I-405 MP 21.94 Juanita Creek (WDFW ID 998602):

Draft Final Hydraulic Design Report

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1 Introduction

To comply with United States et al. vs. Washington et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the Interstate 405 (I-405) crossing of Juanita Creek at milepost (MP) 21.94 within WSDOT's Northwest region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (WDFW Site ID 998602) and has an estimated 1,309 linear feet of habitat gain.

The Juanita Creek restored stream connection discussed herein is part of a larger roadway project that will address fish barriers while providing a high-capacity roadway for the traveling public. Consistent with the long-term I-405 Master Plan (WSDOT 2002), the I-405 State Route (SR) 522 Vicinity to SR 527 Express Toll Lanes Improvement Project (Project) is intended improve transit reliability on I-405 and reduce congestion between the cities of Kirkland and Bothell.

The overall Project will include the following improvements:

- A dual express toll lanes (ETL) system will be created from MP 21.79 (south of I-405/SR 522 interchange) to MP 27.06 (just north of I-405/SR 527 interchange).
- The existing lanes will be restriped and I-405 will be resurfaced and widened I-405 to add one ETL in each direction, creating a dual ETL system.
- New direct access ramps will be constructed in the SR 522 interchange, and two inline transit stations will be constructed in the I-405 median. A new bridge will be constructed for I-405 northbound lanes using the reconfigured ramps. A bus stop and turnaround loop with pick-up and drop-off facilities will be constructed in the northwest quadrant.
- The northbound I-405 overcrossing will be widened at 228th Street SE.
- Just south of SR 527 at 17th Avenue SE, new direct access ramps will be constructed to the north, south, and east, and two inline transit stations will be constructed in the I-405 median.
- 17th Avenue SE and portions of 220th Street SE and SR 527 will be reconfigured to include a roundabout at the Canyon Park Park and Ride; bicycle and pedestrian improvements will also be made.
- Six fish barriers will be replaced with restored stream connections, and new noise and retaining walls will be constructed.
- Flow control and enhanced runoff treatment will be provided, based on the WSDOT *Highway Runoff Manual* (WSDOT 2019).

According to the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT evaluated the crossing using the stream simulation methodology because the permanent federal injunction allows for the use of the stream simulation method and bridge design method unless extraordinary circumstances exist on site. Juanita Creek does not meet all the criteria for the bridge design method, so the stream simulation methodology is the optimal choice.

The crossing is in King County, Washington. The crossing is in WRIA 8. The highway runs north to south at this location and is about 2.9 miles upstream from the confluence with Lake Washington. Juanita Creek generally flows east to west beginning 0.5 miles upstream of the I-405 crossing (see **Figure 1-1** for the vicinity map).

The proposed Juanita Creek project will replace the 358.6-foot-long, 48-inch-diameter corrugated steel pipe with a structure designed to accommodate a minimum hydraulic width of 23 feet. It is being recommended that the selected 30-foot structure be bottomless to reduce the potential of streambed material washout within the structure. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation criteria described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013) and commitments made between WSDOT, WDFW, the National Marine Fisheries Service, and the Muckleshoot Indian Tribe Fisheries Division (MITFD) during preliminary design and permitting. This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a).

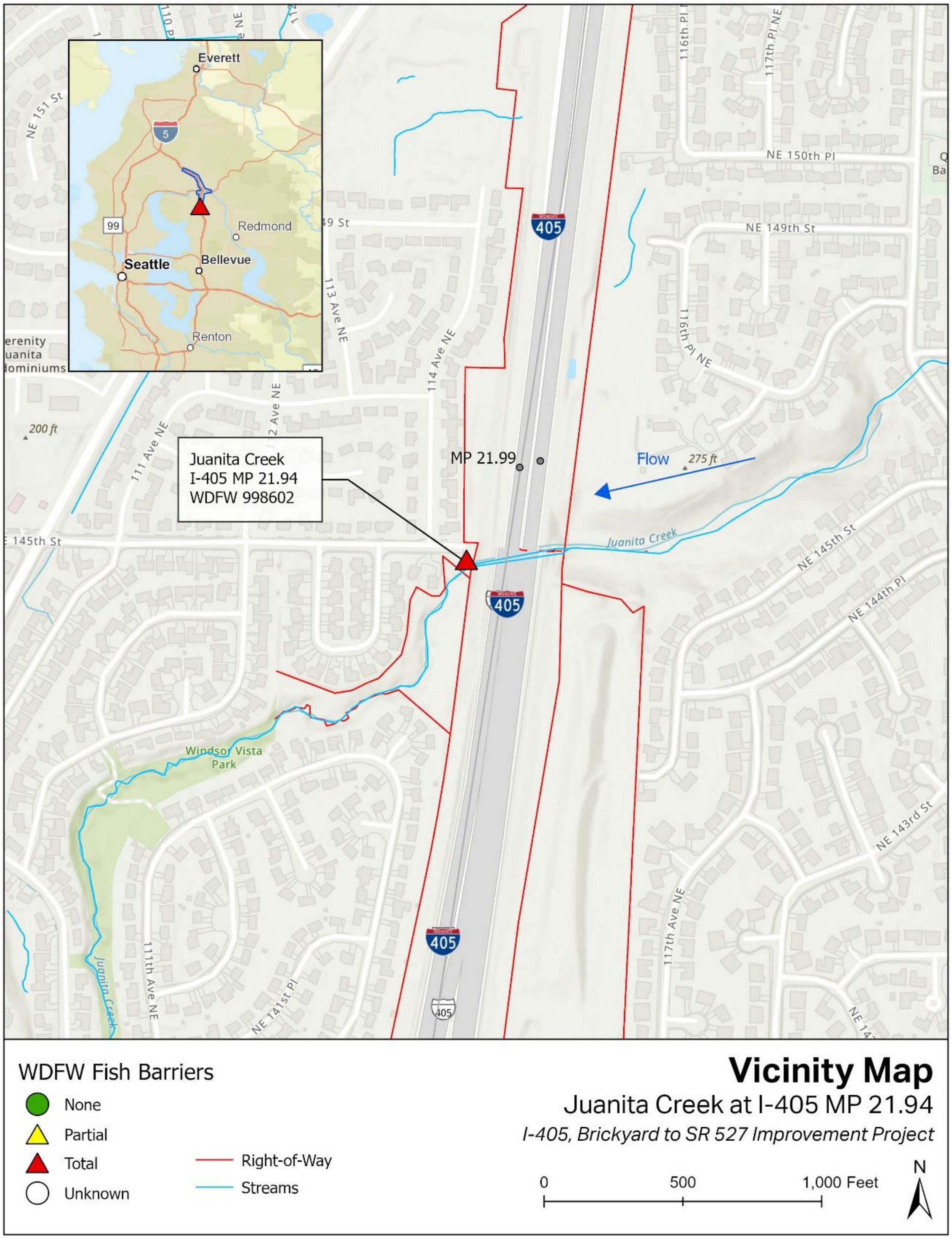


Figure 1-1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. Assessments were performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, along with past observations, maintenance, and fish passage evaluations.

2.1 Site Description

Juanita Creek contains flow year-round and originates approximately 0.5 miles east of I-405 in a forested area of low-density residential development. From its origin, the stream flows through two culverts located at 122nd Avenue NE and 119th Avenue NE. Downstream of the culvert at NE 122nd Avenue NE, the creek is conveyed in pipes until the outlet at 119th Avenue NE. Just downstream of 119th Avenue NE, the creek flows in a well-defined channel through a mixed forest valley. The stream crosses I-405 at MP 21.94 in a 48-inch corrugated steel pipe with a grated 4-foot concrete box (**Figure 2-2**). The detention area on Juanita Creek upstream of the culvert inlet is known as the “High Woodlands Regional Detention Pond Project #047007.”

Juanita Creek outlets downstream of I-405 through a 48-inch corrugated steel pipe with a debris cage (**Figure 2-1**). Downstream of the crossing, the stream then flows through a vegetated area in the middle of a housing development dominated by Himalayan blackberry with some trees. An active beaver dam is present approximately 400 feet downstream of I-405, which is outside the project limits (**Figure 2-3**). Any beavers or beaver dams found as part of this project will be removed and/or relocated following WDFW protocols.

The creek flows through a series of open channels and culverts (**Figure 2-4**), passing through residential areas, Edith Moulton Park, and commercial areas, until it finally reaches the northeast end of Lake Washington at Juanita Beach Park.

Figure 2-2: Inlet to Juanita Creek under I-405

Figure 2-1: Outlet to Juanita Creek

Figure 2-3: Beaver Dam downstream of I-405

Figure 2-4: Culvert downstream of the I-405 crossing

The existing culvert at I-405 is a complete barrier to fish because there is a 2.62-foot water surface drop at the outlet, and there is a flow control structure at the inlet. As a result of this inlet control structure detaining upstream flows, sediment and debris transport is inhibited crossing I-405 at this location.

The Juanita Creek fish passage project location is not within a designated FEMA Flood Zone. The proposed structure is anticipated to improve upon the existing flooding conditions by replacing the existing regional detention facility with a fish passable structure. More discussion on floodplain impacts is provided in **Section 6**. Hydraulic modeling of existing conditions as part of preliminary analysis is included in **Section 5.2** and confirms the backwatered condition caused by this detention facility.

WDFW has identified 24 crossings between the I-405 crossing and Lake Washington, most of which have been identified as non-barriers for fish passage. Of these culverts near the project, two have been identified as complete barriers and five have been identified as partial barriers. The crossing at 119th Avenue NE upstream of I-405 is a full barrier, with the next upstream crossing at 122nd Avenue NE identified as partial barrier 431.76 (WDFW 2019a).

The linear length of potential habitat gain from correcting the barrier (998602) was determined by the WDFW Fish Passage and Diversion Screening Inventory Database – Level A Assessment to be 399 meters (1,309 feet) (**Appendix J**).

WSDOT Area 5 Maintenance was contacted to determine if there are ongoing maintenance problems at the existing structure due to large woody material (LWM) racking at the inlet or sedimentation. The maintenance representative indicated there was not a record of LWM blockage and/or removal or sediment removal at this crossing.

2.2 Watershed and Land Cover

Juanita Creek consists of approximately 0.5 miles of stream length upstream of the I-405 crossing and drains to the northeast end of Lake Washington approximately 2.9 miles downstream of the I-405 crossing. The contributing watershed upstream of the I-405 crossing has an area of 0.67 square miles, which receives annual precipitation of 41.2 inches (USGS

2019). Elevations within the contributing watershed range from 222 to 422 feet, referenced to the North American Vertical Datum of 1988 (NAVD 88). The watershed boundary shown in **Figure 2-5** was delineated using 2-foot contours generated from the 2021 King County Light Detection and Ranging (LiDAR) dataset and City of Kirkland stormwater utility data. The 2021 King County impervious surface data layer (100-foot resolution; WGS 2023) was used to calculate existing impervious surface areas within the watershed. Land cover in the watershed, as documented by the 2021 National Land Cover database (NLCD 2021) and illustrated on **Figure 2-6** consists of a mix of impervious and pervious surfaces:

- Impervious, predominantly residential and commercial development (approximately 45.6 percent)
- Forested (approximately 10 percent)
- Other pervious surfaces (approximately 44.4 percent)

A summary of the land use for area surrounding Juanita Creek is provided in **Table 2-1**.

Table 2-1: Land cover

Land Cover Class	Basin Coverage (%)
Barren land	0.05
Deciduous forest	1.55
Developed, high intensity	8.74
Developed, low intensity	34.7
Developed, medium intensity	40.7
Developed, open space	5.79
Evergreen forest	6.52
Hay/pasture	0
Mixed forest	1.97
Open water	0
Shrub/scrub	0
Woody wetlands	0

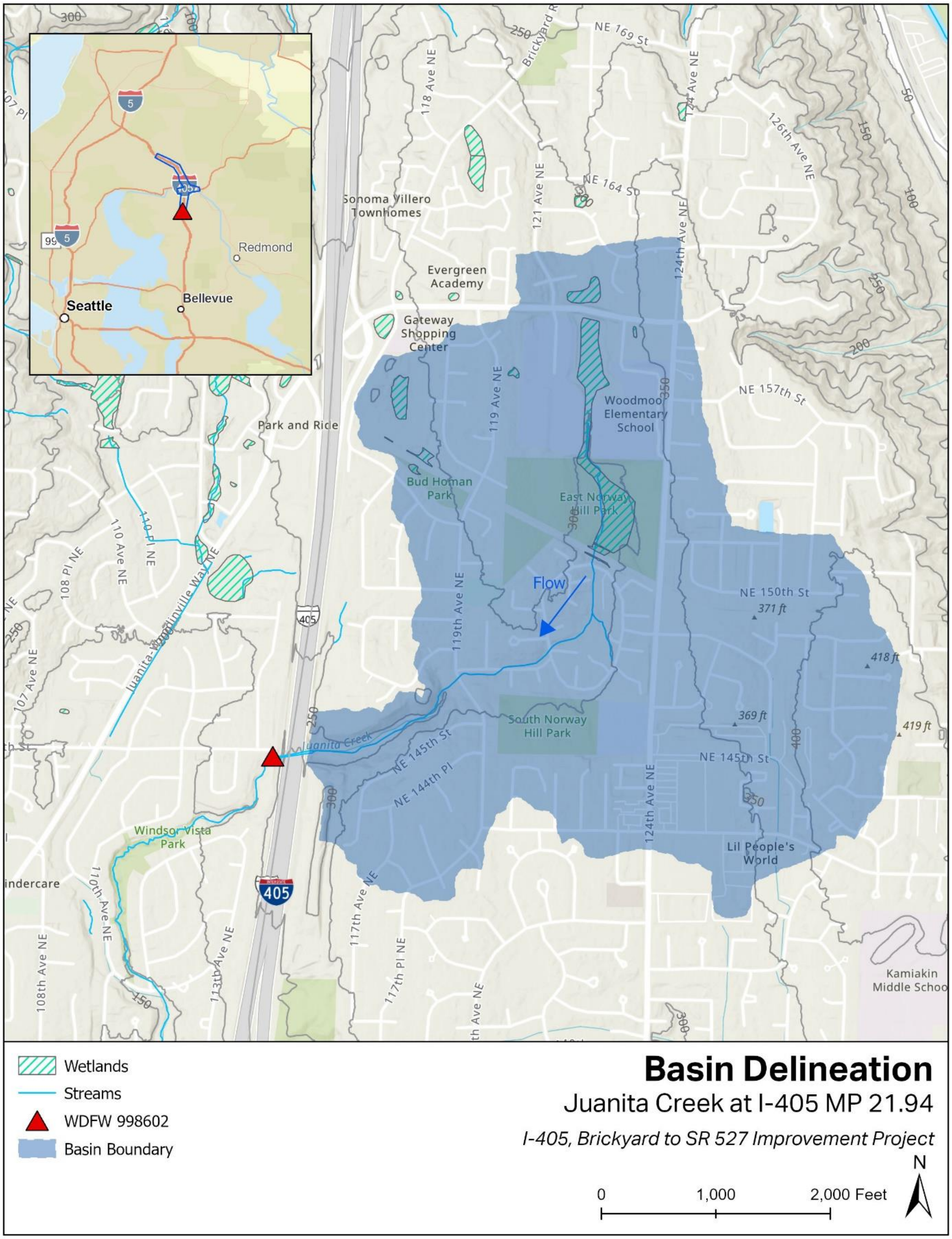


Figure 2-5: Watershed map

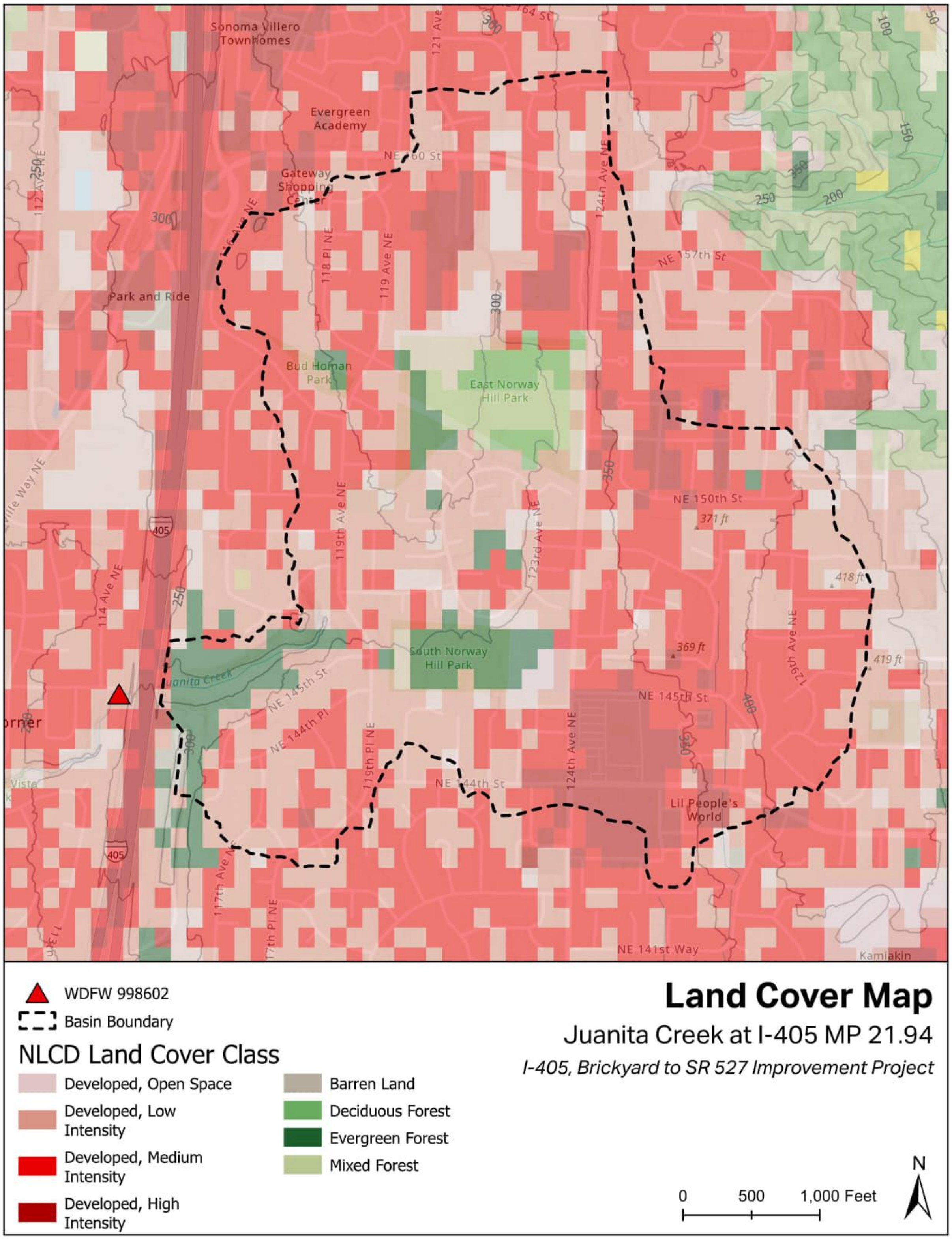


Figure 2-6: Land cover map (NLCD 2021)

2.3 Geology and Soils

Geology at the stream crossing was assessed using the USGS National Geologic Map Database (USGS 2022). USGS map (MF-1543) confirms that the area surrounding the Juanita Creek crossing is composed of advance outwash from the Vashon drift. The advance outwash underlies till and is typically composed of clean pebbly sand with an increasing gravel component closer to the ground surface. Some of the sediments associated with this outwash are stained by iron oxide precipitated from groundwater, indicating that the groundwater table in the area may be high. The soils are generally well drained and provide a stable foundation where not close to steep slopes (USGS 2023). **Figure 2-7** shows the geology in and around the Juanita Creek crossing.

Soil assessments conducted at the stream crossing were completed using United States Department of Agriculture's Natural Resources Conservation Service Gridded Soil Survey Geographic (gSURRGO) Database (USDA 2022). The predominant soil type found in the vicinity of the I-405 crossing is Alderwood gravelly sandy loam, a classification encompassing approximately 51.3 percent of the basin area. The specific soil variant can be attributed to historical outwash soils deposited from glacial activity and some alluvial soils, including Ragnar-Indianola association and Arents, Alderwood material upstream of the I-405 crossing, and Ragnar-Indianola association downstream of the crossing. **Figure 2-8** shows the soils map for the Juanita Creek watershed and crossing.

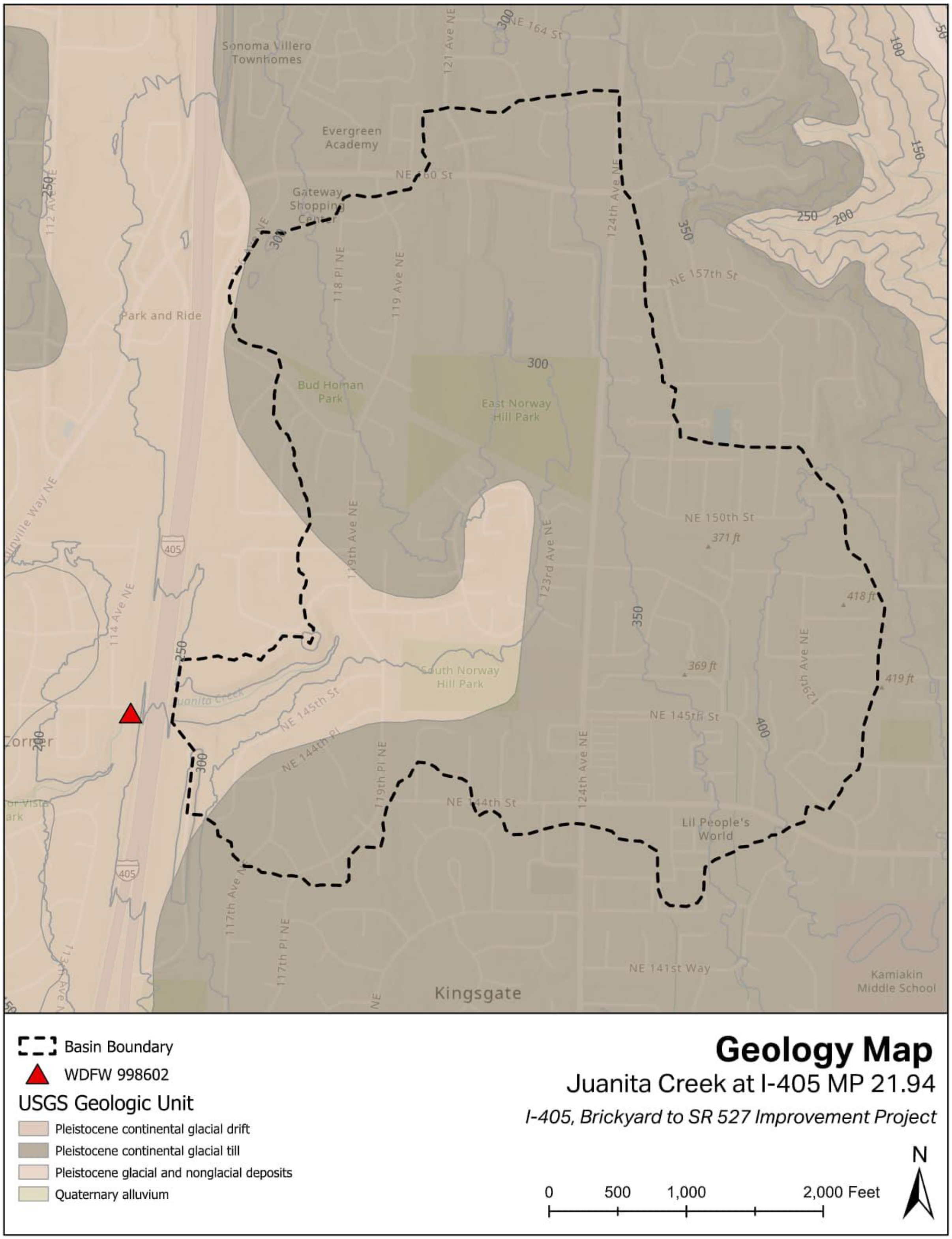


Figure 2-7: Geologic map

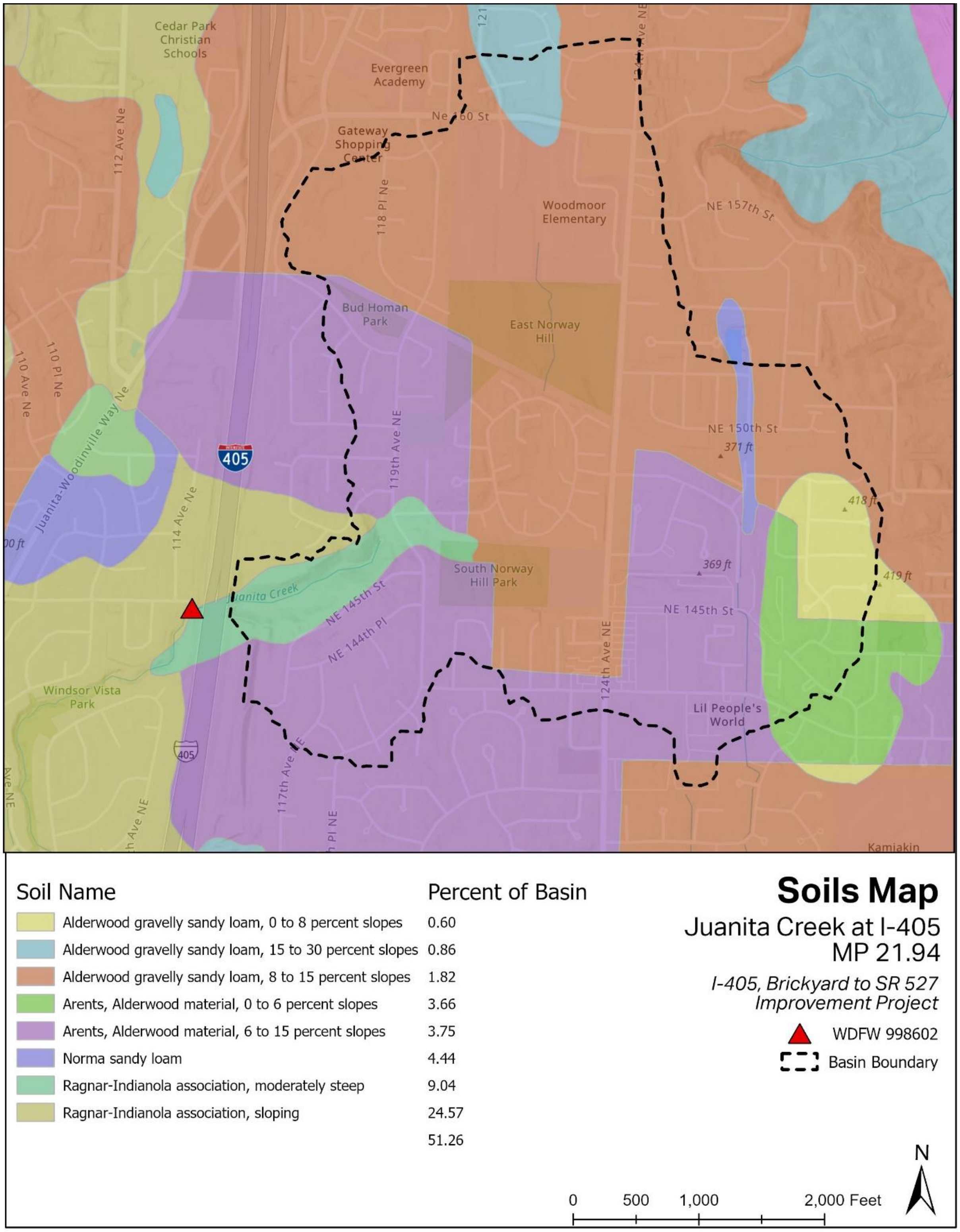


Figure 2-8: Soils map

2.4 Fish Presence in the Project Area

The WDFW online SalmonScape application documents sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), Chinook salmon (*O. tshawytscha*), and resident coastal cutthroat trout (*O. clarkii*) as potentially present in Juanita Creek at the I-405 crossing. According to SalmonScape, coho salmon have been documented as spawning in Juanita Creek, and resident coastal cutthroat have been documented as present in the creek. Sockeye, Chinook, and steelhead are presumed present based on a lack of gradient barrier (WDFW 2019b). The Washington State Fish Passage mapping tool (WDFW 2019c) shows sockeye, coho, steelhead, and sea-run and resident cutthroat trout as potentially present in Juanita Creek based on suitable habitat.

Historically, Juanita Creek supported a small population of Chinook salmon throughout the basin (King County 2018a). According to the WDFW Spawning Ground Database (WDFW 2019e), Chinook salmon sightings have not been documented during stream surveys conducted annually since 1990. Spawning surveys conducted by King County did not identify any Chinook salmon adults spawning in Juanita Creek (King County 2002b). There are no available data confirming steelhead or sockeye presence in Juanita Creek, but presence is assumed based on the availability of suitable habitat.

Despite undesirable water quality conditions described in **Section 2.6.3** below (low dissolved oxygen and bacteria), migratory access is presumed to be the limiting factor for species to be found at the Juanita Creek I-405 crossing. **Table 2-2** shows the species potentially present within the project area.

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

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Sockeye salmon (*Oncorhynchus nerka*)	Presumed	SalmonScape (WDFW 2019b)	Not Warranted
Coho salmon (*O. kisutch*)	Documented	SalmonScape (WDFW 2019b)	Not Warranted
Steelhead trout (*O. mykiss*)	Presumed	SalmonScape (WDFW 2019b)	Threatened
Chinook salmon (*O. tshawytscha*)	Presumed	SalmonScape (WDFW 2019b)	Threatened
Resident coastal cutthroat trout (*O. clarkia*)	Documented	SalmonScape (WDFW 2019b)	Not Warranted

2.5 Wildlife Connectivity

Juanita Creek ranked medium priority for Ecological Stewardship and low priority for Wildlife-related Safety by WSDOT Headquarters (HQ) ESO. A wildlife connectivity memorandum will not be provided for this site, and additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes.

2.6 Site Assessment

The site was assessed through a desktop analysis, including a review of previously compiled information from WSDOT and through multiple site visits conducted by both WSDOT and AECOM.

2.6.1 Data Collection

WSDOT site assessments were conducted in June and December 2019 at the crossing within WSDOT right-of-way, as well as 300 feet upstream and downstream. On December 3, 2019, WSDOT, WDFW, and MITFD performed the site assessment at Juanita Creek to determine and concur on field-measured bankfull width, discuss possible alternatives for the proposed crossing, and observe existing site conditions. On December 3, 2023, AECOM completed a site assessment that included bankfull width measurements and existing site condition observations. Ten bankfull width measurements were taken in 2019, and three bankfull width measurements were taken in 2023. See **Section 2.7.2** for the bankfull width measurement summary. Three Wolman pebble counts were completed in 2019 near where bankfull widths were measured and specifically at the locations indicated in **Figure 2-9**. The pebble counts are discussed in **Section 2.7.3**. WSDOT performed stream surveys in October 2019 to gather the necessary survey data to build a surface model for analysis and design. The survey extended upstream approximately 300 feet to an existing pedestrian bridge of Juanita Creek and extended downstream approximately 700 feet. An additional stream survey was conducted in February 2024 to capture updated stream geometries and elevations in order to ensure the design ties into the existing stream and ensure accuracy of the hydraulic model. The WSDOT field report for WDFW Site ID 998602 is presented in **Appendix B**.

Figure 2-9: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

Juanita Creek, originating east of I-405, flows southwest through commercial development before entering forested areas. The stream features riffle-pool habitat and is bordered by red alder (Alnus rubra), bigleaf maple (Acer macrophyllum), western red cedar (Thuja plicata), and Douglas fir (Pseudotsuga menziesii).

Based on the WDFW *Fish Passage and Diversion Screening Inventory Database Report* provided in **Appendix Q** (WDFW 2019d), the existing culvert at the I-405 crossing is a 358.6-foot-long corrugated metal pipe (CMP) with a slope of 3.0 percent. There is a water surface drop of 2.62 feet at the outlet, and there is no plunge pool present. At the outlet, the culvert downstream daylights onto rocks, which creates white water conditions and dissipates the energy (**Figure 2-1**). There is no apron on either the upstream or the downstream end. The culvert is not countersunk and does not contain sediment throughout its length. The culvert is not backwatered and does not slow the flow of water through its length. There is approximately 40 feet of road fill atop the culvert. The existing culvert is a complete barrier to fish because of the 2.6-foot water surface drop (WDFW 2019a).

There is an inline detention facility located just upstream of I-405 known as the “High Woodlands Regional Detention Pond Project #047007” that influences channel shape and riparian and floodplain conditions. In this area, the stream channel is 5 to 7 feet wide and 1 foot deep. This detention facility area has a poorly defined channel where water spreads out and is very shallow. During a recent site visit, backwater was observed on the upstream side of the culvert, and the inlet was completely submerged. No spawning or rearing habitat is present within the first 170 feet of open channel upstream of the crossing. Just upstream of the poorly defined and shallow channel, the stream has incised down through accumulated sediments that were deposited due to the detention facility. The channel in this ravine was reconstructed following installation of the sanitary sewer in the 1960s. Downcutting and erosion have been persistent issues since that time. Fine sediment accumulates at the site of the detention facility as a result of these past actions. Due to this incision, this reach of the stream is straight and offers minimal habitat for fish. Sediment substrate is dominated by fines and provides no benefit to fish in its current state.

Downstream of the crossing, the stream is dominated by angular riprap that provides no immediate fish habitat benefits. The riprap extends to the next downstream barrier, two property access culverts that are located approximately 70 feet downstream. No beneficial spawning or rearing habitat is present immediately downstream of the crossing.

2.6.3 Fish Habitat Character and Quality

There is no open channel habitat within the I-405 right-of-way. Upstream of the I-405 crossing, the stream flows through an inline detention facility that alters the natural channel characteristics and affects its connectivity to the floodplain and riparian area. Substrates are mostly fine materials. Downstream, the creek is confined to a narrow flow path between a housing development and the I-405 right-of-way.

Upstream of the I-405 culvert, Juanita Creek flows through a mixed forested area that is dominated by riffle and pool habitat and a wide vegetated riparian zone. As the stream flows through the inline detention facility peak flowrate is attenuated which helps to reduce erosion downstream; however floodplain connectivity and riparian habitat are negatively affected. Downstream, the creek flows through a vegetated area in the middle of a housing development. This area is dominated by Himalayan blackberry (*Rubus armeniacus*), but the stream does receive some terrestrial nutrient input and shade. Substrates remain fine materials. A WDFW habitat survey detected juvenile salmonids throughout this downstream reach. According to residents, salmon and lamprey (Petromyzontiformes*)* are often seen downstream of the detention basin. Throughout its flow path, the channel has been armored in most segments of the stream. Channel complexity, floodplain connectivity, and riparian condition and function are heavily degraded due to bank armoring. There appears to be no habitat features that are likely to be used by fish species at any life stage in the current configuration.

Washington Department of Ecology (Ecology) lists impaired water bodies that do not meet water quality standards, which is referred as the 303(d) list. Juanita Creek is identified on the 303(d) list for dissolved oxygen and bacteria (WSDOE 2019). According to the City of Kirkland watershed report card (City of Kirkland 2023), the average temperature for Juanita Creek remains below 60°F throughout the year; however, low concentrations of dissolved oxygen have been recorded during summer months, and 24 pesticides were detected in the system.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

There are several pieces of LWM upstream of the I-405 crossing. The Juanita Creek system has good LWM recruitment potential in this area, as it flows through a steep wooded ravine. Downstream of the crossing, the stream has some LWM available as it flows through short reaches with vegetated riparian habitat (**Figure 2-10**).The riparian buffer, while steep, is wide and intact (**Figure 2-11**). In general, however, the downstream reach is dominated by a developed riparian buffer with little LWM or potential for recruitment.

Figure 2-10: LWM downstream of I-405

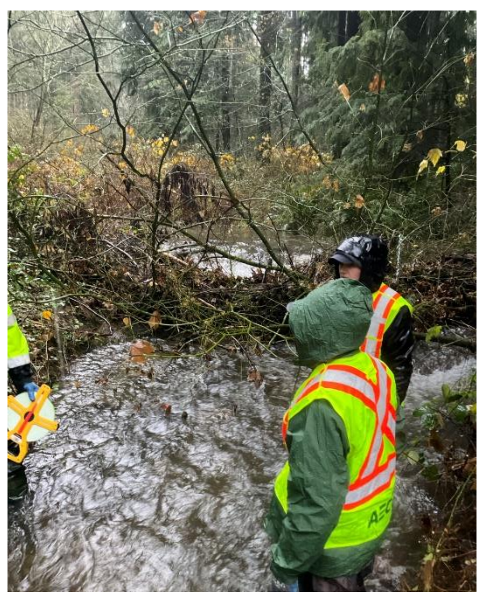


Figure 2-11: Riparian area upstream of I-405

2.7 Geomorphology

The following sections describe the geomorphic characteristics of Juanita Creek. The discussion of geomorphic information includes reference reach selection, channel geometry, sediment, and channel stability in both the vertical and lateral directions. The geomorphic characteristics of the channel were observed during the 2019 WSDOT and 2023 AECOM field investigations.

2.7.1 Reference Reach Selection

Upstream of the I-405 crossing, Juanita Creek is located in a forested reach within a drainage basin that is highly urbanized. The highly urbanized nature of the basin makes it difficult to find a reach that is representative of the historical natural conditions of the stream. A reference reach approximately 300 feet upstream of the crossing was selected (**Figure 2-9** and **Figure 2-12**). This reach was assumed to be above the influence of the backwater caused by the existing inline detention facility and has similar gradient to the section of stream at the crossing. The gravels found in this reach are consistent with the materials found in the adjacent stream banks and are likely representative of the sediments routinely transported by the channel.

Figure 2-12: Reference reach, looking upstream

2.7.2 Channel Geometry

The reference reach channel can be described as a relatively confined, moderately sinuous urban stream. Historical aerial imagery suggests it is generally stable and is not subjected to much lateral migration. Minimal upstream channel incision is apparent, but some bank erosion is present, which is representative of the majority of lowland Washington streams. Existing cross sections are generally 1.0–1.5 feet in depth with steeper banks and are gently sloped down to the channel thalweg. The longitudinal slope of the reference reach was determined via a desktop investigation to be approximately 1.7 percent. **Figure 2-13** shows existing cross-section geometries upstream of the I-405 crossing.

Bankfull width measurements for were determined in the field on December 3, 2019, by WSDOT, WDFW, and MITFD. Bankfull width measurements were obtained from 10 locations upstream of the I-405 crossing. These measurements were taken approximately 32.8 feet apart. Measurements upstream of I-405 ranged from 9.5 feet to 17.5 feet. Bankfull measurements are shown in **Table 2-3**. AECOM's three measurements were not included in the design because the average of 12.0 feet and the minimum hydraulic opening of the proposed structure of 23 feet were concurred with previously by WSDOT and other parties; however, AECOM's measurements confirm that the channel geometry has not altered greatly from 2019 to 2023.

Table 2-3: Bankfull width measurements

BFW Number	Width (ft)	Included in Design Average?	Site Assessment
1	10.5	Yes	WSDOT 2019
2	14.5 (12.8)	Yes (No)	WSDOT 2019 (AECOM 2023)
3	13.3 (11.6)	Yes (No)	WSDOT 2019 (AECOM 2023)
4	11.5 (10.4)	Yes (No)	WSDOT 2019 (AECOM 2023)
5	10.0	Yes	WSDOT 2019
6	9.5	Yes	WSDOT 2019
7	11.5	Yes	WSDOT 2019
8	11.0	Yes	WSDOT 2019
9	17.5	Yes	WSDOT 2019
10	11.5	Yes	WSDOT 2019
Design Average	12.08		

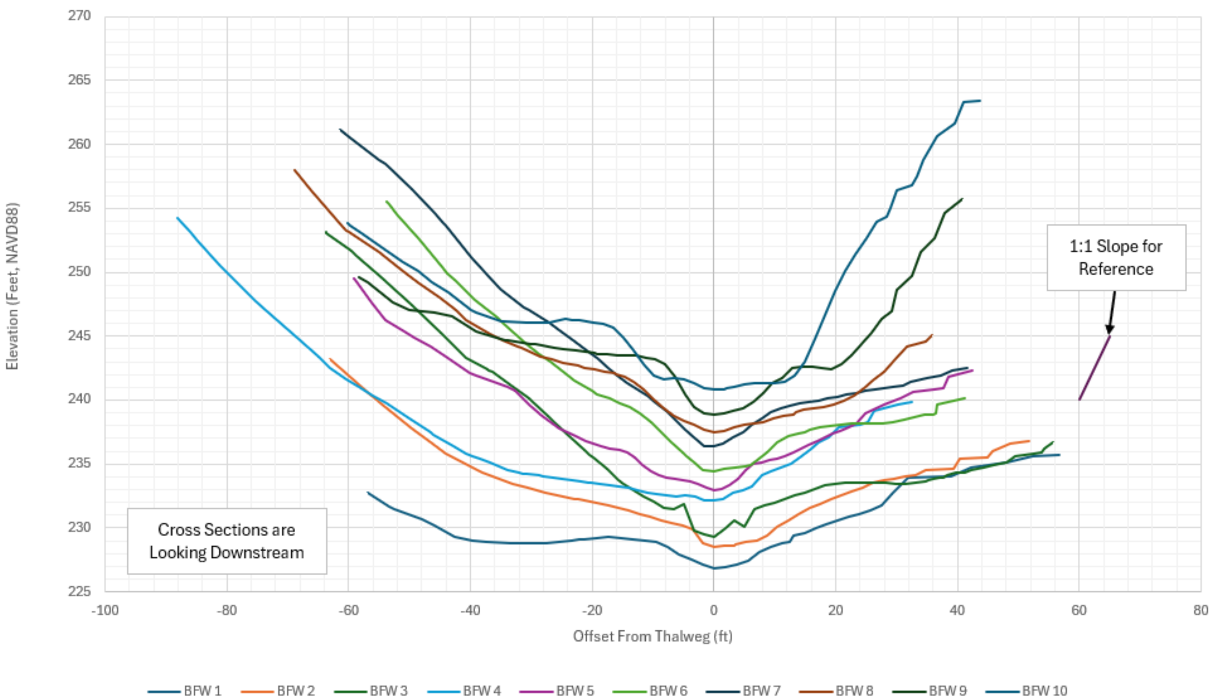


Figure 2-13: Existing cross-section examples

The bankfull widths reported in **Table 2-3** are understood to reflect a moderately confined channel in a forest reach of a highly urbanized basin. In coordination with WSDOT, WDFW and MITFD, a bankfull width of 12.0 feet was accepted as the basis for completing the preliminary restored stream connection design.

During final design, grading, and modeling using detailed terrain, it was determined that bankfull widths need to vary along the length of Juanita Creek to meet hydraulic criteria. Riffles are typically twice as steep as average channel slope, and it was not possible to achieve desired 2-year and 10-year floodplain activation using a bankfull width of 12.0 feet. Thus, design bankfull widths for proposed conditions vary from 10 feet to 10.5 feet (**Table 2-4**) in the riffle-pool section of the stream. The step-pool section has bankfull widths ranging from 10 to 16.4 feet (**Table 2-4**) to optimize constructability and fish passage requirements. All these values fall within the range of measured bankfull widths between 9.5 feet and 17.5 feet (**Table 2-3**). See **Section 4.3** and **Appendix N** for further details on channel design.

Table 2-4. Design bankfull widths

Reach Section		Bankfull Width (ft)
Riffle-pool	Riffle	10
	Pool	10.5
Step-pool	Step	10
	Pool	15
	Resting pool	16.4

2.7.2.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel. The FUR was determined and confirmed by WSDOT using measurements upstream in a location that was outside of the culvert influence, and further detail was not necessary. The average FUR value upstream of the crossing was determined to be 2.11, which is considered unconfined. See **Table 2-5** for a summary of these metrics.

Table 2-5: FUR determination

Metric	Value
Average FUR Near Crossing	2.11
Bankfull Width (ft)	12.08
Slope Ratio	1.25

2.7.3 Sediment

On February 28, 2020, a field investigation of the sediment distribution upstream of Juanita Creek was conducted. Three Wolman pebble counts were conducted in the reference reach. Sediment in this valley is largely immobile due to the existing inline detention facility. Fines have accumulated over the years at the existing structure inlet. As shown on **Figure 2-14,** sediment included a wide distribution of gravels mixed with a smaller distribution of fines and cobbles (**Table 2-6**). The gradation curves for these pebble counts are found in **Figure 2-14**.

Table 2-6: Sediment properties near the project crossing

Particle Size	Pebble Count 1 Diameter (in.)	Pebble Count 2 Diameter (in.)	Pebble Count 3 Diameter (in.)	Average Diameter for Design (in.)
Included in average?	Yes	Yes	Yes	
$\mathbf{D_{16}}$	0.4	0.3	0.5	0.4
$\mathbf{D_{50}}$	0.9	0.9	1.3	1.0
$\mathbf{D_{84}}$	1.9	2.1	2.6	2.2
$\mathbf{D_{95}}$	3.5	3.3	3.5	3.5
$\mathbf{D_{100}}$	5.9	4.9	6.0	5.7

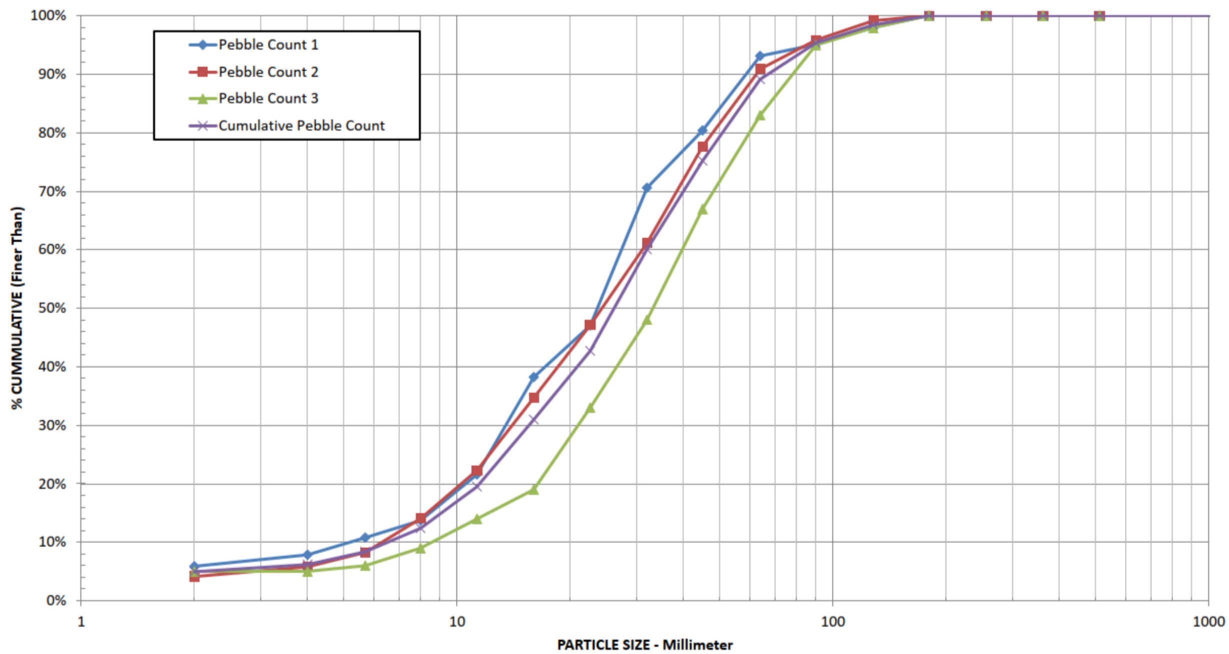


Figure 2-14: Sediment size distribution

Two grab samples were collected on December 3, 2023, one from the downstream side of I-405 located on the right bank of the outlet of property access culvert looking downstream and one from the upstream side of I-405 on the right bank looking downstream. The sediment samples were used for particle size distribution (ASTM D422) and liquid and plastic limits (ASTM D4318) tests completed by Otto Rosenau & Associates, Inc. The sediment samples consist of gray silty sand with trace organics.

2.7.3.1 Vertical Channel Stability

This reference reach of Juanita Creek has a moderately low slope (approximately 2 percent) and appears to have minimal risk of major aggradation or degradation. There is some incision and erosion identified downstream of the I-405 crossing, but this does not appear to be a major issue within the project area. See **Figure 2-15,** which was taken approximately 230 feet downstream of the existing culvert outlet.

Figure 2-15: Signs of erosion downstream of I-405

The longitudinal profile in **Figure 2-16** consists of LiDAR acquired from King County (WGS 2021) that has been supplemented with the survey completed in 2024. It shows the project location with the proposed crossing slope relative to the exiting ground elevations beginning at Lake Washington and extending upstream of I-405.

Sediment supply in the system is likely limited by the upstream culvert crossings. There is some potential in the immediate valley reach for sediment recruitment, but the presence of the undersized culverts upstream limits the ability for the sediment from further upstream in the system to migrate and travel through this reach. The I-405 crossing sits in a transition zone where the slope changes from steep to flat as Juanita Creek flows towards Lake Washington (**Figure 7-1**).

Aggradation is occurring in the current configuration due to the regional detention facility, but as this control structure is removed, the potential for aggradation upstream will be reduced. One of the project benefits is to restore more natural sediment transport continuity between the upstream and downstream reaches of the project site. Temporarily, some sediment will move into the culvert, especially into pools where there is slower velocity. Sediment will then be transported through the project reach downstream during higher flows. Some sediment will migrate to the next culvert and some will continue to transport further downstream.

Much of the fine sediment that has accumulated directly upstream of the existing culvert will not be mobilized because the new crossing is 50 feet south of the existing culvert, and this portion of the channel will no longer be connected to Juanita Creek. The majority of fine sediment that does migrate from upstream will be transported as wash load and deposit near the mouth of Juanita Creek at Lake Washington.

The proposed crossing will connect the upstream and downstream ends of the project with an improved channel alignment that maintains a slope of approximately 3 percent as discussed in **Section 4.1.3.**

As described in **Section 7.2**, Juanita Creek may be at risk for long-term degradation under proposed conditions because the Project would replace the existing I-405 culvert with a deformable channel bed. Equilibrium slope estimates and the potential for bed armoring were evaluated and indicate that degradation is expected to be minimal through the project area under proposed condition.

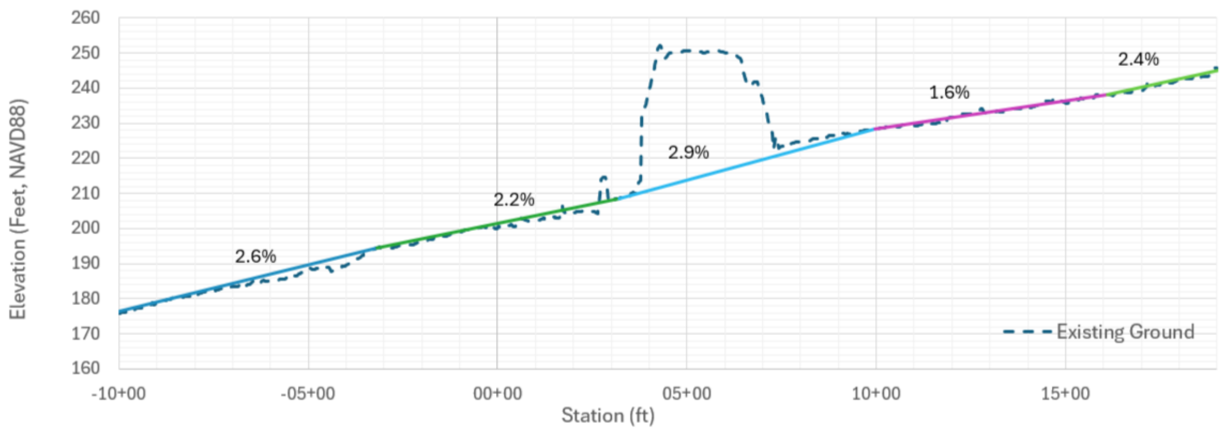


Figure 2-16. Watershed Longitudinal Profile

2.7.4 Channel Migration

Upstream of the I-405 crossing, Juanita Creek flows through a forested ravine with low to moderate channel migration potential until it reaches the inline detention facility. There is also limited channel migration potential immediately downstream of the crossing, as the stream flows through a narrow, vegetated area within a housing development. Further downstream, the creek continues to flow through pipes and developed areas with little opportunity for significant channel migration.

3 Hydrology and Peak Flow Estimates

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

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. **Appendix G** contains the projected increase information for the project site. The design flow for the crossing is 111 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 21.8 percent, yielding a projected 2080 100-year flow of 135 cfs.

In May 2021, WSDOT completed the preliminary Hydraulic Design (PHD) report, which details the design elements necessary to comply with the federal injunction as coordinated with the permitting agencies and affected tribe. Following the completion of the PHD Report, WSDOT coordinated with the City of Kirkland and its consultant, Northwest Hydraulic Consultants (NHC), to better understand the basin hydrology and floodplain impacts for existing and proposed conditions (City of Kirkland 2022). A technical memorandum documents the hydrology to be used for final design and the finding for potential downstream effects that result from the removal of the flow control structure. Based on NHC's field inspections, the original design ponding depths do not appear to match the actual performance within the regional pond. To address this, the City of Kirkland used current GIS data to update existing land cover for the study area and contracted NHC to perform a calibration of a 2012 King County Hydrological Simulation Program – FORTRAN (HSPF) model for Juanita Creek. NHC provided four model outputs for use in the design based on their updated and calibrated King County HSPF model. Their results, documented in **Table 3-1,** will be used as the basis for the final design directed by the City of Kirkland and WSDOT. The upstream subbasin of the I-405 culvert is called the "At I-405" and the "Above Norway Hill Trib" subbasin is one of the downstream subbasins that provides lateral flows to Juanita Creek. The 500-year discharge was not provided by this updated HSPF model but was extrapolated using the 2-to-100-year outputs. Also, the 2080 projected 100-year discharge was determined from the predicted percentage increase obtained from WDFW's Culvert and Climate Change web application.

Table 3-1: Peak flows for Juanita Creek at I-405

	Project Scenario	2-year	10-year	25-year	100-year	Extrapolated 500-year	2080 Projected 100-year
At I-405	Pre	25	32	35	41	51	50
	Post	40	65	81	111	174	135
Above Norway Hill Trib	Pre	30	39	44	51	65	62
	Post	45	74	94	129	205	157

4 Water Crossing Design

This section describes the water crossing design developed for I-405 MP 21.94 Juanita Creek, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

The WCDG contains methodologies for five different types of crossings: No-Slope Culverts, Stream Simulation Culverts, Bridges, Temporary Culverts or Bridges, and Hydraulic Design Fishways (Barnard et al. 2013). The permanent federal injunction allows for the use of the stream simulation method and bridge design method unless extraordinary circumstances exist on site. According to the WCDG, the stream simulation method should be considered for a site if the following conditions are met:

- the FUR is greater than 3.0,
- the stream has a bankfull width of 10 to 15 feet,
- the channel is believed to be moderately stable, and
- the channel is believed to be moderately debris prone

This section describes the channel design developed for Juanita Creek, including channel planform and shape, alignment, and gradient.

4.1.1 Channel Planform and Shape

The channel shape was based on reference reach channel information described and shown in **Section 2.7.2,** with some engineering judgment modifications. The meander wavelengths of the original WSDOT PHD stream design were measured and compared to stable channel planforms based on various equations recommended by NRCS (2007). All meanders were measured to be within acceptable lengths, except the meander at the entrance to the proposed crossing; this meander was straightened because it was measured to be less than an appropriate length, as recommended by Soar and Thorne (2001) (see **Appendix N**).

The channel is split into two different reaches based on slope. Through the structure and downstream of the structure are riffle-pool reaches at a milder slope, described below. Upstream of the structure is a step-pool system dissipating energy of the higher slope, described in **Section 4.3.2.5**.

The riffle-pool section of the stream has typical riffle sections with a 10-foot bankfull width and the left pool and right pool typical cross sections with a 10.5-foot bankfull width (**Table 2-4**). The riffle typical section includes cross slopes of 8H:1V between the thalweg and toes of the banks, to increase depths for fish passage at low flows. The riffle typical section has slopes of 2H:1V between the toes of the banks and the top of bank (see **Figure 4-1** and **Appendix N**). Bentley FlowMaster (see **Appendix N**) was used to test riffle bankfull widths at their common 6.0 percent slope through the reach to achieve appropriate floodplain activation at the 2-year and 10-year flow rates. Bend scour was investigated to determine the depth of the bankfull pools (**Appendix K**). An SRH-2D model with the 10-foot riffle bankfull width and 10.5-foot pool bankfull width confirmed that 2-year and 10-year water surface elevations (WSEs) are spilling outside of the bankfull channel as desired.

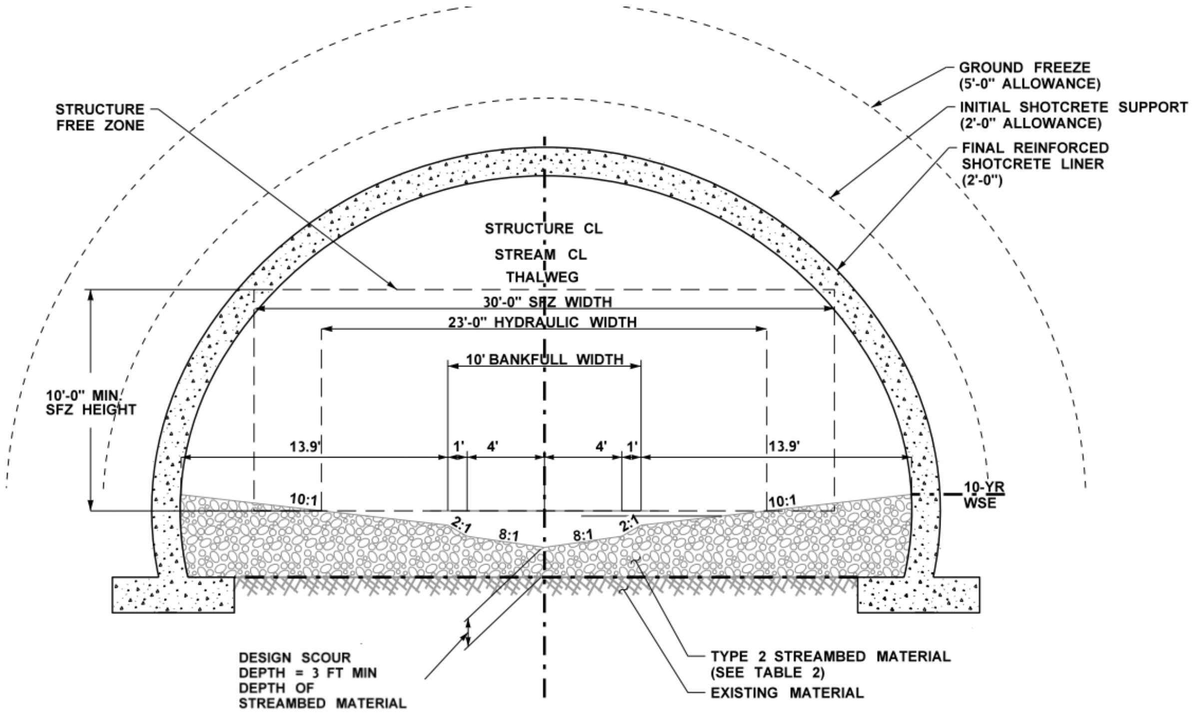


Figure 4-1: Design riffle cross section

The left and right typical pool sections are mirror images. As shown in **Figure 4-2,** pool bank slope will vary, but will not exceed a maximum slope of 2H:1V. Typical pool sections have a bankfull depth of 1.5 feet, providing a residual pool depth of approximately 0.5 feet below the elevation of the tailwater control at the downstream riffle crest thalweg.

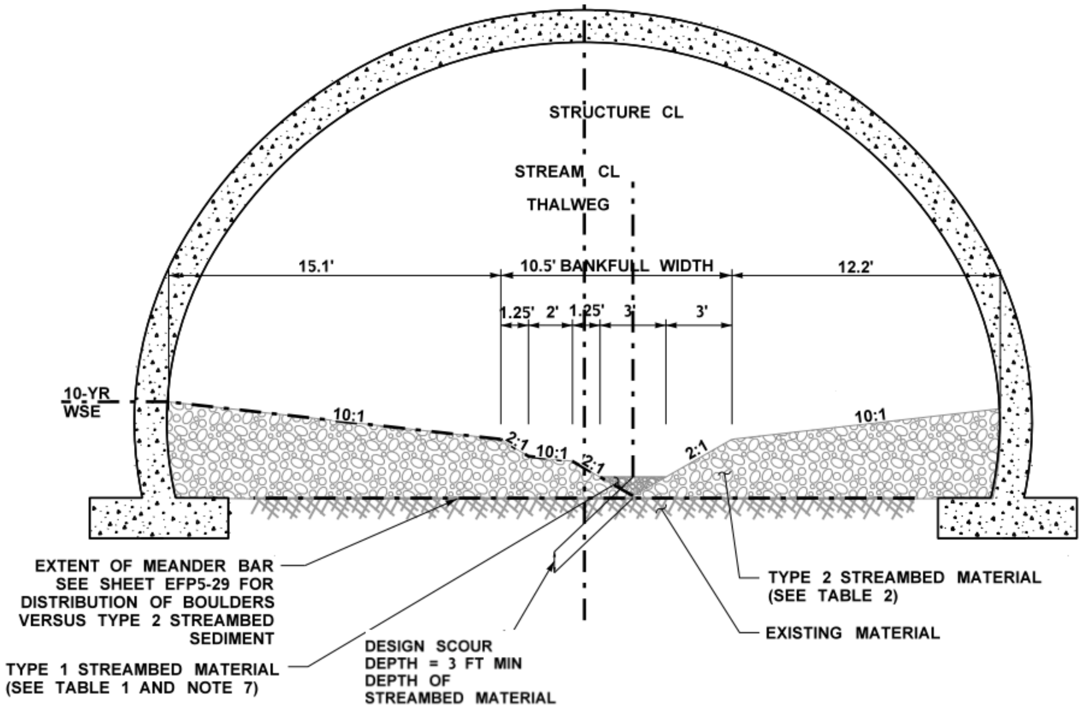


Figure 4-2: Design right pool cross section

Juanita Creek's existing channel upstream of I-405 flows into a stormwater detention facility surrounded by wetland vegetation. The stormwater detention facility drains through a 359-foot-long 48-inch CMP under I-405 to its downstream channel. The downstream channel flows for 70 feet and then enters two 25-foot-long, 24- and 36-inch culverts (both of which will be removed) and then flows into its channel again. The 48-inch CMP will be abandoned and replaced with a 37.8-foot-wide clear span shotcrete-lined open-bottom circular arch offset 50 feet south from the existing culvert.

Upstream of the Juanita crossing, the existing channel will be preserved and used as high flow fish habitat. The proposed channel is lower and offset from the existing channel and existing 48-inch CMP crossing under I-405. The proposed channel's right bench will extend at a 10H:1V slope up to the existing channel. This right bank will vary 10 to 45 feet and be vegetated with wetland plants. The left bank is near a valley wall and will not have a bankfull bench. It will extend at a 2H:1V slope up to existing ground.

Through the proposed Juanita crossing, the left and right banks have benches at 10H:1V slopes. These benches vary between 5 to 13 feet wide based on the location of the meandering channel's centerline.

Downstream of the existing Juanita crossing, the existing channel will be infilled down to the two smaller culverts. From these two smaller culverts to the proposed channel, the existing channel will remain in place, to allow for additional high flow refugia. The downstream proposed channel's right bank has a 10-foot bench at 10H:1V side slopes. The left bank does not have a bench and ties into existing surface at 2H:1V slopes.

Updated 2024 existing stream survey was included in this phase of the modeling. A MicroStation InRoads corridor model was created with the typical cross sections at riffles and pools carving the proposed channel and benches. Channel meandering within the proposed alignment will provide increased habitat diversity. These meanders will be maintained through construction of meander bars and placed LWM that will enhance the instream channel diversity and encourage the stream to self-maintain this habitat over its design life.

The proposed typical cross sections create a low-flow channel with steeper 8H:1V slope on the riffle and "v" shaped pool cross sections. These changes will connect habitat features so the project does not produce a low-flow barrier. Additional input directed by the engineer in the field will be needed to ensure this low-flow channel is built. **Figure 4-3** illustrates the proposed channel section.

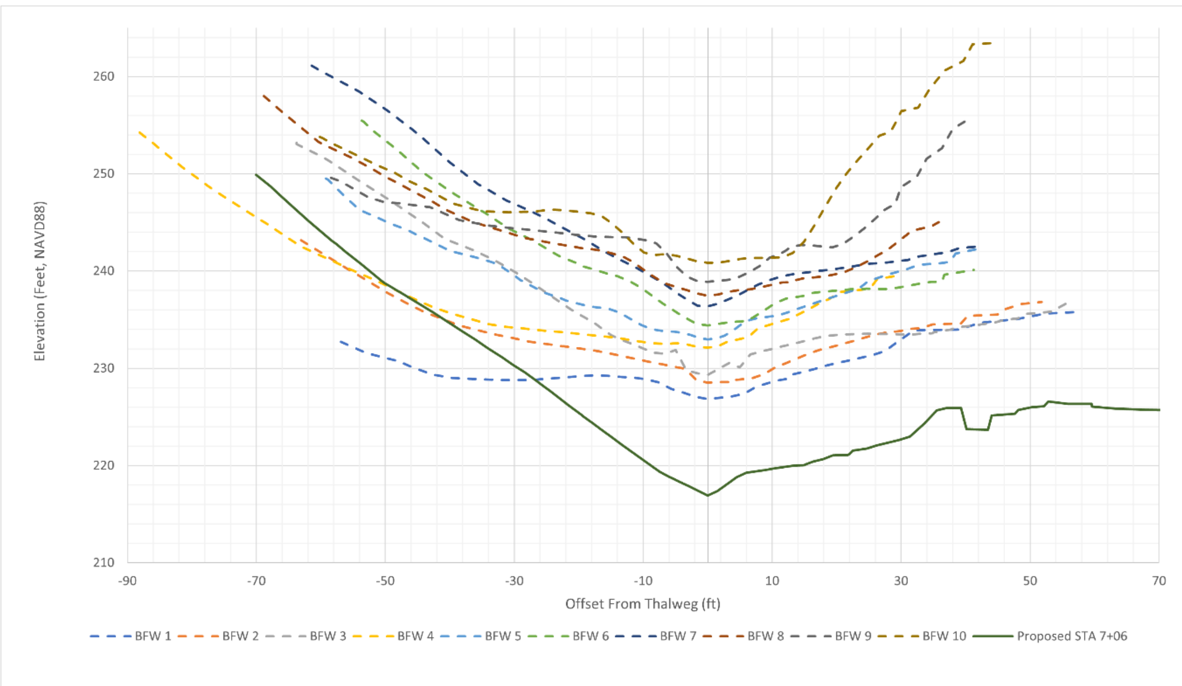


Figure 4-3: Proposed cross section superimposed with existing survey cross sections

4.1.2 Channel Alignment

The proposed channel alignment is approximately 697 feet in length, incorporating meanders to enhance habitat and mimic stream sinuosity. A factor that influenced the horizontal alignment of the proposed crossing included keeping the existing inline detention facility on-line during construction. A lateral separation from the existing structure was deemed necessary in the event that the City of Kirkland could not decommission the inline detention facility during construction due to their municipal stormwater treatment commitments. The meander configuration of the proposed alignment was driven by meander belt width data collected from the upstream reference reach and slightly smoothed out inside the crossing. The upstream reference reach meander belt width was measured to be 30 feet (**Figure 2-9**).

4.1.3 *Channel Gradient*

The WCDG recommends that the proposed culvert bed gradient not be more than 25 percent steeper than the stream gradient upstream of the crossing (WCDG Equation 3.1, Barnard et al. 2013). The slope ratio for the crossing and immediate upstream grading is shown in **Table 4-1**. The first 100 feet of existing stream slope upstream of the tie-in location exhibits an average slope of 2.4 percent. The roadway crossing of Juanita Creek was constructed at the location of a natural grade break, where a steep confined valley begins to flatten. As a result, minimal headcutting upstream of the proposed structure is expected. There is potential for long-term degradation of the channel bed, as discussed in **Section 7.2**.

Table 4-1: Channel gradient

Crossing Location	Approximate Upstream Channel Grade	Proposed Structure Grade	Slope Ratio
I-405	2.4% (Existing)	3.0%	1.25
	3.0% (Proposed)		1.0

4.2 Minimum Hydraulic Opening

This section describes the minimum hydraulic width and vertical clearance; for discussion of the scour elevation, see **Section 7**. See **Figure 4-4** for an illustration of the minimum hydraulic opening.

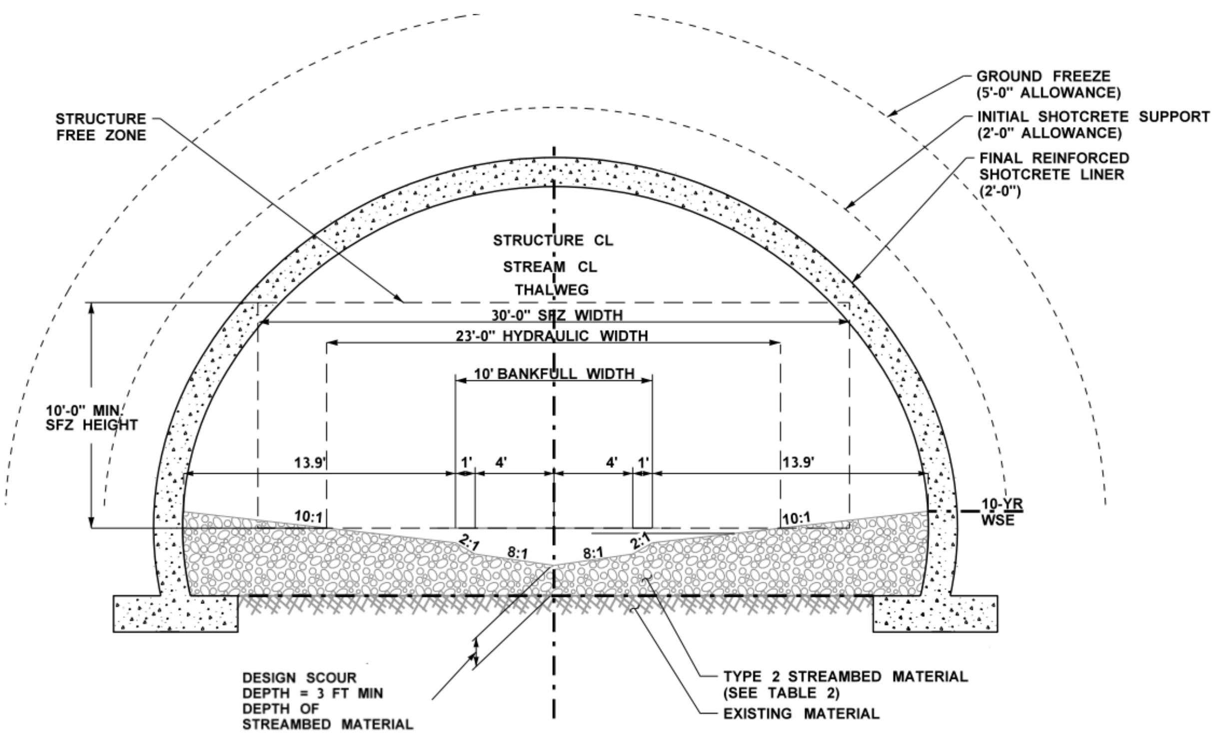


Figure 4-4: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing. The following metrics aided in this conclusion:

- Bankfull width – 12 feet[1]
- FUR – 2.11 (upstream), 1.31 (downstream)
- Slope ratio – maximum 1.25
- Length of crossing – 250 feet
- Channel stability – moderate
- Channel migration potential – low to moderate
- Climate Resiliency – negligible increase in WSEs

4.2.2 Hydraulic Width

The hydraulic width is defined as the minimum width perpendicular to the structure centerline that is necessary to convey stream design flow and allow for stream processes.

The starting point for the minimum hydraulic width determination of all WSDOT crossings is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 17.0 feet was determined to be the minimum starting point as:

$$(1.2 * BFW) + 2 = 16.5 = 17.0$$

However, because this crossing is defined as a long culvert by WDFW (length-to-width ratio > 10), the required minimum hydraulic width is increased by 30 percent, to 23 feet.

Note that the structure free zone (SFZ) width is different from the hydraulic width. The SFZ width is the horizontal width perpendicular to the stream between the nearest surfaces of the structure. To allow for the implementation of meander bars and LWM, a SFZ width of 30 feet was agreed on by MITFD, WDFW, and WSDOT

Considering climate change resilience, the minimum hydraulic width was evaluated under current and 2080 100-year flow events. **Table 4-2** compares the discharge velocities from the 100-year and projected 2080 100-year events at three locations along the crossing. No size increase was determined to be necessary to accommodate climate change. For detailed hydraulic results, see **Section 5.4**.

Table 4-2: Average velocity comparison

Location	100-year Velocity (ft/s)	Projected 2080 100-year Velocity (ft/s)
Upstream of structure (STA 7+06)	2.5	2.8
Through structure (STA 5+22)	3.1	3.4
Downstream of structure (STA 2+98)	2.6	2.8

[1] Design bankfull width varies from 10 feet for riffles to 16.4 feet for resting pools of the step-pool system (Table 2-4).

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in **Table 4-3**. The minimum SFZ and maintenance heights are consistent with previous drafts of the PHD and design developed by the WSDOT engineer. The SFZ height does meet the Chapter 2 SFZ definition requirement. The proposed SFZ and maintenance clearance for Juanita Creek is 10 feet, SFZ height measured from highest point within the hydraulic width, as indicated in WSDOT Chapter 2: Technical Requirements for this project, and preliminary design developed by WSDOT.

According to the WSDOT *Hydraulics Manual* (WSDOT 2022a), a standard of 3 feet of freeboard is prescribed for all structures exceeding 20 feet in length and for all bridge structures unless an alternative is approved by HQ Hydraulics. In the current proposed configuration, the structure offers 9.6 feet of freeboard (relative to the SFZ height) at the 100-year event, satisfying the minimum requirements. The internal structure height is constrained to a minimum of 10 feet without necessitating alterations to the I-405 roadway profile. This freeboard condition is described in **Table 4-3**.

Table 4-3: Vertical clearances

Crossing Location	100-Year Design Freeboard Requirement (ft)	Proposed Internal Clearance from Top of Bank (ft)	Estimated Freeboard with Proposed Structure Height (ft)
I-405	3.0	10	9.6

4.2.3.1 Past Maintenance Records

WSDOT Area 5 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

As mentioned in **Section 2.6.4**, the Juanita Creek system has good LWM recruitment potential both upstream and downstream of the I-405 crossing, as it flows through a steep wooded ravine. Future urban growth in the basin is unlikely under current City of Kirkland Zoning and Land Use ordinances. The riparian buffer, while steep, is wide and intact. Although minimal large wood is currently present in the system, the upper reach of this system has clear potential for significant wood recruitment. Currently, the inline regional detention facility is preventing large amounts of sediment from transporting through the system. Once removed, a portion of that accumulation will likely transport downstream.

4.2.4 Hydraulic Length

The maximum allowable hydraulic length determined by WSDOT for the I-405 crossing of Juanita Creek is 358.6 feet. If the hydraulic length is increased beyond 358.6 feet, the hydraulic width and vertical clearance will need to be reevaluated. The proposed crossing is 253.5 feet.

4.2.5 Future Corridor Plans

The existing structure is being replaced as part of the Project, as summarized in **Section 1**. Structure alignment and length have been designed to accommodate this future widening. As a result, there will be no requirement for subsequent lengthening or modifications to accommodate the specifications outlined in the master plan conditions. Therefore, this structure will be forward compatible.

4.2.6 Structure Type

The proposed structure is an open-bottom circular arch with a reinforced shotcrete final liner. It has a width of 37.8 feet, with an SFZ width of 30 feet and SFZ height of 10 feet. The construction of the final liner will be facilitated with a ground freezing technique to stabilize the ground and the sequential excavation method with initial shotcrete liner to create the underground space within which the final liner will be constructed. The thickness of the ground freeze allowance and initial and final shotcrete liners will be refined for final design. A bottomless structure is recommended by WSDOT HQ Hydraulics for the proposed crossing for multiple reasons. A bottomless structure will allow for the crossing to have a natural bottom and will allow for natural channel adjustment. This type of structure will eliminate the risk of a plunge pool developing at the structure outlet, impeding fish passage.

4.3 Streambed Design

This section describes the streambed design developed for Juanita Creek at I-405 MP 21.94.

4.3.1 Bed Material

Existing condition hydraulics of Juanita Creek are influenced by the regional detention facility located under I-405. The Project will remove this facility, which will lead to higher velocities than existing conditions. Proposed bed materials will need to be substantially coarser than current bed materials to resist scour and mobilization.

In order to model proposed hydraulic conditions and accurately size bed material, riffles and pools were graded into the terrain using MicroStation. While the average slope through the proposed fish passage structure is approximately 3 percent, riffle slopes in the structure are as high as 6 percent (**Appendix D**). Cross sections in the model were taken through three riffles and three pools within the structure, and average main channel shear stresses were estimated. The largest average shear stress of the three riffle sections and the largest average shear stress of the three pool sections were used for sediment sizing calculations. As the upstream portion of the stream is a step-pool system with log weirs, it was not used for sediment sizing.

Three methods were used to size sediment: the Modified Shields Methodology (USFS 2008), the Bathurst Equation (Bathurst 1987), and the U.S. Army Corps of Engineers (USACE) riprap equation (Barnard 2013). The Modified Shields Methodology produced the most conservative results and was used for sediment sizing (**Appendix C**). **Table 4-4** provides a comparison of sediment sizes. Note that a ratio of D_{84}/D_{100} equal to 0.7 was used instead of the typical ratio of 0.4, so that the D_{100} could be kept to less than one quarter of the bankfull width.

Table 4-4: Comparison of observed, WSDOT PHD, and proposed riffle and meander bar streambed material

Sediment size	Existing Average Diameter (in.)	Previously Proposed Riffle-Pool System Diameter from WSDOT PHD (in.)	Proposed Diameter for Riffles and Meander Bars Based on Updated Hydraulics (in.)
$\mathbf{D_{16}}$	0.38	0.78	0.61
$\mathbf{D_{50}}$	1.01	3.89	7.68
$\mathbf{D_{84}}$	2.21	13.20	19.20
$\mathbf{D_{100}}$	5.69	18.00	28.00

The streambed sediment mix will not be increased by the WSDOT *Hydraulics Manual* (WSDOT 2022a)-prescribed 20 percent, as shown in **Table 4-4**. A sediment mix within 20 percent of the existing streambed material is unstable for the design storm, therefore the design requires a coarser mix for stability (**Appendix C**). The larger increase to the streambed sediment will account for this stream reach being returned to a natural flowing channel rather than a reach affected by backwatering of the regional detention facility. As discussed with WSDOT, the upper one foot of bankfull channel will consist of standard WSDOT streambed sediment (**Table 4-5**).Using the Modified Shields Methodology, the D_{50} and D_{84} for pools were calculated as 2.59 inches and 6.5 inches, respectively. However, because pools are intended to scour and fill, with most of their sediment moving through the system, the sediment gradation for pools was decreased to the standard WSDOT streambed sediment; a D_{50} of 1 inch was calculated to be mobile at the 2-year flow (**Appendix C**) (**Table 4-5**).

Table 4-5: Proposed pool streambed material (WSDOT streambed sediment)

Sieve Size (inches)	Percent Passing
2.5	99-100
2.0	85-100
1.0	50-82
0.5	28-68
0.017 (No. 40)	10-20
0.003 (No. 200)	5-10

To provide the needed channel stability and prevent entrainment along the culvert walls, meander bars will be included within the structure to prevent streambed sediment from being washed out. These meander bars will be composed of the same sediment gradation as the riffle sections (**Table 4-4**). In addition, mobile wood material will be arranged within the structure and LWM outside the structure to provide additional roughness, channel stability, and habitat variability.

In addition to the riffle gradation providing channel and general bedform stability, this bed material will also act as a profile stability measure that will limit long-term degradation of the channel bed. As discussed in **Section 7.2** in detail, this bed material will help to prevent LTD.

A mix of WSDOT standard specification streambed aggregates (WSDOT 2022b) will be used to create the Type II Streambed Material. The WSDOT stream aggregate type and proportions recommended to create a ten-part mix of Type II Streambed Material are listed in **Table 4-6** (see **Appendix C**).

Table 4-6: WSDOT standard specification aggregate mix for Type II Streambed Material

WSDOT Standard Specification Stream Aggregate Type	Parts Needed
Streambed sediment, 9-03.11(1)	1 part
Streambed fine sediment, 9-03.11(2)	1 part
Streambed cobbles 12 inch, 9-03.11(4)	6 parts
Type Two streambed boulders, 9-03.11(5)	2 parts

A risk assessment regarding streambed material can be found in **Appendix P**. The risk assessment indicates that habitat complexity features which overcoarsened the channel are required (WSDOT 2022a) to maintain channel stability. These features include LWM, meander bars, and deformable grade control, and are described further in the following sections.

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Juanita Creek at I-405 MP 21.94.

Channel complexity within the structure will be created with the use of meander bars and LWM that partially obstruct low flows to create habitat diversity and act to prevent the stream from capturing the structure wall and avoid plane-bed configurations. Final LWM configuration design will be approved by the WSDOT HQ Hydraulics Office. LWM will be installed according to Chapter 10 of the *Hydraulics Manual* (WSDOT 2022a) within the project limits, as defined for permitting. Channel complexity inside the crossing structures will include meander bars, riffles and pools, marginally mobile wood, and restored streambank shape as shown in the plans (**Appendix D**).

4.3.2.1 Design Concept

Multiple channel complexity elements will be incorporated into the channel design to meet the functional goals, as described in more detail in the following subsections and shown in **Figure 4-5**.

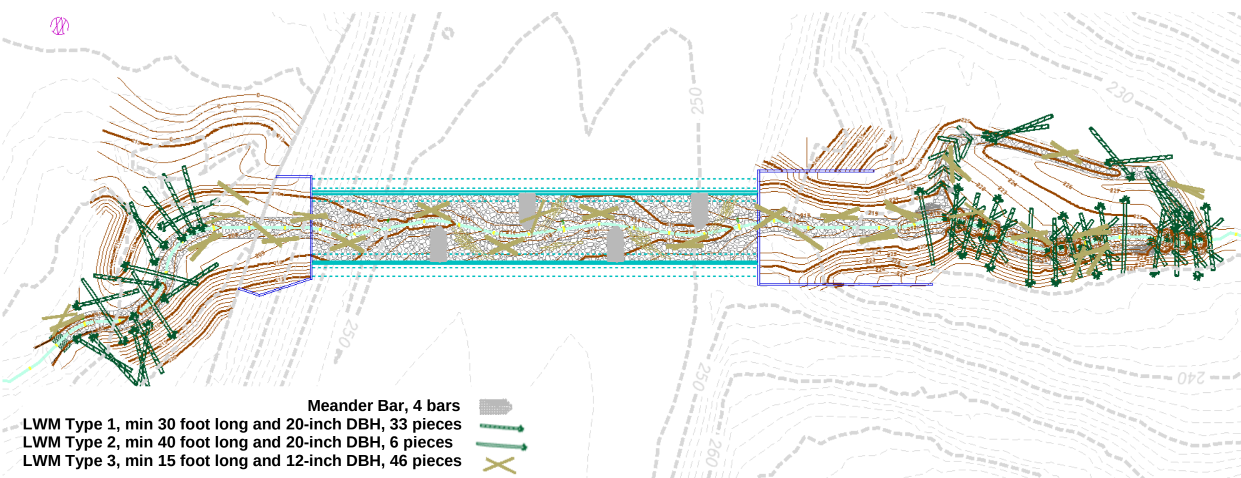


Figure 4-5: Conceptual layout of habitat complexity

4.3.2.2 Woody Material

LWM will be placed to emulate instream habitat functions in a manner that mimics natural wood loads, at the 75th percentile key-piece density levels found by Fox and Bolton (2007) (**Appendix F**) in other natural streams in the region. LWM can provide multiple benefits, including reducing overall channel creek velocities and associated scour due to increased roughness, supporting pool hydraulics, habitat complexity, and slope stability.

For Juanita Creek at I-405, a total of 85 pieces of LWM will be placed over the 697 feet of constructed channel. The total pieces will encompass 33 pieces of type 1, 6 pieces of type 2, and 46 pieces of mobile wood type 3. For each main channel step pool, one type 1 key log with rootwad is used and is included in the 85 total LWM log count. Not included in this total, are the additional logs that support the step-pool stability and function, these are discussed in **Section 4.3.2.5.** Type 1 and 2 are key pieces and will be buried and wedged between other pieces of LWM when feasible, so as not to require additional anchoring, or will be placed entirely above the 100-year WSE. The type 1 key pieces will have a minimum 20-inch diameter at breast height (DBH), be 30 feet long, and have rootwads attached for increased instream habitat complexity. Three type 1 key pieces will be incorporated into a right bank engineered log jam, designed to partially divert flows to use the existing channel as a side channel for habitat enhancement and refuge at high flows. Six 40-foot-long type 2 channel-spanning logs placed above the 100-year WSE have also been incorporated into the design. The 46 mobile wood type 3 pieces will be a minimum 12-inch DBH and 15 feet long. They will not be buried and will be designed to be mobile above the 10-year design storm. This marginally mobile wood will be ballasted by key pieces of wood in some instances and will be placed strategically throughout the channel, both within and outside of the structure, to maximize instream habitat function. The LWM layout can be found in **Appendix D**.

Because MWM is intentionally designed to be mobile and may pose a risk to downstream infrastructure, a risk assessment of the structure and downstream constraints is presented in **Appendix P**.

Materials for LWM and LWM anchoring will follow the guidance in Chapter 10 of the WSDOT *Hydraulics Manual* (WSDOT 2022a) and any environmental commitments noted in the contract.

4.3.2.3 Meander Bars

Channel meandering in the proposed structure will be maintained through construction of meander bars that will enhance the instream channel diversity and encourage the stream to self- maintain this habitat over its design life.

Meander bar spacing is designed to mimic the spacing of existing meanders in the adjacent reaches and is approximately four times the bankfull width, per contract requirements. The preliminary meander wavelengths developed by WSDOT were confirmed and adjusted using guidance from NRCS (2007) and Soar and Thorne (2001). See **Appendix N**.

Four meander bars will be constructed in an alternating pattern on left and right banks. Meander bars will protrude into the low-flow channel to encourage meandering of the channel in low-flow conditions. These meander bars will only be constructed in the crossing structure.

To maintain channel shape, the apex of the meander bar height is set to the 10-year flow depth, so the materials change the channel shape through the culvert structures rather than the typical channel section. **Table 4-4** shows the proposed meander bar material gradation. The meander bar will consist of three components: (1) structure head; (2) structure tail; and (3) other considerations (such as small wood material or slash placed in front of structure head rocks to encourage racking and add additional habitat complexity).

All boulders in the meander bar heads will be stable at the 100-year. At least 70 percent of the material in the meander bar tails will be larger than the D100 of the observed streambed material (5.69 inches). Slash will be incorporated in the meander bar head to increase habitat complexity. As noted in **Section 4.3.1**, the meander bar material gradation is the same as the Type II Streambed Material. The D_{100} of this sediment gradation (**Table 4-4**) specifies the boulder size to construct the meander bar head, while the rest of the gradation defines the composition of the sediment in the meander bar tail. Meander bar sediment sizing calculations are found in **Appendix C**.

4.3.2.4 Riffle Features

Riffle features will be built of coarser streambed material to help stabilize the pool-riffle sequences and overall channel grade and to help mitigate the risk of long-term degradation (see **Section 7.2**). They are not intended to be fixed grade control or rigid structures that do not deform over time.

The riffle feature gradation will include some larger material compared to the streambed sediment and will be constructed of rounded material (**Table 4-4)**. The D84 fraction of the riffle features is designed to be stable at the 100-year discharge. Thus, meander bars and riffle features have the same gradation.

Note that the hydraulic conditions of riffle sections assume a local slope that is steeper than the overall average channel grade because the pool sections are assumed to be flat. Riffle features will span the entire SFZ width, thereby providing increased stability along the longitudinal profile of the channel bed.

Sediment sizing calculations for riffle features are found in **Appendix C**.

4.3.2.5 Step-Pools

Based on the Juanita Creek PHD, the two most upstream riffles in the system have a slope ranging from 6.9 percent to 9.8 percent, which is too steep for a typical riffle-pool system. Thus, for the Junita Creek FHD, the three upstream riffles were changed to step-pools. These consist of four log steps separated by pools, with longer resting pools in between each four step-pool sequence. The drop height between steps is less than 0.8 feet, meeting WDFW and Washington Administrative Code requirements for step-pool design.

As seen in **Appendix N, Figure 4-6**, **Figure 4-7**, and **Figure 4-8**, the step-pool design consists of multiple logs and boulders that aid in creating a stable system that also provides components that support salmonid habitat and use through this steeper portion of the restored stream reach. The base level of the step-pool sequence consists of a base of WSDOT Type 2 boulders arranged in rows that create an area for the channel spanning logs to sit on. In addition to this, these base boulders line the toe of the slope within the pools to prevent failure at this location.

Three 30-foot logs are used to create the step, with two at the base and one resting on top of the base logs. The base log on the upstream side of the step includes a rootwad for added structural stability. These logs are 30 feet long in order to be adequately keyed into the bank for stability and to avoid the possibility of flanking. All three of these logs are sloped at an 8H:1V slope, which allows flows to be funneled to one side of the weir and have enough flow over the weir at low flows as to not form a barrier.

The next component of the step-pool system is a series of coir sacks filled with streambed material. These line the upstream face of the step and wrap around to create the banks of the pools. The coir sacks at the upstream face of the weir are placed down to a depth 1 foot below the base boulders. The purpose of the coir sacks is to provide initial stability of the channel and aid in preventing piping through the step and keeping flow above the surface. These will degrade over time and allow the channel to adjust but will provide initial stability when the first high flow events flow through the system. A layer of streambed material will be placed on top of the coir sacks upstream of the weir logs to provide a surface layer of material that can participate in sediment transport and provide fish with a more natural substrate. Coir sacks along the sides of the banks will be left uncovered, as these can support a steeper side slope of 1.5H:1V, which is necessary in order to have pool widths that are not overly widened.

Two logs are used as ballast weight to aid in the stability of the step-pool system but also serve functional purposes in terms of the channel geometry and habitat. Both the cover log and ballast logs (14-foot and 12-foot minimum lengths, respectively) make up the banks of the weir, which provides a more stable bank than streambed material or on-site soil and helps funnel flow to the low point of the 8H:1V sloping 30-foot top weir log. On top of each log rests a WSDOT Type 4 boulder with a minimum diameter of 36 inches, which acts as ballast weight on both logs and the underlying three weir logs. In addition to these benefits, the cover log includes a rootwad that at low flows will provide overhead cover and shade for fish that are migrating through the system, especially juvenile salmonids. At higher flows, the rootwad will interact with more flow and provide slower velocity areas for fish to rest. The ends of the three weir logs, cover logs, ballast logs, and the Type 4 boulders will be buried beyond the top of bank lines.

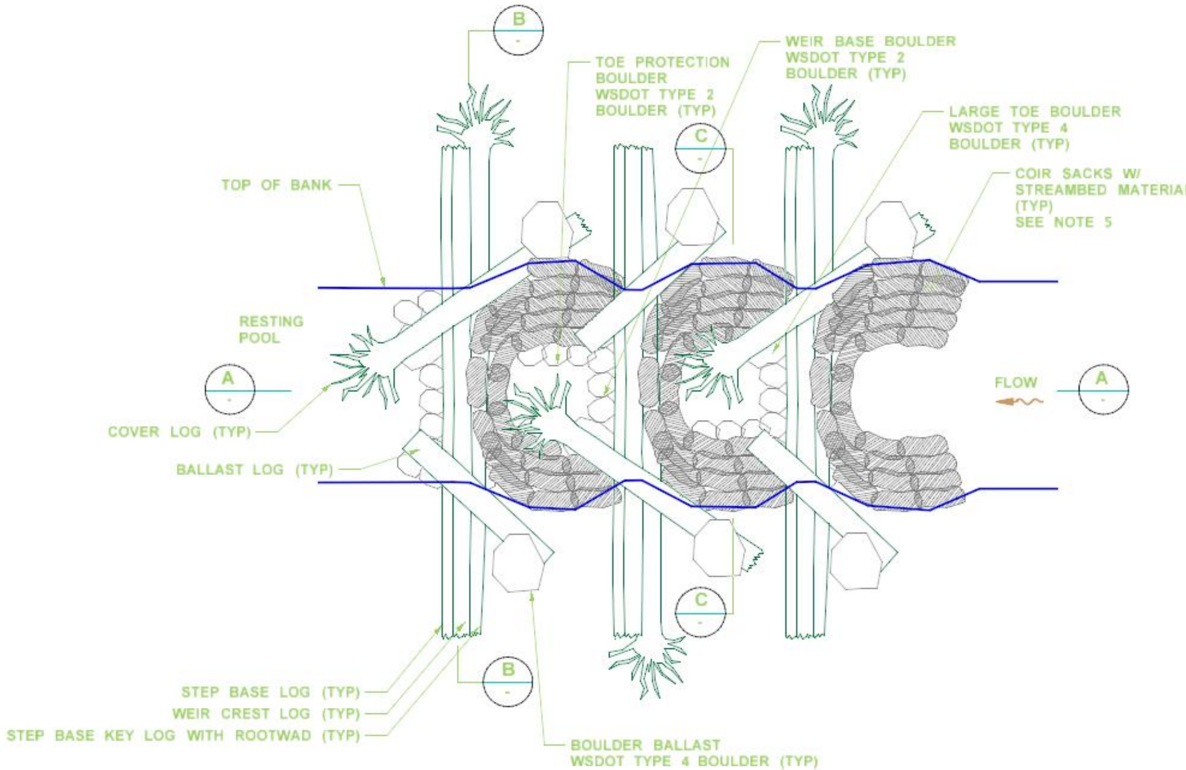


Figure 4-6: Typical Step-Pool Sequence Plan

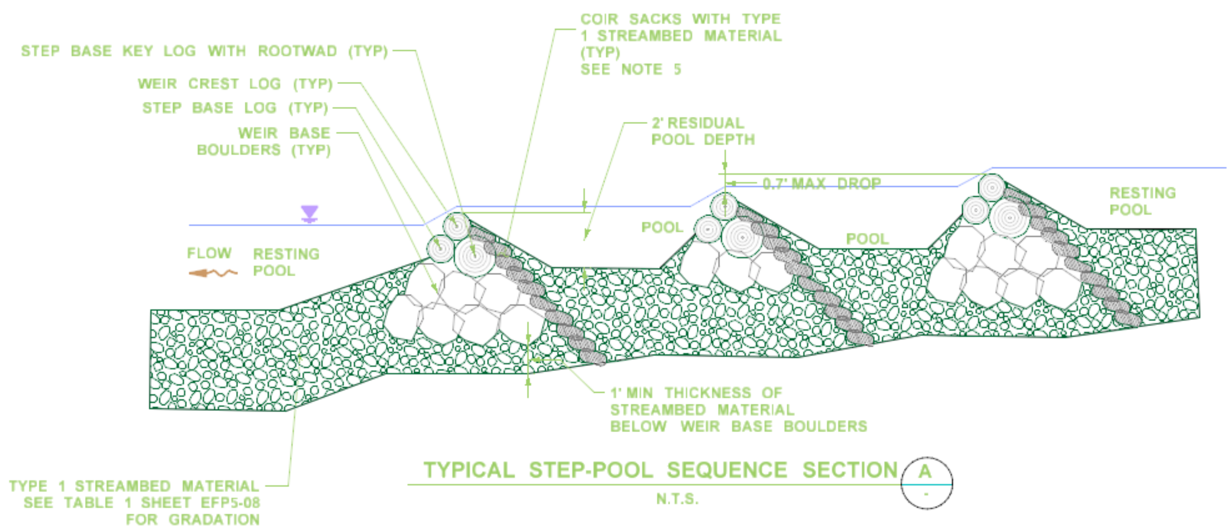


Figure 4-7: Typical Step-Pool Section – Profile

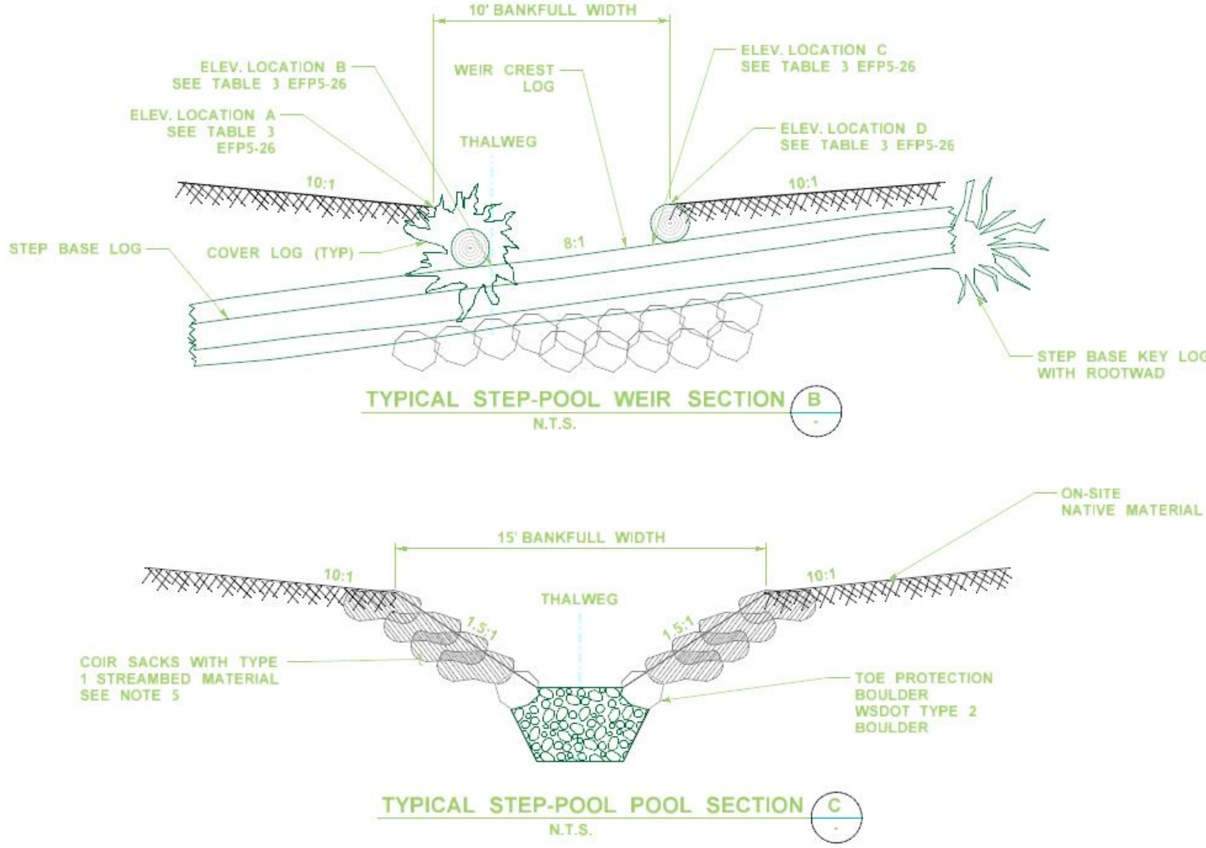


Figure 4-8: Typical Step-Pool Sections – Weir and Pool Sections

4.3.2.6 Deformable Grade Control

Deformable grade control will be included at the downstream ends of the channel improvements to help mitigate the risk of long-term degradation (**Section 7.2**). They are not intended to be fixed-grade control or rigid structures that do not deform over time. Within the specified gradation, the deformable grade control structure will include material larger than streambed sediment; this will provide additional protection against channel degradation. The deformable grade control structure will extend beyond the top of bank and will include woody debris that will be slightly exposed above finished grade. Material sizing calculations are provided in **Appendix C**. Deformable grade control is not recommended at the upstream end of the channel improvements because the log weirs of the step-pool system will act as grade control.

4.3.2.7 Stability Analysis

Stability analyses for Type I (pool) sediment, Type II (riffle and bank) sediment, and meander bar material was performed using the Modified Critical Shear Stress Approach. See **Table 4-4** for a summary of the different streambed sediment gradations. The Type I pool sediment is expected to be mobile at the 100-year design discharge. The Type II riffle and bank sediment and meander bar material has D84 size designed to be stable at the 100-year design discharge. These calculations can be found in **Appendix C**.

Stability analyses for LWM key pieces were completed for the 13 log structures that are formed by the arrangement of key pieces. Each log structure has a unique layout that includes the burial depth, centerline offset, horizontal angle, vertical dip, and placement relative to the channel geometry. Due to the unique layouts, the stability of each log structure was calculated separately using the U.S. Forest Service's *Computational Design Tool for Evaluation the Stability of Large Wood Structures* (Rafferty 2016). The analysis was completed to determine the design and anchoring requirements for each structure to withstand the hydraulic forces of the 100-year design discharge with a 1.5 minimum factor of safety.

The SRH-2D proposed conditions model was used to extract hydraulic conditions at each log structure. A cross section was placed at the approximate midpoint of each log structure, and model outputs were used to find the maximum water depth, average velocity, and wetted area of the channel. In addition to the hydraulic conditions, the geotechnical conditions that were used as inputs into the stability calculations include the streambed substrate of coarse gravel and bank soil of fine, dense sand.

Stability can be achieved by self-ballasting, ballasting by other logs, and partially burying LWM, and no anchors are required. A summary of log characteristics used in LWM stability calculations and resulting factors of safety and ballast requirements is shown in **Table 4-7.**

In order to ensure that the step-pools that are included in the Juanita Creek main channel and side channel would be stable enough at the 100-year discharge, stability calculations were also performed for each side channel step and a single calculation was done for the main channel step-pools. This single calculation used the typical weir section, as shown in **Figure 4-8** and **Appendix D**, and the most extreme hydraulics from all the weir locations taken from the SRH-2D model were used. This includes using the greatest depth and the highest velocities within the step-pool reach. It is worth noting that many of the cross-sections that these step logs are installed at have more soil cover than the typical weir section provides. Because of this cover and using the most extreme hydraulic results at weir locations for the calculation, this stability analysis is expected to be conservative, and most main channel steps may be more stable than indicated by the stability calculations. A summary of logs, required ballast, applied ballast, and factors of safety for the various step-pools, is provided in **Table 4-8.**

Mobile woody material (MWM) is designed to be mobilized at approximately the 10-year flow and is placed at various elevations and locations relative to LWM and bedforms as to not all mobilize simultaneously.

Materials for LWM and LWM anchoring will follow the guidance in Chapter 10 of the WSDOT *Hydraulics Manual* (WSDOT 2022a) and any environmental commitments noted in the contract. Native conifers will be used for LWM.

Table 4-7: Summary of log ballast requirements and factors of safety

Log Structure	Log Number	Diameter (in.)	Length (ft)	Vertical Factor of Safety	Anchor Requirements	
					Minimum Required Ballast (lbf)	Applied Ballast
A	5	20	30	12.69	–	18,741 lbs from log 6 resting on top of log 5
	6	20	30	88.02	–	–
B	7	20	30	4.13	–	3,294 lbs from log 8 resting on top of log 7
	8	20	40	51.49	–	–
C	9	20	30	12,966.00	–	–
	10	20	30	29,511.00	–	12,599 lbs from log 9 and 7,734 lbs from log 11, both resting on top of log 10
	11	20	30	12.32	–	–
D	12	20	40	3,393.00	–	–
	13	20	30	4.46	–	3,393 lbs from log 12 resting on top of log 13
E	14	20	30	4.09	–	3,198 lbs from log 15 resting on top of log 14
	15	20	40	26.07	–	–
F	16	20	30	3.41	–	–
	17	20	30	2.64	–	1,490.00 lbs from log 16 resting on top of log 16
G	18	20	30	2.43	–	–
	19	20	30	2.16	–	340 lbs from log 18 resting on top of log 18
	20	20	30	2.30	–	340 lbs from log 18 resting on top of log 18
	21	20	30	2.33	–	340 lbs from log 18 resting on top of log 18
H	54	20	40	219.77	–	–
I	59	20	40	36,004.30	–	–
J	65	20	40	31.32	–	–
K	66	20	30	16.28	–	1,250 lbs from log 67 resting on top of log 66.
	67	20	30	25.09	–	–
	68	20	30	8.66	–	1,250 lbs from log 67 resting on top of log 68.
M	71	20	30	26,204.86	–	–
	72	20	30	10.96	–	2,658 lbs from log 71 resting on top of log 72.
L	75	20	30	14.38	–	
	76	20	30	3.31	–	2,381 lbs from log 75 resting on top of log 76.

Table 4-8: Main channel and side channel step-pool log ballast requirements and factors of safety

Step-Pool Structure	Log Type	Diameter (in.)	Length (ft)	Vertical Factor of Safety	Anchor Requirements	
					Minimum Required Ballast (lbf)	Applied Ballast
Typical main channel step-pool	Step base log	12	30	5.36	–	1,903 lbs from the weir top log
	Step base key log with rootwad	20	30	3.37	–	1,903 lbs from the weir top log
	Weir crest log	12	30	3.73	–	731 lbs from the cover log and 1,230 lbs from the ballast log resting on top of the weir crest log
	Cover log	18	14	1.79	796	1,588 lbs from one 36” WSDOT Type 4 boulder
	Ballast log	18	12	2.43	510	1,740 lbs from one 36” WSDOT Type 4 boulder
Side channel step-pool #79	Right	18	10	1.84	–	1,259 lbs from one 30” WSDOT Type 2 boulder
	Left	18	10	2.26	560	1,402 lbs from the right log
Side channel step-pool #80	Right	18	10	1.53	–	–
	Left	18	10	1.53	138	240 lbs from the right log
Side channel step-pool #81	Right	18	10	2.16	–	–
	Left	18	10	2.32	158	1,064 lbs from the right log
Side channel step-pool #82	Right	18	10	2.16	–	–
	Left	18	10	2.32	158	1,064 lbs from the right log
Side channel step-pool #83	Right	18	10	1.80	–	220 lbs from the left log
	Left	18	10	1.80	–	114 lbs from the right log

4.3.2.8 Additional Habitat Features

In an effort to maximize the available salmon habitat in Juanita Creek, the upstream reach of the Juanita Creek fish passage design has been updated to use the existing Juanita Creek channel as a side channel in the ultimate configuration. The inclusion of the side channel and the proposed grading between the new Juanita Creek channel and the existing channel will promote wetland connectivity and provide increased habitat enhancement, additional rearing habitat, and high flow refuge. The downstream connection of this side channel is a short step-pool reach into the main stem of Juanita Creek to ensure fish do not get stranded in the existing channel during periods of low flow. This side channel step-pool reach will be designed in a manner to avoid the potential for subsurface flow and any juvenile salmonids getting trapped in that subsurface flow. The hydraulic analysis included the implementation of an engineered log jam at the intersection where the proposed new channel diverges from the existing channel to help direct flow at the 2-year event and higher into this new side channel. Additional LWM has been included in the existing channel for added habitat diversity and cover.

In addition to the streambed materials that make up the main portion of the proposed channel, two nourishment piles will be placed on the edge of the bankfull resting pools upstream of the structure, each with a volume of 10 cubic yards. They are located at station 7+10.00 and station 8+35.00. These nourishment piles were designed with the observed optimal sediment size for the documented species in Juanita Creek (coho salmon (O. kisutch and cutthroat trout (O. clarkia)). This prioritized a gradation between 6mm to 102mm (Saldi, et. al., 2004). A mix of 50% WSDOT standard “streambed sediment” and 50% WSDOT standard “streambed cobbles 6” accomplishes this gradation (see **Appendix C**). Over time as flow encounters these piles, spawning-sized gravels will be washed into the main channel and will aid in replenishing any spawning-sized gravels that may not be present or may be transported away from the project reach. Note that the rate of sediment supply from upstream does not drive the design of nourishment piles; rather, it is the gradation of the nourishment piles relative to the gradation of the incoming supply (as estimated by the gradation of sample of the existing material). The gradation of the nourishment material was designed such that nearly all of that material will be within the size range that the salmonids present in the stream prefer to use when spawning. The intent is that when entrained, the nourishment material will increase the percentage of the material in the stream that is within that preferred spawning size range. As previously mentioned, the proposed channel must be significantly coarser than the existing material to provide adequate channel stability, and the use of these nourishment piles is aimed at providing additional finer gravels that will over time become useful for salmonid spawning.

4.3.3 Planting Restoration

This section describes the planting restoration developed for Juanita Creek at I-405 MP 21.94. The development of the planting plan was guided by a close review of Juanita Creek—the existing vegetation, hydrology, climatic conditions, and ecological functions in its current condition. The planting plan focuses on the restoration of ecological processes and functions in the project area by placing native, locally occurring plants in the most species-appropriate microhabitats of the project site. This will allow them to thrive and provide key riparian vegetation functions such as erosion protection, bank stabilization, nutrient cycling and production, habitat creation, water retention, and many others. A proposed plan of the planting restoration for Juanita Creek can be seen in **Figure 4-9**.

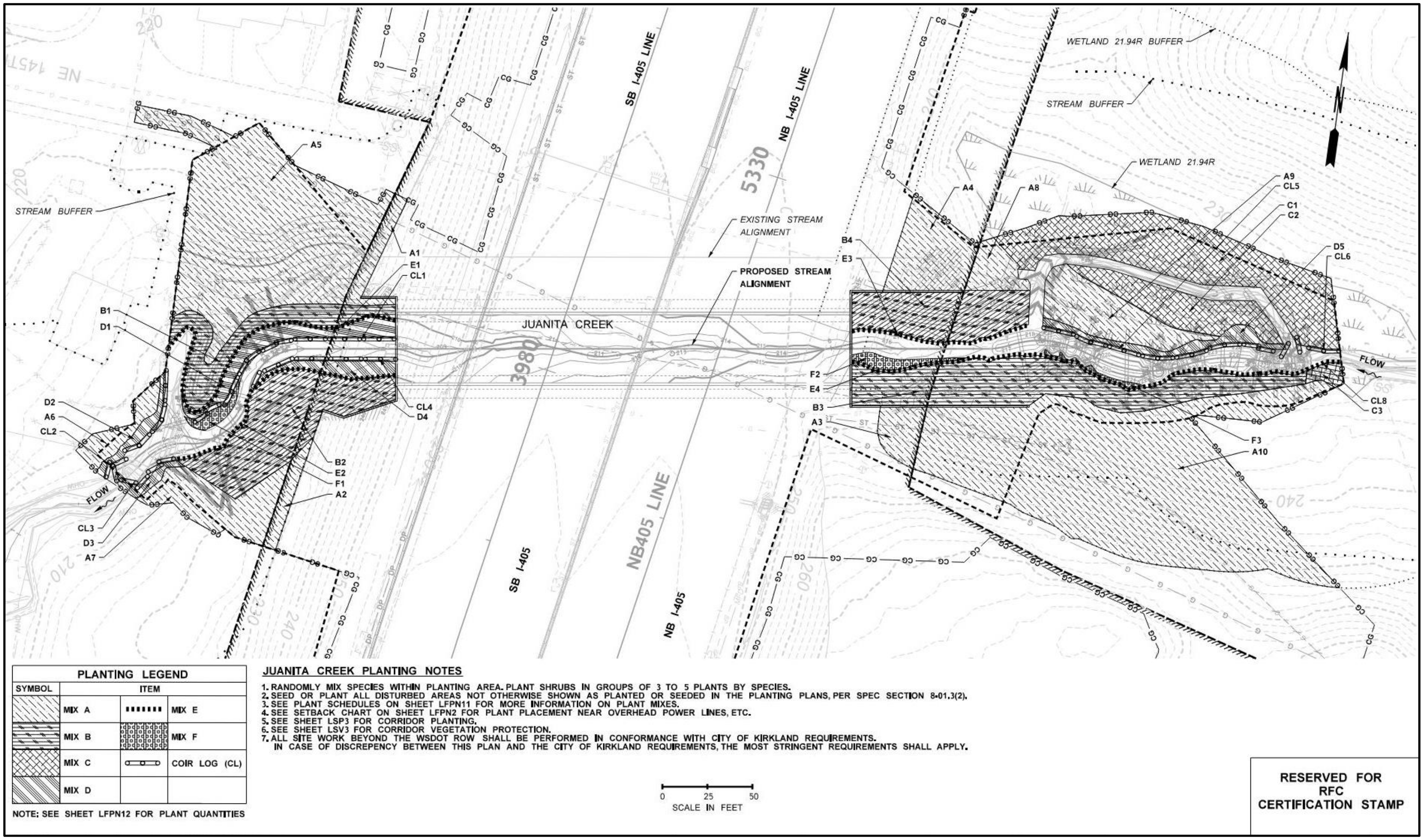


Figure 4-9: Proposed plan of planting restoration

4.3.3.1 Riparian Zones and Plant Selection

Riparian planting zones at the project site are defined as the lands adjacent to streams whose soils and vegetation are influenced by channelized water. They are the transition areas between aquatic and upland habitats with elements of both ecosystems. With this context, plant species selection and soil preparation were closely tied to the plant's role and function along the riparian gradient. The plant species that constitute the proposed planting grow naturally both at the project site and in its immediate vicinity. They were grouped into two zones based on water needs and degree of inundation, which are reflected by projected water surface elevations including the ordinary high-water mark (OHWM), 2-year, 25-year, and 100-year flood lines. For Juanita Creek, the proposed OHWM coincides with the 2-year flood line. This information has been thoroughly studied and is well documented in the Stream Habitat Restoration Guidelines (Cramer 2012) for riparian habitat protection and restoration. The proposed planting zones loosely correspond to upper and lower riparian areas. As described above, the delineation of planting zones was driven by the expected hydraulic, environmental, and substrate conditions along Juanita Creek.

4.3.3.2 Riparian Tree/Shrub Planting

The upper riparian zone consists of upland riparian trees and shrubs, selected to restore the site's native riparian habitat and crowd out invasive species. For compliance with WSDOT standards, species selection was based on the WSDOT Appendix L Approved Sensitive Area Restoration Plant List. Installation for this zone begins above the 100-year flood line. The plant mix consists of native species, both trees and shrubs, arranged in natural patterns to emulate surrounding riparian vegetation and corridor character. Heights and species of vegetation are also taken into consideration based on proximity to utilities, safety concerns, and visibility as it relates to the roadway and stream.

4.3.3.3 Stream Bank Planting

For sloped banks, flatter than 3H:1V, the lower riparian zone consists of emergent stream bank planting. Located between the 2-year and the 100-year flood lines, this zone is closest to the stream's base flow edge. The plant species proposed for this zone are emergent plants that are well adapted to growing in permanently saturated soils. Along with emergent wetland shrubs, a diverse mix of grasses, sedges, and rushes are proposed to help infill between these plants and occupy smaller habitat niches. Emergent plant benefits include creation of important habitat and food sources for wildlife, filtering and trapping soil, and absorption of nutrients from runoff. Ultimately this planting zone will provide necessary roughness at the water's edge, without creating an inaccessible dense wall of planting at the foot of the bank.

4.3.3.4 Wetland Planting

For wetlands and flatter floodplain areas, the lower riparian zone consists of native planting that is appropriate for lower water velocities and longer periods of inundation. At Juanita Creek, wetland planting is proposed upstream of the I-405 crossing, along the existing Juanita Creek channel and Wetland 21.94R. Wetland planting typically begins at the edge of the streambed sediment and terminates at the 100-year flood line. Species selection is based on existing native plant material found on site, as well as the addition of woody trees and shrubs to support a diverse wetland plant community and provide shade along the channel.

4.3.3.5 Brush Mattress Zone Planting

For slopes steeper than 3H:1V, the lower riparian zone consists of bioengineering methods including brush mattressing in conjunction with live staking and live fascines. At Juanita Creek, brush mattressing is proposed both upstream and downstream of the I-405 crossing where slopes are 2H:1V. The zone begins at the 2-year flood line, where the primary live fascine occurs, extending to the top of the bank slope. The willow and ninebark species proposed can withstand periods of inundation but require oxygenated soils for at least part of the growing season. These bank stabilization elements will provide important ecosystem benefits. They will also contribute to improved bank stability, enhance physical channel features, provide organic debris recruitment, and serve as a major source of nutrients to support in-stream fauna and flora. Additionally, brush mattressing develops dense willow thickets and has the potential to provide increased habitat complexity.

4.3.3.6 Supplemental Bioengineering

For slopes flatter than 3H:1V, along the 2-year flood line, supplemental bioengineering is proposed for stream bank erosion control. Bioengineering methods include live fascines and coir logs. Live fascine locations include channel openings that require additional erosion control at the 2-year flood line. For the remainder of the channel, coir logs are proposed in tandem with emergent and wetland planting for channel edge reinforcement and plant establishment.

4.3.3.7 Revegetation and Erosion Prevention in Bank Treatments

Establishment of the integrated plantings is critically important for the proper performance of each of the bank treatments. Detailed pre-installation planning and site preparation will be conducted to maximize the potential for survival of the plant materials installed and to enhance their ability to grow quickly. The key restoration tasks to construct a good quality, well-armored vegetated bank will be:

- Planting of vegetation after grading work and soil preparation is complete.
- Installation of bioengineering for stream bank erosion control and overall bank stability.
- Installation of irrigation equipment and emitters before the plants to ensure they receive adequate water immediately after installation and during the initial establishment period.
- Planting during the rainy season to increase survival rates because newly installed riparian vegetation needs almost constant water for the first year in the ground.
- Making sure that soil compaction does not exceed 80 percent relative density for a depth of 24 inches to promote good aeration, root growth, water-holding capacity, and natural composting processes.

4.3.3.8 Irrigation Design

The temporary irrigation system used for establishment will be located outside of the OHWM to prevent the potential effects of high-water events and flood flows. The temporary irrigation zones are split into two main areas based on planting types and associated water requirements: an upland zone and a wetland zone. The upland irrigation zone will serve more drought-tolerant, non-aquatic plantings at a higher elevation. The wetland zone will serve plants that require periodic or permanently saturated soils, bordering the OHWM. The irrigation basis of design includes two points of connection occurring east and west of the I-405 crossing in the vicinity of Juanita Creek. Watering frequency will ultimately depend on soil texture, weather, and planting depth. During the five-year plant establishment period, plants should generally be watered more frequently during first growing season or until plants develop root systems capable of reaching a depth where the soils are permanently moist.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed I-405 Juanita Creek crossing was performed using the U.S. Bureau of Reclamation's Sedimentation and River Hydraulics (SRH-2D) Version 3.6.5 computer program, a two-dimensional hydraulic and sediment transport numerical model (USBR 2024). Pre- and post-processing for this model was completed using Surface-Water Modeling Systems (SMS) Version 13.3.10 (Aquaveo 2024).

Two scenarios were analyzed for determining stream characteristics for Juanita Creek with the SRH-2D models: (1) existing conditions with the 48-inch CMP and (2) future conditions with the proposed 30-feet clear span structure.

5.1 Model Development

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

5.1.1 Topographic and Bathymetric Data

The existing conditions SRH-2D surface data were established from a combination of different field survey techniques. The first survey captured the entire Project vicinity and was obtained from an aerial LiDAR survey conducted in fall of 2021. More detailed supplemental field surveys were performed in fall of 2020 and spring of 2024, which more accurately captured open channel cross sections, culvert locations, and invert elevations. The InRoads digital terrain model (DTM) surface used as the basis of the existing conditions model is a merged version of these surveys. All survey and LiDAR data are referenced against the NAVD 88 vertical datum.

Because the combined 2020 and 2024 field survey data did not provide coverage for the northeastern corner of the model domain that includes upland residential areas and part of 20th Avenue, 2021 King County West LiDAR data were used to fill this data gap (WGS 2023).

The proposed conditions SRH-2D terrain data consist of the MicroStation InRoads DTM created from typical riffle and pool cross sections described in **Section 4.1.1**. This surface is supplemented outside of the stream channel grading limits by the existing merged DTM that incorporates the 2024 survey. These surfaces were merged to create a single terrain for use in the SRH-2D proposed conditions model.

The existing and proposed DTM surfaces and 2021 King County LiDAR data were imported into SMS for mesh generation of existing and proposed conditions.

5.1.2 Model Extent and Computational Mesh

The existing and proposed conditions models have the same model extents with a total area of about 43 acres. The upstream limit of the computational mesh, on the northeast end, is approximately 1,300 feet upstream of the I-405 crossing along Juanita Creek. The downstream boundary of the mesh is approximately 1,370 feet downstream of the I-405 crossing.

The existing conditions mesh includes 103,826 elements (shown on **Figure 5-1**), and the proposed conditions mesh has 113,524 elements (shown on **Figure 5-2**: and **Figure 5-3**). Since the proposed terrain includes detailed grading of the riffle-pool and step-pool systems, cell sizes in the SRH-2D model were kept relatively small in the main channel to capture this detail. Cell sizes and length-to-width ratios vary and are, on average, approximately 2 feet long by 1 foot wide. There are no poor-quality cell elements in the main channel; the only poor-quality cell elements – below the red line in the Angle Representation Region (ARR) plots – are triangular mesh elements in the overbanks near sharp turns in the channel.

Figure 5-1: Existing conditions ground surface elevation mesh, model extents, boundary conditions

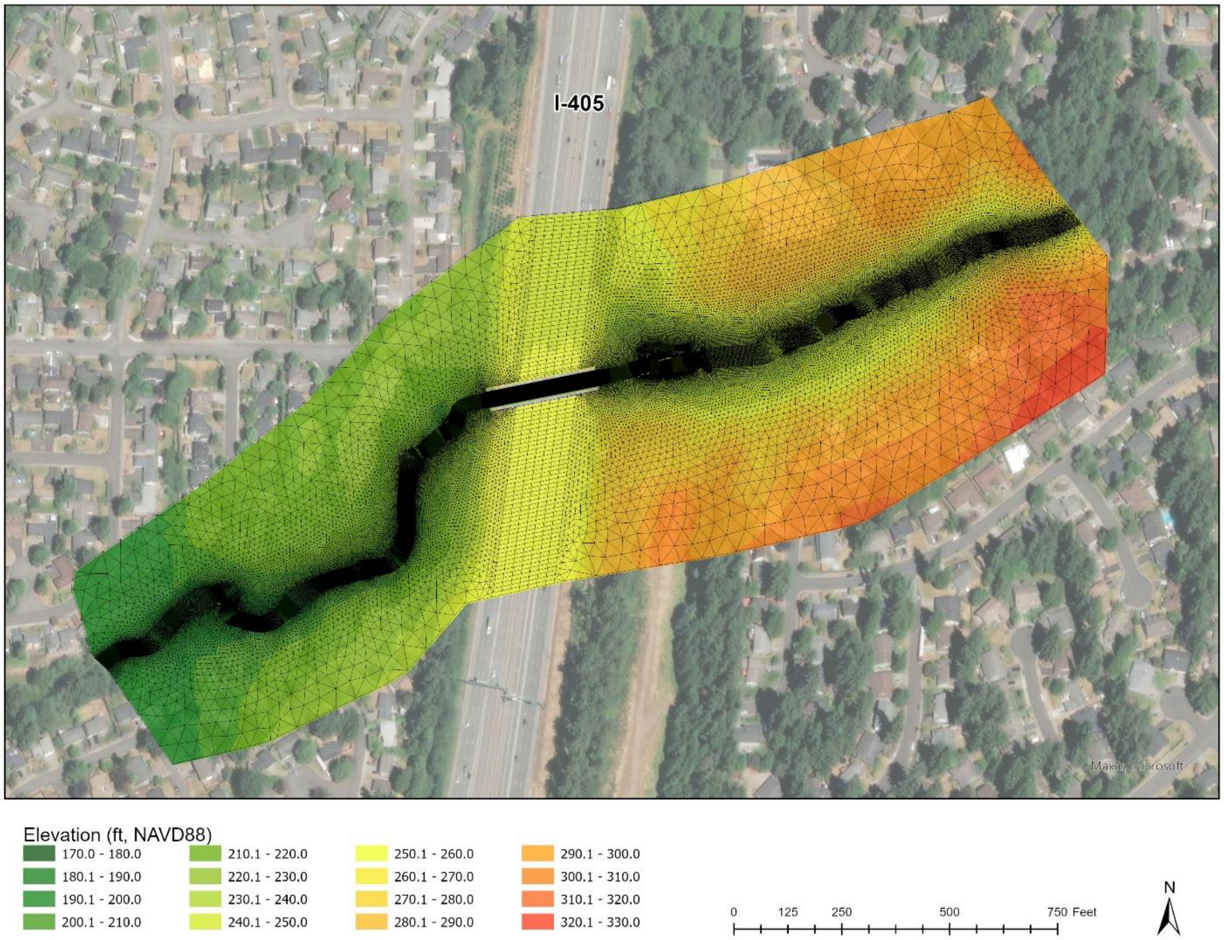


Figure 5-2: Proposed conditions ground surface elevation mesh, model extents, boundary conditions

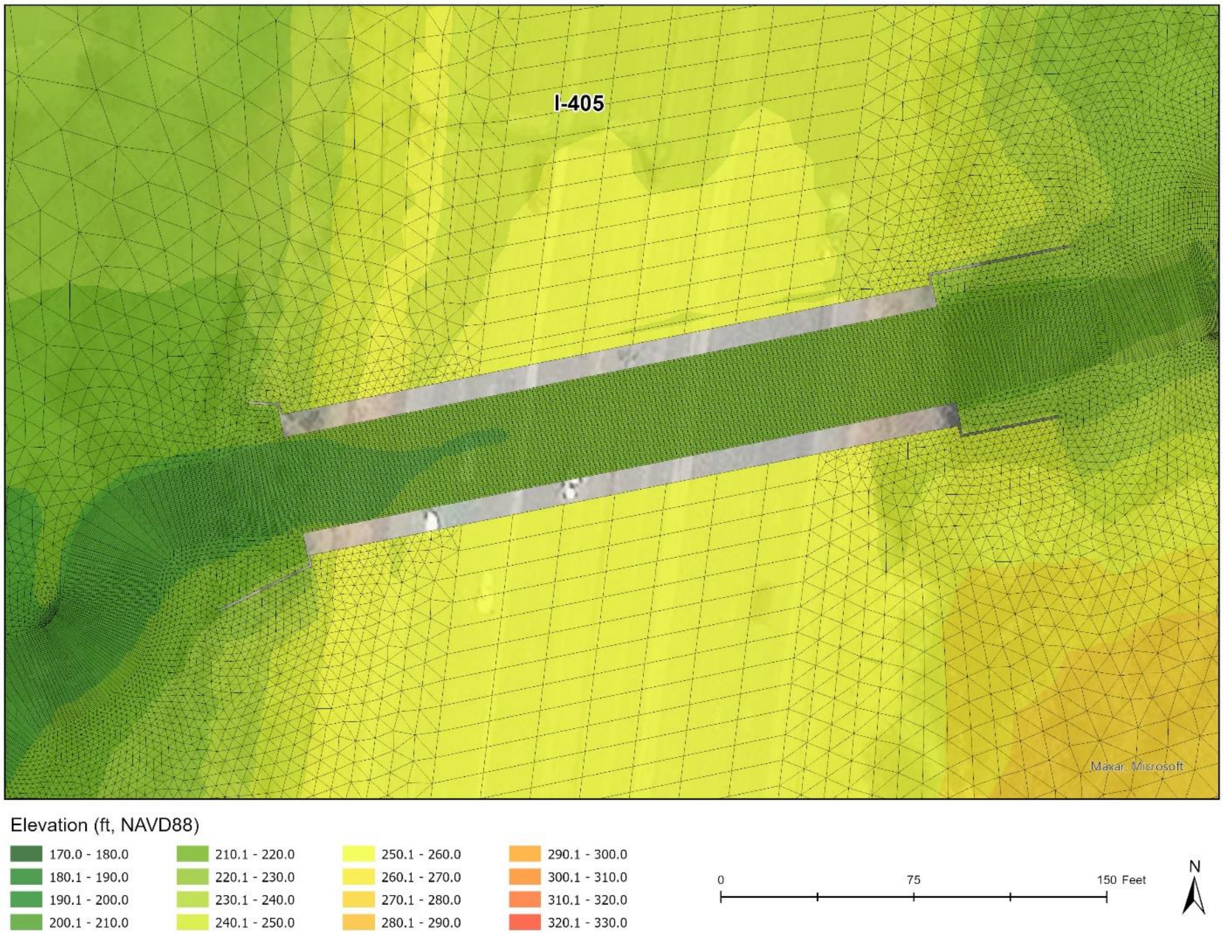


Figure 5-3: Proposed conditions ground surface elevation near I-405 crossing

5.1.3 Materials/Roughness

Manning's n values were determined by site observations, aerial topography, GIS land cover data, and standard empirical values. Calculations for Manning's roughness values are found in **Appendix E**, following guidance from Arcement and Schneider (1984) and Yochum, et al. (2014). **Table 5-1** summarizes the values used in the existing and proposed model.

The existing channel was assigned a Manning's roughness value of 0.075 due to the presence of thick vegetation, such as Himalayan blackberry, and MWM throughout the reach. This falls within the high end of the range provided for streams with regular sections and some weeds and medium brush on banks, as indicated in the WSDOT *Hydraulics Manual* (WSDOT 2022a) reference for Manning's roughness coefficients.

The proposed channel inside and outside of the crossing will have a larger sediment size and MWM but less vegetation than the existing channel and was assigned a Manning's roughness value of 0.086. LWM was assigned a Manning's roughness value of 0.098. In order to estimate a Manning’s n value for the step-pools in the Juanita Creek side channel, a stream with a similar slope was identified in Yochum (2014).

Figure 5-4 and **Figure 5-5** show the spatial distribution of Manning’s n roughness values for existing and proposed condition models, respectively.

Table 5-1: Manning's n hydraulic roughness coefficient values used in the SRH-2D models

Existing		Proposed	
Material	**Manning's n**	**Material**	**Manning's n**
Existing Channel	0.075	Existing Channel	0.075
Overbank	0.150	Overbank	0.150
Roadway	0.012	Roadway	0.012
Residential	0.060	Residential	0.060
Existing Culverts	0.024	Proposed Channel with MWM	0.086
		LWM	0.098
		Engineered Log Jam	0.121
		Side Channel Step-Pool	0.290
		Proposed Planting (Riparian Tree/Shrub)	0.150
		Proposed Planting (Emergent Mix)	0.087
		Proposed Planting (Wetland Mix)	0.087

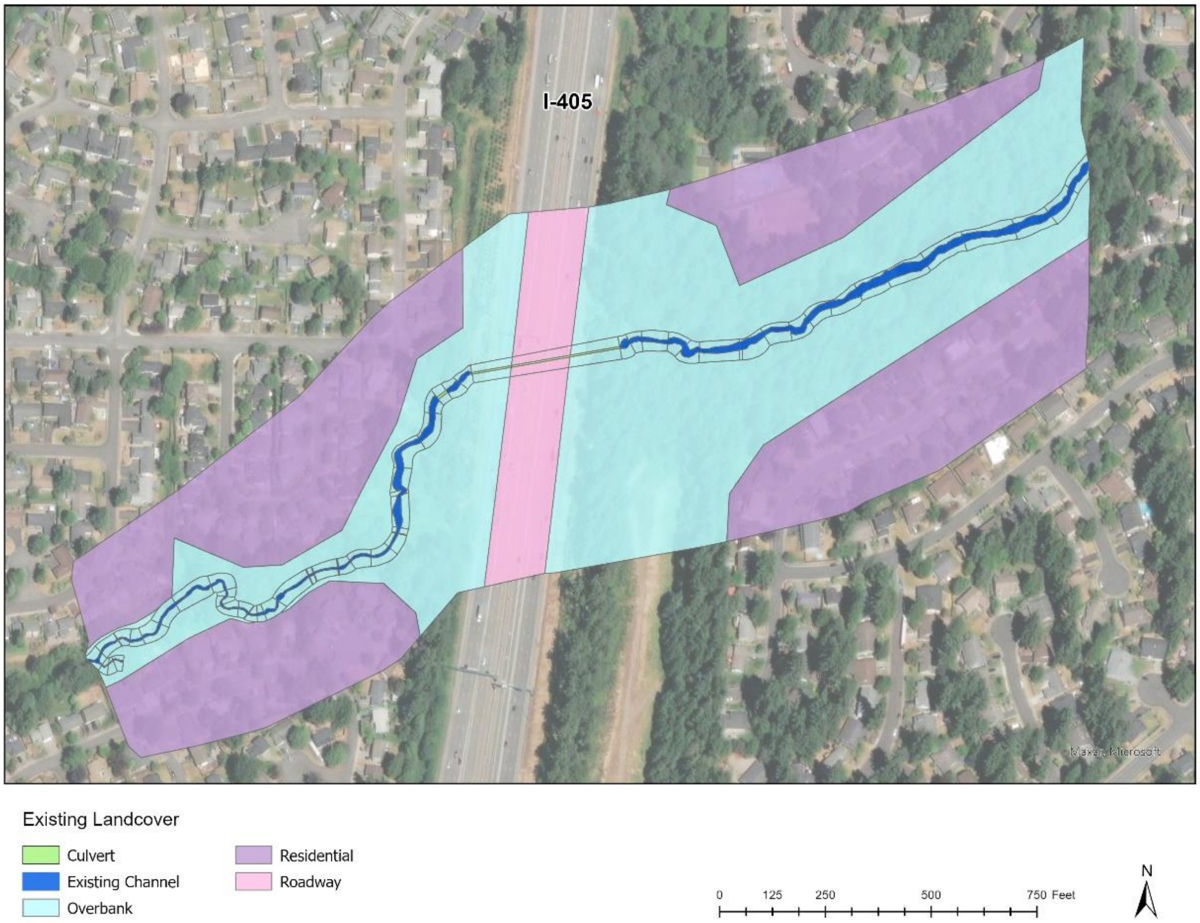


Figure 5-4: Spatial distribution of existing conditions roughness regions in SRH-2D model

Figure 5-5: Spatial distribution of proposed conditions roughness regions in SRH-2D model

5.1.4 Boundary Conditions

The existing conditions hydraulic model uses the boundary conditions as shown in **Figure 5-6**. An inflow boundary condition is placed 1,300 feet upstream of the crossing and flow was simulated as subcritical distributed via conveyance. An additional inflow immediately downstream of the existing I-405 crossing was added on the right bank as an inflow boundary condition for the model. The hydraulic model was run with one outflow boundary condition, downstream of the access road pipe crossing of Juanita Creek. A normal depth exit boundary was assigned using the SMS built-in normal depth calculator to efficiently calculate the expected WSE given the stream's cross-section area and gradient. The proposed hydraulic model uses the same boundary conditions, excluding the HY-8 boundaries, as shown in **Figure 5-7**.

Each of the three existing structures along the surveyed reach of Juanita Creek were modelled within SMS using FHWA HY-8 for one-dimensional culvert hydraulics. Inputs for each structure follow the characteristics and geometry obtained in the stream survey.

Existing conditions model development included implementation of HY-8 internal boundary conditions to represent the existing 48-inch CMP at the I-405 crossing, as shown in **Figure 5-8**.

There are two culverts (36-inch and 24-inch) 70 feet downstream of the I-405 culvert outlet, as shown in **Figure 5-9** and **Figure 5-10,** respectively. The existing culverts were modelled as conventional thin-edge projecting end treatments. The proposed conditions model uses the boundary conditions without the existing culvert boundaries, as shown in **Figure 5-7.**

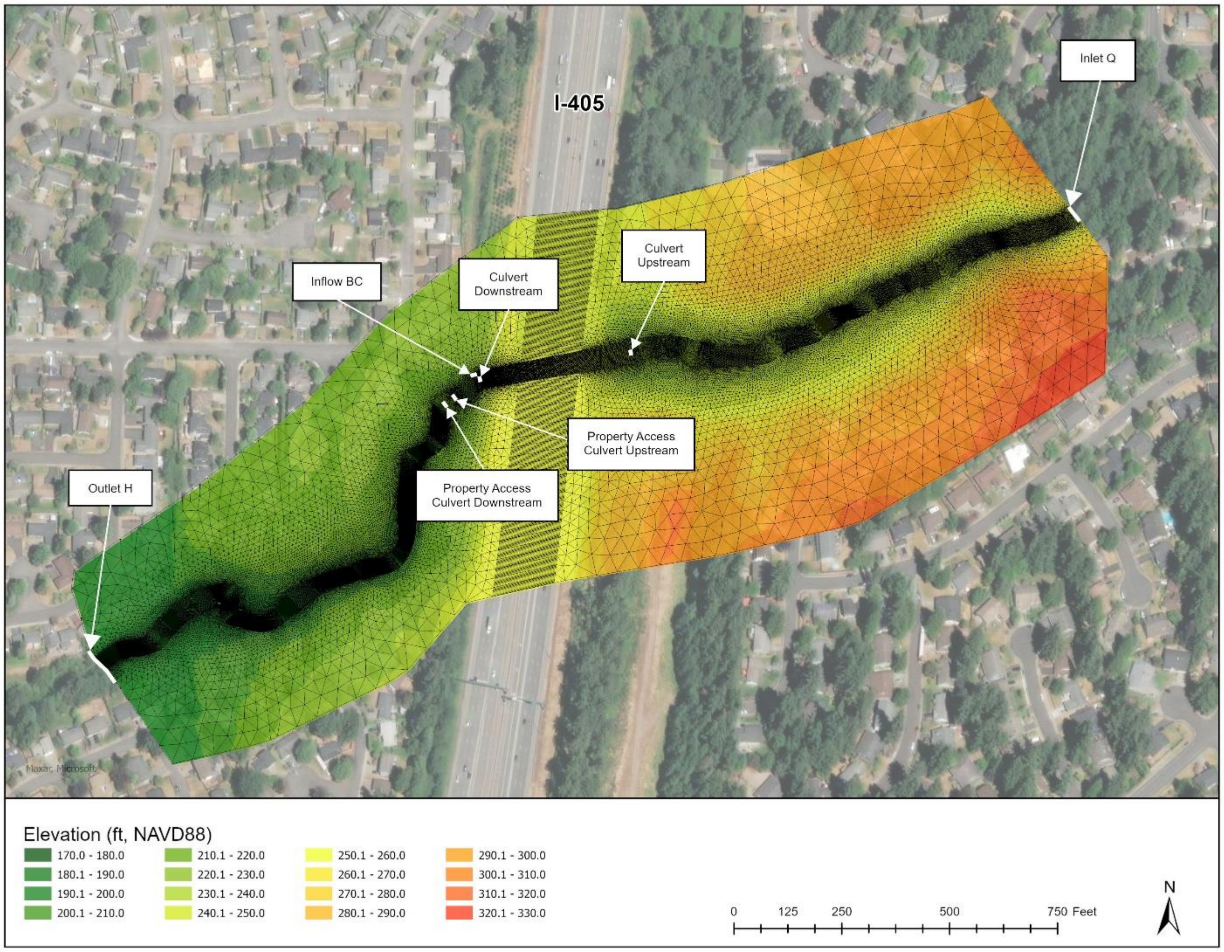


Figure 5-6: Existing conditions boundary conditions

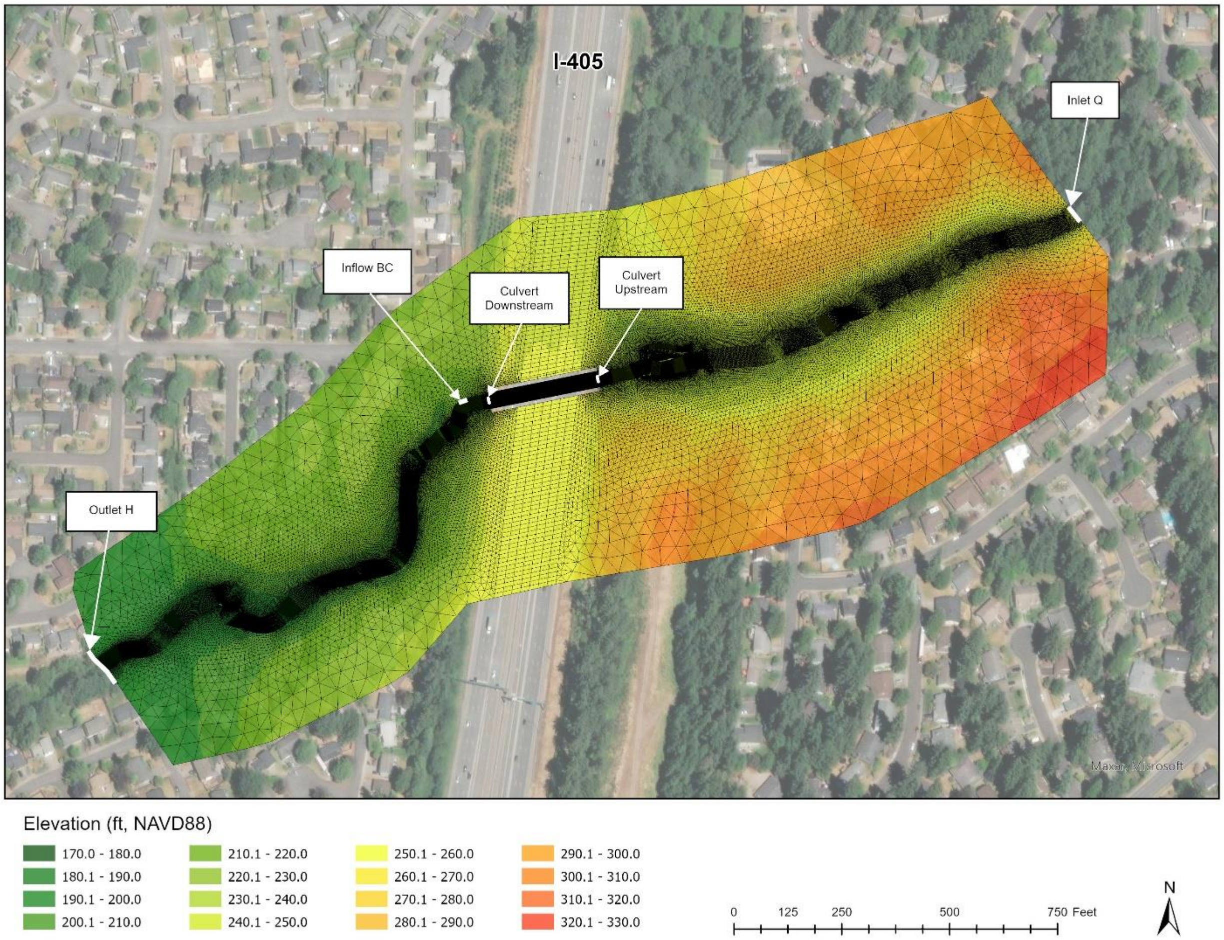
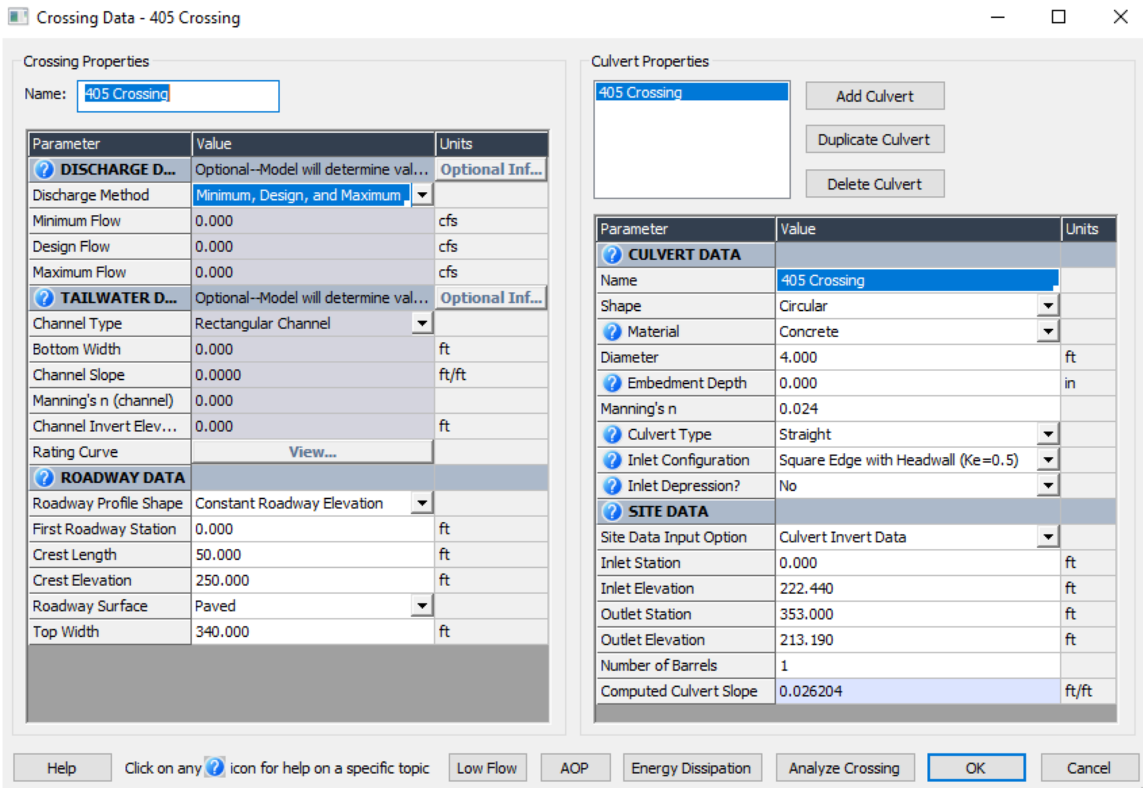


Figure 5-7: Proposed conditions boundary conditions



Crossing Data - 405 Crossing

Crossing Properties

Name: 405 Crossing

Parameter	Value	Units
DISCHARGE D...	Optional--Model will determine val...	Optional Inf...
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	0.000	cfs
Design Flow	0.000	cfs
Maximum Flow	0.000	cfs
TAILWATER D...	Optional--Model will determine val...	Optional Inf...
Channel Type	Rectangular Channel	
Bottom Width	0.000	ft
Channel Slope	0.0000	ft/ft
Manning's n (channel)	0.000	
Channel Invert Elev...	0.000	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	50.000	ft
Crest Elevation	250.000	ft
Roadway Surface	Paved	
Top Width	340.000	ft

Culvert Properties

405 Crossing

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	405 Crossing	
Shape	Circular	
Material	Concrete	
Diameter	4.000	ft
Embedment Depth	0.000	in
Manning's n	0.024	
Culvert Type	Straight	
Inlet Configuration	Square Edge with Headwall (Ke=0.5)	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	222.440	ft
Outlet Station	353.000	ft
Outlet Elevation	213.190	ft
Number of Barrels	1	
Computed Culvert Slope	0.026204	ft/ft

Help | Click on any icon for help on a specific topic | Low Flow | AOP | Energy Dissipation | Analyze Crossing | OK | Cancel

Figure 5-8: HY-8 I-405 crossing 48-inch culvert parameters

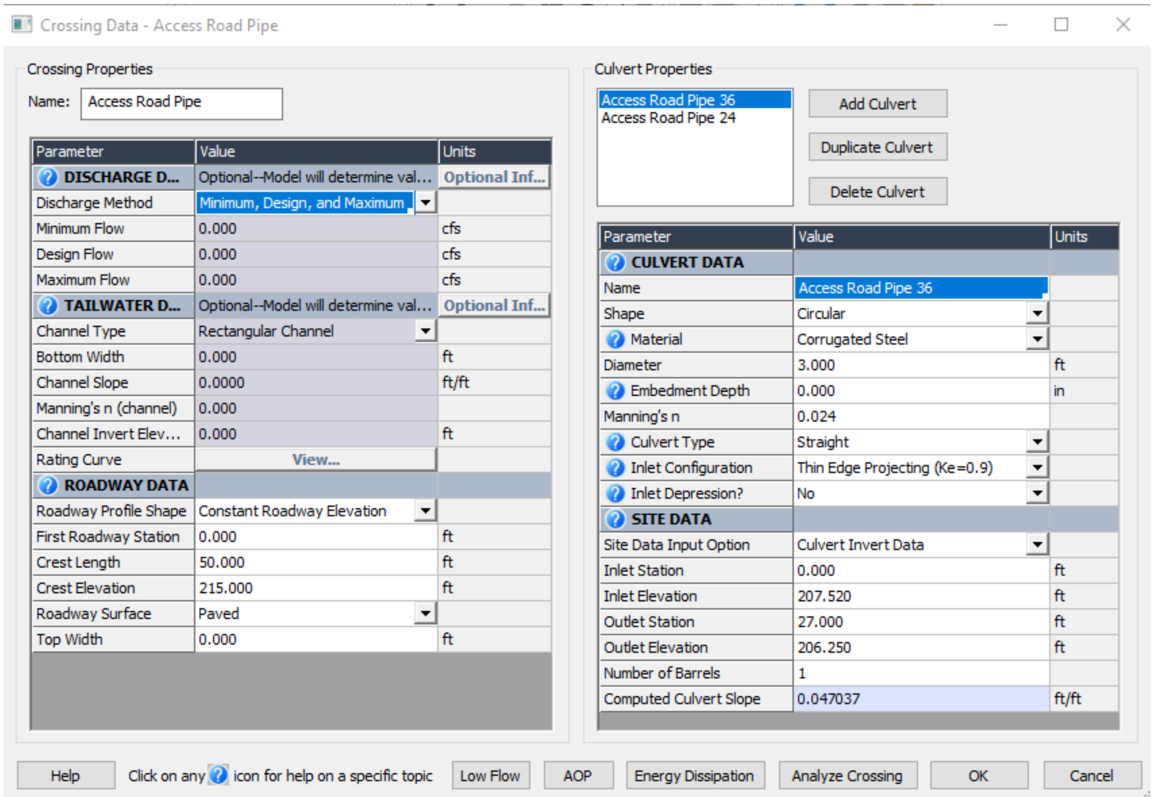


Figure 5-9: HY-8 property access crossing 36-inch culvert parameters

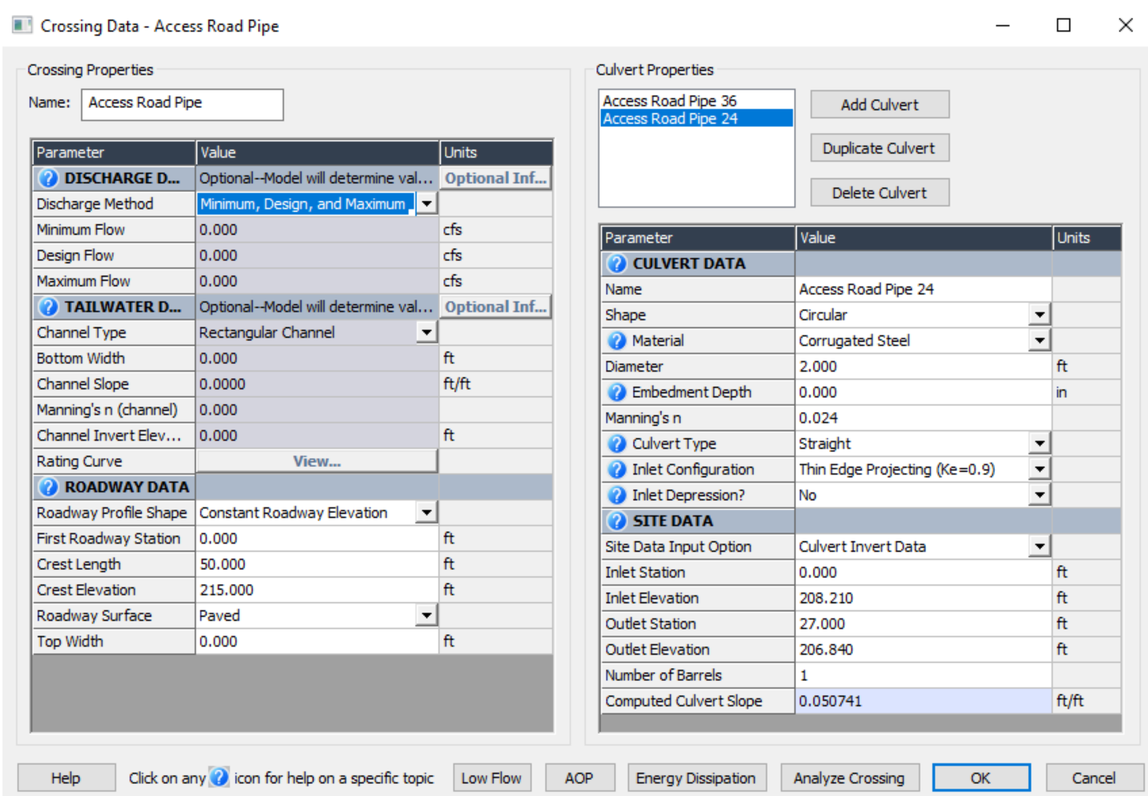


Figure 5-10: HY-8 property access crossing 24-inch culvert parameters

5.1.5 Model Run Controls

Model control for the existing conditions included a start time of 0 hours and an end time of 2 hour. Simulations were run with a 0.05-second time step, with an initial condition of dry. The output frequency was set to 6.0 minutes (0.1 hour), and the default parabolic turbulence was left as 0.7. The model was run as unsteady with three iterations per time step.

Model control for the proposed conditions included a start time of 0 hours and an end time of 2 hours. Simulations were run with a 0.05-second time step, with an initial condition of dry. The output frequency was set to 6.0 minutes (0.1 hour), and the default parabolic turbulence was left as 0.7. The model was run as unsteady with three iterations per time step.

Results showing the SRH-2D models' stability/continuity for the existing and proposed conditions can be found in **Appendix I**. The results display plots for net Q/inlet Q, mass balance, wet elements, monitor points WSE, monitor points z, and monitor lines.

5.1.6 Model Assumptions and Limitations

The difficulties and uncertainties associated with the validation of the existing model stem from the lack of documented flood inundation within the ravine. The Juanita Creek reach between I-405 and NE 141st Street is relatively confined, and floodplain areas are limited. As a result, large storm events are confined to the ravine. This was confirmed during the hydraulic modelling effort for the *Juanita Creek Hydrology and Hydraulics Study H21 Report (*City of Kirkland 2022), as shown in the 100-year existing and proposed hydraulic model depth maps. The model was developed by the WSDOT I-405 SR 167 Megaprogram staff and validated by peer review using an independent consultant expert in SRH-2D modelling.

5.2 Existing Conditions

This section presents the key results from the hydraulic analysis of the existing I-405 Juanita Creek crossing, modeled as a 48-inch-diameter CMP. Illustrations summarizing the WSE, velocity, and depths under the 2-,10- 25-, 100- and 500-year recurrence interval flows are provided in **Appendix H**. **Figure 5-11** depicts the SRH-2D existing conditions elevation mesh and location of cross sections used for results reporting. All results are presented relative to the NAVD88 datum.

Table 5-2 lists the existing conditions hydraulic results of the average WSE, maximum water depth, average velocity, and average shear stress at the cross sections shown on **Figure 5-11**. **Figure 5-12** shows the existing conditions water surface profiles, **Figure 5-13** provides a typical upstream existing channel cross section, and **Figure 5-14** presents the existing conditions 100-year velocity map. **Table 5-3** lists the existing conditions average channel and floodplain velocities.

The SRH-2D model of the existing conditions and the WSE figures indicate that the existing 48-inch CMP is insufficient for passing all recurrence interval flows, as significant backwatering occurs upstream for flows greater than the 2-year. The existing conditions inundated extents and depths upstream of the crossing are similar to the results in the Juanita Creek Hydrology and Hydraulics Study (City of Kirkland 2022), which was used for updated flows. Also, the same modeling approach was taken as this study, where potential clogging at the inlet is not accounted for. Note that the way in which the detention area was modeled for the existing conditions was with decreased flow (existing conditions 100-year peak flow = 41 cfs; proposed conditions 100-year peak flow = 111 cfs), as recommended by the 2022 report. This impacts the floodplain analysis, particularly upstream of the crossing outside of the influence of the detention area, where modeled existing and proposed water surface elevations do not match.

Further downstream no overtopping occurs at the 36- and 24-inch culverts for all recurrence interval flows. Velocities and shear stresses are significant at the outlets of the culverts, which could cause scour immediately downstream.

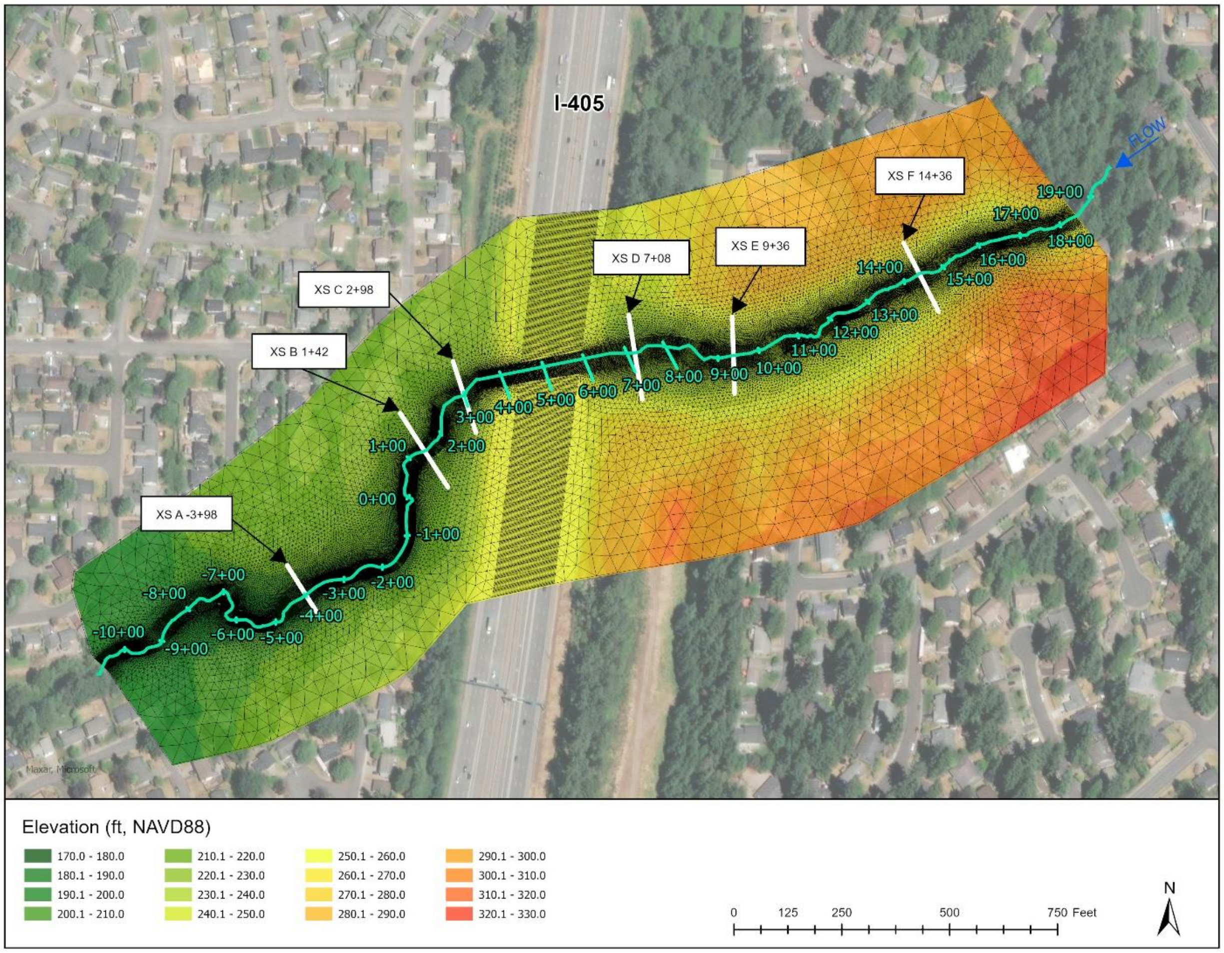


Figure 5-11: Locations of cross sections used for existing results reporting

Table 5-2: Average main channel hydraulic results for existing conditions

Hydraulic Parameter	Cross Section	2-year	100-year	500-year
Average WSE (ft)	DS -3+98 (A)	190.93	191.29	191.49
	DS 1+42 (B)	205.02	205.48	205.74
	DS 2+98 (C)	210.39	212.16	213.90
	US 7+06 (D)	224.49	225.19	225.58
	US 9+36 (E)	229.49	229.86	230.05
	US 14+36 (F)	238.17	238.53	238.71
Max depth (ft)	DS -3+98 (A)	1.40	1.76	1.96
	DS 1+42 (B)	1.67	2.13	2.39
	DS 2+98 (C)	2.12	3.89	5.63
	US 7+06 (D)	1.50	2.21	2.60
	US 9+36 (E)	1.28	1.65	1.84
	US 14+36 (F)	1.95	2.32	2.50
Average velocity (ft/s)	DS -3+98 (A)	3.01	3.42	3.61
	DS 1+42 (B)	1.80	2.09	2.29
	DS 2+98 (C)	1.11	0.74	0.62
	US 7+06 (D)	1.95	1.90	1.91
	US 9+36 (E)	1.90	2.36	2.55
	US 14+36 (F)	1.47	1.84	2.05
Average shear (lb/SF)	DS -3+98 (A)	3.28	3.91	4.20
	DS 1+42 (B)	0.79	0.94	1.07
	DS 2+98 (C)	0.20	0.07	0.05
	US 7+06 (D)	0.70	0.56	0.52
	US 9+36 (E)	0.70	0.85	0.94
	US 14+36 (F)	0.35	0.5	0.59

Notes: Main channel extents were approximated.

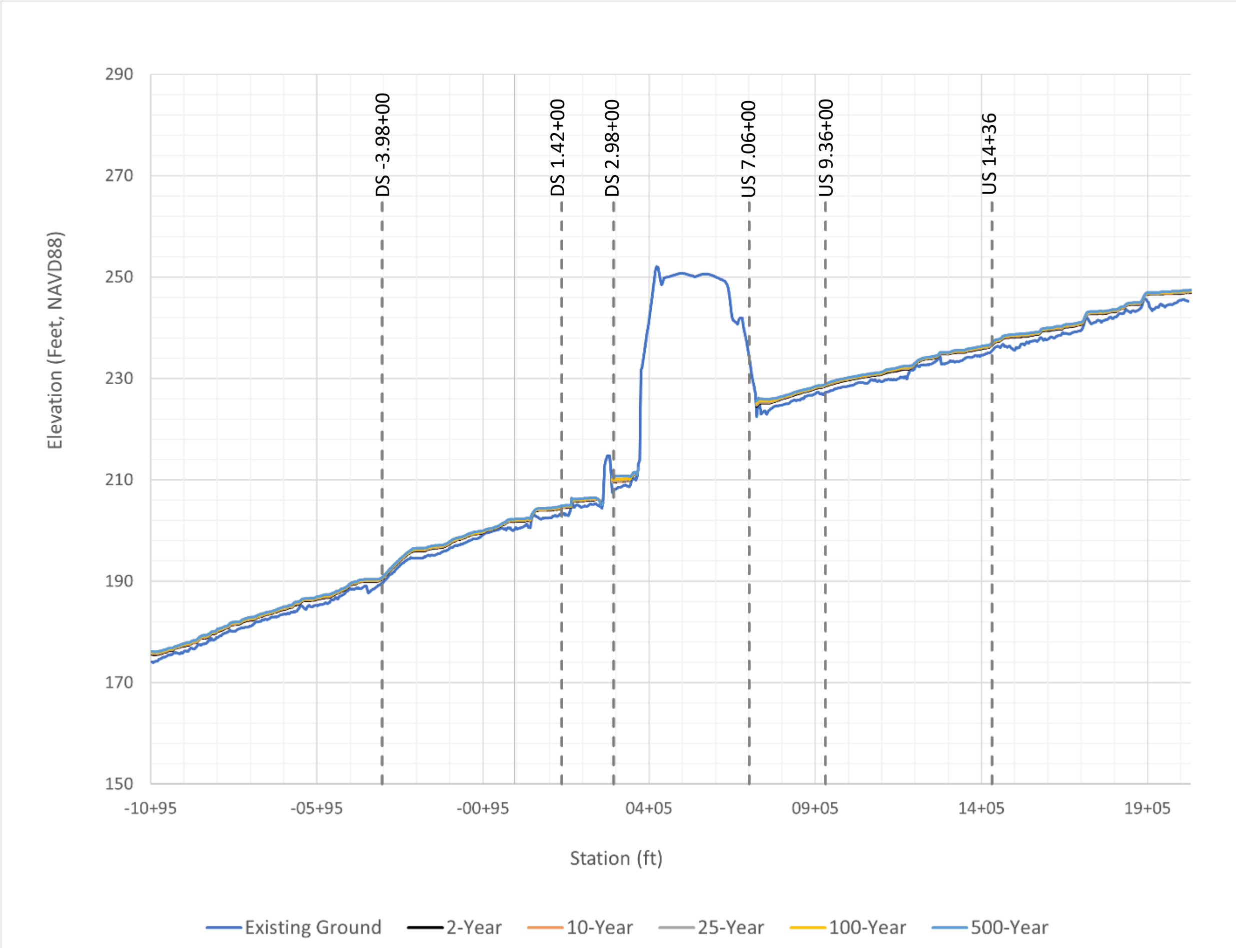


Figure 5-12: Existing conditions water surface profiles

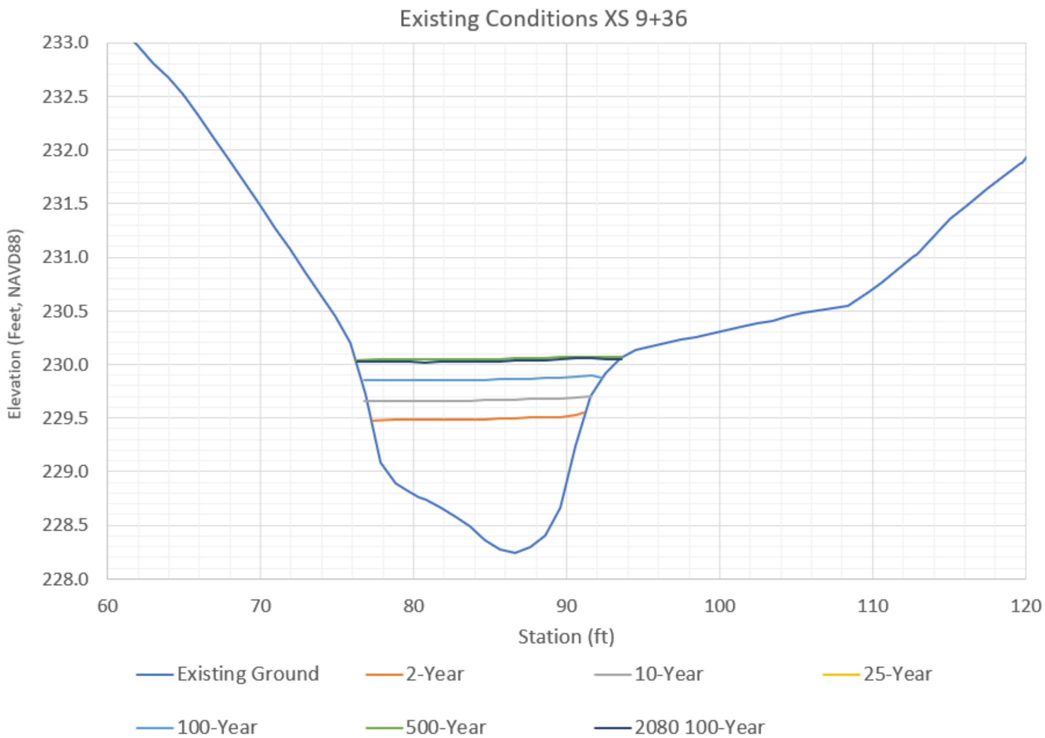


Figure 5-13: Typical upstream existing channel cross section (STA 9+36)

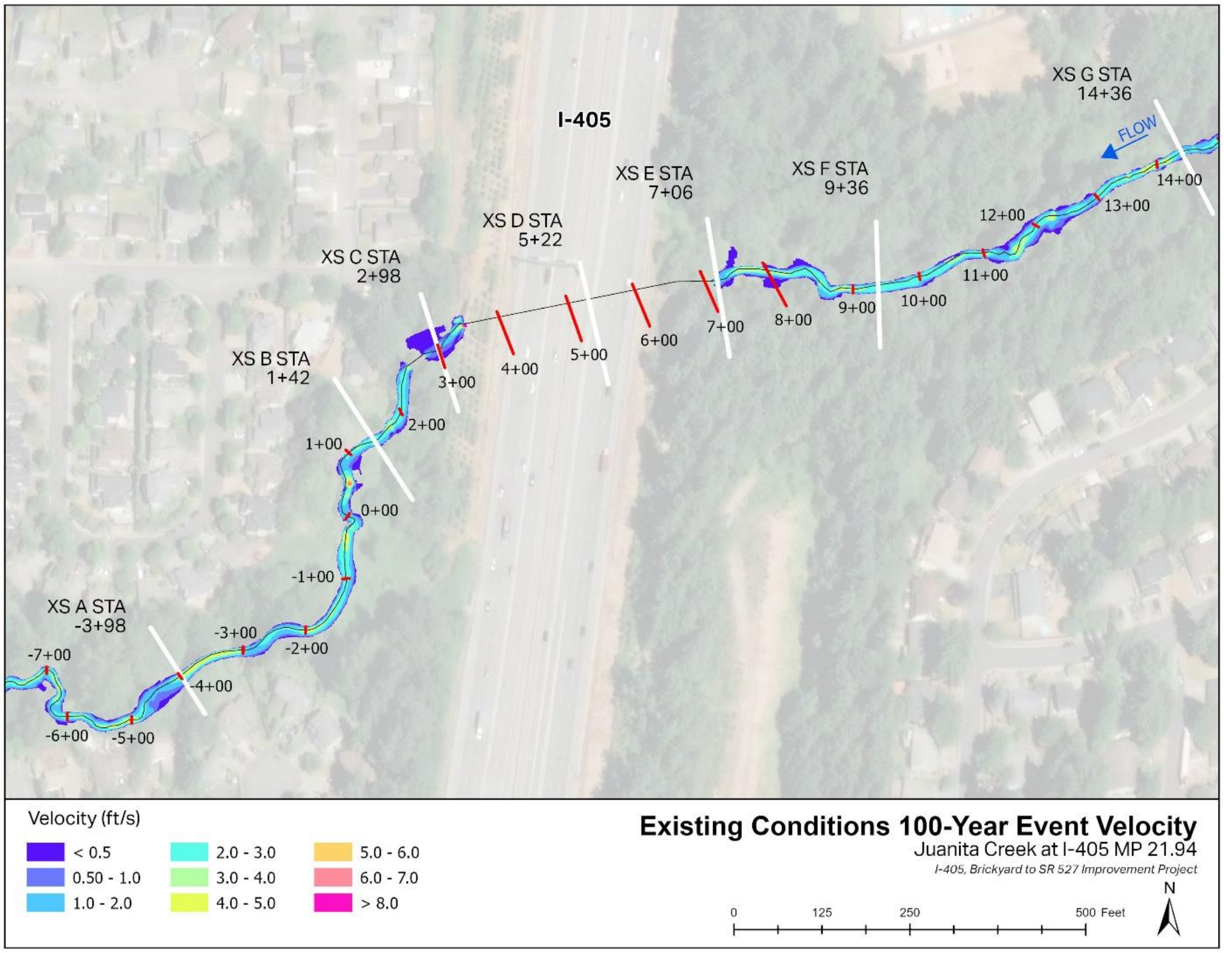


Figure 5-14: Existing conditions 100-year velocity map with cross-section locations

Table 5-3: Existing conditions average channel and floodplain velocities

Cross-section Location	Q100 Average Velocities Tributary Scenario (ft/s)		
	LOB[1]	Main Channel	ROB[1]
DS -3+98 (A)	1.18	1.84	0.38
DS 1+42 (B)	0.63	2.36	0.66
DS 2+98 (C)	NA	1.90	0.39
US 7+06 (D)	0.25	0.74	0.23
US 9+36 (E)	NA	2.09	0.29
US 14+36 (F)	3.05	3.42	1.55

Note:
[1] Right overbank (ROB)/left overbank (LOB) locations were approximated.

5.3 Natural Conditions

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

5.4 Proposed Conditions: 30-foot Minimum SFZ Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes a structure width of 37.8. See **Section 4.2.2** for a description of how the minimum hydraulic width was determined. **Figure 5-15** shows the locations of cross sections on the proposed alignment used for results reporting. **Table 5-4** lists the average main channel hydraulic results for the proposed conditions.

Figure 5-16 shows water surface profiles for the proposed conditions. Outside of the 2024 survey extents, LiDAR elevations were compared to the bathymetry data used for the Juanita Creek Hydrology and Hydraulics Study (City of Kirkland 2022) and were mostly found to have lower elevations; thus, LiDAR was used to supplement the 2024 survey instead of supplementing with the City of Kirkland 2022 data.

Figure 5-17 shows a typical section through the proposed structure. **Figure 5-18** presents the 100-year velocity map for the proposed conditions, and **Table 5-5** lists the proposed conditions average channel and floodplain velocities.

The SRH-2D model of the proposed conditions and the WSE figures indicate the proposed 37.8-foot wide open-bottom circular arch, with an SFZ width of 30 feet, and an SFZ height of 10 feet easily passes flow through the project site without overtopping or creating a buildup of headwater upstream. The culvert immediately downstream of the I-405 culvert outlet is removed in proposed conditions, so there is no overtopping or flooding. Proposed velocities and shear stresses are inherently higher in the proposed conditions due to the lack of impoundment caused by existing culverts. Although there is an increase in these values, they are expected given the proposed channel geometry and do not pose any ill effects to fish migration upstream. A benefit of the project is restoring more natural hydrology and hydraulics to Juanita Creek. Proposed velocities and shear stresses are higher during peak flood flow events. Fish do not migrate during the peak of high flow events. Fish passage flows are much lower than modeled flows, typically lower than half the 2-year event. Thus, while peak flows will increase, there will still be flow ranges to allow for fish migration.

Flow is present at all discharge events in the proposed side channel design located on the right bank upstream of the I-405 crossing while looking downstream. Flow begins to spill over into the benches at the beginning of the side channel for all recurrence interval flows.

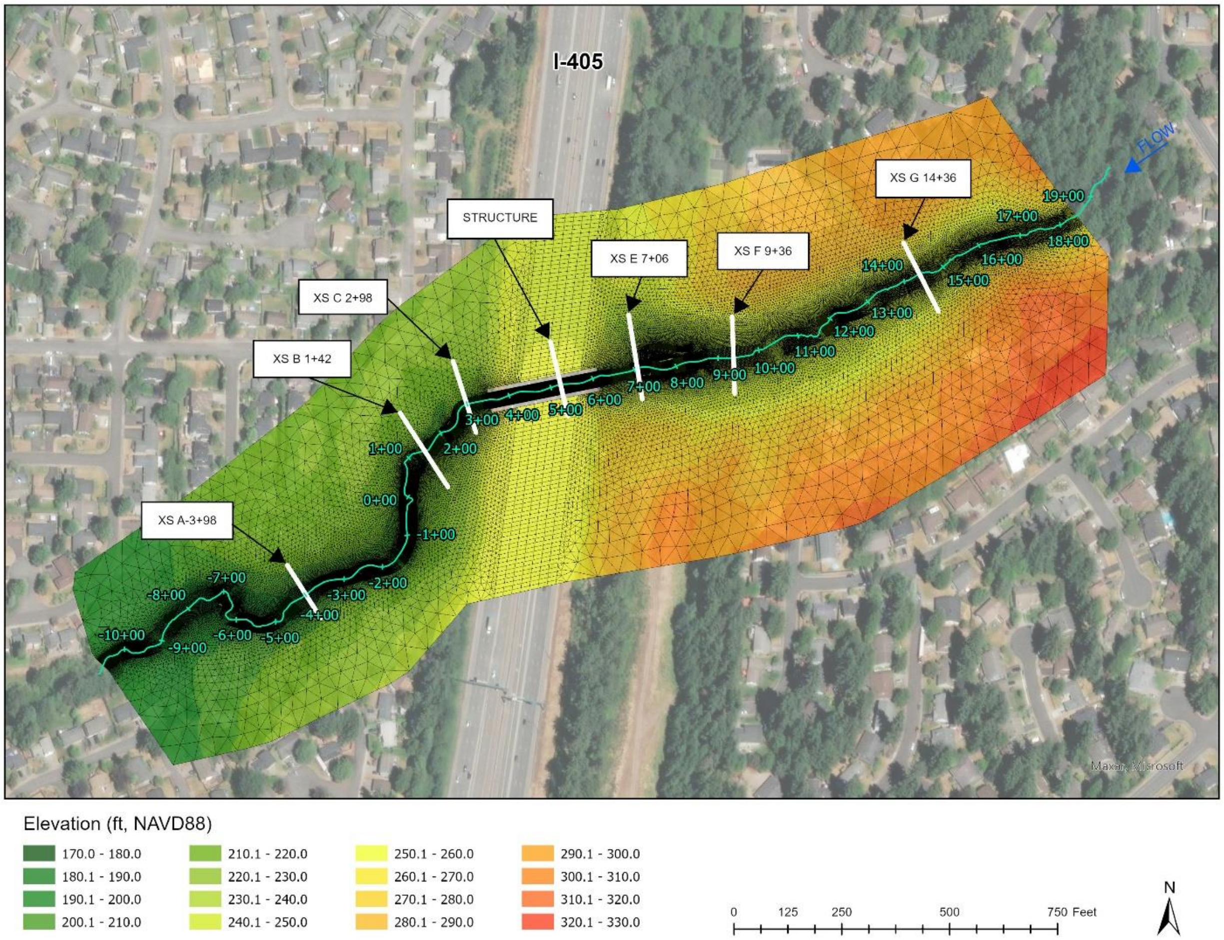


Figure 5-15: Locations of cross sections on proposed alignment used for results reporting

Table 5-4: Average main channel hydraulic results for proposed conditions

Hydraulic Parameter	Cross Section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS -3+98 (A)	191.20	192.22	192.48	192.87
	DS 1+42 (B)	205.40	206.61	206.88	207.28
	DS 2+98 (C)	207.64	208.66	208.92	209.32
	Structure 5+22 (D)	214.39	215.11	215.27	215.49
	US 7+06 (E)	219.74	220.51	220.92	220.97
	US 9+36 (F)	229.85	230.73	230.92	231.17
	US 14+36 (G)	238.52	239.48	239.70	240.02
Max depth (ft)	DS -3+98 (A)	0.70	2.66	2.92	3.32
	DS 1+42 (B)	NA	3.2	3.48	3.88
	DS 2+98 (C)	0.34	3.15	3.41	3.81
	Structure 5+22 (D)	0.18	2.79	2.95	3.17
	US 7+06 (E)	0.19	4.18	4.36	4.63
	US 9+36 (F)	0.12	2.49	2.68	2.93
	US 14+36 (G)	0.85	3.16	3.39	3.71
Average velocity (ft/s)	DS -3+98 (A)	3.32	4.24	4.44	4.74
	DS 1+42 (B)	1.98	2.79	3.01	3.33
	DS 2+98 (C)	1.95	2.4	2.75	2.85
	Structure 5+22 (D)	1.97	3.14	3.40	3.75
	US 7+06 (E)	1.29	2.49	2.79	3.20
	US 9+36 (F)	2.37	3.52	3.82	4.23
	US 14+36 (G)	1.82	3.04	3.36	3.81
Average shear (lb/SF)	DS -3+98 (A)	3.72	5.21	5.58	6.14
	DS 1+42 (B)	0.86	1.50	1.70	2.03
	DS 2+98 (C)	0.72	1.10	1.15	1.19
	Structure 5+22 (D)	0.77	1.64	1.87	2.21
	US 7+06 (E)	0.28	NA 0.92	1.13	1.14
	US 9+36 (F)	0.87	1.59	1.82	2.15
	US 14+36 (G)	0.49	1.12	1.32	1.64

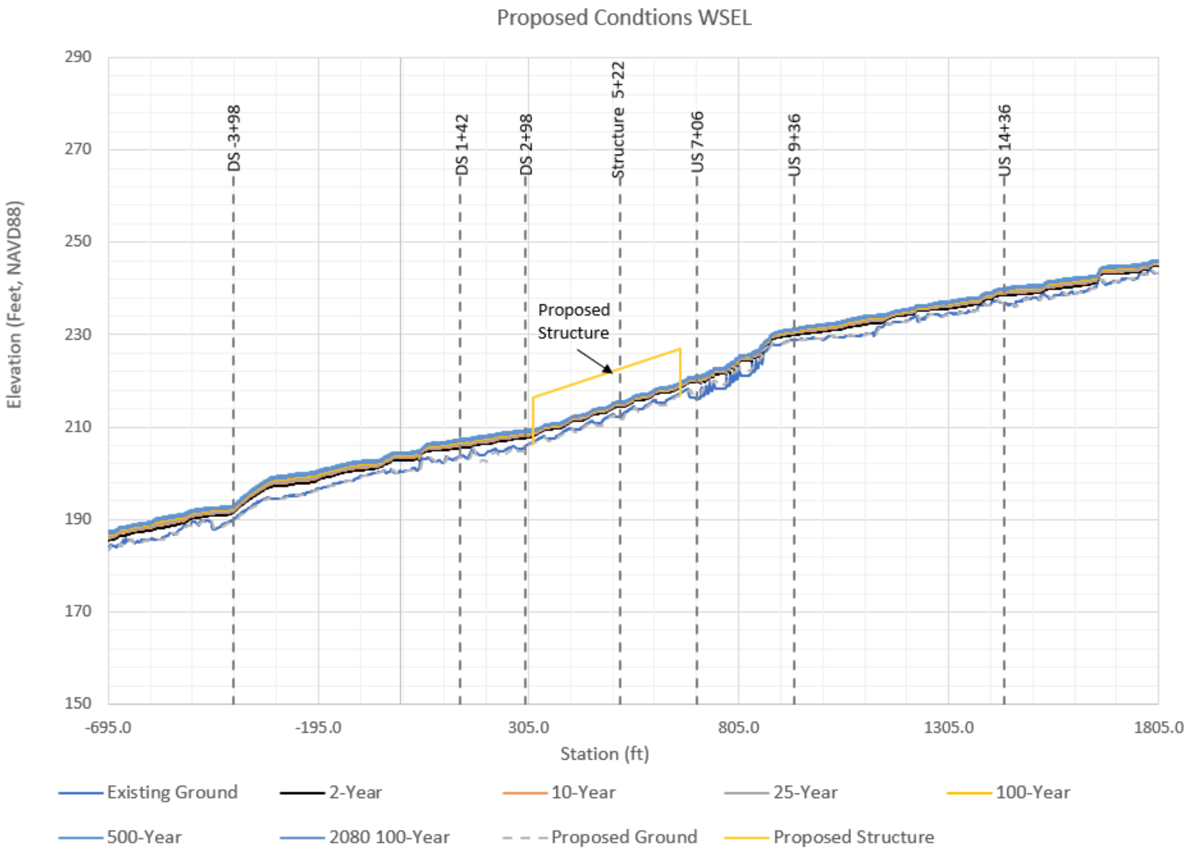


Figure 5-16: Proposed conditions water surface profiles

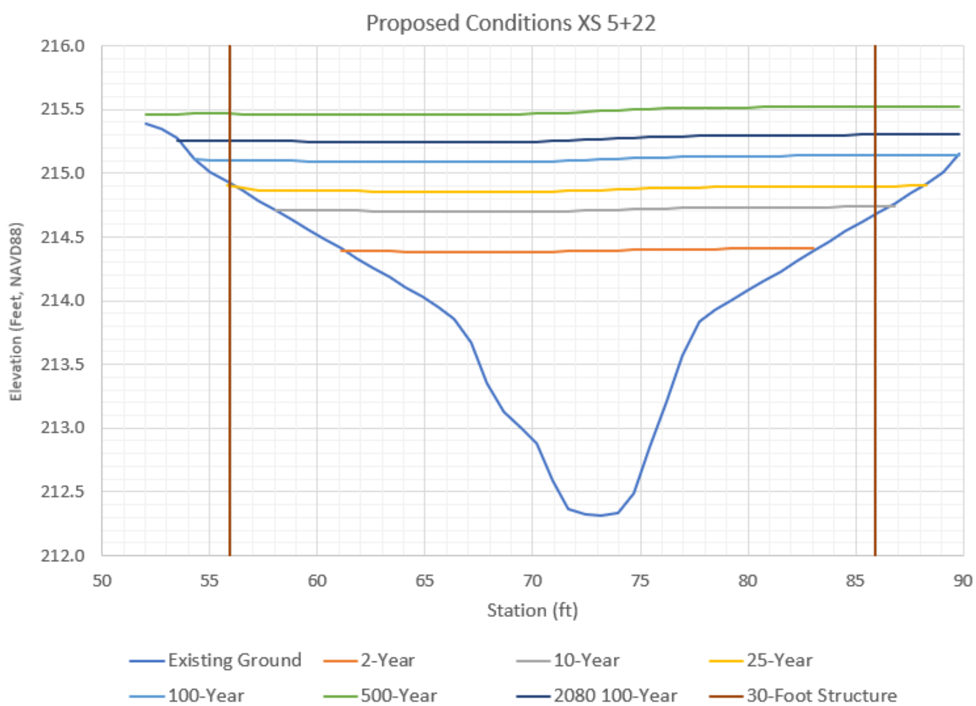


Figure 5-17: Typical section through proposed structure (STA 5+22)

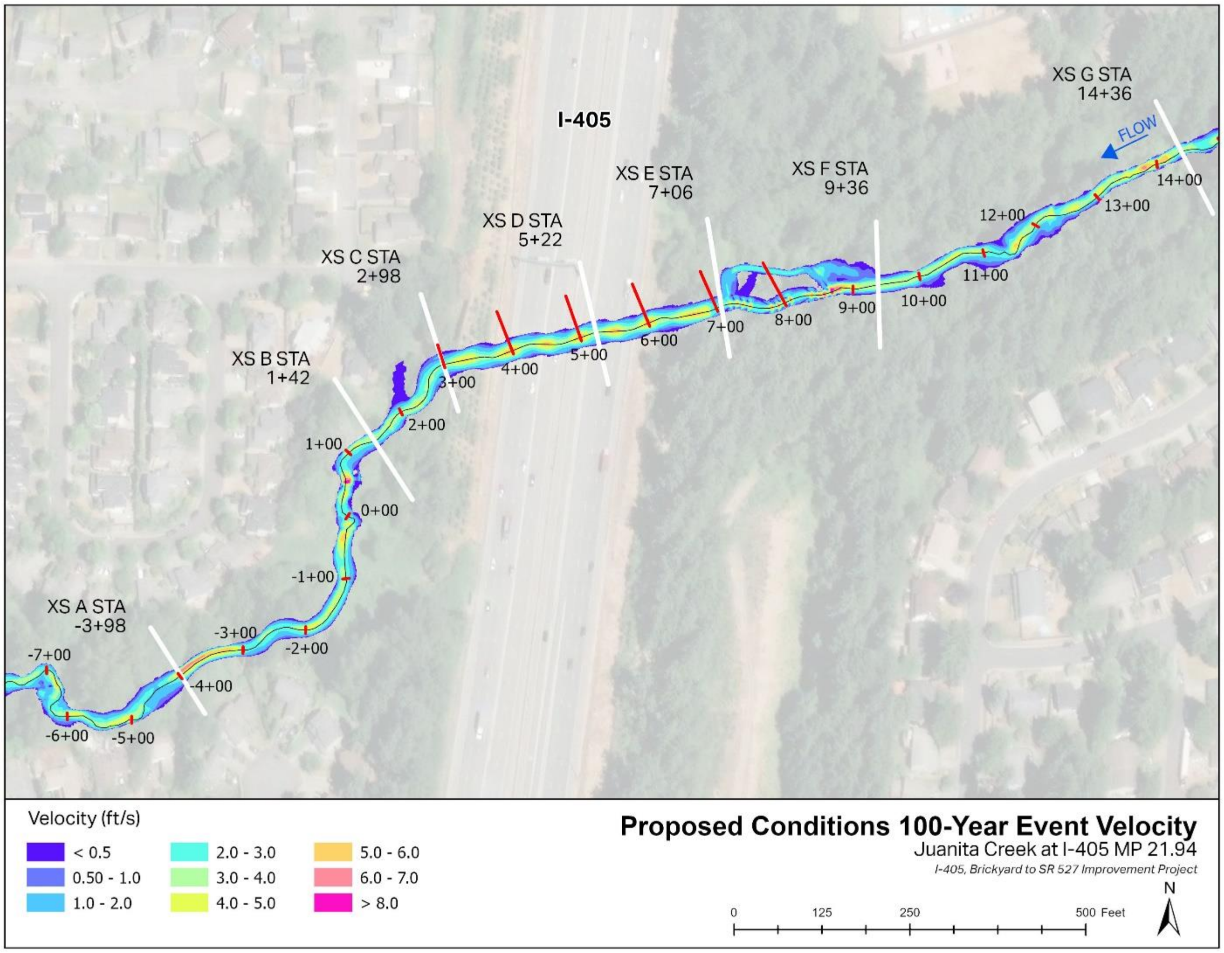


Figure 5-18: Proposed conditions 100-year velocity map

Table 5-5: Proposed conditions average channel and floodplains velocities

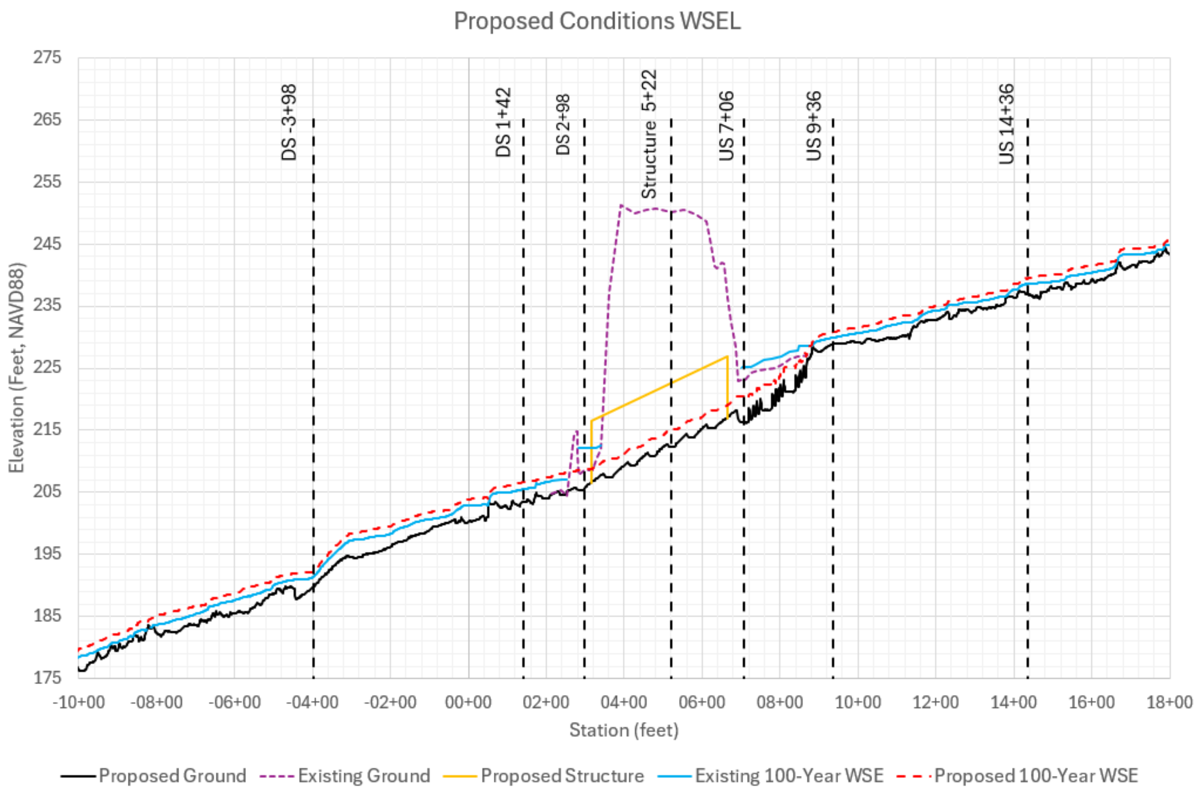
Cross-section Location	Q100 Average Velocities (ft/s)			2080 Q100 Average Velocity (ft/s)		
	LOB[1]	Main Channel	ROB[1]	LOB[1]	Main Channel	ROB[1]
DS -3+98 (A)	1.88	4.24	3.32	1.84	4.44	3.34
DS 1+42 (B)	0.73	2.79	0.36	0.89	3.01	0.54
DS 2+98 (C)	1.25	2.64	0.76	1.49	2.75	0.91
Structure 5+22 (D)	1.67	3.14	1.15	1.90	3.40	1.42
US 7+06 (E)	1.45	2.49	0.89	1.56	2.79	1.09
US 9+36 (F)	1.05	3.52	0.83	1.10	3.82	0.98
US 14+36 (G)	0.55	3.04	1.88	0.64	3.36	1.91

Note:
[1] Right overbank (ROB)/left overbank (LOB) locations were approximated.

6 Floodplain Evaluation

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

Based on the Juanita Creek Hydrology and Hydraulics Study (City of Kirkland 2022), peak flows on Juanita Creek will increase due to the removal of the regional detention facility. The 100-year flows upstream of the I-405 crossing will increase from 41 cfs to 111 cfs, and thus proposed conditions WSEs will be higher than existing conditions. **Figure 6-1** compares existing and proposed 100-year water surface profiles along the proposed alignment. **Figure 6-2** and **Figure 6-3** show the 100-year WSE change from existing to proposed conditions. There are ongoing investigations into potential downstream flooding, outside of the design-build contract.



Note: Existing and proposed conditions 100-year flows at the upstream BC are 41 cfs and 111 cfs, respectively (**Table 3-1**).

Figure 6-1: Existing and proposed conditions 100-year water surface profile comparison along proposed alignment

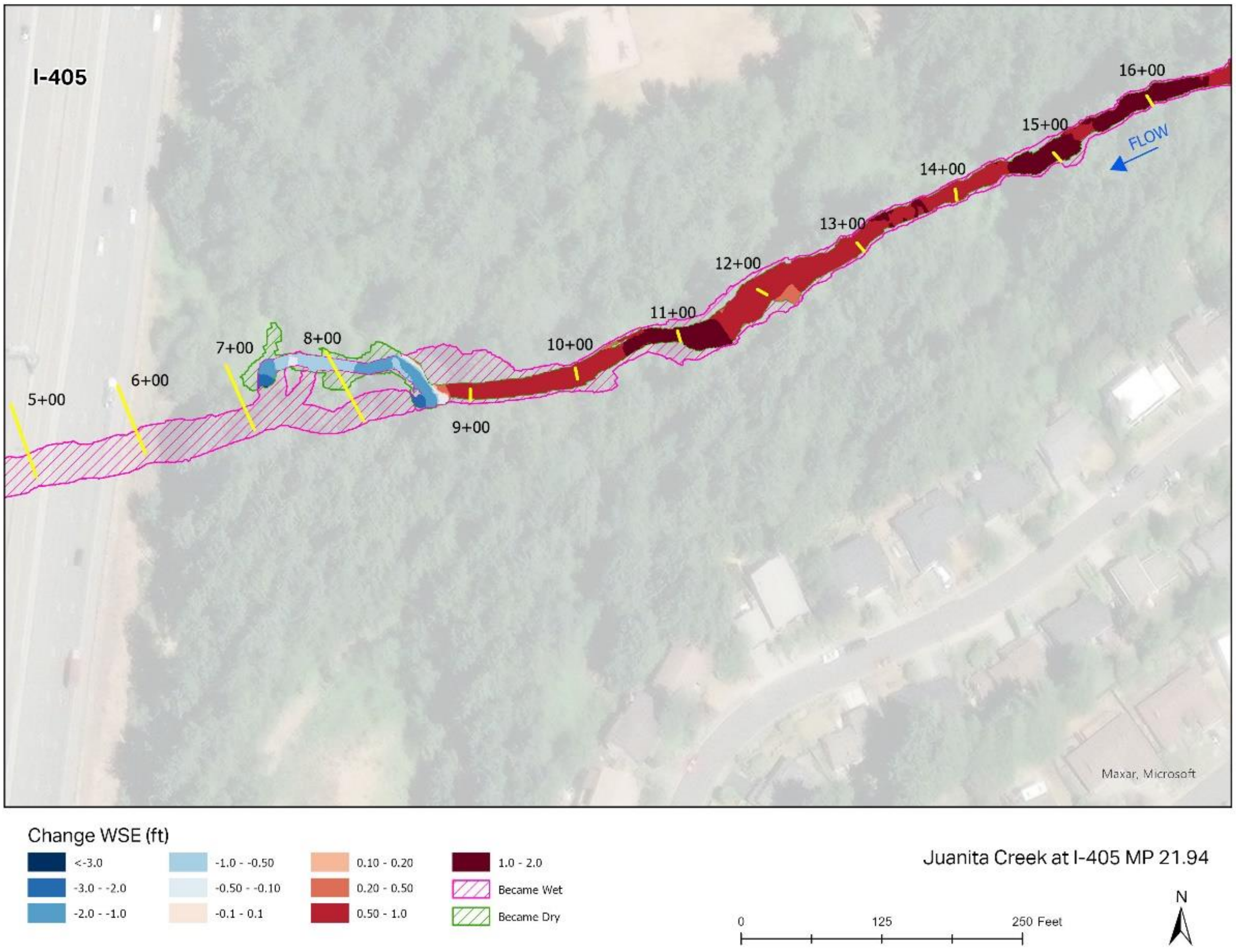


Figure 6-2: Upstream 100-year WSE change from existing to proposed conditions

Figure 6-3: Downstream 100-year WSE change from existing to proposed conditions

7 Final Scour Analysis

Scour components considered in the analysis include long-term degradation, contraction scour, and local scour. The potential for lateral migration was also assessed to evaluate total scour at the proposed highway infrastructure. These various scour components will be discussed in the following sections. All calculations are included in **Appendix K.**

7.1 Lateral Migration

The risk of lateral migration within the project reach was assessed based on the variables and evaluations described in this section and on the conditions described in **Section 2.7.4**. The assessment shows that there is low to moderate potential for lateral migration within the project reach.

Historical aerial imagery available through the King County GIS Spatial Data Warehouse and Google Earth Pro was reviewed for potential evidence of bend meander or channel widening. The available imagery dates from 1990 to the present. The resolution of available imagery is not refined enough to document small to moderate changes in the Juanita Creek channel and does not show any significant realignment of the channel.

A rapid assessment of stream stability was completed following the procedure outlined in the Federal Highway Administration's (FHWA's) *Hydraulic Engineering Circular No. 20 Stream Stability at Highway Structures* (HEC-20) (FHWA 2012). The existing conditions were used to assign a score for each of the 13 stability indicators listed in HEC-20 Table 5.5. The rapid assessment is used to classify overall channel stability as either excellent, good, fair, or poor, based on the stream channel classification and the summation of the 13 indicator scores. Observations made during a site visit in December 2023, along with field observations reported in the 2022 WSDOT PHD, were used to inform the rapid assessment scoring. Characteristics of the stream that contribute to instability are the urbanization of the watershed, channel confinement, adjacent infrastructure limiting floodplain interaction, sandy bank soil texture, steep bank slope angles, and the upstream distance from meander impact point to stream alignment at the crossing. All other indicators rate as fair or good for channel stability. The overall score of 69 indicates that Juanita Creek has good stream stability. A fractional score based on the vertical and lateral stability indicators is used to determine the dominant direction of instability. For Juanita Creek, the vertical rating of 0.43 and a lateral rating of 0.47 indicate that vertical instability is slightly dominant. See **Appendix O** for the scoring assessment.

Although the risk for lateral migration is considered low to moderate, the risk in relation to the structure is assumed to occur for the purposes of scour analysis and estimation of total scour. The geotechnical data available at this time are not sufficient to exclude the risk of lateral migration from the scour analysis until detailed geotechnical data (i.e., competent bedrock, geotechnical evaluation for soil erodibility, stream power versus soil erodibility, etc.) is available to support the assessment of no lateral migration being anticipated over the life (75+ years) of the proposed structure.

7.2 Long-term Degradation of the Channel Bed

For Juanita Creek, the design is required to allow for the channel to naturally regrade, which could come in the form of long-term degradation (LTD) or aggradation. As discussed in **Section 2.7.3** and shown in **Figure 2-15**, there were some signs of erosion visible throughout the length of the project reach.

LTD of the channel bed was evaluated using two equilibrium slope methods and a downstream grade control feature as the basis for base level control. The two equilibrium slope methods used are the Meyer-Peter Muller (MP) and the Schoklitsch (SCH) methods. The D_{50} and D_{90} from the pebble counts (as described in **Section 2.7.3**) were used to estimate the equilibrium slope (Pemberton and Lara 1984). Hydraulic information used in these equations comes from the 2-year hydraulic results. This is because the dominant discharge is responsible for affecting the ultimate shape and conditions of the channel. This dominant discharge that influences the channel geometry and function is the bankfull flow that is often estimated as the 2-year flow (Pemberton and Lara 1984).

Because there are no identifiable and definitive grade control points caused by non-erodible geologic features or other permanent structures, Juanita Creek's confluence with an unnamed tributary near the southwest corner of Edith Moulton Park in the City of Kirkland was used as the base level control. This location is chosen as the base level control because equilibrium slopes are not applicable past this point due to changes in hydrology and channel geometry. This location is approximately 1.3 miles downstream of the I-405 crossing and represents the limit at which an equilibrium slope calculation may be considered applicable. Equilibrium slope equations such as the Meyer-Peter Muller and Schoklitsch methods use reach-specific hydraulic parameters including bankfull width, dominant discharge, and sediment size. As Juanita Creek flows towards Lake Washington, this tributary confluence is the first significant flow change that greatly influences stream conditions such as discharge and bankfull width; therefore, using a base level control any further downstream of this location may be considered inappropriate. Plotted on **Figure 7-1** is the entire profile extending to Lake Washington, along with the two equilibrium slopes using the tributary confluence as the base level control. As shown on the figure, the average of these two methods produces the blue line that is above the ground elevation line and results in no LTD at the I-405 crossing. The averaged line is taken as the recommended approach in the *Technical Guideline for Bureau of Reclamation, Computing Degradation and Local Scour* (Pemberton and Lara 1984). Because the profile begins to flatten out as Juanita Creek approaches Lake Washington, moving the base level control farther downstream would also result in zero LTD.

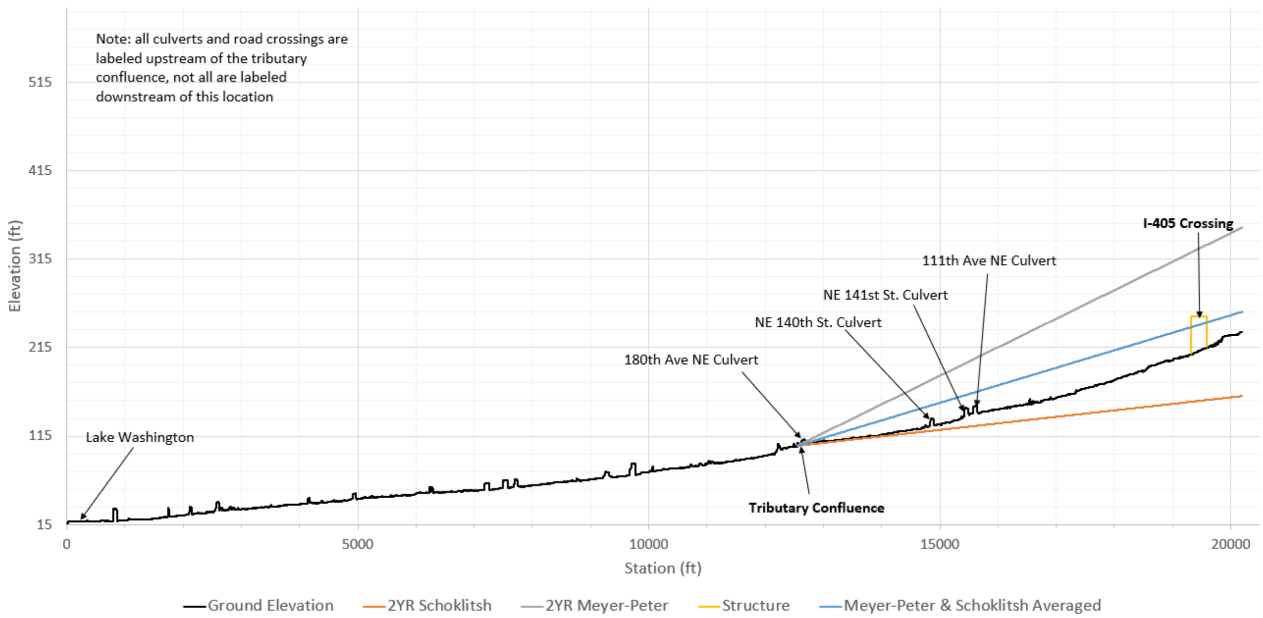


Figure 7-1. LTD Profile

Even though the equilibrium slope approach discussed above estimated no LTD for the Juanita crossing, an additional approach was considered for comparison. The Technical Guideline for Bureau of Reclamation, Computing Degradation and Local Scour recommends analyzing the ability for a streambed to develop a natural armor layer that would arrest any degradation to the depth at which this armor layer forms (Pemberton and Lara 1984). This approach is recommended for situations where a minimum of 10 percent of the material is coarse enough to resist transport. This in turn could limit degradation to a depth shallower than that calculated using equilibrium slope methods. This armor layer approach used the existing stream bed gradation (D_{50} = 1.01 inches), calculated from the pebble count data taken upstream of I-405; this material is likely less coarse than material downstream due to the in-line detention facility, and thus produces a conservative estimate of armoring depth. The armoring depth from this analysis is 1.47 feet and would likely be less if data were collected for material downstream of I-405. This result indicates that a coarse armor layer would develop at a depth of 1.47 feet, at which point LTD would be arrested. Note that the armoring layer approach does not use a base level control and thus the choice of base level control location does not impact the estimate for long-term degradation.

A degradation of 1.47 feet would be applied to total scour using existing conditions as degradation or incision is initiated downstream. For the proposed design, in order to provide a stable bed, the streambed material needs to be coarser than existing material as described in **Section 4.3.** This difference in size creates a more stable streambed and also acts as a profile stability measure. In order to quantify the effects of this coarser streambed, the same armor layer depth approach was used. Using the design riffle and meander bar gradation (D_{50} = 7.68 inches), which will make up the majority of the streambed (and will be placed beneath the finer pool streambed sediment to a depth of 5 feet), the armoring depth for the proposed I-405 crossing is 0.12 feet (**Table 7-1**). This indicates that the riffle and meander bar sediments will act as an armor layer and not degrade significantly. Downstream of the proposed grading limits, if a scour depth of 1.47 feet developed over time and began to headcut up to the downstream end of the proposed streambed, the proposed riffle material will stop the headcut from migrating further upstream to the structure. The proposed streambed material outside of the structure is placed to a depth of 3 feet and therefore would be protected down to the LTD depth of 1.47 feet and an additional 1.53 feet. If this condition (or greater degradation) were to occur, it would also not likely result in a fish passage barrier (due to water drop) because the proposed riffle material would respond by creating a ramp connecting the degraded portion of the stream to the proposed streambed. This would effectively function as a steeper riffle. The proposed bed material acting as a profile stability measure from this analysis has implications on applicable structural total scour.

The armoring depth approach produced a more conservative estimate than the equilibrium slope approach for calculating LTD, and thus was chosen for the final LTD estimate. A LTD depth of 0.12 feet will be included in the total scour estimate.

The armoring layer equations do not directly include shear stress as input but rather use streambed material size – and streambed material was sized based on shear stress, using the Modified Critical Shear Stress approach, sized so that the D84 would be stable at the 100-year flow event. The calculations indicate that the streambed material will be large enough to arrest potential headcuts migrating up to the downstream end of the proposed streambed. A deformable grade control will be installed at the downstream end of the project area as added protection to prevent downstream incision from migrating upstream into the project reach.

The approaches described in this section and **Appendix K** follow guidance from FHWA HEC-18 and HEC-20 and are appropriate for analyzing Juanita Creek. The average slopes for the reaches along the creek upstream and downstream of the I-405 crossing are shown in **Figure 2-16**. They range from 1.6% to 2.9%. The slope of the blue line in **Figure 7-1**, which represents the average of the Meyer-Peter and Schoklitsh equilibrium slopes is 2.0%, which falls within the range of the average slopes for the reaches along Juanita Creek. The slopes are likely anthropogenically influenced. As described in **Section 2.1** and **Section 2.2**, the watershed primarily has a low and medium developed land use classification. There is another complete fish barrier culvert (WDFW ID 935036) located approximately 1,500 feet upstream of the I-405 crossing.

A benefit of the project is restoring more natural hydrology, hydraulics, and sediment transport to Juanita Creek. Due to the increases in peak flood flows resulting from the removal of the attenuation capacity of the detention area, velocity and shear stress will likely increase downstream. Some of this will be offset by the increase in sediment transport capacity; the system will be more able to transport sediment downstream and at the same time there will be more sediment coming in from upstream.

All calculations for evaluating LTD are found in **Appendix K.2** and **K.3.**

Table 7-1: LTD Summary table

	Long-term Degradation Depth (ft)
Equilibrium slope	0.0
Depth to armor layer (downstream of grading extents)	1.47
Depth to armor layer including stability measures (proposed streambed)	**0.12***

*Included in estimate of total scour

7.3 Contraction Scour

Based on the structure with an SFZ of 30 feet, contraction scour was calculated using clear-water conditions because the critical velocity of existing sediment at the approach section is greater than that of average velocity at the approach section (5.5 and 5.3 feet per second, respectively). The 2-, 10-, 25-, 100-, 2080 100-, and 500-year events were evaluated for contraction scour, and no events resulted in a positive scour depth. This calculation was performed as a separate check on contraction scour than what is discussed in **Section 7.4.3,** where abutment and contraction scour are evaluated jointly using the National Cooperative Highway Research Program 24-20 (NCHRP) method.

Within the SRH-2D hydraulic model, all flow events were evaluated using the same bridge scour coverage in the FHWA Hydraulic Toolbox, per SRH-2D and SMS best practices. FHWA Hydraulic Toolbox scour calculations are found in **Appendix K.**

The sediment size used for contraction scour analysis at the contracted section was the designed riffle sediment, as seen in **Section 4.3.1**. This is because a straight riffle bedform is designed to be present at the entrance of the culvert and is expected to be relatively stable over time. The design will allow sediment transport and deformability as is beneficial and required for fish passage projects, but the bedforms are designed to be stable and not rapidly wash through the structure to provide reliable fish passage and resistance to degradation of the streambed.

7.4 Local Scour

7.4.1 Scour at LWM

LWM is expected to create local scour holes, which are beneficial for creating habitat diversity and complexity but can potentially destabilize logs or expose structural elements to scour. Caution needs to be taken when placing LWM near structural elements such as culvert wing walls. Per the WSDOT *Hydraulics Manual* Chapter 10-6.5 (WSDOT 2022a), reliable methods for estimating scour at LWM placements have not yet been developed in either the engineering or scientific communities. In some cases, equations developed for bridge piers and abutments have been used to predict scour, but these are overly conservative for gravel bed streams found in much of Washington and may not accurately represent the unique geometry of LWM. Scour analysis for LWM projects will therefore often rely heavily on engineering judgment and lessons learned from practical experience.

In order to estimate the potential scour from LWM, the *Hydraulic Engineering Circular No.18* (HEC-18) pier scour equation will be used at LWM structures and at various flows. It is worth noting that the HEC-18 pier scour equation is based on the Colorado State (CSU) equation (FHWA 2012); after development of this approach, Landers et al. concluded that the CSU equation frequently over-predicted the observed scour in laboratory studies, resulting in maximum scour depths (FHWA 2012). When applying the HEC-18 equation to geometries like LWM that differ from the pier shapes that the equation was developed for, caution needs to be taken with the resulting scour depths. Thus, the less conservative Julien 2002 equation will also be evaluated (USBR 2015). The U.S. Bureau of Reclamation *Bank Stabilization Guidelines* (2015) outline methods for the design of engineered log jams for bank stabilization that include the evaluation of local scour using the Julien equation, which generally provides less conservative results than the HEC-18 method. Thus, the less conservative Julian equation (USBR 2015) was also used to evaluate potential scour at LWM.

Both methods described are dependent on the geometry of LWM. It was assumed the front, or most prominent rootwad, in the channel would be the main obstruction (see **Appendix K.4**).

Local scour at LWM was evaluated for the 2-year, 10-year, 25-year, 100-year, projected 2080 100-year, and 500-year events in the proposed conditions model (**Section 5.4**). Results are presented in **Table 7-2**. The maximum scour depth for the HEC-18 equation is 3.3 feet at structure C under the projected 500-year flow. For the Julian method, the maximum scour depth of 2.3 feet occurs at structure I also under the projected 500 100-year flow.

The width of a pier scour hole is typically assumed to be twice the scour hole depth. Using the overall maximum scour depth from both equations, the largest scour hole width is approximated at 6.6 feet. All of the LWM is placed with clearances to wing walls greater than this scour hole width and therefore any local scour at LWM is not anticipated to impact structural elements of the crossing.

Table 7-2: Depth of local scour at LWM

LWM Structure		A	B	C	D	E	F	G	H	I	J	K	L	M
2-year Scour Depth (ft)	Julian	1.0	1.1	1.6	1.3	1.3	1.2	1.3	1.3	1.6	1.6	1.6	1.0	1.1
	HEC-18	1.6	1.9	2.5	2.2	2.3	2.1	2.2	1.9	2.2	2.2	2.2	1.6	1.9
10-year Scour Depth (ft)	Julian	1.2	1.2	1.8	1.5	1.4	1.4	1.4	1.5	1.8	1.7	1.7	1.2	1.2
	HEC-18	1.8	2.0	2.7	2.4	2.4	2.3	2.3	2.2	2.5	2.4	2.4	1.8	2.0
25-year Scour Depth (ft)	Julian	1.4	1.3	1.9	1.6	1.5	1.5	1.5	1.6	1.9	1.6	1.6	1.4	1.3
	HEC-18	1.9	2.1	2.9	2.5	2.5	2.4	2.4	2.3	2.6	2.4	2.4	1.9	2.1
100-year Scour Depth (ft)	Julian	1.4	1.5	2.0	1.8	1.7	1.6	1.5	1.8	2.0	1.8	1.8	1.4	1.5
	HEC-18	2.0	2.3	3.0	2.7	2.7	2.5	2.4	2.6	2.7	2.5	2.5	2.0	2.3
500-year Scour Depth (ft)	Julian	1.8	1.9	2.3	2.1	2.0	2.0	1.9	2.1	1.6	1.9	1.9	1.8	1.9
	HEC-18	2.3	2.5	3.3	3.0	2.9	2.8	2.7	2.9	2.4	2.7	2.7	2.3	2.5
2080 100-year Scour Depth (ft)	Julian	1.6	1.7	2.1	1.9	1.9	1.8	1.7	1.9	2.0	1.8	1.8	1.6	1.7
	HEC-18	2.2	2.4	3.1	2.8	2.8	2.6	2.5	2.7	2.8	2.6	2.6	2.2	2.4

Note: Structures K, L, and M are in the proposed side channel upstream of the structure inlet.

7.4.2 Pier Scour

There are no existing piers present in the project vicinity and the proposed work does not include any new piers. Therefore, pier scour was not evaluated.

7.4.3 Abutment Scour

Abutment scour was estimated using the NCHRP 24-20 approach for all flood events up to the scour design flood and scour check flood using a clear-water condition. The NCHRP 24-20 method jointly evaluates contraction scour and abutment scour by applying an amplification factor to contraction scour. As outlined in HEC-18, these results (separate from those found in **Section 7.3**) represent total scour at the abutment and would not be added to contraction scour if the calculation in **Section 7.3** resulted in positive scour depths (FHWA 2012).

Abutment scour equations estimate scour depths of 0.53 and 1.0 feet at the 25-year event and the 500-year event, respectively. See **Appendix K.1** for the hydraulic toolbox report and abutment scour detailed information.

Abutment scour is evaluated at the entrance of the proposed culvert. For the FHD, the wing walls were approximated and incorporated into the hydraulic model geometry. In the FHWA Hydraulic Toolbox, a vertical wall abutment with wing walls was assumed as the abutment type.

7.4.4 Bend Scour

Bend scour was evaluated with two methods within the I-405 fish passage culvert and details are included in **Appendix K.3**. Because Juanita Creek is a gravel bed stream, bend scour equations such as the Maynord Equation and Wattanabe Equation are not as applicable as those that were developed for use with gravel bed channels (Cramer 2012). Therefore, the Thorne Equation and the USACE Equation were evaluated for Juanita Creek, as these were developed for use in gravel streams (USACE 1994). As seen in **Figure 7-2**, bend scour was calculated at each bend within the proposed crossing.

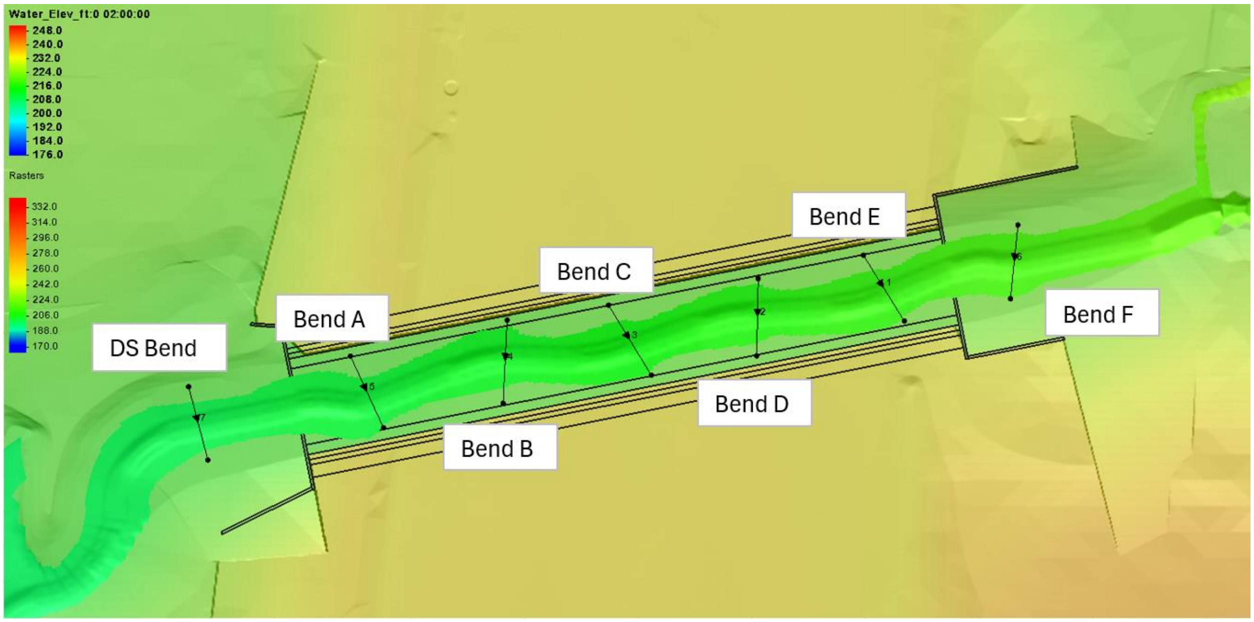


Figure 7-2. Bend scour locations

As seen in **Table 7-3**, resulting scour values for the Thorne method produce results two times higher than the USACE Method. The overall maximum bend scour estimate is 1.2 feet at the furthest upstream Bend F**,** using the Thorne Equation.

Table 7-3: Bend scour results

	Bend A	Bend B	Bend C	Bend D	Bend E	Bend F	DS Bend
Thorne Equation Scour Depth (ft)	1.0	1.1	0.8	1.1	0.6	1.2	1.0
USACE Equation Scour Depth (ft)	0.4	0.4	0.3	0.5	0.3	0.4	0.5

Scour depths for bend scour are not included in the total scour estimate because riffles and pre-scoured pools are included in the design of Juanita Creek's bedform. The residual pool depth (difference in depth between the riffle typical section and pool typical section) is 0.5 feet, which was designed to provide adequate energy dissipation and resting pools for fish. Because this residual pool depth is within the range of bend scour depths, it is not expected that scour at pools due to bends will remove material much further below the already graded pool bottoms. Bend scour is not anticipated to interact with changing bedforms because of the and the relative locations of pools and riffles are designed to be stable over time and generally hold their locations. Furthermore, the bend scour estimates are less than the total scour and minimum 3 feet of scour used for structural design and are unlikely to create a condition where this local scour extends below the total scour value because of the general stability of bedform locations.

The bend downstream of the I-405 crossing (denoted by DS Bend) was evaluated for bend scour because the stream at this location meanders and the outside of the bend is near existing fences and properties. Some property owners have already installed their own rock protection measures likely due to concerns of erosion. The more conservative estimated bend scour at this location is approximately 1 foot using the Thorne Equation. Although this calculated bend scour is not excessive, a bank protection LWM structure is included at this location to help redirect flow and help protect adjacent properties from impacts due to realigning Juanita Creek.

7.5 Total Scour

For Juanita Creek, there are three components of total scour: long-term degradation, contraction scour, and local scour in the form of abutment scour.

For Juanita Creek, all flows were evaluated up to the 500-year flow. Of all returns periods up to and including the 2080 100-year event, the 25-year event produced the largest scour of 0.53 feet, and is thus considered the scour design flood. The scour check flood is the 500-year event and produced a deeper scour of 1.04 feet. This 1.04-foot depth is applied below the channel thalweg and horizontally to the structure walls due to the risk of lateral migration over the lifespan of the crossing structure. Per the WSDOT *Hydraulics Manual* (WSDOT 2022a), a minimum scour depth of 3 feet shall be used for all 3-sided water crossing structures. Because the estimated total scour is less than 3 feet, the minimum value is reported for total scour.

Calculated total depths of scour for the scour design flood and scour check flood at the proposed Juanita Creek crossing are summarized in **Table 7-4**, and shown on the drawings, which are provided in **Appendix D.**

Table 7-4: Scour analysis summary

Calculated Scour Components and Total Scour for Juanita Creek		
Long-term degradation (ft)	0.12	
	Scour design flood	**Scour check flood**
HEC-18 contraction scour (ft)	0	0
NCHRP 24-20 contraction and abutment scour (ft)	0.53	1.04
Total depth of scour (ft)	0.65	1.16
WSDOT minimum scour depth (ft)	3	

8 Scour Countermeasures

As described in **Section 7.5**, the scour analysis shows no contraction scour and minimal local abutment scour. However, the scour analysis did not consider the various channel complexity features that were added to mitigate the potential for long-term degradation (see **Sections 4.3.2** and **7.5**).

No countermeasures are recommended to protect the abutments from scour at the Juanita Creek crossing of I-405.

9 Summary

Table 9-1 presents a summary of the results of this FHD Report.

Table 9-1: Report summary

Stream Crossing Category	Element	Value	Report Location
Habitat gain	Total length	1,309 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	varies	2.7.2 Channel Geometry
	Concurrence BFW	12 feet	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	12.08 feet	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	2.11	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100-year flow existing/proposed	41 cfs/111 cfs	3 Hydrology and Peak Flow Estimates
	2080 100-year flow existing/proposed	50 cfs/135 cfs	3 Hydrology and Peak Flow Estimates
	2080 100-year used for design	Yes	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	No	2.1 Site Description
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	3.0%	2.6.2 Existing Conditions
	Reference reach	1.7%	2.7.1 Reference Reach Selection
	Proposed	3.0%	4.1.3 Channel Gradient
Hydraulic width	Existing	12 feet	2.7.2 Channel Geometry
	Proposed	23 feet	4.2.2 Hydraulic Width
	Added for climate resilience	Yes	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3 feet	4.2.3 Vertical Clearance
	Required freeboard applied to 100-year or 2080 100-year	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	10 feet	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	358.6 feet	2.6.2 Existing Conditions
	Proposed	250 feet	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Buried (bottomless)	4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	Yes	4.3.2 Channel Complexity

Stream Crossing Category	Element	Value	Report Location
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	Yes	4.3.2 Channel Complexity
	Meander bars	4	4.3.2 Channel Complexity
	Boulder clusters	4	4.3.2 Channel Complexity
	Coarse bands	No	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.4 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Evaluation
Scour	Analysis	See link	7 Final Scour Analysis
	Scour countermeasures	No	8 Scour Countermeasures
Channel degradation	Potential?	0.12 feet	7.2 Long-term Degradation of the Channel Bed
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

References

Aquaveo. 2024. SMS Version 13.3.10.

Arcement, G. J. Jr. and Schneider, V. R. 1984. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*. U.S. Geological Survey Water-Supply Paper 2339.

Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. *Water Crossing Design Guidelines*. Washington State Department of Fish and Wildlife. Olympia, Washington.

Bathurst, J. C. 1987. *Critical conditions for bed material movement in steep, boulder-bed streams*. International Association of Hydrological Sciences Publication 165: 309-318.

City of Kirkland, Northwest Hydraulic Consultants (NHC), WSDOT. 2022. *Technical Memorandum – Juanita Creek Hydrology Hydraulics Study*. I-405 Brickyard Park and Ride Inline Freeway Station BRT Project.

City of Kirkland. 2023. Juanita Creek Watershed Report Card. Retrieved in June 2024 from https://www.kirklandwa.gov/files/sharedassets/public/v/1/public-works/surface-water/watershed-report-cards/2023-juanita-creek-report-card.pdf.

Cramer, Michelle L. (managing editor). 2012. *Stream Habitat Restoration Guidelines*. Co-published by the Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, and the U.S. Fish and Wildlife Service. Olympia, Washington.

FHWA (Federal Highway Administration). 2012. *Hydraulic Engineering Circular No. 20 – Stream Stability at Highway Structures, Fourth Edition*. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif12004.pdfUSGS.

Fox, Martin, and Susan Bolton. 2007. *A Regional and Geomorphic Reference for Quantities and Volumes of Instream Wood in Unmanaged Forests Basins of Washington Stat. North American Journal of Fisheries Management.* Vol. 27, Issue 1. Pg. 342–359.

King County. 2002b. Habitat Inventory and Assessment of Juanita Creek in 2000. Prepared by S. Rush, K. Fevold, and C. May (April 2002) for King County Department of Natural Resources and Parks, Water and Land Resources Division; and City of Kirkland, Washington.

King County. 2018a. Stream Report: Juanita Creek – 0446. Retrieved in December 2018 from https://green2.kingcounty.gov/streamsdata/watershedinfo.aspx?Locator=0446.

Lagasse, P.F., P.E. Clopper, J.E. Pagan-Ortiz, L.W. Zevenbergen, L.A. Arneson, J.D. Schall, L.G. Girard. 2009. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance—Third Edition*. Federal Highway Administration. Fort Collins, Colorado. Publication FHWA-NHI-09-111.

NLCD (National Land Cover Database). 2021. "NLCD 2021 Land Cover (CONUS)." *Multi-Resolution Land Characteristic Consortium.* Accessed at: https://www.mrlc.gov/data?f%5B0%5D=category%3ALand%20Cover.

NRCS (Natural Resources Conservation Service). 2007. *National Engineering Handbook, Part 654: Stream Restoration Design, Chapter 12. Channel Alignment and Variability Design*. US Department of Agriculture, NRCS (210–VI–NEH, August 2007).

Rafferty, Michael. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* US Department of Agriculture, U.S. Forest Service (TN-103.2, April 2017).

Saldi-Caromile, K., K. Bates, P. Skidmore, J. Barenti, D. Pineo. 2004. *Stream Habitat Restoration Guidelines: Final Draft*. Co-published by the Washington Departments of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service. Olympia, Washington.

Soar, P.J. and C.R. Thorne. 2001. *Channel Restoration Design for Meandering Rivers*. Coastal and Hydraulics Laboratory, US Army Engineer Research and Development Center, Vicksburg, MS.

USACE (United States Army Corps of Engineers). 1994. *Hydraulic Design of Flood Control Channels, EM 1110-2-1601*. Washington D.C.

USBR (United States Department of the Interior, Bureau of Reclamation). 2015. Bank Stabilization Design Guidelines. Report No.: SRH-2015-25. Technical Service Center. Denver, Colorado.

USBR. 2024. SRH-2D Version 3.6.5.

Pemberton, E.L., and Lara J.M. 1984. *Computing Degradation and Local Scour – Technical Guideline for Bureau of Reclamation.* Bureau of Reclamation Engineering and Research Center. Denver, Colorado.

Rafferty, Michael. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* United States Forest Service. https://www.fs.usda.gov/biology/nsaec/assets/rafferty_usfs_nsaec_tn-103-2_stabilitylargewoodstructurestool.pdf.

USDA (United States Department of Agriculture). 2022. Gridded Soil Survey Geographic (gSSURGO) Database for Washington. United States Department of Agriculture, Natural Resources Conservation Service. Accessed at: https://gdg.sc.egov.usda.gov/. September 8, 2022.

USFS (United States Forest Service). 2008. *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. Forest Service Stream-Simulation Working Group. May. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm91_054564.pdf

USGS (United States Geological Survey). 2023. National Geologic Map Database. https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

USGS. 2019. The StreamStats program, online at http://streamstats.usgs.gov, accessed on December 18, 2023.

WDFW. (Washington Department of Fish and Wildlife). 2019a. *Fish Passage and Surface Water Diversion Screening Assessment and Prioritization Manual.* Olympia, Washington.

WDFW. 2019b. SalmonScape. online mapper. Accessed at: http://apps.WDFW.wa.gov/ salmonscape/.

WDFW. 2019c. Washington State Fish Passage. Website accessed online: https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html

WDFW. 2019d. *Fish Passage and Diversion Screening Inventory Database Report.* Fish Passage Map Application. Retrieved in February 2019 from https://geodataservices.wdfw.wa.gov/hp/fishpassage/index.html.

WDFW. 2019e. Spawning Ground Survey Database (SGS). Washington Department of Fish and Wildlife, Olympia, WA. Data received on March 7, 2019.

WGS (Washington Geological Survey). 2023. King County West 2021 Dataset. http://lidarportal.dnr.wa.gov/, accessed on December 15, 2023.

WSDNR (Washington State Department of Natural Resources). 2019. Geology GIS Data and Databases. Accessed at: https://www.dnr.wa.gov/programs-and-services/geology/publications-and-data/gis-data-and-databases.

WSDOE (Washington State Department of Ecology). 2019. Water Quality Assessment. Retrieved in February 2019 from https://ecology.wa.gov/Water-Shorelines/Water-quality/ Water-improvement/Assessment-of-state-waters-303d.

WSDOT (Washington State Department of Transportation). 2002. *I-405 Corridor Program Final Recommendation Report*. https://wsdot.wa.gov/sites/default/files/2021-11/I405RecommendationReport2002.pdf.

WSDOT (Washington State Department of Transportation). 2022a. *Hydraulics Manual*. Olympia, Washington. Publication M 23-03.07.

WSDOT. 2022b. *Standard Specifications for Road, Bridge, and Municipal Construction*. Olympia, Washington. Publication M 41-10.

Yochum, S.E., F. Comiti, E. Wohl, G.C.L David, L. Mao. 2014. *Photographic guidance for selecting flow resistance coefficients in high-gradient channels*. Gen. Tech. Rep. RMRS-GTR-323. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning’s Calculations

Appendix F: Large Woody Material Calculations

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Not applicable.

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Not applicable.

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