U.S. 101 MP 357.4 Griggs Creek (WDFW ID 997161): 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] 1–23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the United States Highway 101 (U.S. 101) crossing of Griggs Creek at Mile Post (MP) 357.4. This existing structure on U.S. 101 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] 997161) and has an estimated 5,600 linear feet (LF) of habitat gain.

Per the 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 as defined in the injunction. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT is proposing to replace the existing crossing structure with a structure designed using the stream simulation design methodology.

The crossing is located in unincorporated Thurston County 12 miles northwest of Olympia, Washington, in WRIA 14. The highway runs in a northwest–southwest direction at this location and is about 700 feet (ft) south from the confluence with Schneider Creek. Griggs Creek generally flows from south to north beginning within a steep valley 1,600 feet upstream of the U.S. 101 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 3-foot-diameter, 193-foot circular concrete culvert with a structure designed to accommodate a minimum hydraulic opening of 17 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 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2019).

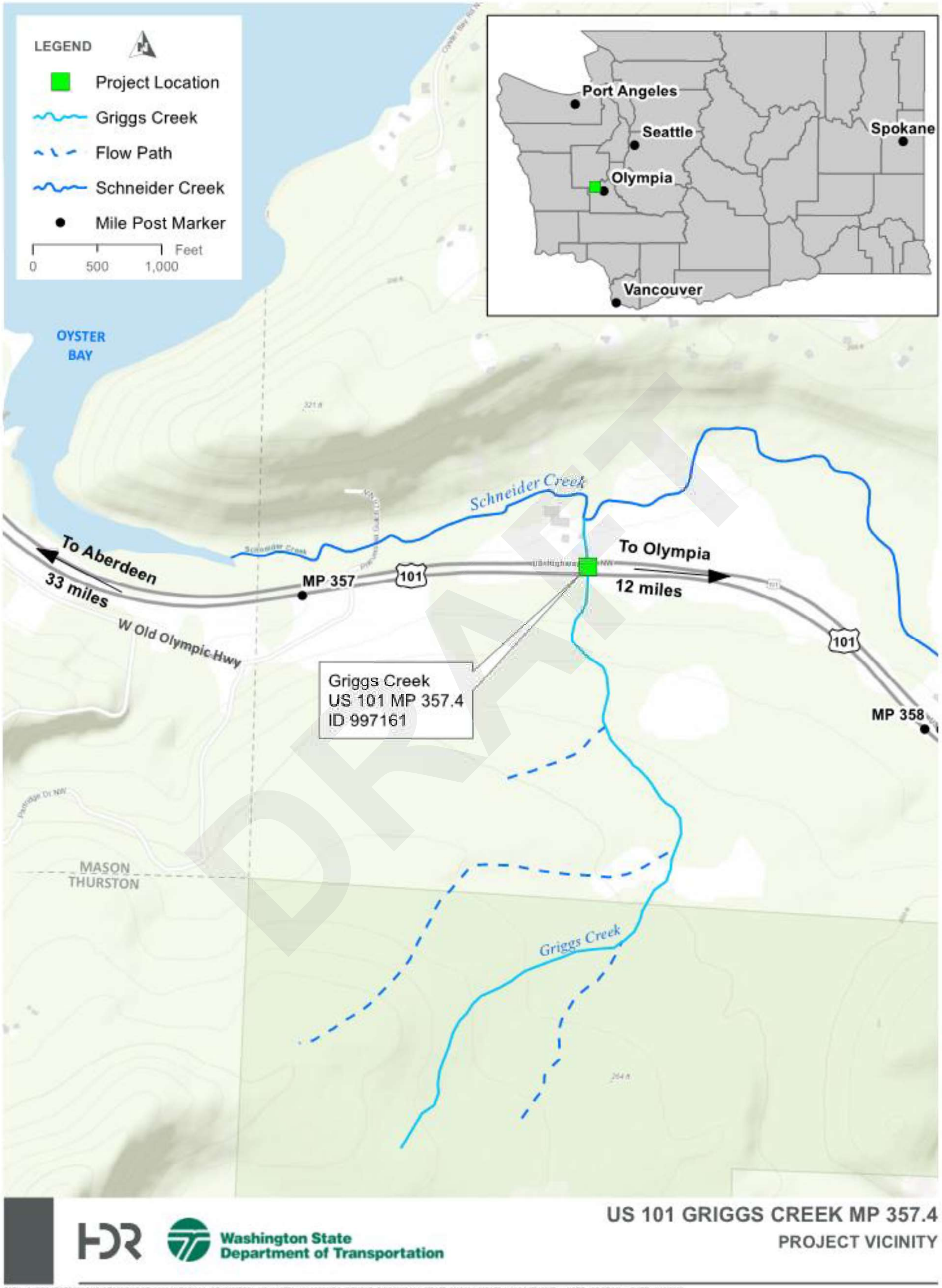

Figure 1: Vicinity map

2 Watershed and Site Assessment

This section presents a watershed and site assessment for Griggs Creek.

2.1 Watershed and Land Cover

The project watershed has a contributing drainage area to the site of 212.72 acres (0.33 square mile); the watershed is south of the U.S. 101 crossing (see Figure 2). The basin was delineated using Arc Hydro and light detecting and ranging (LiDAR) data (Washington State Department of Natural Resources [DNR] LiDAR Portal: 2017 Southwestern Washington). Three smaller tributaries contribute flow to Griggs Creek within this watershed, which lies in the Schneider Prairie with the major stream being Schneider Creek. Land cover for the watershed is generally forested, with some history of cleared land for either logging or agriculture.

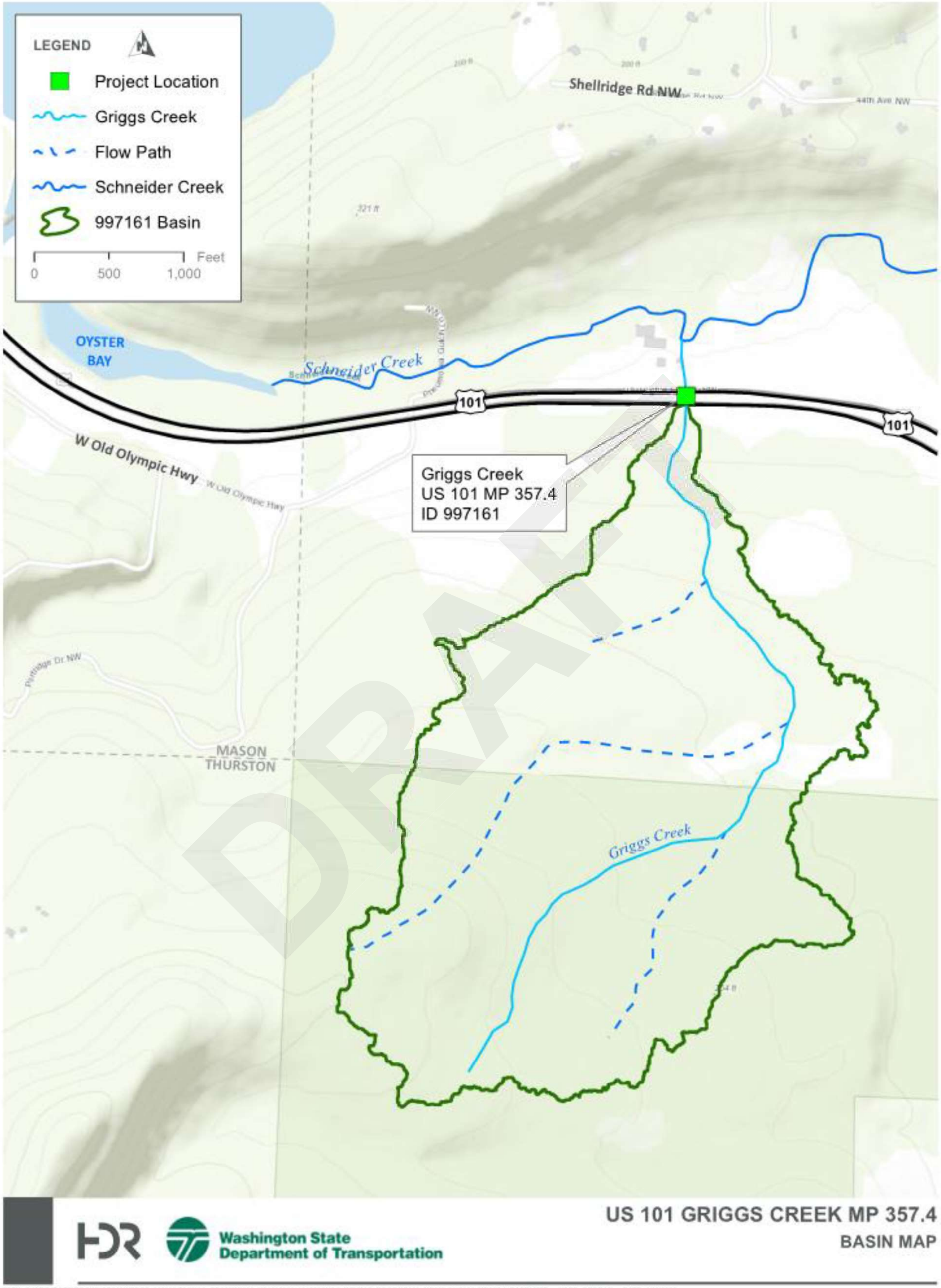

Figure 2: Griggs Creek basin map

2.2 Geology and Soils

The surficial geology of the watershed is primarily glacial till deposited thinly along the areas of Puget Sound (Figure 3). As defined and summarized in the 7.5-foot quadrangle mapping by the United States Geological Survey (USGS) (Logan 2003), the following geologic units are present within the basin:

- **Qgt**: Pleistocene continental glacial till. This unit is an unsorted and highly compacted mixture of clay, silt, sand, and gravel deposited directly by glacier ice with very low permeability.
- **Qga:** Pleistocene continental glacial drift. Made up of sand and gravel and lacustrine clay, silt, and sand of northern source, this was deposited during glacial advance but may contain some nonglacial sediments, such as cobbles and rip-up clasts of silt or peat.
- **Qgo:** Pleistocene continental glacial drift. Similar to Qga, a moderately to well-rounded and poorly to moderately sorted outwash sand and gravel of northern or mixed northern and Cascade source, that locally contains silt and clay; it also contains lacustrine deposits and ice-contact stratified drift.
- **Qa:** Quaternary alluvium. Consists of silt, sand, gravel, and peat deposited in streambeds, alluvial fans, and estuaries; includes some lacustrine and beach deposits.
- **Qls:** Quaternary mass-wasting deposits. This unit contains rock, soil, and organic matter deposited by mass wasting; depending on degree of activity, location within the slide mass, type of slide, cohesion, and competence of materials, may be unstratified, broken, chaotic, and poorly sorted or may retain primary bedding structures.
- **Ev(c):** Eocene Crescent Formation, volcanic rocks. Most commonly consists of breccias, columnar-jointed flows or sills, and glomerophyric dikes; filled lava tubes common in breccias.

The soil map units within the watershed are primarily silt loam and very gravelly loam in areas of mild slopes (Figure 4) as mapped by the Natural Resources Conservation Service (NRCS) (Soil Survey Staff 2020). The soil map units in the vicinity of the crossing are Kapowsin silt loam (upstream) and Giles silt loam (downstream). The upper basin is composed of Grove gravelly sandy loam and Kapowsin silt loam.

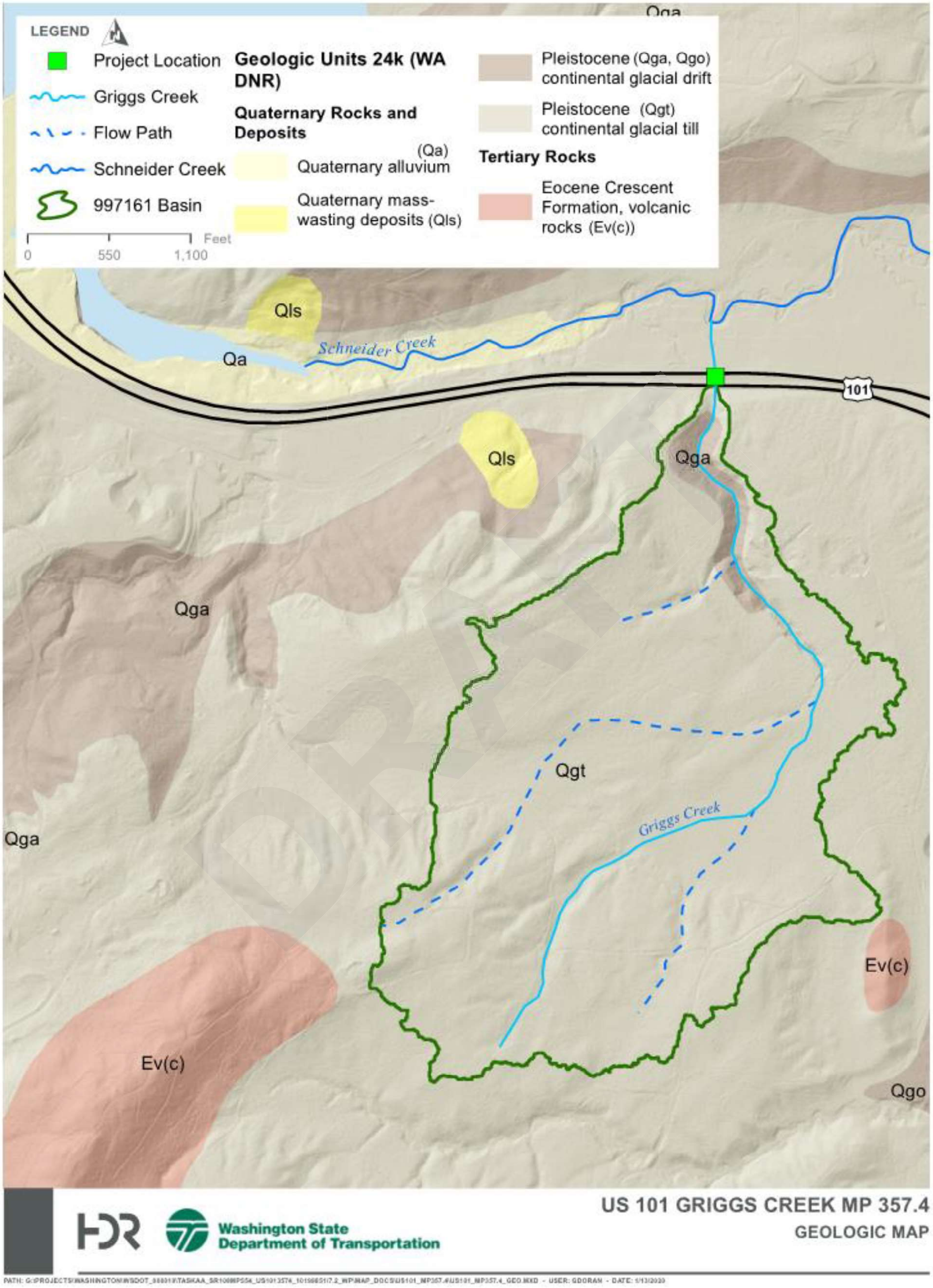

Figure 3: Griggs Creek geologic map (Washington Division of Geology and Earth Resources 2016)

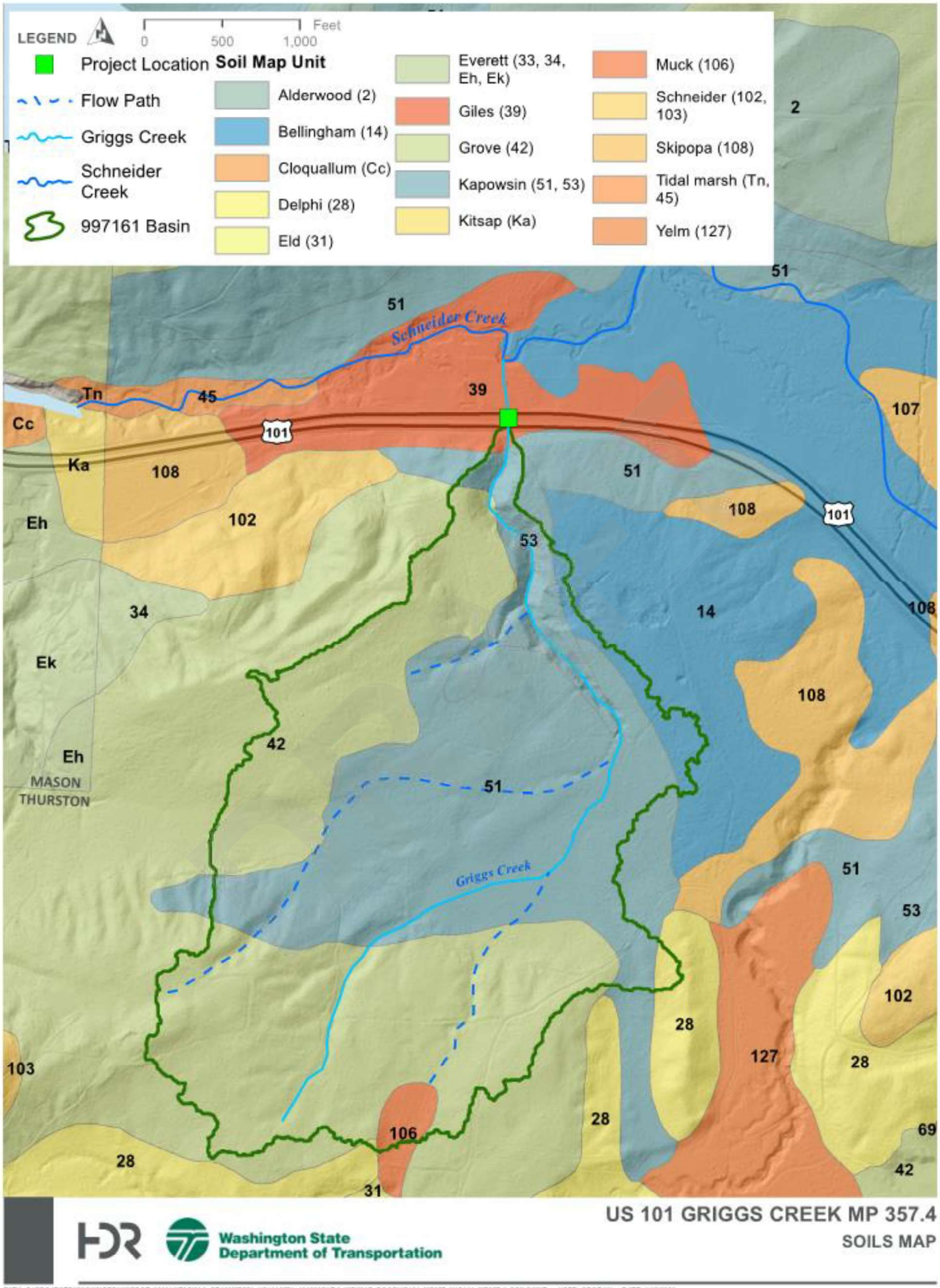

Figure 4: Griggs Creek soils map (Soil Survey Staff 2020)

2.3 Floodplains

The project is not within a regulatory Special Flood Hazard Area, which is the 1 percent or greater annual chance of flooding in any given year. Maintenance records were requested and have not been provided, flooding history is currently unknown. The existing U.S. 101 culvert is located in Zone X (unshaded) based on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) 53067C0127F effective May 15, 2018. An unshaded Zone X represents areas of minimal flood hazard from the principal source of flooding in the area (Schneider Creek) and is determined to be outside the 0.2 percent annual chance floodplain. See Figure 5.

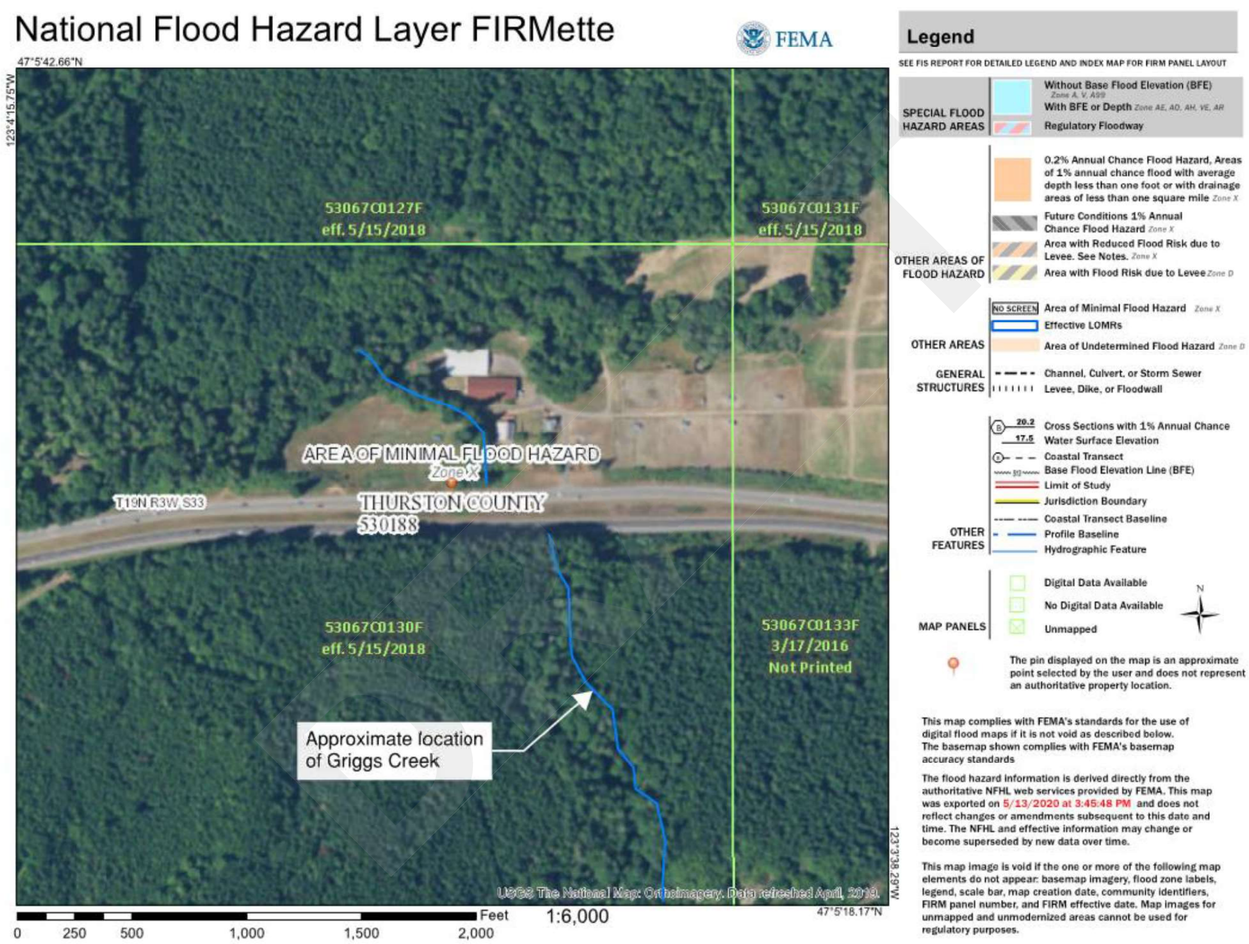

Figure 5: FEMA FIRMette for Griggs Creek

2.4 Site Description

Griggs Creek at U.S. 101 MP 357.4 is listed as a 33 percent passable barrier within the WDFW Fish Passage database because of a steep slope that impairs fish ability to swim upstream at all life stages. It is currently not listed as a chronic environmental deficiency or failing structure. Maintenance history has been requested but has not yet been provided. The potential habitat gain that comes with replacing this fish barrier is 5,600 LF.

2.5 Fish Presence in the Project Area

Griggs Creek, a left bank tributary to Schneider Creek, supports the occurrence of fall-run coho salmon (*Oncorhynchus kisutch*). Chum salmon (*Oncorhynchus keta*) are documented as occurring in Griggs Creek by WDFW during their fish passage culvert assessment in 2011 (report ID 997161) where live and dead adult chum were observed in the reach downstream of the culvert crossing. Because of its unimpeded connection with Schneider Creek, Griggs Creek in the study area also has the potential for winter-run steelhead (*Oncorhynchus mykiss*), and resident coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) (WDFW 2020a; WDFW 2020b; StreamNet 2020). Of these fish species, winter steelhead that inhabit Schneider Creek are part of the Puget Sound distinct population segment and are federally listed as threatened under the Endangered Species Act (ESA) of 1973. Besides salmonids, several additional fish species, including sculpin and lamprey, inhabit the watershed.

Table 1 provides a list of fish species that occur in the study area in Griggs Creek and that would be affected by the culvert crossing. The confluence of Griggs Creek is approximately 700 feet downstream of the project culvert crossing. Flows in the creek during the time of the site visit in January 2020 were only a few inches (in) to about 1 foot in depth, and no fish were observed.

Table 1: Native fish species potentially present within the project area

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Coho salmon (*Oncorhynchus kisutch*)	Documented	SWIFD (2020), Salmonscape and PHS online data (WDFW 2020a,b)	Not warranted
Chum salmon (*Oncorhynchus keta*)	Documented	SWIFD (2020), Salmonscape and PHS online data (WDFW 2020a,b) observed WDFW Report 997161	Not warranted
Winter steelhead (*Oncorhynchus mykiss*)	Presumed (documented in Schneider Creek)	SWIFD (2020), Salmonscape and PHS online data (WDFW 2020a,b)	Federally threatened
Coastal cutthroat (*Oncorhynchus clarkii clarkii*)	Documented	SWIFD (2020), PHS online data (WDFW 2020b)	Not warranted

2.6 Wildlife Connectivity

WSDOT considered U.S. 101 at MP 357.4 a low wildlife priority route.

2.7 Site Assessment

The existing crossing at U.S. 101 MP 357.4 has potential to improve fish habitat by providing 5,600 LF of habitat gain with a fish-passable structure. The following sections describe the existing conditions of Griggs Creek as observed during multiple site visits conducted in early 2020.

2.7.1 *Data Collection*

HDR Engineering, Inc. (HDR) performed a site visit on January 21, 2020, to collect pertinent information to support the basis of design for Griggs Creek at U.S. 101 MP 357.4 (site ID 997161). An additional site visit was conducted as a bankfull width concurrence meeting with representatives from WSDOT, WDFW, and the Squaxin Island Tribe; see Appendix A for the Field Report from the site visit conducted on March 6, 2020. The Chehalis Tribe was not on site, but deferred to WDFW for bankfull width (BFW) measurements. Bankfull width measurements are summarized in Section 2.8.2.

A detailed topographic survey, conducted in March 2020 by 1 Alliance Geomatics, LLC (1 Alliance), encompasses what was seen during the site visit, approximately 800 feet of channel. Roadway survey was collected a distance of 1,000 feet in both directions from the crossing.

The following paragraphs and Figure 6 through Figure 27 describe field observations of Griggs Creek from upstream to the downstream confluence with Schneider Creek.

The upstream reach habitat is split between a wooded and heavily vegetated area (approximately 500 feet to 250 feet upstream of the crossing), and a slightly vegetated area with highly eroded banks (250 feet upstream to the culvert inlet). Beginning approximately 500 feet upstream of the crossing, Griggs Creek meanders through an area of abundant large woody material (LWM) within the densely vegetated area (see Figure 6). Steep valley walls constrain the channel and incur some occasional undercutting.

Figure 6: Looking upstream taken from the top of the woody material

Within the stream channel an instance of LWM creates a 1.5- to 2.0-foot hydraulic drop as seen in Figure 7.

Figure 7: Looking upstream at the woody material jam

Downstream of the influence of the hydraulic drop, four bankfull width measurements were taken, the average being a 9-foot bankfull width. See Figure 8 for an example bankfull width measurement. Within this reach the material was primarily fine to very coarse gravel with some cobbles and bank heights, approximately 2 feet on the left and right.

Figure 8: Bankfull width measurement being taken

The largest material observed within the reach was a 10-inch cobble; see Figure 9 below.

Figure 9: Largest material observed within stream

Downstream of the wooded reach, the banks are higher and more eroded, and there is less LWM within the channel (see Figure 10). This reach begins approximately 250 feet upstream of the culvert inlet, ending at the crossing.

Figure 10: Looking downstream at eroded right banks

Approximately 100 feet upstream of the culvert inlet, the channel takes a 90-degree left turn, leaving a gravel bar on the left bank and a highly eroded 8-foot bank on the right (see Figure 11). A second bend, nearly 90 degrees, creates an S-curve (see Figure 12 below).

Figure 11: Looking downstream at the gravel bar and eroded right banks

Figure 12: Looking upstream at the meandering channel

Downstream of the S-curve, deadfall trees within the stream have created some flow path deflection and a slight channel meander. Sediment and material have accumulated to surround the LWM. Because of the LWM and sediment buildup, the channel has a 1-foot hydraulic drop (see Figure 13).

Figure 13: Looking upstream at the hydraulic drop

Immediately downstream of the hydraulic drop, the channel is incised with 2- to 3-foot-high vegetated banks (see Figure 14). This incised channel is straight and had quarry spalls within it as it approaches the culvert inlet. A roadside ditch flows into Griggs Creek immediately upstream of the culvert on the right bank (see Figure 15).

Figure 14: Looking downstream at incised banks

Figure 15: Roadside ditch entering on the right bank upstream of the culvert inlet

The 36-inch concrete culvert invert is clear of sediment and has concrete headwalls that come out at roughly a 45-degree angle. The right headwall is broken. See Figure 16 below.

Figure 16: Culvert inlet

The downstream reach is fairly vegetated, significant amounts of reed canarygrass are present, and the channel meanders until the confluence with Schneider Creek.

On the day of the first site visit the culvert outlet was completely inundated and not visible (see Figure 17). The culvert outfalls into a vegetated wetland area that is divided by a raised vegetated island (see Figure 18 below). A roadside ditch comes in from the left bank (see Figure 19). A wire fence appears to have caught debris and caused several feet of deposition upstream of it that extends to the culvert outlet. There was an approximate 2-foot hydraulic drop across the fence.

Figure 17: Submerged culvert outlet

Figure 18: Looking downstream atop the culvert outlet

Figure 19: Looking downstream from the left bank

After the drop, the channel continues to meander through vegetated banks, taking a hard left turn, and reaches a 2-foot-diameter high-density polyethylene (HDPE) culvert that goes underneath an access road (see Figure 20 below). There is a scour pool at the culvert outlet before the channel continues to the left (see Figure 21).

Figure 20: Access road culvert inlet

Figure 21: Access road culvert outlet

There is some small wood within the channel, mostly branches fallen from larger trees (see Figure 22). The banks range from 1 to 3 feet high, are well vegetated, and consist of a clayey sand material. The channel substrate is consistent gravel throughout the reach. Downstream of the influence of the auxiliary culvert, three bankfull widths were taken resulting in an average 8.6-foot bankfull width.

Figure 22: Looking downstream of smaller woody material in the stream

Approximately 150 feet downstream of the access road culvert, the channel steepens and becomes more incised with 3-foot-high vegetated banks. Two trees and LWM within the stream create a 2-foot hydraulic drop, shown in Figure 23 and Figure 24 below.

Figure 23: Looking downstream at woody material within the stream and hydraulic drop

Figure 24: Closer look at hydraulic drop and woody material within stream

Downstream of the drop, the channel meanders, taking left and right turns and creating eroded and undercut banks. Many roots are lying in the channel, shown in Figure 25.

Figure 25: Roots within meandering stream and undercut banks

The channel meanders for another 300 feet until reaching the confluence with Schneider Creek, roughly 700 feet downstream of the U.S. 101 crossing. Directly upstream of the confluence, the right bank is slightly eroded as the channel takes a left turn to meet the much larger Schneider Creek (see Figure 26 and Figure 27 below).

Figure 26: Looking downstream at the Schneider Creek confluence

Figure 27: Looking downstream at Schneider Creek

2.7.2 *Existing Conditions*

The existing 3-foot-diameter, 193-foot-long concrete culvert has a 2.9 percent slope according to the March 2020 survey. The structure is slightly skewed beneath U.S. 101. The culvert outlet is completely submerged, and the top of the culvert is not visible beneath the elevated water surface and debris. The outlet is filled with approximately 2 feet of sediment. The culvert inlet was not observed to have sediment or any obstructions.

Directly upstream of the structure, Griggs Creek is fairly steep at a 5.5 percent slope with a log jam approximately 20 feet upstream of the culvert inlet. There are small roadside ditches to the east and west of the culvert inlet, with flow generally flowing to the west. From observing the existing hydraulic model simulations, when the U.S. 101 culvert is full, flow runs to an existing culvert approximately 900 feet to the west. Another culvert about 700 feet to the east is roughly 4 feet higher than the U.S. 101 crossing. Both culverts in the vicinity cross U.S. 101 running from south to north.

Downstream of the culvert outlet, a large sediment buildup has caused the culvert to be submerged. Flow travels around the buildup, creating an island (see Figure 18 above). A small tributary coming in from the left bank is assumed to be from roadside drainage. The tributary joins Griggs Creek upstream of the fence that has accumulated debris and sediment. Approximately 200 feet downstream of the culvert outlet, there is a small privately owned access road with a 2.5-foot-diameter, 32-foot-long HDPE culvert that Griggs Creek flows through.

While on site no obvious signs of maintenance activity were observed; however, others have indicated that some maintenance occurred in the past to remove sediment buildup at the culvert outlet. As-builts were not obtained for this crossing.

This crossing is listed in WDFW's database as a significant reach. As a current barrier it limits fish spawning and rearing habitat by 4,004 square feet (SF) and 26,135 SF, respectively. By removing and replacing the crossing with an acceptable fish passage structure the potential habitat gain is 5,600 LF.

2.7.3 *Fish Habitat Character and Quality*

Upstream of the U.S. 101 crossing, Griggs Creek flows through a mature mixed forested valley of primarily Douglas fir (*Pseudotsuga menziesi*i), alder (*Alnus rubr*a), and some large western red cedars (*Thuja plicata*). There is a dense shrub understory with native and non-native species including salmonberry (*Rubus spectabilis*), willows (*Salix* spp.), vine maple (*Acer circinatum*), Himalayan blackberry (*Rubus armeniacus*), and sword ferns (*Polystichum munitum*). The mature forest and shrub cover provides good shading, nutrient inputs, and potential for LWM recruitment. LWM is important in western Washington streams in that it provides cover for fish and contributes to stream complexity, which is beneficial to salmonids. There were 4 places where large logs and woody material were present within the stream channel and banks that provide instream habitat complexity. Near the upstream end of the surveyed reach, LWM creates a small hydraulic drop and provides a small pool in the bend upstream (Figure 7 above). Another small hydraulic drop occurs over a LWM and debris jam just upstream of the culvert inlet (Figure 13 above). Neither of these drops pose passage barriers to fish, particularly during periods when flows are higher. However, some upstream movements of juveniles would be impeded during low flows. In the reach upstream of the culvert, LWM appears to be functionally abundant and continues through the reach visible upstream from the end of the surveyed reach.

Substrate in the upstream reach is predominantly gravel and small cobble, with fines present in slow flow areas and near stream margins. There are some areas of potential spawning habitat in the streambed gravels. Habitat in this reach is predominantly suited to seasonal migration and some rearing, particularly during higher flow periods. Much of the reach consists of shallow riffle habitat and deep pools are lacking. There are a few small pools along eroded banks and under rootwads in the bank. Juvenile coho and possibly juvenile steelhead could use the stream for some rearing and overwintering habitat, particularly during higher flows in the larger streams downstream.

Downstream of the U.S. 101 culvert crossing, Griggs Creek flows through a small, reed canarygrass–dominated wetland ditch along the roadside within right-of-way (Figure 18 above). A wire fence has accumulated sediment and woody material to create a small hydraulic drop to where the channel continues within more defined vegetated banks. Downstream of this area, the creek flows through a mixed canopy of deciduous and conifer trees, predominantly alder and western red cedar, with some Douglas fir. There is a dense shrub understory with native and non-native species including salmonberry, vine maple, Himalayan blackberry, and western sword ferns. The mature forest and shrub cover provides good shading, nutrient inputs, and some potential LWM recruitment. The riparian corridor along the left bank is constrained to a narrow strip along the edge of a fenced pasture, downstream of the farm access road culvert. The riparian vegetation in this reach is dominated by blackberry. The riparian area on the right bank is constrained by a driveway near the project crossing, but widens downstream toward Schneider Creek where it consists of mixed forest canopy.

Twelve pieces of LWM were observed in the downstream reach, and a small cascade where the channel narrows at the downstream end of the surveyed reach. Some LWM recruitment potential occurs in the downstream end of the study reach where the forest canopy widens on the right bank.

Fish habitat in the downstream reach is suited primarily for migration and rearing of juvenile salmonids. This substrate composition is not suitable for large spawning salmonids such as steelhead. There were some stream bed gravels, but the habitat was predominantly shallow riffles, and large pools for refuge and cover are lacking. Cutthroat trout do seek out small streams, with relatively small particles in the substrate including sand, and habitat in the action area is suitable for them to reside.

2.8 Geomorphology

This section presents a description of the geomorphology of Griggs Creek.

2.8.1 *Reference Reach Selection*

A section of stream approximately 150 feet upstream of the culvert (Figure 28 and Figure 29) was chosen as the reference reach, because it is most representative of a naturally occurring streambed, with the least amount of anthropogenic influences. This reach has an approximate average channel gradient of 3.2 percent. Results of a pebble count conducted at the reference reach are summarized in Section 2.8.3.

Figure 28: Photo of reference reach, looking upstream

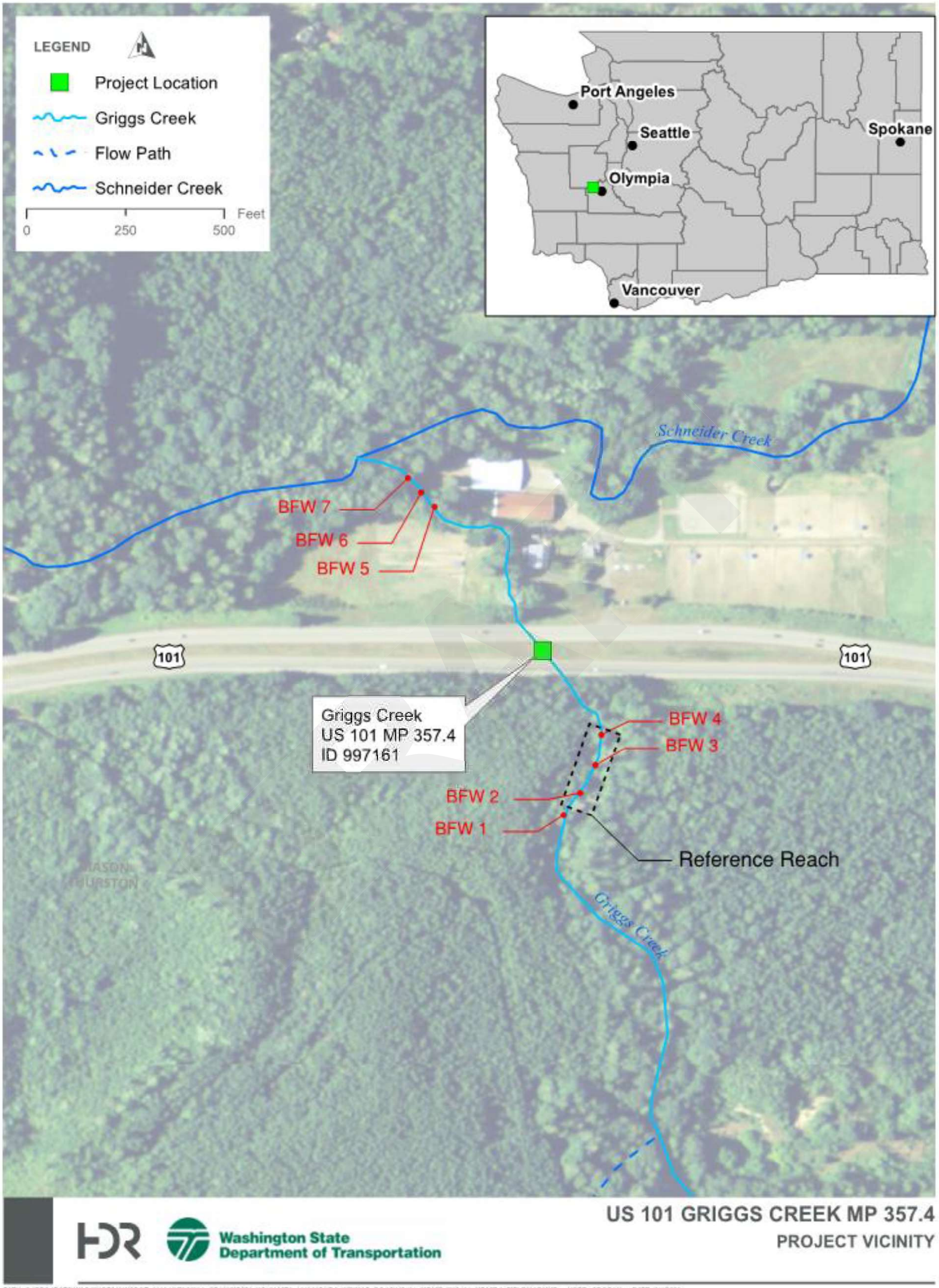

Figure 29: Reference reach

2.8.2 *Channel Geometry*

The channel planform meanders with a medium amount of sinuosity upstream and downstream of the crossing, fairly confined within a valley upstream and tall banks downstream. Downstream, the channel meanders through a farm and horse stable area including a second culvert at an access road and reed canarygrass–filled floodplains with limited cover. The channel cross section is narrow with the thalweg primarily in the middle of the channel besides at bends. At the upstream reference reach, as described in Section 2.8.1, the gradient is 3.2 percent.

Bankfull width measurements were collected upstream and downstream of the crossing. Seven bankfull widths were taken, ranging from 7.6 to 10.0 feet. During the bankfull width concurrence meeting on March 6, 2020, with WDFW, WSDOT, and the Squaxin Island Tribe representative, previously measured bankfull widths were evaluated for concurrence. The Chehalis Tribe was not on site but concurred with WDFW's opinion. Table 2 summarizes bankfull measurements that were used to determine the design bankfull width. The agreed-upon bankfull widths resulted in a design average bankfull width of 9 feet. Approximate locations of bankfull widths and the reference reach are identified in Table 2.

For comparison, a bankfull width was calculated based on the WCDG (Barnard 2013) regression equation for high-gradient, coarse-bedded streams in western Washington. Using the basin area (0.37 square mile) and average mean annual precipitation (61.2 inches/year) the regression equation estimates a bankfull width of 7.5 feet. This bankfull width was not used to determine a design bankfull width, but is provided for informational purposes.

Table 2: Bankfull width measurements

BFW #	Width (ft)	Included in Design Average	Concurrence Notes
Upstream			
1	10.0	Yes	WDFW and Tribe concurred on 3/6/2020
2	8.1	Yes	WDFW and Tribe concurred on 3/6/2020
3	8.7	Yes	WDFW and Tribe concurred on 3/6/2020
4	9.3	Yes	WDFW and Tribe concurred on 3/6/2020
Downstream			
5	7.6	Yes	WDFW and Tribe concurred on 3/6/2020
6	9.7	Yes	WDFW and Tribe concurred on 3/6/2020
7	8.5	Yes	WDFW and Tribe concurred on 3/6/2020
Design average	9.0		WDFW and Tribe concurred on 3/6/2020

The width:depth ratio is the bankfull width divided by the mean depth of the bankfull channel. For the 100-year event, the width:depth ratio is 18 within the reference reach. A series of cross sections obtained from survey data is presented in Figure 30; Station (STA) 7+39 and STA 7+06 are located within the reference reach.

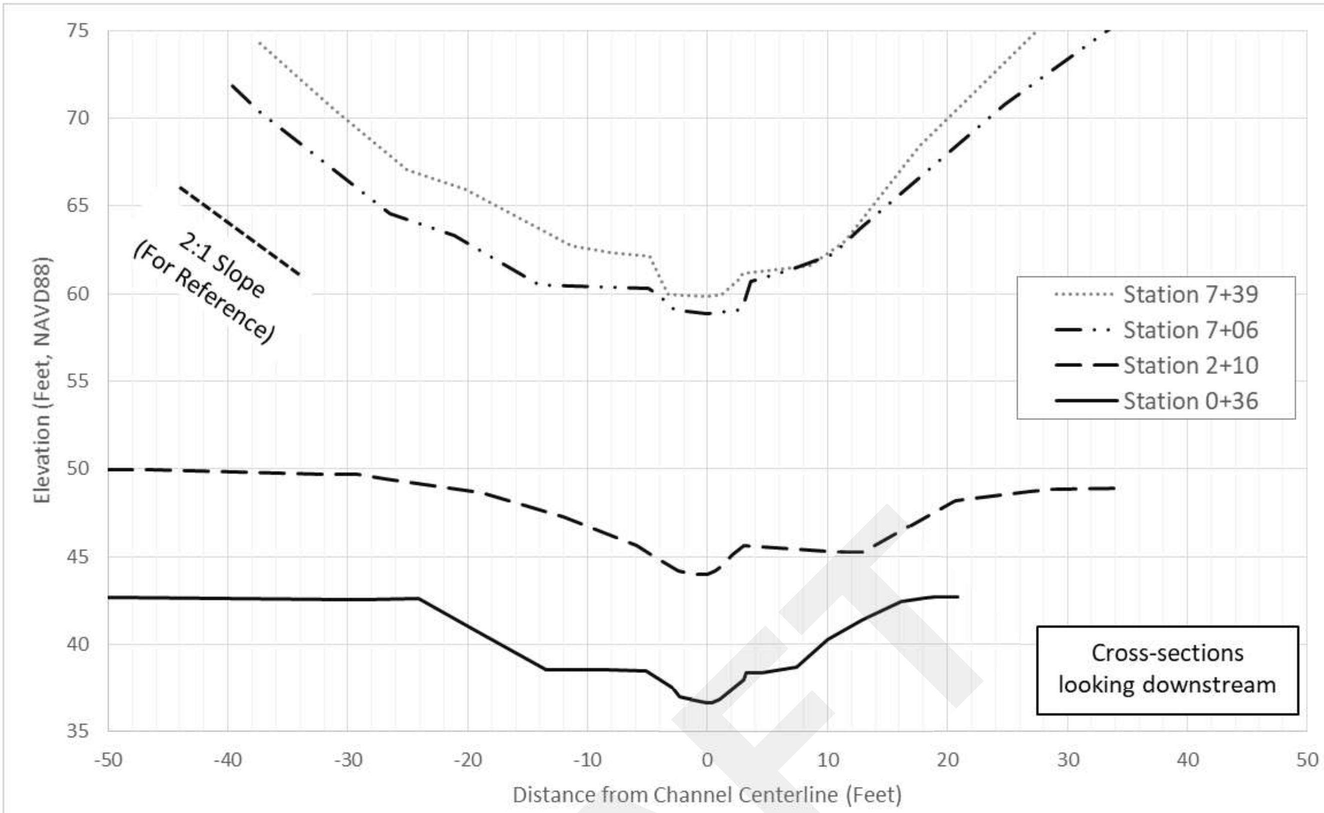

Figure 30: Existing cross-section examples

2.8.3 *Sediment*

Two Wolman pebble counts were conducted on January 21, 2020, at the upstream reference reach, between bankfull widths 2 and 4, with the D_{50} being 0.6 inch; see Figure 29 above for pebble count location. It was obvious after two pebble counts the channel material would be categorized as streambed sediment so a third pebble count would not be needed. The pebble count was located in an area that was beyond the influence of the culvert. The results of the pebble count indicated that the substrate was composed primarily of fine to very coarse gravel with some cobbles. The bed material is a mixture of very fine to coarse gravel, generally smaller than streambed sediment. The largest sediment size in the reference reach observed was a 10-inch-diameter cobble (see Figure 9). Within the watershed the sediment supply is healthy, there was evidence of material moving within the system as sediment deposits were observed downstream of the culvert outlet and upstream of log jams. Table 3 provides a summary of pebble count data. Figure 31 shows sediment size distribution and Figure 32 shows sediment within the reference reach.

Table 3: Sediment properties upstream of project crossing

Particle Size	Upstream Diameter (in)
D_{16}	0.2
D_{50}	0.6
D_{84}	1.4
D_{95}	2.3
D_{100}	10.0

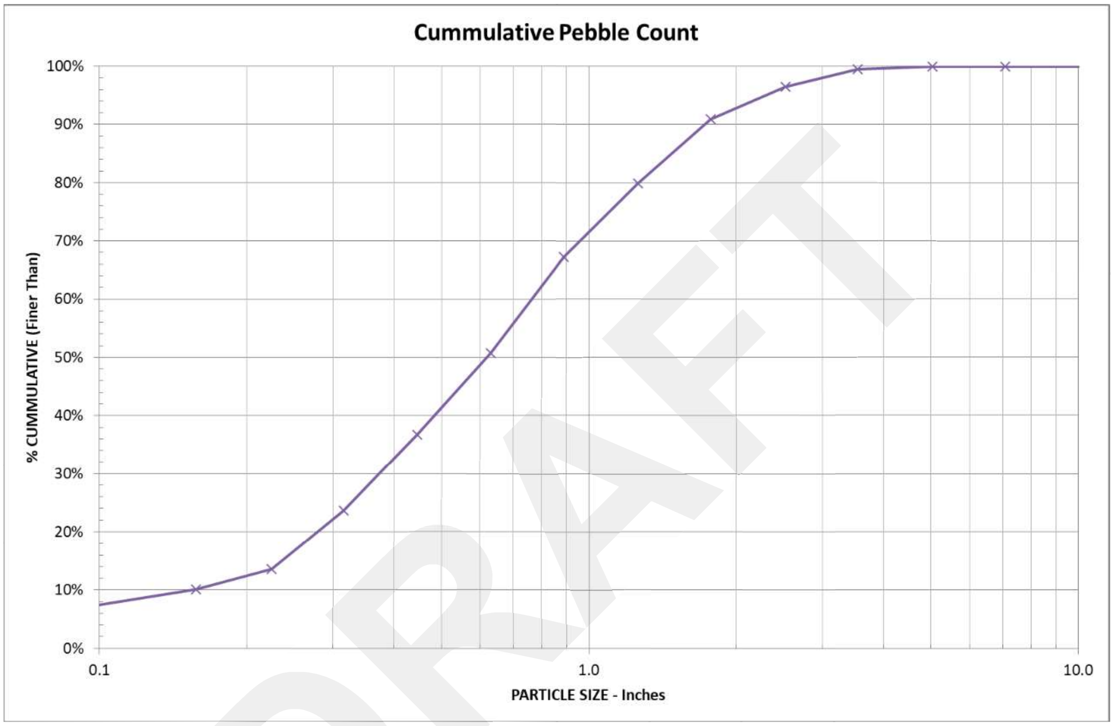

Figure 31: Sediment size distribution

Figure 32: Sediment within reference reach

2.8.4 *Vertical Channel Stability*

A long channel profile was developed from 2020 survey data and 2017 Southwestern Washington LiDAR data (Washington DNR LiDAR Portal 2017). The long channel profile (Figure 33) describes slopes approximately 1,000 feet upstream and 800 feet downstream from the project culvert and includes major landmarks along the tributary. Upstream of the survey extents the slope ranges from approximately 3.7 to 5.0 percent. The slope within the reference reach is approximately 3.2 percent. Downstream of the survey, the slope changes to approximately 2.1 percent for about 75 feet and then steepens to 4.2 percent for 200 feet until the confluence with Schneider Creek.

At the farthest upstream point of the survey the channel is within a confined forested valley with an average slope of 3.2 percent. A fallen log within the channel 60 feet upstream of the culvert inlet acts as a catalyst for a steep 5.5 percent slope that continues to the culvert inlet.

Downstream, the channel begins with an inundated wetland area with intense sediment buildup at the outlet. A fence acts as a debris rack approximately 30 feet downstream of the culvert outlet. The channel continues for about 100 feet at a 3.1 percent slope in a somewhat confined channel, most likely altered by the surrounding residential property until reaching an access road culvert. At that outlet the channel continues another 100 feet at a 1.9 percent slope to the end of the survey.

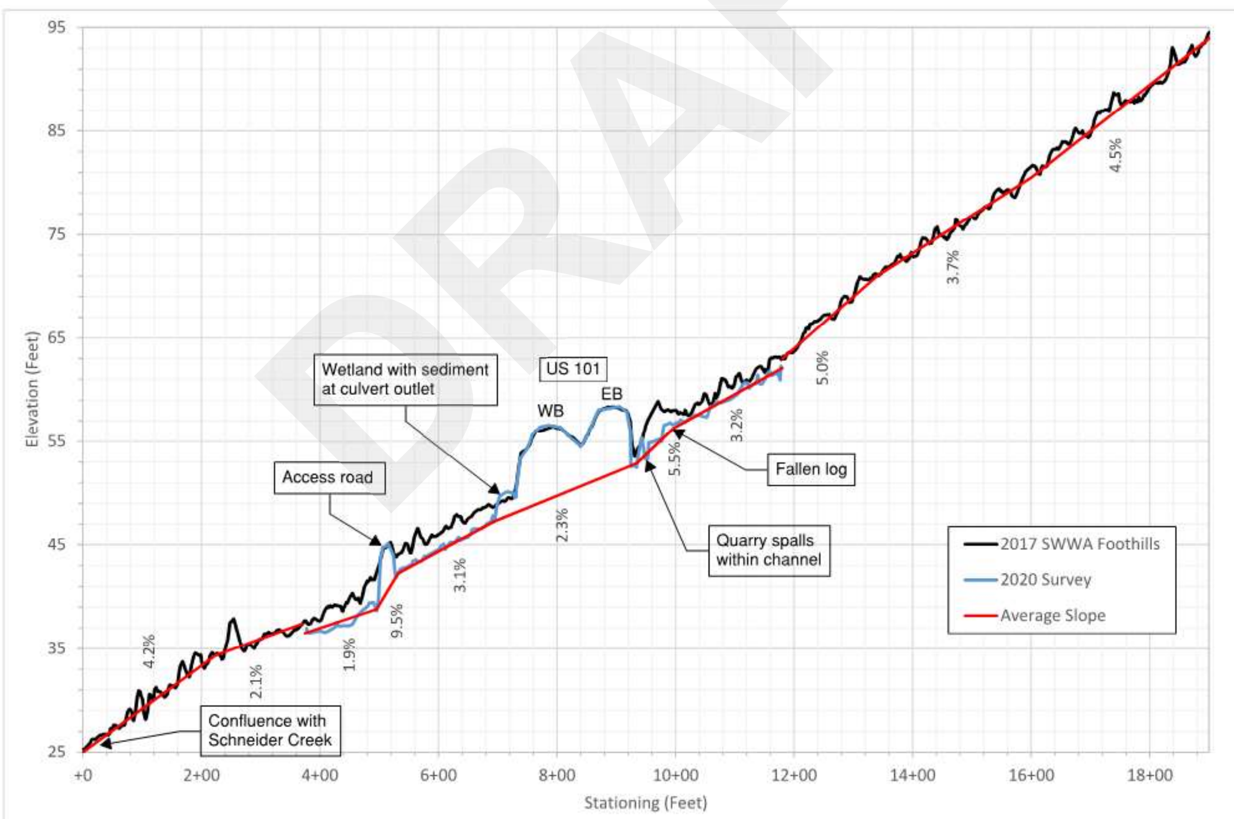

Figure 33: Watershed-scale longitudinal profile

The provided survey shows sediment buildup at the culvert outlet greater than 3 feet. Most of the sediment deposition downstream appears to be caused by the fence as there is a 2-foot drop in bed

elevation there. The fence is within grading extents and will be removed in the proposed condition. See Section 8.2 for detailed information on aggradation and degradation.

2.8.5 *Channel Migration*

Griggs Creek is a confined channel and, based on Google Earth and USGS topography maps, has not migrated much since the 1940s. Channel migration concerns are anticipated to be minimal as the channel is confined upstream by a narrow valley and downstream within tall banks.

2.8.6 *Riparian Conditions, Large Wood, and Other Habitat Features*

The canopy surrounding the project area is forested with a mixture of young and older trees. In general, Griggs Creek lies within the Schneider Prairie, a forested area on the shores of Oyster Bay with some agriculture and residential land throughout. LWM is naturally present within the upstream reach, with less material downstream. The stream includes wood pieces with small log jams that create pools and channel complexity.

The upstream reach is within a forested valley with significant cover along the left and right banks throughout. The mature forest canopy provides good shading and LWM recruitment. Approximately 250 feet upstream of the crossing and beyond there are two logs within the channel that have created a hydraulic drop and provides a small pool in the bend upstream. Another small hydraulic drop occurs over a LWM and debris jam just upstream of the culvert inlet.

The downstream reach is heavily influenced by the surrounding horse ranch. There is not much woody material, and the cover consists of younger trees and a large amount of reed canarygrass. Most of the wood seen in this reach is downstream of the access road culvert on the way to the Schneider Creek confluence. This includes smaller woody material and roots within the channel, within an instance of two live trees covering the channel and creating a 2-foot hydraulic drop. Some LWM recruitment potential occurs in the downstream end of the surveyed reach where the forest canopy widens on the right bank near Schneider Creek.

No evidence of beaver activity was observed during the site visit.

3 Hydrology and Peak Flow Estimates

Griggs Creek is within an ungaged basin, with no long-term historical flow data available. No hydrologic studies, models, or reports were found that summarized peak flows in the basin. A gaged basin with similar characteristics was not located. As a result, USGS regression equations (Mastin et al. 2016) for Region 3 were used to estimate peak flows at the U.S. 101 crossing (Table 4). Inputs to the regression equation included basin size and mean annual precipitation. Griggs Creek has a basin area of 0.37 square mile and a mean annual precipitation within the basin of 61.2 inches (PRISM 2004). The basin was delineated from LiDAR data acquired from the Washington DNR LiDAR Portal (2017 Southwestern Washington) using Arc Hydro. The 2-year peak flow was estimated to be 16.2 cubic feet per second (cfs) and the 100-year flow was estimated to be 51.2 cfs. Average standard error varied from 43.2 to 57.7 percent. Standard error was not applied to the flows used in the hydraulic modeling. Table 4 shows the

calculated peak flows for Griggs Creek at U.S. 101. For more information on the 2080 predicted 100-year flow determination see Section 7.2. Summer low flow conditions are unknown.

Table 4: Peak flows for Griggs Creek at U.S. 101

Mean Recurrence Interval (MRI)	USGS Regression Equation (Region 3) (cfs)	Regression Standard Error (percent)
2	16.2	43.2
10	31.6	45.6
25	39.3	48.1
50	45.0	50.5
100	51.2	51.8
500	65.7	57.7
2080 predicted 100	56.9	NA

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed U.S. 101 Griggs Creek crossing was performed using the United States Bureau of Reclamation's SRH-2D Version 3.2.4 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.0.12 (Aquaveo 2018).

Two scenarios were analyzed for determining stream characteristics for Griggs Creek with the SRH-2D models: (1) existing conditions with the 3-foot-diameter concrete culvert and (2) future conditions with the proposed 17-foot hydraulic opening.

4.1 Model Development

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

4.1.1 *Topographic and Bathymetric Data*

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by Parametrix, which were developed from topographic surveys performed by 1 Alliance in March 2020. The survey data were supplemented with 2017 Southwestern Washington LiDAR data (Washington DNR LiDAR Portal 2017). Proposed channel geometry was developed from the proposed grading surface created by HDR. All survey and LiDAR information is referenced against the North American Vertical Datum of 1988 (NAVD88) and WSDOT horizontal project datum. All elevations presented in this Preliminary Hydraulic Design (PHD) Report are NAVD88.

4.1.2 *Model Extent and Computational Mesh*

The hydraulic model upstream and downstream extents start and end with the edge of the survey. The detailed survey data are stitched into the LiDAR where survey is not available, starting approximately 250 feet upstream of the existing culvert inlet and ending 350 feet downstream of the existing culvert

outlet, measured along the channel centerline. The computational mesh elements are a combination of patched (quadrilateral) and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain. The existing mesh covers a total area of 628,533 SF, with 10,715 quadrilateral and 15,613 triangular elements (see Figure 34). The proposed mesh covers a total area of 628,533 SF, with 11,302 quadrilateral and 15,627 triangular elements (see Figure 35).

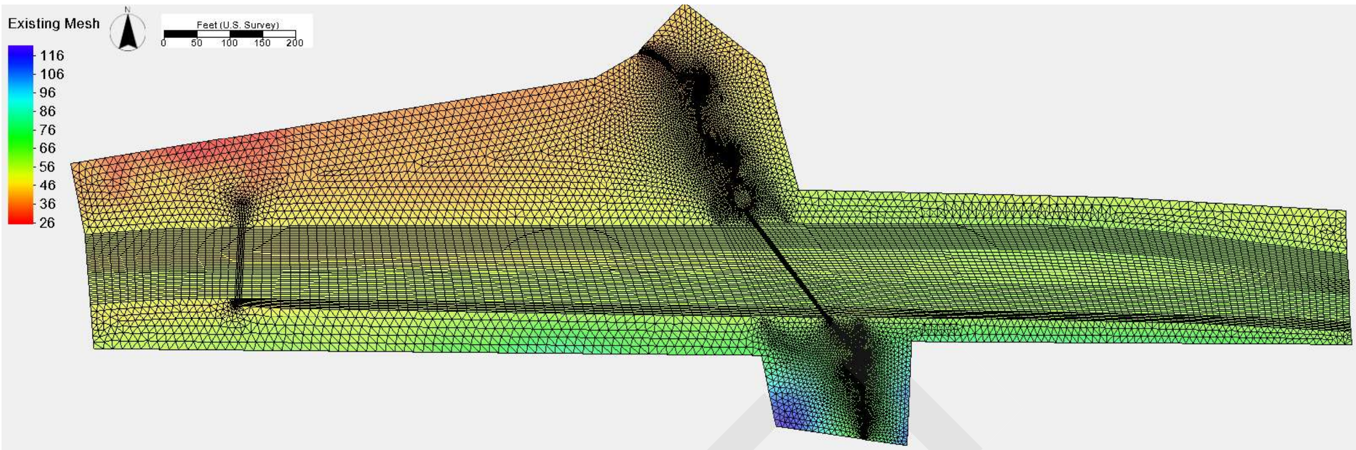

Figure 34: Existing-conditions computational mesh with underlying terrain

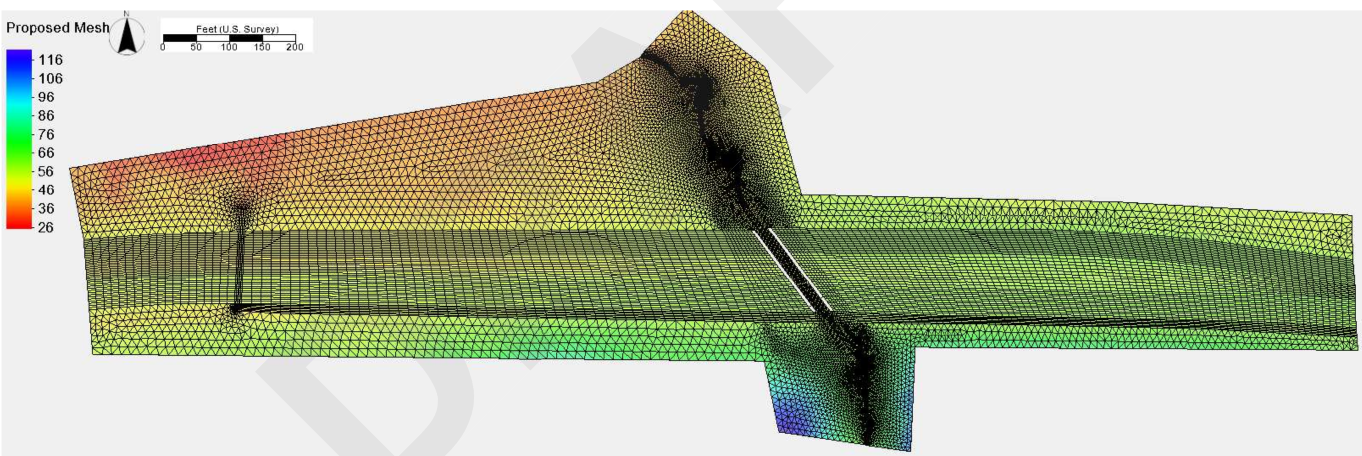

Figure 35: Proposed-conditions computational mesh with underlying terrain

4.1.3 *Materials/Roughness*

Manning’s n values were estimated based on site observations, aerial photography, and standard engineering values (Chow 1959) and are summarized below (Table 5). Aerial imagery was used to get plan form extents of vegetation coverage and compare them with field observations within the floodplains. Roughness in the upstream and downstream floodplains is characterized by 0.03 and 0.1 based on land cover. The upstream and downstream channel is characterized by 0.045. See Figure 36 and Figure 37 for a spatial distribution of hydraulic roughness coefficient values.

Table 5: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Land Cover Type	Manning's n
Channel	0.045
Grass	0.03
Roadway	0.02
Forest	0.1

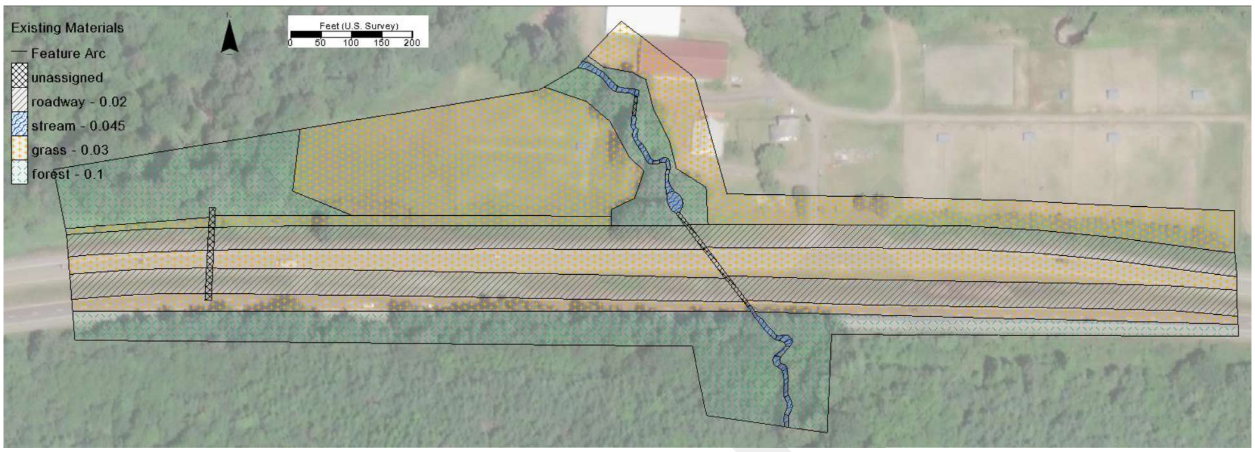

Figure 36: Existing spatial distribution of roughness values in SRH-2D model

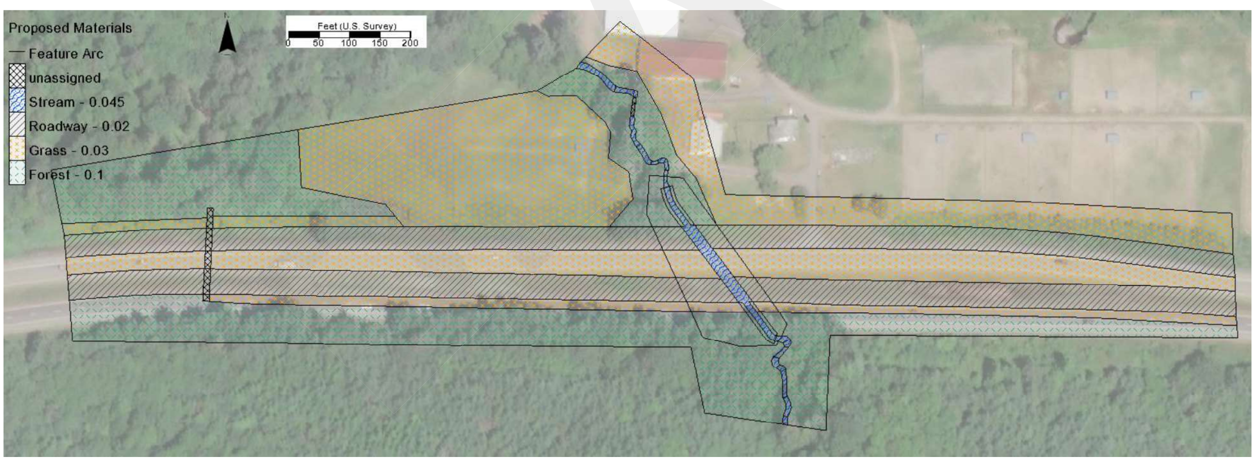

Figure 37: Proposed spatial distribution of roughness values in SRH-2D model

4.1.4 *Boundary Conditions*

Model simulations were performed using constant discharges ranging from the 2-year to 500-year peak flow events summarized in Section 3. External boundary conditions (BCs) were applied at the upstream and downstream extents of the model domain. A constant flow rate was specified at the upstream external boundary condition. Model simulations were run for a sufficiently long duration until the results stabilized across the model domain.

As shown in Figure 38, there are three outflow boundary conditions. The outflow BC 1 at the downstream boundary is used in both the existing and proposed conditions as a normal depth rating

curve. The rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 1.5 percent as measured from the survey and a composite roughness of 0.045. See Figure 39 for a rating curve.

For the existing conditions, two additional outflow boundary conditions were incorporated in the model because of backwater from the undersized culvert. For outflow BC 2, a constant water surface elevation (WSEL) developed from SMS was used based on an assumed downstream slope of 6 percent as measured from the LiDAR data (this area was outside survey extents) and a composite roughness of 0.045. For outflow BC 3, a normal depth rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 0.05 percent as measured from the survey and a composite roughness of 0.045. See Figure 40 for a rating curve.

Figure 38: Boundary condition locations

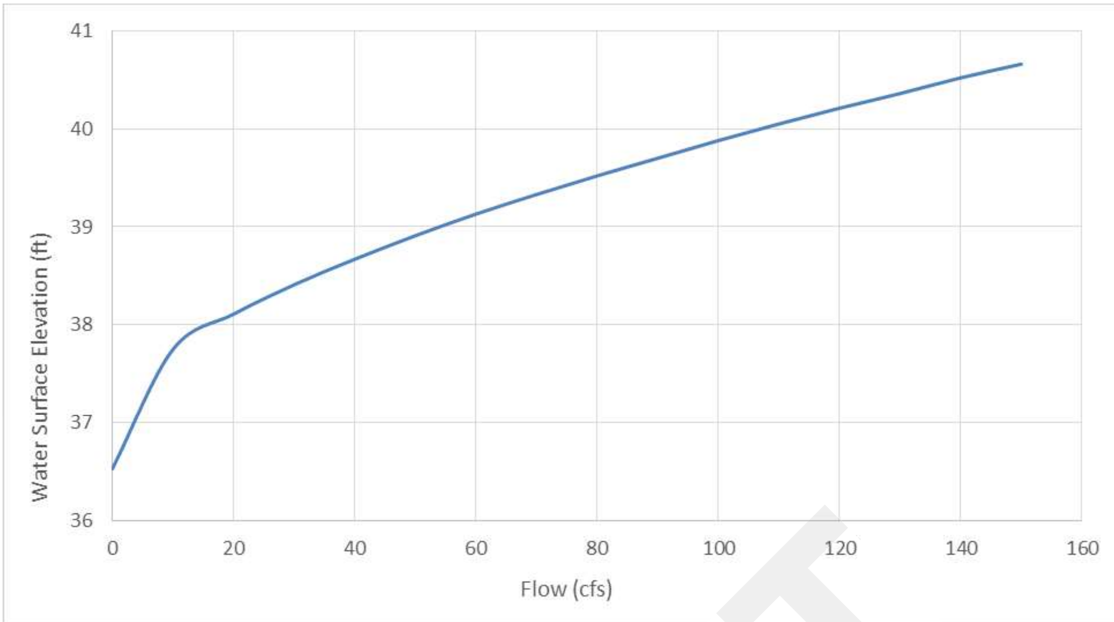

Figure 39: Griggs Creek downstream normal depth rating curve for BC 1

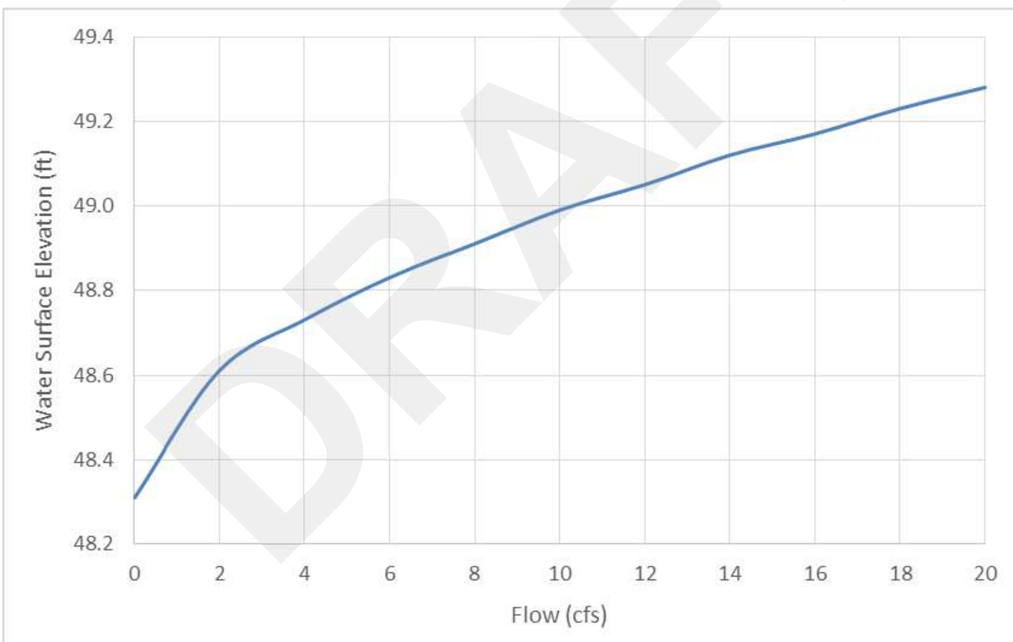

Figure 40: Normal depth rating curve for BC 3

A HY-8 internal boundary condition was specified in the existing-conditions model to represent the Griggs Creek existing circular concrete culvert crossing. The existing crossing was modeled as a 3-foot-diameter circular pipe within HY-8. A Manning's roughness of 0.012 was assigned to the culvert. The culvert was assumed to have an embedment depth of 9 inches based on field observations. See Figure 41.

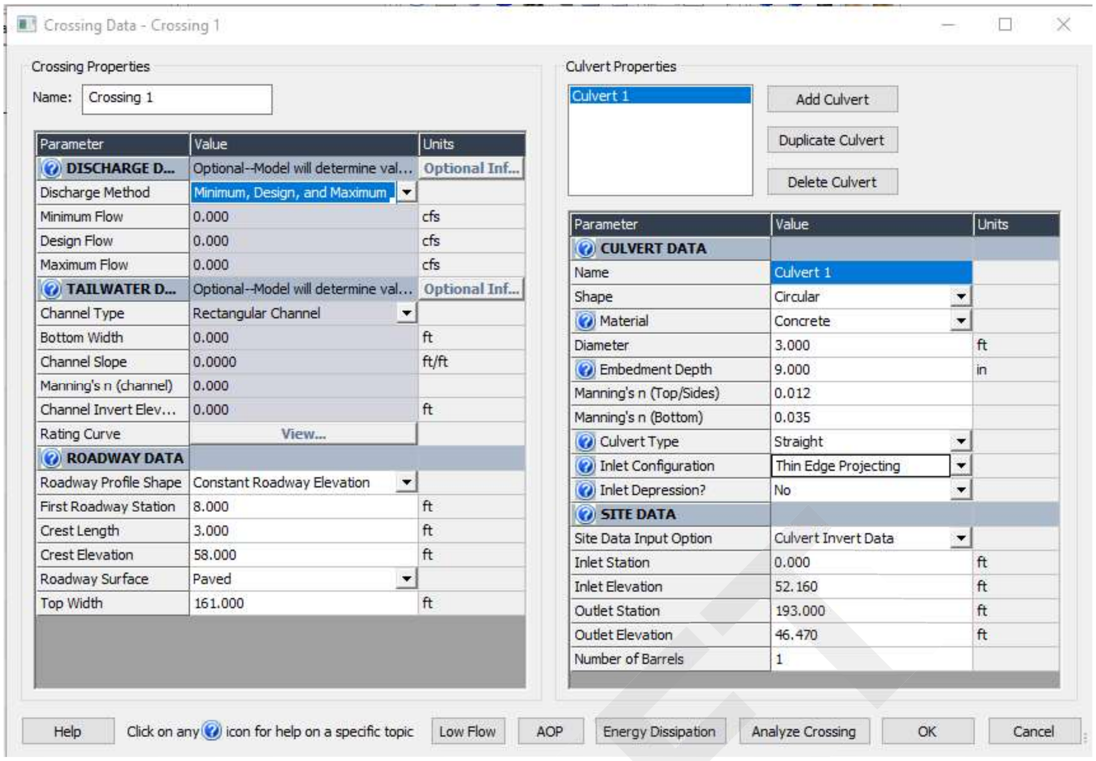

Figure 41: HY-8 Griggs Creek culvert parameters

AHY-8 internal boundary condition was specified in the existing-conditions model to represent the access road culvert downstream of the U.S. 101 Griggs Creek crossing. The crossing was modeled as a 2.5-foot diameter polyvinyl chloride (PVC) circular pipe within HY-8. A Manning's roughness of 0.011 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel. See Figure 42. This crossing is not used by flow in the proposed conditions.

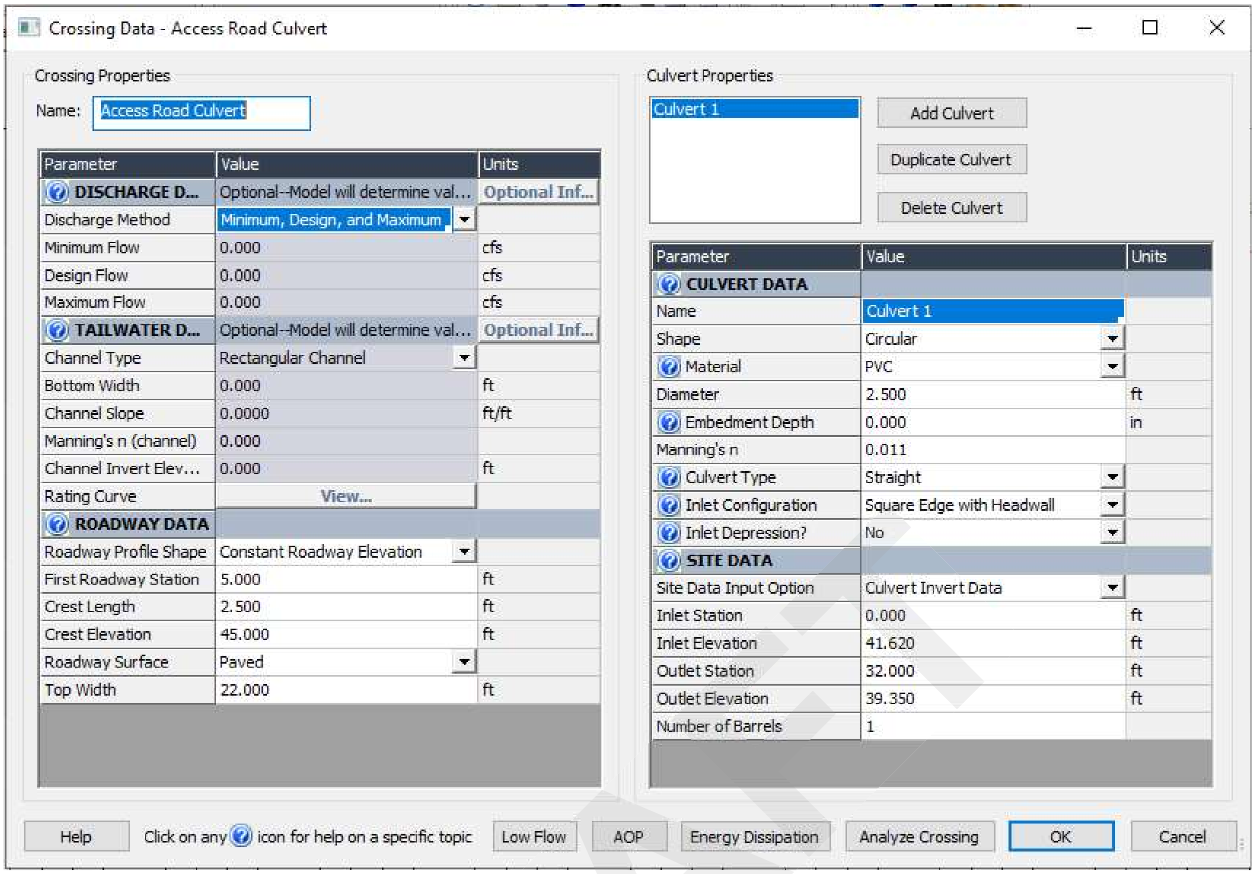

Figure 42: HY-8 Griggs Creek access road culvert parameters

A HY-8 internal boundary condition was specified in the existing-conditions model to represent the culvert approximately 750 feet to the west of the Griggs Creek culvert. This culvert crosses U.S. 101, and is used only in the existing condition when the Griggs Creek culvert is backwatered. It connects with Schneider Creek downstream of the crossing. The culvert was modeled as a 1.5-foot-diameter concrete circular pipe within HY-8. A Manning's roughness of 0.012 was assigned to the culvert. The culvert was assumed to be unobstructed and free from any stream material within the barrel. See Figure 43.

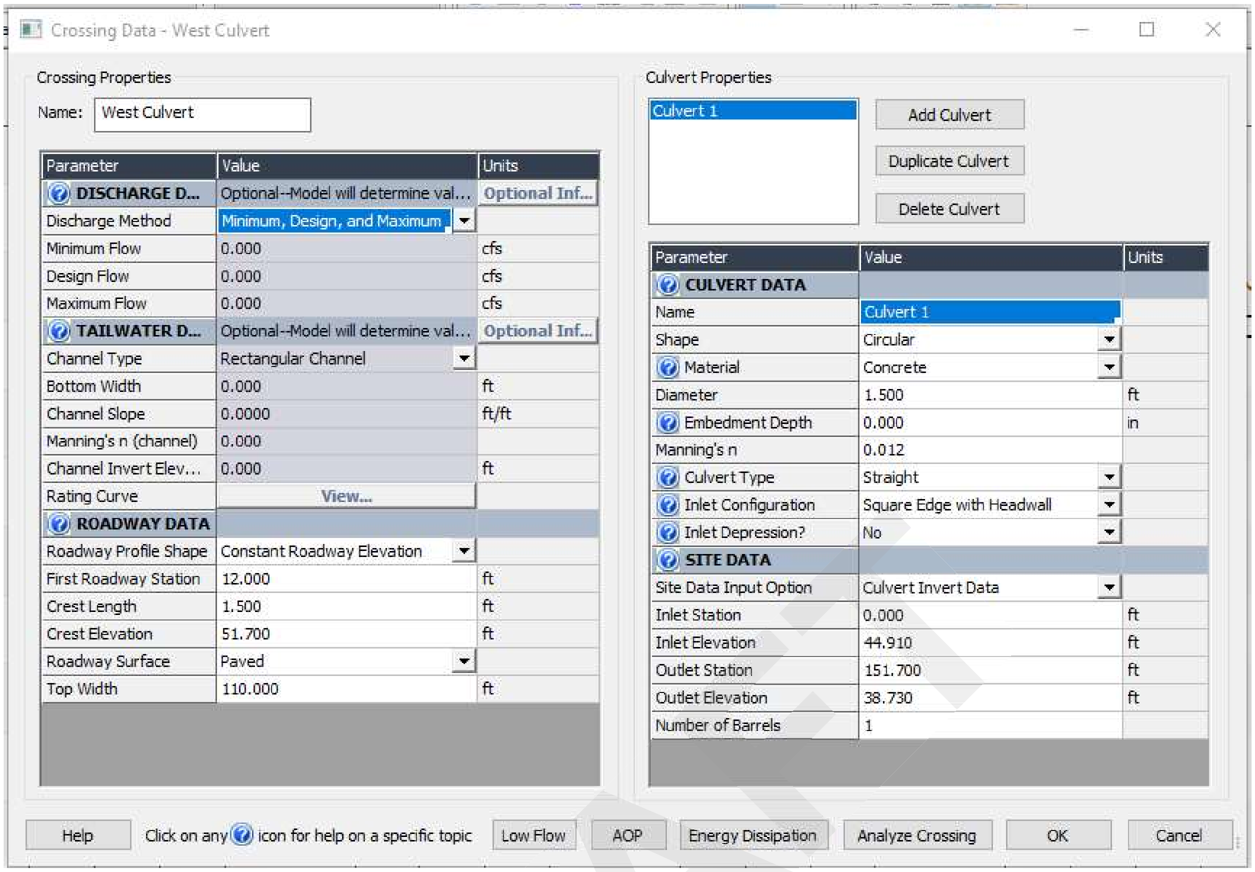

Figure 43: HY-8 U.S. 101 culvert parameters

4.1.5 *Model Run Controls*

Settings in the SRH-2D model control were kept consistent between existing- and proposed-conditions models. The model began at time zero and ended at 2 hours with a 0.5-second time step. The initial condition was dry and the default flow module was used.

4.1.6 *Model Assumptions and Limitations*

The SRH-2D hydraulic model was developed to determine the minimum hydraulic structure opening, establish the proposed structure low chord elevation (and associated freeboard), and characterize hydraulic parameters used to design the crossing. The use of a constant inflow rate is an appropriate assumption to meet the model objectives. Using a constant inflow rate provides a conservative estimate of inundation extents and water surface elevation associated with a given peak flow, which is used to determine the structure size and low chord.

Using the approach described in this study, each scenario is run for a sufficient time to fill storage areas and for water surface elevations to stabilize until flow upstream equals flow downstream. This modeling method does not account for the attenuation of peak flows between the actual upstream and downstream hydrographs, in particular with a large amount of storage upstream of the existing undersized culvert. During an actual runoff event, it is unlikely that the area upstream of the culvert would fill up entirely. An unsteady simulation could be used to route a hydrograph through the model to estimate peak flow attenuation for existing and proposed conditions. During an unsteady simulation, the

areas upstream of the existing culvert would act as storage and, as a result, the flow downstream of the crossing would likely be less than the current design peak flow event. Estimates of the downstream increases to water surface elevation and flow based on the constant inflow model results may then underestimate the downstream flood impacts. An unsteady analysis is outside the current scope of this preliminary study, but could be considered at a later stage of design. Therefore, the changes to the peak flow rate downstream of the project cannot be quantified with this approach.

The model results and recommendations in this PHD Report are based on the conditions of the project site and the associated watershed at the time of this study. Any modifications to the site, man-made or natural, could alter the analysis, findings, and recommendations contained herein and could invalidate the analysis, findings, and recommendations. Site conditions, completion of upstream or downstream projects, upstream or downstream land use changes, climate changes, vegetation changes, maintenance practice changes, or other factors may change over time. Additional analysis or updates may be required in the future as a result of these changes.

4.2 Existing-Conditions Model Results

The existing-conditions model shows that the existing U.S. 101 crossing is undersized. All flows above the 2-year storm use the roadside ditch west of the crossing to a culvert approximately 700 feet away. For the 100-year event, 30 percent of the flow travels down the roadside ditch exiting via the west culvert and farther west down the roadside ditch. Exit boundary conditions were placed at these exit points; downstream of both points, the excess flow enters Schneider Creek.

Because of the confined nature of the stream, the 2-year flow does not use the floodplains, but for the 100-year event and above the floodplains both upstream and downstream are activated. The roadway does not overtop for any scenarios.

For the 100-year event velocities within the upstream reference reach range from 4.3 to 5.6 feet per second (ft/s), and the velocities within the downstream reach range from 3.0 to 4.6 ft/s. High areas for velocity (6.5 to 8.6 ft/s for the 100-year event) include areas of steep slopes and downstream of obstructions such as woody material jams.

Hydraulic characteristics are summarized within the main channel in Table 6. Locations of the cross sections are illustrated in Figure 44 and stream stationing in Figure 45.

The existing-conditions hydraulic profile is provided in Figure 46. The profile shows that water backwaters approximately 150 feet upstream of the existing culvert during the 100-year flood event. A cross section upstream is provided in Figure 47. All other cross-section figures are provided in Appendix C.

Velocity magnitudes are illustrated at the 100-year event in Figure 48 and Figure 49 and summarized for the main channel and left overbank (LOB) and right overbank (ROB) in Table 7.

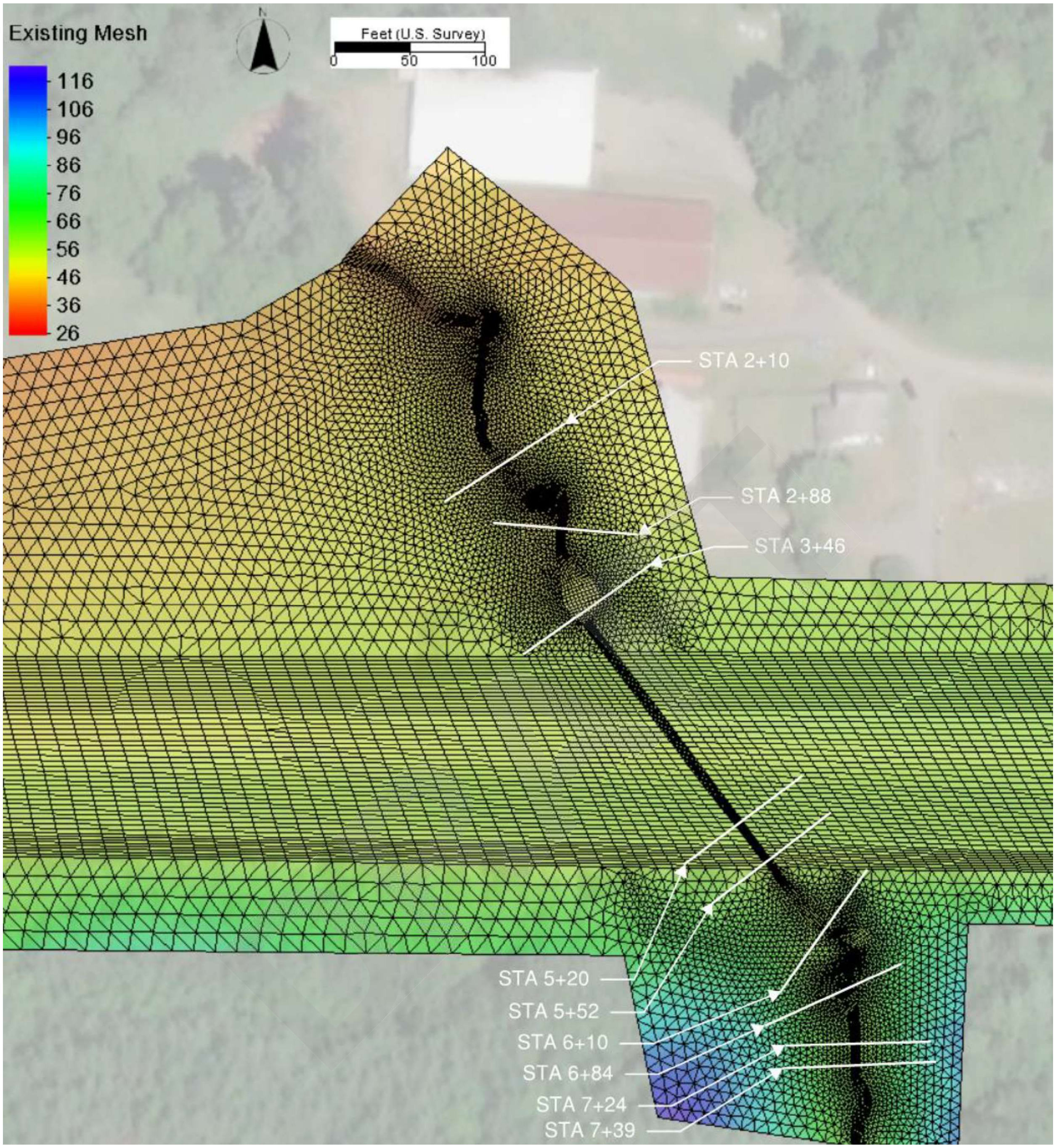

Figure 44: Locations of cross sections used for results reporting

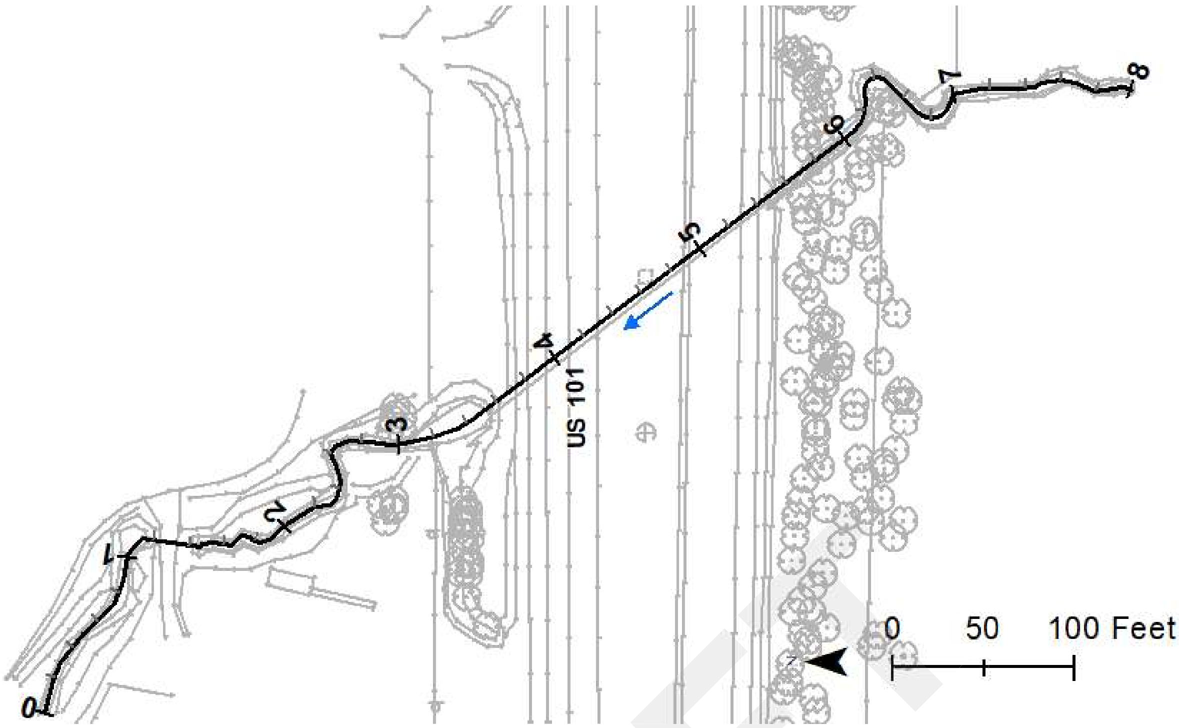

Figure 45: Longitudinal profile stationing for existing and proposed conditions

Table 6: Hydraulic results for existing conditions within the main channel

Hydraulic Parameter	Cross Section	2-year	25-year	50-year	100-year	500-year
Average Water surface elevation (ft)	XS 2+10	45.0	45.4	45.5	45.5	45.5
	XS 2+88	47.3	47.7	47.7	47.7	47.8
	XS 3+46	50.4	50.5	50.6	50.6	50.6
	XS 5+52	54.7	56.5	56.7	56.9	57.3
	XS 6+10	57.3	57.7	57.8	57.9	58.1
	XS 6+84	59.0	59.5	59.7	59.8	60.0
	XS 7+24	60.2	60.7	60.8	60.9	61.1
	XS 7+39	60.6	61.1	61.3	61.4	61.6
Max depth (ft)	XS 2+10	1.0	1.5	1.5	1.5	1.5
	XS 2+88	0.9	1.2	1.3	1.3	1.3
	XS 3+46	0.5	0.7	0.7	0.8	0.8
	XS 5+52	2.5	4.3	4.5	4.7	5.0
	XS 6+10	0.7	1.2	1.2	1.4	1.6
	XS 6+84	0.7	1.3	1.4	1.5	1.8
	XS 7+24	0.8	1.3	1.4	1.5	1.7
	XS 7+39	0.8	1.3	1.4	1.5	1.8
Average velocity (ft/s)	XS 2+10	3.2	4.4	4.5	4.6	4.6
	XS 2+88	3.3	4.2	4.2	4.3	4.3
	XS 3+46	2.1	2.9	2.9	3.0	3.0
	XS 5+52	1.1	1.1	1.2	1.3	1.4
	XS 6+10	4.1	5.4	5.7	5.9	6.4
	XS 6+84	3.3	4.3	4.3	4.3	4.4
	XS 7+24	3.7	5.2	5.5	5.6	5.9
	XS 7+39	3.7	5.2	5.3	5.4	5.7
Average shear (lb/SF) [a]	XS 2+10	0.9	1.1	1.2	1.2	1.2
	XS 2+88	1.0	1.4	1.4	1.4	1.4
	XS 3+46	0.4	0.7	0.7	0.7	0.7
	XS 5+52	0.1	0.1	0.1	0.1	0.1
	XS 6+10	1.2	1.9	2.0	2.1	2.4
	XS 6+84	1.1	1.3	1.2	1.2	1.2
	XS 7+24	1.0	1.6	1.7	1.8	1.9
	XS 7+39	1.1	1.6	1.7	1.7	1.8

a. lb/SF = pounds per square foot.

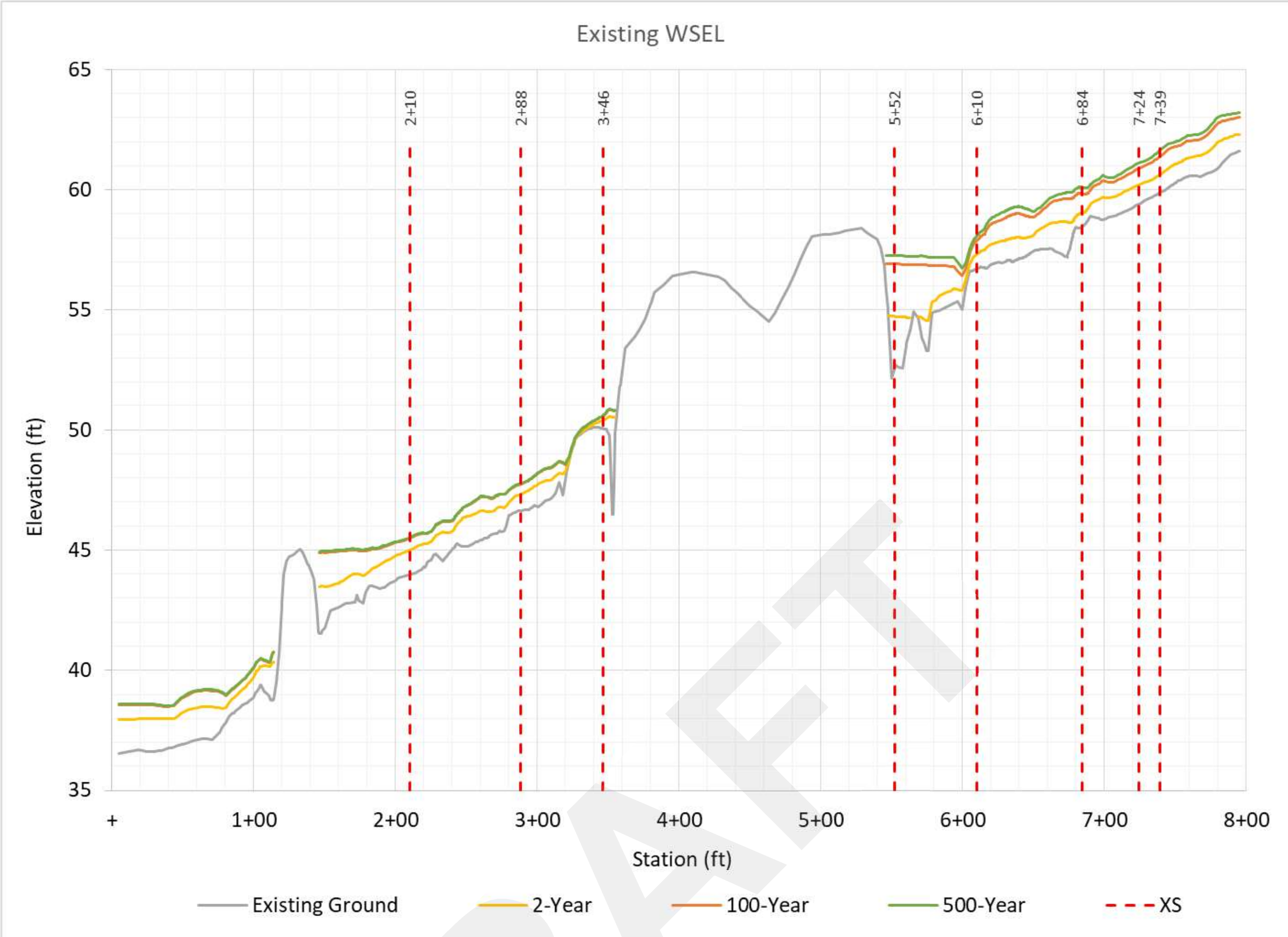

Figure 46: Existing-conditions water surface profiles

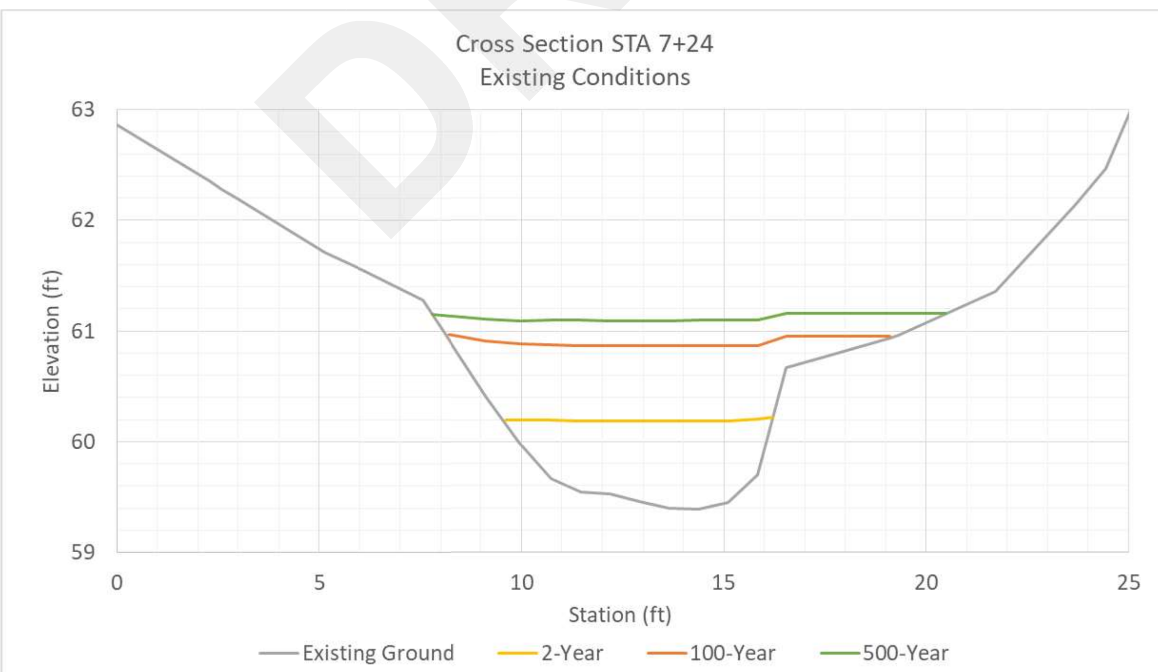

Figure 47: Typical upstream existing channel cross section

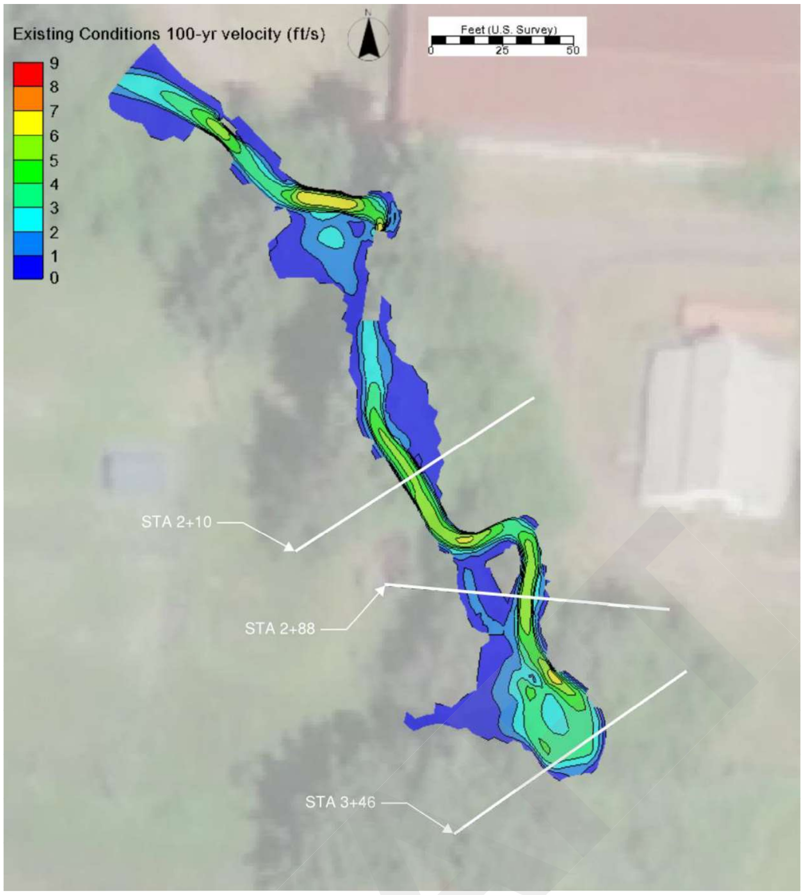

Figure 48: Downstream existing-conditions 100-year velocity map with cross-section locations

Figure 49: Upstream existing-conditions 100-year velocity map with cross-section locations

Table 7: Existing-conditions velocities including floodplains at select cross sections

Location	Q100 Average Velocities (ft/s)		
	LOB[a]	Main Ch.	ROB[a]
Downstream reach (2+10)	1.8	4.6	0.4
Downstream of structure (2+88)	0.6	4.3	1.0
Immediately downstream of structure (3+46)	0.8	3.0	0.7
Immediately upstream of structure (5+52)	0.5	1.3	0.2
Upstream of structure 2 (6+10)	1.9	5.9	2.8
Upstream of structure 1 (6+84)	0.5	4.3	1.5
Reference reach 2 (7+24)	1.7	5.6	1.1
Reference reach 1 (7+39)	1.5	5.4	1.1

a. LOB/ROB locations determined from existing-conditions Q2 extent.

4.3 Channel Design

This section describes the channel design developed for Griggs Creek.

4.3.1 *Floodplain Utilization Ratio*

Because of the confined reach, Griggs Creek's floodplain utilization ratio (FUR) is well below 3.0. Using the 100-year flood as the assumed flood-prone width (FPW), the upstream FUR is 1.3 within the reference reach and the downstream FUR is 1.8.

4.3.2 *Channel Planform and Shape*

The proposed channel planform and shape were determined from the reference reach and observation of the existing conditions via the site visit and provided survey. Both upstream and downstream the channel generally maintains a consistent shape, which was used for the proposed design. At the top of the banks, benches extend out at a 12:1 slope for 5 feet (see Figure 50).

The proposed channel is expected to perform similarly to the existing channel but without the backwater effect at the U.S. 101 crossing from the undersized culvert. Based on the proposed hydraulic model the 2-year flow almost reaches the left and right floodplain, similar to existing.

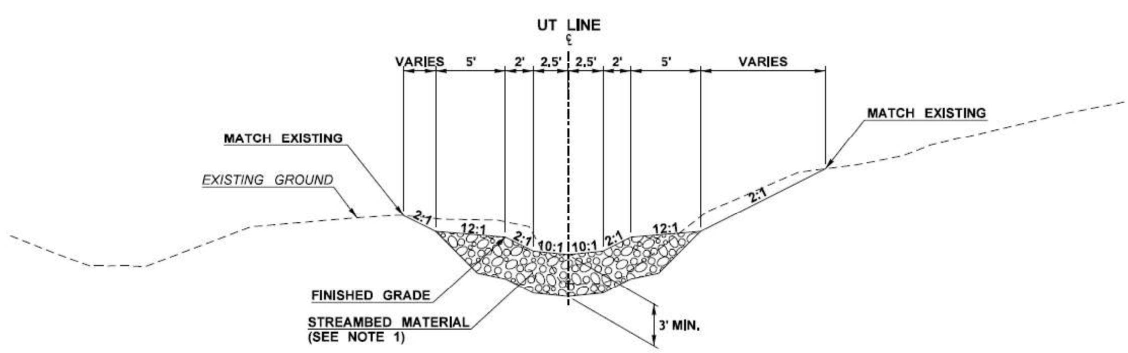

Figure 50: Design cross section

4.3.3 *Channel Alignment*

The channel grading totals 308 LF, with grading 70 LF upstream and 45 LF downstream of the existing structure. The channel follows the same horizontal planform shape and alignment as the existing conditions, there have been no constraints identified.

4.3.4 *Channel Gradient*

The WCDG recommends that the proposed culvert bed gradient not be more than 25 percent steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 3.11 percent and the average upstream channel gradient is approximately 3.2 percent, resulting in a slope ratio of 0.97.

There are signs of aggradation at the existing culvert outlet. Most of the aggradation appears to be caused by deposition of material upstream of a debris jam at a fence.

4.4 Design Methodology

The proposed fish passage design was developed using the 2013 *Water Crossing Design Guidelines* (Barnard 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2019). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because of the bankfull width, FUR, and slope ratio.

The bankfull width of Griggs Creek is 9.0 feet, below the threshold to require bridge design methodology. The floodplain width of the 100-year storm was not 3 times greater than the bankfull width so that did not require a move to an unconfined bridge. The slope ratio was less than the threshold of 1.25 required to use the bridge design methodology. Stream simulation design methodology was deemed appropriate for this crossing.

4.5 Future Conditions: Proposed 17-Foot Minimum Hydraulic Opening

The hydraulic opening 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 opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified.

The starting point for the design of all WSDOT structures is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic opening of 13 feet was determined to be the minimum starting point. The existing culvert length, 193 feet, is greater than 15 times the bankfull width. Considered a long culvert, the proposed span was increased by 30 percent to 17 feet, to account for meandering within the structure. The northbound and southbound lanes could have separate culverts with a short segment of open channel in the median, and is shown in the Appendix D plan sheets. However, because the open-channel segment in the middle is short, the long structure criterion is still being recommended to provide additional structure width to accommodate planform variations.

The proposed design surface was created based on existing conditions directly upstream and downstream of the crossing and taking into consideration what was observed in the natural-conditions

simulation. This resulted in a proposed surface with an overall slope of 3.11 percent. Within the 17-foot structure, the left and right banks are equidistant from the thalweg. Culvert walls were simulated in the SRH-2D model by creating voids in the mesh that were offset from the thalweg. In the model, the 2-year storm remains within the banks, typical for the existing conditions within the reference reach. For the 100-year storm the structure has a wetted top width of 11 feet, with a maximum thalweg depth of 1.4 feet. The proposed structure is able to pass all flows, and the overflow culvert to the west is not used for any of the flow events with the proposed condition.

The proposed results within the structure show that the 100-year, 100-year climate change, and 500-year water surface elevations activate the floodplain but do not reach the structure walls.

The velocity within the structure is an average of 5.8 ft/s within the main channel for the 100-year event. At the two upstream reference reach cross sections the average velocity ranges from 5.4 to 5.5 ft/s at the 100-year event. At the downstream reach the velocity ranges from 4.8 to 5.8 ft/s at the 100-year event. Hydraulic characteristics are summarized within the main channel in Table 8. Locations of the cross sections are illustrated in Figure 53 and Figure 54.

The proposed-conditions hydraulic profile is provided in Figure 51. The profile shows that water no longer backwaters upstream of the roadway during all flood events. A cross section within the structure is provided in Figure 52. All other cross-section figures are provided in Appendix B.

Velocity magnitudes are illustrated at the 100-year event in Figure 53 and Figure 54 and summarized for the main channel and floodplains in Table 9.

Table 8: Average main channel hydraulic results for proposed condition upstream and downstream of structure

Hydraulic Parameter	Cross Section	2-year	25-year	50-year	100-year	100-year Climate Change	500-year
Average water surface elevation (ft)	XS 2+10	45.0	45.5	45.6	45.7	45.8	45.9
	XS 2+88	47.3	47.8	47.8	47.9	48.0	48.0
	XS 3+46	49.1	49.5	49.6	49.7	49.7	49.8
	XS 5+20 [a]	54.5	54.9	55.0	55.1	55.1	55.2
	XS 5+52	55.5	55.9	56.0	56.1	56.1	56.2
	XS 6+10	57.3	57.7	57.8	57.9	57.9	58.0
	XS 6+84	59.0	59.5	59.6	59.8	59.9	60.0
	XS 7+24	60.2	60.7	60.8	60.9	61.0	61.1
	XS 7+39	60.6	61.1	61.3	61.4	61.5	61.6
Max depth (ft)	XS 2+10	1.0	1.6	1.6	1.7	1.8	1.9
	XS 2+88	0.9	1.3	1.4	1.4	1.5	1.6
	XS 3+46	0.8	1.2	1.3	1.4	1.5	1.6
	XS 5+20 [a]	0.8	1.2	1.3	1.4	1.4	1.5
	XS 5+52	0.8	1.2	1.3	1.4	1.4	1.5
	XS 6+10	0.8	1.2	1.3	1.4	1.5	1.6
	XS 6+84	0.7	1.3	1.4	1.5	1.6	1.8
	XS 7+24	0.8	1.3	1.4	1.5	1.6	1.7
	XS 7+39	0.8	1.3	1.4	1.5	1.6	1.8
Average velocity (ft/s)	XS 2+10	3.3	4.8	5.0	5.2	5.4	5.7
	XS 2+88	3.4	4.5	4.6	4.8	4.9	5.1
	XS 3+46	3.5	5.3	5.5	5.8	6.0	6.3
	XS 5+20 [a]	3.5	5.3	5.6	5.8	6.0	6.3
	XS 5+52	3.6	5.3	5.6	5.9	6.1	6.4
	XS 6+10	3.7	5.3	5.5	5.7	5.9	6.1
	XS 6+84	3.3	4.3	4.0	4.3	4.3	4.4
	XS 7+24	3.6	5.1	5.3	5.5	5.6	5.8
	XS 7+39	3.7	5.2	5.3	5.4	5.6	5.7
Average shear (lb/SF) [b]	XS 2+10	0.9	1.2	1.3	1.4	1.5	1.6
	XS 2+88	1.1	1.5	1.5	1.6	1.7	1.8
	XS 3+46	1.1	1.6	1.8	1.9	2.0	2.1
	XS 5+20 [a]	1.1	1.7	1.8	1.9	2.0	2.1
	XS 5+52	1.1	1.7	1.8	1.9	2.0	2.2
	XS 6+10	1.1	1.7	1.7	1.8	1.9	2.0
	XS 6+84	1.1	1.3	1.3	1.2	1.2	1.2
	XS 7+24	1.0	1.6	1.7	1.8	1.8	1.9
	XS 7+39	1.1	1.6	1.7	1.7	1.7	1.8

a. Within structure.

b. lb/SF = pounds per square foot.

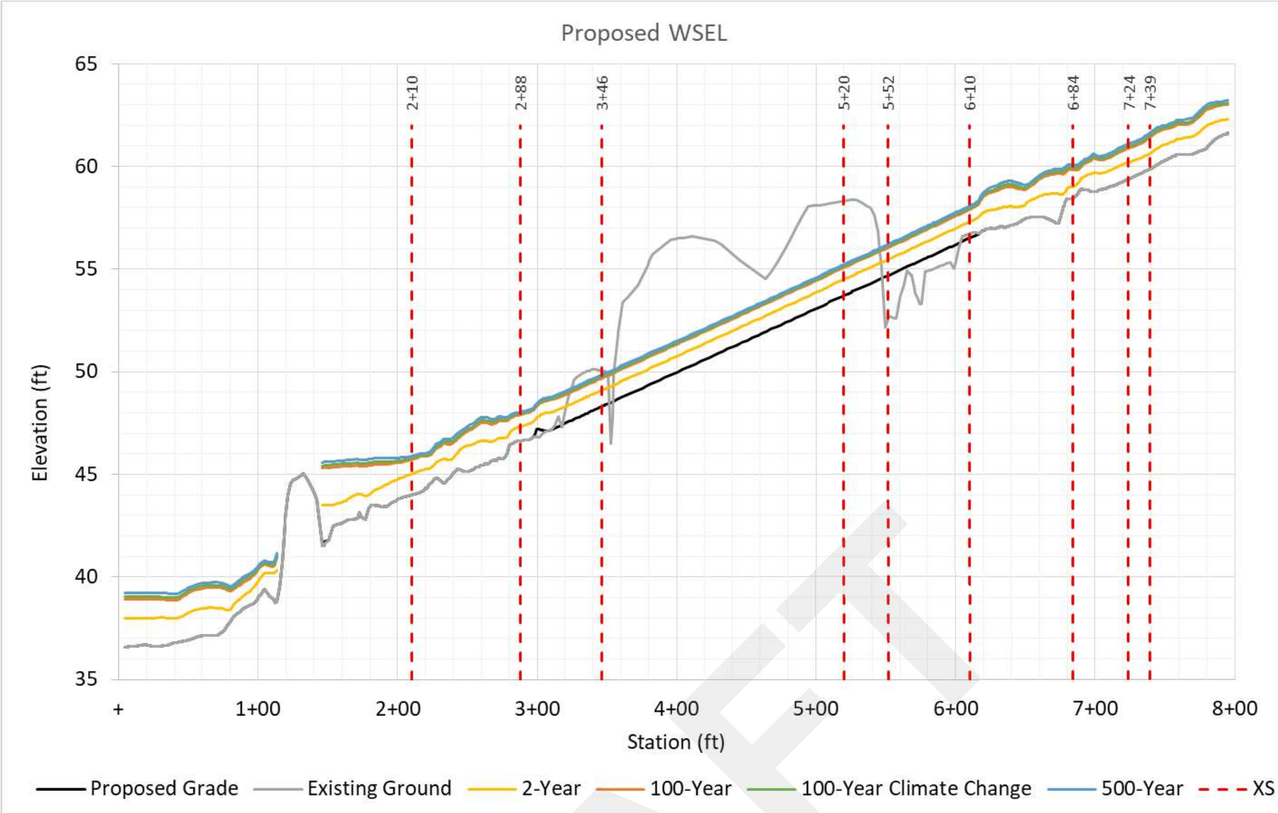

Figure 51: Proposed-conditions water surface profiles

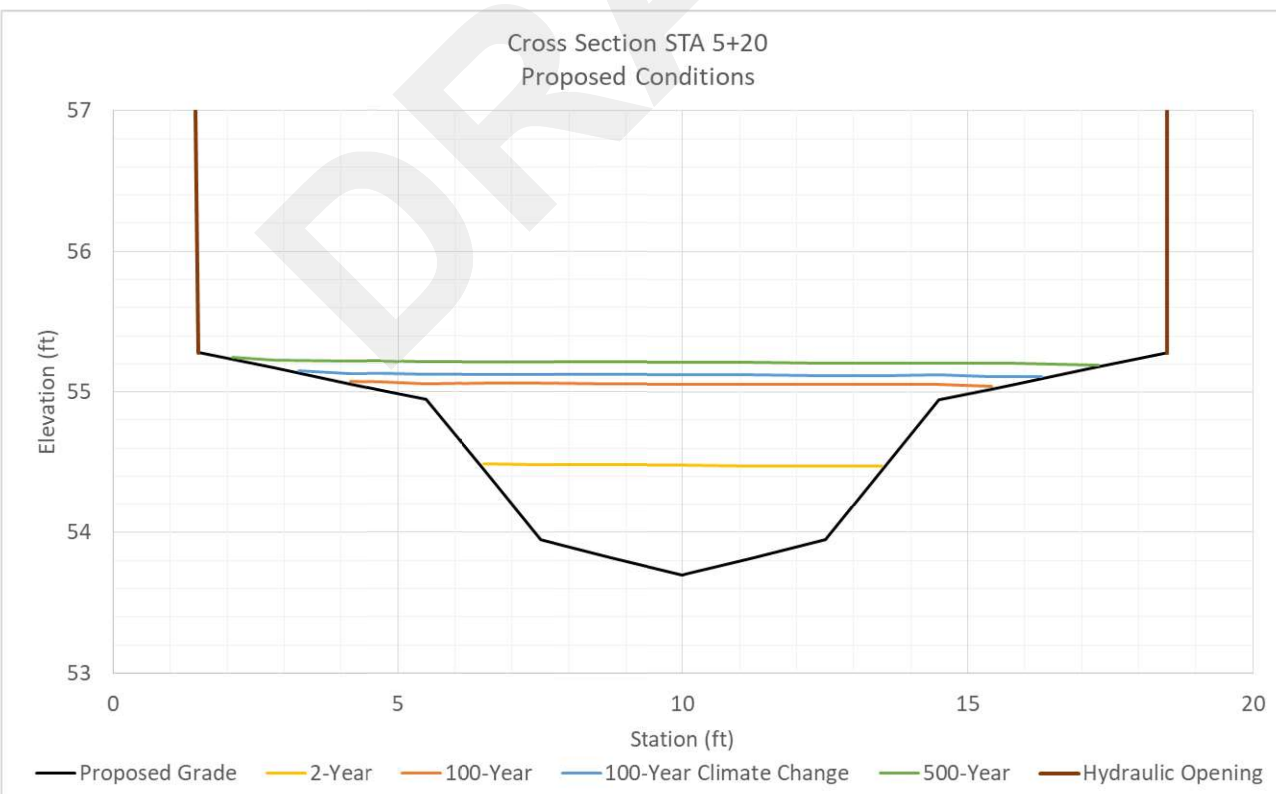

Figure 52: Typical section through proposed structure

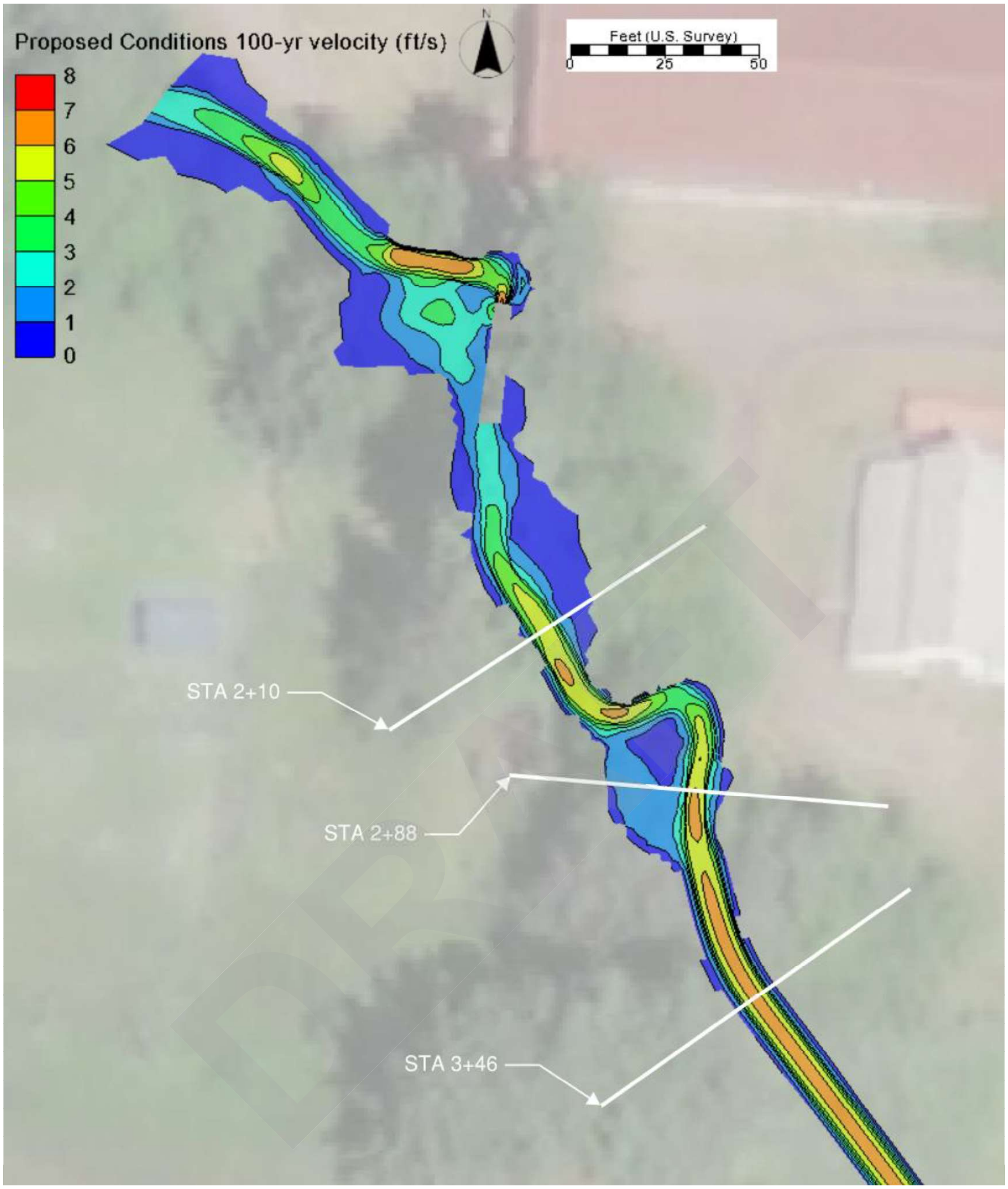

Figure 53: Downstream proposed-conditions 100-year velocity map

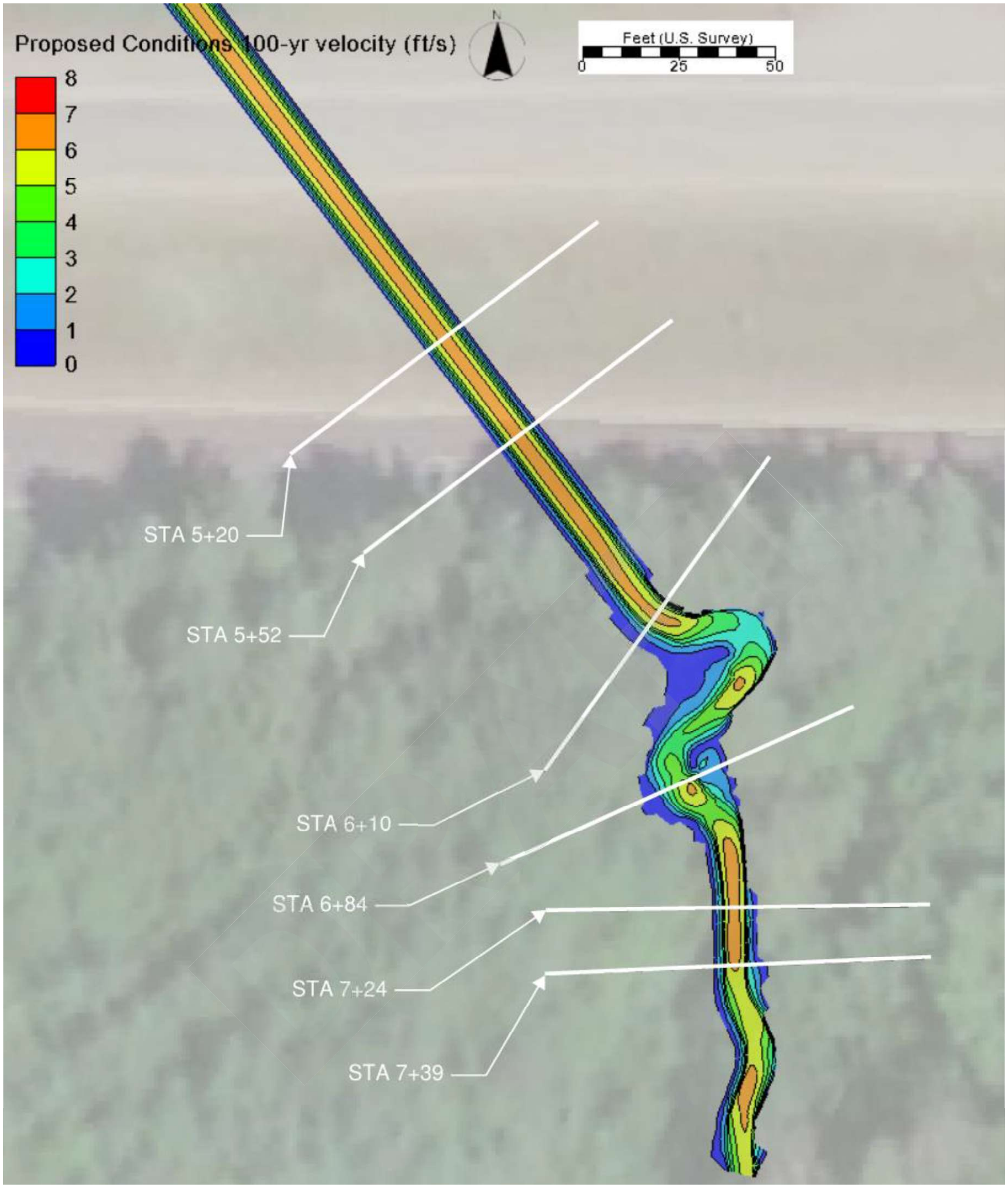

Figure 54: Upstream proposed-conditions 100-year velocity map

Table 9: Proposed velocities including floodplains at select cross sections

Location	Q100 Average Velocities (ft/s)		
	LOB[a]	Main Ch.	ROB[a]
Downstream reach (2+10)	3.1	5.2	1.1
Downstream of structure (2+88)	1.3	4.8	1.1
Immediately downstream of structure (3+46)	1.8	5.8	1.9
Through structure (5+20)	2.5	5.8	2.1
Immediately upstream of structure (5+52)	2.0	5.9	1.9
Upstream of structure 2 (6+10)	1.7	5.7	2.0
Upstream of structure 1 (6+84)	0.5	4.3	1.5
Reference reach 2 (7+24)	1.4	5.5	1.1
Reference reach 1 (7+39)	1.5	5.4	1.1

a. LOB/ROB locations determined from proposed-conditions 2-year storm extent.

4.6 Water Crossing Design

This section describes the water crossing design for Griggs Creek.

4.6.1 *Structure Type*

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

4.6.2 *Minimum Hydraulic Opening Width and Length*

Using Equation 3.2 of the WCDG, a minimum 13-foot opening was considered for the crossing based on the 9-foot bankfull width. The proposed structure length is approximately 185 feet, assuming a single structure. Based on the structure length being greater than 15 times the bankfull width, the structure was increased by 30 percent to account for additional channel meander within the structure.

Based on the factors described above, a minimum hydraulic opening of 17 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. Within the reference reach the valley toe width is 16-17 feet wide, matching the proposed 17-foot wide structure and allowing room for the stream to meander similar to the reference reach. The projected 2080 100-year flow event was evaluated and the velocity comparisons for these flow rates can be seen in Table 10 below.

Table 10: Velocity comparison for 17-foot structure

Location	100-Year Velocity (ft/s)	Projected 100-Year Velocity (ft/s)	Difference (ft/s)
Reference reach (7+24)	5.5	5.6	0.2
Upstream of structure	5.9	6.1	0.2
Through structure	5.8	6.0	0.2
Downstream of structure	5.8	6.0	0.2
Velocity ratio	0.9	0.9	-

Note: Velocity ratio calculated as Vstructure/Vupstream.

No size increase was determined to be necessary to accommodate climate change.

A minimum hydraulic opening of 17 feet is recommended. This includes the 30 percent increase in structure span because of a longer structure length. The northbound and southbound lanes could have separate culverts with a short segment of open channel in the median. However, because the open-channel segment in the middle is short, the long structure criterion is still being recommended to provide additional structure width to accommodate planform variations.

4.6.3 *Freeboard*

The WCDG recommends the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate, allow the free passage of debris expected to be encountered, and generally suggests a minimum of 2-foot freeboard for streams of this size above the 100-year water surface elevation. WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year water surface elevation and the projected 2080 100-year water surface elevation.

The minimum required freeboard at this location based on bankfull width was 2 feet at the 100-year flow event. The water depth at the 100-year flow event at the deepest point within the structure is 1.36 feet. The 2080 projected 100-year water depth at this point is 1.43 feet, an increase of 0.07 foot. A minimum structure height of 3.5 feet above the thalweg is required to meet the minimum freeboard requirement at the 2080 projected 100-year event. If it is practicable to do so, a minimum of 5 feet between the channel thalweg elevation and inside top of structure is recommended for maintenance and monitoring purposes. The PHD drawings currently show a structure with 5 feet of clearance, but the impacts to the roadway profile may be deemed too significant in the future. At a minimum, the structure must provide 3.5 feet of clearance above the thalweg to meet the freeboard requirements.

Long-term degradation, aggregation, and debris risk were also evaluated at this location. Aggradation can currently be seen directly downstream of the crossing. However, the aggradation appears to be attributed primarily to a debris jam at the downstream fence. Additionally, the minimum hydraulic opening has been increased by 30 percent for the long culvert criterion, which will provide room for lateral migration if aggradation does occur. More information on the risk for long-term degradation and aggradation can be found in Section 8.

4.6.3.1 Past Maintenance Records

As discussed previously in Section 2.4, WSDOT Area 2 Maintenance was contacted to determine whether there were ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance records were requested but not yet provided.

4.6.3.2 Wood and Sediment Supply

The upstream reach has a high potential for local recruitment as it flows through a heavily forested valley. The downstream reach has less potential for local recruitment as the riparian corridor has fewer large trees. The narrow valley upstream and 9-foot bankfull width limits the size of wood that can be transported. Currently, there is more wood material within the upstream reach than the downstream reach. Existing LWM is described further in Section 2.8.6.

There is a risk for aggradation as previously discussed based on the site observations. It is not anticipated that LWM would have an impact on the aggradation potential. See Sections 4.3.4 and 8.2 for further discussion.

4.6.3.3 Flooding

As stated in Section 2.3, the crossing is not within a regulated floodplain. The existing-conditions model does not show the roadway flooding during higher flows. Instead, the culvert backwaters and flows parallel to U.S. 101 along established roadside ditches to an overflow culvert to the west of the crossing. The proposed condition reduces upstream water surfaces and removes the flow going down the ditch to the next culvert to the west.

4.6.3.4 Future Corridor Plans

There are currently no long-term plans to improve U.S. 101 through this corridor.

5 Streambed Design

This section describes the streambed design developed for U.S. 101 MP 357.4 Griggs Creek.

5.1 Bed Material

The proposed bed material gradation was created using WSDOT Standard Specification material to mimic the gradation documented in the pebble count as closely as possible. The proposed mix will consist of 100 percent streambed sediment. A comparison of the observed and proposed streambed material size distribution is provided in Table 11.

Table 11: Comparison of observed and proposed streambed material

Particle Size	Observed Diameter (in)	Proposed Diameter (in)
D_{16}	0.2	0.02
D_{50}	0.6	0.8
D_{84}	1.4	2.1
D_{95}	2.3	2.4
D_{100}	10.0	2.5

For sediment mobility, the Modified Critical Shear Stress Approach as described in Appendix E of the United States Forest Service (USFS) Guidelines for all systems under 4 percent were used to analyze mobility for the proposed streambed material at Griggs Creek. The sediment mobility analysis indicates that all material sizes are anticipated to move at the 2-year flow and higher. The sediment supply within the system appeared to be healthy during the site visit, and it was deemed acceptable to place material that is mobile because the proposed streambed material is very close in size to the observed existing material. See Appendix C for streambed sizing and sediment mobility calculations.

5.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Griggs Creek.

5.2.1 *Design Concept*

The proposed channel is designed to mimic existing conditions as much as possible by following natural bends and disturbing only the area necessary to adequately tie in to the existing ground and replace the structure under U.S. 101. LWM will be placed to offer channel-forming features, complexity, and enhanced habitat for fish passage. Within the structure, meander bars will be included to introduce hydraulic complexity to the channel and to avoid channel entrainment on the culvert walls. The meander bars will consist of 70% 8-inch cobbles and 30% streambed sediment and will partially span the channel. Sediment mobility, the Modified Critical Shear Stress Approach, was used to determine the size of the meander bars, based on this analysis the D84 is stable at the 2-year event, and unstable at the 25-year event and above. Sediment mobility calculations for meander bars is included in Appendix C.

The 75th percentile of key piece density in accordance with Fox and Bolton (2007) recommends 10 key pieces, 36 total LWM pieces, and 121.6-cubic-yard (yd^3) volume for the total 308 LF regraded channel. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading due to development. A conceptual LWM layout that has been developed for this project area is provided in Figure 55. The conceptual layout proposes 16 key pieces, 38 total LWM pieces, and 103.2 yd^3 for the project reach. Of the 308 LF project reach, 185 LF is the proposed structure, limiting the amount of channel available for wood placement outside the structure but within proposed grading limits. Key pieces and total number of LWM pieces satisfies and exceeds Fox and Bolton (2007) 75th percentile, and wood volume satisfies 85 percent of Fox and Bolton's 75th percentile criterion.

It is not expected that fish stranding during summer flows will be a risk as the proposed structure provides a consistent connection between the upstream and downstream reaches. LWM will encourage the formation of deep pools in areas of the channel for fish refugia.

Because of the downstream access road 2.5-foot-diameter PVC culvert, it is anticipated that wood will be anchored to avoid downstream travel and a potential barrier at the culvert inlet. Final stability of LWM and mobile wood will be assessed during FHD.

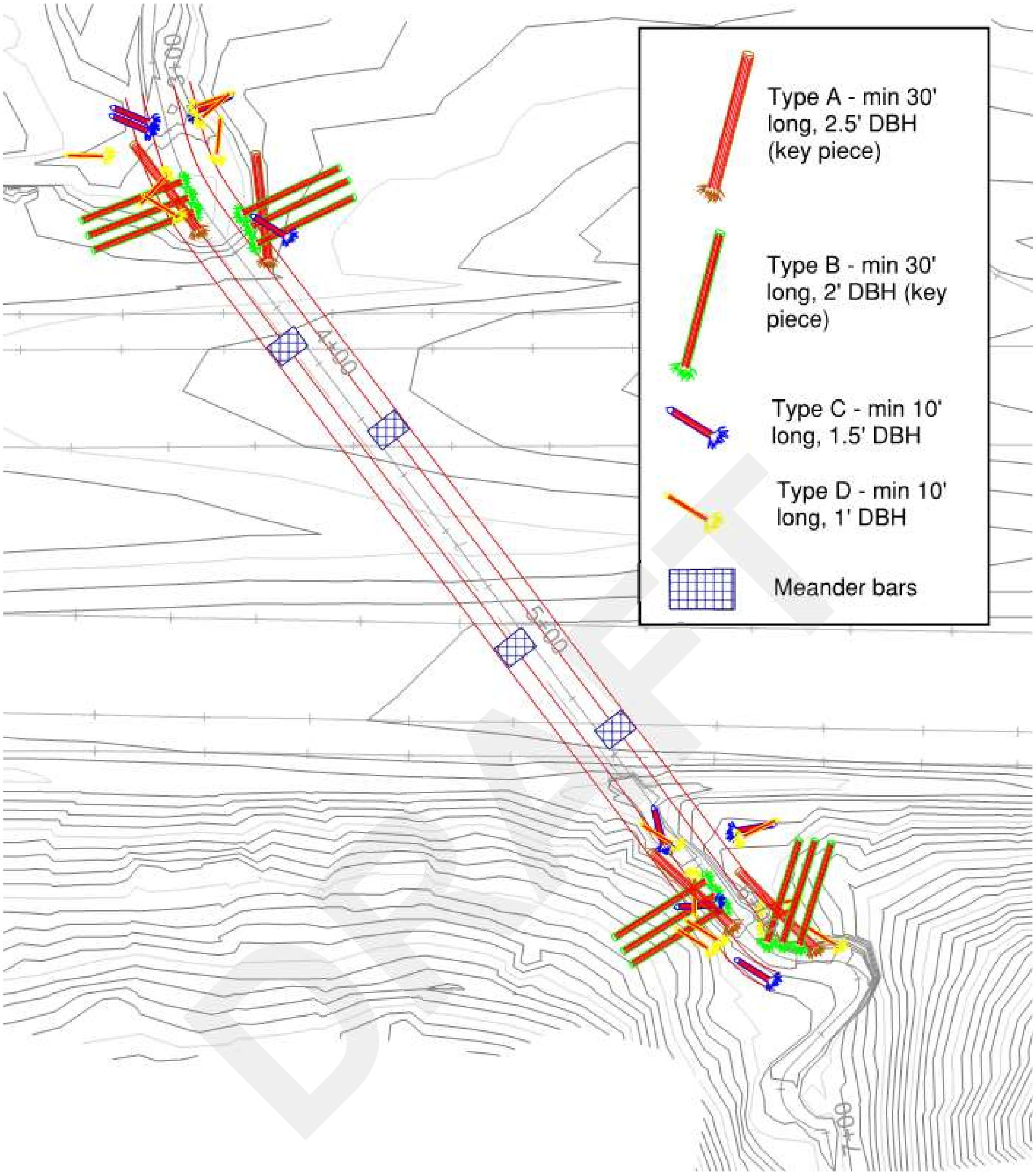

Figure 55: Conceptual layout of habitat complexity

6 Floodplain Changes

This project is not within a mapped floodplain. The pre-project and expected post-project conditions were evaluated to determine whether there would be a change in water surface elevation and floodplain storage.

6.1 Floodplain Storage

Floodplain storage is anticipated to be impacted by the proposed structure. The installation of a larger hydraulic opening will reduce the amount of backwater and associated peak flow attenuation that was

being provided by the smaller, existing culvert. There is not anticipated to be infrastructure risks with the changed floodplain storage. A comparison of pre- and post-project peak flow events was not quantified as the models were run with a constant flow rate specified at the upstream boundary of the model.

6.2 Water Surface Elevations

Installation of the proposed structure would eliminate the backwater impacts upstream of the existing culvert, resulting in a reduction in water surface elevation upstream. The water surface elevation is reduced by as much as 1 foot at the inlet of the existing culvert at the 100-year event as shown in Figure 56, Figure 57 and Figure 58.

Figure 57 and Figure 58 provide a plan view of changes in WSEL from existing to proposed conditions along the channel thalweg. The dark gray areas represent locations of new flooding extents that were not inundated under existing conditions. Because the existing culvert was modeled using HY-8 (see description in Section 4.1.4), flow underneath the roadway did not show up in the 2D results (as seen in plan view), making the area underneath the proposed structure all dark gray. The dark purple areas represent extents of flow from the existing-conditions 100-year simulation that are not activated by proposed conditions.

Downstream of the culvert, channel regrading for proposed conditions causes a rise as much as 0.2 foot in water surface elevation near STA 3+20. Past the outlet, the proposed 100-year water surface elevation increases by 0.1 to 0.5 foot. The downstream water surface elevation rise is a result of an increase in flow within Griggs Creek downstream of the U.S. 101 culvert when compared to existing conditions because all flow is conveyed through the proposed channel and the overflow culvert is not engaged. Figure 58 shows the extent to which backwater is eliminated. Within this figure, negative values represent a decrease or elimination of wetness and water surface elevation from existing to proposed conditions. Positive values represent an increase in water surface elevation from existing to proposed conditions.

The increase in water surface elevations and floodplain extents downstream is not anticipated to impact existing buildings as the flooding stays within the channel banks except for the overtopping of the private road access culvert. However, overtopping already occurred at the private road access culvert and the increase in water surface elevation does not push flow outside the banks horizontally.

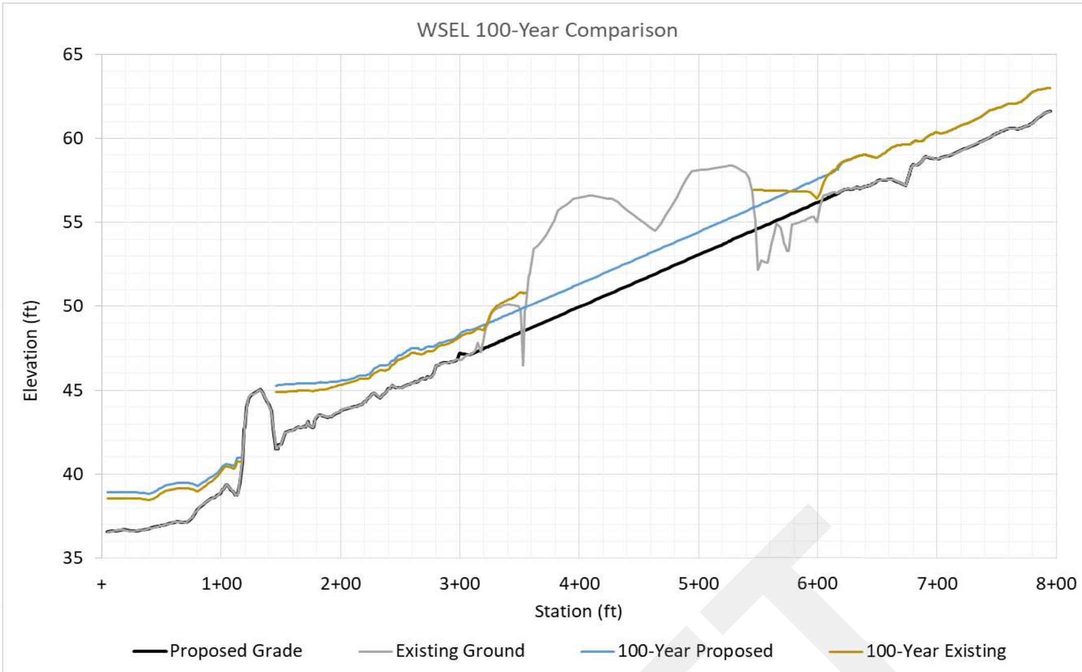

Figure 56: Existing and proposed 100-year water surface profile comparison

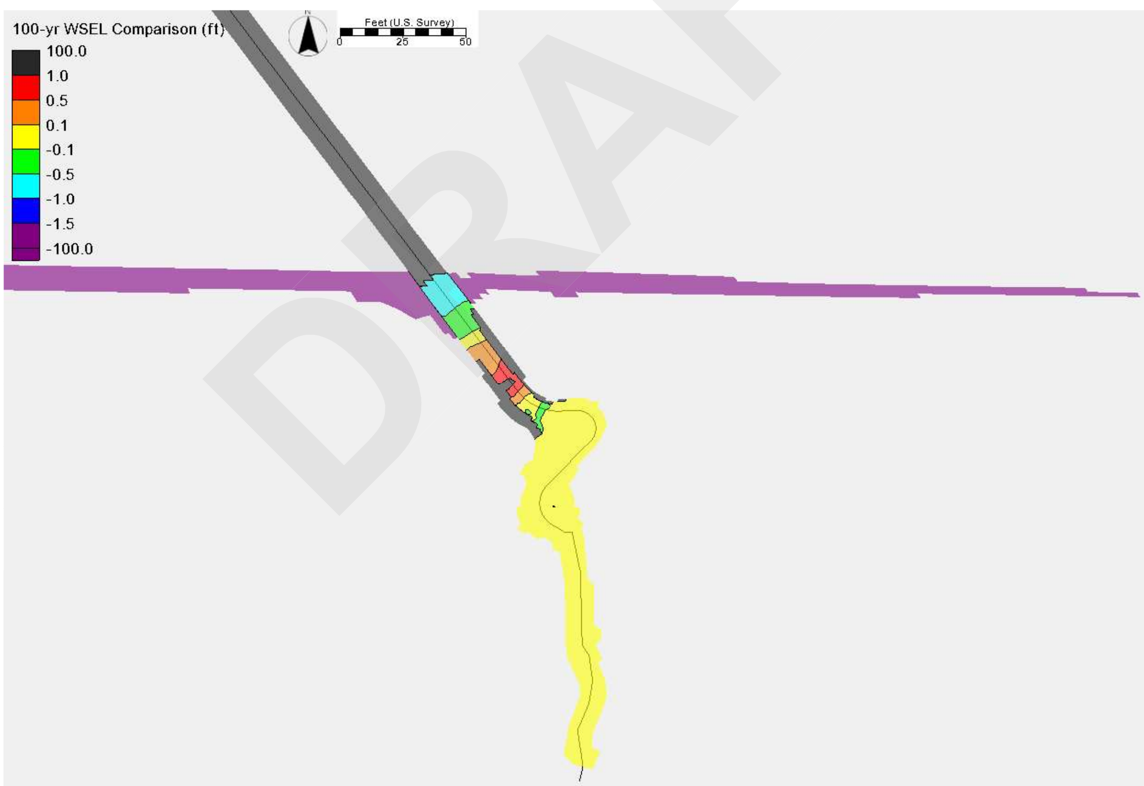

Figure 57: Upstream water surface elevation change from existing to proposed conditions

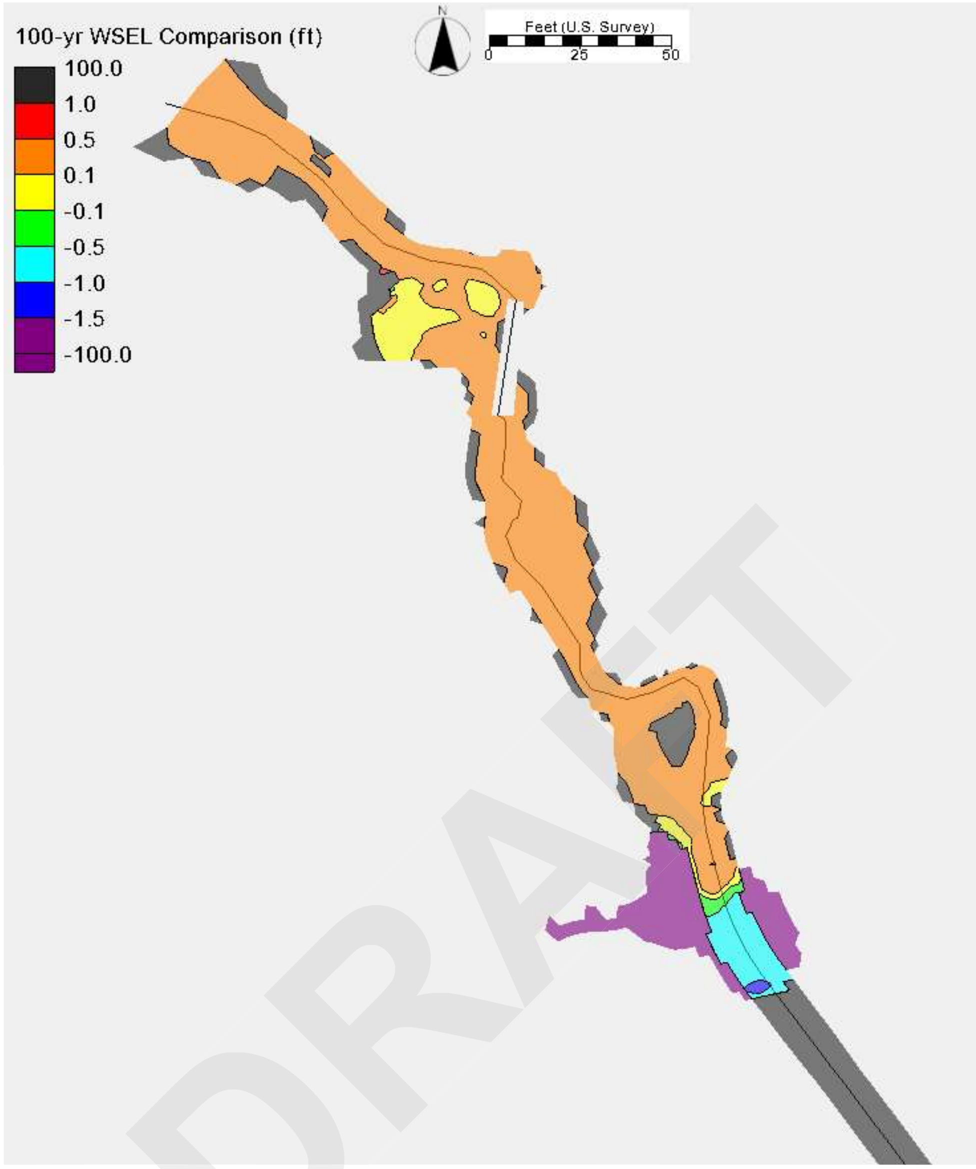

Figure 58: Downstream water surface elevation change from existing to proposed conditions

7 Climate Resilience

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. For bridges and buried structures, the largest risk to the 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 maintain passability for all expected life stages and species in a system.

7.1 Climate Resilience Tools

WSDOT also 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 2080 percent

increase throughout the design of the structure. Appendix E contains the information received from WDFW for this site.

7.2 Hydrology

For each design WSDOT uses, the best available science is used for assessing site hydrology. The predicted flows are analyzed in the hydraulic model and compared to field and survey indicators, maintenance history, and any other available information. Hydraulic engineering judgment is used to compare model results to system characteristics; if there is significant variation, then the hydrology is reevaluated to determine whether adjustments need to be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 predicted 100-year flow event to check for climate resilience. The design flow for the crossing is 51.2 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 11.1 percent, yielding a projected 2080 flow rate of 56.9 cfs.

7.3 Climate Resilience Summary

A minimum hydraulic opening of 17 feet and a minimum freeboard of 2 feet allows for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2080 100-year flow event. This will help to ensure that the structure is resilient to climate change and the system is allowed to function naturally, including the passage of sediment, debris, and water in the future.

8 Scour Analysis

Total scour will be computed during later phases of the project using the 100-year, 500-year, and projected 2080 100-year flow events. The structure will be designed to account for the potential scour at the projected 2080 100-year flow events. For this phase of the project, the risk for lateral migration and potential for degradation are evaluated on a conceptual level. This information is considered preliminary and is not to be taken as a final recommendation in either case.

8.1 Lateral Migration

Lateral migration is expected to be low, but any lateral migration will be accommodated by the increased structure size for exceeding the long culvert criteria. The structure span was increased by 30 percent from 13 feet to 17 feet.

8.2 Long-term Aggradation/Degradation of the River Bed

The proposed stream will be graded at a slope very similar to the existing upstream and downstream gradient (see Figure 51 above). It is anticipated that the previous aggradation issues should be nearly eliminated as they were previously driven by a debris jam at the fence downstream of the culvert, capturing sediment and a discontinuity in stream gradient. Therefore, it is anticipated that long-term aggradation and degradation is less than 1 foot.

Summary

Table 12: Report summary

Stream Crossing Category	Elements	Values	Report Location
Habitat gain	Total length	5,600'	2.4 Site Description
Bankfull width	Average BFW	9'	2.8.2 Channel Geometry
	Reference reach found?	Y	2.8.1 Reference Reach Selection
Channel slope/gradient	Existing crossing	2.9%	2.8.4 Vertical Channel Stability
	Reference reach	3.2%	2.8.2 Channel Geometry
	Proposed	3.11%	4.3.2 Channel Planform and Shape
Countersink	Proposed	FHD	4.6.3 Freeboard
	Added for climate resilience	FHD	4.6.3 Freeboard
Scour	Analysis	See link	8 Scour Analysis
	Streambank protection/stabilization	See link	8 Scour Analysis
Channel geometry	Existing	See link	2.8.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Planform and Shape
Floodplain continuity	FEMA mapped floodplain	N	6 Floodplain Changes
	Lateral migration	N	2.8.5 Channel Migration
	Floodplain changes?	Y	6 Floodplain Changes
Freeboard	Proposed	2'	4.6.3 Freeboard
	Added for climate resilience	Y	4.6.3 Freeboard
	Additional recommended	0.1'	4.6.3 Freeboard
Maintenance clearance	Proposed	5'	4.6.3 Freeboard
Substrate	Existing	See link	2.8.3 Sediment
	Proposed	See link	5.1 Bed Material
Hydraulic opening	Proposed	17'	4.6.2 Minimum Hydraulic Opening Width and Length
	Added for climate resilience	N	4.6.2 Minimum Hydraulic Opening Width and Length
Channel complexity	LWM	Y	5.2 Channel Complexity
	Meander bars	Y	5.2 Channel Complexity
	Boulder clusters	N	5.2 Channel Complexity
	Mobile wood	Y	5.2 Channel Complexity
Crossing length	Existing	193'	2.7.2 Existing Conditions
	Proposed	185'	4.6.2 Minimum Hydraulic Opening Width and Length
Floodplain utilization ratio	Flood-prone width	12'	4.2 Existing-Conditions Model Results
	Average FUR upstream and downstream	1.6'	4.2 Existing-Conditions Model Results
Hydrology/design flows	Existing	See link	3 Hydrology and Peak Flow Estimates
	Climate resilience	See link	3 Hydrology and Peak Flow Estimates
Channel morphology	Existing	See link	2.8.2 Channel Geometry
	Proposed	See link	5.2 Channel Complexity
Channel degradation	Potential?	N	8.2 Long-term Aggradation/Degradation of the River Bed
	Allowed?	Y	8.2 Long-term Aggradation/Degradation of the River Bed
Structure type	Recommendation	N	4.6.1 Structure Type
	Type	N/A	4.6.1 Structure Type

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Appendices

Appendix A: Hydraulic Field Report Form

Appendix B: SRH-2D Model Results

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: WDFW Climate Change Analysis

Appendix A: Hydraulic Field Report Form

WSDOT **Hydraulics Section**	# Hydraulics Field Report	Project Number:
	Project Name: US 101 MP 357.4 Griggs Creek (WDFW 997161)	Date: 1) January 21, 2020 2) March 6, 2020
	Project Office: Olympia Project Engineers Office	Time of Arrival: 2) 9:30 AM
	Location: Griggs Creek US 101 MP 357.4	Time of Departure: 2) 10:30 AM
Purpose of Visit: Site Reconnaissance	Weather:	Prepared By: Doran

Meeting Location:
Griggs Creek, Thurston County, US 101 MP 357.4

Attendance List:

Name	Organization	Role
First Visit (1/21/2020)		
Shaun Bevan	HDR	Water Resource Engineer
Grace Doran	HDR	Water Resource EIT
Ian Welch	HDR	Biologist
Second Visit- Stakeholder Reconnaissance (3/6/2020)		
Brett Boogerd	WSDOT	Engineer
Cliff Mansfield	WSDOT	Consultant
Sarah Zaniewski	Squaxin Tribe	Biologist
Pad Smith	WDFW	Habitat Engineer
Dave Collins	WDFW	Habitat Biologist
Beth Rood	HDR	Hydraulics Lead
Paul Ferrier	HDR	Project Manager
Grace Doran	HDR	Water Resource EIT
Lisa Danielski	HDR	Senior Environmental Scientist

Bankfull Width:

Describe measurements, locations, known history, summarize on site discussion

HDR conducted an independent site visit on January 21, 2020 prior to the stakeholder meeting to measure bankfull widths, collect pebble count data, and locate a reference reach. HDR walked the stream approximately 500 feet upstream and approximately 700 feet downstream of the existing 3' diameter circular concrete culvert crossing. HDR took seven bankfull width measurements upstream and downstream of the crossing, see Table 1. All seven measurements were included in the design average BFW of 9 ft. See Figure 1 for measurement locations.

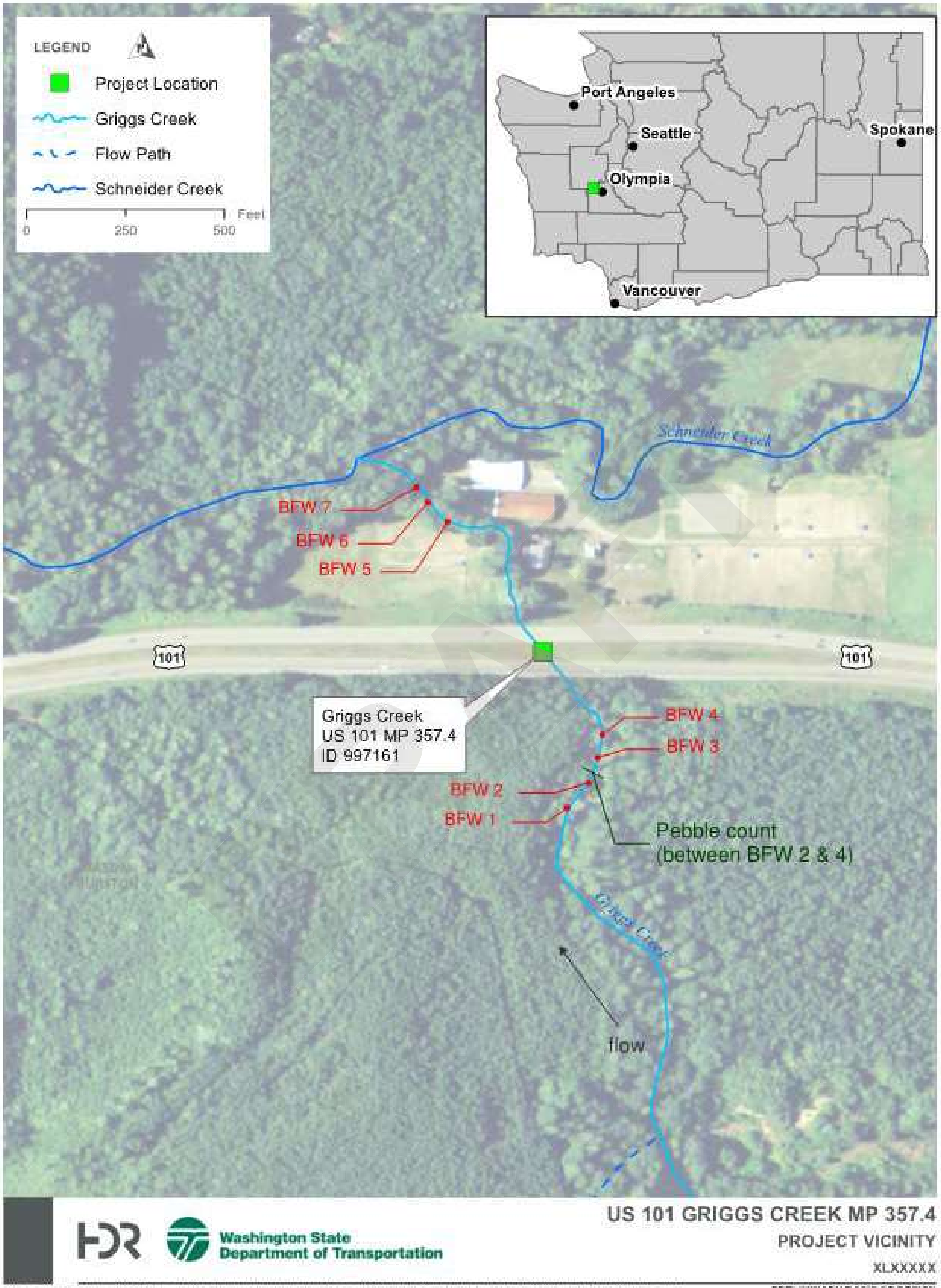


Figure 1 - Bankfull width measurements and pebble count locations from January 21, 2020 site visit

During the stakeholder meeting on March 6th, 2020, HDR, WDFW, WSDOT and a Squaxin Tribal representative took additional bankfull measurements that were similar in width to HDR's previous measurements. Based on all measurements taken, all parties agreed on a **design bankfull width of 9 feet** for design. This crossing will likely exceed the length to width ratio and the minimum hydraulic opening size would be increased if so.

Table 1 Bankfull Width Measurements

BFW #		Width	Included in Design AVG?	Concurrence Notes
Regression Eqn		7.5 ft	No	
US	1	10.0 ft	Yes	WDFW/Tribe concurred
	2	8.1 ft	Yes	WDFW/Tribe concurred
	3	8.7 ft	Yes	WDFW/Tribe concurred
	4	9.3 ft	Yes	WDFW/Tribe concurred
DS	5	7.6 ft	Yes	WDFW/Tribe concurred
	6	9.7 ft	Yes	WDFW/Tribe concurred
	7	8.5 ft	Yes	WDFW/Tribe concurred
Design Average		**9 ft**		

Reference Reach:

Describe location, known history, summarize on site discussion, appropriateness, bankfull measurement

A reference reach was selected between the bankfull width measurement locations upstream. This reach appeared to be natural and not manipulated. A pebble count was also conducted in this reach. This reach will be used to help guide the design of the channel shape.

Data Collection:

Describe who was involved, extents collection occurred within

HDR conducted an independent site visit on January 21, 2020 prior to the stakeholder site meeting. HDR walked the stream approximately 500 feet upstream of the existing culvert crossing and approximately 700 feet downstream to the confluence with Schneider Creek. HDR took seven bankfull width measurements upstream and downstream of the culvert crossing.

HDR, WDFW, WSDOT, and a Squaxin tribal representative conducted a stakeholder meeting on March 6, 2020 to discuss preliminary hydraulic design criteria and gain concurrence on bankfull width.

Observations:

Describe site conditions, channel geomorphology, habitat type and location, flow splits, LWM location and quantity, etc.

Upstream Reach

The upstream reach habitat is split between a wooded and heavily vegetated area (approximately 500' to 250' upstream of the crossing), and a slightly less vegetated area with a few locations of highly eroded banks (250' upstream to the culvert inlet). Beginning approximately 500' upstream of the

crossing, Griggs Creek meanders through large woody material within the densely vegetated area. There are steep valley walls with some areas of small incision and some undercutting throughout.

Within the stream channel there is an instance of large woody material that creates a 1.5-2’ hydraulic drop. Downstream of the influence of the hydraulic drop, four bankfull width measurements were taken, the average being a 9’ BFW. Within this reach the material consists of gravel and cobble substrate and bank heights were approximately 2’ on the left and right.

Downstream of the wooded reach, the banks are higher and much more eroded, and there is hardly any large woody material within the channel. This reach begins approximately 250’ upstream of the culvert inlet, ending at the crossing. Approximately 100’ upstream of the culvert inlet, the channel takes a 90 degree left turn, leaving a gravel bar on the left bank and a highly eroded 8’ bank on the right. The channel takes a slight bend to the right, creating an “S” curve. Downstream of the “S” curve, due to deadfall trees within the stream has created some channel meandering. Sediment and material has accumulated to surround the large woody material. Upstream of the culvert inlet there is a roadside ditch that outfalls just upstream of the culvert on the right bank.

The 36” concrete culvert invert is clear of sediment and has concrete headwalls that come out at roughly a 45 degree angle. The right headwall is broken.

Downstream Reach

The downstream reach is fairly vegetated, significant amounts of reed canary grass are present right around the culvert outlet, and the channel meanders until the confluence with Schneider Creek. Both days of the site visits the culvert outlet was completely inundated and not visible. The culvert outfalls into a vegetated wetland area that is divided by a raised vegetated island. This area appears to be created by material accumulation at the existing right-of-way fence. A roadside ditch comes in from the left bank. To the left of the satellite dish there is a wire fence that has accumulated sediment, material and wood that has created a 1’ hydraulic drop. After the drop, the channel continues to meander through vegetated banks, taking a hard left turn and reaches a 2’ diameter PVC culvert that goes underneath a private access road. There is a scour pool at the culvert outlet before the channel continues to the left.

There is some small wood within the channel, mostly branches fallen from larger trees. The banks range from 1-3’ high, are well vegetated and is comprised of a clayey sand material. The channel substrate is consistent gravel throughout the reach. Downstream of the influence of the private culvert, three bankfull widths were taken resulting in an average width of 8.6’ BFW. Approximately 150’ downstream of the access road culvert, the channel becomes very steep and incised with 3’ high vegetated banks, with many roots laying in the channel.

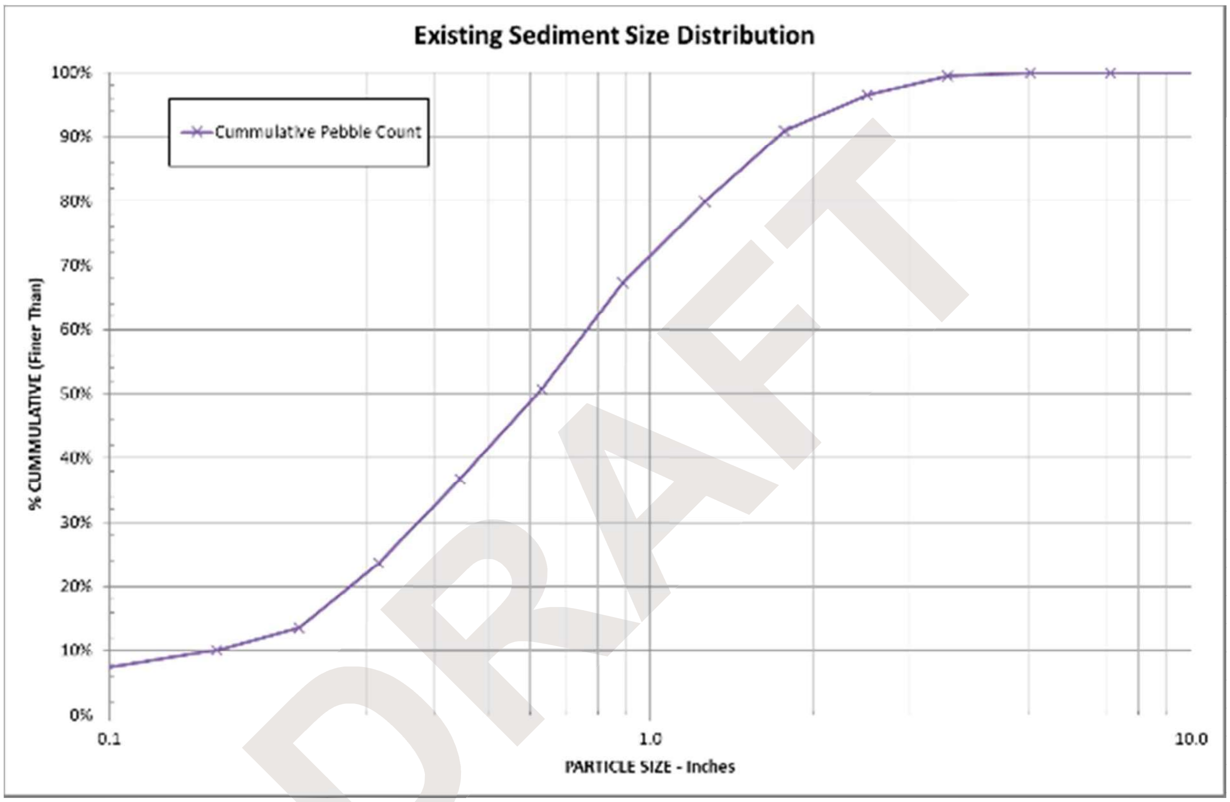
The channel meanders for another 300’ feet until reaching the confluence with Schneider Creek, roughly 700’ downstream of the US 101 crossing. Directly upstream of the confluence, the right bank is slightly eroded as the channel takes a left turn to meet the much larger Schneider Creek.

Pebble Counts/Sediment Sampling:

Describe location of sediment sampling and pebble counts if available

One pebble count was taken on the upstream side, in between original bankfull measurements 2 and 4. The cumulative distribution and specific pebble sediment sizes are provided in the following chart and table.

During the stakeholder meeting, it was decided streambed sediment would be used to mimic the existing streambed material.



Particle	Observed Material Diameter (in)	Proposed Material Diameter (in)
D_{15}	0.24	0.02
D_{35}	0.43	0.19
D_{50}	0.62	0.75
D_{84}	1.43	2.09
D_{95}	2.29	2.36

Photos:

Any relevant photographs listed above

Figure 2 - Culvert inlet

Figure 3 – Looking downstream at the woody material buildup

Figure 4 – Looking downstream at the gravel bar and eroded banks

Figure 5 - Upstream bankfull width measurement location

Figure 6 – Looking upstream at the woody material jam

Figure 7 - Culvert outlet

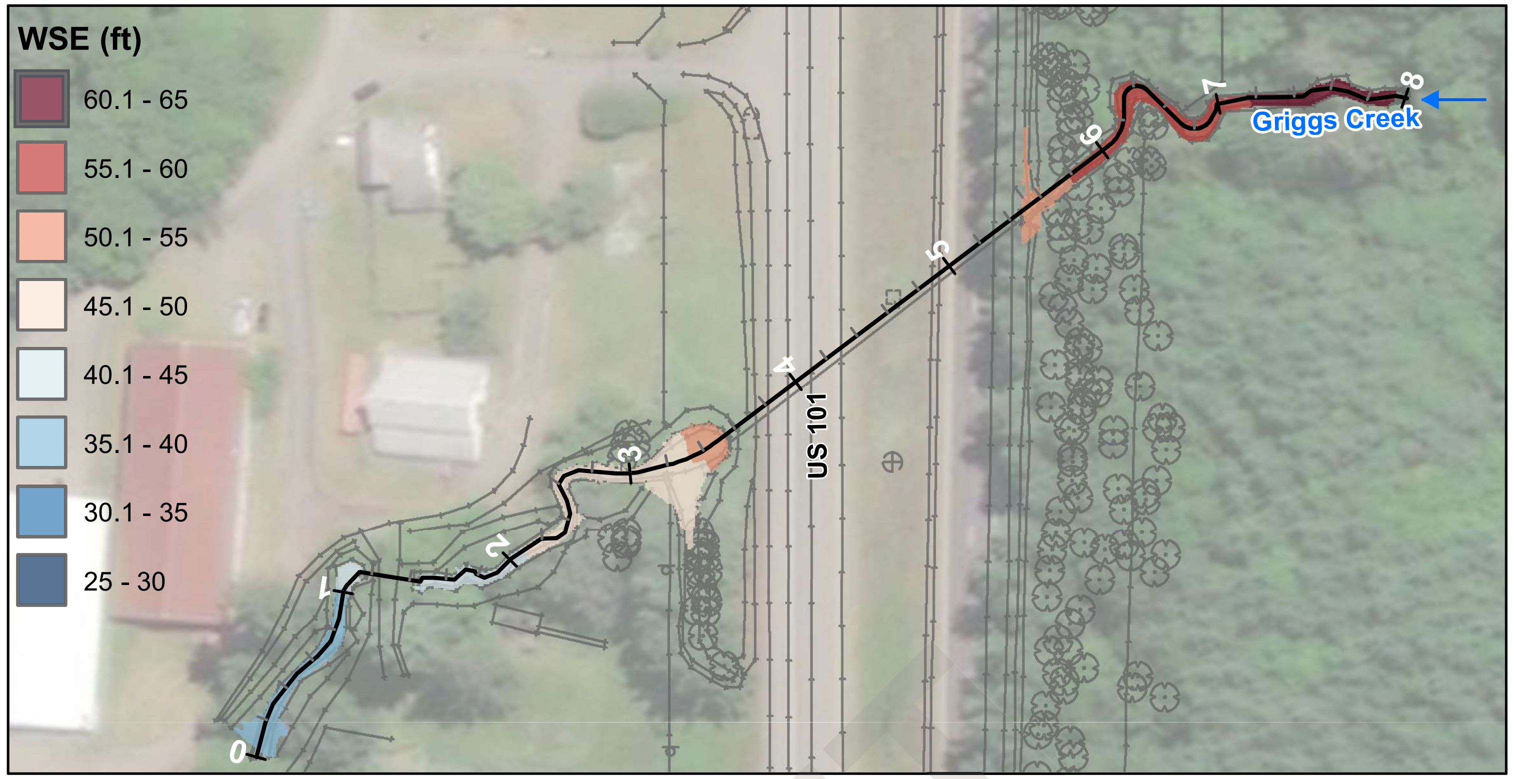
Figure 8 – Looking downstream atop culvert outlet

Figure 9 – Access road culvert outlet

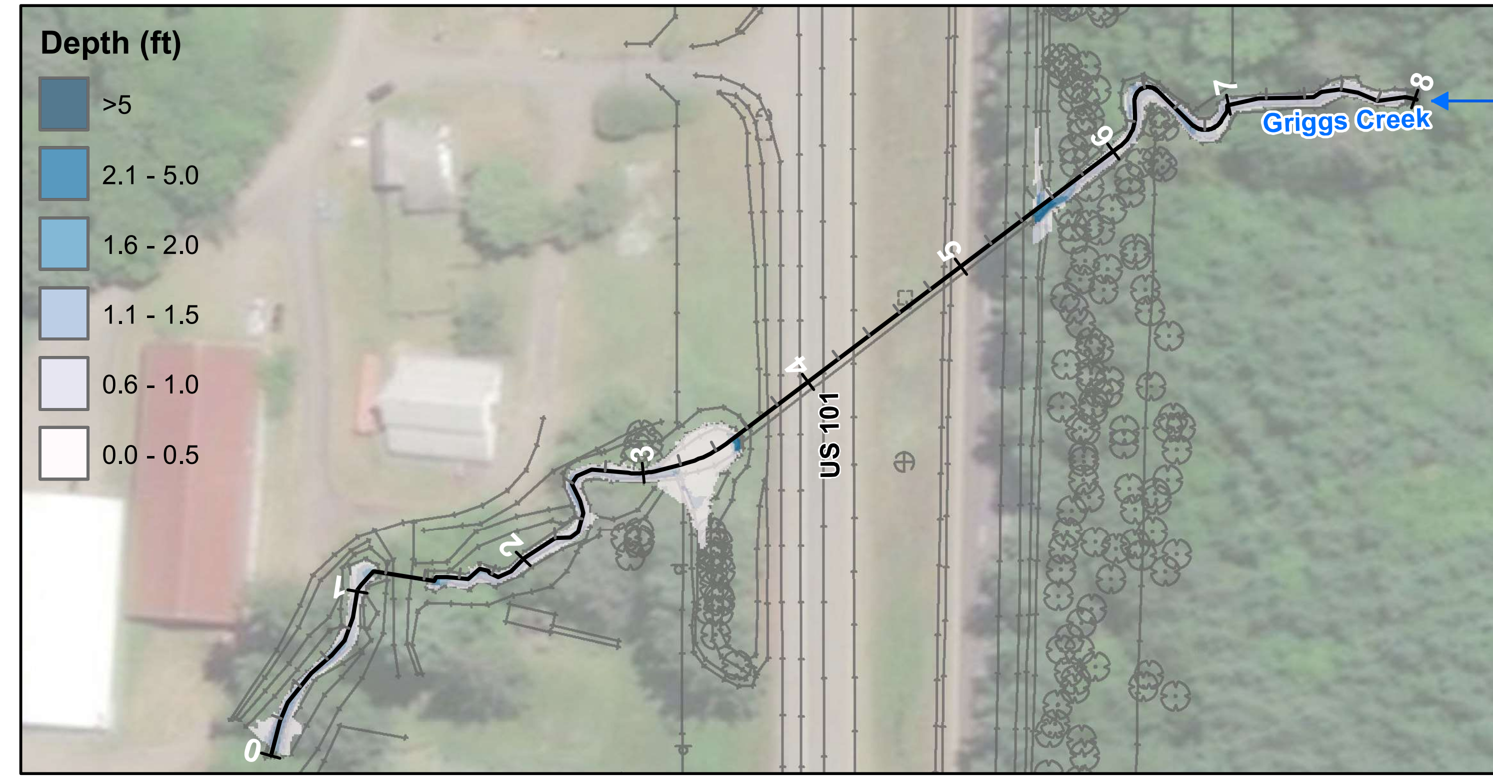
Figure 10 – Roots within meandering stream and undercut banks

Figure 10 – Looking downstream at the confluence with Schneider Creek

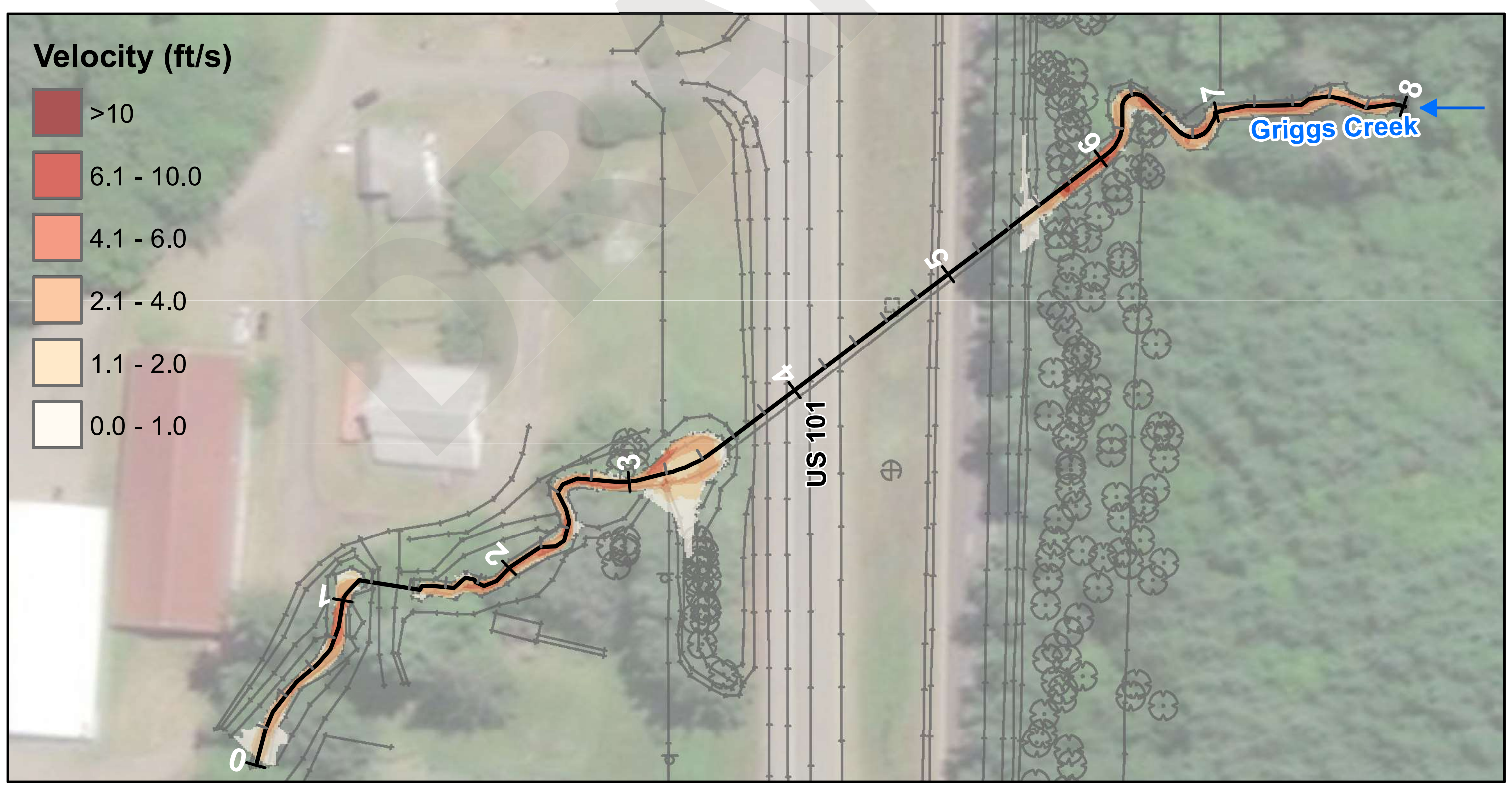
Appendix B: SRH-2D Model Results



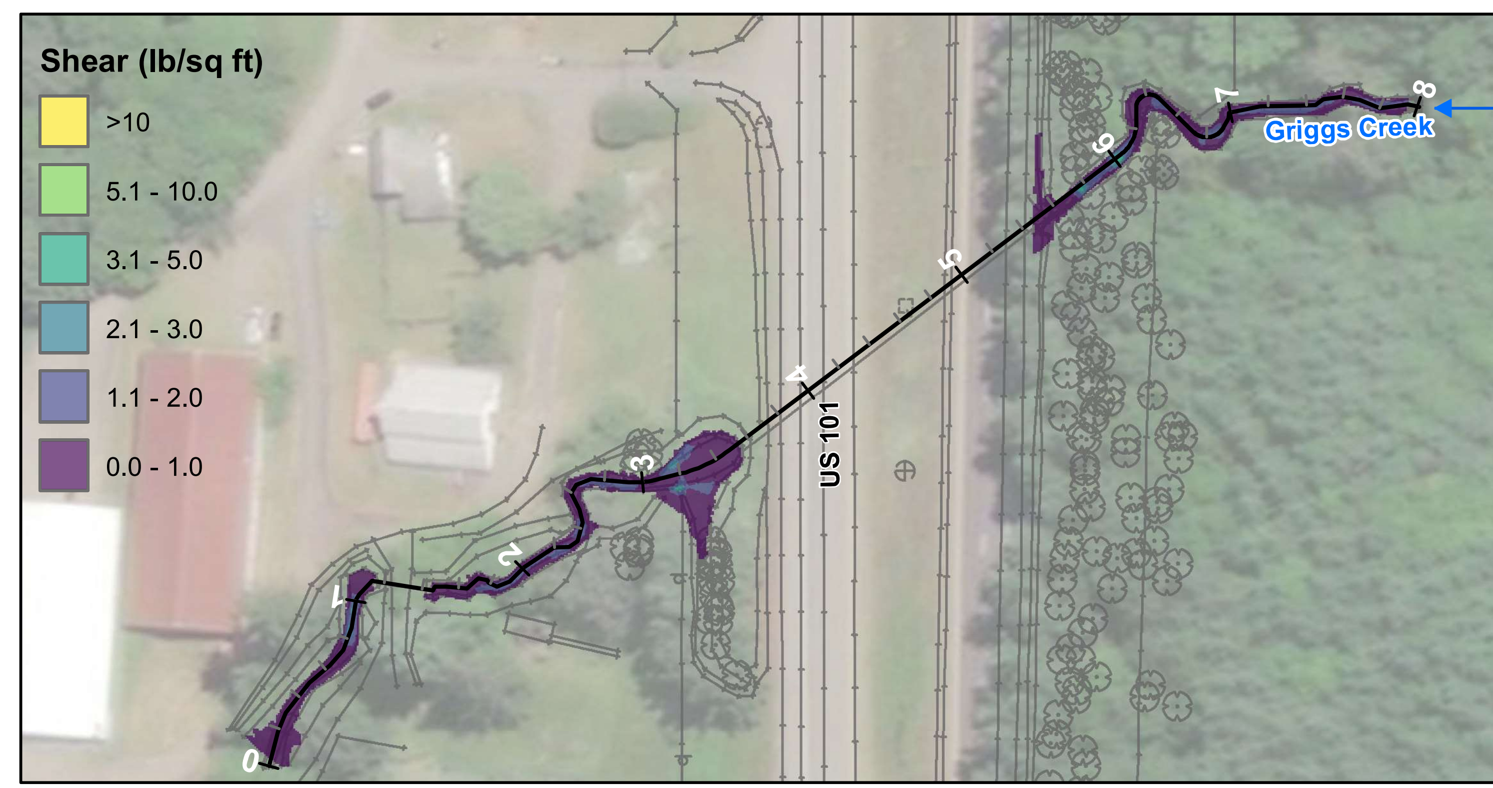
WATER SURFACE ELEVATION



DEPTH



VELOCITY



SHEAR

N

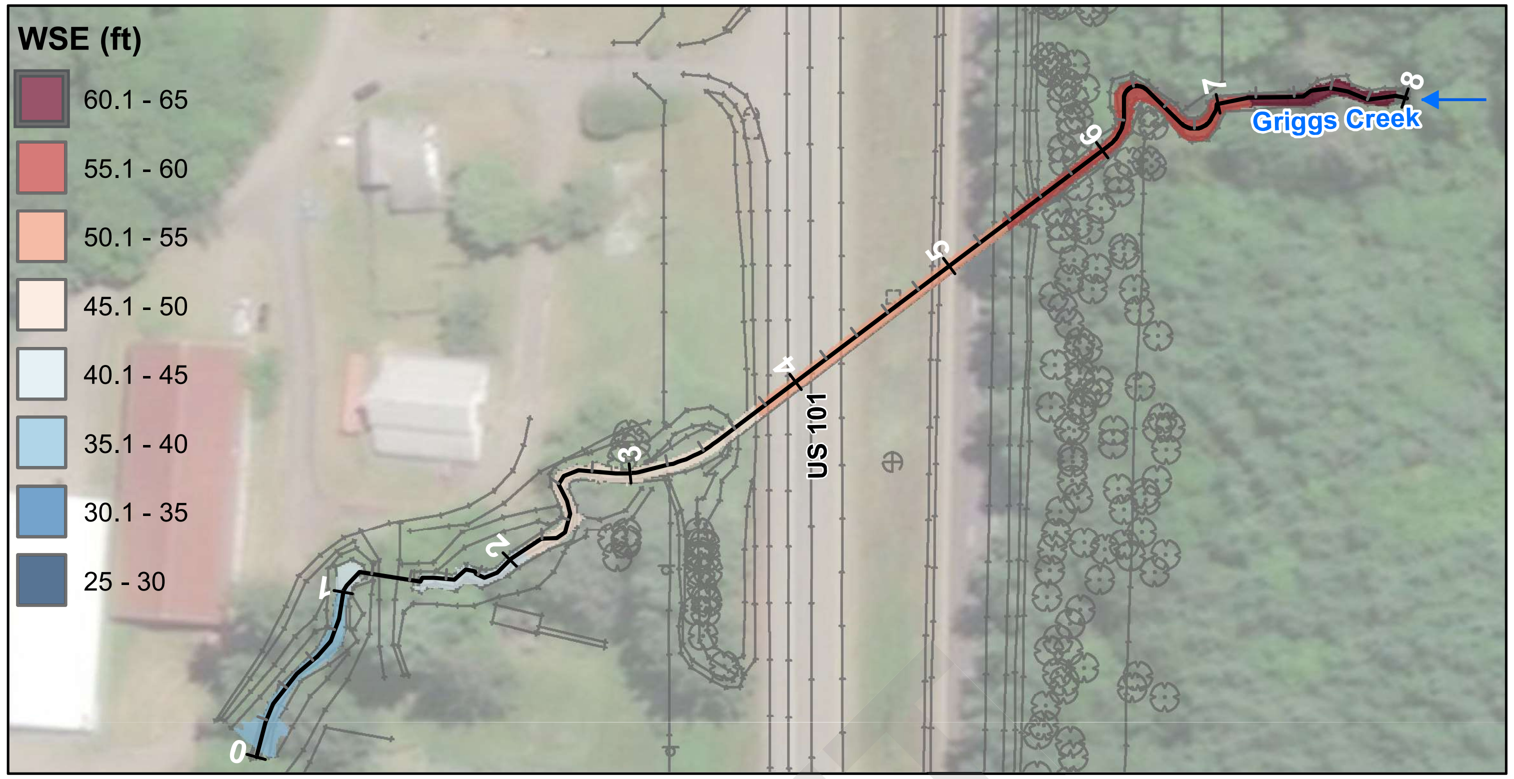
0 50 100 Feet

HDR

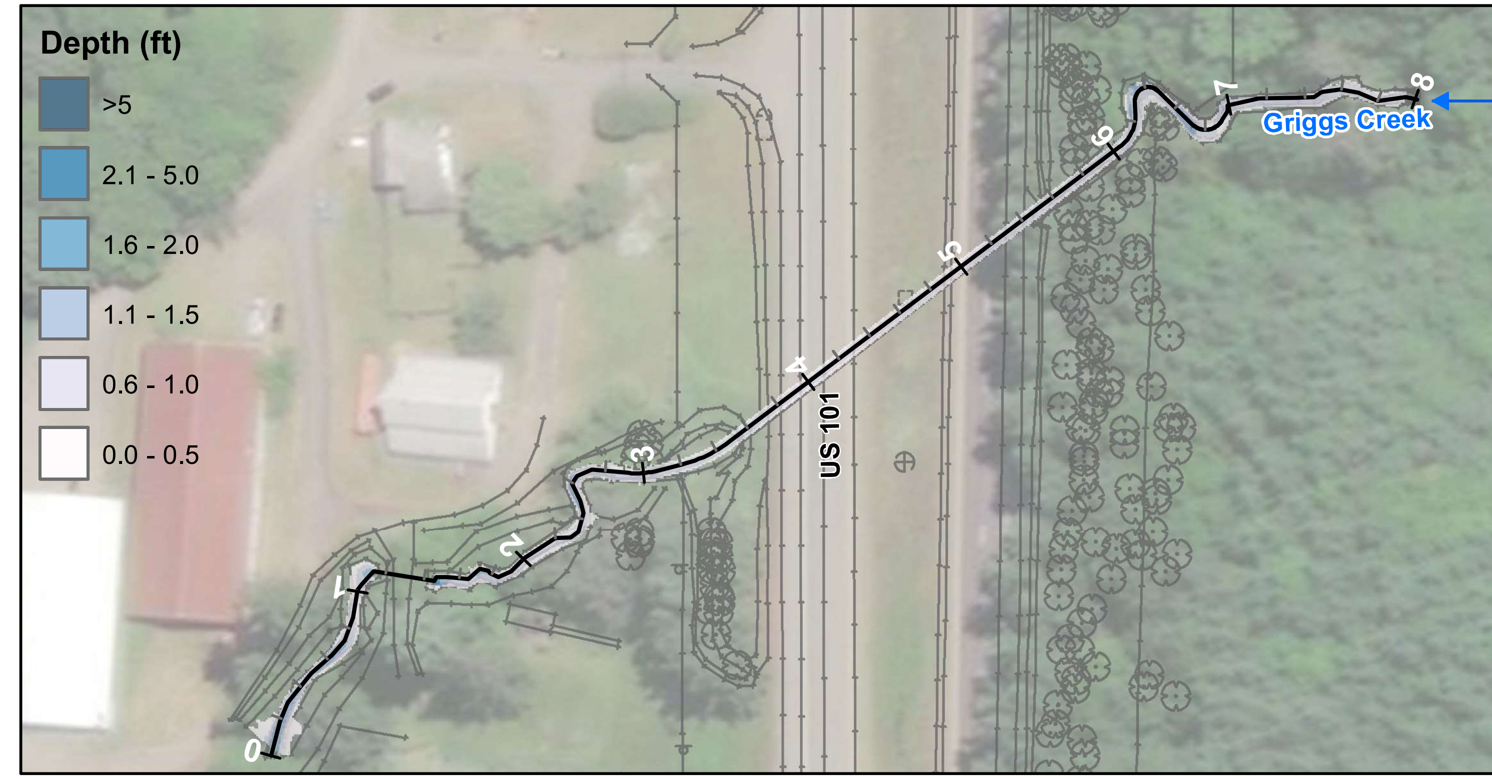
Washington State Department of Transportation

EXISTING CONDITIONS 2-YEAR

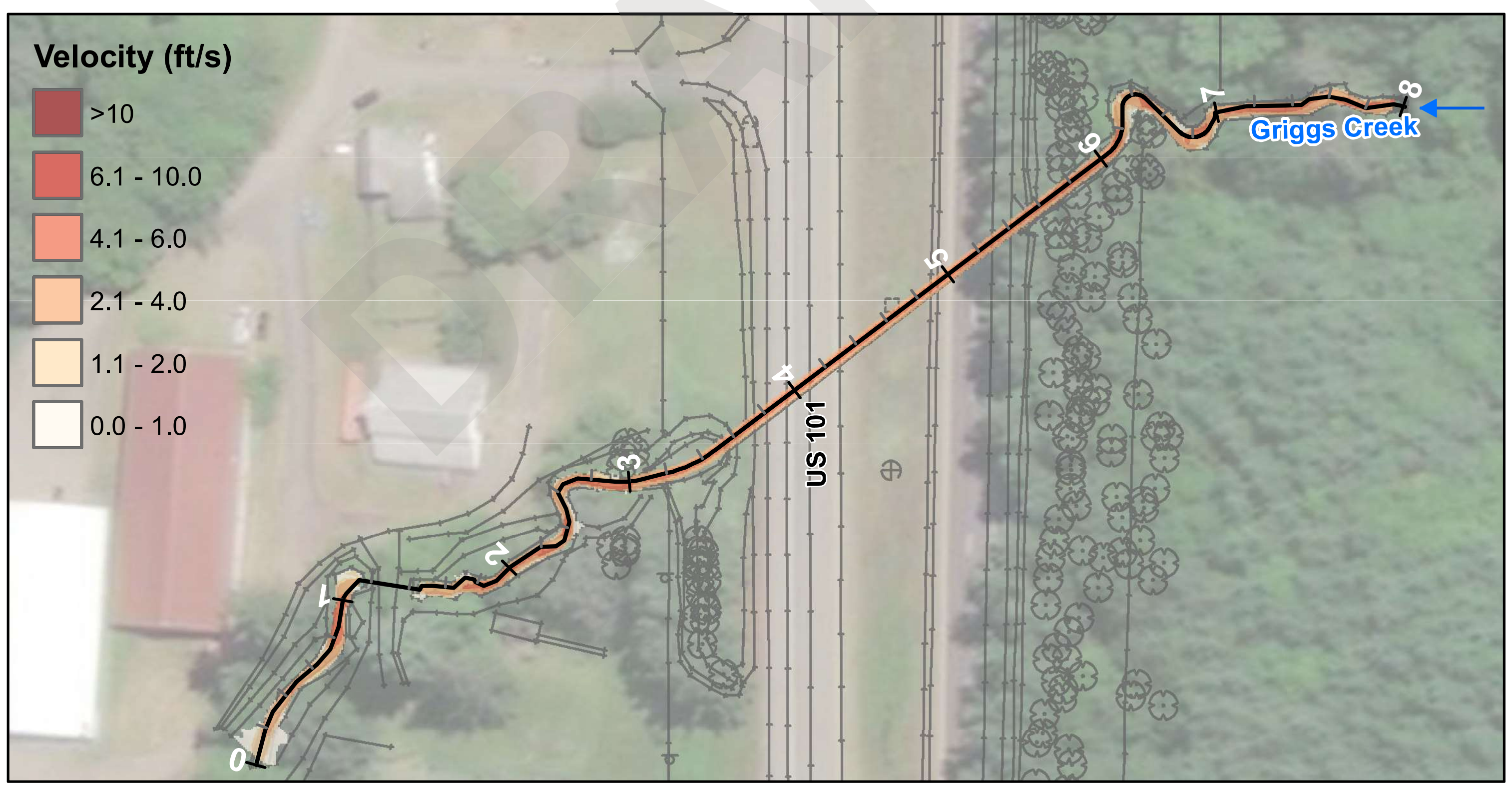
US 101 GRIGGS CREEK
MP 357.4



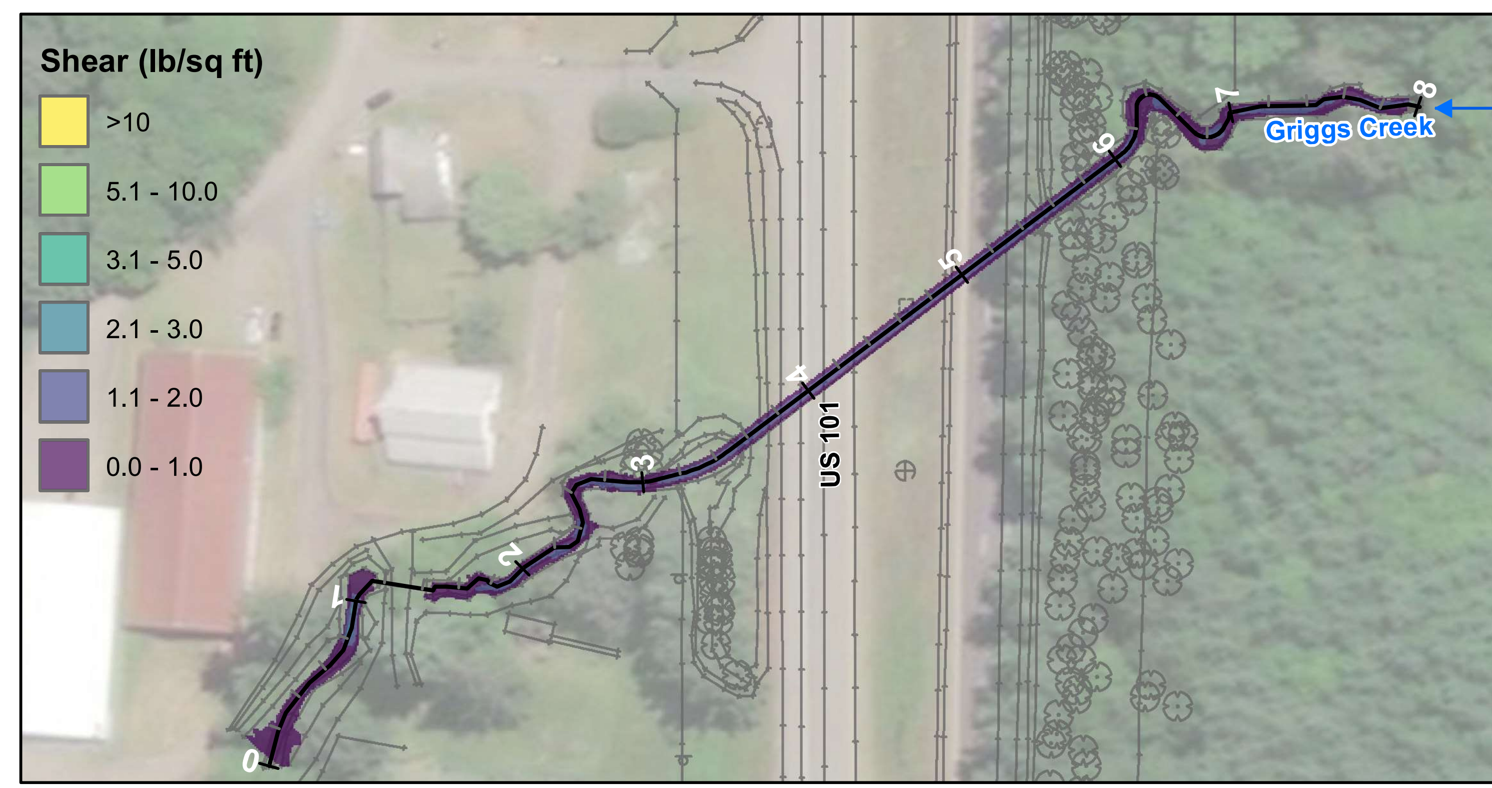
WATER SURFACE ELEVATION



DEPTH



VELOCITY



SHEAR

N

0 50 100 Feet

HDR

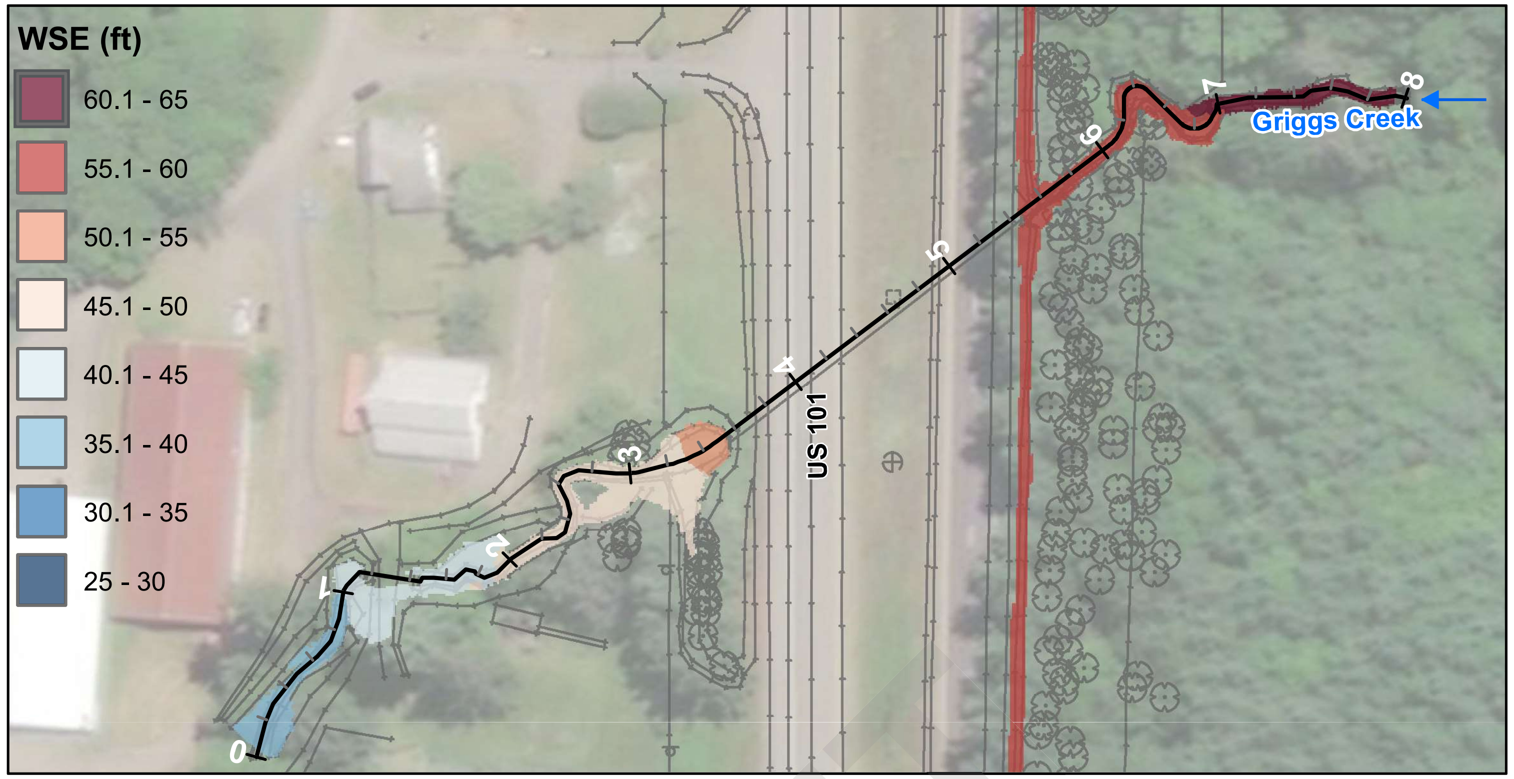
Washington State Department of Transportation

PROPOSED CONDITIONS 2-YEAR

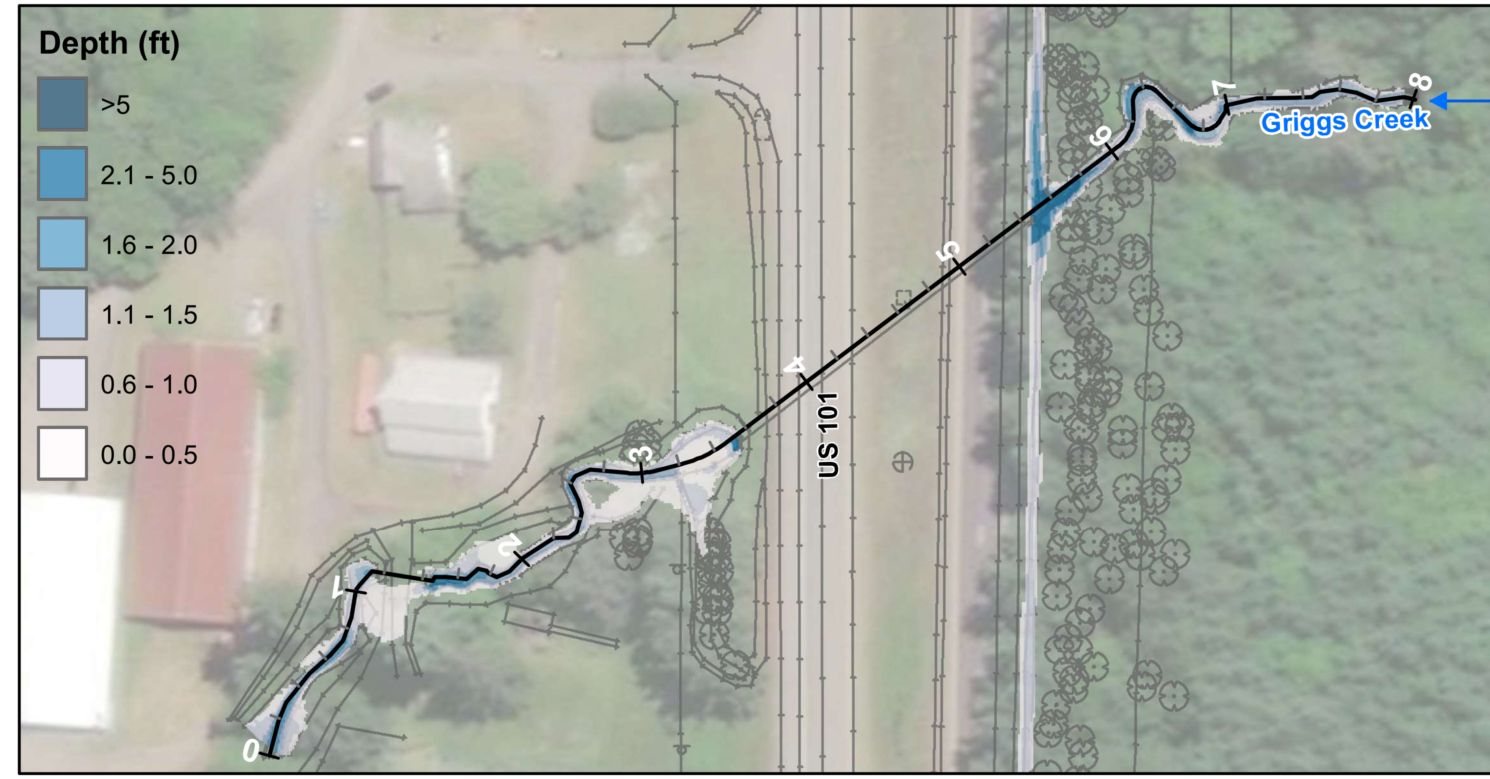
US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

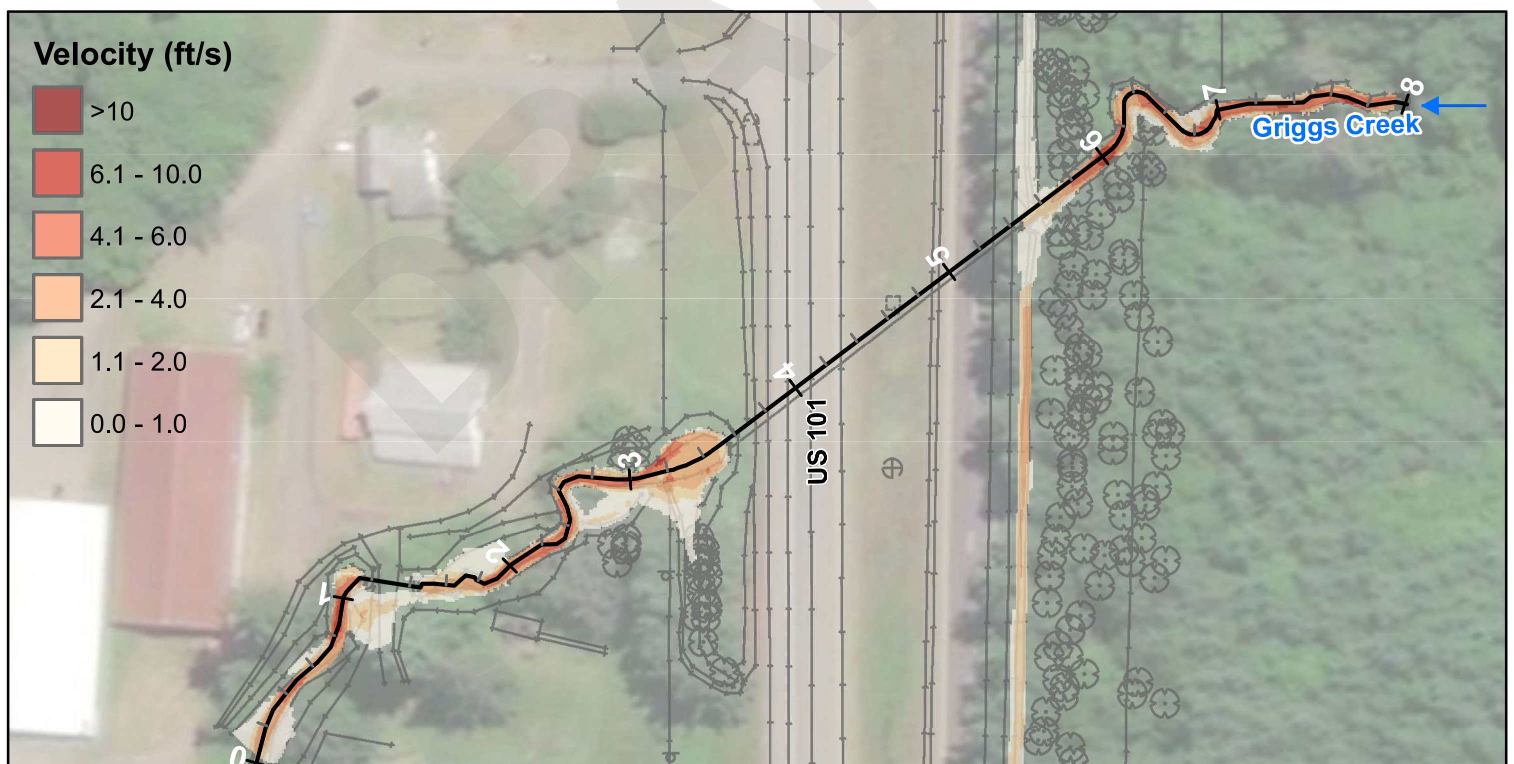
PRELIMINARY HYDARULIC DESIGN



WATER SURFACE ELEVATION



DEPTH



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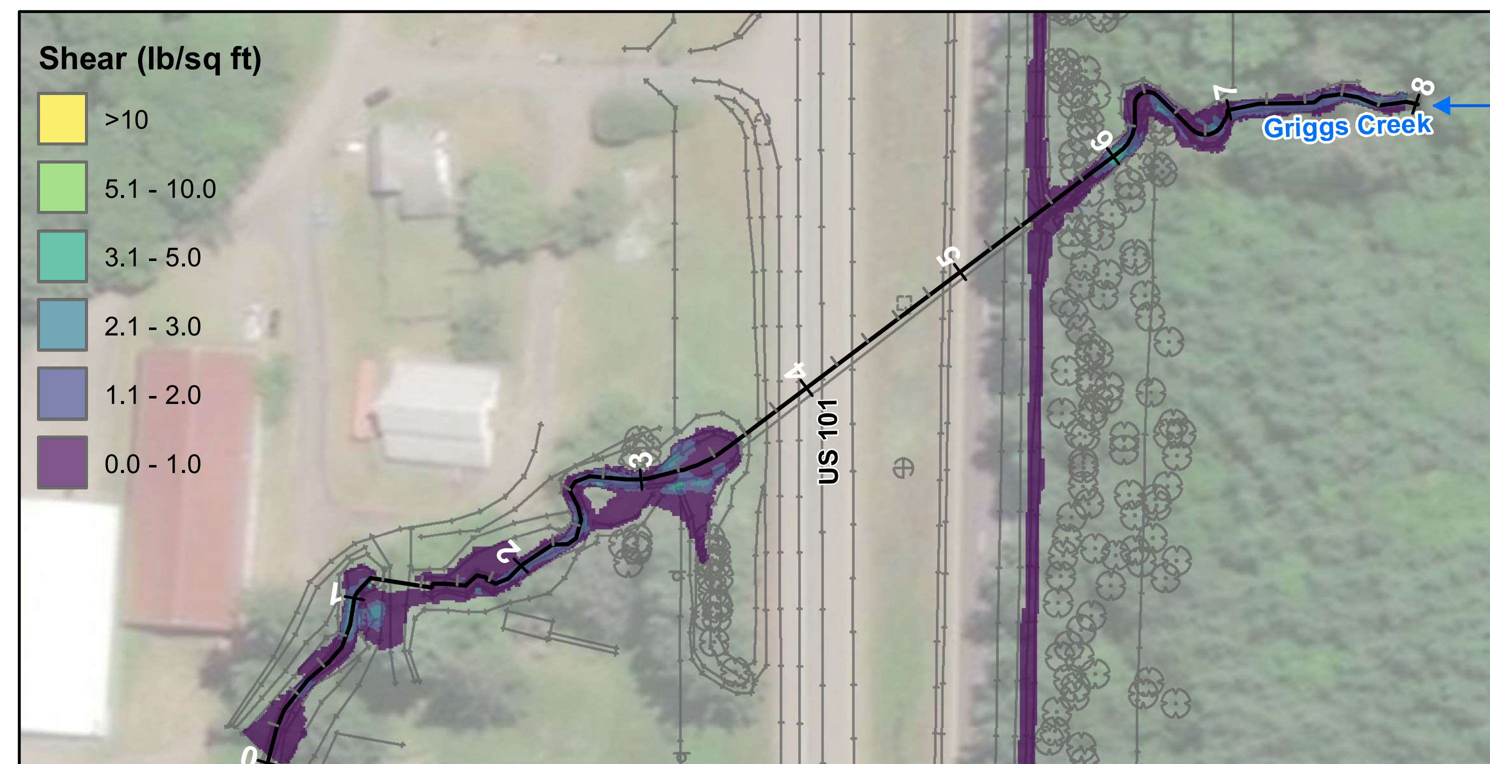


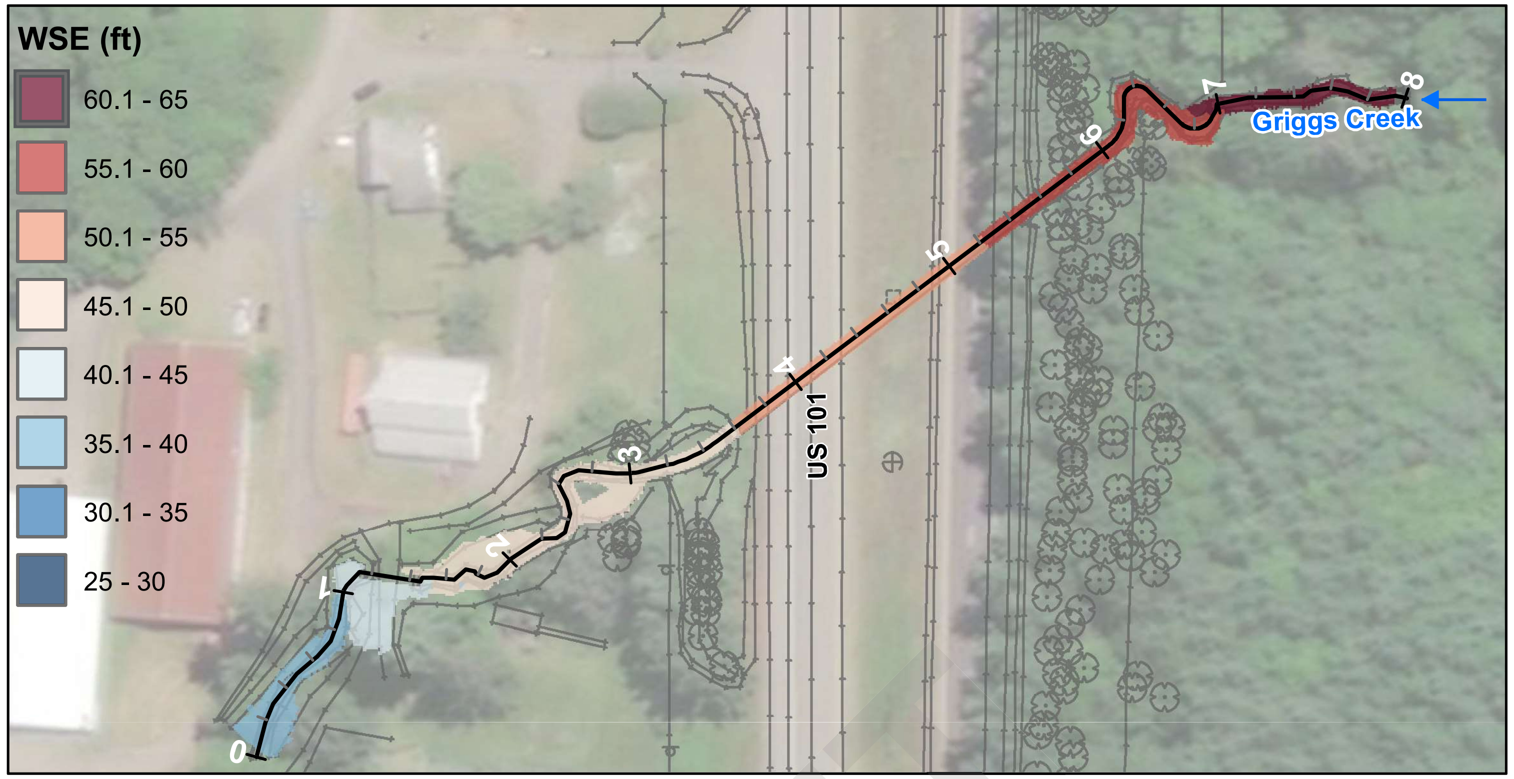
SHEAR

N
0 50 100 Feet

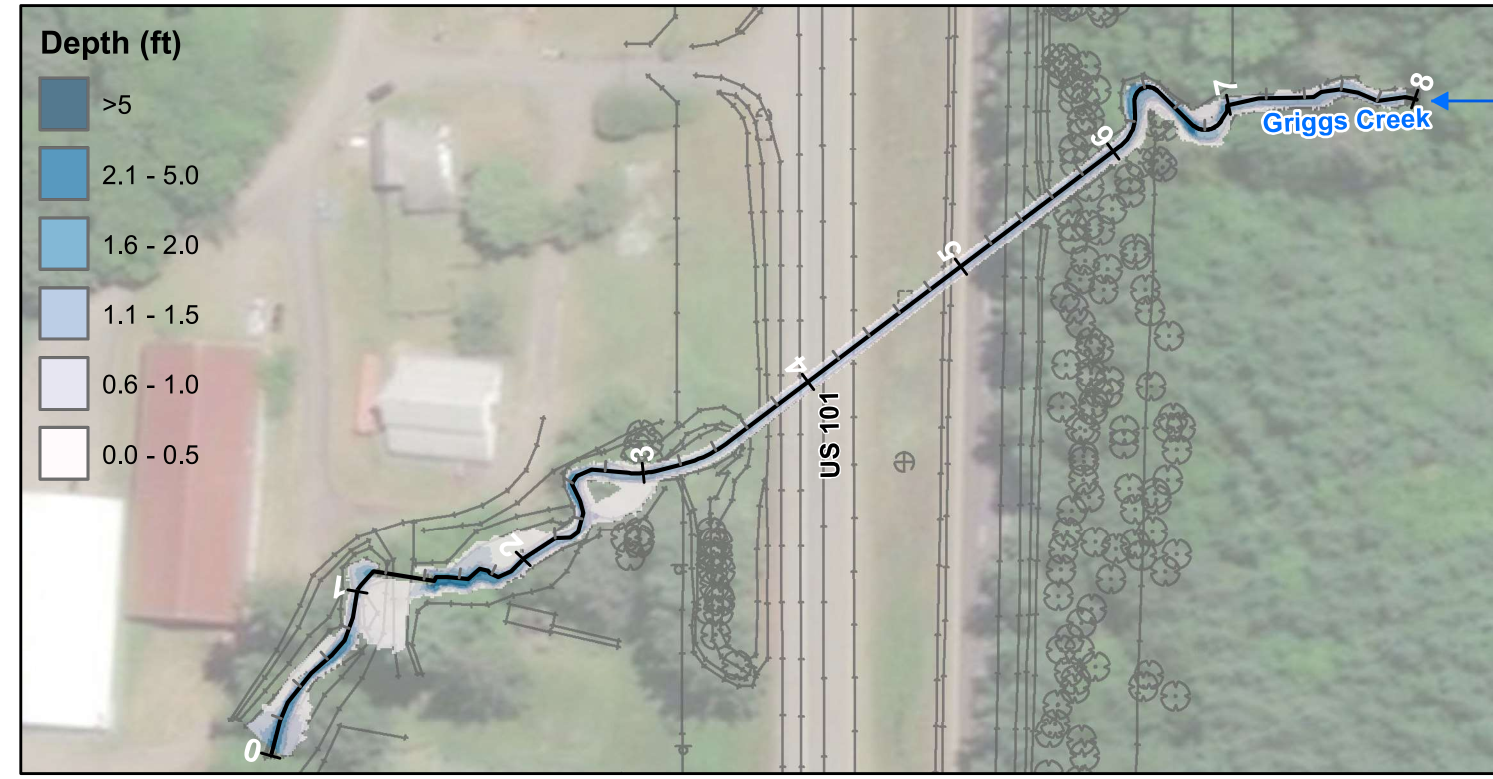
HDR
Washington State Department of Transportation

EXISTING CONDITIONS 25-YEAR

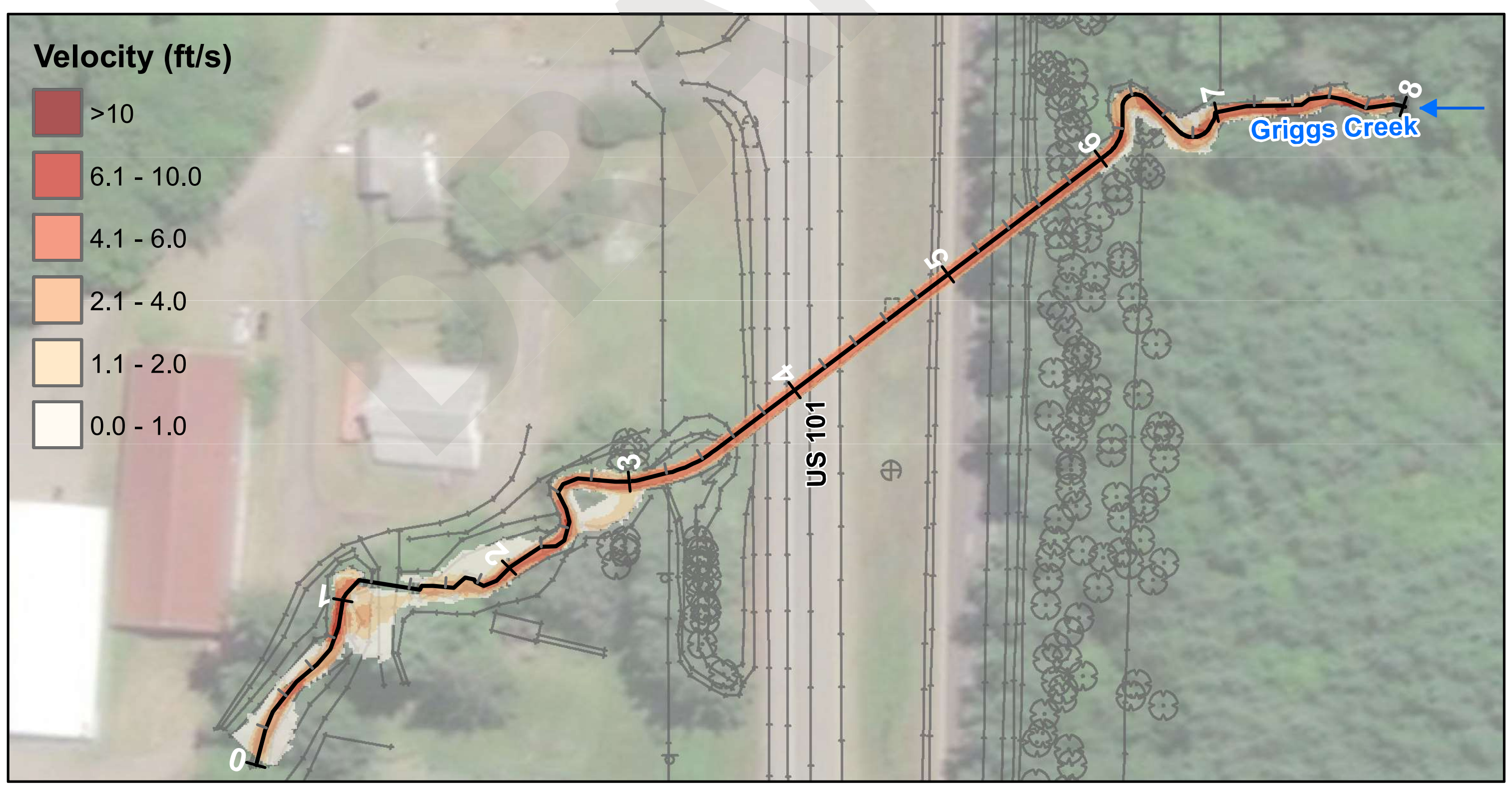
US 101 GRIGGS CREEK
MP 357.4



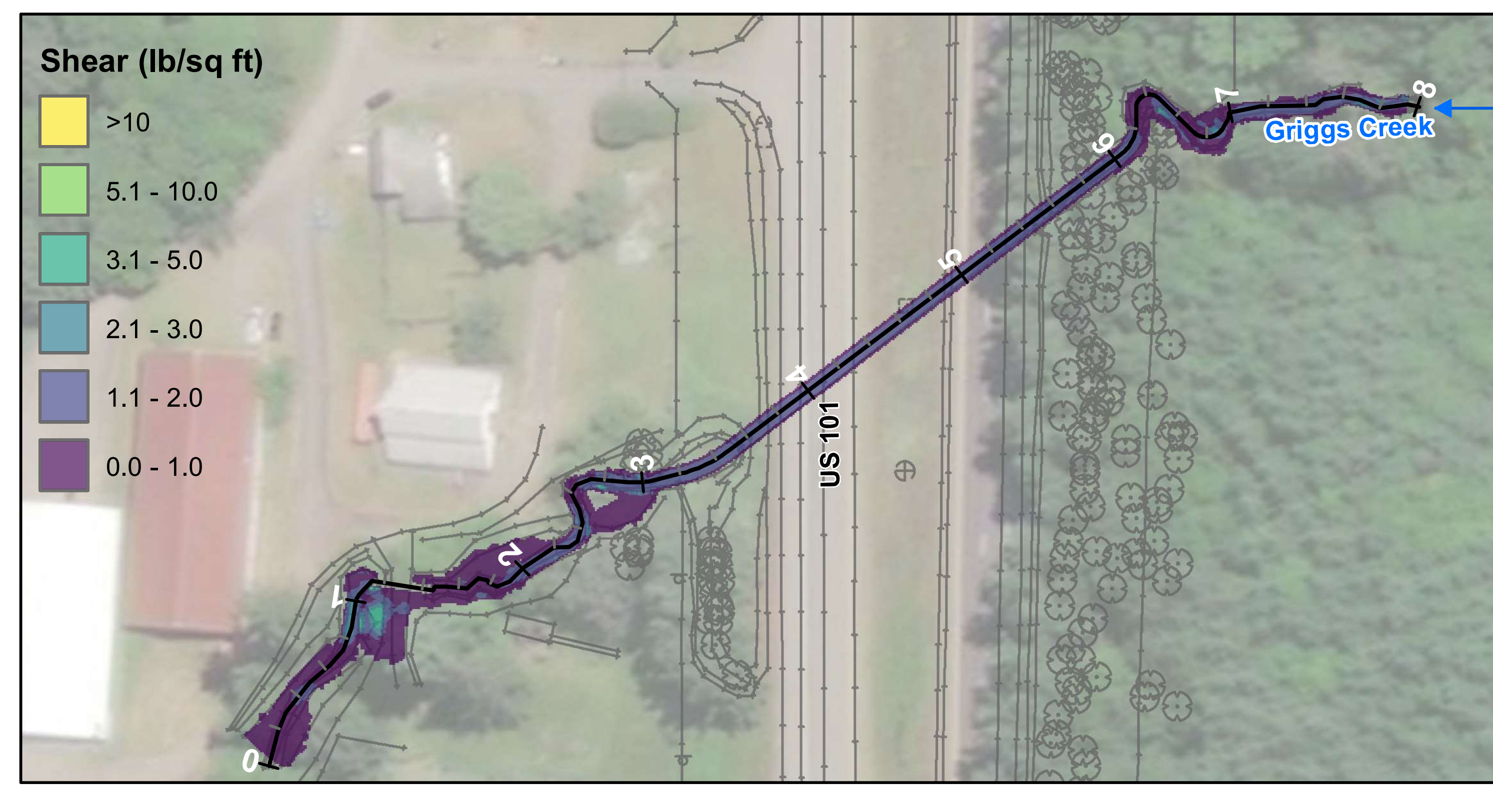
WATER SURFACE ELEVATION



DEPTH



VELOCITY



SHEAR

N 0 50 100 Feet

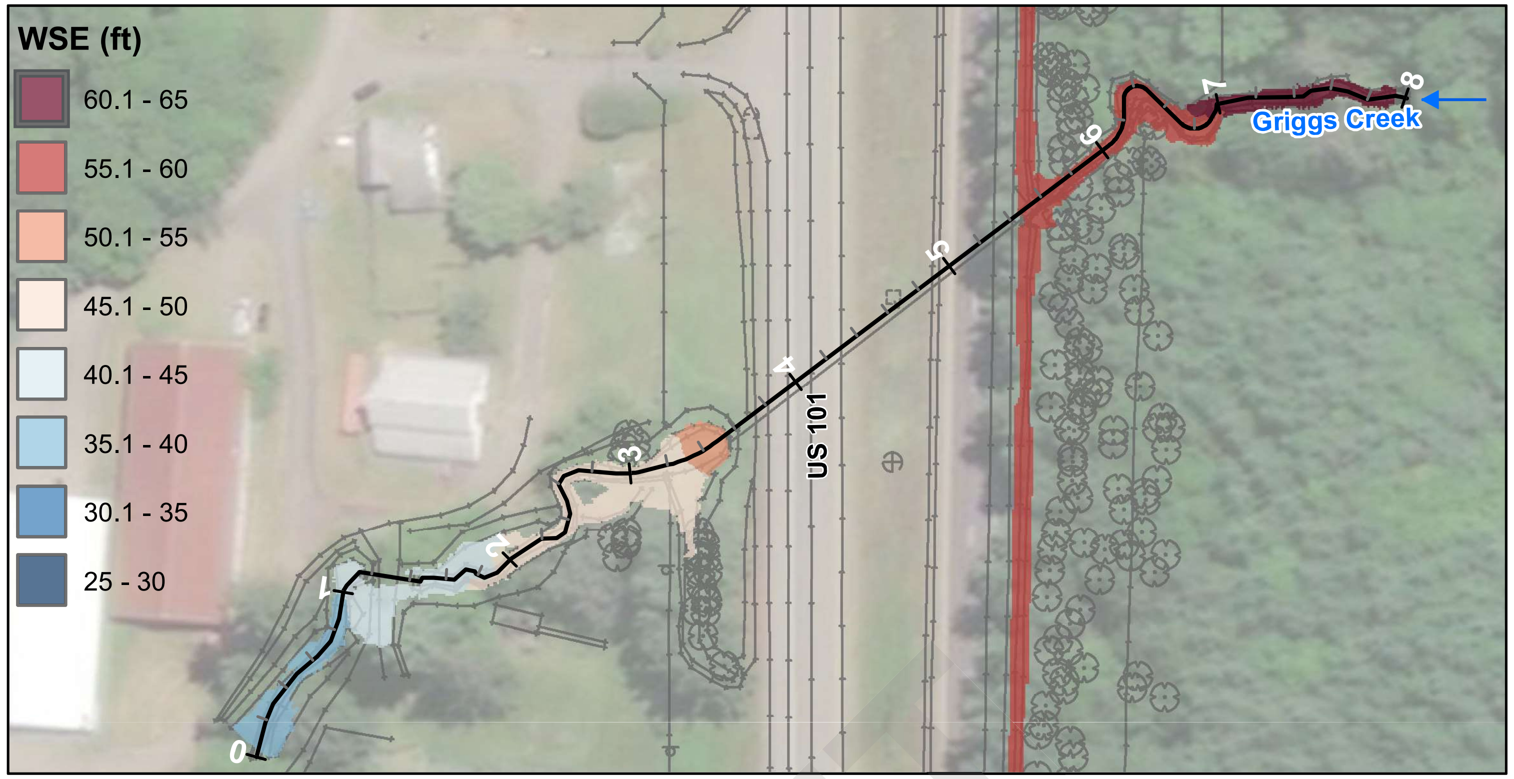
Washington State Department of Transportation

PROPOSED CONDITIONS 25-YEAR

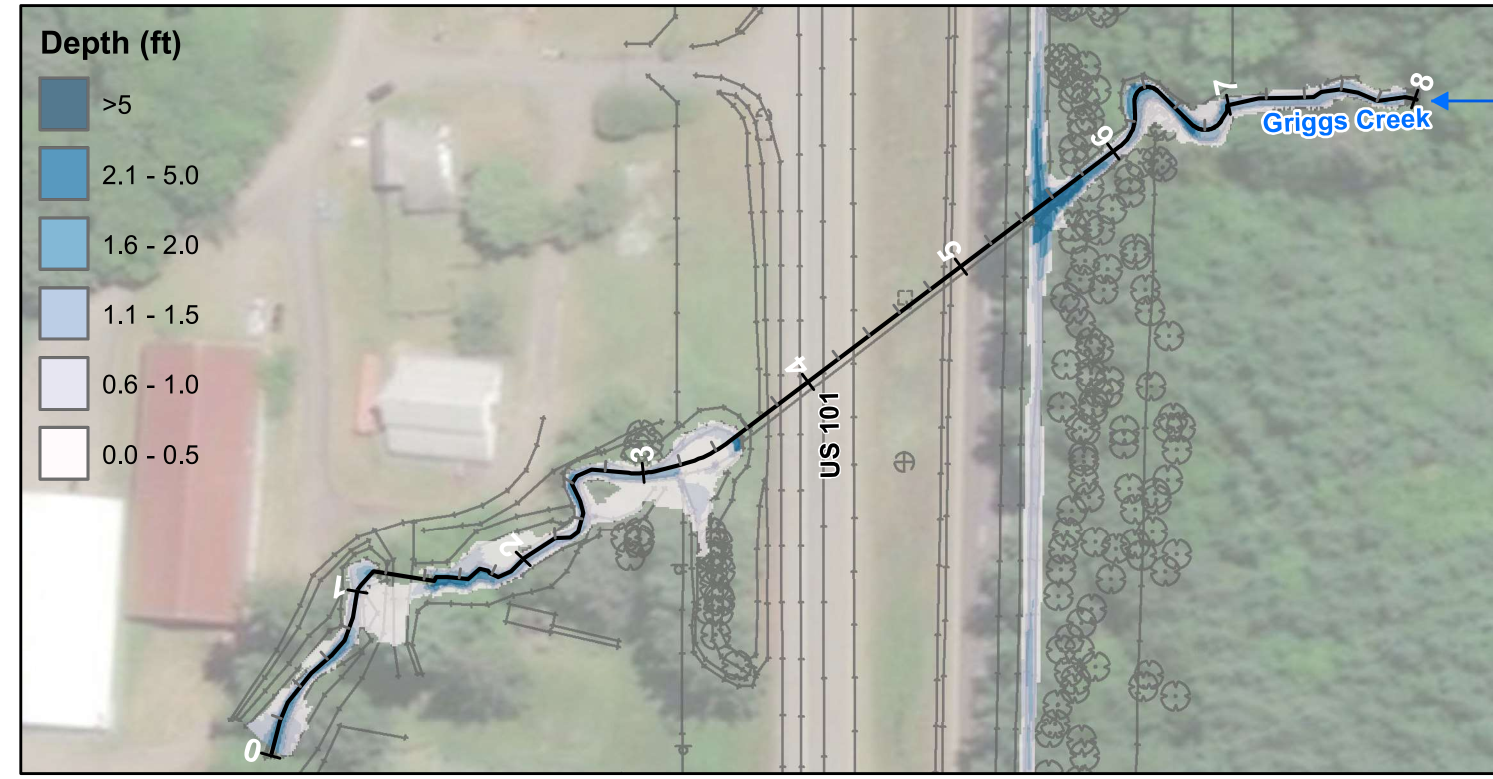
US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

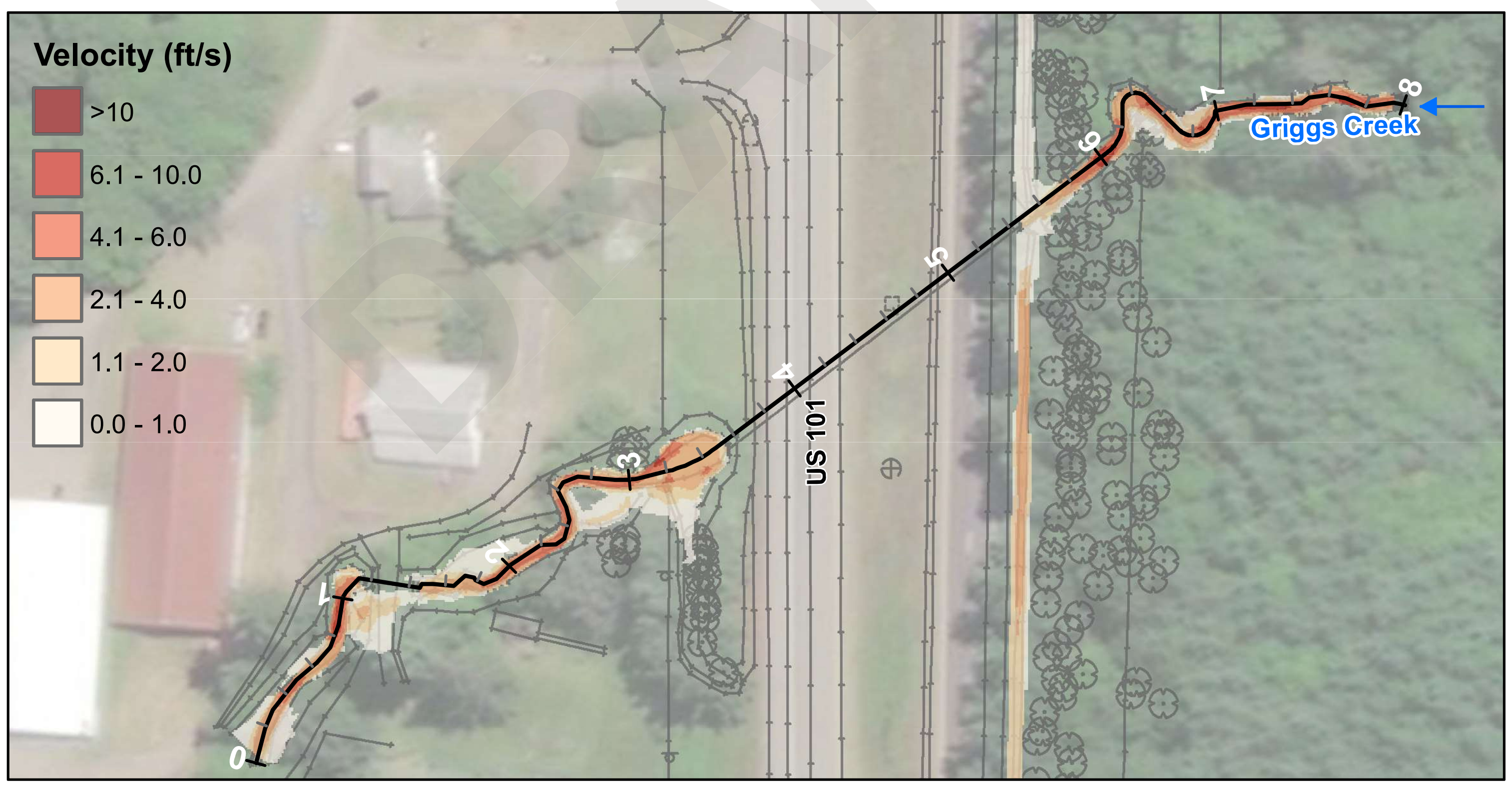
PRELIMINARY HYDARULIC DESIGN



WATER SURFACE ELEVATION



DEPTH



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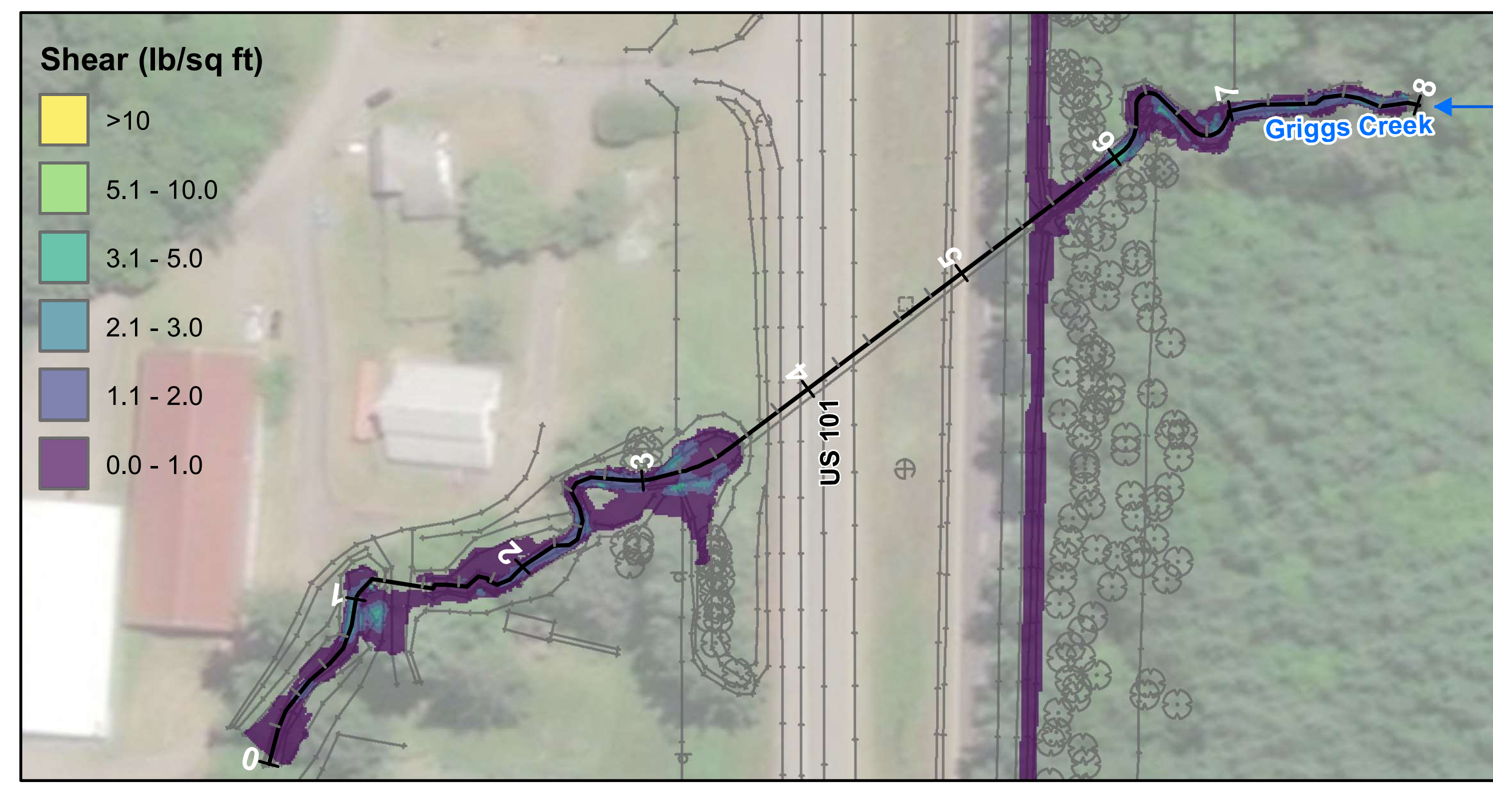

SHEAR

N

0 50 100 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 50-YEAR

US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

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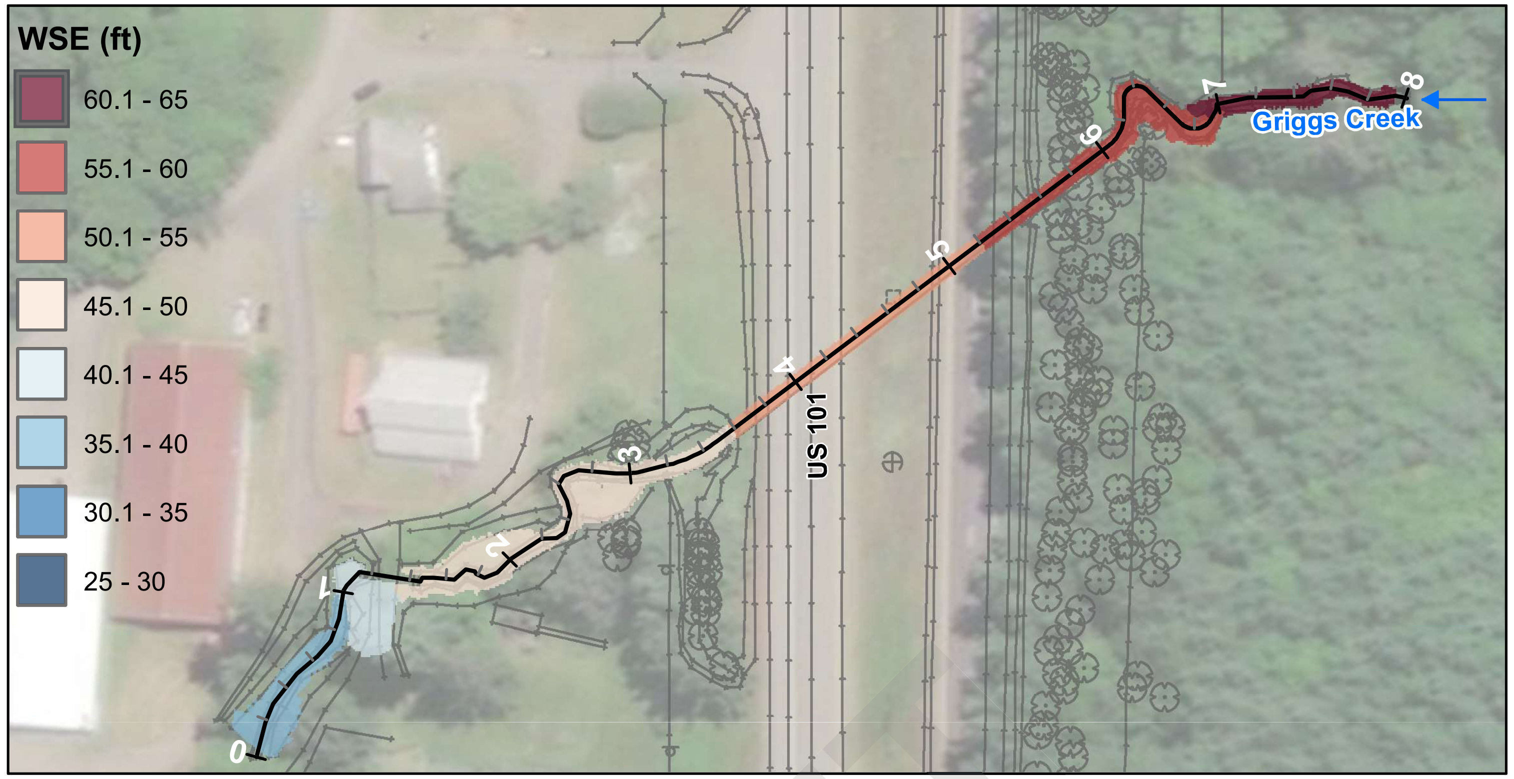
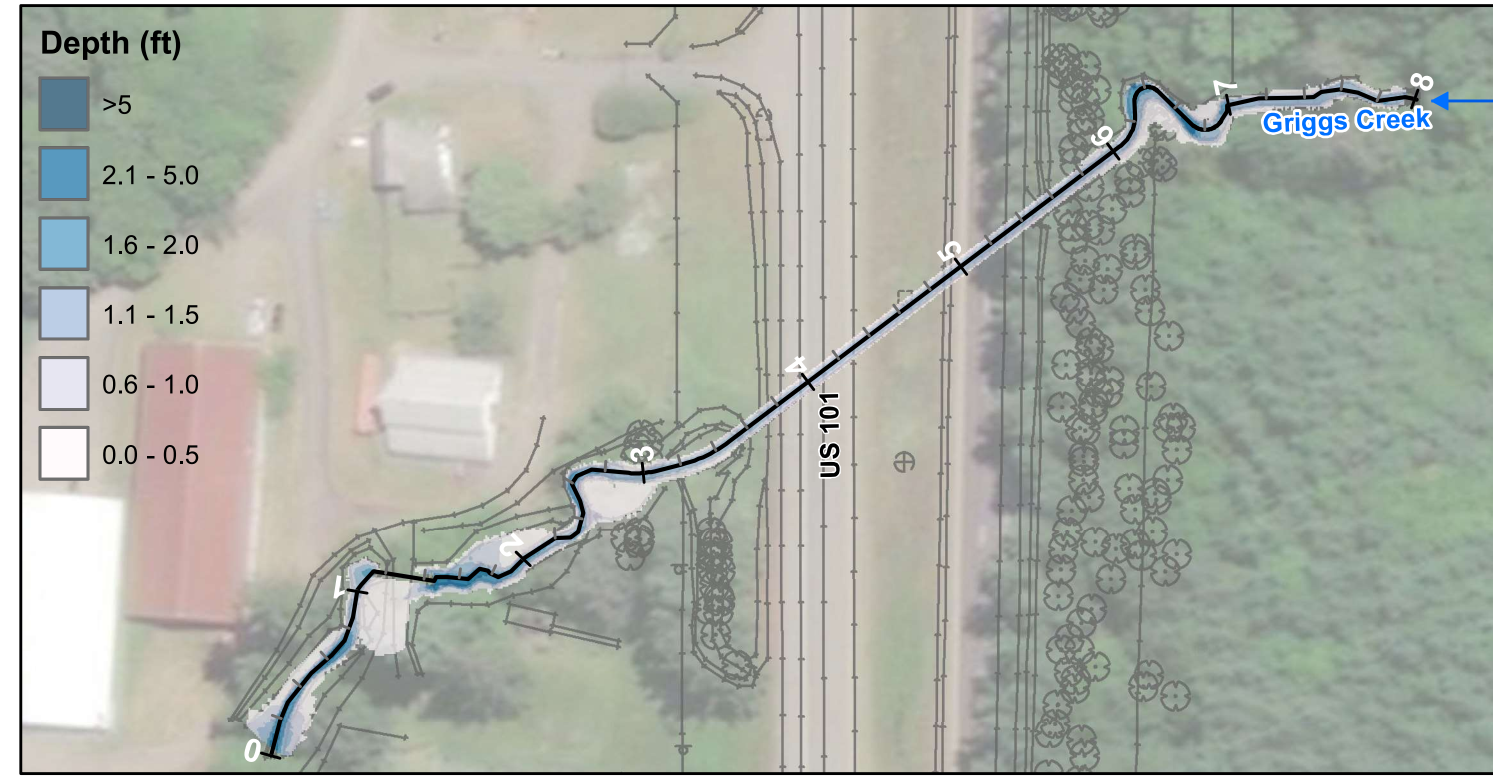


WATER SURFACE ELEVATION



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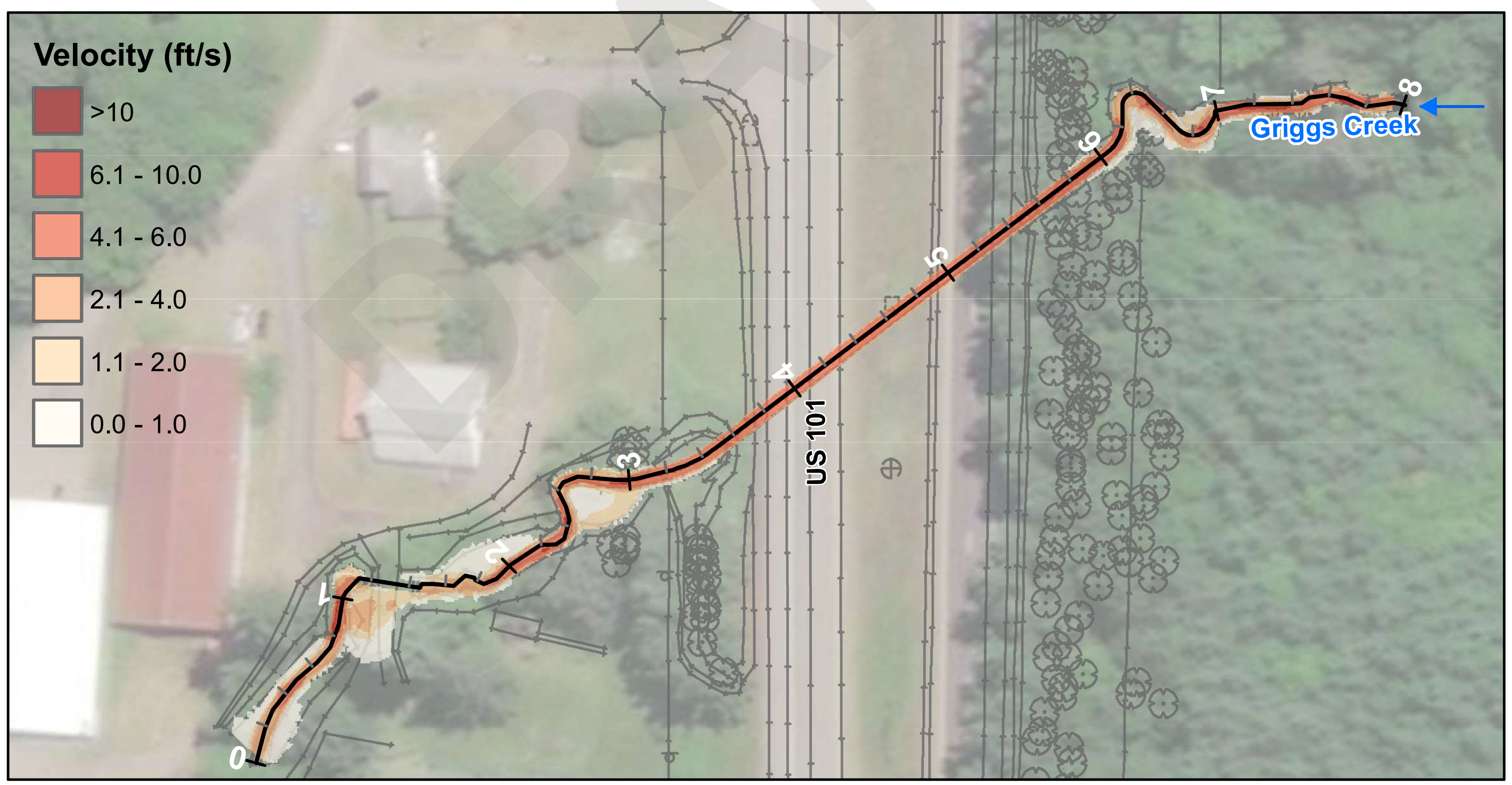

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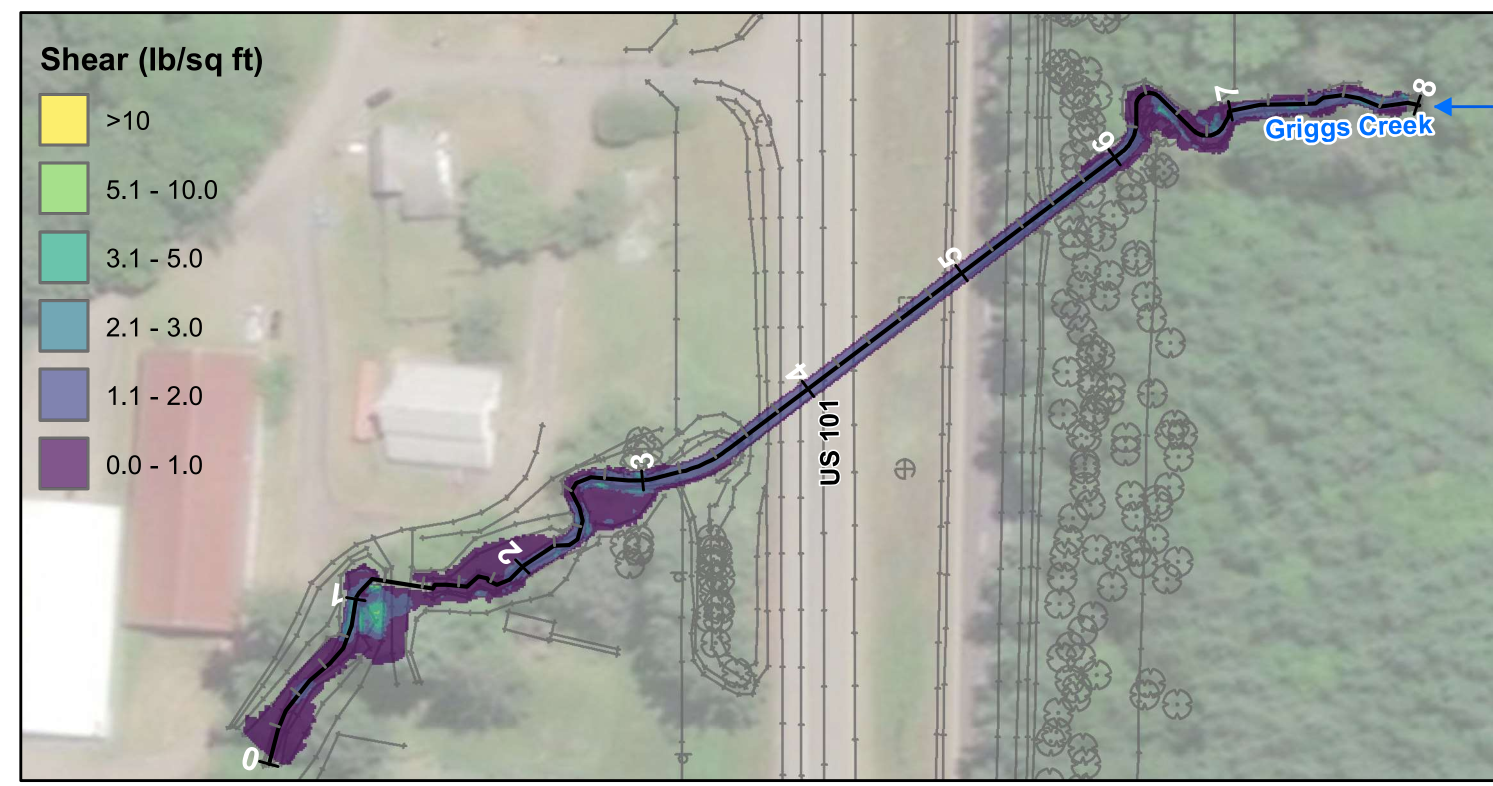

SHEAR

N 0 50 100 Feet

HDR Washington State Department of Transportation

PROPOSED CONDITIONS 50-YEAR

US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

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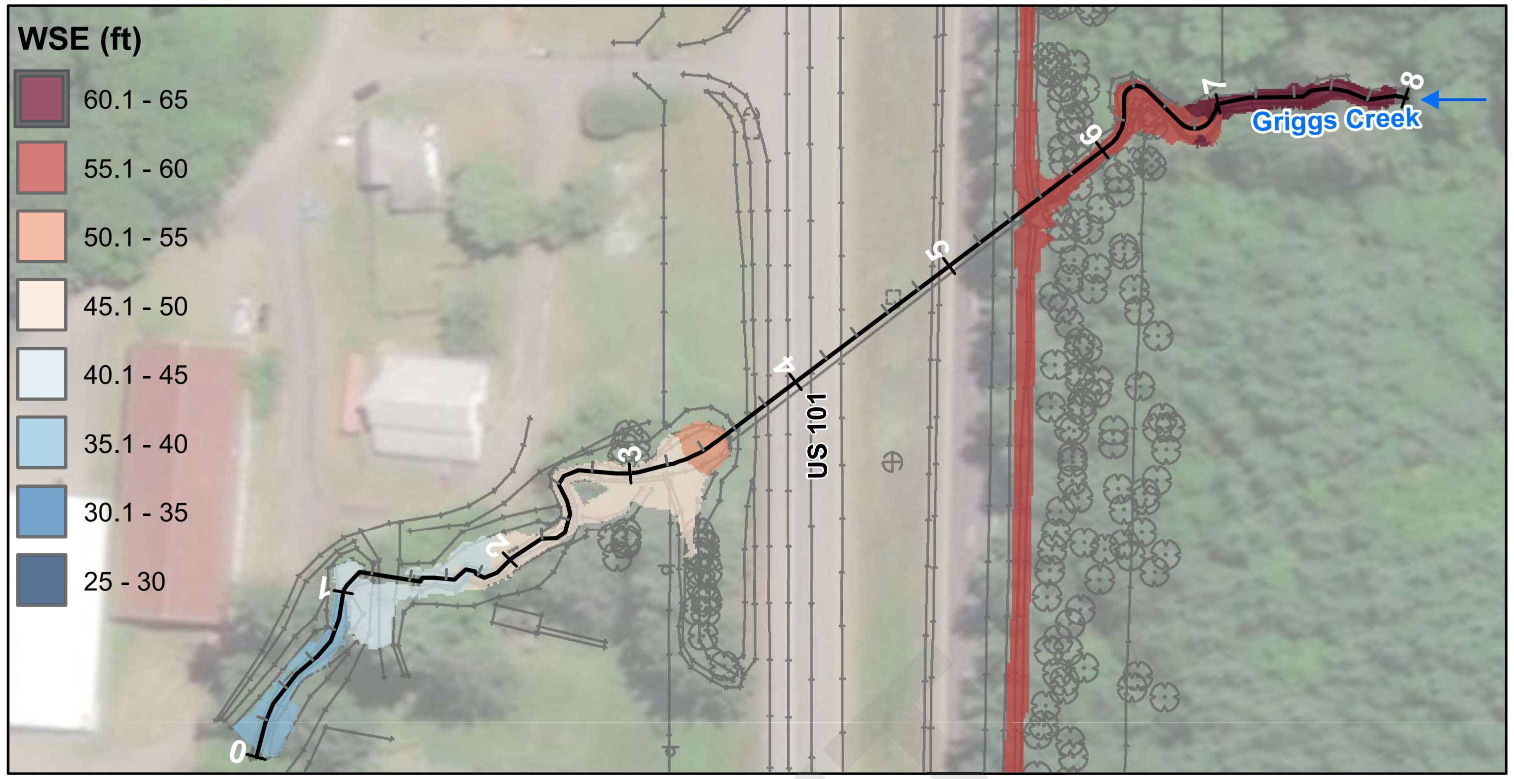

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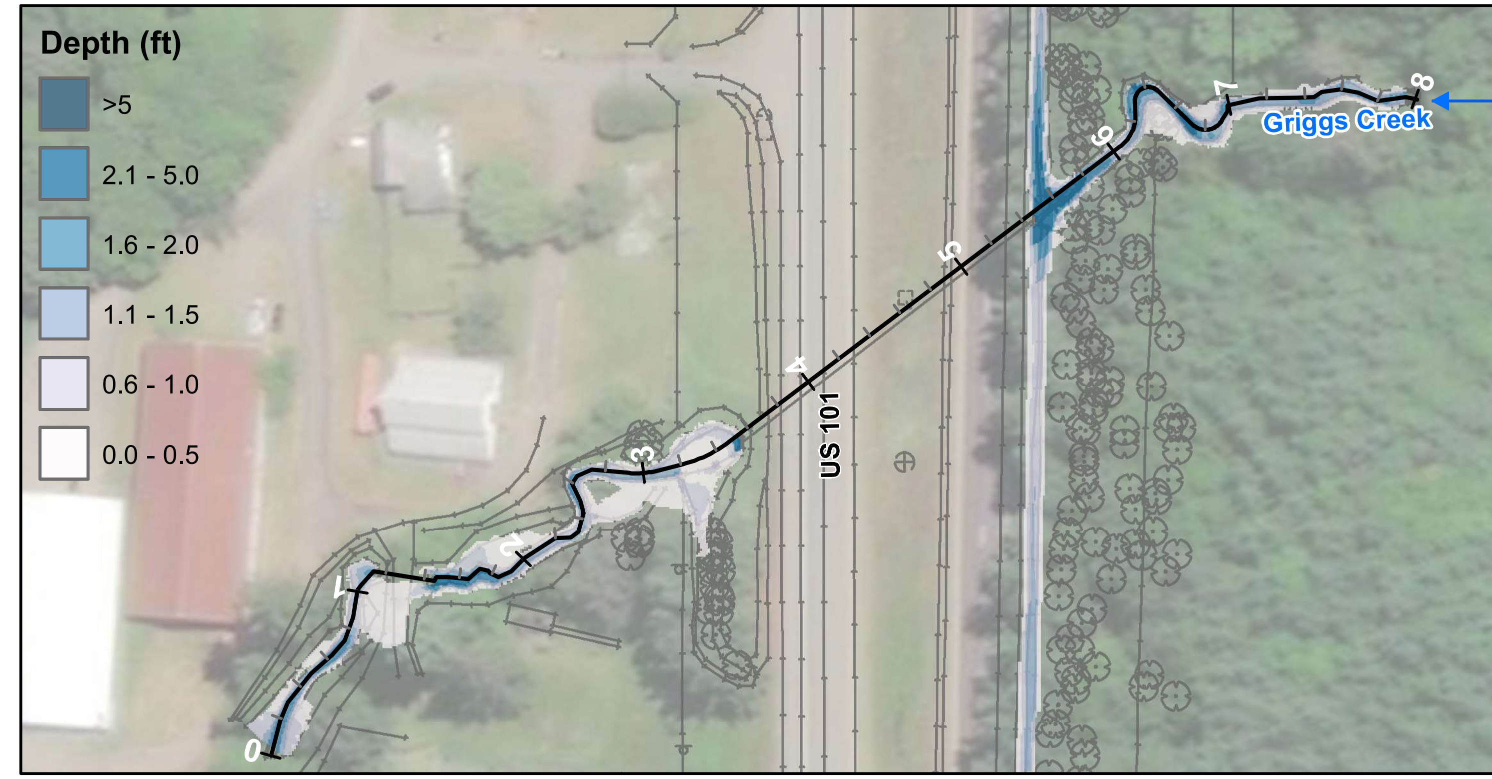
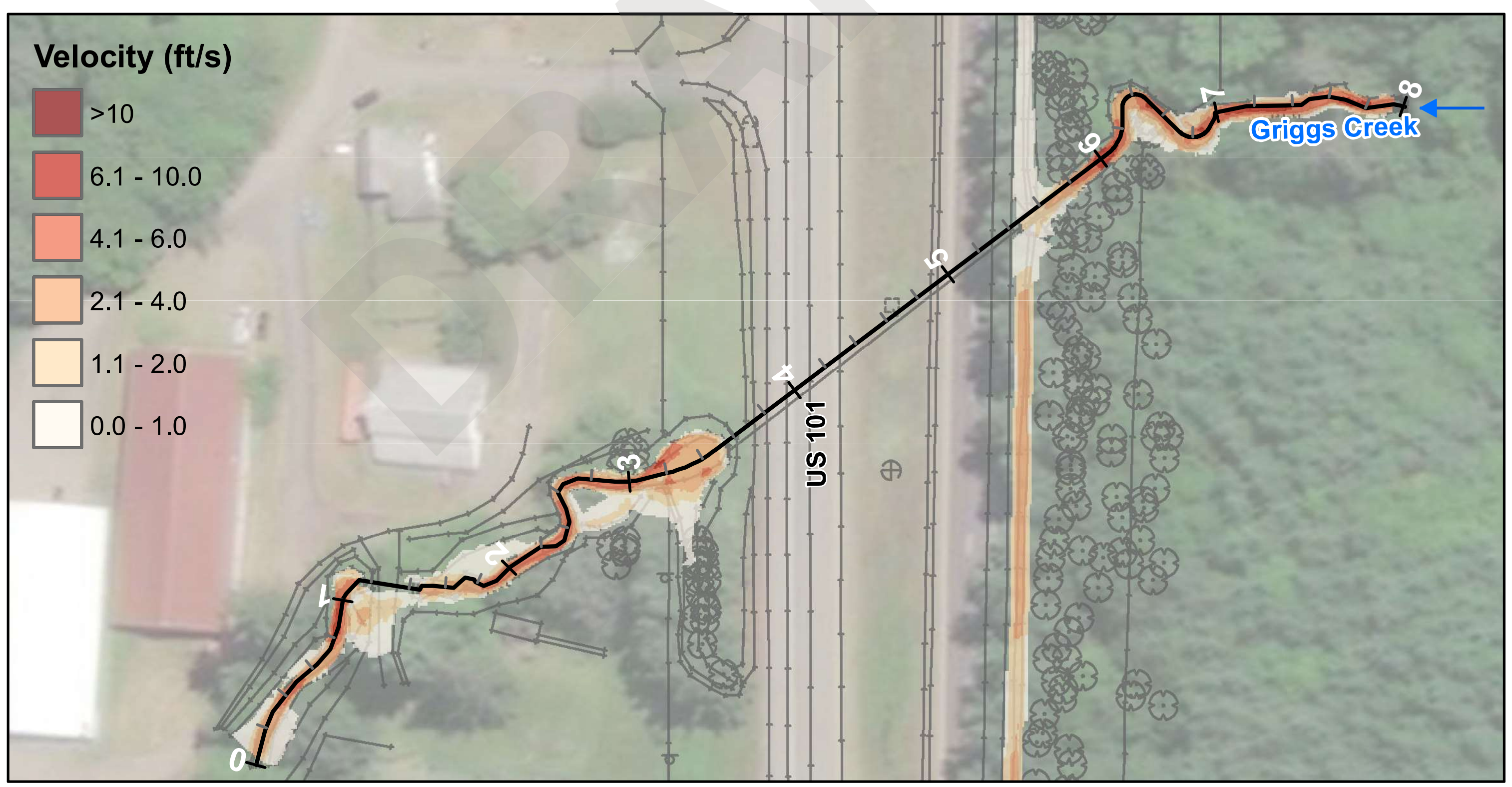


DEPTH



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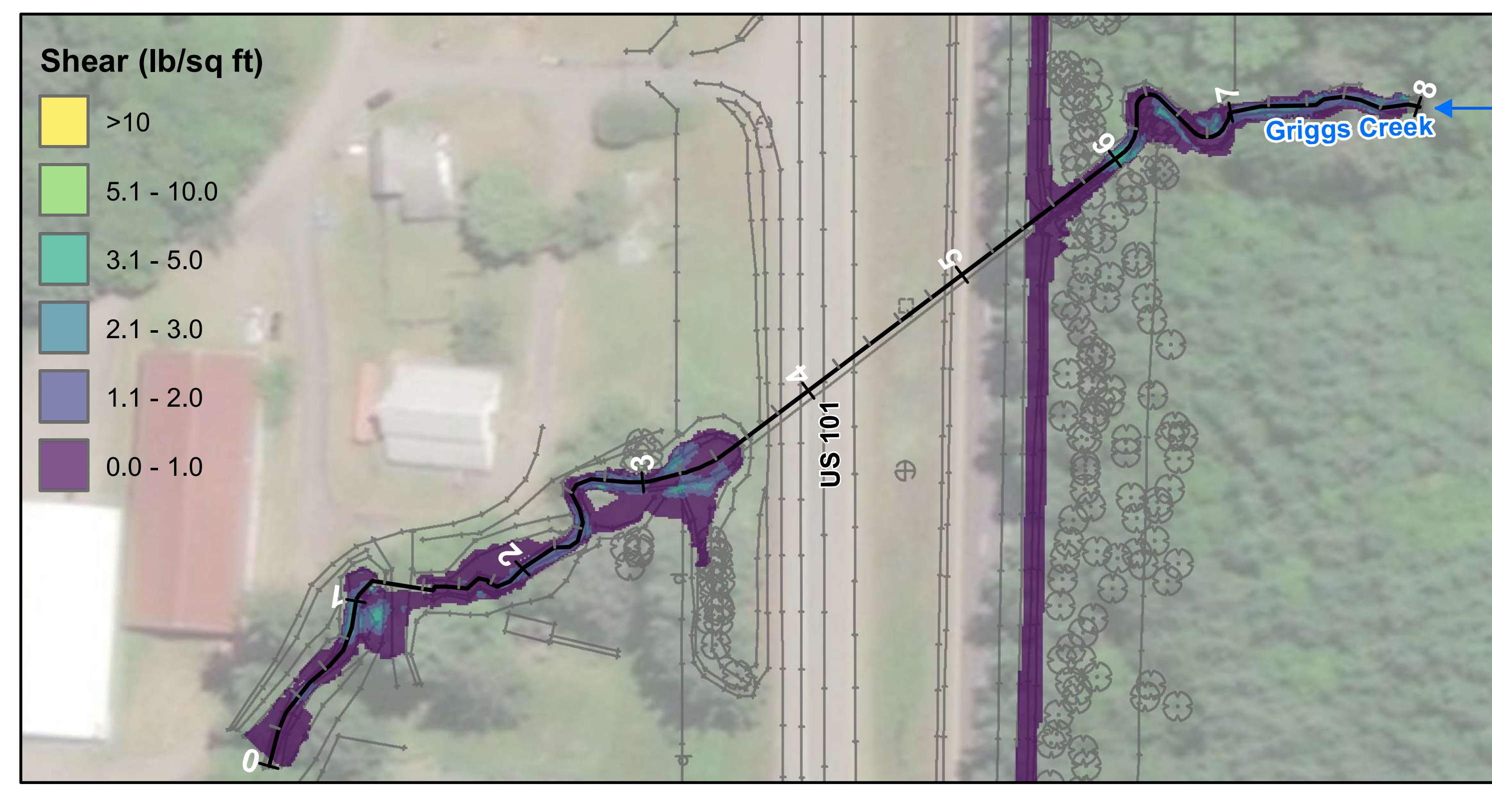


SHEAR

N

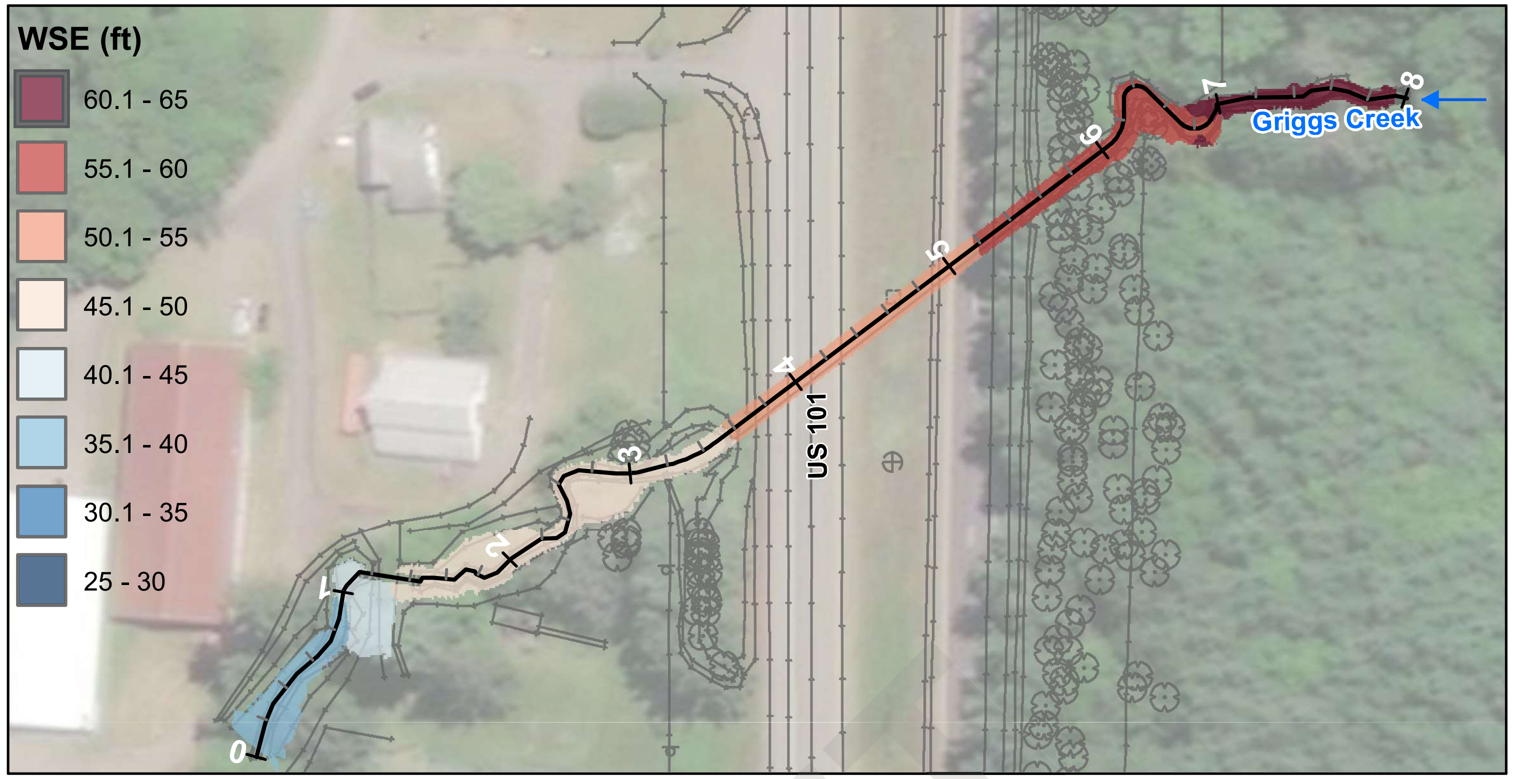
0 50 100 Feet

HDR

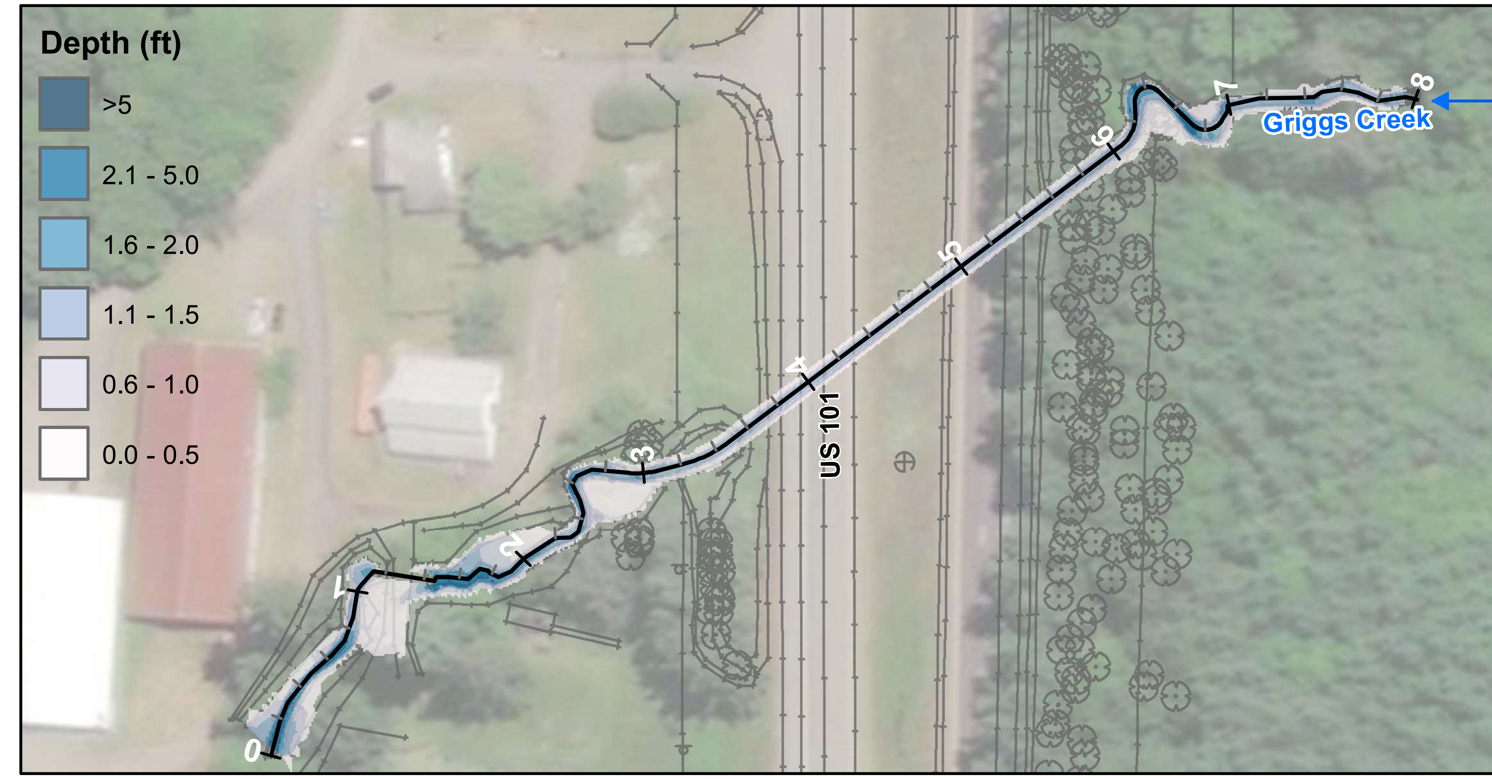
Washington State Department of Transportation

EXISTING CONDITIONS 100-YEAR

US 101 GRIGGS CREEK
MP 357.4



WATER SURFACE ELEVATION



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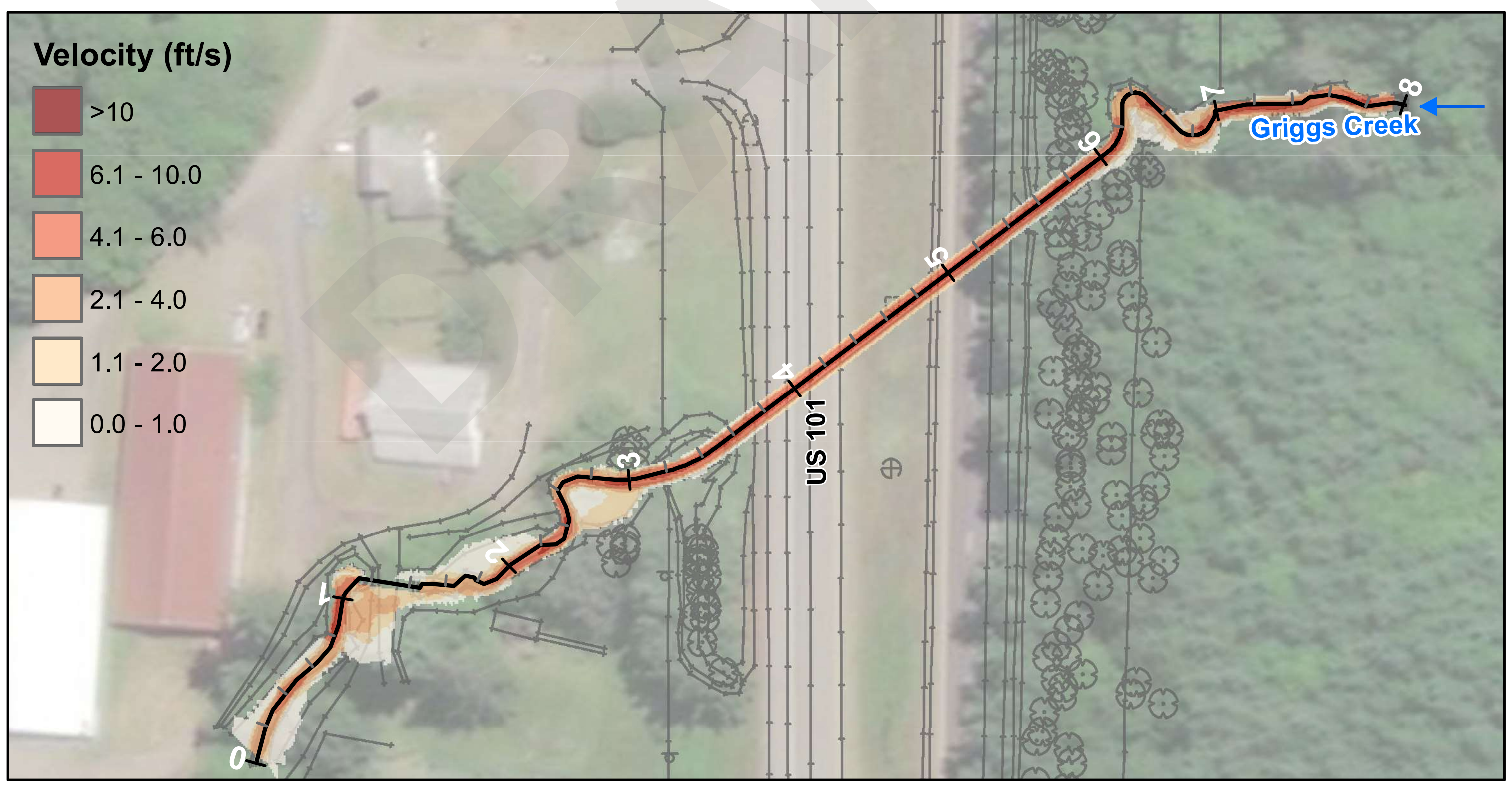

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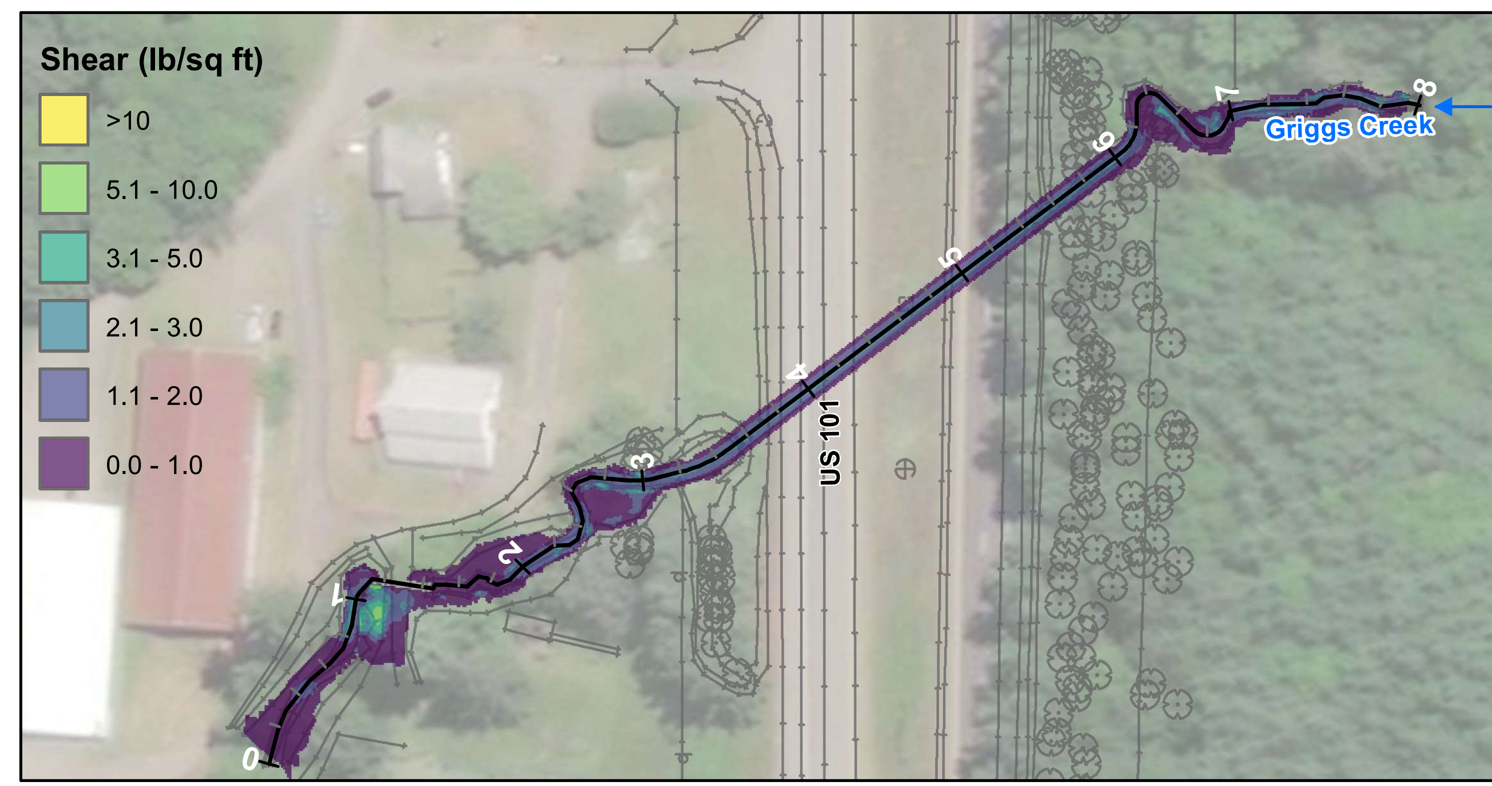


SHEAR

0 50 100 Feet

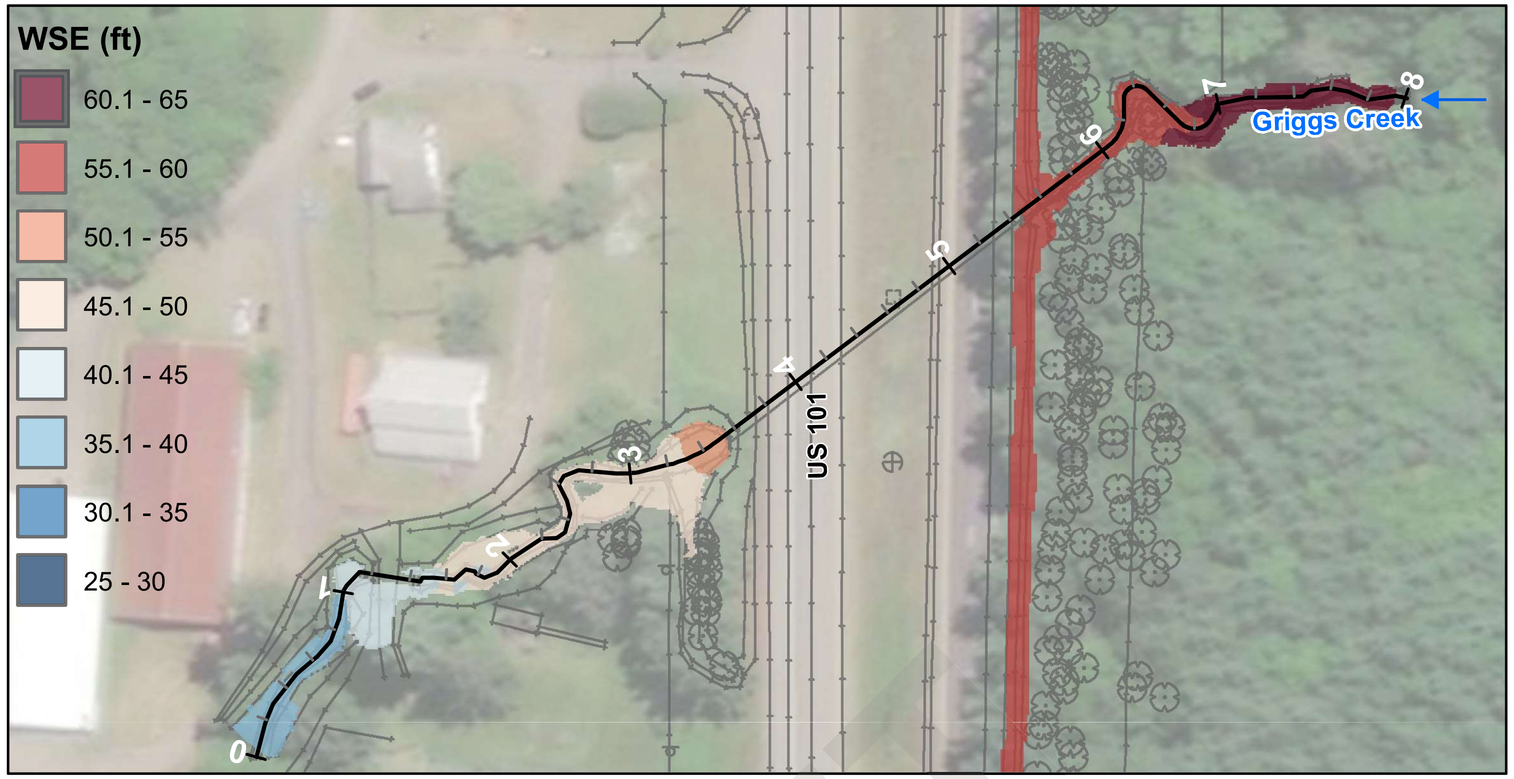
HDR Washington State Department of Transportation

PROPOSED CONDITIONS 100-YEAR

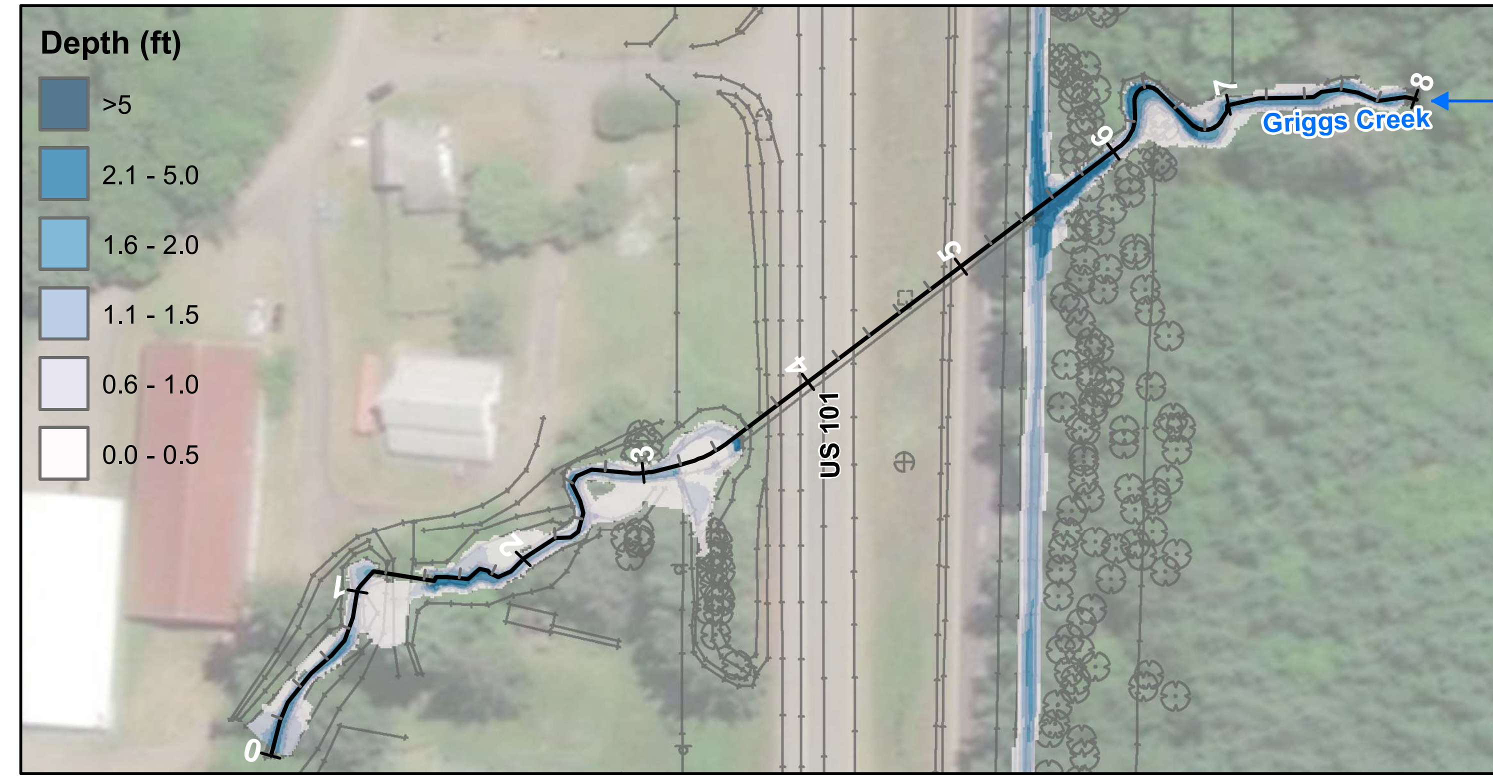
US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

PRELIMINARY HYDARULIC DESIGN



WATER SURFACE ELEVATION



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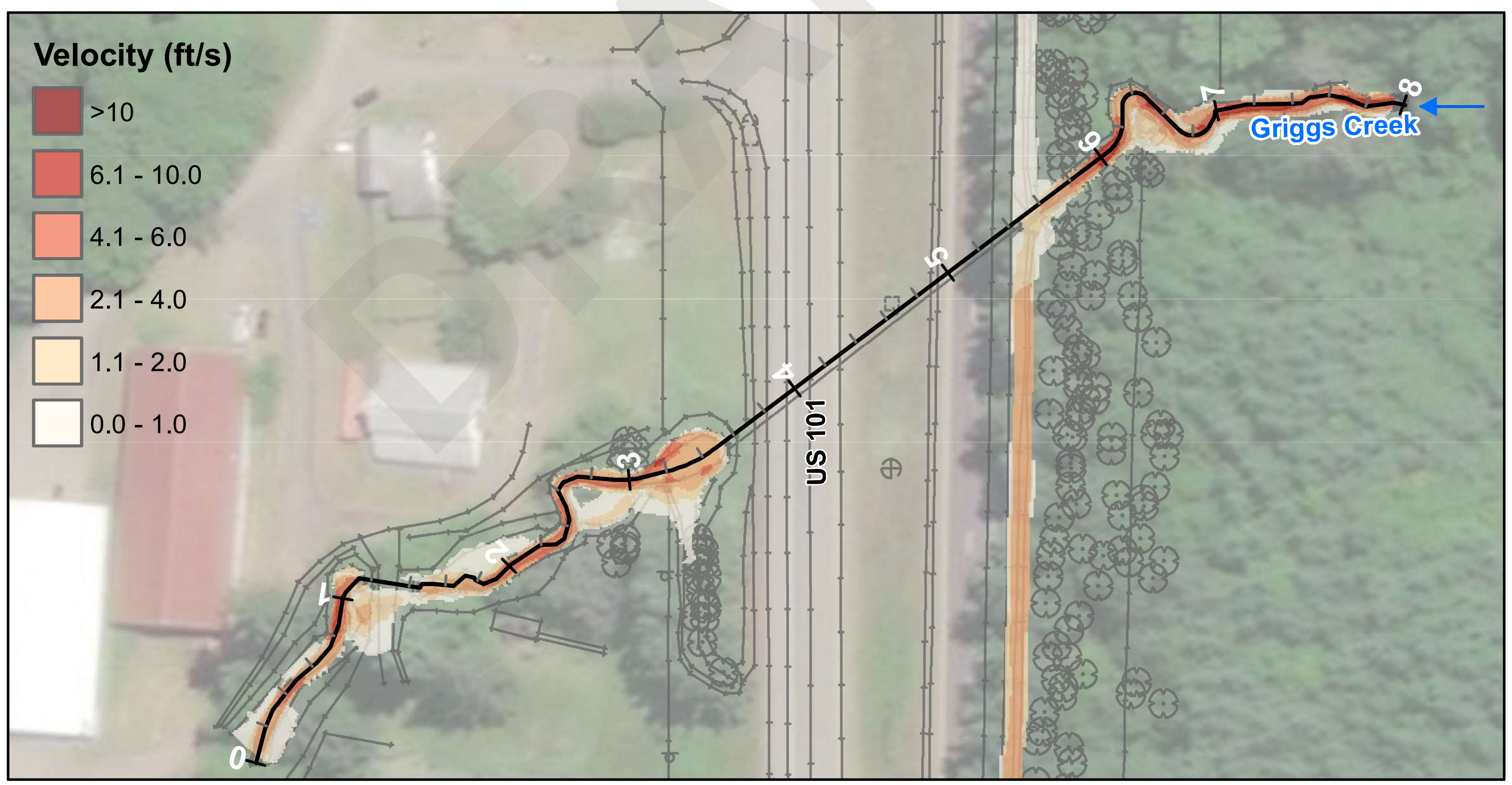

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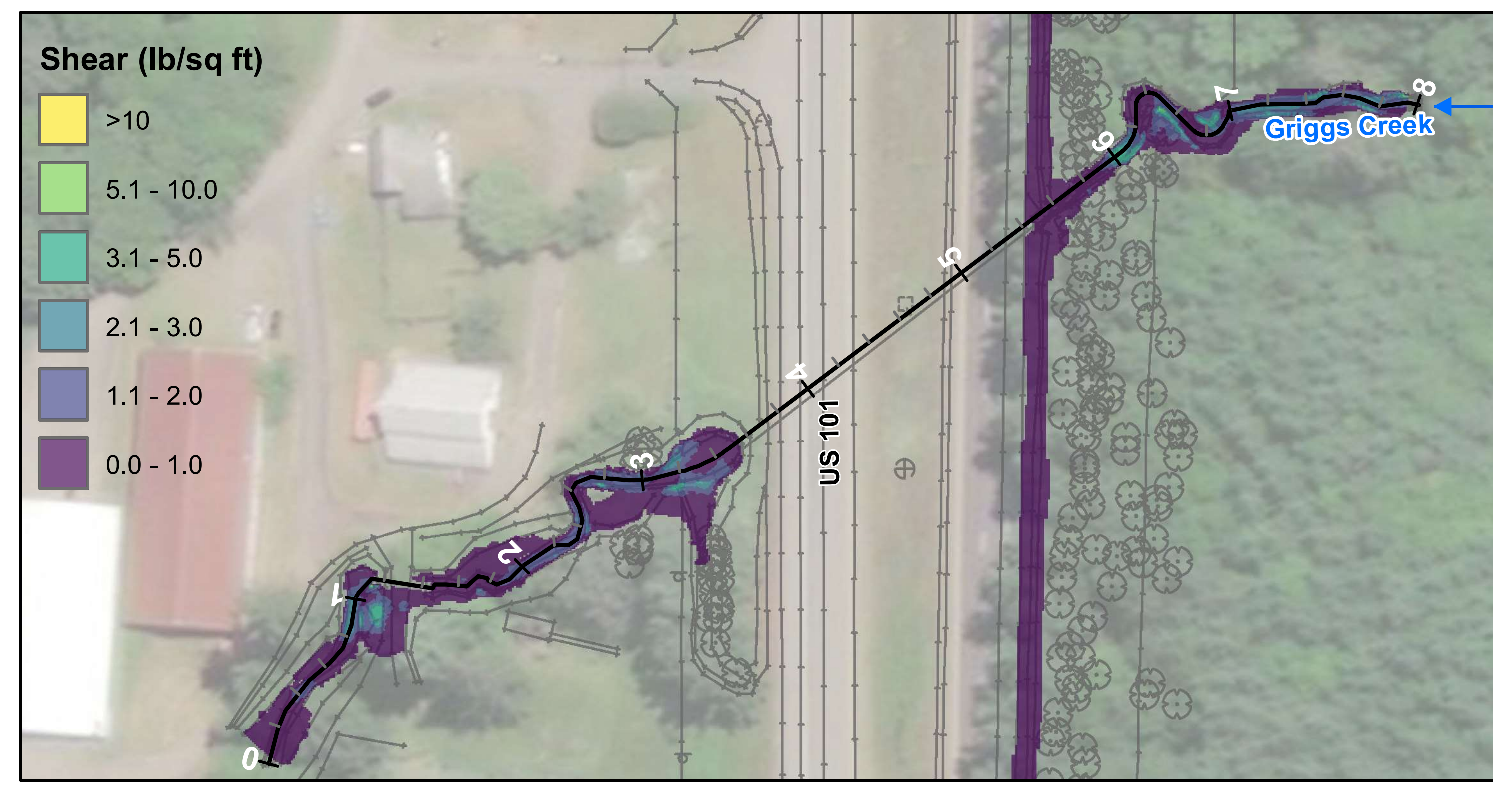


SHEAR

N
0 50 100 Feet

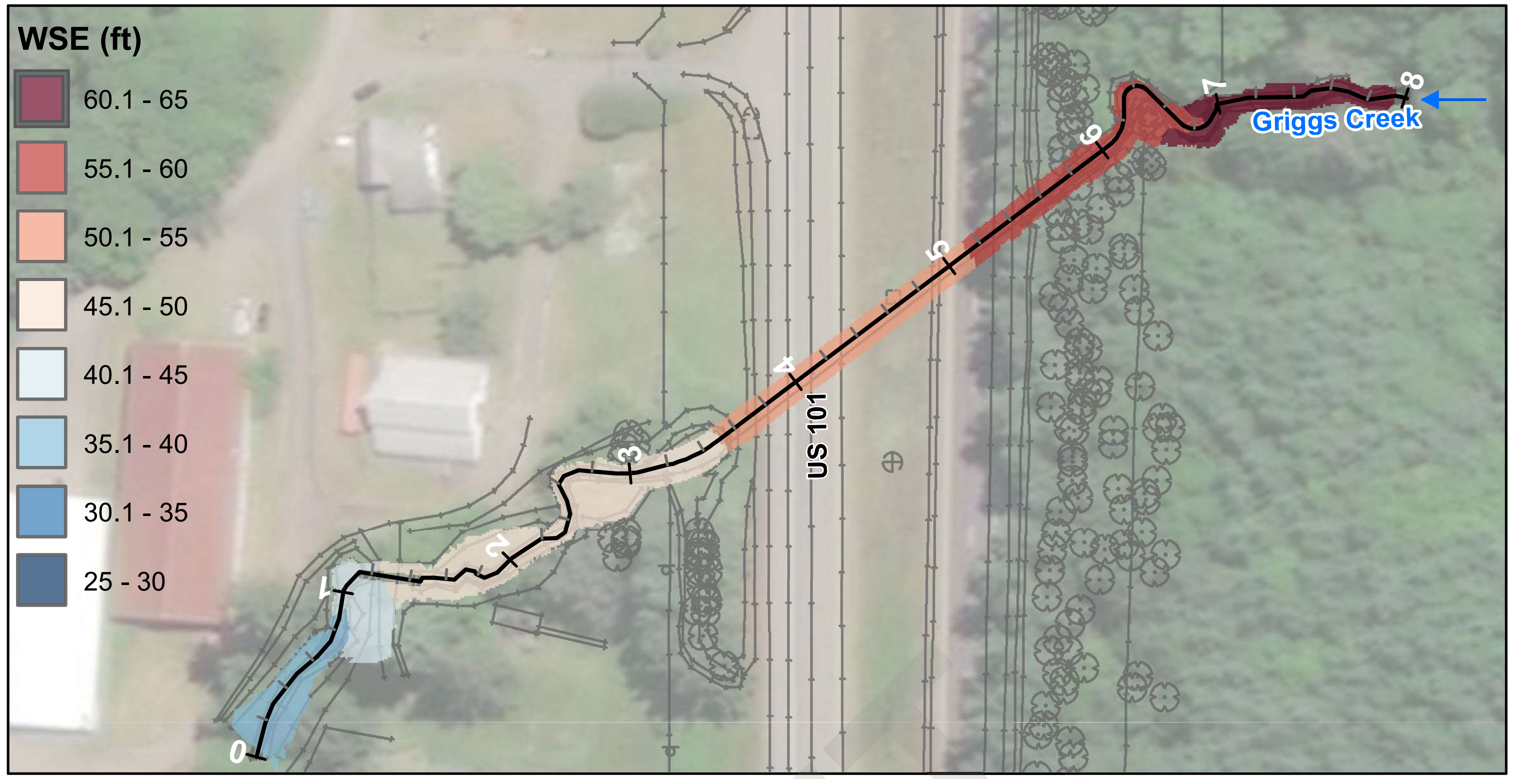
Washington State Department of Transportation

EXISTING CONDITIONS 500-YEAR

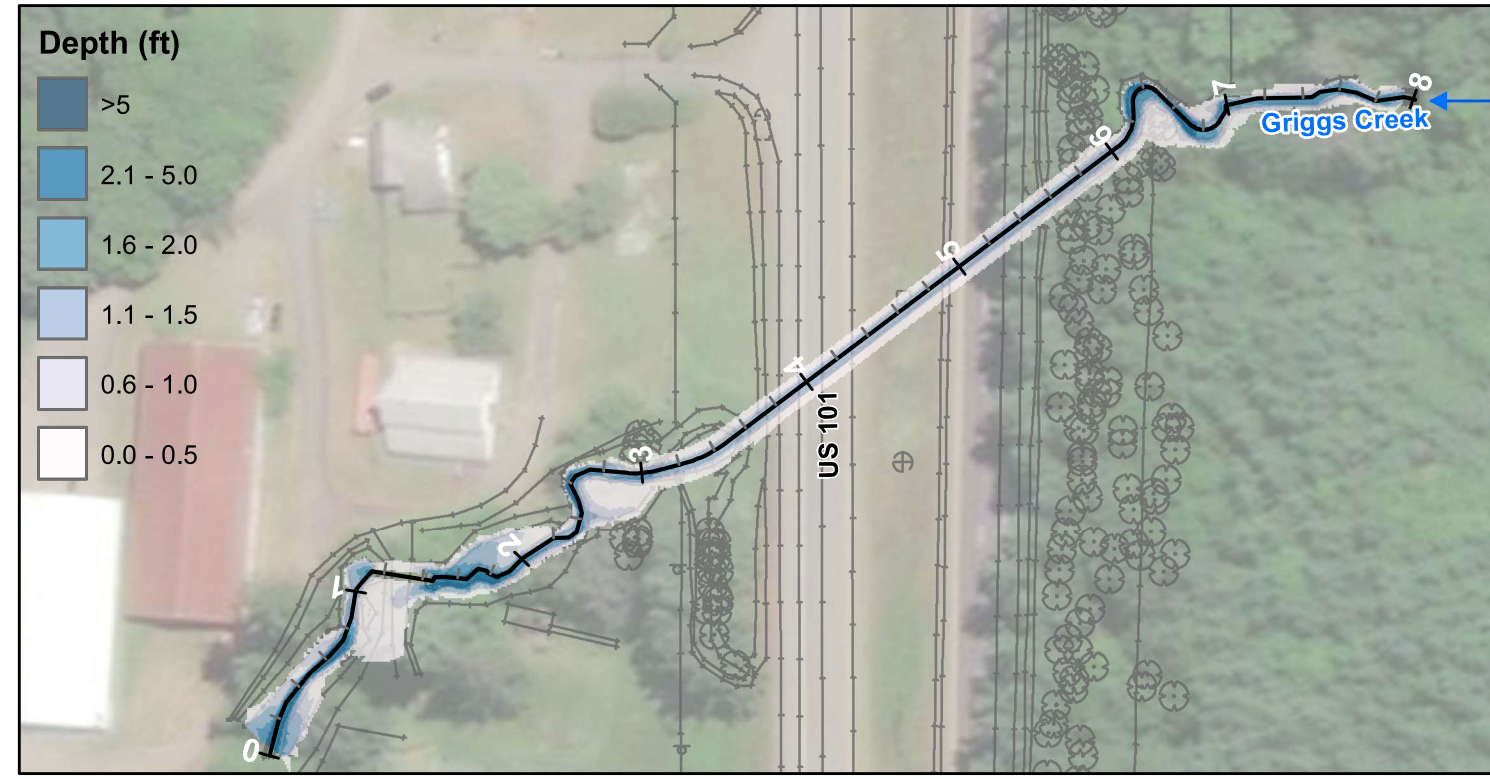
US 101 GRIGGS CREEK
MP 357.4

PATH: C:\APPENDIX_FIGS\US101_MP357.4\RESULTS\OUTPUT FIGURES\4PANE_US101_357.4.MXD - USER: DMINNER - DATE: 5/30/2020

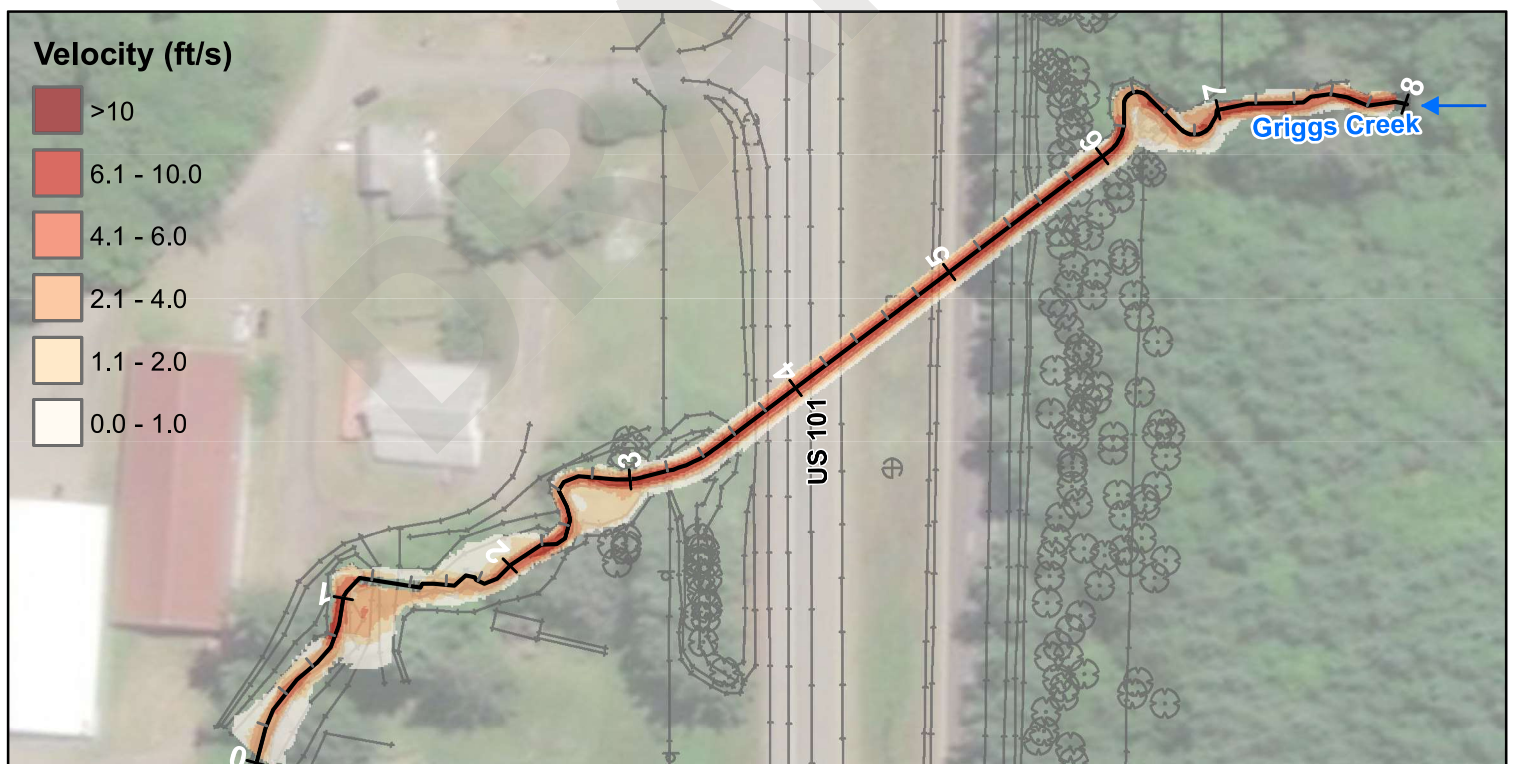
PRELIMINARY HYDARULIC DESIGN



WATER SURFACE ELEVATION



DEPTH



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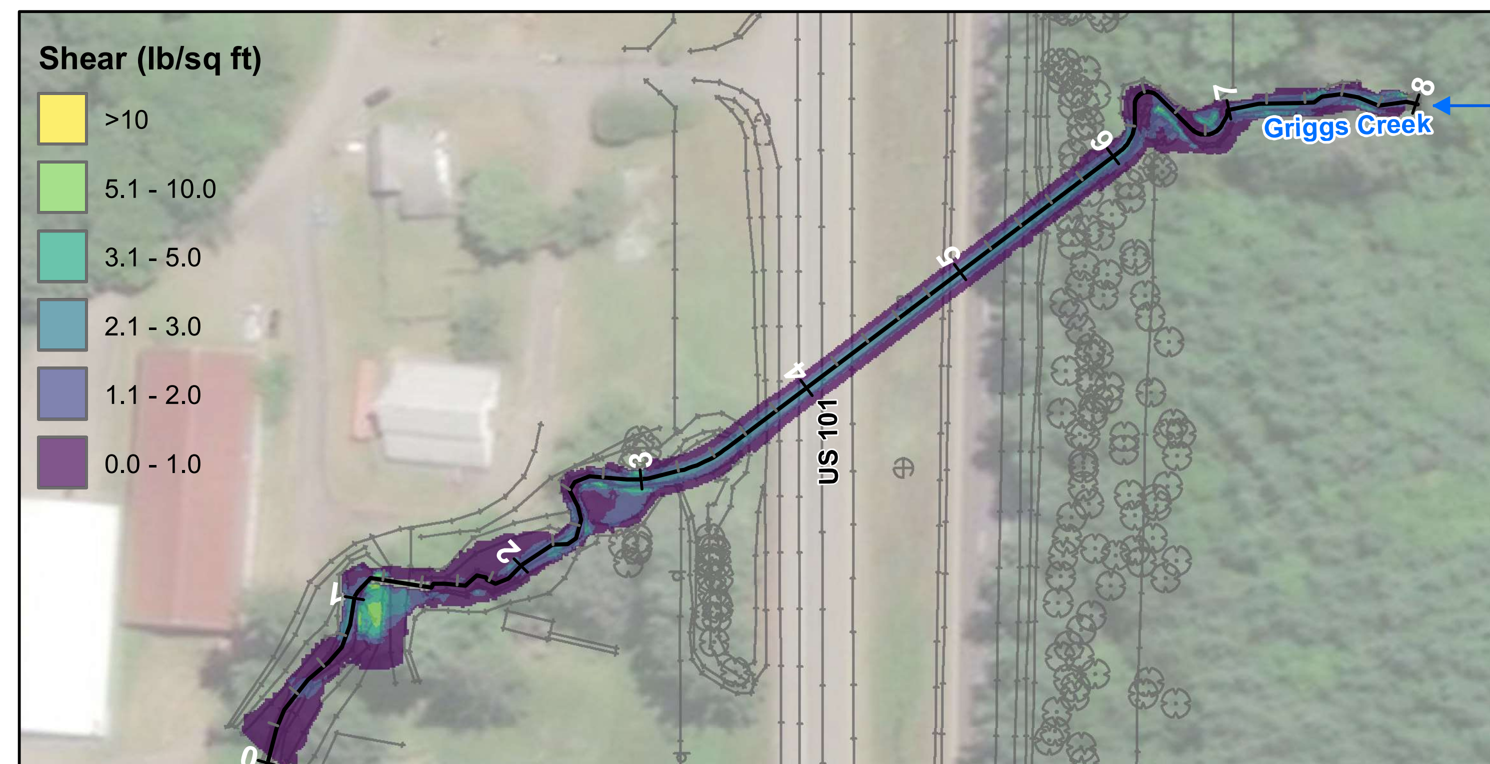


SHEAR

N

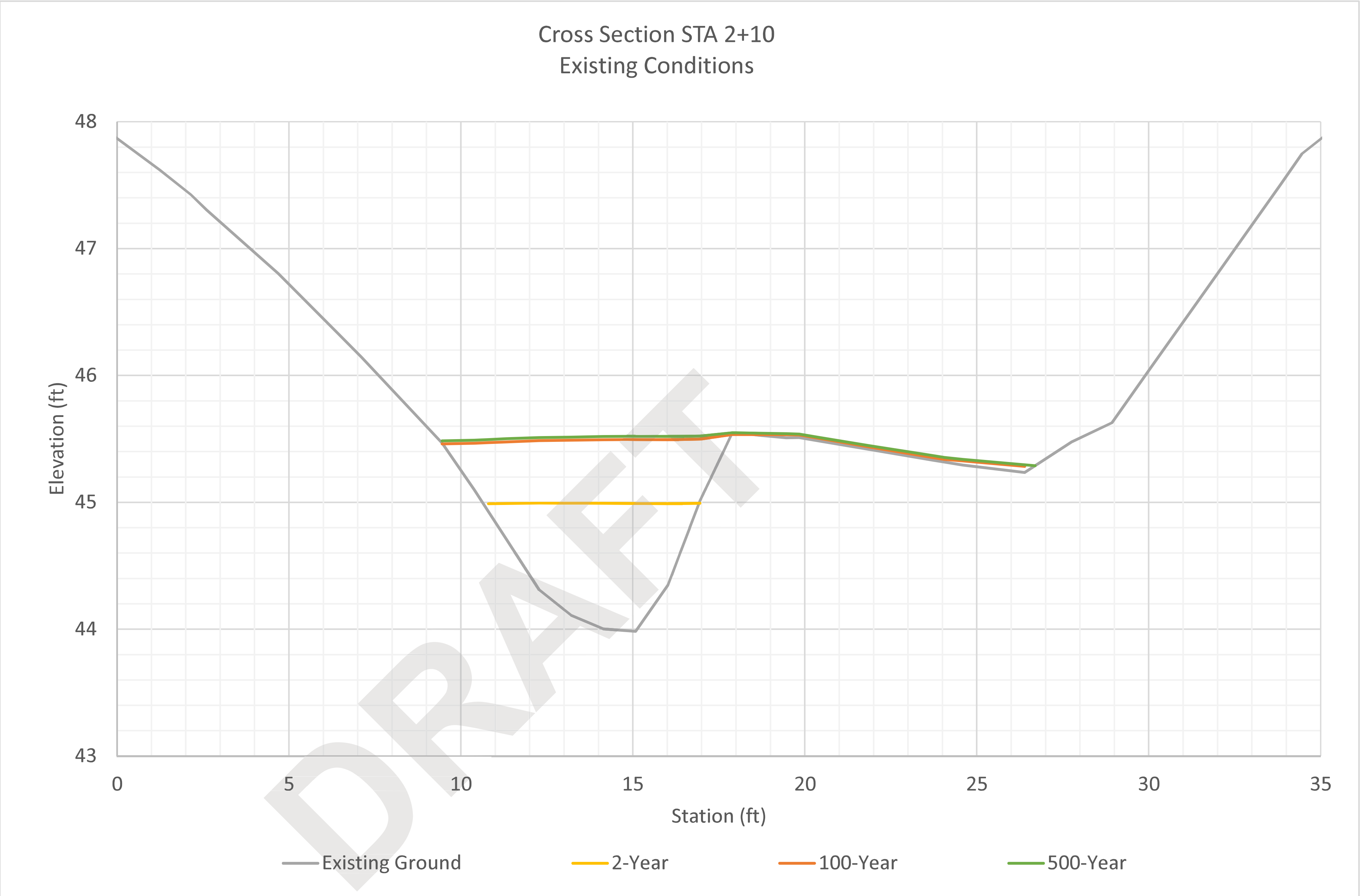
0 50 100 Feet

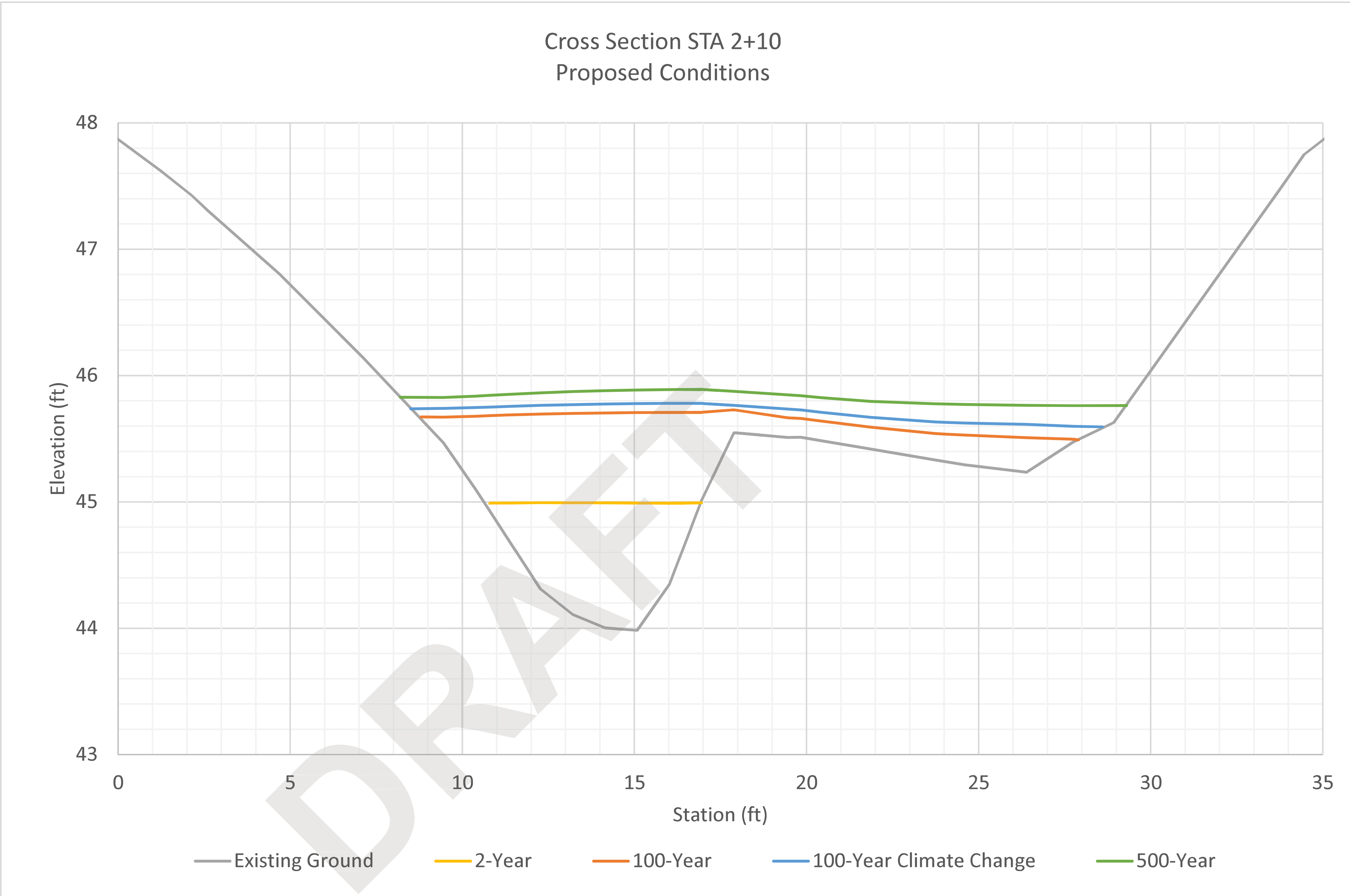
HDR

Washington State Department of Transportation

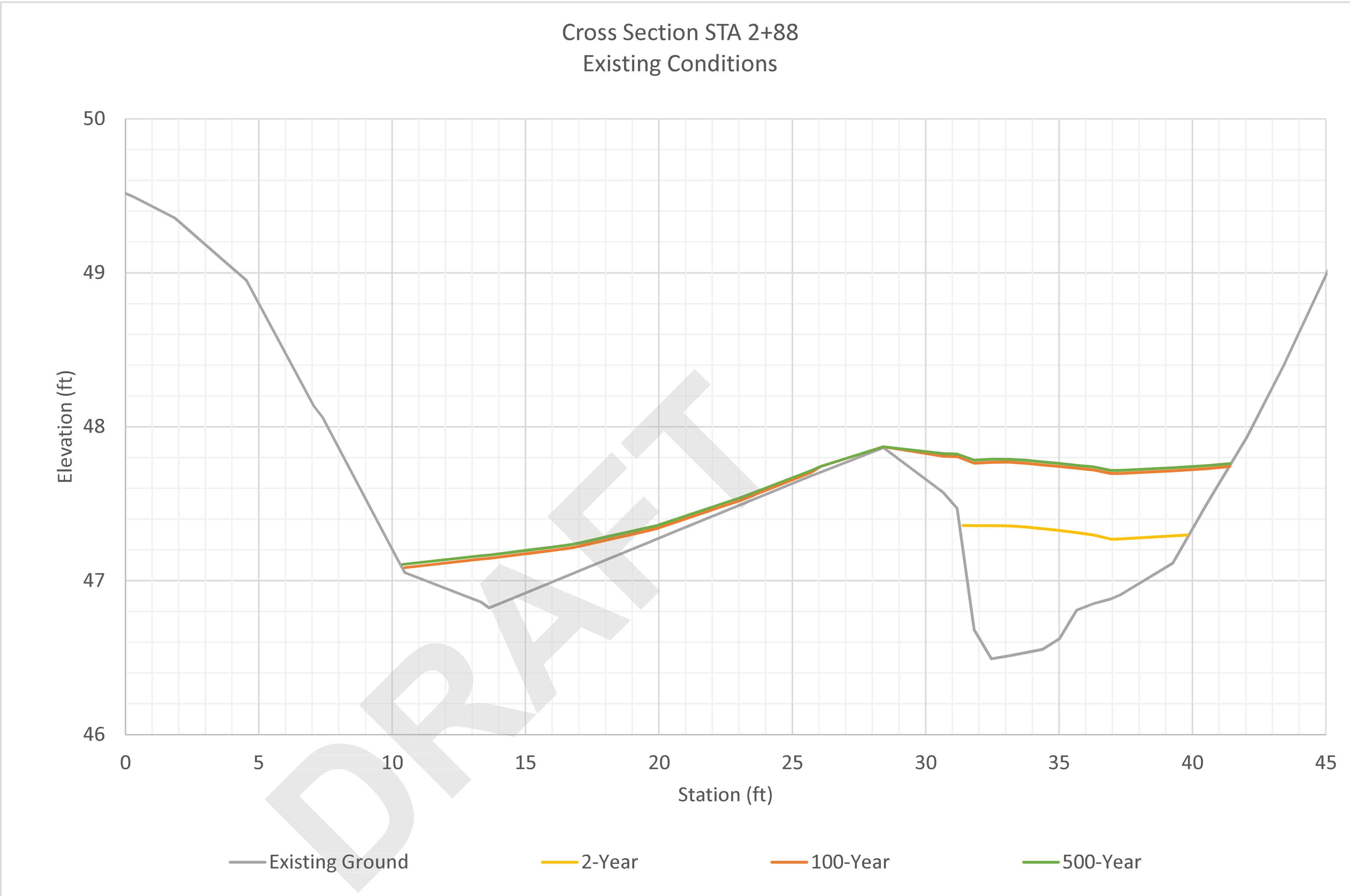
PROPOSED CONDITIONS 500-YEAR

US 101 GRIGGS CREEK
MP 357.4

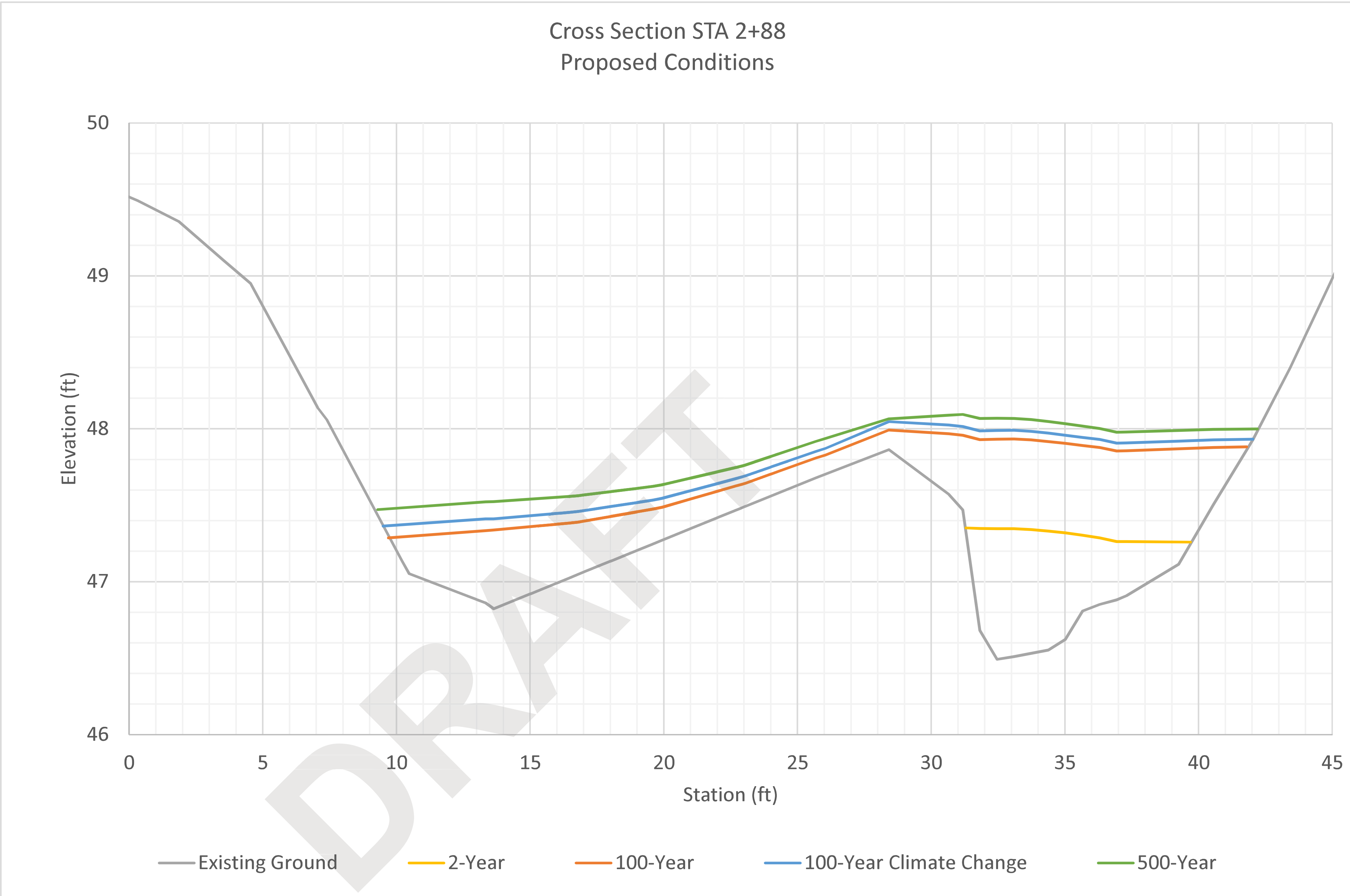

Cross Section STA 2+10
Existing Conditions
48
47
46
45
44
43
Elevation (ft)
0
5
10
15
20
25
30
35
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT

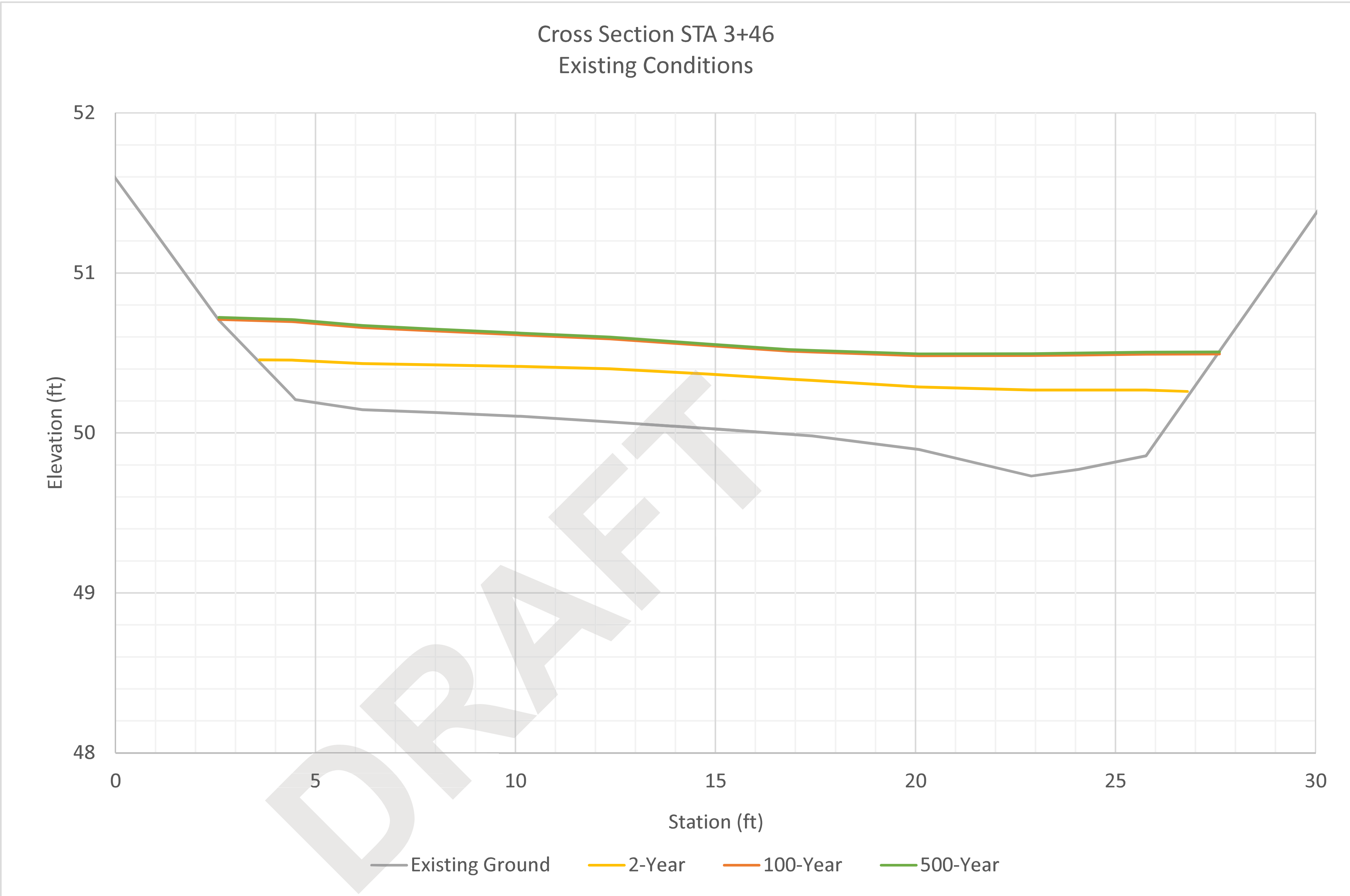


Cross Section STA 2+10
Proposed Conditions
Elevation (ft)
48
47
46
45
44
43
0
5
10
15
20
25
30
35
Station (ft)
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT

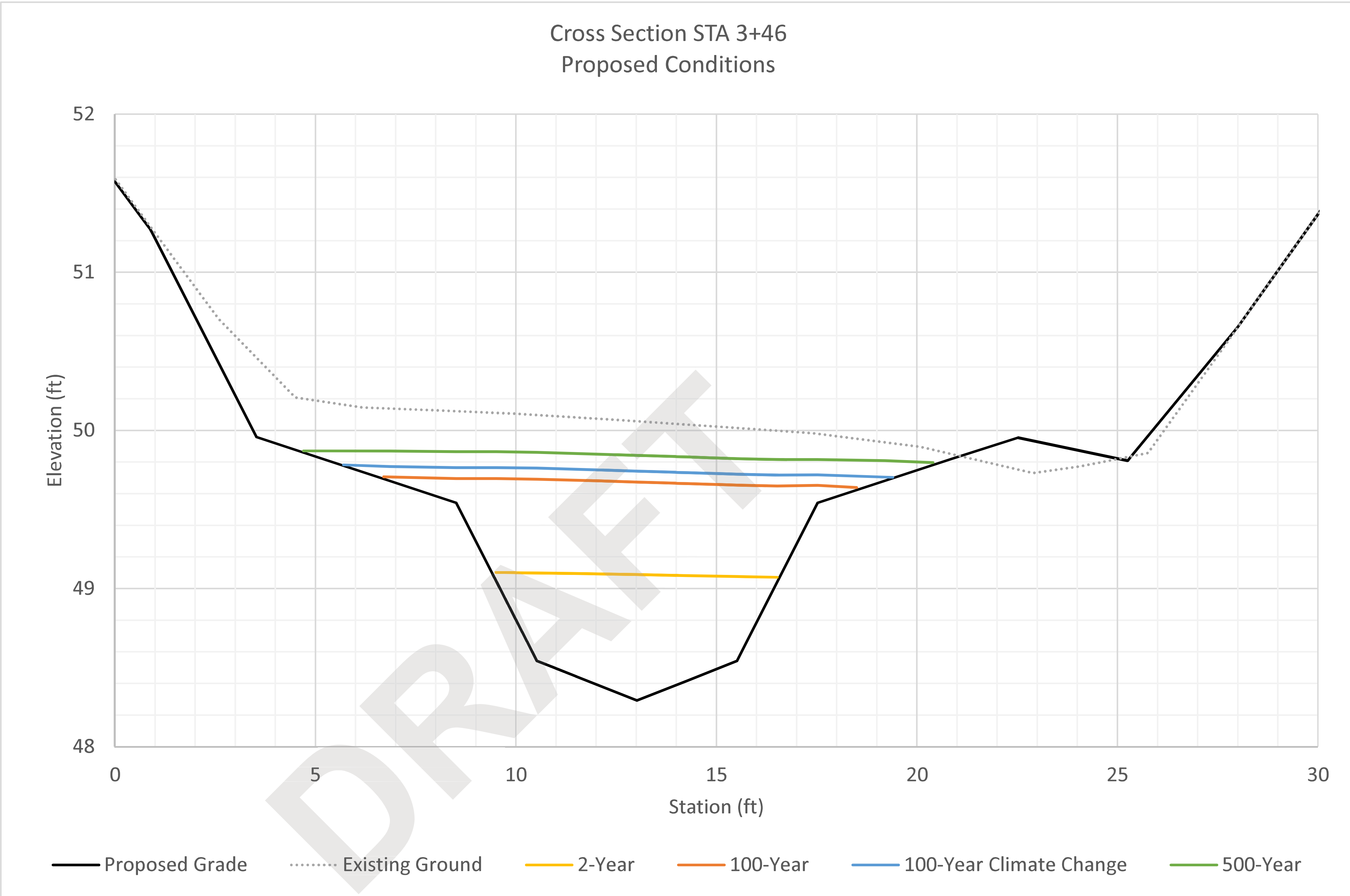


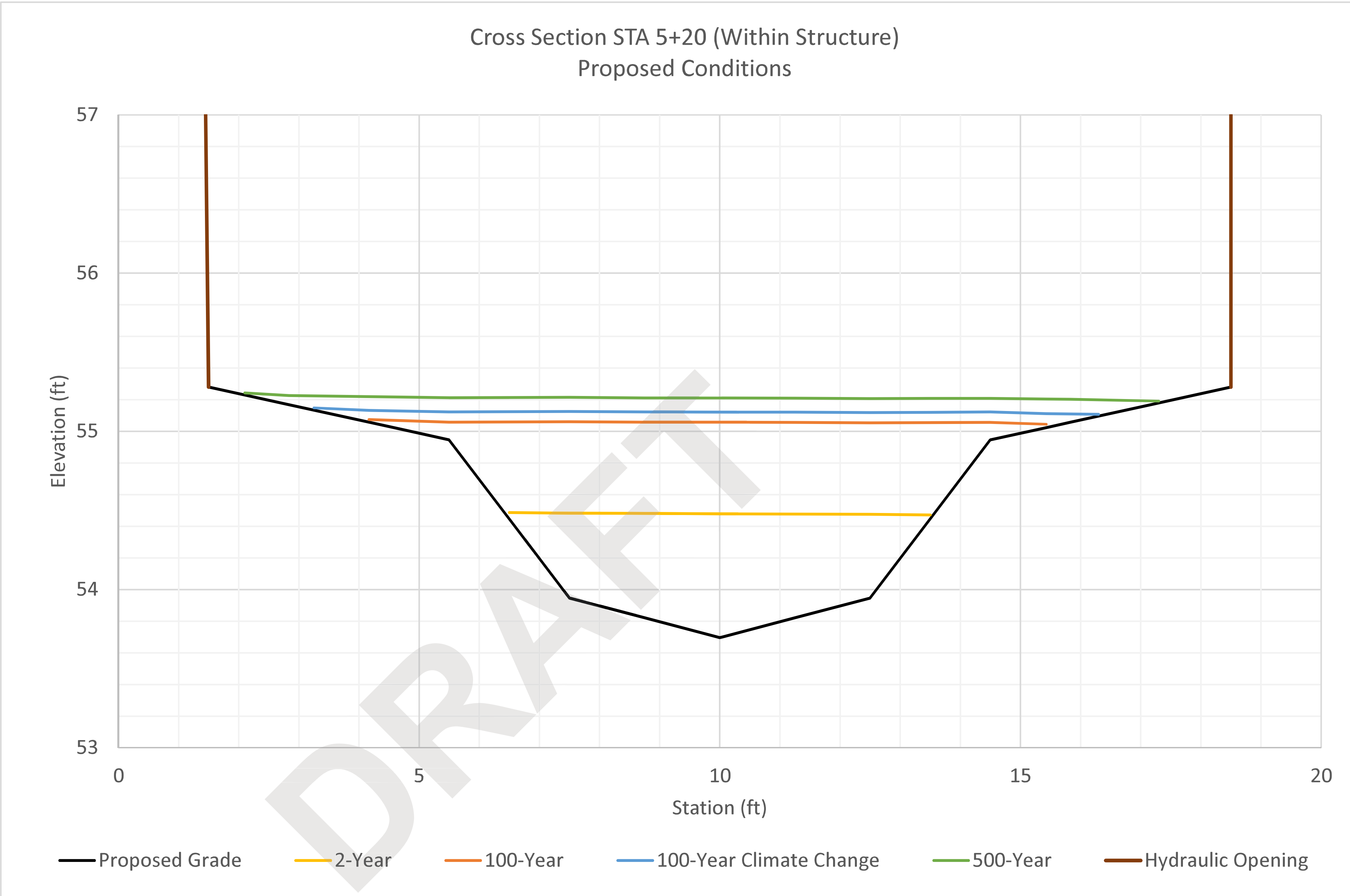
Cross Section STA 2+88
Existing Conditions
Elevation (ft)
50
49
48
47
46
0
5
10
15
20
25
30
35
40
45
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT

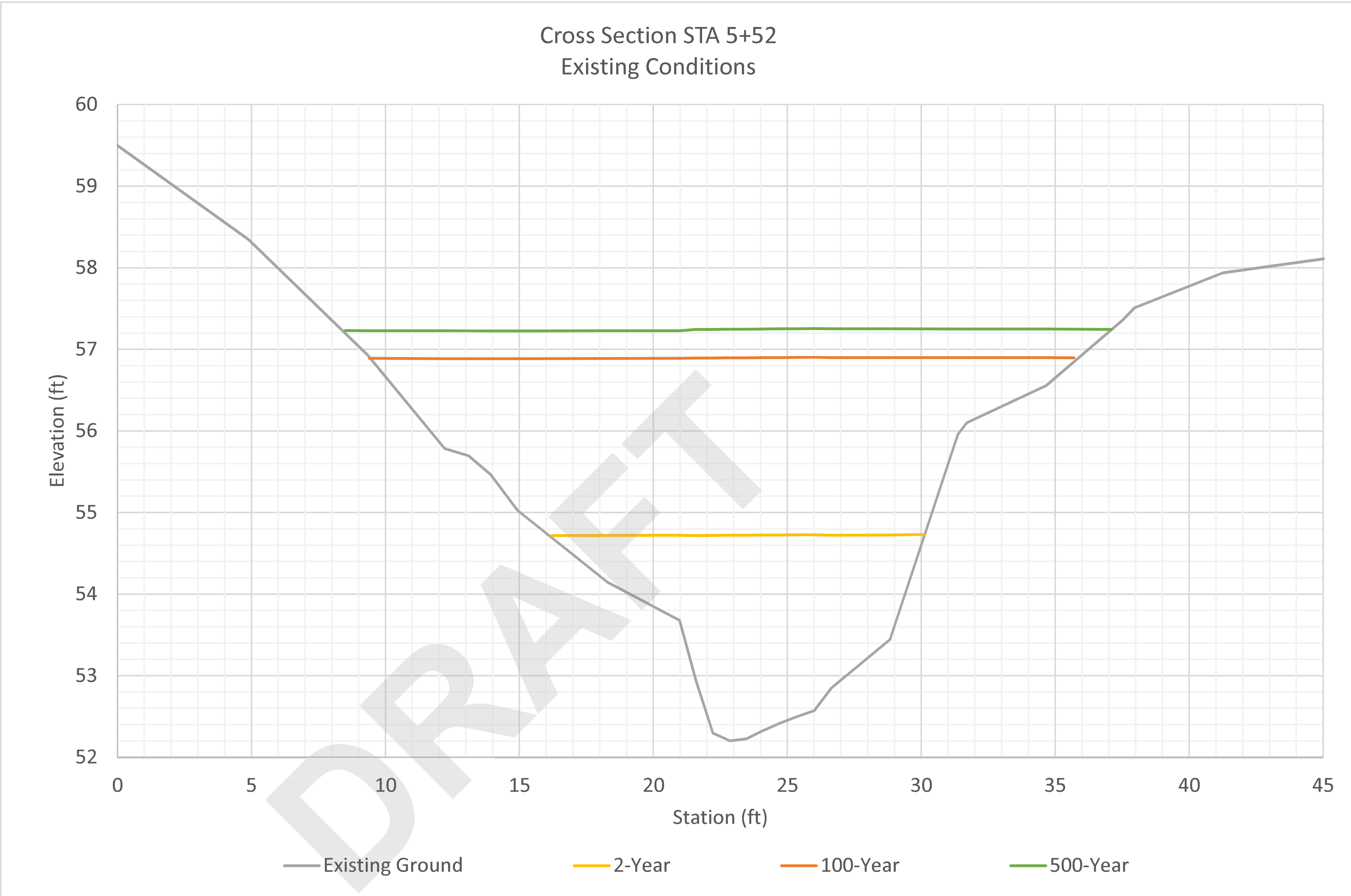

Cross Section STA 2+88
Proposed Conditions
Elevation (ft)
Station (ft)
50
49
48
47
46
0
5
10
15
20
25
30
35
40
45
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT



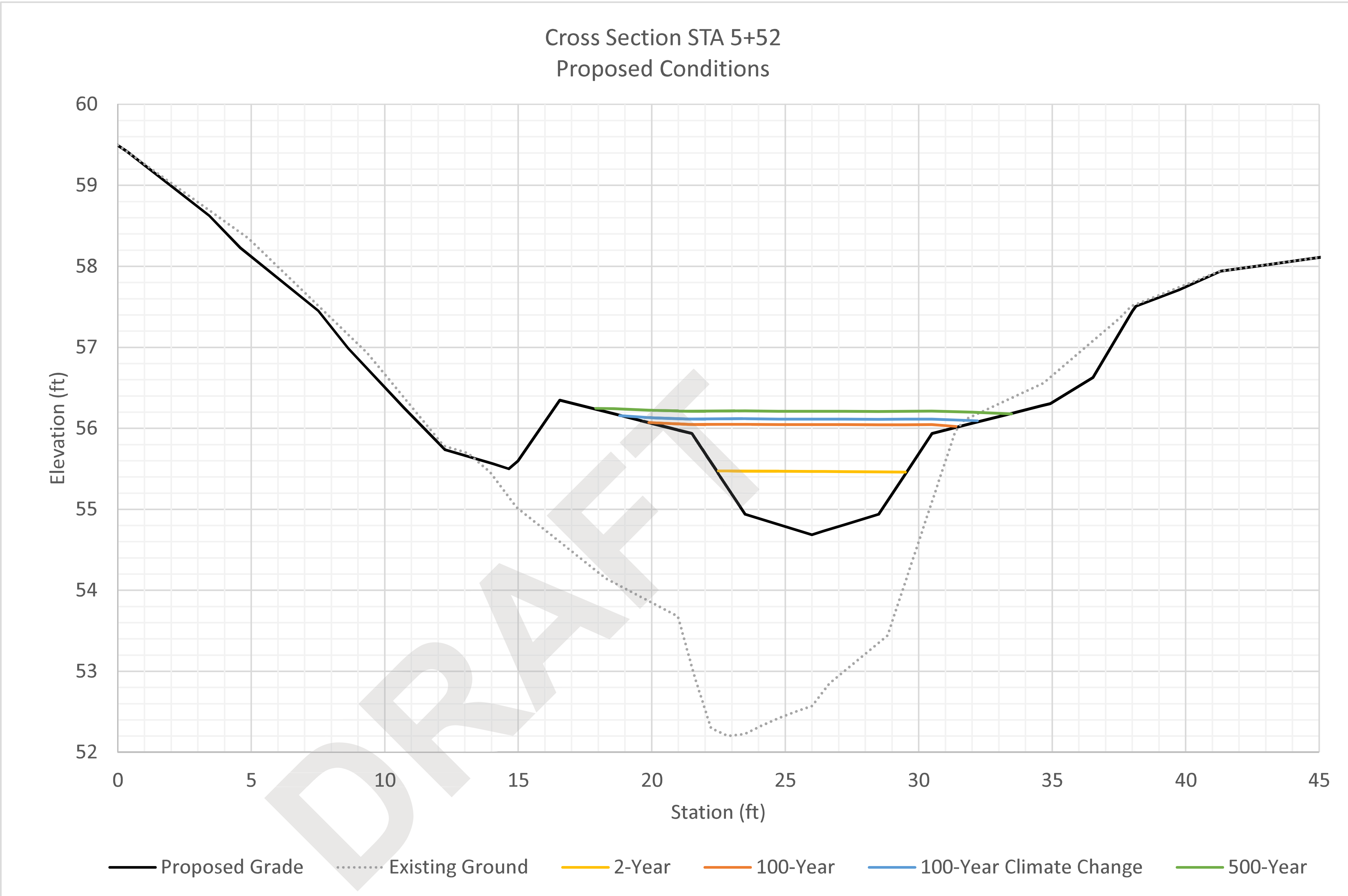
Cross Section STA 3+46
Existing Conditions
52
51
50
49
48
Elevation (ft)
0
5
10
15
20
25
30
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT


Cross Section STA 3+46
Proposed Conditions
52
51
50
49
48
Elevation (ft)
0
5
10
15
20
25
30
Station (ft)
Proposed Grade
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT

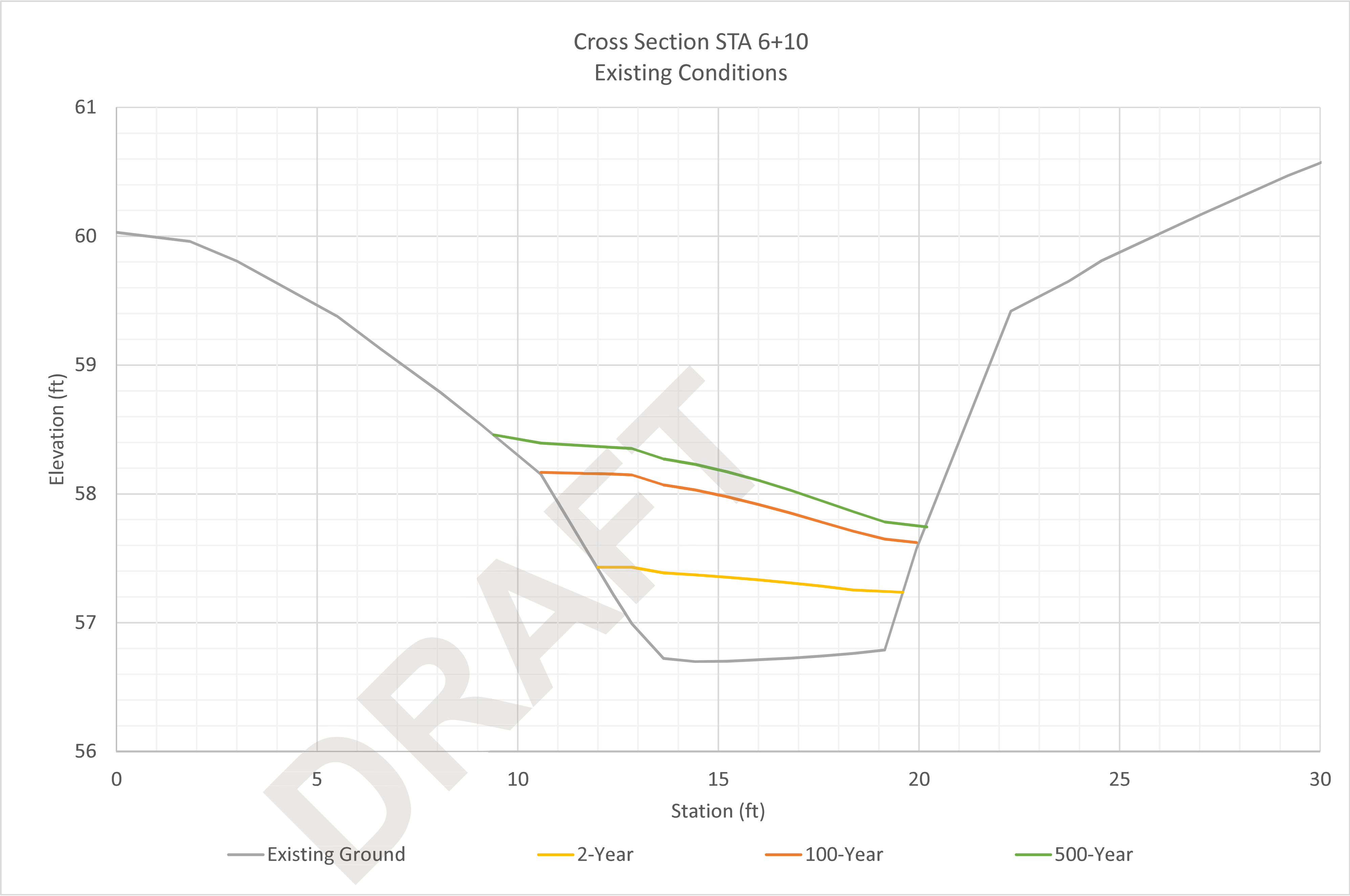

Cross Section STA 5+20 (Within Structure)
Proposed Conditions
57
56
55
54
53
Elevation (ft)
0
5
10
15
20
Station (ft)
Proposed Grade
2-Year
100-Year
100-Year Climate Change
500-Year
Hydraulic Opening
DRAFT



Cross Section STA 5+52
Existing Conditions
Elevation (ft)
60
59
58
57
56
55
54
53
52
0
5
10
15
20
25
30
35
40
45
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT



Cross Section STA 5+52
Proposed Conditions
60
59
58
57
56
55
54
53
52
Elevation (ft)
0
5
10
15
20
25
30
35
40
45
Station (ft)
Proposed Grade
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT



Cross Section STA 6+10
Existing Conditions
Elevation (ft)
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60
59
58
57
56
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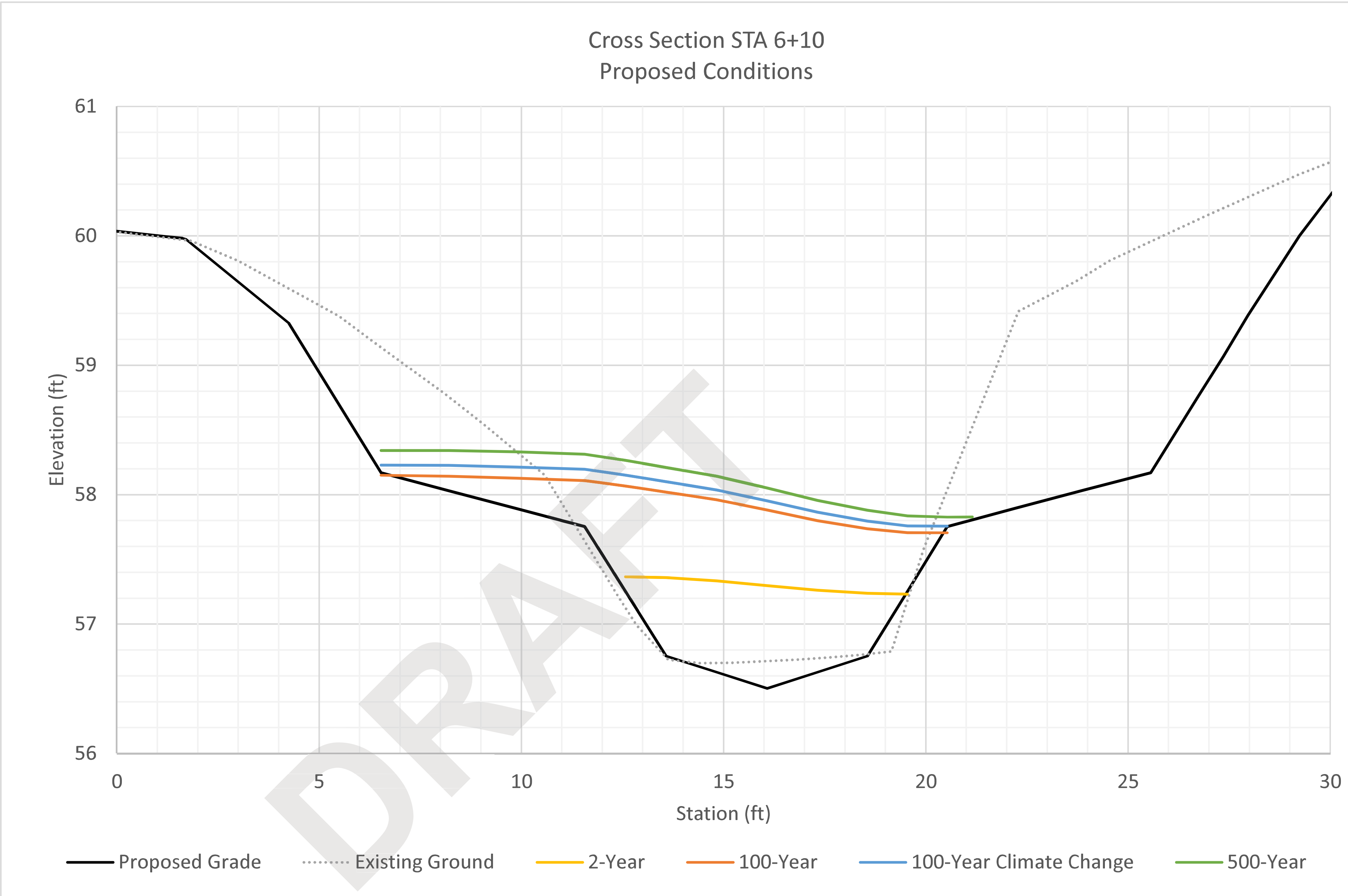
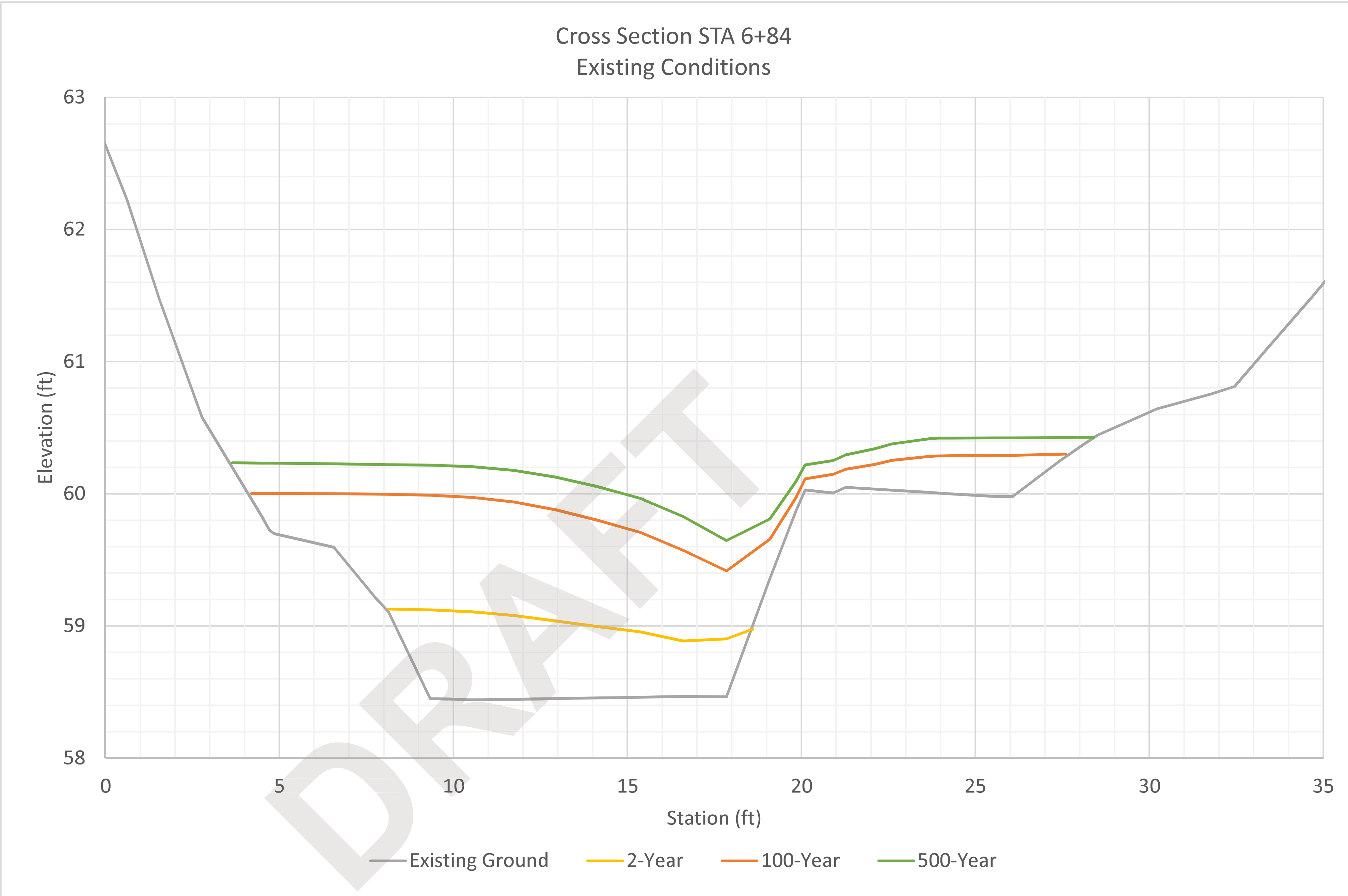
5
10
15
20
25
30
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT



Cross Section STA 6+10
Proposed Conditions
Elevation (ft)
61
60
59
58
57
56
0
5
10
15
20
25
30
Station (ft)
Proposed Grade
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT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Existing Conditions
Elevation (ft)
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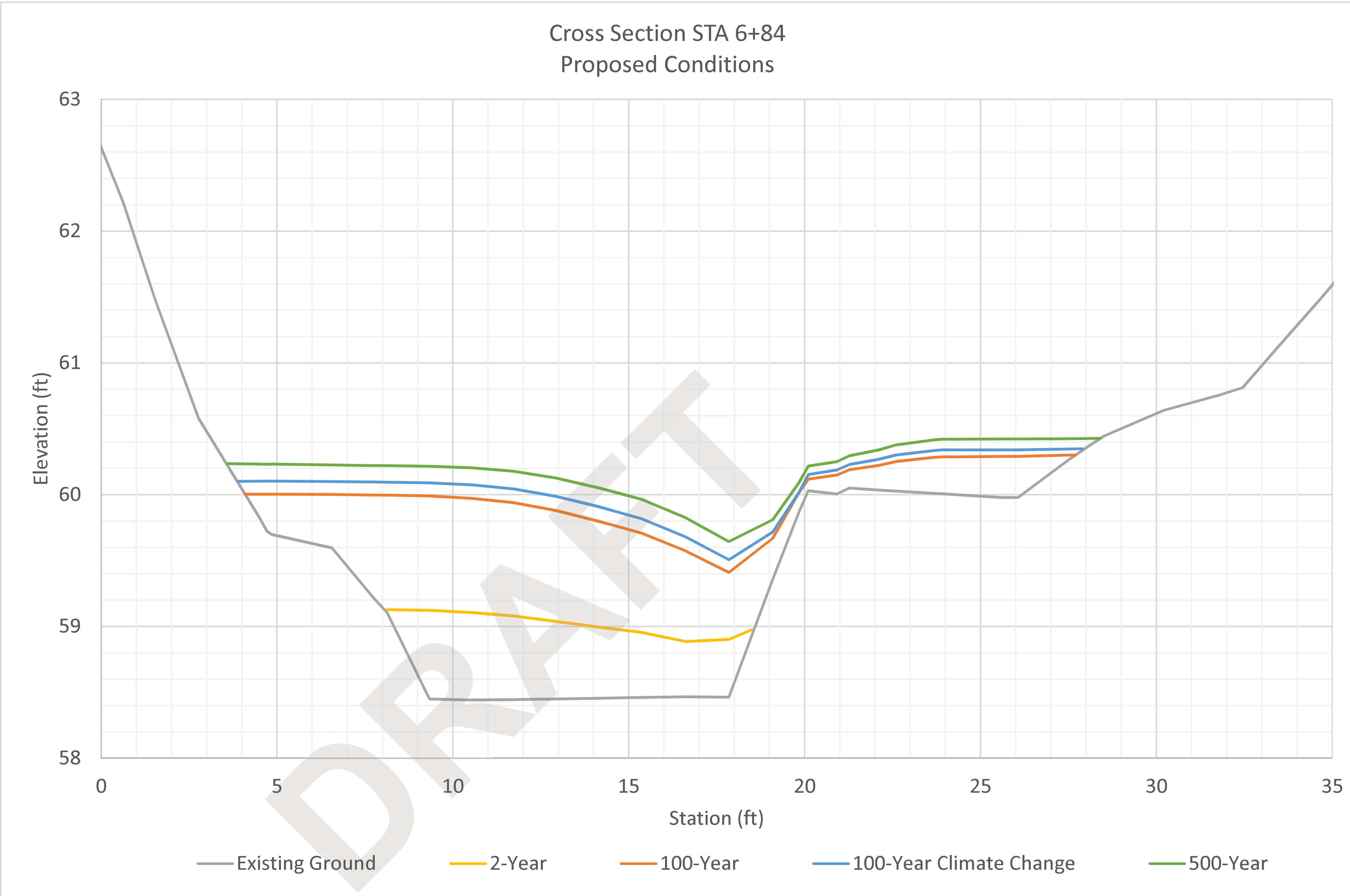
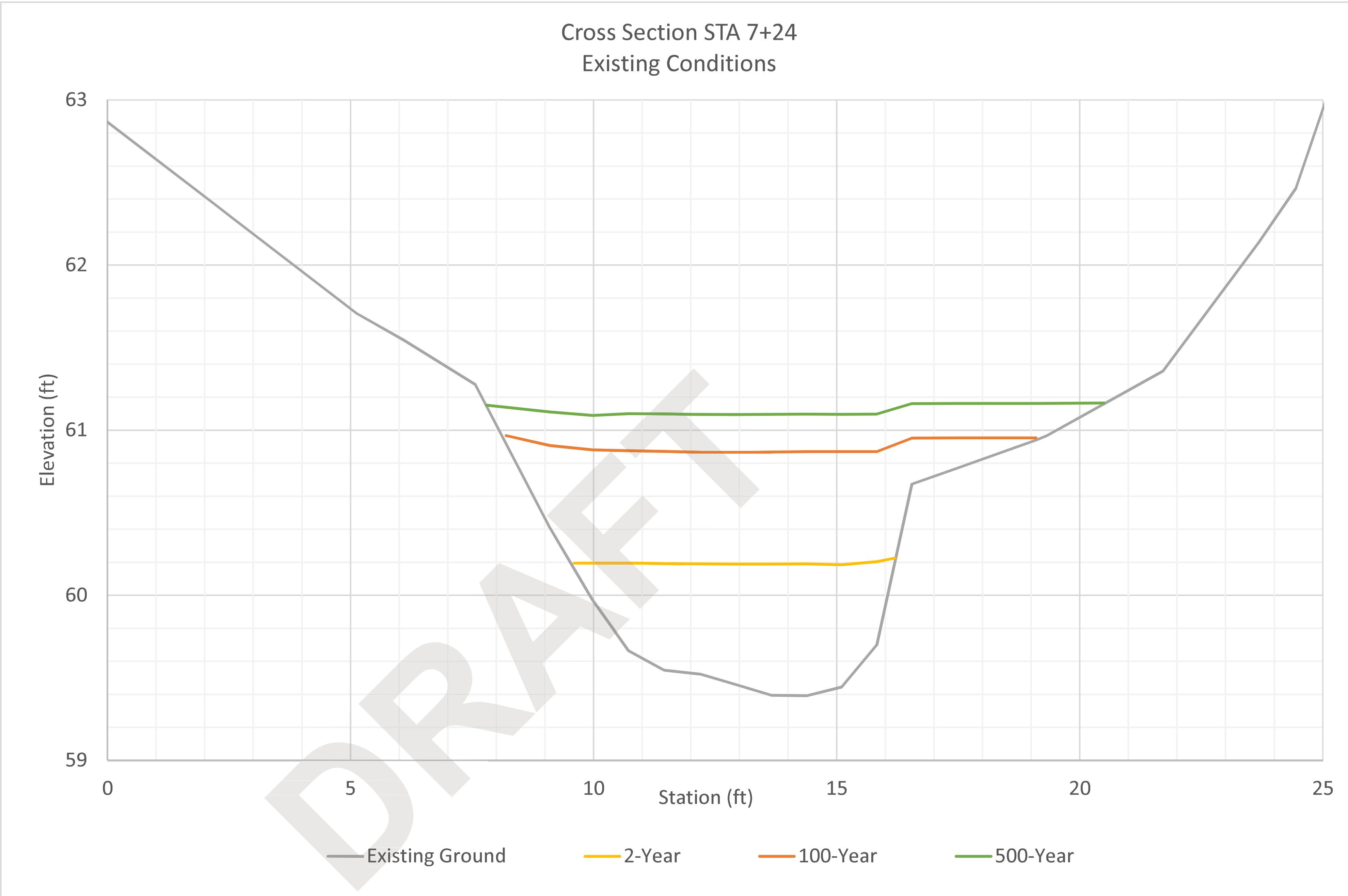
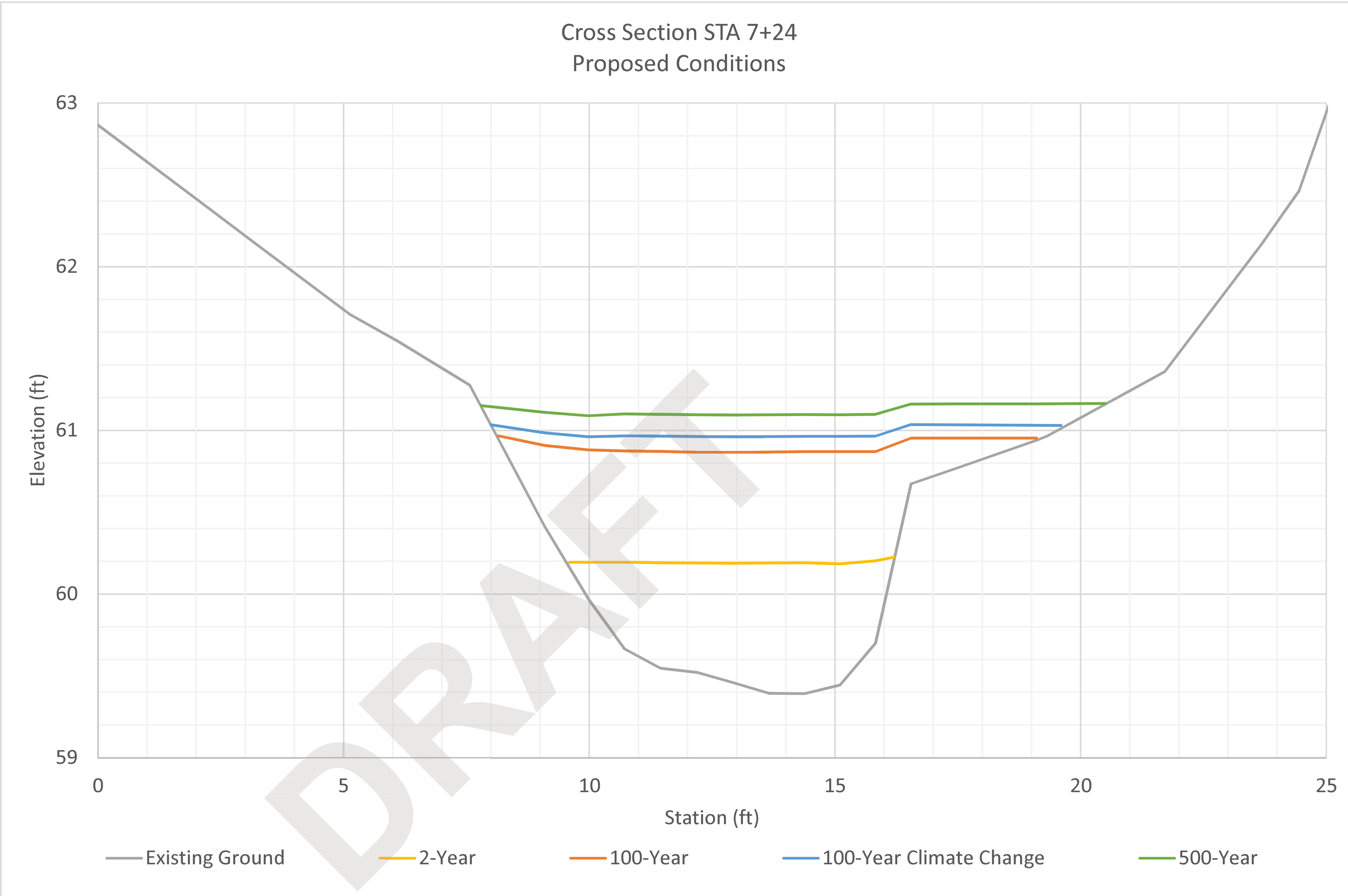
62
61
60
59
58
0
5
10
15
20
25
30
35
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT

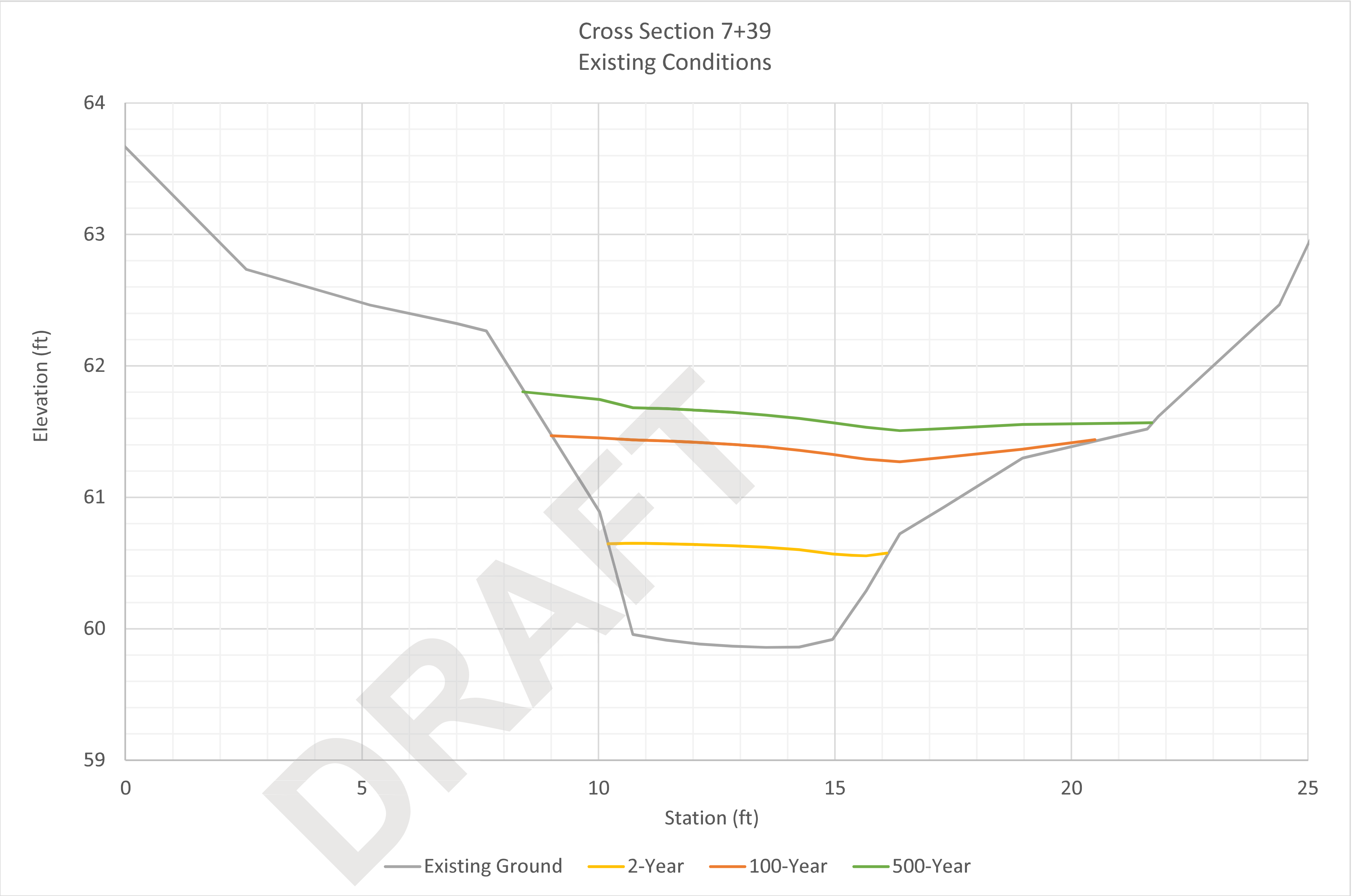


Cross Section STA 6+84
Proposed Conditions
Elevation (ft)
63
62
61
60
59
58
0
5
10
15
20
25
30
35
Station (ft)
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT

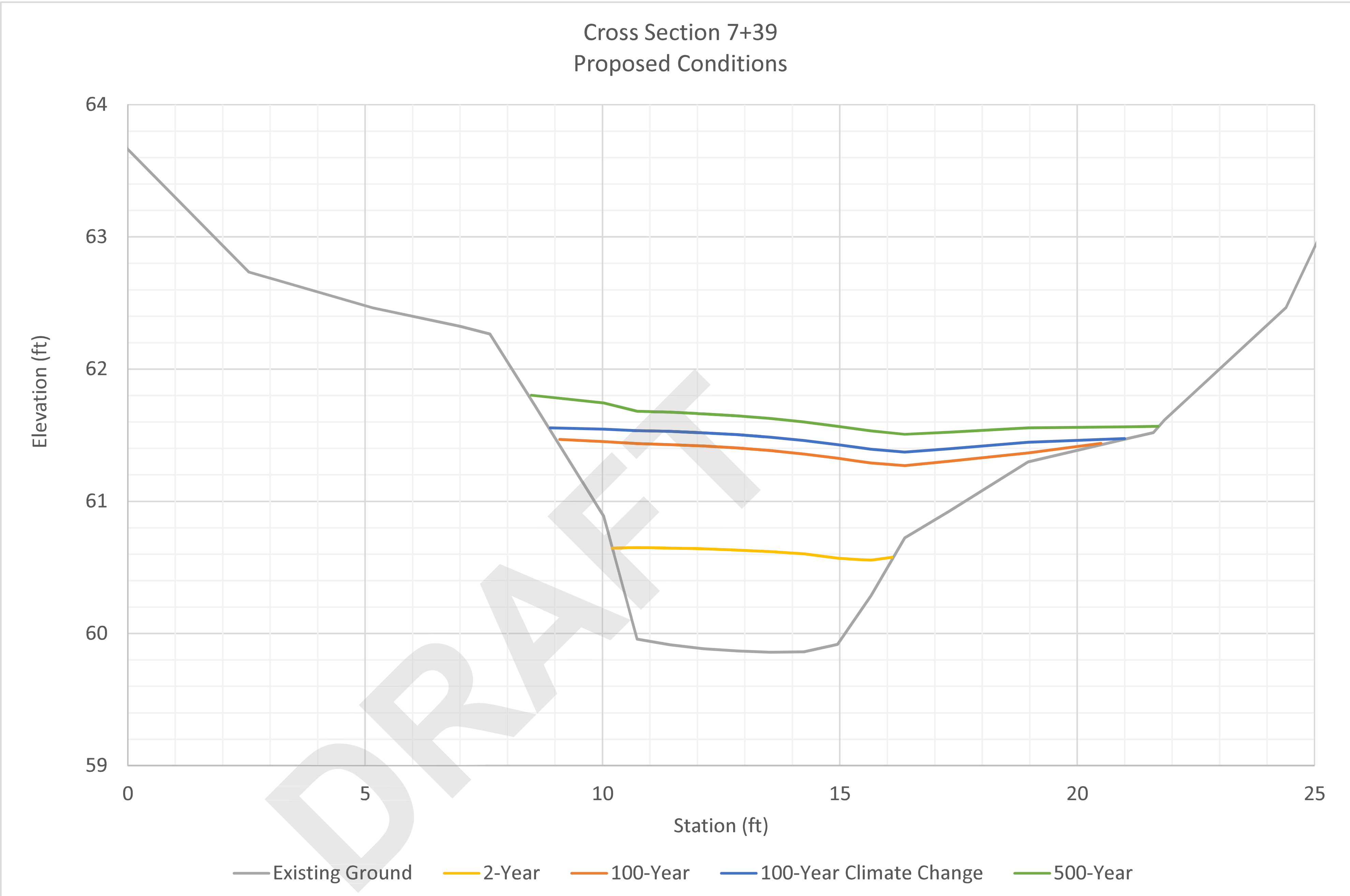


Cross Section STA 7+24
Existing Conditions
Elevation (ft)
63
62
61
60
59
0
5
10
15
20
25
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT


Cross Section STA 7+24
Proposed Conditions
Elevation (ft)
Station (ft)
63
62
61
60
59
0
5
10
15
20
25
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year
DRAFT



Cross Section 7+39
Existing Conditions
Elevation (ft)
64
63
62
61
60
59
0
5
10
15
20
25
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
DRAFT



Cross Section 7+39
Proposed Conditions
Elevation (ft)
64
63
62
61
60
59
0
5
10
15
20
25
Station (ft)
Existing Ground
2-Year
100-Year
100-Year Climate Change
500-Year

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	WSDOT US 101 MP 357.4
By:	Grace Doran

Observed Gradation:				
Location:	Reference Reach			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.8	0.1	0.1	0.02
in	10.0	1.4	0.6	0.2
mm	254	36	15.7	6.1

Design Gradation:				
Location:	Proposed Grading Area			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.2	0.2	0.1	0.00
in	2.5	2.1	0.8	0.0
mm	64	53	20.3	0.5

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]	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	50.8	80	50	45	29	25	22				80.0
1.5	38.1	73	35	32	21	18	16				72.5
1.0	25.4	65	20	18	13	12	11				65.0
0.75	19.1	50	5	5	5	5	5				50.0
0.187	4.75	35									35.0
No. 40 =	0.425	16									16.0
No. 200 =	0.0750	7									7.0
% per category		100	0	0	0	0	0	0	0	0	--> 100%

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:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

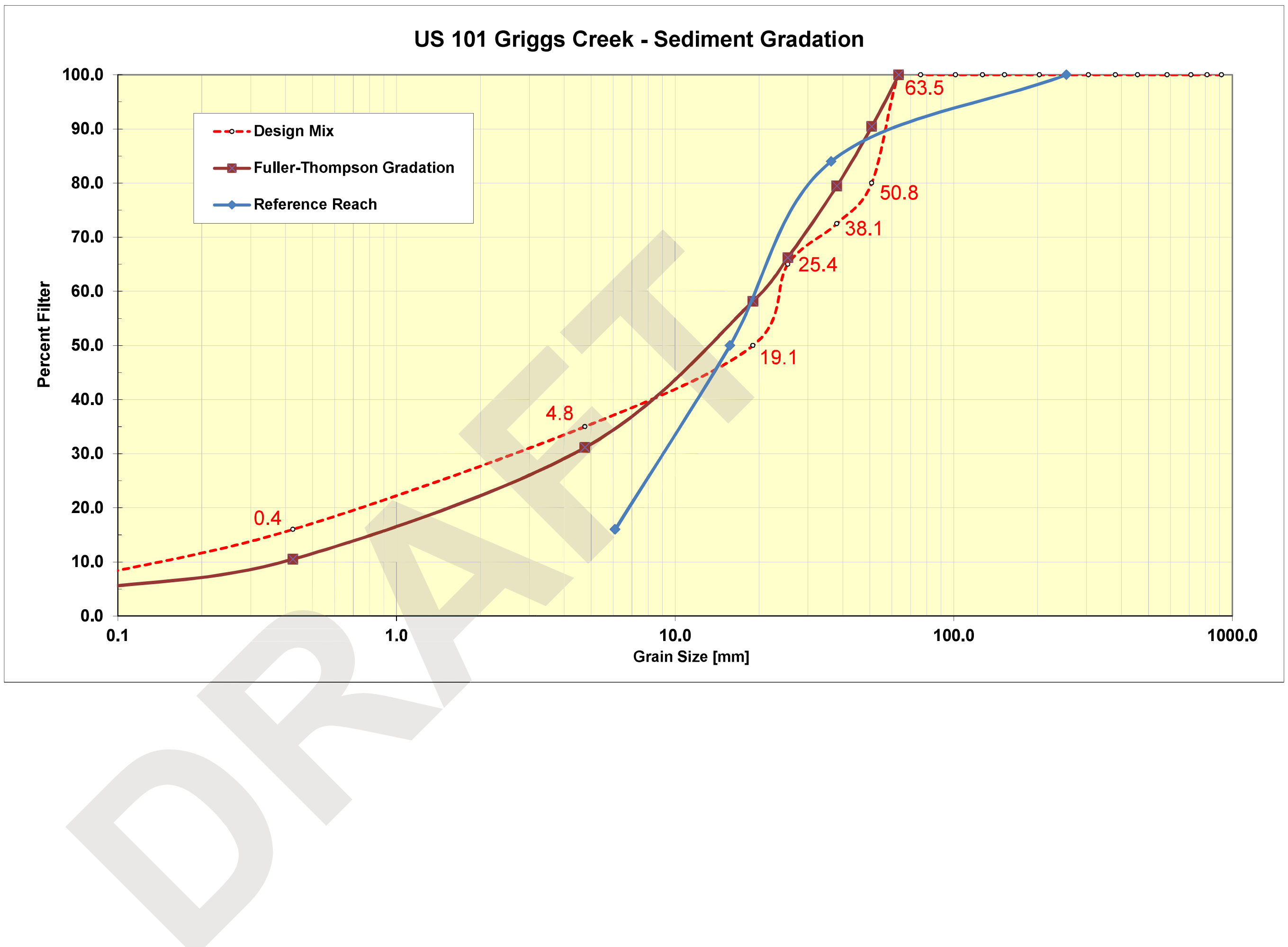
Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.047	dimensionless Shields parameter for D50

Flow	2-YR (16.2 cfs)	25-YR (39.4 cfs)	50-YR (45.1 cfs)	100-YR (51.3 cfs)	500-YR (65.7 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.1	1.7	1.8	1.9	2.1
τ_{ci}					
0.96	Motion	Motion	Motion	Motion	Motion
0.93	Motion	Motion	Motion	Motion	Motion
0.89	Motion	Motion	Motion	Motion	Motion
0.84	Motion	Motion	Motion	Motion	Motion
0.78	Motion	Motion	Motion	Motion	Motion
0.74	Motion	Motion	Motion	Motion	Motion
0.69	Motion	Motion	Motion	Motion	Motion
0.66	Motion	Motion	Motion	Motion	Motion
0.61	Motion	Motion	Motion	Motion	Motion
0.56	Motion	Motion	Motion	Motion	Motion
0.53	Motion	Motion	Motion	Motion	Motion
0.50	Motion	Motion	Motion	Motion	Motion
0.46	Motion	Motion	Motion	Motion	Motion
0.43	Motion	Motion	Motion	Motion	Motion
0.40	Motion	Motion	Motion	Motion	Motion
0.37	Motion	Motion	Motion	Motion	Motion
0.33	Motion	Motion	Motion	Motion	Motion
0.30	Motion	Motion	Motion	Motion	Motion
0.20	Motion	Motion	Motion	Motion	Motion

	D95	D84	D50	D35	D16
Mix Size Interpolation	95	84	50	35	16
(mm)	60.1	53.1	19.1	4.8	0.4
(inches)	2.4	2.1	0.8	0.2	0.02
(feet)	0.2	0.2	0.1	0.02	0.00

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010



Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Meander Bars Material Design

Project:	WSDOT US 101 MP 357.4
By:	Grace Doran

Observed Gradation:				
Location:	Reference Reach			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.8	0.1	0.1	0.02
in	10.0	1.4	0.6	0.2
mm	254	36	15.7	6.1

Design Gradation:				
Location:	Proposed Grading Area			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.2	0.2	0.1	0.00
in	2.5	2.1	0.8	0.0
mm	64	53	20.3	0.5

Meander Bar Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	[mm]	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				86.0
5.0	127			80	68	57	45				77.8
4.0	102		100	71	57	45	39				69.7
3.0	76.2		80	63	45	38	34				61.5
2.5	63.5	100	65	54	37	32	28				55.9
2.0	50.8	80	50	45	29	25	22				44.3
1.5	38.1	73	35	32	21	18	16				36.5
1.0	25.4	65	20	18	13	12	11				28.6
0.75	19.1	50	5	5	5	5	5				18.5
0.187	4.75	35									10.5
No. 40 =	0.425	16									4.8
No. 200 =	0.0750	7									2.1
% per category		30			70			0	0	0	--> *100%*

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:

D_{84} must be between 0.40 in and 10 in

uniform bed material (Di < 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

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

Flow	2-YR (16.2 cfs)	25-YR (39.4 cfs)	50-YR (45.1 cfs)	100-YR (51.3 cfs)	500-YR (65.7 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.1	1.7	1.8	1.9	2.1
τ_{ci}					
2.20	No Motion	No Motion	No Motion	No Motion	No Motion
2.12	No Motion	No Motion	No Motion	No Motion	No Motion
2.04	No Motion	No Motion	No Motion	No Motion	Motion
1.92	No Motion	No Motion	No Motion	No Motion	Motion
1.78	No Motion	No Motion	Motion	Motion	Motion
1.69	No Motion	Motion	Motion	Motion	Motion
1.58	No Motion	Motion	Motion	Motion	Motion
1.50	No Motion	Motion	Motion	Motion	Motion
1.40	No Motion	Motion	Motion	Motion	Motion
1.28	No Motion	Motion	Motion	Motion	Motion
1.22	No Motion	Motion	Motion	Motion	Motion
1.14	No Motion	Motion	Motion	Motion	Motion
1.04	Motion	Motion	Motion	Motion	Motion
0.99	Motion	Motion	Motion	Motion	Motion
0.92	Motion	Motion	Motion	Motion	Motion
0.85	Motion	Motion	Motion	Motion	Motion
0.75	Motion	Motion	Motion	Motion	Motion
0.69	Motion	Motion	Motion	Motion	Motion
0.45	Motion	Motion	Motion	Motion	Motion
	D95	D84	D50	D35	D16
Mix Size Interpolation	95	84	50	35	16
(mm)	183.4	145.7	56.7	35.4	12.3
(inches)	7.2	5.7	2.2	1.4	0.49
(feet)	0.6	0.5	0.2	0.12	0.04

Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix D: Stream Plan Sheets, Profile, Details

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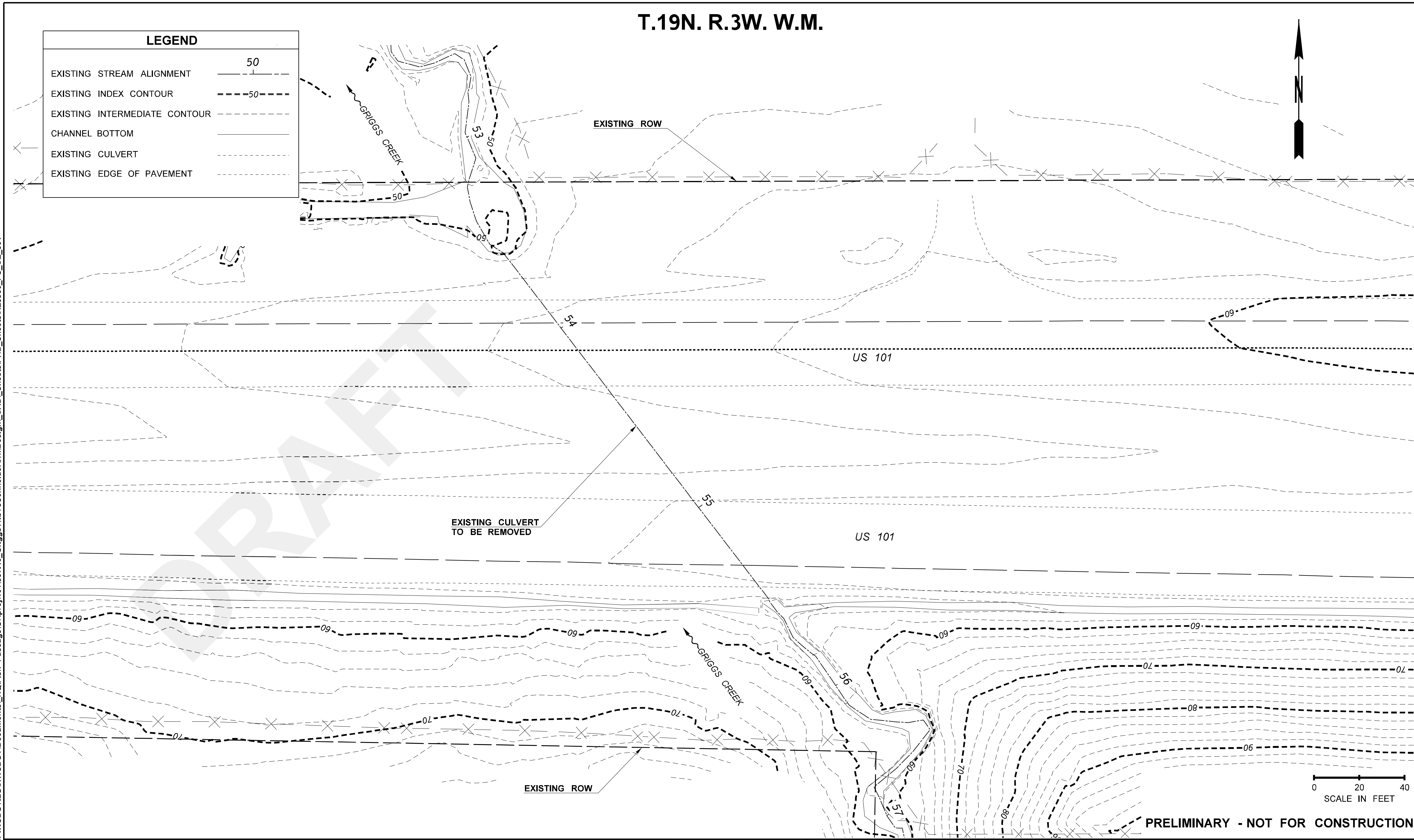

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DESIGNED BY	S. BEVAN			
ENTERED BY	C. TIDWELL			
CHECKED BY	J. HEILMAN			
PROJ. ENGR.	J. METTLER			
REGIONAL ADM.	J. WYNANDS	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL5950

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

HDR

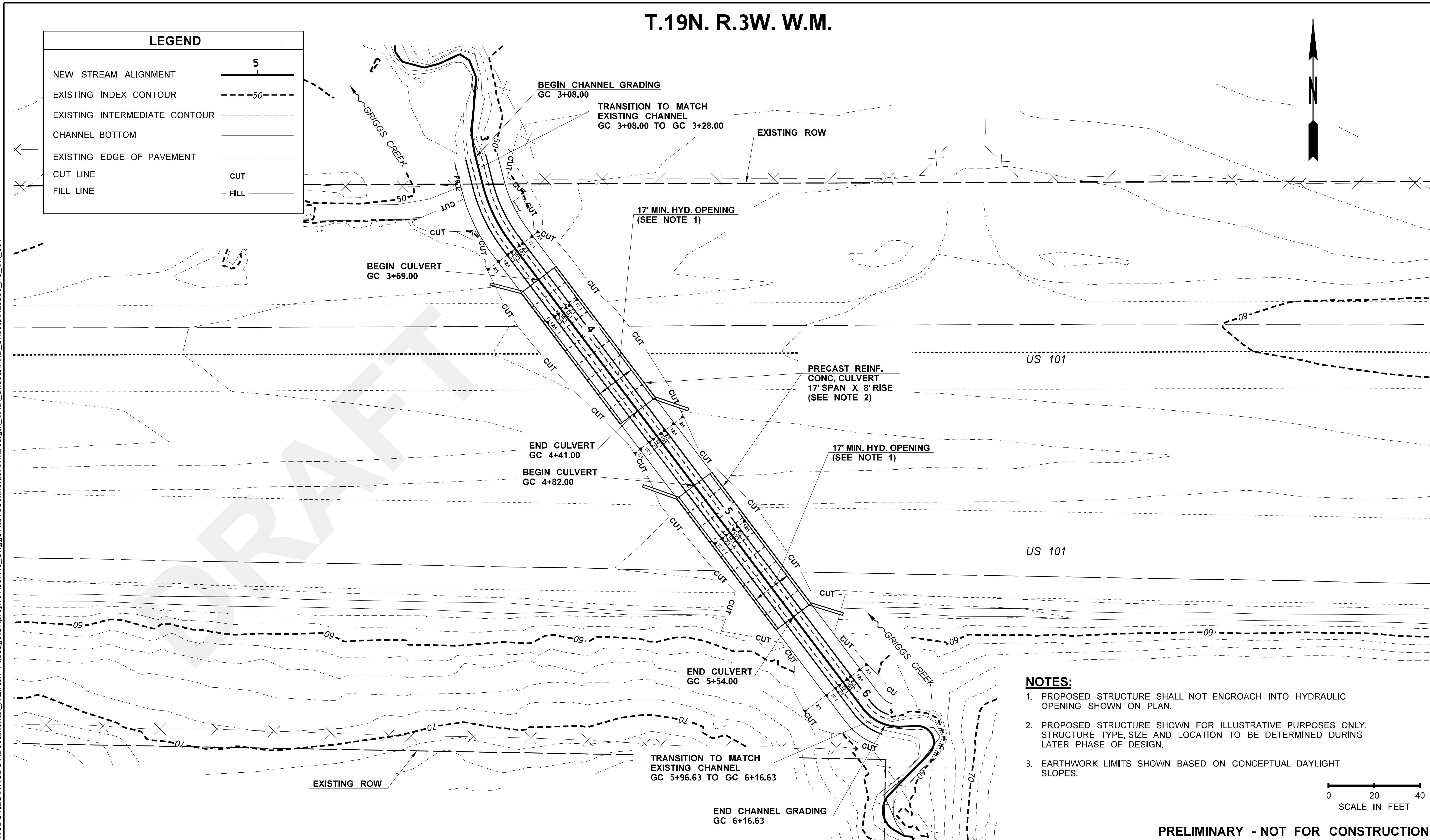
US 101 MP 357.40
GRIGGS CREEK
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

T.19N. R.3W. W.M.



NOTES:

1. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO HYDRAULIC OPENING SHOWN ON PLAN.
2. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.
3. EARTHWORK LIMITS SHOWN BASED ON CONCEPTUAL DAYLIGHT SLOPES.

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PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL5950

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation

HDR

US 101 MP 357.40
GRIGGS CREEK
FISH BARRIER REMOVAL

STREAM PLAN

PLAN REF NO CR1

SHEET 2 OF 4 SHEETS

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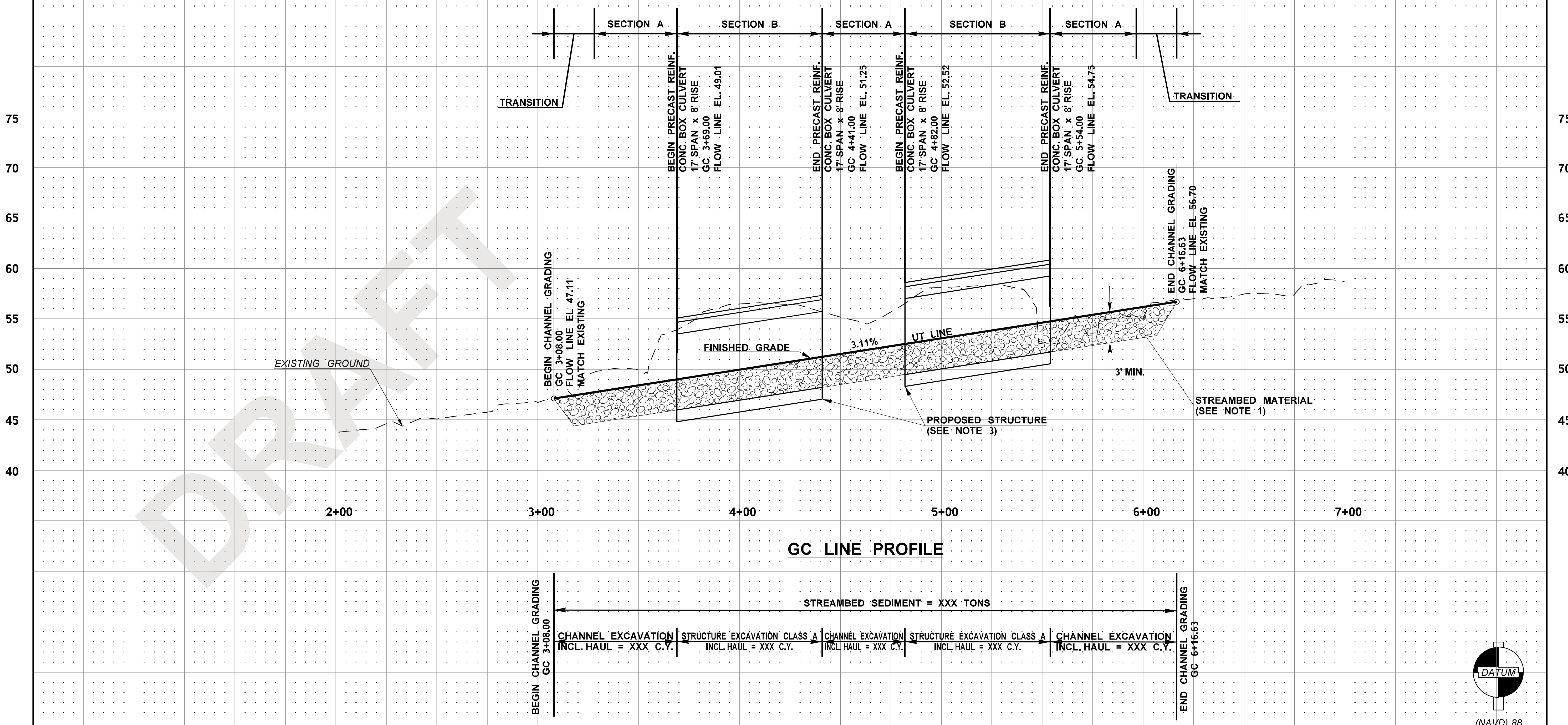
NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES FOR STREAMBED MATERIALS.
2. SEE SHEET CD1 FOR STREAM SECTIONS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN.



PRELIMINARY - NOT FOR CONSTRUCTION

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PROJ. ENGR.	J. METTLER		
REGIONAL ADM.	J. WYNANDS	REVISION	DATE / BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX | CONTRACT NO. | LOCATION NO. XL5950

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation

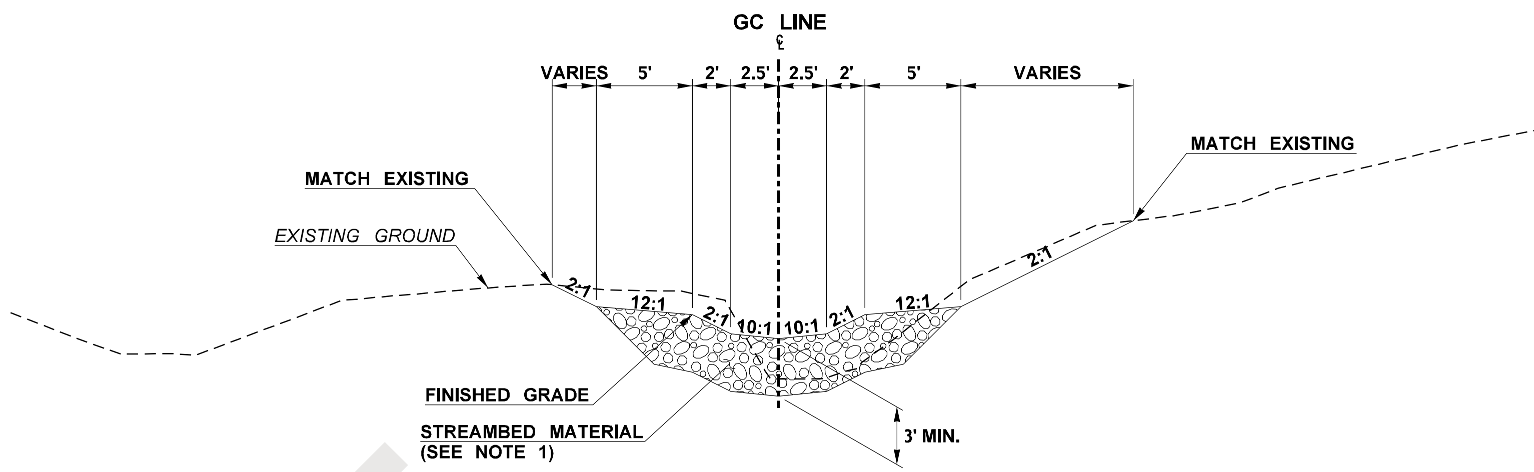
HDR

US 101 MP 357.40
GRIGGS CREEK
FISH BARRIER REMOVAL

STREAM PROFILE

PLAN REF. NO. CP1

SHEET 3 OF 4 SHEETS



SECTION A

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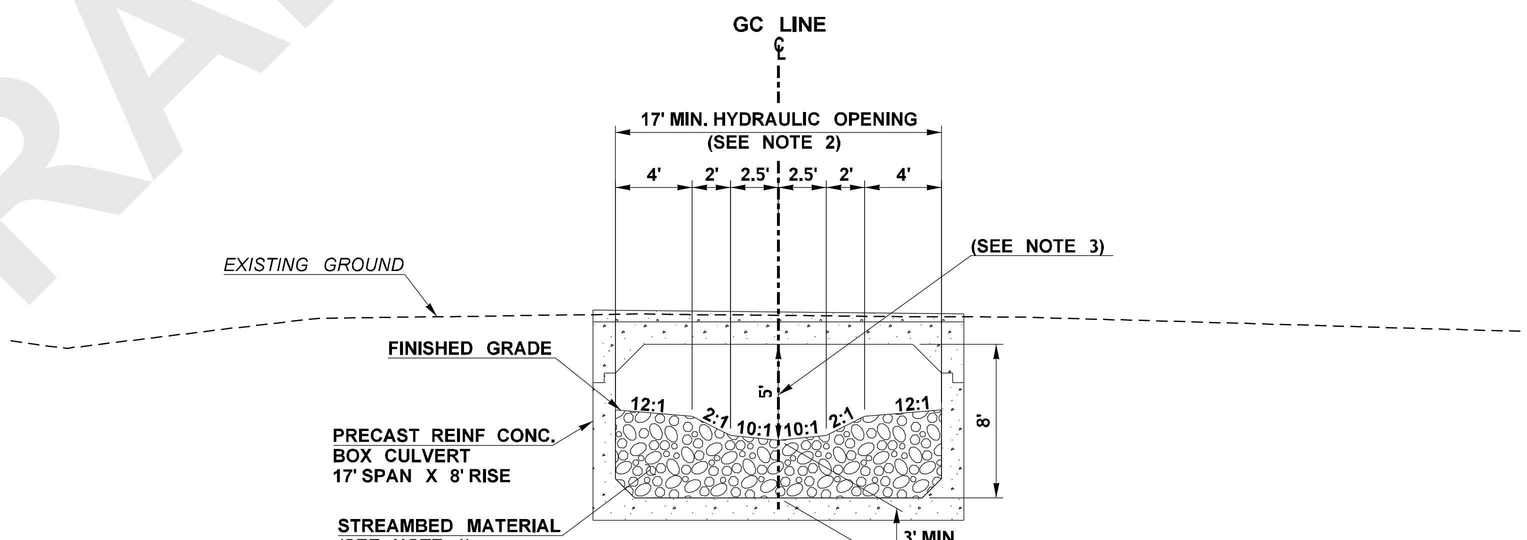
GC 4+41.00 TO 4+82.00
GC 5+54.00 TO 5+96.63



SECTION B

STATION
GC 3+69.00 TO 4+41.00
GC 4+82.00 TO 5+54.00

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL.
2. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.
3. STRUCTURE SHOWN PROVIDES 5' MAINTENANCE CLEARANCE. IF DEEMED IMPRACTICABLE A MINIMUM OF 3.5' OF CLEARANCE MUST BE PROVIDED ABOVE THE THALWEG TO MEET FREEBOARD REQUIREMENTS.

PRELIMINARY - NOT FOR CONSTRUCTION

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PROJ. ENGR.	J. METTLER
REGIONAL ADM.	J. WYNANDS

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER XXXXX
CONTRACT NO. | LOCATION NO. XL5950

P.E. STAMP BOX DATE | P.E. STAMP BOX DATE

Washington State Department of Transportation
HDR

US 101 MP 357.40
GRIGGS CREEK
FISH BARRIER REMOVAL
STREAM DETAILS

PLAN REF NO CD1
SHEET 4 OF 4 SHEETS

Appendix E: WDFW Climate Change Analysis

Future Projections for Climate-Adapted Culvert Design

Project Name: 997161

Stream Name: Griggs Creek

Drainage Area: 146 ac

Projected mean percent change in bankfull flow:

2040s: 13.9%

2080s: 20.4%

Projected mean percent change in bankfull width:

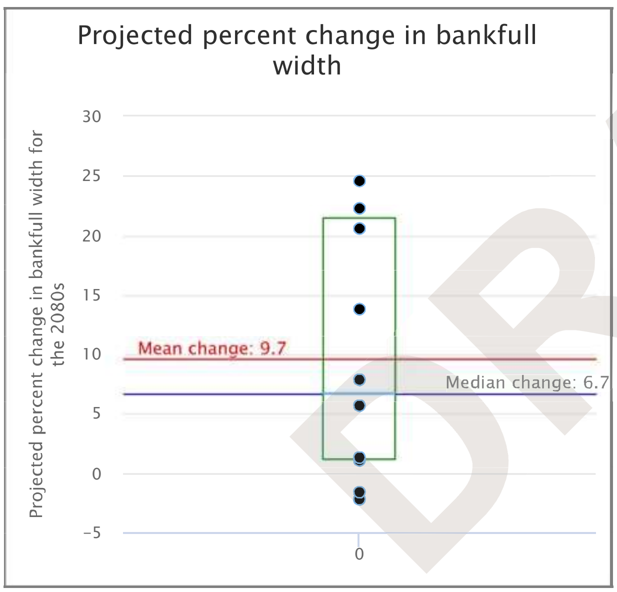
2040s: 6.7%

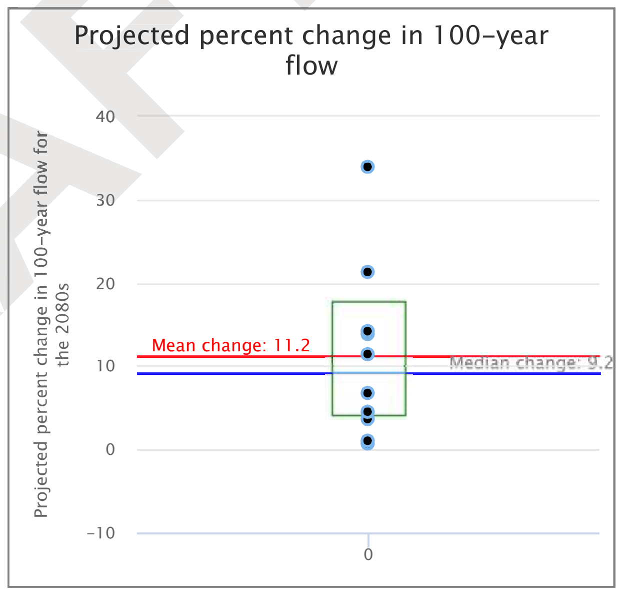
2080s: 9.7%

Projected mean percent change in 100-year flood:

2040s: 6.6%

2080s: 11.2%





Black dots are projections from 10 separate models