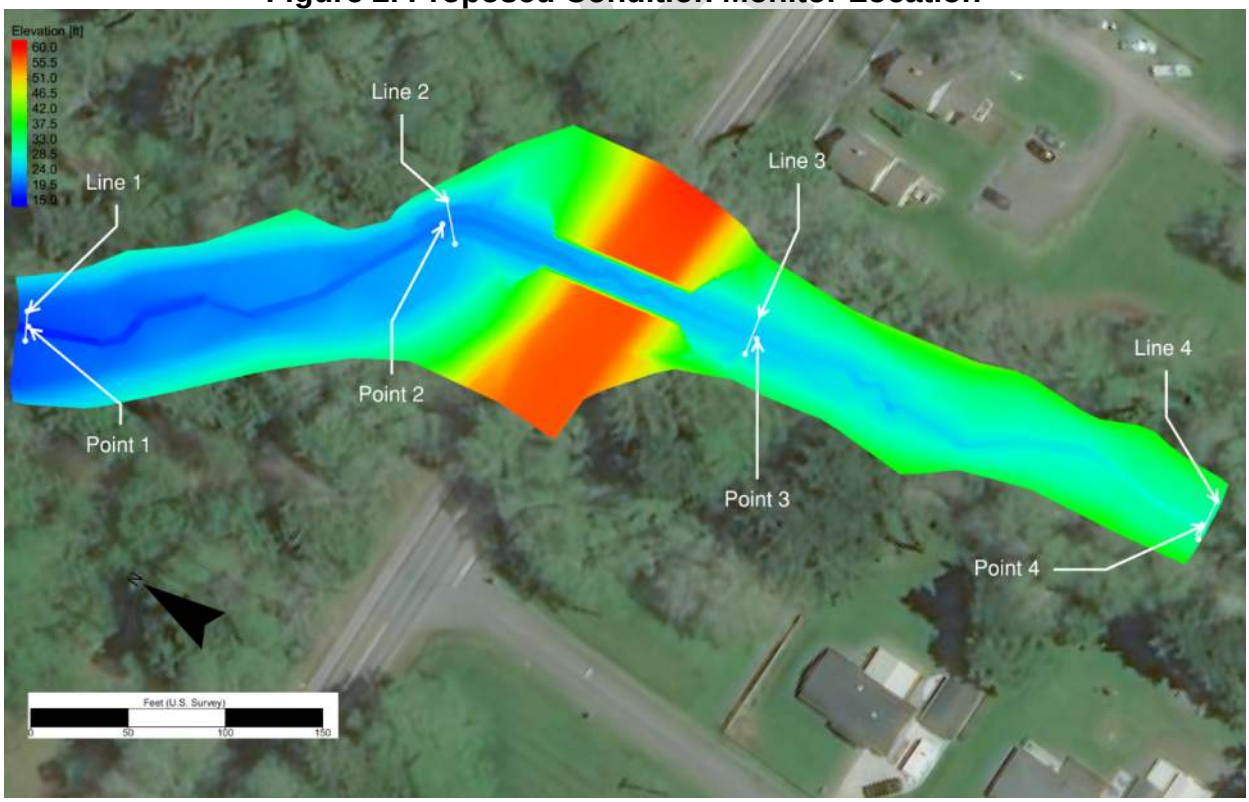


Figure 3. Existing Condition Monitoring Point Plots

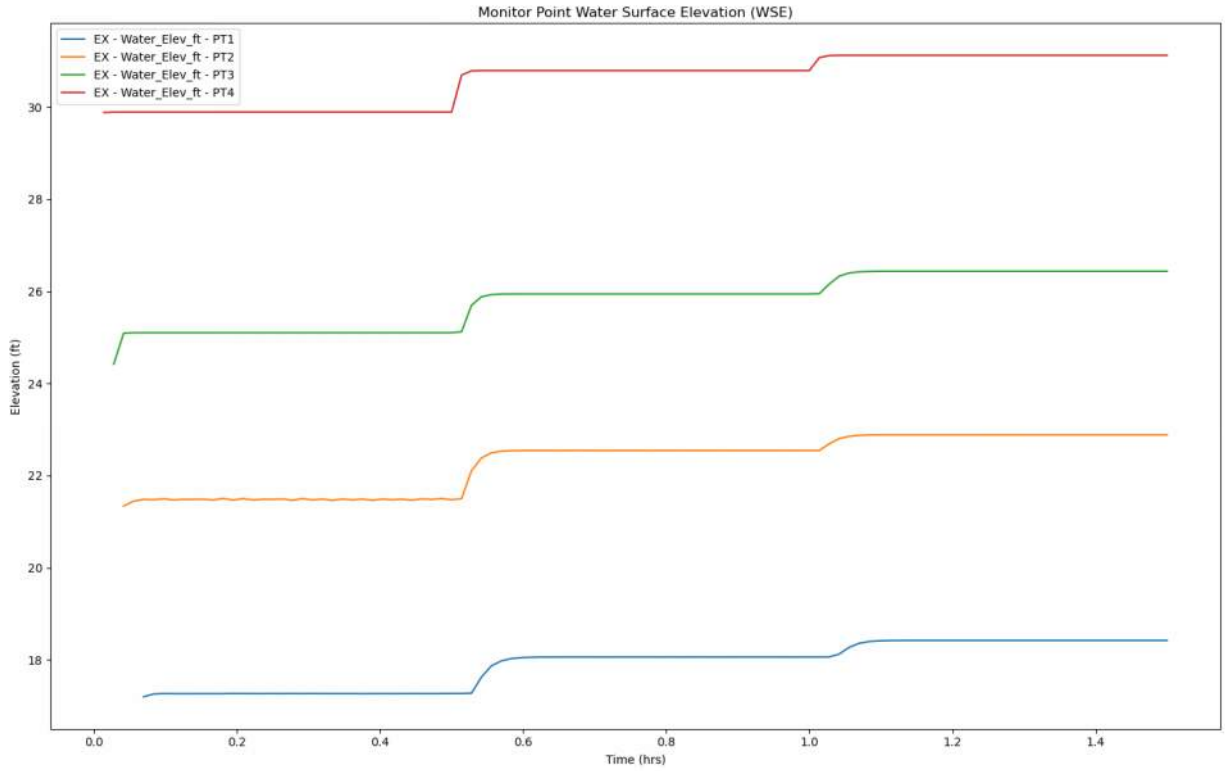


Figure 4. Proposed Condition Monitoring Point Plots

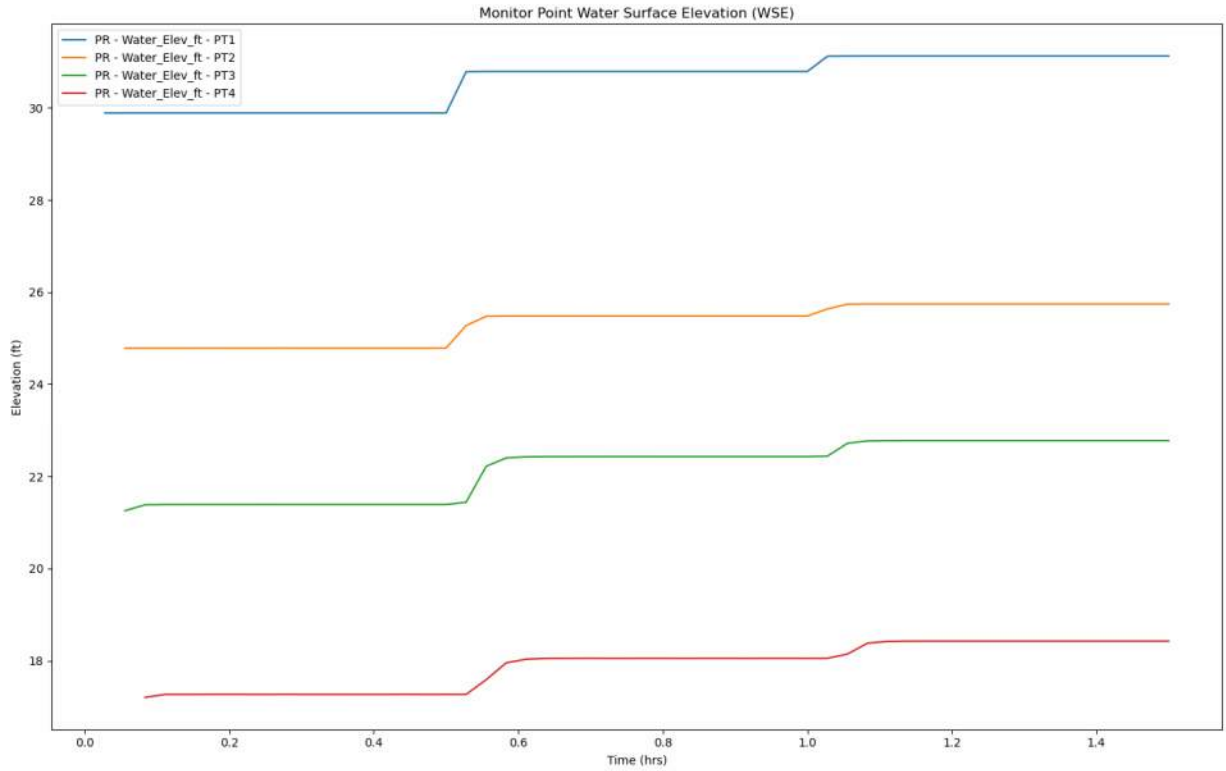


Figure 5. Existing Condition Monitor Line Plots

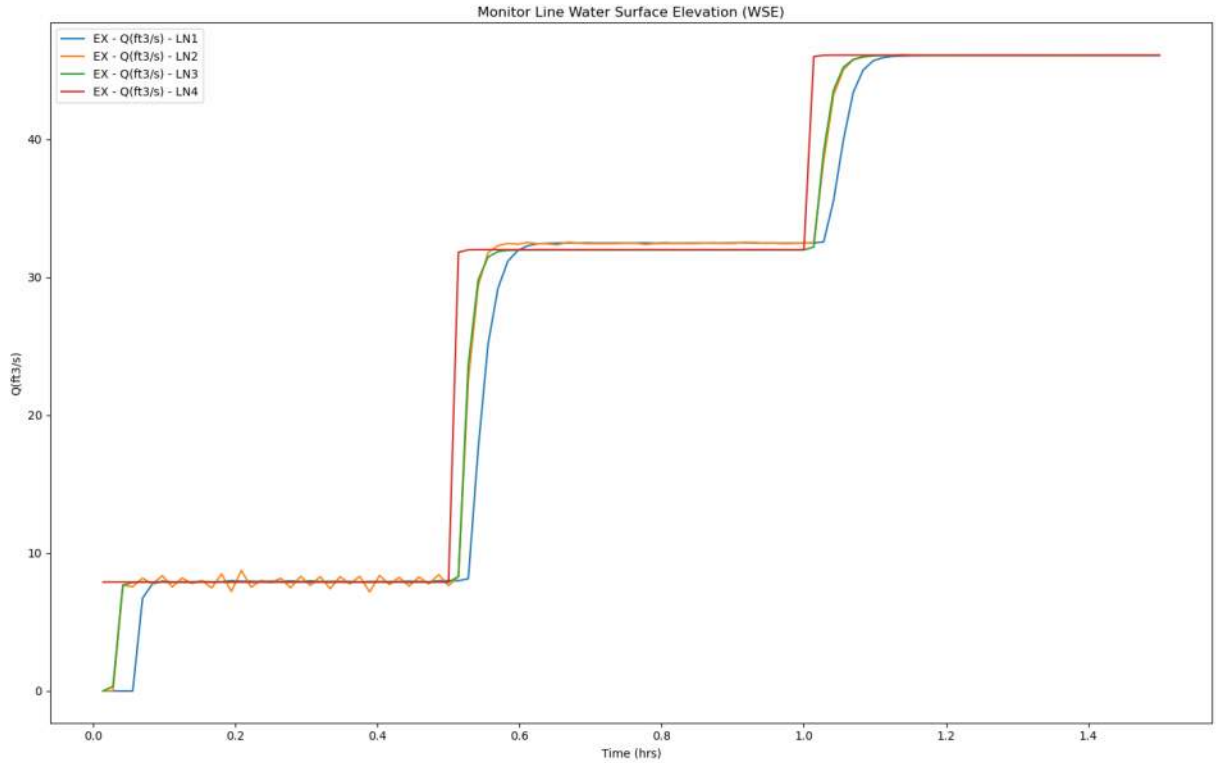
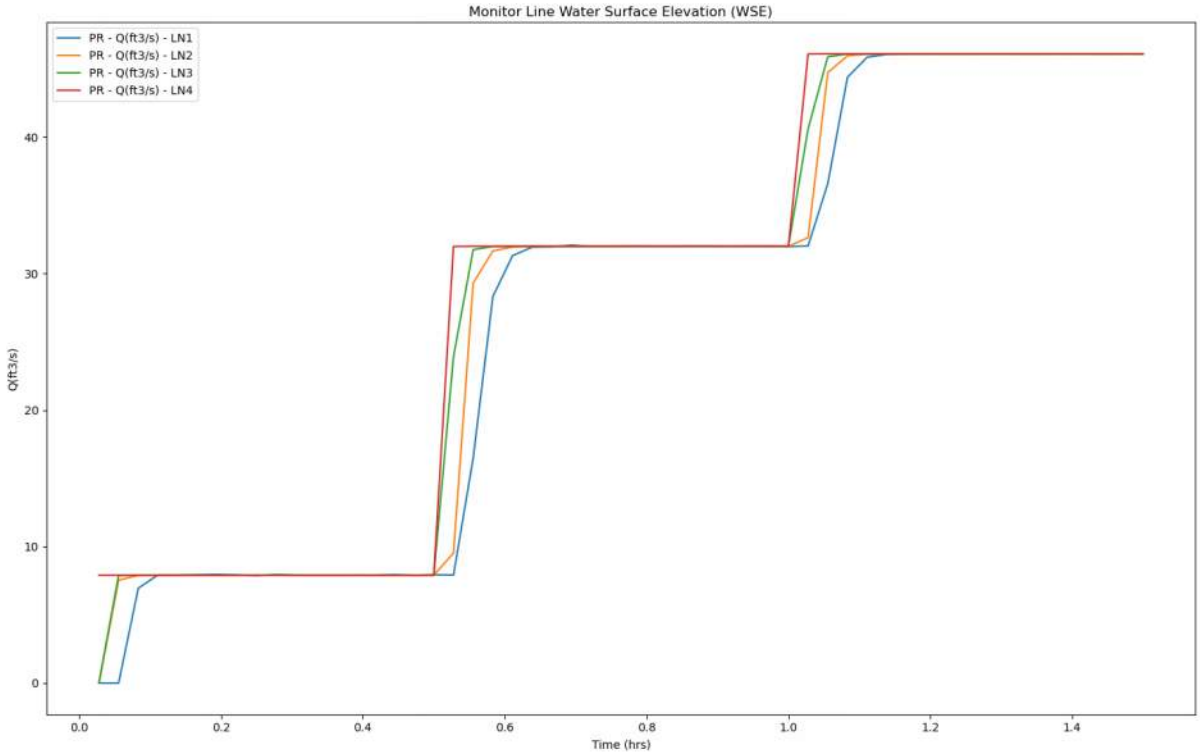


Figure 6. Proposed Condition Monitor Line Plots



Appendix J: Reach Assessment

No reach assessment is available for the project site.

Appendix K: Scour Calculations

Figure 1. 2080 projected 100-year critical velocity index with bridge scour coverage arcs locations

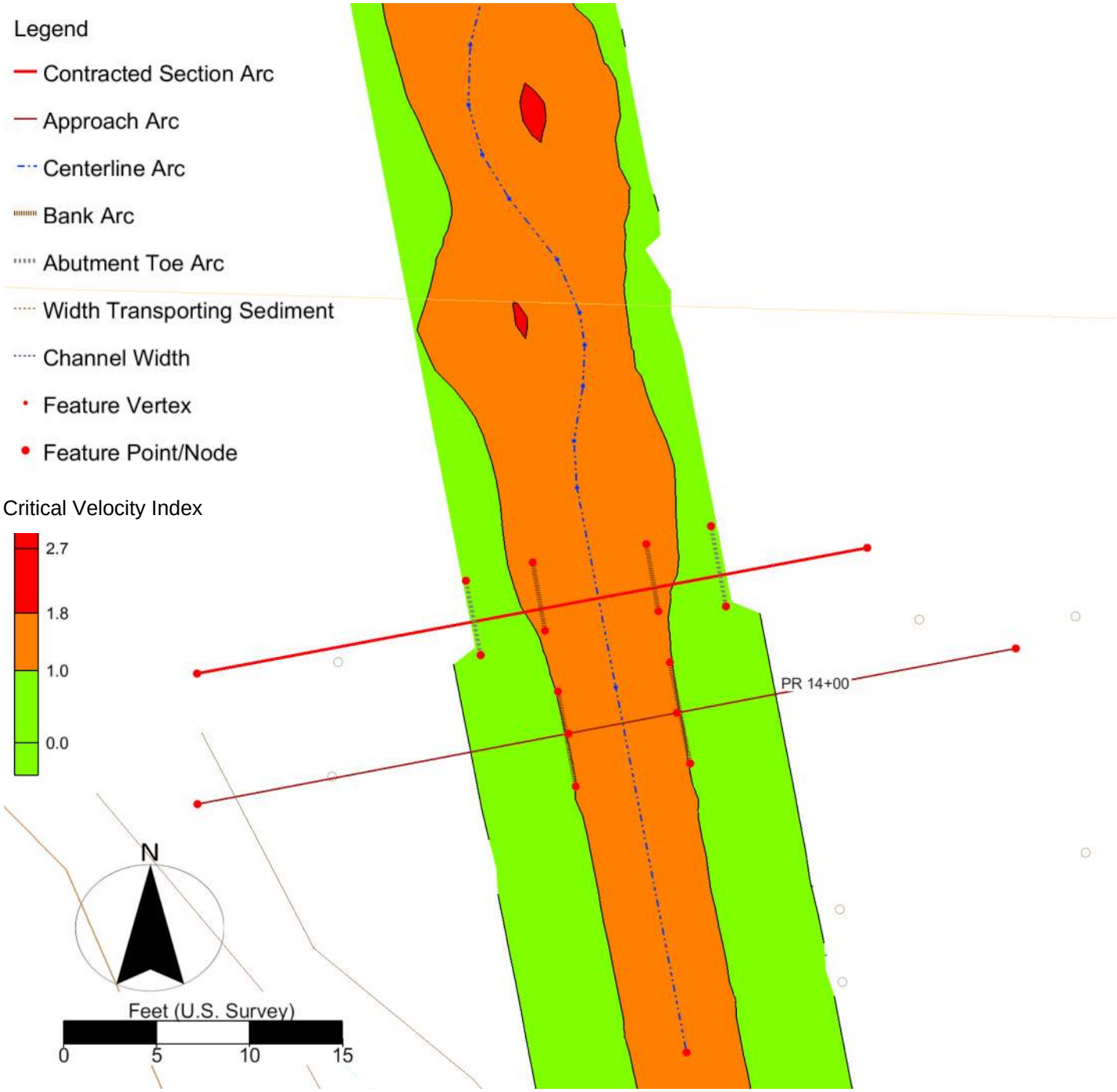


Figure 2. 2080 projected 100-year flow contraction scour results

Contraction Scour

Computation Method: Clear-Water or Live-Bed Scour

Parameter	Value	Units	Notes
Input Parameters			
Average Depth Upstream of Contraction	1.34	ft	
D50	4.876800	mm	0.2 mm is the lower limit for ...
Average Velocity Upstream	4.34	ft/s	
Results of Scour Condition			
Critical velocity above which bed material of size D and s...	2.95	ft/s	
Contraction Scour Condition	Live Bed		
Live Bed Input Parameters			
Temperature of Water	60.00	°F	
Slope of Energy Grade Line at Approach Section	0.003200	ft/ft	
Discharge in Contracted Section	36.37	cfs	
Discharge Upstream that is Transporting Sediment	36.18	cfs	
Width in Contracted Section	6.19	ft	Remove widths occupied by ...
Width Upstream that is Transporting Sediment	6.24	ft	
Depth Prior to Scour in Contracted Section	1.23	ft	
Unit Weight of Water	62.40	lb/ft^3	
Unit Weight of Sediment	165.00	lb/ft^3	
Results			
k1	0.590000		
Shear Velocity	0.37	ft/s	
Fall Velocity	1.06	ft/s	
Average Depth in Contracted Section after Scour	1.35	ft	
Scour Depth	0.12	ft	Negative values imply 'zero' ...
Scour may be limited by armoring. Compute all m...			

Figure 3. 2080 projected 100-year flow abutment scour results

Abutment Scour

Computation Method: NCHRP

Parameter	Value	Units	Notes
Input Parameters			
Scour Condition	Compute		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	5.80	cfs/ft	
Unit Discharge in Constricted Area (q2)	5.88	cfs/ft	
D50	4.876800	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	1.34	ft	
Define Shear Stress of Floodplain	☐		
Flow Depth prior to Scour	1.56	ft	Depth at Abutment Toe
Results			
q2 / q1	1.01		
Average Velocity Upstream	4.34	ft/s	
Critical Velocity above which Bed Materal of Size D and Sm...	2.95	ft/s	
Scour Condition	Live Bed		
Scour Condition	a (Main Channel)		
Amplification Factor	1.27		
Flow Depth including Contraction Scour	1.35	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	1.72	ft	Including the long-term scour de...
Scour Hole Depth	0.16	ft	Negative values imply 'zero' sco...
Scour Hole			
Angle of Repose	44.00	degrees	
Ratio of Bottom Width of Scour Hole to Scour Hole Depth	0.00		1.0 means the bottom width will ...
Scour Hole Bottom Width	0.00	ft	
Scour Hole Top Width	0.17	ft	

*Note: 500-year event has the same flow with 2080 projected 100-year flow

Appendix L: Floodplain Analysis

Floodplain analysis will be included in FHD.