SR 527 MP 2.76 Queensborough Creek (WDFW ID): 993084
Final Hydraulic Design Report

Yacoub Raheem, PE, Water Resources Engineer
WSDOT Fish Passage and Stream Restoration Design Certification #FPT20-18166
WSDOT Scour Certification #SCR23-08666
AECOM Portland, OR

Meredith Cote, PE, Water Resources Engineer, AECOM Seattle, WA
Samuel Boyce, PE, Water Resources Engineer, AECOM Oakland, CA
Grace Tandus, EIT, Water Resources Engineer, AECOM Oakland, CA
Seth Gentzler, PE, Water Resources Engineer, AECOM Oakland, CA
Steve McNeely, PE, Fluvial Geomorphologist, AECOM Oakland, CA
Andy Clodfelter, Fish Biologist & ESA Specialist, AECOM Portland, OR

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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 State Route (SR) 527 crossing of Queensborough Creek at SR 527 milepost (MP) 2.76 in 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 ID 993084); it has an estimated 1,139 linear feet of potential habitat gain (WDFW 2021a).

There is another fish barrier along Queensborough Creek, approximately 750 linear feet upstream of the SR 527 crossing at Interstate 405 (I-405) MP 26.90 (WDFW ID 993109). It should be noted that to realize the potential habitat gain upstream at the SR 527 crossing, the fish barrier upstream at I-405 is also being replaced with a similar improved fish passage structure. As described in the WDFW Level A assessment for these barriers the total habitat gained from correcting both fish barriers along Queensborough Creek is approximately 6,663 linear feet (WDFW 2021b).

As part of the overall project described below, the barrier at I-405 will be replaced, and a separate final hydraulic design (FHD) report for that crossing has been developed (AECOM 2024).

The Queensborough Creek stream crossings discussed herein are 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 SR 522 Vicinity to SR 527 Express Toll Lanes Improvement Project* (Project) is intended to improve safety and reduce congestion along I-405 between SR 522 and SR 527, address increasing traffic congestion, and improve transit reliability on I-405 in the cities of Kirkland and Bothell.

The overall Project will include following improvements:

- A dual express toll lanes (ETL) system will be created from MP 21.79 (south of the I-405/SR 522 interchange) to MP 27.06 (just north of the I-405/SR 527 interchange).
- The existing lanes will be restriped, and I-405 will be resurfaced and widened 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 in-line 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 in-line 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 *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. According to Section 9 of the injunction, WSDOT is required to design and build a restored stream connection at each identified barrier to pass all species of salmon at all life stages at all flows where the fish would naturally seek passage. To that end, WSDOT evaluated design options as defined in Section 9 of the injunction. WSDOT is proposing to replace the existing culvert with a crossing structure designed using the stream simulation methodology, with site-specific dimensions established to maximize stream restoration through the crossing. The stream simulation culvert described herein restores stream connection under the roadway and simulates natural stream functions within the proposed structure that meet the terms of the injunction.

The crossing is in Snohomish County, in the immediate vicinity of the I-405 and SR 527 interchange in the City of Bothell, Washington, which is in WRIA-8. I-405 runs in a southeast-to-northwest direction at this location. Queensborough Creek generally flows from west to east beginning in the Queensborough/Brentwood neighborhood, west of the interstate and is about 1,600 feet from its confluence with North Creek at the SR 527 crossing (**Figure 1-1**).

The proposed Project will replace the existing 215-foot-long, 48-inch corrugated steel pipe (CST) under SR 527 with a buried structure designed to accommodate a minimum hydraulic width of 20 feet and an overall structure open span (i.e., structure-free width) of 30 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation criteria described in the WDFW *Water Crossing Design Guidelines* (Barnard et al. 2013). This design also meets the requirements of the *Hydraulics Manual* (WSDOT 2022a).

This approach has been agreed on by WSDOT, WDFW, the National Marine Fisheries Service, and the Muckleshoot Indian Tribe Fisheries Division (MITFD) during preliminary design and permitting.

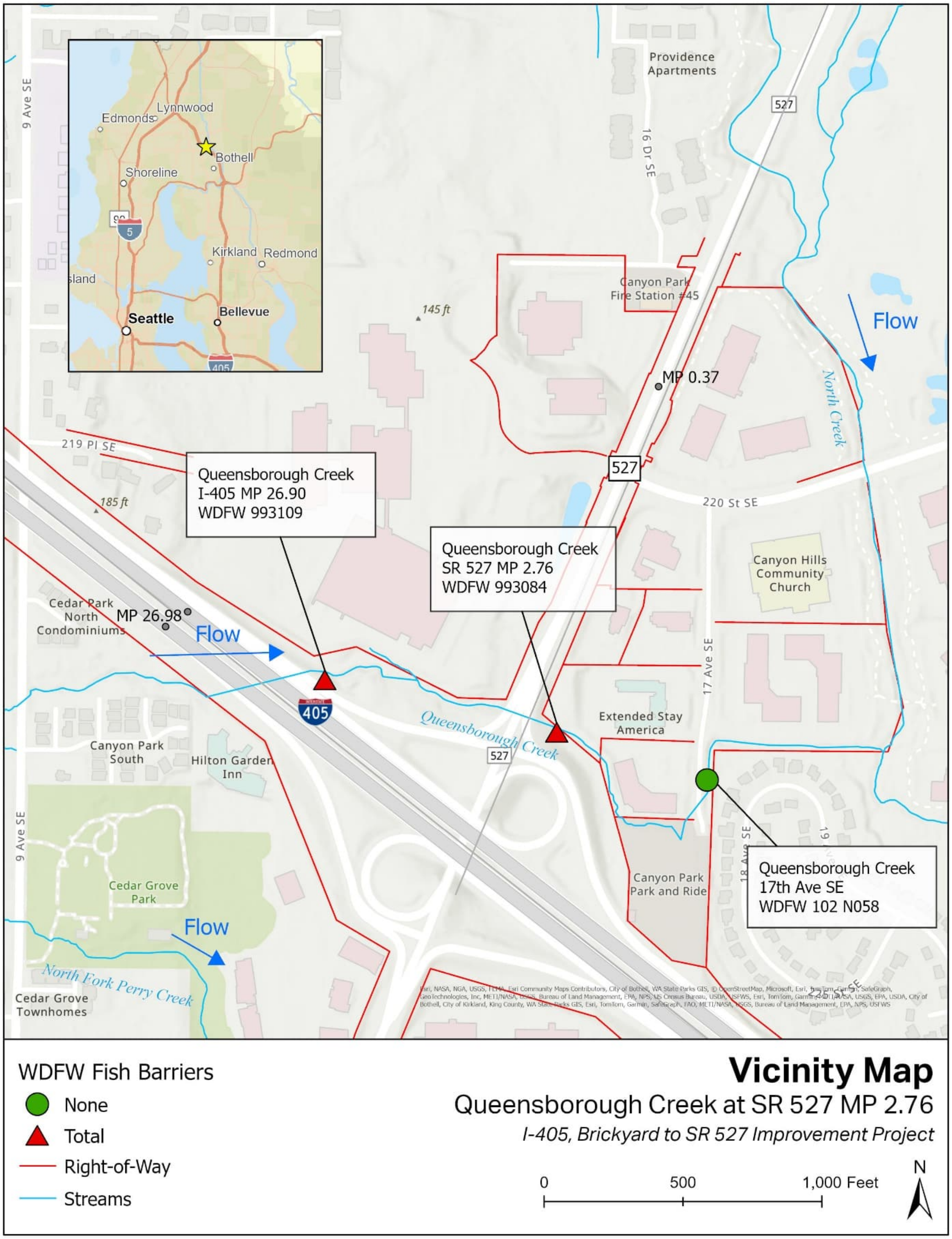


Figure 1-1: Vicinity map

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 using site visits and desktop research. Resources included the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and Washington Department of Fish and Wildlife (WDFW), along with past observations, maintenance records, and fish passage evaluations.

2.1 Site Description

Queensborough Creek originates approximately 4,950 feet west of the SR 527 crossing (WDFW ID 993084), in a residential area, and extends slightly over a mile in length before converging with North Creek (WDFW 2021b). The existing culvert at the SR 527 crossing (WDFW ID 993084) is 215 feet long and is a complete barrier to fish because it has a slope of 2.57 percent and is greater than 59 feet long (WDFW 2021a). There is no water surface drop at the outlet. There is an apron at the upstream end of the culvert. The culvert is not countersunk. There was sediment built up at the outlet of SR 527, indicating sediment along some portion of the culvert; however, no sediment was present at the inlet. The culvert was not observed to induce backwater effects or slow the flow of water along its span. However, backwatering is observed in the existing conditions hydraulic model (see **Section 5.2**). There is 20 feet of road fill atop the culvert. The invert of the culvert under SR 527 is positioned approximately 750 feet downstream of the outlet of the I-405 crossing measured along the existing stream centerline. The existing culvert has an inlet elevation of 120.2 feet above mean sea level and an outlet elevation of 117.3 feet above mean sea level with respect to the North American Vertical Datum of 1988 (NAVD 88). It is noted that the inlet and outlet elevations, from a 2024 field survey, indicate the existing culvert has a slope of 1.35 percent, which does not agree with previous measurements (WDFW 2021a; WSDOT 2021).

Seven additional fish barriers have been identified on Queensborough Creek outside the Project area that are not proposed for correction as part of the Project. Six potential fish barriers are found upstream of the I-405 crossing—one dam (WDFW ID 930787) that has been assessed as passable and five culverts. Two culverts are owned by the City of Bothell (WDFW IDs 102 N121 and 102 N124) and are identified as total fish passage blockages. Three additional culverts are privately owned (WDFW IDs 930788, 930790, 930871) and are identified as partial fish passage blockages. All six features are located between 9th Avenue SE and 4th Avenue SE, approximately 600 to 1,800 feet upstream of the I-405 crossing. Downstream of the Project, Queensborough Creek flows through one fish-passable culvert at 17th Avenue SE (WDFW ID 102 N058) owned by the City of Bothell before reaching its confluence with North Creek. There are no known plans to replace the 17th Avenue culvert.

Replacing the existing culvert at SR 527 (WDFW ID 993084) will provide an estimated 1,139 linear feet of potential habitat gain (WDFW 2021a). As described in **Section 1**, replacing both the SR 527 culvert and the I-405 culvert (WDFW ID 993109) will provide an estimated 6,663 linear feet of potential habitat gain (WDFW 2021b). See **Appendix R** for WDFW Fish Passage and Diversion Screening Database Reports.

The City of Bothell performs regular stream health monitoring on Queensborough Creek, but no restoration efforts were identified at the time of this report.

Past maintenance records do not indicate that there are ongoing maintenance problems at the existing structure, see **Section 4.2.3.1** for more details.

The Queensborough Creek crossing at SR 527 MP 2.76 is not in a mapped floodplain, as shown in **Appendix A** on FEMA Flood Insurance Rate Map Number 53061C1337, revised November 8, 1999 (FEMA 2019). The proposed structures are anticipated to improve capacity of the crossings compared to existing conditions by reducing the crossing slope and increasing the hydraulic width. Changes between existing and proposed water surface elevations (WSEs) are evaluated based on hydraulic modeling described in **Section 5**, and discussed in a separate flood risk assessment (FRA); see **Appendix L**.

2.2 Watershed and Land Cover

Queensborough Creek is in the City of Bothell, Snohomish County. The contributing watershed for the SR 527 crossing has an area of approximately 0.57 square miles and receives mean annual precipitation of 39.6 inches (USGS 2024).

Queensborough Creek is a tributary to North Creek, which is in turn a tributary to the Sammamish River, and is in the lower elevations of Water Resource Inventory Area 8 (WRIA-8). WRIA-8 comprises a 692-square-mile watershed that funnels all rivers, streams, and other water courses into Lake Washington, which then discharges to Puget Sound via Lake Union at Shilshole Bay. There are three major drainage basins within WRIA-8: the Cedar River, the Sammamish River, and the Lake Washington Basin.

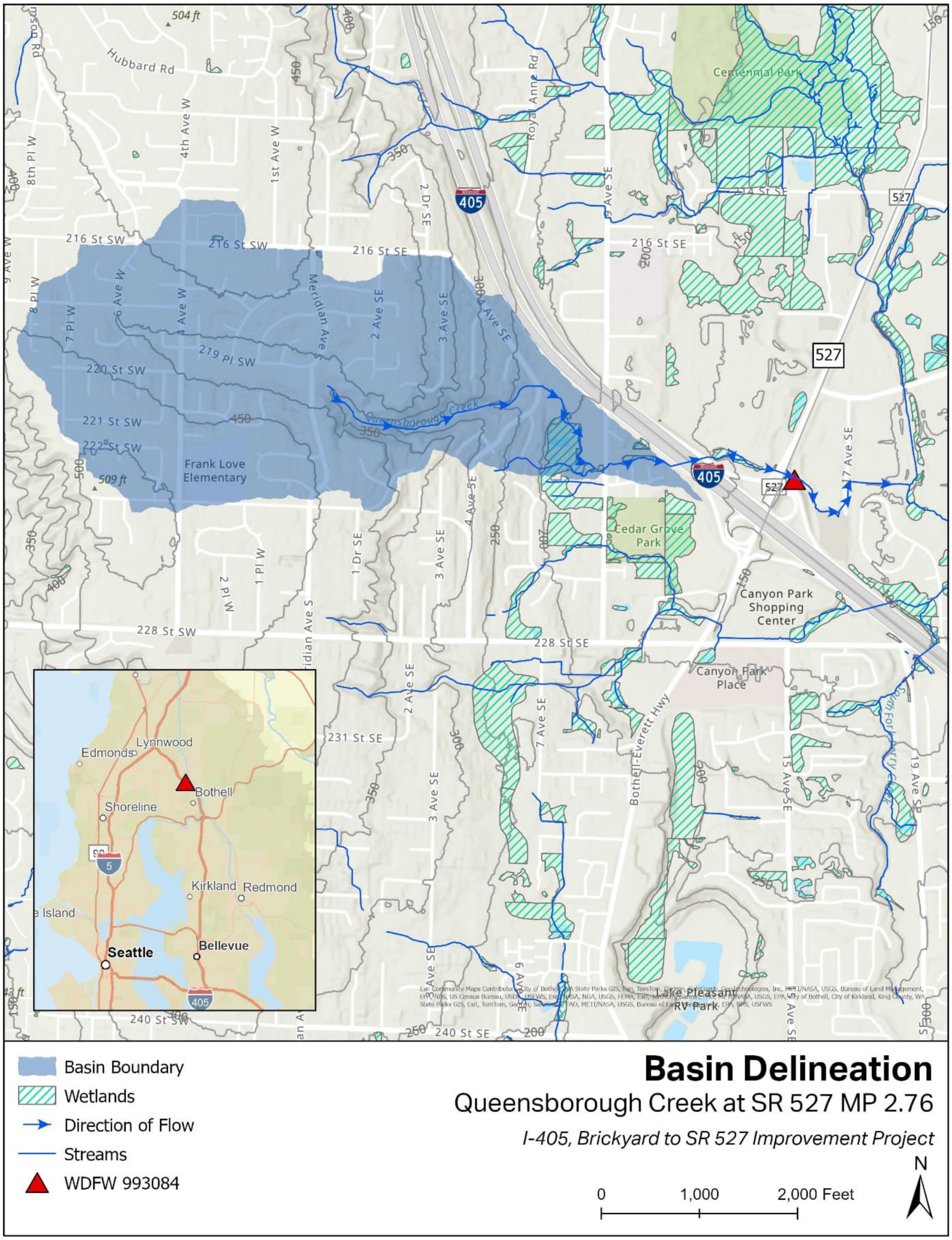
The watershed boundary shown in **Figure 2-1** was delineated using 2-foot contours generated from the 2016 King County Light Detection and Ranging (LiDAR) dataset and City of Bothell stormwater utility data. Topographic elevations are defined by the NAVD 88 datum.

The watershed is a mix of impervious surfaces, predominately residential and commercial development, mixed-canopy forested areas, and other pervious surfaces. A land cover map of the Queensborough Creek watershed is shown in **Figure 2-2** (NLCD 2021). A summary of the land use for the SR 527 crossing is provided in **Table 2-1**.

Table 2-1: Land cover

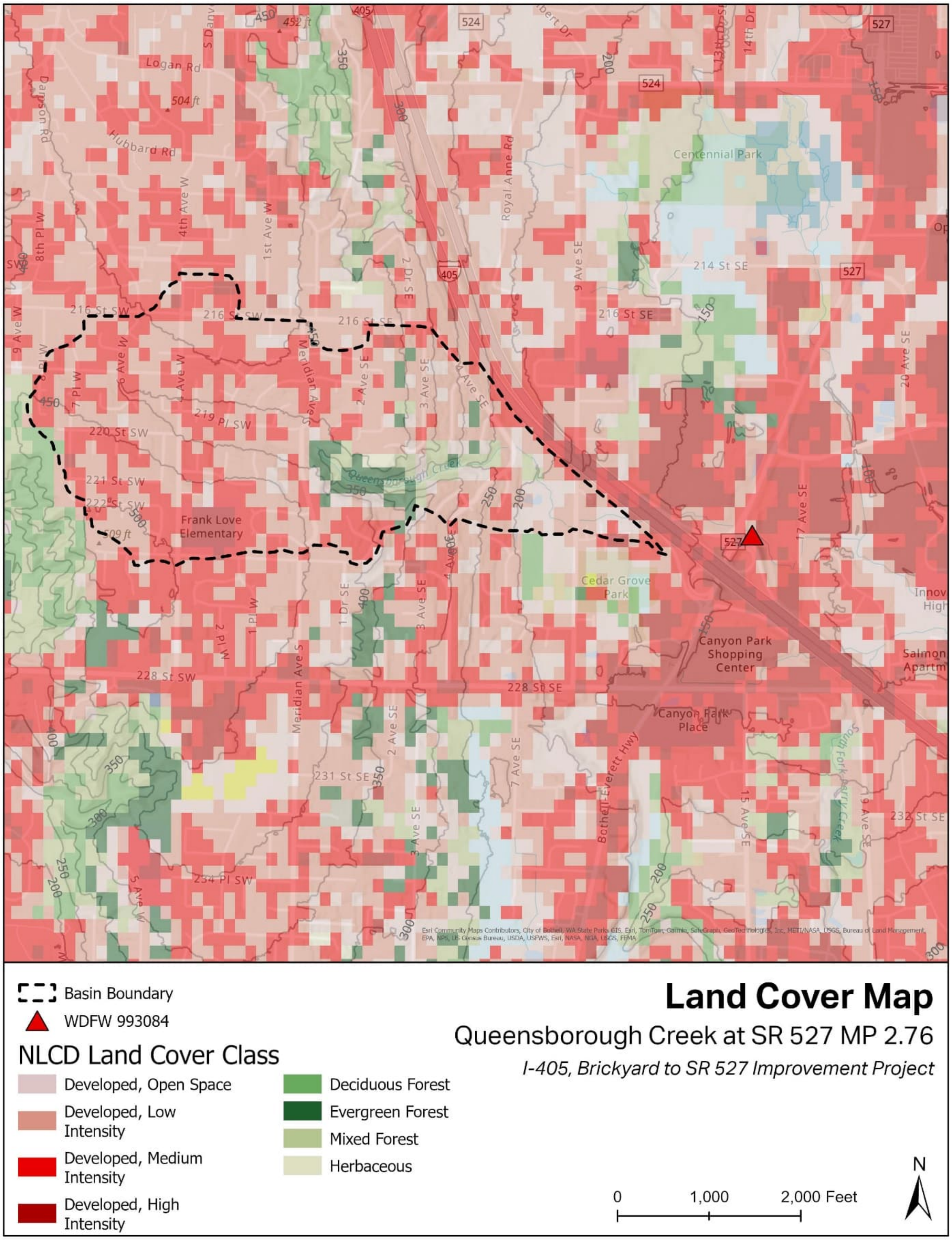
Land Cover Class	Basin Coverage (%)
Developed, open space	7.8
Developed, low intensity	46.6
Developed, medium intensity	34.1
Developed, high intensity	2.8
Deciduous forest	0.3
Evergreen forest	4.1
Mixed forest	3.9
Herbaceous	0.4

Note that I-405 runoff is collected and conveyed to stormwater pond facilities in the I-405/SR 527 interchange for runoff treatment and flow control. Flow collected in this system discharges to Queensborough Creek on the downstream side of the SR 527 crossing. Commercial developments in the area also collect their site stormwater and convey associated runoff into Queensborough Creek on the downstream side of the 17th Avenue crossing. The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible. As stated in the *Preliminary Technical Information Report* (Perteet 2024), "[t]he result of stormwater management…has resulted in the channel receiving very little additional stormwater runoff from the densely overgrown area between the two crossings." Therefore, the basin area and associated flow peaks are assumed the same for both the I-405 and SR 527 crossings (WDFW IDs 993109 and 993084, respectively). This assumption is supported by the USGS (2024) StreamStats web application, which indicates a difference in 100-year discharge of approximately 1.0 cfs between the two crossings.



Note: The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible.

Figure 2-1: Watershed map



Note: The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible.

Figure 2-2: Land cover map

2.3 Geology and Soils

For this report, geology at the stream crossing was assessed using the Washington State Department of Natural Resources Geology geographic information system (GIS) Database (WSDNR 2024), and the USGS National Geologic Map Database (USGS 2023). **Figure 2-3** shows a map of the geology in and around the Queensborough Creek watershed.

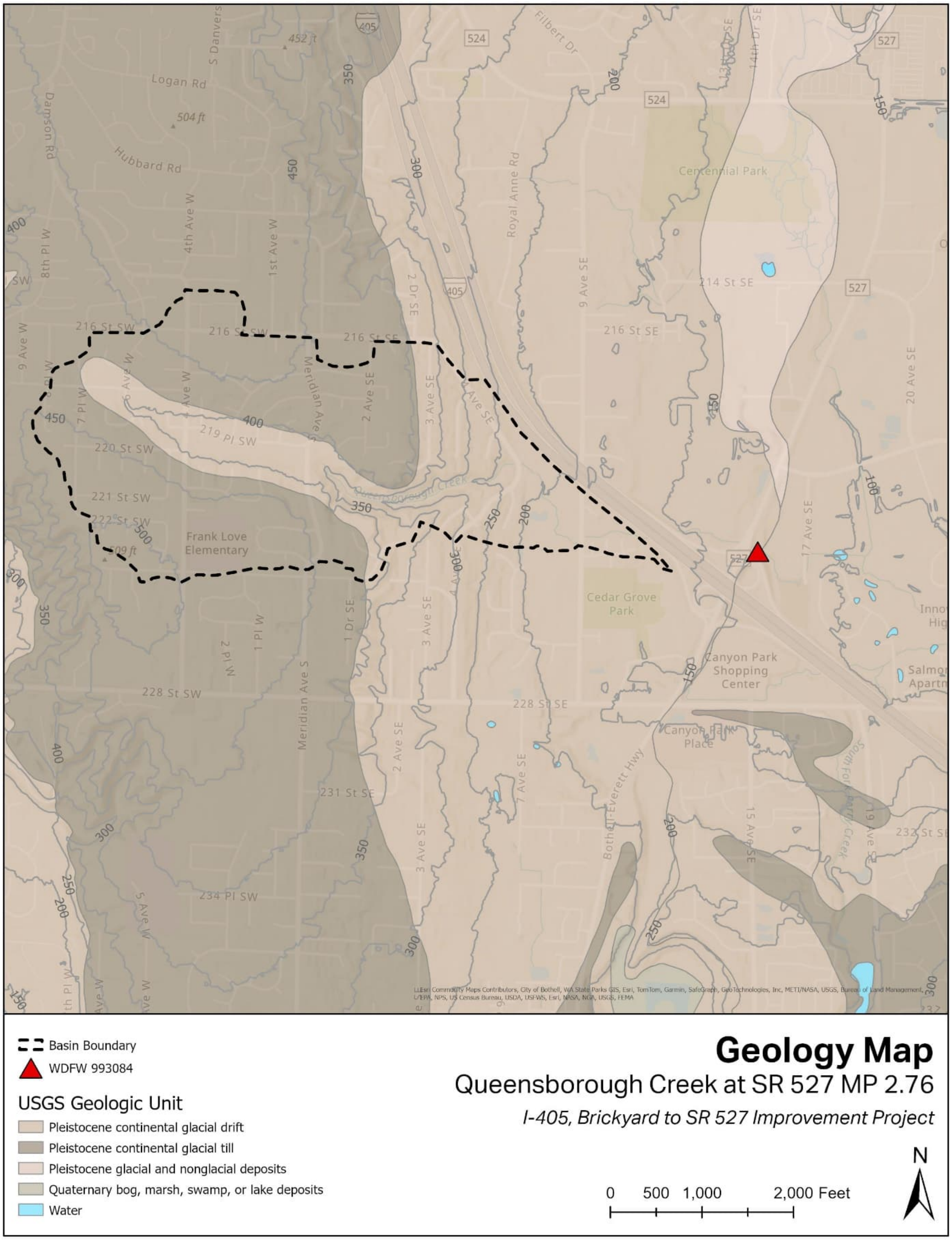
A geologic study from Western Washington State College (Capps et al. 1973) reports that the uppermost layers in the region of the crossing are primarily post-glacial fluvial sediments – clay, silt, and sand originating from flooding activity from the Snohomish and Sammamish Rivers. These fluvial deposits sit atop layers of gravel and a densely compacted hardpan.

USGS map MF-1747 confirms that the areas surrounding the Queensborough Creek crossings are composed of Vashon drift which consists of clean gray deposits of stratified glacial sand and gravel (USGS 1985). More specifically, downstream of the SR 527 crossing (WDFW ID 993084), is Recessional outwash (Q_{vr}), which consists of loose, permeable, stratified sand and gravel with well-draining sediments. Upstream of the SR 527 crossing is Advance outwash (Q_{va}), which has deposits of well stratified, unconsolidated sand with pebbles and some cobbles.

Another component of Vashon drift found in the Queensborough Creek watershed is till (Q_{vt}) – a nonsorted mixture of mud, sand, pebbles, cobbles, and boulders, which looks like concrete mix, and is commonly called hardpan (USGS 1985). Drainage of Vashon till is good in the top 3-6 feet of weathered material, but ponding and lateral movement of water occurs along the surface of the hardpan.

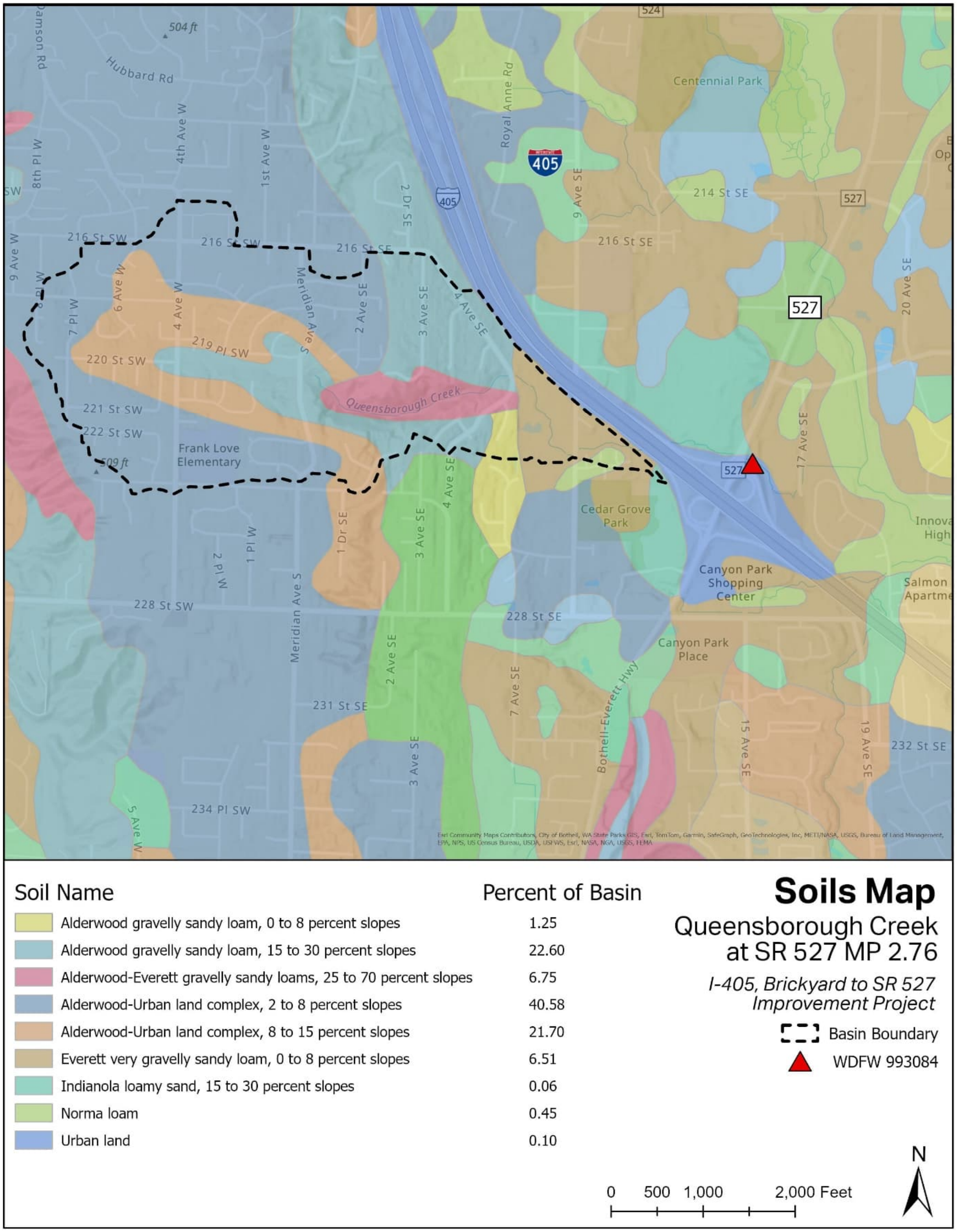
The basin has low to very low susceptibility for liquefaction (Mickelson et al. 2018). The soil assessments conducted at the crossing were done using the United States Department of Agriculture’s Gridded Soil Survey Geographic Database (USDA 2022). Soils mapped in the area are primarily outwash soils deposited from glacial activity and some alluvial soils. These include Indianola loamy sand, which is observed upstream of the SR 527 crossing, and Alderwood gravelly sandy loam and Alderwood urban land complex, which are seen downstream of the crossing. Undeveloped ground is vegetated, suggesting a relatively low risk of erosion and sediment runoff. Given the prevailing loam constitution of the soil, the likelihood of landslides is low. **Figure 2-4** shows the soils map for the Queensborough Creek watershed and crossings.

The geologic and soil assessments summarized here, are used with information provided in the *RFC Geotechnical Engineering Report, Design Package 8* dated January 8, 2025, developed by Terracon (2025), for the evaluation of lateral migration and long-term degradation at the fish passage structures; see **Section 7**.



Note: The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible.

Figure 2-3: Geologic map



Note: The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible.

Figure 2-4: Soils map

2.4 Fish Presence in the Project Area

Numerous data sources were reviewed to evaluate potential presence of anadromous and resident fish species in Queensborough Creek and the project area. These include the Washington State Fish Passage tool (WDFW 2025a), WDFW online SalmonScape application (WDFW 2025b), WDFW Priority Habitats and Species mapper (WDFW 2025c), Statewide Integrated Fish Distribution (SWIFD) online mapper (NWIFC 2025), and the National Marine Fisheries Service (NMFS) Protected Resources App (NMFS 2025).

These data sources do not document presence of any anadromous or resident salmonids in Queensborough Creek, upstream or downstream from the SR 527 crossing (WDFW ID 993084). However, based on (1) documented presence of anadromous salmonids downstream in North Creek, (2) lack of downstream fish passage barriers, and (3) gradient accessible habitat at the project site, it is possible that Endangered Species Act (ESA)-listed populations of fall Chinook salmon (*Oncorhynchus tshawytsha*) and winter steelhead (*O. mykiss*), as well as non-listed populations of coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*) could migrate into the project area (NMFS 2025; NWIFC 2025; WDFW 2025a,b).

It is noted that the WDFW culvert assessment report for the SR 527 crossing (WDFW ID 993084) did not include Chinook salmon as one of the priority index species that might be present at the project site, despite the stream reach being modeled as gradient accessible for Chinook salmon (WDFW 2021a; **Appendix R**).

Queensborough Creek is a tributary to North Creek and the confluence is located approximately 1,600 feet downstream of the SR 527 crossing (WDFW ID 993084). North Creek is known to support fall Chinook salmon, coho salmon, sockeye/kokanee salmon, winter steelhead, and coastal cutthroat trout (*O. clarkii clarkii*) (WDFW 2025b). One fish-passable culvert (WDFW ID 102 N058) is located at the 17th Avenue SE crossing of Queensborough Creek, downstream from the project site. Queensborough Creek is modeled as gradient accessible up to 350 feet downstream from the project site. However, WDFW biologists have determined that fish passage improvements at the SR 527 crossing could result in up to 2,031 meters (6,663 feet) of potential habitat gain if fish passage is improved upstream of the project site (WDFW 2021a).

Table 2-2 lists native fish species potentially present in Queensborough Creek. Modeled habitat is based on a qualification of NWIFC SSHIAP gradient segments which were originally mapped from USGS 7.5-minute Topographic Quadrangle maps. This includes habitat upstream of known species presence, but downstream of any known natural barrier (WDFW 2014).

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

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Chinook salmon (*O. tshawytscha*)	Modeled	SalmonScape [a], SWIFD [b]	Threatened
Coho salmon (*O. kisutch*)	Modeled	SalmonScape [a]; SWIFD [b], WDFW ID 993084 Culvert Assessment [c]	Species of Concern
Sockeye/kokanee salmon (*O. nerka)*	Modeled	SalmonScape [a]; SWIFD [b], WDFW ID 993084 Culvert Assessment [c]	None
Winter steelhead (*O. mykiss*)	Modeled	SalmonScape [a], SWIFD [b], WDFW ID 993084 Culvert Assessment [c]	Threatened
Resident and sea-run cutthroat trout (*O. clarkii clarkii*)	Potential (not modeled)	WDFW ID 993084 Culvert Assessment [c]	None

Notes: ESA = Endangered Species Act; WDFW = Washington Department of Fish and Wildlife. 'Modeled' presence indicates that fish species have not been documented in the project area but there is potential for presence because the stream profile gradient downstream is suitable for fish passage.

Sources: [a] WDFW 2025b

[b] NWIFC 2025

[c] WDFW 2021a

2.5 Wildlife Connectivity

The 1-mile-long segment of SR 527 nearest the Queensborough Creek crossing does not have a priority status for ecological stewardship or wildlife-related safety according to the WSDOT headquarters (HQ) ESO (WSDOT 2018). A wildlife connectivity memorandum will not be provided at 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

On July 1, 2019, WSDOT, WDFW, and MITFD conducted a site assessment at Queensborough Creek to determine and concur on field-measured bankfull widths, discuss possible alternatives for the proposed crossing, and observe existing site conditions.

As described in **Section 2.1**, the existing culvert at SR 527 MP 2.76 (WDFW ID 993084) is 215 feet long, with a slope of 2.57 percent. There is a scour hole at the culvert outlet that is approximately 10.0 feet long, 9.5 feet wide, and 2 feet deep; there is no water surface elevation drop. There is approximately 20 feet of road fill above the culvert (WDFW 2021a).

In addition to bankfull width measurements, WSDOT also conducted three Wolman pebble counts at unidentified locations upstream of the I-405 crossing. See **Section 2.7.2** and **Section 2.7.3** for bankfull width and pebble count results, respectively.

On December 6, 2023, AECOM completed a site visit to confirm site conditions and document any changes evident in the field since the 2019 assessment. Three bankfull width measurements were taken upstream of the I-405 crossing (WDFW 993109), two were taken between the I-405 and SR 527 crossings, and two more bankfull measurements were taken downstream of the SR 527 crossing. Additionally, four grab samples were taken from the creek bank, one upstream of I-405, two upstream of SR 527, and one downstream of SR 527. The approximate locations of the bankfull field measurements and grab samples near the SR 527 crossing are shown in **Figure 2-5**.

Topographic survey of the stream was completed in September 2019. The diameter, length, material, and slope of the existing crossing structure were measured during this survey effort and corroborate the data provided in the WDFW *Fish Passage and Diversion Screening Inventory Database Reports* (**Appendix R**).

An additional topographic survey of Queensborough Creek was conducted in December 2023 and February 2024 by 1Alliance Geomatics from approximately 300 feet upstream of the I-405 crossing, to approximately 100 feet downstream of the SR 527 crossing. Cross sections were taken every 50 feet and identified tops of bank, water's edge, thalweg, and water depth at thalweg. Additionally, culvert diameter, length, and inlet and outlet elevations were measured for the existing crossings at I-405, SR 527, and 17th Avenue SE. The 2024 survey data were used to refine the topographic base map and included in the hydraulic analysis, as shown on the plan set (**Appendix D**).

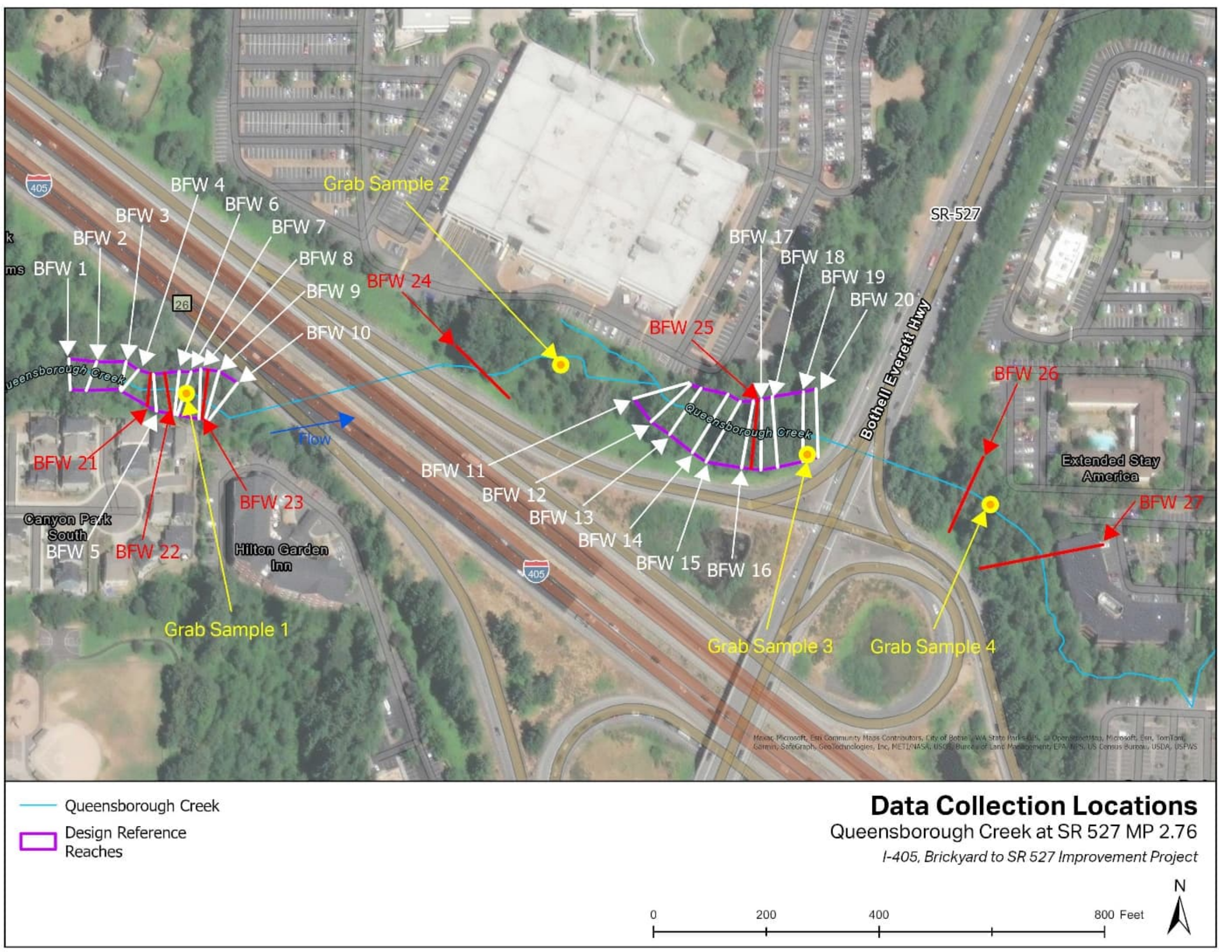


Figure 2-5: Design reference reaches bankfull width, and grab sample locations

2.6.2 Existing Conditions

As described in **Section 2.1**, Queensborough Creek originates in a residential area approximately 4,950 feet upstream of SR 527 (WDFW ID 993084), between 216th Street SW and 224th Street SW. The creek flows east through a deep, forested ravine and residential area for approximately 2,400 feet before crossing under 4th Avenue SE (WDFW ID 102 N124). From there, the creek exits the ravine and flows for approximately 1,200 feet through a mixed canopy of alder, maple, and cedar trees, crosses 9th Avenue SE (WDFW ID 102 N121), and continues approximately 600 additional feet until it enters the 42-inch CST crossing under I-405. Downstream of the I-405 crossing, the stream flows approximately 750 feet southeast through a mixed-canopy forested area before crossing under SR 527 (WDFW ID 993084) through a 48-inch CST. Downstream of the SR 527, Queensborough Creek flows approximately 1,600 feet, including one fish-passable 48-inch culvert at 17th Avenue SE (WDFW ID 102 N058), before reaching its confluence with North Creek.

The channel upstream of I-405 is slightly incised but still maintains a moderate level of floodplain connectivity at higher than 2-year storm events. It has a pool-riffle bedform, and the substrate consists of gravels and small cobbles. Between I-405 and SR 527 the stream is slightly more incised than the upper reach, with moderate-to-low floodplain connectivity at higher storm events (**Figure 2-6** and **Figure 2-7**). The stream is dominated by riffle habitat, with the substrate consisting of gravels and cobbles. After crossing under SR 527 , the creek flows through a narrow, forested area (**Figure 2-8** and **Figure 2-9**) between a business park and Canyon Park Park-and-Ride. This section of creek contains numerous downed small trees; the channel has numerous braids and is not well defined. Silts and sands dominate the substrate in this reach. After crossing under 17th Avenue SE, the creek is channelized and flows north for approximately 200 feet along 17th Avenue SE, makes a 90-degree turn, and then enters North Creek approximately 700 feet to the east. This section is highly incised and has little to no floodplain area or connectivity.

Observations of channel incision and diminished floodplain connectivity are consistent with Stage 2 (Channelized) and Stage 3 (Degradation) of the stream evolution model (SEM) proposed by Cluer and Thorne. These stages are associated with reduced hydraulic diversity and fewer habitat and ecosystem benefits than early (0-1) or late (6-8) stage channels (Cluer and Thorne 2014). However, the system generally remains connected to its floodplain at higher than 2-year storm events (**Section 2.7.2.1; Section 5**) and appears capable of substrate sorting (**Section 2.7.3**) which are both indicators of a Stage 1 (Sinuous Single Thread) stream in the SEM. Further discussion of channel incision and degradation is presented in **Section 2.7.4** and **Section 7.2**.

Figure 2-6: Queensborough Creek habitat upstream of SR 527

Figure 2-7: Inlet of Queensborough Creek under SR 527

Figure 2-8: Outlet of Queensborough Creek under SR 527

Figure 2-9: Queensborough Creek habitat downstream of SR 527

2.6.3 Fish Habitat Character and Quality

Fish habitat conditions in the project reach were evaluated during the 2019 WDFW culvert assessment (2021a) and the 2023 AECOM site assessment. Downstream of the SR 527 crossing (WDFW ID 993084), Queensborough Creek outlets into a narrow, incised channel where gravel has accumulated. This area provides some suitable substrate for spawning, although gravels are embedded with fines. This stream reach provides braided riffle/run habitat with few pools. Small woody debris is abundant in some areas, but it is only available to fish during high flows and does not play a major role in pool formation. The riparian canopy provides good shading in this reach, but signs of bank erosion were observed so shoreline plantings coupled with invasive species removal would help stabilize banks and improve riparian function. Moving further downstream, the stream channel becomes less well defined, and includes a higher percentage of fine substrates, which reduces spawning suitability. Fine sediment deposition was observed along the streambanks, as shown in **Figure 2-9**. Studies conducted by the City of Bothell have found that excessive amounts of sediment are caused by mass wasting in the upper watershed, with accumulated sediment levels ranging between 36 and 52 percent between 2010 and 2016 (Steward and Associates 2004; Bothell 2017).

Upstream of the crossing, Queensborough Creek flows through a riffle/run dominated system with few pools. Substrate is dominated by cobble/gravel substrate which provides some good potential salmonid spawning habitat. Fine substrate is still common at the upper portion of the reach (~200 feet upstream of SR 527 culvert crossing (**Figure 2-6**)**.** Some small wood and undercut banks are present that provide limited cover and complexity, but the stream reach is lacking large wood to influence pool development. As such, rearing habitat is limited. The mixed riparian forest (**Section 2.6.4**) generally provides good shading but invasive Himalayan blackberry (*Rubus armeniacus*) along the shoreline reduces habitat function. The creek flows through a small pool before dropping over a 6” log that acts as a weir at the culvert inlet (**Figure 2-7)**. The reach provides low to moderate floodplain connectivity, with most of the riparian area much higher in elevation than the small floodplain area adjacent to the stream. Through coordination with Muckleshoot Indian Tribal representatives, it is also noted that the Queensborough system upstream of 4th Avenue SE has exceptional fish habitat through an older forested ravine extending to Meridian Avenue.

The entire length of Queensborough Creek is listed on the 303(d) list for dissolved oxygen and temperature (WDOE 2025). The creek has been recorded to have high temperatures in the summer months. City of Bothell recorded 21.0°C (69.8°F) in Queensborough Creek in July 2015, which was the highest temperature recorded between 2010 and 2016, potentially creating migration barriers for adult salmon (City of Bothell 2015). Under proposed conditions, a continuous canopy of riparian and wetland tree species will provide shade along the channel, helping lower stream temperatures; see **Section 4.3.3.**

Although salmonids are not known to use Queensborough Creek, within the project area, the creek does provide areas of potential spawning habitat for most salmonids, although Chinook typically prefer larger substrates and higher water flows so are less likely to spawn in the creek. Although rearing habitat is limited due to lack of pools, cover, and complexity, some juvenile coho, steelhead, and cutthroat may be able to overwinter in the project area following construction. High water temperatures in the creek likely restrict rearing habitat for all salmonids during the summer months. Improved fish passage at the SR 527 and I-405 crossings would allow salmonids access to 2,031 meters (6,663 feet) of upstream spawning and rearing habitats if upstream fish passage barriers are removed in the future (WDFW 2021a).

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

Within the project limits, 114 total existing trees were surveyed. The diameter at breast height (DBH) of the largest trees ranges from 44 to 20 inches, indicating the possibility of both old growth and mature second growth forests. A majority of trees surveyed are Douglas fir (*Pseudotsuga menziesii*). Other existing trees recorded are big-leaf maple (*Acer macrophyllum*), western redcedar (*Thuja plicata*), pacific willow (*Salix lucida*), black walnut (*Juglans nigra*), black cottonwood (*Populus balsamifera trichocarpa*), and apple (*Malus domestica*).

A qualitative description of large woody material (LWM) potential in the Queensborough Creek system is provided below.

Immediately upstream of the SR 527 crossing, Queensborough Creek flows through a mixed canopy dominated by mature big-leaf maple (*Acer macrophyllum*) and western redcedar (*Thuja plicata*), generally located upland of the stream. Downstream of the SR 527 crossing, the canopy is primarily mature Douglas fir (*Pseudotsuga menziesii*). The riparian area, with pool-riffle morphology, is dominated by weeds including Himalayan blackberry (*Rubus armeniacus*), reed canary grass (*Phalaris arundinacea*), scotch broom (*Cytisus scoparius*), purple loosestrife (*Lythrum salicaria*), Hedge Bindweed (*Calystegia sepium*), giant hogweed (*Heracleum mantegazzianum*), Canadian thistle (*Cirsium arvense*), butterfly bush (*Buddleia davidii*), common reed (*Phragmites australis*), Japanese knotweed (*Reynoutria japonica*), and yellow flag iris (*Iris pseudacorus*). This lower reach is incised, and signs of erosion were observed.

Immediately upstream of the I-405 crossing, Queensborough Creek flows through a mixed canopy of red alder (*Alnus rubra*), big-leaf maple (*Acer macrophyllum*) and western redcedar (*Thuja plicata*), generally located upland of the stream. The riparian area is dominated by Himalayan blackberry (*Rubus armeniacus*). Upstream of 9th Avenue SE, the creek flows in a ditch through western redcedar trees and then mowed grass yards. Upstream of 4th Avenue SE, the creek flows through a mixed-conifer ravine greenbelt. This ravine is populated with large wood and the riparian area is an intact old-growth forest with minimal disturbance and high large wood recruitment potential. Upstream of Meridian Avenue S., Queensborough Creek runs through a residential neighborhood with stormwater inputs. No fish use is available in the Queensborough system upstream of the stormwater inputs due to low flows.

Queensborough Creek has a moderate likelihood of recruiting and transporting LWM. It is possible that trees adjacent to the channel could be recruited into the system upstream of 4th Avenue SE in the mixed-conifer ravine greenbelt, but transport of this LWM would likely be limited by the additional culverts upstream of I-405 as described in **Section 2.1**. LWM recruited between I-405 and SR 527, or downstream of SR 527, would likely be transport-limited by the culvert at 17th Avenue, before the confluence with North Creek. Smaller wood may be mobile through the system.

No sign of beaver activity was observed by AECOM during the December 2023 field visit.

Refer to **Section 4.3.3** for the proposed planting approach.

2.7 Geomorphology

The following sections describe the geomorphic characteristics of Queensborough Creek. The discussion of geomorphic information includes design 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.

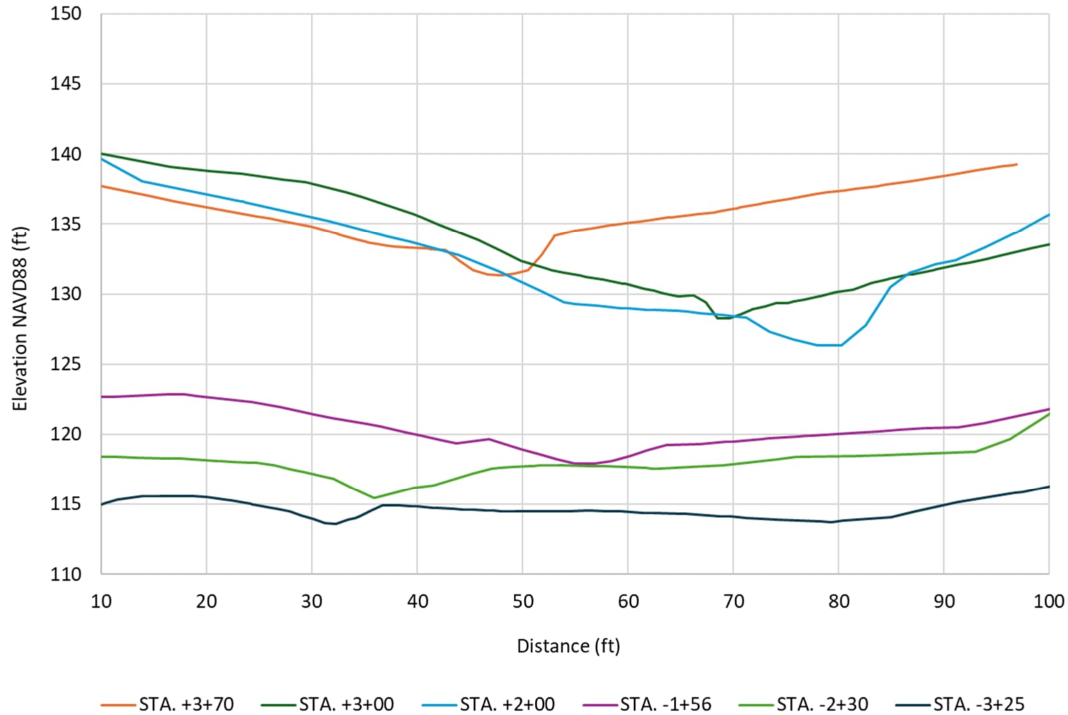
2.7.1 Design Reference Reach Selection

Queensborough Creek and the streams surrounding the proposed crossings have been impacted by urbanization and are not suitable for use as reference reaches. However, the information presented in **Sections 2.7.2** through **2.7.5** does rely on investigations of reaches immediately upstream and downstream of the I-405 (WDFW ID 993109) and SR 527 (WDFW ID 993084) crossings. Although no reference reach was identified, information gathered from reaches adjacent to the crossing will be used to inform the design (**Section 4**), and these areas may be considered the design reference reach.

2.7.2 Channel Geometry

Existing channel characteristics were determined through field survey of reaches immediately upstream and downstream of the crossing as described in **Section 2.6.1**. The 2024 field survey captured cross-section geometry at the top of bank, water edge, thalweg, channel bottom point offset of thalweg, and major grade breaks along cross sections surveyed every 50 feet and at all channel bends. Survey data of the longitudinal profile was consistent with previous assessments (WSDOT 2021) upstream of the SR 527 crossing (~2.5%) and downstream of the crossing (~2.2%).

Figure 2-10 shows three cross sections upstream and downstream of the SR 527 crossing. Proposed channel dimensions mimic these existing conditions. See **Section 4.1.1** for proposed channel planform and shape.



Notes: STA = Station. Stationing approximate, measured along stream centerline from existing culvert midpoint (WDFW ID 993084). Negative stations are downstream.

Figure 2-10: Existing cross-section examples

As described in **Section 2.6.1**, bankfull width measurements for Queensborough Creek were determined in the field on July 1, 2019, by WSDOT, WDFW, and MITFD. Bankfull width measurements were obtained from 10 locations within 500 feet upstream of the SR 527 crossing (**Table 2-3**). These measurements were taken approximately 30 feet apart. Measurements upstream of SR 527 ranged from 5.7 feet to 12.3 feet. The average bankfull width throughout the assessment area is 9.7 feet. These bankfull width measurements were corroborated during the 2023 AECOM site visit (**Figure 2-11**).

The bankfull widths reported in **Table 2-3** are understood to reflect unnaturally confined channel conditions associated with the urban setting. In coordination with WSDOT, WDFW and MITFD, a bankfull width of 10.1 feet has been accepted as the basis for completing the restored creek design.


Figure 2-11: Bankfull measurement location #15 (looking downstream)

Table 2-3: Bankfull width and depth measurements

BFW Number	Width (feet)	Depth (feet)	Included in Design Average?	Site Assessment	Concurrence Notes
Upstream of SR 527 Crossing					
11	9.0	N/A	Yes	WSDOT 2019	Stakeholder concurred
12	9.2	N/A	Yes	WSDOT 2019	Stakeholder concurred
13	12.2	N/A	Yes	WSDOT 2019	Stakeholder concurred
14	11.8	N/A	Yes	WSDOT 2019	Stakeholder concurred
15	11.4	N/A	Yes	WSDOT 2019	Stakeholder concurred
16	12.3	N/A	Yes	WSDOT 2019	Stakeholder concurred
17	5.7	N/A	Yes	WSDOT 2019	Stakeholder concurred
18	7.3	N/A	Yes	WSDOT 2019	Stakeholder concurred
19	8.6	N/A	Yes	WSDOT 2019	Stakeholder concurred
20	9.1	N/A	Yes	WSDOT 2019	Stakeholder concurred
24	5.4	0.7	No	AECOM 2023	None
25	9.2	0.3	No	AECOM 2023	None
Downstream of SR 527 Crossing					
26	8.0	0.4	No	AECOM 2023	None
27	5.9	N/A	No	AECOM 2023	None

Notes: BFW = bankfull width; N/A = not available. Field measurements upstream of I-405 (1-10 and 21-23) omitted; see I-405 MP 26.09 FHD (AECOM 2024).

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 (BFW). The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood (WSDOT 2022a). A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel.

The FUR was determined using existing conditions hydraulic model results for the 100-year flood from six locations outside of the culvert influence, three upstream and three downstream of the SR 527 crossing. Average results are summarized in **Table 2-4** and compared to the FUR previously determined by WSDOT using field measurements (WSDOT 2021); see **Appendix S** for details.

As determined by both WSDOT (2021) and AECOM, the FUR downstream of the crossing is at least two-times larger than the FUR upstream of the SR 527 crossing. This indicates there is more interaction with the floodplain downstream of the crossing. However, the average FUR value of the crossing is less than 3.0 and corresponds to a confined channel.

Table 2-4: FUR determination

Location	Source (Year)	FPW (ft)	FUR	Confined/Unconfined
Upstream	AECOM (2024)	16.5	1.6	Confined
	WSDOT (2021)	10.5	1.3	Confined
Downstream	AECOM (2024)	41.7	4.1	Unconfined
	WSDOT (2021)	23.7	2.6	Confined
Average	AECOM (2024)	58.2	2.9	Confined
	WSDOT (2021)	34.2	1.9	Confined

Notes: ft = feet; FPW = flood-prone width; FUR = floodplain utilization ratio

2.7.3 Sediment

Sediment along the streambed and banks of Queensborough Creek vary in composition. Downstream from the SR 527 crossing, substrate contained a mix of fines, gravel, and high organic material content, with the most suitable spawning substrate found just downstream from the culvert (**Section 2.6.3**). Upstream from the SR 527 crossing, substrate predominantly consisted of gravels and cobbles. Additionally, it was evident that sands and fines were being conveyed through the system. There were several sand bars noted downstream from the culvert, and most of the banks directly adjacent to the creek consisted of sand and silt. Due to heavy sediment loading in the creek, spawning gravels tend to have high silt embeddedness which reduces habitat value. **Figure 2-12** and **Figure 2-13** show existing in-stream sediment at the culvert outlet and at the upper part of the surveyed reach.

Figure 2-12: Sediment at SR 527 outlet

Figure 2-13: Sediment in Queensborough Creek upstream of SR 527

Three Wolman pebble counts were conducted by WSDOT upstream of the I-405 crossing in areas of Queensborough Creek that were not influenced by the presence of culverts (WSDOT 2021). The sediment size distribution results from the pebble counts are shown in **Figure 2-14**. The results of the pebble counts indicate that the substrate is primarily composed of medium to coarse gravels, with some fine gravels and some very coarse gravel as shown in **Table 2-5**. The largest observed substrate was a small cobble (WSDOT 2021)**.**

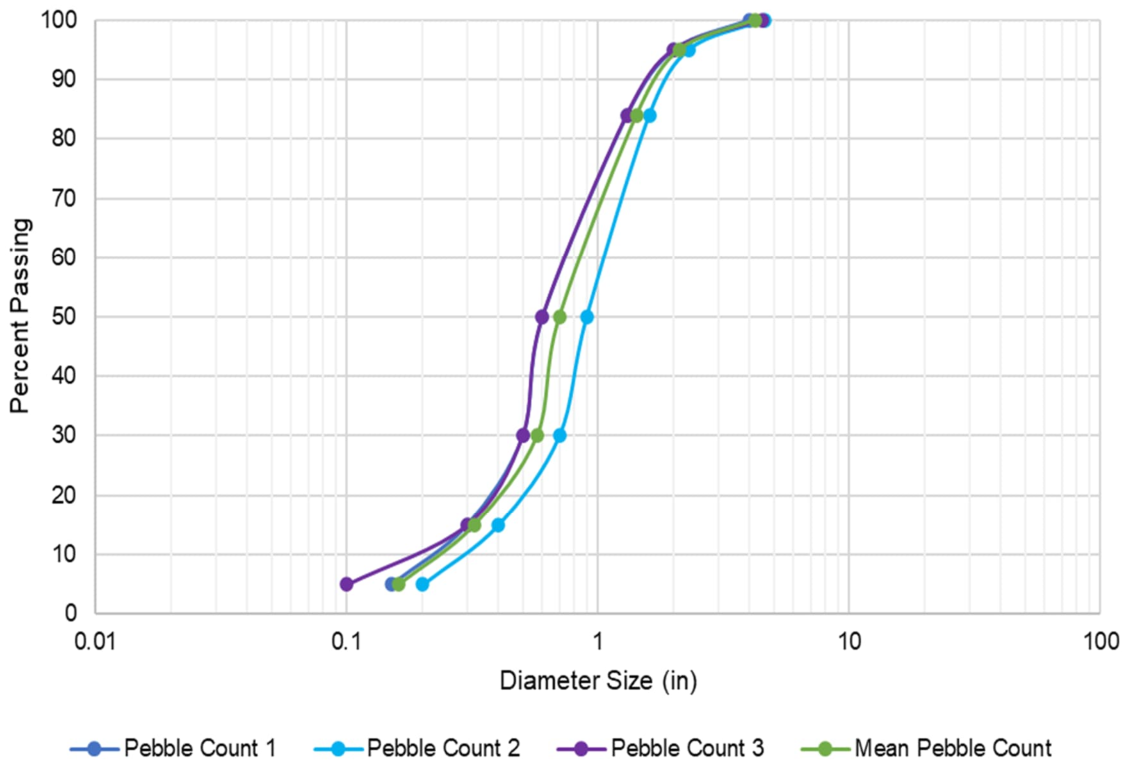
Additionally, four grab samples of bank material were collected by AECOM as shown previously in **Figure 2-5**. All grab samples were classified as a silty sand. Consistent with field observations, sediment from the banks is finer than the pebbles found in the channel bed and is evidence of sands and fines being conveyed through the system. See **Appendix O** for the grab sample particle size distribution reports.

No boulders were observed within design reference reaches upstream or downstream of the SR 527 crossing.

Table 2-5: Sediment properties upstream of the Project crossing [a]

Particle size	Pebble count 1 (in.)	Pebble count 2 (in.)	Pebble count 3 (in.)	Pebble count average (in.)
Included in average?	Yes	Yes	Yes	-
$\mathbf{D_{16}}$	0.3	0.4	0.3	0.3
$\mathbf{D_{50}}$	0.6	0.9	0.6	0.7
$\mathbf{D_{84}}$	1.3	1.6	1.3	1.4
$\mathbf{D_{95}}$	2.0	2.3	2.0	2.1

[a] Pebble counts conducted in unidentified locations upstream of I-405 by WSDOT



Note: Pebble counts conducted in unidentified locations upstream of I-405 by WSDOT

Figure 2-14: Pebble count sediment size distributions

2.7.4 Vertical Channel Stability

As previously described, upstream of I-405 (WDFW ID 993109), the Queensborough Creek channel is slightly incised with evidence of erosion and undercut banks in some locations. The section of the stream between the I-405 crossing and the SR 527 (WDFW ID 993084) crossing is slightly more incised than the upper reach. Queensborough Creek at SR 527 has a steeper gradient than the upstream portion and is consistent through the culvert. Aggradation is possible downstream of the culvert, where the transition to a lower gradient exists. The lower reach of Queensborough Creek along 17th Avenue SE is heavily incised in a confined channel along the road, with eroding banks. There is no head cutting observed in the project area. No existing natural or man-made grade control features were encountered during field visits except for the crossings discussed in **Section 2.1**.

Information regarding sediment supply in the Queensborough Creek basin is limited. Excessive amounts of sediment downstream of SR 527 was noted due to mass wasting in the upper watershed (City of Bothell 2004), and fine sediment is said to dominate lower Queensborough Creek (City of Bothell 2017).

The longitudinal profile of Queensborough Creek is shown in **Figure 2-15**, originating from its confluence with North Creek. It combines 2019 and 2024 field survey data with 2021 aerial LiDAR (see **Section 2.6.1**) Analysis of potential aggradation/degradation is found in **Section 7.2**.

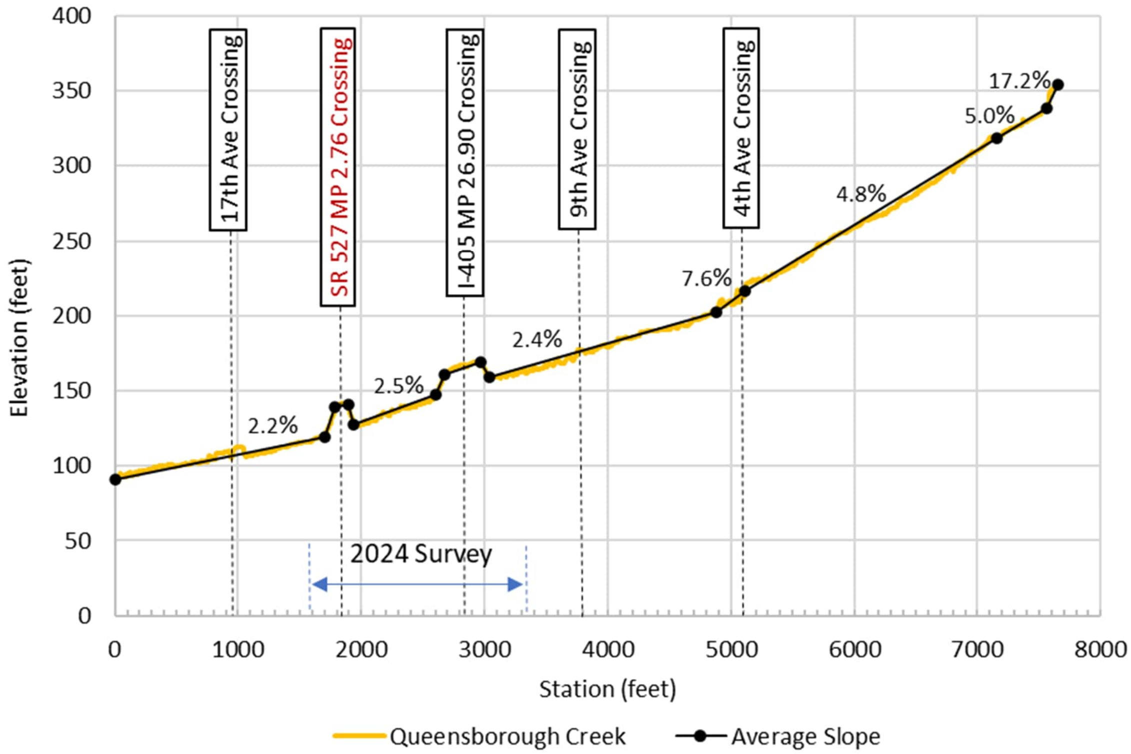


Figure 2-15: Watershed-scale longitudinal profile

2.7.5 Channel Migration

The potential for channel migration of Queensborough Creek has been influenced by urbanization in the watershed. The stream is conveyed through developed areas both upstream of I-405 and downstream of SR 527, which restricts lateral channel migration (WSDOT 2021).

Upstream of 4th Avenue SE (WDFW ID 102 N124), the creek flows through a mixed-conifer ravine greenbelt. The creek between 4th Avenue SE and 9th Avenue SE (WDFW ID 102 N121) has increased floodplain availability but still limited opportunity for channel migration due to channel incision. Upstream of the I-405 crossing (WDFW ID 993109), the channel is fairly U-shaped, with little obvious floodplain. The area between the I-405 crossing and the SR 527 crossing (WDFW ID 993084) has moderate to low floodplain connectivity and flows adjacent to a small wetland complex (WDFW 2025c). Immediately downstream of the SR 527 crossing, the channel has increased floodplain connectivity. The lower reach of Queensborough Creek along 17th Avenue SE (WDFW ID 102 N058) and out to North Creek straight is heavily incised in a confined channel along the road and has little to no opportunity for migration. The channel has been previously characterized (WSDOT 2021) as generally uniform, straight, with pool-riffle morphology.

See **Section 7** for additional discussion of lateral migration and long-term degradation.

3 Hydrology and Peak Flow Estimates

Due to the lack of available stream gage data for Queensborough Creek, hydrology was developed for the existing land use conditions based on GIS landcover and land use data available from the City of Bothell, Washington State Department of Ecology, and the Natural Resources Conservation Service (NRCS) Web Soil Survey information. Due to the lack of available field data for hydrologic verification, the hydrology developed below was validated by comparing the modeled 2-year existing conditions flood extent against the ordinary high-water mark (OHWM) delineated by field survey.

Note that I-405 runoff is collected and conveyed to stormwater pond facilities in the I-405/SR 527 interchange area for runoff treatment and flow control. Flow collected in this system discharges to Queensborough Creek on the downstream side of the SR 527 crossing (WDFW ID 993084). Commercial developments in the area also collect their site stormwater and convey associated runoff into Queensborough Creek on the downstream side of the 17th Avenue crossing (WDFW ID 102 N058). The contributing runoff for the open channel reach between the I-405 and SR 527 crossings is considered negligible, so the basin area and associated flow peaks is assumed the same for the full length of the creek through both I-405 and SR 527 crossings.

The design flows were created and verified using the MGSFlood continuous hydrology model as described in **Section 3.1**. For basin delineation, land cover, and soils input used in the MGSFlood model, see **Figure 2-1**, **Figure 2-2,** and **Figure 2-4**, respectively. Hydrologic analysis computed by MGSFlood was compared to the USGS regression equation analysis, as described in **Section 3.2**. MGSFlood hydrologic results were selected for design and are summarized in **Table 3-1**. It should be noted that the culvert at the I-405 crossings is undersized, resulting in backwater conditions upstream of I-405 during storms equal to or greater than the 25-year event under existing conditions. Excess flows that exceed the culvert capacity are diverted into a drainage ditch and routed to a system of stormwater facilities. This diverted flow is assumed to re-enter the system downstream of the SR 527 culvert. Under existing conditions, the flows at SR 527 match those conveyed by the existing I-405 culvert (see **Section 5.1.4** and **Table 5-2**). Under proposed conditions, the flows at SR 527 match those in **Table 3-1**.

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

WSDOT also evaluates future crossing conditions using the mean percent change in 100-year flood discharge from the WDFW Future Projections for Climate-Adapted Culvert Design program. All Project sites consider the projected percent increase by the year 2080 for the design of the structure. **Appendix G** contains the projected increase information for the Queensborough SR 527 site. The design flow for the crossing is 89.0 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 23.7 percent, yielding a projected 2080 100-year flow of 110.1 cfs.

Furthermore, to successfully achieve the goal of providing fish passage, it is important to consider low flows during summer months. The USGS StreamStats web application provides a 7-day 10-year low flow ($Q_{7,10}$) estimation for ungaged streams in Western Washington. This $Q_{7,10}$ is defined as the lowest average streamflow for a consecutive 7-day period that recurs on average once every 10 years (Curran et al. 2012). For Queensborough Creek, the $Q_{7,10}$ is 0.04 cfs (USGS 2024). Additionally, the City of Bothell reported minimum monthly flow in Queensborough Creek as 0.13 and 0.20 cfs for the years of 2014 and 2015 but makes no mention of dry summer conditions.

Table 3-1: Peak flows for Queensborough Creek at SR 527 crossing under proposed conditions

Mean return period (years)	Design peak flow (cfs) [b]
2	37.4
10	58.7
25	75.1
50	85.6
100	89.0
500	143.0
Projected 2080 100 [a]	110.1

Notes: cfs = cubic feet per second

[a] See **Appendix G** for details on the projected 2080 100-year flow

[b] Note that under existing conditions, the flows at SR 527 were less than the design peak flows due to backwater effects and routing to stormwater ponds, see **Section 5.1.4** for details

3.1 MGSFlood Hydrologic Model

Peak flow estimates previously developed by WSDOT (2021) were calculated in MGSFlood Version 4.42 with GIS data from the City of Bothell, Washington State Department of Ecology, and the NRCS Web Soil Survey. Since the publication of the WSDOT *Preliminary Hydraulic Design* (PHD) *Report* in 2021, updates to GIS datasets and the MGSFlood software have become available. The 2021 National Land Cover Database land cover dataset was released in July 2023 and provides more recent mapping of land cover than the Washington State Department of Ecology land use dataset from 2010. The City of Bothell also updated its impervious surface, streets, and surface water GIS datasets in 2023, and NRCS released updated soil survey information in 2023. With the availability of more recent GIS data, it was determined that peak flow estimates should be verified with an updated MGSFlood model. Peak flow estimates were calculated by AECOM in MGSFlood Version 4.59 using the data sources summarized in **Table 3-2.**

The results from the 2021 hydrologic analysis and the 2024 MGSFlood v4.59 model are presented and compared in **Table 3-3**. The 2024 hydrologic model results did not vary significantly from the estimated peak flows presented in the initial hydrologic analysis developed by WSDOT. Therefore, the 2021 flows will be used for the creek channel design, except for the 500-year flow, which was only developed during the 2024 analysis.

Table 3-2: MGSFlood Version 4.59 model data sources

Dataset	Source	Data Year
National Land Cover Database 2021	USGS	2021
Impervious surface	City of Bothell	2023
Streets	City of Bothell	2023
Surface water	City of Bothell	2023
Gridded Soil Survey Geographic Dataset (gSSURGO)	NRCS	2023
LiDAR – King County West 2021 DTM	Washington LiDAR Portal – Washington State Department of Natural Resources, Division of Geology and Earth Resources	2021

Notes: DTM = digital terrain model; LiDAR = Light Detection and Ranging; NRCS = Natural Resources Conservation Service; USGS = U.S. Geological Survey

Table 3-3: Peak flows of the Queensborough Creek drainage from MGSFlood Versions 4.42 and 4.59

Mean return period	MGSFlood 4.42 peak flow (cfs) [a]	MGSFlood 4.59 peak flow (cfs)	Percent difference
2-year	37.4	37.0	-0.9
10-year	58.7	56.8	-3.2
25-year	75.1	74.3	-1.0
50-year	85.6	80.6	-5.8
100-year	89.0	90.4	+1.6
500-year	137.0 [b]	143.0	+4.4

Notes: cfs = cubic feet per second; WSDOT = Washington State Department of Transportation
[a] Source: WSDOT 2021
[b] 2021 WSDOT MGSFlood analysis did not calculate the 500-year mean flood event

3.2 Regional Regression Comparison

Regional regression equations presented in USGS' *Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014* and *Flood Characteristics of Urban Watersheds in the United States* reports were used to estimate peak flows for Queensborough Creek (Mastin et al. 2017; Sauer et al. 1983). Results of the regional regression equations were compared to the peak flow estimates calculated in MGSFlood to verify the MGSFlood results. Regional rural regression equations for the state of Washington are based on four regression regions, with Queensborough Creek lying in regression region 3. See **Appendix N** for additional details.

Peak flow estimates calculated in MGSFlood are greater than the regional regression equation estimates but within the urban regression equation's average percent of standard error (**Table 3-4**). The MGSFlood model uses more site-specific data with the incorporation of land cover and soil types into the peak flow calculations. Thus, MGSFlood model results are used in the creek channel design.

Table 3-4: Comparison of MGSFlood and urban regression peak flow discharge

Mean recurrence interval	Urban regression peak flow (cfs)[a]	Urban regression standard error (%) [a]	MGSFlood 4.42 peak flow (cfs)[b]	Percent difference (MGSFlood 4.42 to urban regression peak flow)
2-year	29.4	43.0	37.4	25.8
10-year	50.3	41.0	58.7	13.0
25-year	59.9	43.0	75.1	24.2
50-year	67.0	44.0	85.6	20.3
100-year	74.5	46.0	89.0	21.4

Notes: cfs = cubic feet per second

[a] Source: Sauer et al. 1983

[b] Source: WSDOT 2021

4 Water Crossing Design

This section describes the water crossing design developed for the SR 527 MP 2.76 Queensborough Creek project, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for the Queensborough Creek crossing at SR 527 MP 2.76. 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 *Water Crossing Design Guidelines* (WCDG; Barnard et al. 2013), the stream simulation method should be considered for a site if following conditions are met:

- FUR is less than 3.0,
- Stream has a bankfull width of 10 to 15 feet, and
- Channel is believed to be moderately stable.

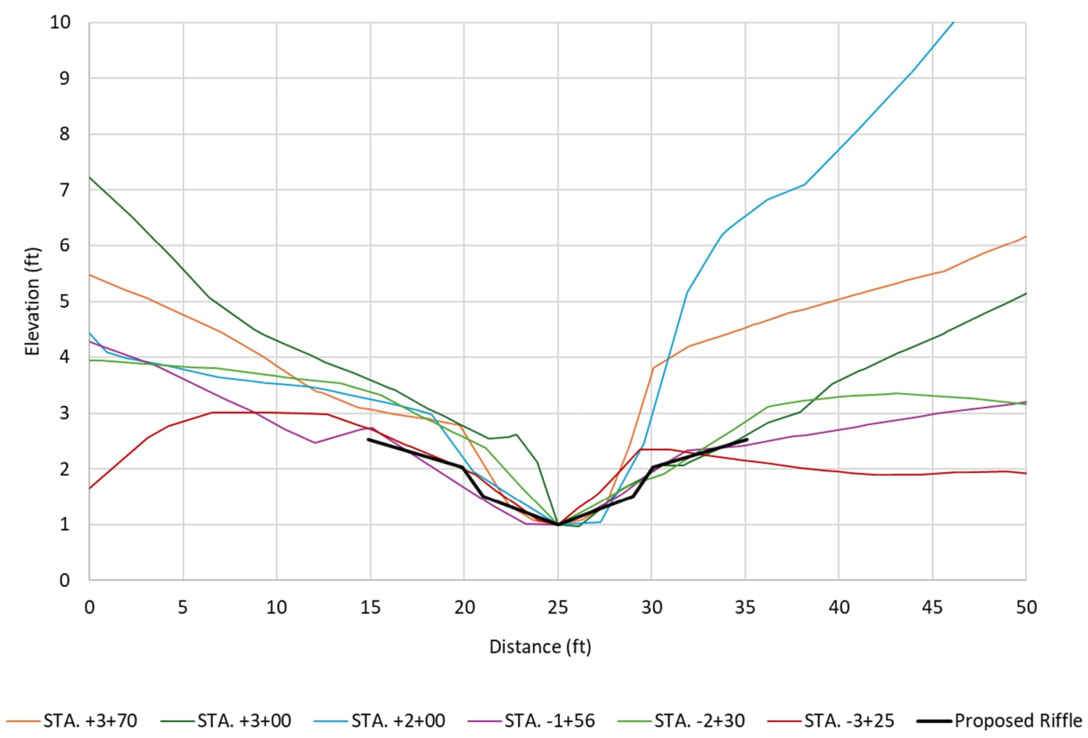
Using these design conditions, the stream simulation criteria was deemed the appropriate method for this crossing because the FUR is 2.9 (**Section 2.7.2.1**), bankfull width is 10.1 feet (**Section 2.7**), and the channel has “fair” stability (**Section 7.1**).

4.1.1 Channel Planform and Shape

The WCDG requires that the channel planform and shape mimic conditions within a reference reach. As described in **Section 2.7.1**, a reference reach could not be located for this project due to the urbanization of the Queensborough Creek system. The existing channel characteristics were determined through field survey directly upstream and downstream of the crossing, in the areas designated as the design reference reach. Outside of the influence of the existing crossings, the channel is generally uniform and straight, with pool-riffle geometry, but pools are small and not well defined. The lack of sinuosity can be attributed to the channel’s proximity to urbanization. The riffle thalweg cross slopes were measured at approximately 10H:1V, with channel bank slopes rising to the bankfull width at approximately 1H:1V.

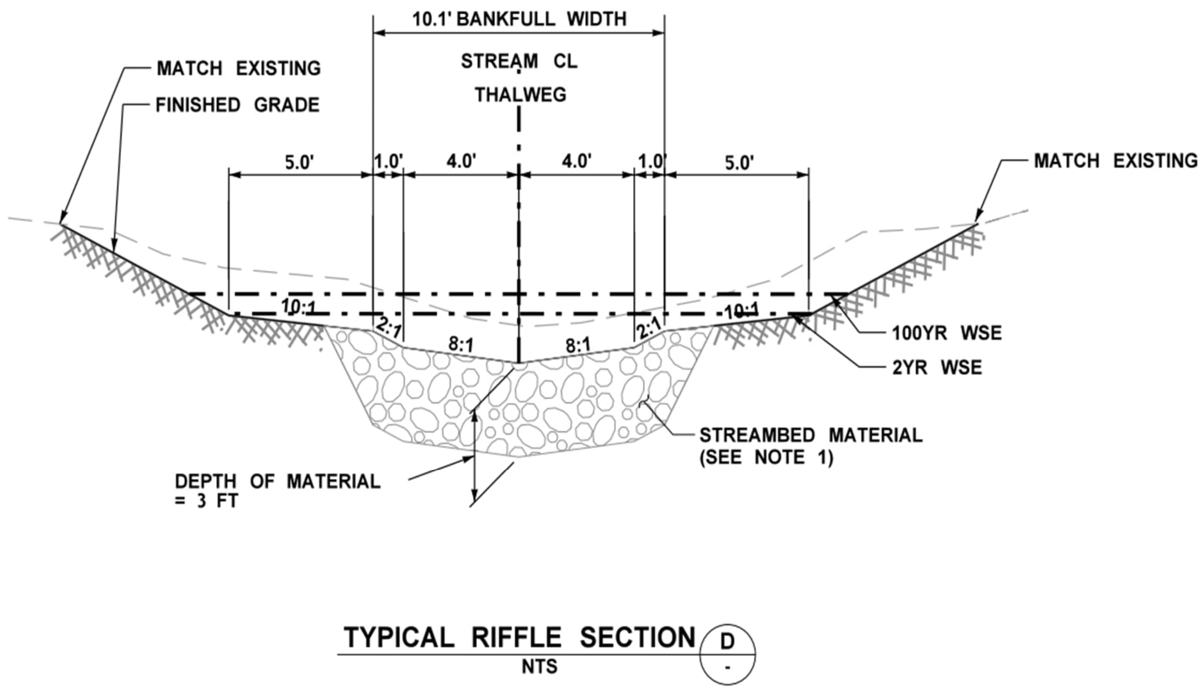
For Queensborough Creek, the proposed channel design follows a meandering pool-riffle morphology. The design proposes variability in the vertical and cross-sectional shape for distinct riffles and pools, as shown in the geometries associated with typical cross sections for riffles and pools, respectively. Slopes mimic existing channel geometry to the extent feasible, as shown in the figures below. **Figure 4-1** superimposes the proposed riffle cross section with existing terrain cross sections upstream and downstream of the crossing. The section shown in **Figure 4-2** has been developed for use in riffle sections, and **Figure 4-3** shows a typical pool section.

Cross slopes in riffles are 8H:1V to promote fish passage in low flows with 2H:1V bank slopes extending to the bankfull width of 10.1 feet. The typical pool section has a wider bankfull width to achieve acceptable residual pool depths. Typical pools are pre-scoured and are not anticipated to scour significantly deeper than the as-built condition as indicated by minimal calculated bend scour depths in **Section 7.4.3**. Typical pool sections also include a 10H:1V bench on the inside of meander bends to mimic the formation of point bars (Cramer 2012). The average meander spacing is approximately four times the bankfull width (see Section 4.3.2).

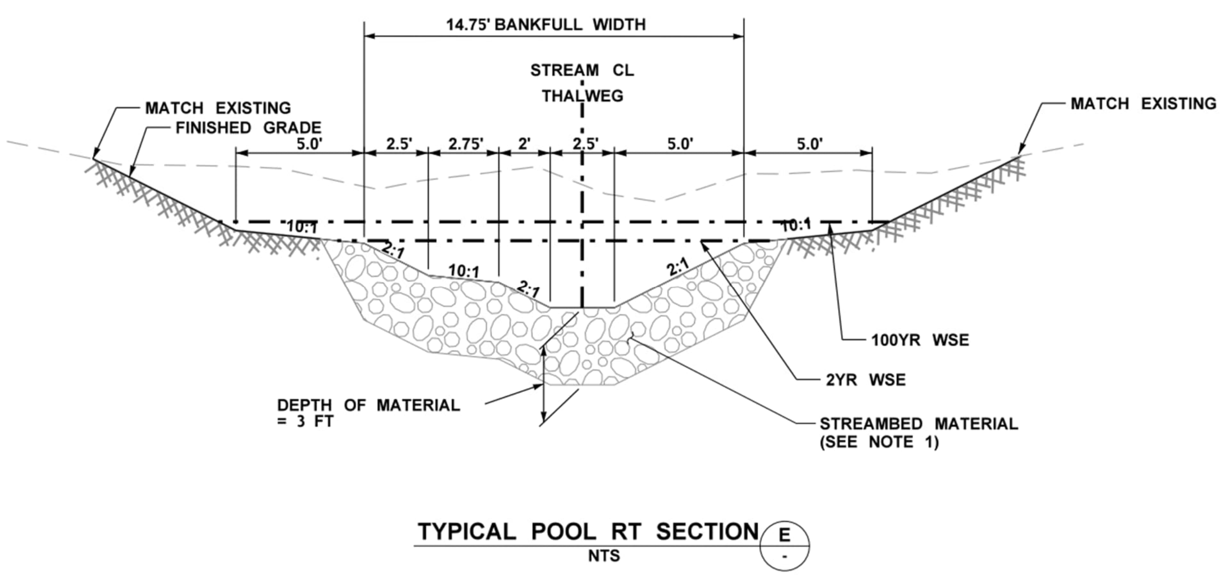


Notes: STA = station; Stationing is approximate, measured along stream centerline from existing culvert midpoint (WDFW ID 993084). Negative stations are downstream. Thalweg normalized to (25.0, 1.0).

Figure 4-1: Proposed cross section superimposed with existing terrain cross sections



Note: see Appendix D for NOTE 1.
Figure 4-2: Typical riffle design cross section



Note: see Appendix D for NOTE 1.
Figure 4-3: Typical pool design cross section

4.1.2 Channel Alignment

The proposed channel alignment under SR 527 is offset approximately 15 to 20 feet south of the existing crossing (WDFW ID 993084). Due to this realignment, a new channel will be constructed at each end that ties into the existing channel. Approximately 215 feet of new channel outside of the SR 527 proposed structure will be constructed and graded to match existing conditions. The design of the proposed channel horizontal and vertical alignment outside the proposed structure was dependent on forward compatibility requirements of the I-405 corridor.

4.1.3 Channel Gradient

The WCDG recommends that the proposed culvert bed gradient not be more than 25 percent steeper than the existing stream gradient upstream of the crossing. **Table 4-1** shows that the proposed grade satisfies this requirement.

Table 4-1: Slope ratios between upstream channel and culvert crossings

Crossing	Approximate upstream channel grade (%)	Proposed structure grade (%)	Slope ratio
SR 527	2.5	2.3	0.9

With a proposed slope of 2.3 percent, this crossing will accommodate a pool-riffle system throughout the constructed profile. This pool-riffle system will be created and maintained through the construction of in-stream habitat features, including large woody material (LWM) and meander bars.

4.2 Minimum Hydraulic Opening

The minimum hydraulic opening is defined horizontally by the hydraulic width and vertically by the vertical clearance plus scour elevation. The following sections describe the minimum hydraulic width and vertical clearance; for discussion on the scour elevation, see **Section 7**. See **Figure 4-4** for an illustration of the bankfull width, minimum hydraulic width, and structure free zone width.

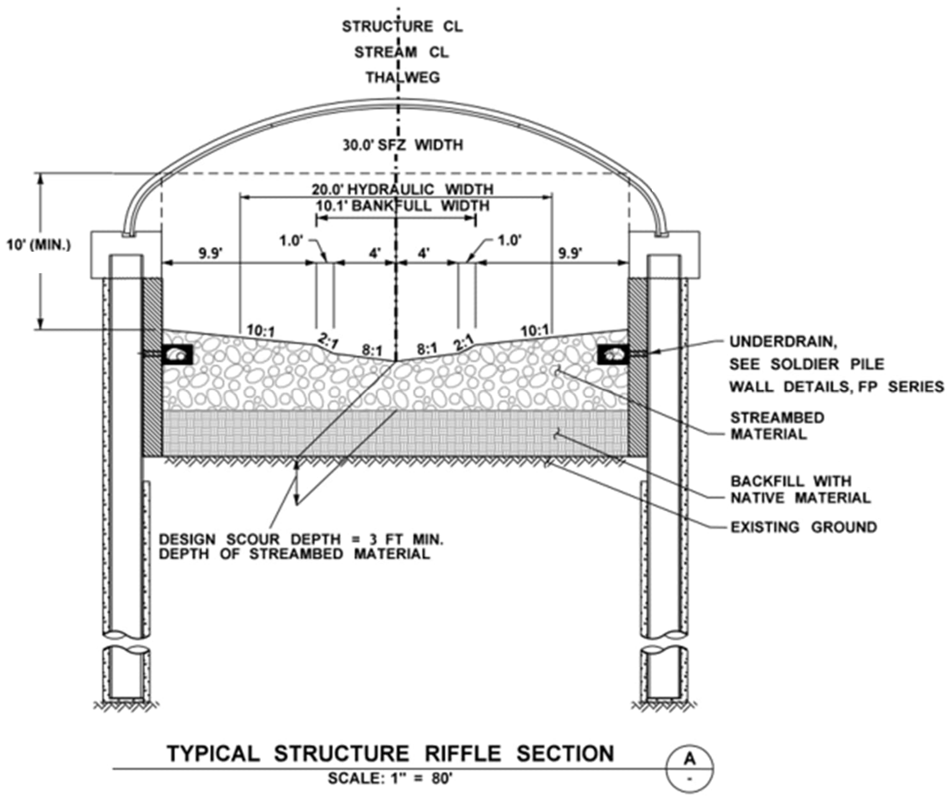


Figure 4-4: Illustration of minimum hydraulic opening and structure free zone

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the *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 because the FUR, BFW, and slope ratio are within the range defined for this methodology (see **Section 4.1**).

4.2.2 Hydraulic Width

The hydraulic width is defined as the minimum width perpendicular to the creek beneath the proposed structure 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 the bankfull width (BFW) and Equation 3.2 of the WCDG (Barnard et al. 2013), rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 15.0 feet was determined to be the minimum starting point as:

$$(1.2 * BFW) + 2 = \lceil 14.1 \rceil = 15.0$$

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 20.0 feet.

Furthermore, existing and proposed geomorphological features were used to guide the overall width of the structure. Large woody material (LWM) will be used upstream and downstream of the structure. Mobile woody material (MWM) will be placed within the structure to provide habitat complexity and diversity. Meander bars will be used within the structure reduce entrainment of flow against structure walls. Considering these elements, a 30-foot structure free zone width was selected, as shown in **Table 4-2**.

Table 4-2: Structure width determination

Crossing location	Bankfull width (feet)	Minimum hydraulic width (feet)	Structure length (feet)	Length: width ratio	Recommended hydraulic width (feet)	Geomorphic-based structure free zone width (feet)
SR 527	10.1	15.0	166.5	11.1	20.0	30.0

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 30.0 feet was agreed on by MITFD, WDFW, and WSDOT.

Considering climate change resilience, the recommended hydraulic width was evaluated under current and projected 2080 100-year flow events. **Table 4-3** 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 5.3**.

Table 4-3: Velocity comparison for SR 527 proposed crossing

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Upstream of structure (STA 15+47)	2.6	2.9
Through structure (STA 14+22)	1.8	2.1
Downstream of structure (STA 11+62)	1.6	1.8

Notes: ft/s = feet per second. STA = station. Stationing measured along proposed stream centerline alignment.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed in this section, and results are summarized in **Table 4-4**. These values have been developed based on requirements outlined in Section 7-4.5 of the *Hydraulics Manual* (WSDOT 2022a) and site constraints.

The minimum required freeboard at the Project location, based on bankfull width, is 3.0 feet above the 100-year WSE (Barnard et. al. 2013; WSDOT 2022a).

WSDOT is incorporating climate resilience in freeboard, where practicable, so freeboard has been evaluated at both the 100-year water surface elevation (WSE) and the projected 2080 100-year WSE. The post-Project 100-year WSE within the structure is projected to increase by 0.2 foot for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience. The freeboard provided by the proposed design easily exceeds the minimum requirement of 3.0 feet.

The second vertical clearance consideration is maintenance clearance. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width. WSDOT HQ Hydraulics determines the maintenance clearance necessary to maintain habitat elements, such as meander bars or large woody material (LWM).

The channel complexity features in **Section 4.3.2** include meander bars and LWM habitat features within the structure that may need to be maintained. Therefore, a maintenance clearance of 10.0 feet to allow for machinery to access and operate under the structure would be ideal, in accordance with the *Hydraulics Manual* (WSDOT 2022a). Maintenance clearance for this crossing will meet the 10.0-foot minimum requirement.

Table 4-4: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	12+75	14+42
Thalweg elevation (feet)	118.5	123.5
Highest streambed ground elevation within hydraulic width (feet)	121.4	125.0
100-year WSE (feet)	121.9	126.8
2080 100-year WSE (feet)	122.1	127.0
Required freeboard (feet)	3.0	3.0
Minimum maintenance clearance (feet)	10.0	10.0
Required minimum low chord, 100-year WSE plus freeboard (feet)	124.9	129.8
Required minimum low chord, 2080 100-year WSE plus freeboard (feet)	125.1	130.0
Required minimum low chord, highest streambed ground elevation within hydraulic width plus maintenance clearance (feet)	131.4	135.0
Required minimum low chord (feet)	131.4	135.0

Notes: WSE = water surface elevation. Stationing measured along proposed stream centerline alignment.

4.2.3.1 Past Maintenance Records

WSDOT Area 5 Maintenance was contacted to discuss maintenance activities and access logistics. Per WSDOT, past maintenance records do not indicate that there are ongoing maintenance problems at the existing structure due to either woody material racking at the inlet or sedimentation in the culvert. The larger proposed fish passage structure will have greater conveyance capacity than the existing undersized structure and will be able to convey woody material and sediment downstream. Access roads are not required, but it was noted that 3H:1V (horizontal to vertical) slopes are acceptable for equipment access down to the structure entrance, as long as landscaping and large woody material (LWM) placement leaves a clear path for access and egress.

4.2.3.2 Wood and Sediment Supply

As mentioned in **Section 2.6.4**, Queensborough Creek has moderate potential for large woody material (LWM) recruitment and transport. The proposed fish passage structures will increase the potential for LWM to be recruited and transported through the system due to the increase in structure span. However, this transport potential will be limited by upstream barriers. Based on field observations there is higher potential for LWM recruitment downstream of the SR 527 crossing.

Regarding sediment supply, observations and field photos by AECOM of sands and fines being conveyed through the system (see **Section 2.7.3**), are consistent with previous descriptions of fine sediment dominating lower Queensborough Creek due to mass wasting in the upper watershed (see **Section 2.7.4**), possibly provided by erosion in the ravine greenbelt upstream of 4th Avenue SE (described in **Section 2.6.4**). Aggradation is not expected to occur at the proposed crossing (see **Section 7.2**), however, fines will likely continue to be provided and transported through the system and may deposit locally as the stream naturally regrades.

4.2.4 Hydraulic Length

The maximum allowable hydraulic length determined by WSDOT for the SR 527 crossing of Queensborough Creek is 250.0 feet. If the hydraulic length is increased beyond 250.0 feet, the hydraulic width and vertical clearance will need to be reevaluated. The hydraulic length of the proposed crossing is 244.6 feet..

4.2.5 Future Corridor Plans

The existing structure is being replaced as part of the overall Project, summarized in **Section 1**. The proposed structure length of 166.5 feet (**Section 4.2.4**) is compatible with other elements of the Project, including the construction one new express toll lane (ETL) in each direction of I-405, two in-line transit stations in the I-405 median and the reconstruction of portions of the SR 527/I-405 interchange.

The Queensborough Creek crossing at SR 527 MP 2.76 will be engineered for forward compatibility with prospective widening of SR 527 as part of the I-405 corridor master plan conditions, because fish passage structure end treatments are designed to allow for their removal and the structures to be extended if needed. Therefore, this structure will be forward compatible.

4.2.6 Structure Type

A buried structure is recommended by WSDOT HQ Hydraulics for the proposed crossing because of the cost benefit it offers while accommodating the large required minimum structure opening. The proposed structure type is a metal arch culvert supported on a soldier pile wall.

Coordination with MITFD has resulted in a WSDOT commitment for the structure to be “bottomless” (no floor or connected structure below the channel). The structure configuration is shown in the plans (see **Appendix D)**.

4.3 Streambed Design

This section describes the streambed design developed for Queensborough Creek at SR 527 MP 2.76.

4.3.1 Bed Material

Per contract technical requirements and stream simulation design methodology (see **Section 4.2.1**), the existing streambed material size is used to develop the proposed streambed material size. **Table 4-5** compares existing and proposed streambed material gradations. Existing streambed material was characterized by pebble counts conducted in the design reference reach (see **Section 2.7.1** and **2.7.3**). Proposed streambed material is 20% larger than existing pebble count data to provide additional streambed stability.

The proposed streambed sediment gradation falls within the range defined by WSDOT's standard streambed sediment as shown in section 2.30.5.3.1 of the Project Technical Requirements. Therefore, WSDOT's standard specification for streambed sediment will be used as the Queensborough SR 527 streambed material (**Table 4-6**).

Table 4-5: Comparison of observed and proposed streambed material

Sediment Size	Existing streambed material diameter (inches)	Proposed streambed material diameter (inches)
D_{16}	0.3	0.4
D_{50}	0.7	0.8
D_{84}	1.4	1.7
D_{95}	2.1	2.5

Table 4-6: WSDOT standard streambed sediment

Sieve size (inches)	Percent passing
2.5	99 to 100
2.0	85 to 100
1.0	50 to 82
0.5	26 to 68
0.017 (No. 40)	10 to 20
0.003 (No. 200)	5 to 10

Source: Project Technical Requirements Section 2.30.5.3.1

4.3.1.1 Stability Analysis of Streambed Material

Consistent with engineering best practices, the Hydraulics Manual (WSDOT 2022), and the Water Crossing Design Guidelines (Barnard et al. 2013), stability of the proposed bed material has been investigated. The analysis indicates that the D_{84} of the proposed streambed material is mobile at the 100-year discharge, and according to the Hydraulics Manual the system is not considered stable (see **Appendix C**)

Although sediment mobility is expected and encouraged in the crossing to mimic natural geomorphic processes, risks associated with the excessive mobility of undersized sediment should be considered. Additionally, because this crossing is considered a long culvert (see **Section 4.2.2**), and "relatively little is known about the design and performance of long stream simulation culverts," special consideration should be given to the proposed design (Barnard et al. 2013). For example, a significant portion of the long crossing will be permanently shaded and unable to support vegetation. Without vegetation, proposed streambanks will be inherently less resistant to erosive forces than vegetated banks in the design reference reach. A risk assessment regarding mobility of streambed material is presented in **Appendix Q**. Due to the risks associated with excessive mobility of undersized sediment described in the risk assessment, the following alternatives were identified and evaluated (sorted coarsest-to-finest by bed material):

- Alternative 1: Design a roughened channel with streambed material and configuration designed to be non-deformable up to the design discharge.

- Alternative 2: Design an overcoarsened channel with D_{84} sized to be stable at the 100-year flow with channel-spanning non-deformable boulder grade controls.
- Alternative 3: Design an overcoarsened channel with D_{84} sized to be stable at the 100-year flow, channel complexity features, and a deformable bedform.
- Alternative 4: Design a channel with streambed material size within 20 percent of the existing pebble-count size, and channel complexity features. (Note: Alternative 4 is consistent with the bed material presented above in **Section 4.3.1**.)

Alternative 1 was determined to have unacceptable impacts on fish life and habitat. Large immobile material can create steep drops and form fish passage barriers. Additionally, oversized material increases void space, which can cause water to infiltrate and flow sub-surface, potentially stranding fish during low-flow periods. Roughened channels also inhibit geomorphic processes and do not meet the criteria or intent of stream-simulation design. Therefore, Alternative 1 is disregarded.

Alternative 2 would reduce the risk of undersized sediment mobility, but it would also potentially increase the risk of a fish barrier forming in the vicinity of the channel-spanning boulder grade controls. Additionally, grade separation and vertical channel stability are not identified as constraints that would require non-deformable grade control features. Therefore, Alternative 2 is disregarded.

Alternative 3 was determined to be an acceptable alternative because it reduces the risk of undersized sediment mobilization to channel banks and infrastructure, while allowing the creek to naturally respond to geomorphic processes due to the absence of rigid boulder grade controls. Furthermore, coarser streambed sediment is more conducive to creating diversity in fish habitat because it allows the stream to develop and maintain riffles and pools, creating hydraulic diversity for microhabitats and multiple pathways for juvenile fish during low flows. Habitat complexity features such as woody material, meander bars, and deformable grade control will also provide added channel stability and hydraulic diversity that will improve instream habitat for fish.

Alternative 4 was also determined to be an acceptable alternative and is consistent with the contract technical specifications. However, with respect to fish life and habitat, it is noted that mimicking the existing streambed gradation is useful only if the existing conditions are beneficial to fish populations. As observed in the field by AECOM and documented by the City of Bothell, “Queensborough Creek contains excessive amounts of sediment downstream of SR 527 due to mass wasting in the upper watershed” (City of Bothell 2004) and “Queensborough has seen up to 52 percent fines in 2013 to 36 percent fines in 2016. At these levels, the fines are having a negative impact on stream insects and fish productivity” (City of Bothell 2017). As explained above (see Alternative 2), providing a coarser streambed may improve the poor conditions present in Queensborough Creek.

To further assess Alternative 3 and Alternative 4, the mobility of streambed material gradations were compared at the 2-, and 25-year flows using the Modified Critical Shear Stress methodology. **Table 4-7** shows the percentage of each gradation that is fine enough to be mobilized via particle entrainment.

Table 4-7: Percent of streambed material gradation susceptible to particle entrainment

Bed Material	2-year	25-year
Alternative 3: D_{84} sized for stability at 100-year flow	43.0	58.0
Alternative 4: within 20% of existing size	100.0	100.0

Both Alternative 3 and Alternative 4 present designs that are consistent with Stream Simulation design methodology and allow the channel to naturally regrade. Given the mobility analysis (**Table 4-7**), the degraded habitat caused by excessive fines, and the special considerations for long culverts in the design guidance, AECOM recommends Alternative 3 for the proposed crossing. However, through coordination with WDFW and WSDOT HQ Hydraulics, it has been determined that no significant constraints exist to justify an overcoarsened channel (Alternative 3). Because the risks described in **Appendix Q** are considered acceptable to the Project's co-managers, Alternative 4 is selected for this crossing.

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for Queensborough Creek at SR 527 MP 2.76. Channel complexity will be created with the use of (1) large woody material (LWM) and mobile woody material (MWM), (2) meander bars, and (3) deformable grade control at the downstream limit of the channel improvements. All three of these components aim to increase channel stability, overall function, and habitat diversity, thus serving both structural and biological goals.

4.3.2.1 Design Layout

The three 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 seen in **Figure 4-5**, and **Figure 4-6** (from **Appendix D**).

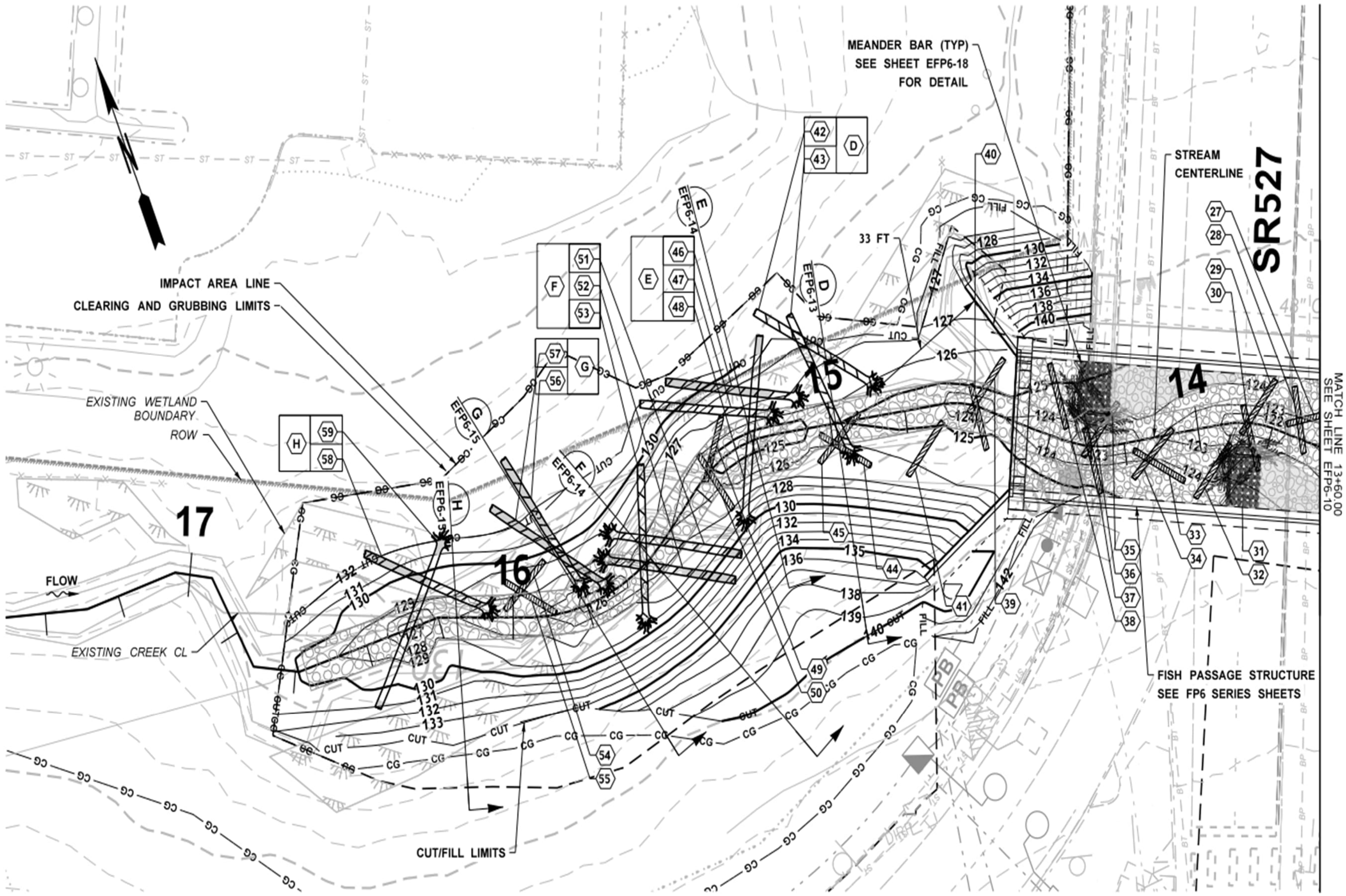


Figure 4-5: Layout of upstream habitat complexity features

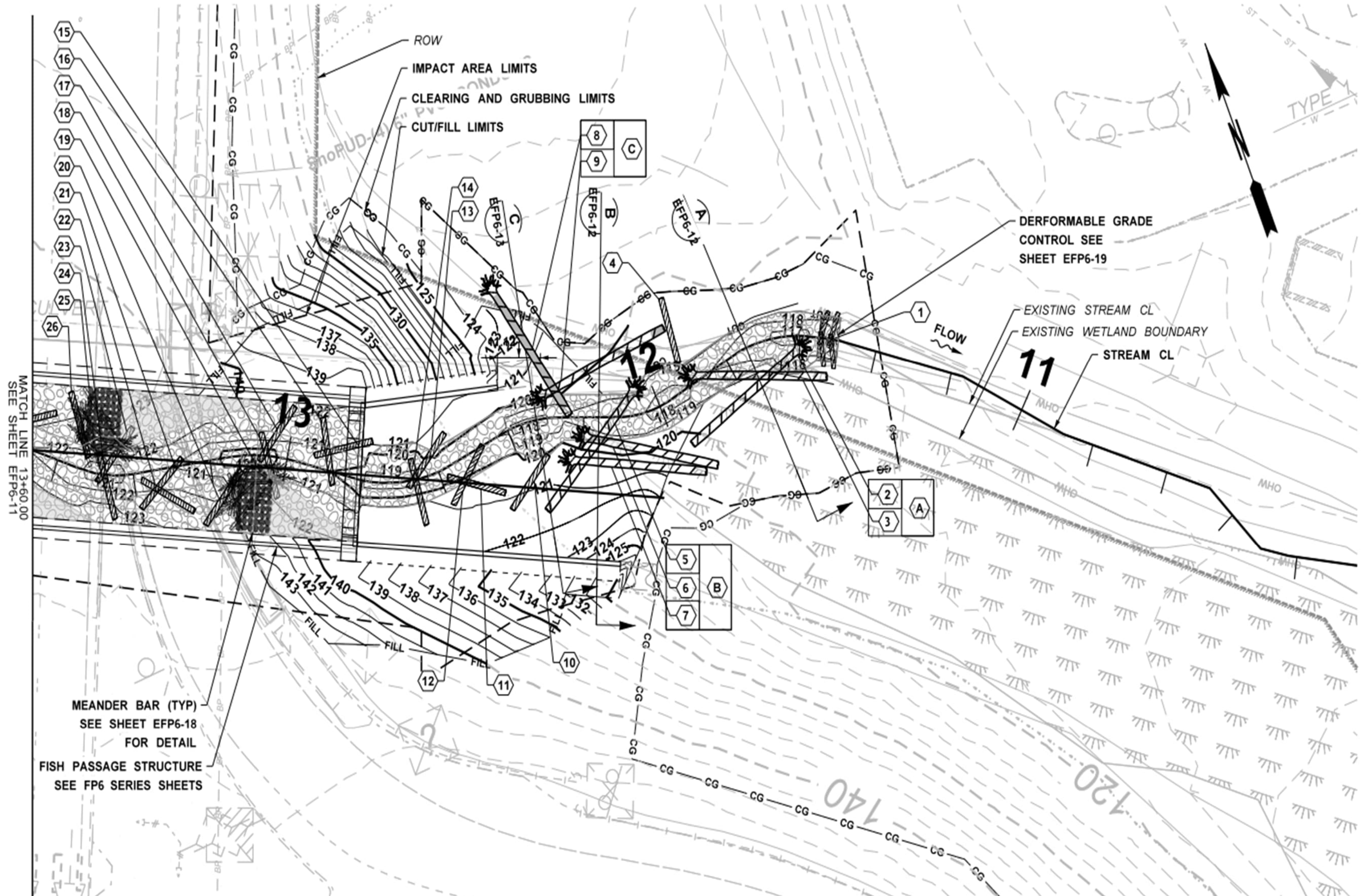


Figure 4-6: Preliminary layout of downstream habitat complexity features

4.3.2.2 Woody Material

Large 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) in other natural streams in the region. LWM can provide multiple benefits, including reducing overall channel velocities and thereby structural scour due to increased channel roughness, while also supporting local pool formation and scour, habitat complexity, and slope stability.

For Queensborough Creek, LWM is categorized as either a key piece or a mobile (non-key) piece. 19 key pieces of LWM will be placed at specific locations along the constructed channel but not within the structure. These key pieces will rely on burying and wedging between existing trees when feasible, so as to limit additional anchoring. The key pieces will have a minimum 20-inch diameter at breast height (DBH), be 30 or 40 feet long, and have rootwads attached for increased instream habitat complexity. Non-key LWM will consist of 15-foot long, 20-inch DBH mobile woody material (MWM) without rootwads.

The mobile pieces of wood will not be buried and will be designed for marginal mobility at the 10-year storm event. This MWM will be placed strategically throughout the channel to minimize downstream and in-structure racking issues. The LWM metrics calculations can be found in **Appendix F**.

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 with respect to woody material is presented in **Appendix Q**.

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 maintain this habitat over its design life. Per contract technical requirements, meander bar spacing is approximately four times the 10.1-foot bankfull width. A total of 4 meander bars will be constructed in an alternating pattern on left and right banks that protrude into the low-flow channel to encourage meandering of the channel in low-flow conditions.

To maintain channel shape, the apex of the meander bar height is set to the 10-year flow depth at the structure wall and the 2-year flow depth at the nose of the bar head, closest to the thalweg. Meander bars extend subgrade to the total scour depth and occupy a substantial portion of the cross-sectional area of the channel.

The proposed meander bar composition follows WSDOT design guidance for three components of the meander bar: (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).

The largest fraction of meander bar material ($D_{84} – D_{100}$) is designed for stability at the design flood (100-year), as calculated by the Modified Critical Shear Stress methodology. The remaining meander bar gradation is designed to minimize sub-surface flow by having a well graded mix using gradation ratios found in natural streambed distributions (Barnard et al. 2013). Additionally, the proposed meander bar tail gradation is designed such that at least seventy percent by volume of the material in the tail of the structure will be larger than the D_{95} of the observed streambed material. **Table 4-8** summarizes the proposed meander bar material gradation.

A mixture of WSDOT standard streambed aggregates from section 2.30.5.3 of the Project Technical Requirements, and the standard specifications (WSDOT 2022b), will be used to create the meander bars. The WSDOT stream aggregate type and proportions needed to create a 10-part mix of meander bar sediment are listed in **Table 4-9**.

The D_{100} of the proposed meander bar material gradation specifies the boulder size to construct the framework of the meander bar head. Type Two streambed boulders are recommended per WSDOT design guidance. The meander bar tails consist of the remaining of the meander bar material gradation, which are the Type One streambed boulders, cobbles, streambed sediment and streambed sand. Slash will be incorporated in the meander bar head to increase habitat complexity. The slash will be interwoven between the meander bar head boulders and wrap around the stream channel side of the meander bar head. Meander bar material sizing calculations are included in **Appendix C**. Refer to plans in **Appendix D** for further details on the meander bar shape.

Table 4-8: Meander bar material gradation

Sediment Size	Proposed meander bar material diameter (inches)
D_{16}	1.6
D_{50}	5.1
D_{84}	12.8
D_{100}	18.0

Table 4-9: WSDOT standard specification streambed aggregate mixture for meander bar tail gradation

WSDOT Standard Specification Streambed Aggregate Type	Parts Needed
Streambed sand, 2.30.5.3.3 - 9-03.11(6)[a]	As needed (see **Appendix D**)
Streambed sediment, 2.30.5.3.1 - 9-03.11(1)[a]	3
Streambed cobbles 8 inch, 9.03.11(2)[b]	3
Streambed cobbles 10 inch, 9.03.11(2)[b]	1
Streambed cobbles 12 inch, 9.03.11(2)[b]	2
Type One streambed boulders, 9-03.11(3)[b]	1

Notes: WSDOT = Washington State Department of Transportation

[a] Source: Project Technical Requirements Section 2.30.5.3
[b] Source: WSDOT 2022b

4.3.2.4 Deformable Grade Control

Deformable grade control (DGC) will be included at the downstream end of the channel improvements to help mitigate the risk of long-term degradation (see **Section 7.2**) and channel avulsion. They are not intended to be fixed-grade control or rigid structures that do not deform over time.

Deformable grade control will consist of meander bar tail material without Type One WSDOT boulders, those being replaced by subgrade logs and slash to provide protection against degradation or headcut migration (see **Appendix D** for DGC details).

4.3.2.5 Stability Analysis of Channel Complexity Features

Stability analysis for meander bar material was performed using the Modified Critical Shear Stress theory, as described in the *Hydraulics Manual* (WSDOT 2022a). Calculations can be found in **Appendix C.3**.

Stability analysis for LWM key-pieces was performed using the Rafferty (2016) Large Wood Stability Analysis spreadsheet tool. Each key-piece log structure was evaluated at the 100-year flood event to ensure a 1.5 minimum factor of safety for vertical, horizontal, and moment forces (**Table 4-10**). LWM stability calculations are provided in **Appendix F.2**.

MWM stability analysis also uses the Rafferty spreadsheet tool. It is first used to ensure stability at the 2-year discharge. However, MWM is also intended to mobilize at less than the 100-year discharge. Mobility is achieved when the factor of safety is less than 1.0 with the Rafferty computational tool. Therefore, standard 1-log and 2-log MWM configurations are placed such that they are stable at the 2-year flow as determined by the factor of safety (FS > 1.5), and unstable at the 100-year flow (FS < 1.0). These two requirements ensure that MWM has a factor of safety equal to 1.0 (FS = 1.0) at a discharge between the 2-year and 100-year flood events. See **Appendix F.3** for details.

Table 4-10: Summary of LWM key piece factors of safety [a]

Log Structure	Log No.	Diameter at midpoint (in)	Length (ft)	Vertical FS	Horizontal FS	Moment FS
A	2 [b]	18	30	11.3	133.9	35.6
	3	18	30	6.2	52.1	6.1
B	5	18	30	2.0	11.6	2.2
	6	18	30	2.2	12.9	6.4
	7 [b]	18	30	1.9	18.2	1.6
C	8 [b]	18	30	1.8	34.2	4.8
	9	18	30	1.8	8.8	4.3
D	42	18	30	11.8	296.9	53.6
	43 [b]	18	30	2.0	46.1	4.2
E	46 [b]	18	30	2.8	30.6	5.6
	47 [b]	18	30	4.6	23.3	14.8
	48	18	40 [c]	48.6	542.7	110.1
F	51 [b]	18	30	9.1	52.6	18.0
	52 [b]	18	30	6.1	20.7	10.9
	53	18	30	18.9	85.7	68.4
G	56	18	30	2.4	38.8	5.3
	57 [b]	18	30	1.8	7.6	4.2
H	58 [b]	18	30	2.9	8.9	4.4
	59	18	40 [c]	11.5	409.6 [c]	46.2

Notes: in = inch, ft = feet, FS = factor of safety

[a] No additional anchoring required.

[b] Denotes bottom log(s).

[c] Denotes channel spanning log set above the 100-year WSE resulting in large factors of safety.

4.3.3 Planting Restoration

This section describes the planting restoration developed for Queensborough Creek at SR 527 MP 2.76. The development of the planting plan was guided by a close review of Queensborough 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 Queensborough Creek at SR 527 can be seen in **Figure 4-7**.

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 Queensborough 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 Queensborough 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.

For slopes steeper than 3H:1V in the upper riparian zone, biodegradable compost socks are proposed for slope stabilization and erosion control during plant establishment. Compost socks are spaced evenly within the riparian tree/shrub mix, running parallel with the slope, helping to reinforce the installation of container plants.

4.3.3.3 Stream Bank Planting

For sloped banks, 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 Queensborough Creek, wetland planting is proposed upstream and downstream of the SR 527 crossing, at existing Wetlands 26.70R, 26.77R, 26.78R, and 26.79R. 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 Queensborough Creek, brush mattressing is proposed upstream of the SR 527 crossing. 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

Bioengineering methods are proposed for stream bank erosion control in the lower riparian zone. Along the 2-year flood line, bioengineering methods include live fascines and coir logs. Live fascine locations include channel openings that require additional erosion control. For the remainder of the channel, coir logs are proposed in tandem with emergent and wetland planting for channel edge reinforcement and plant establishment. For exposed areas that occur between the 2-year flood line and streambed sediment edge, live poles are installed for soil stability and to further restore planting along the channel.

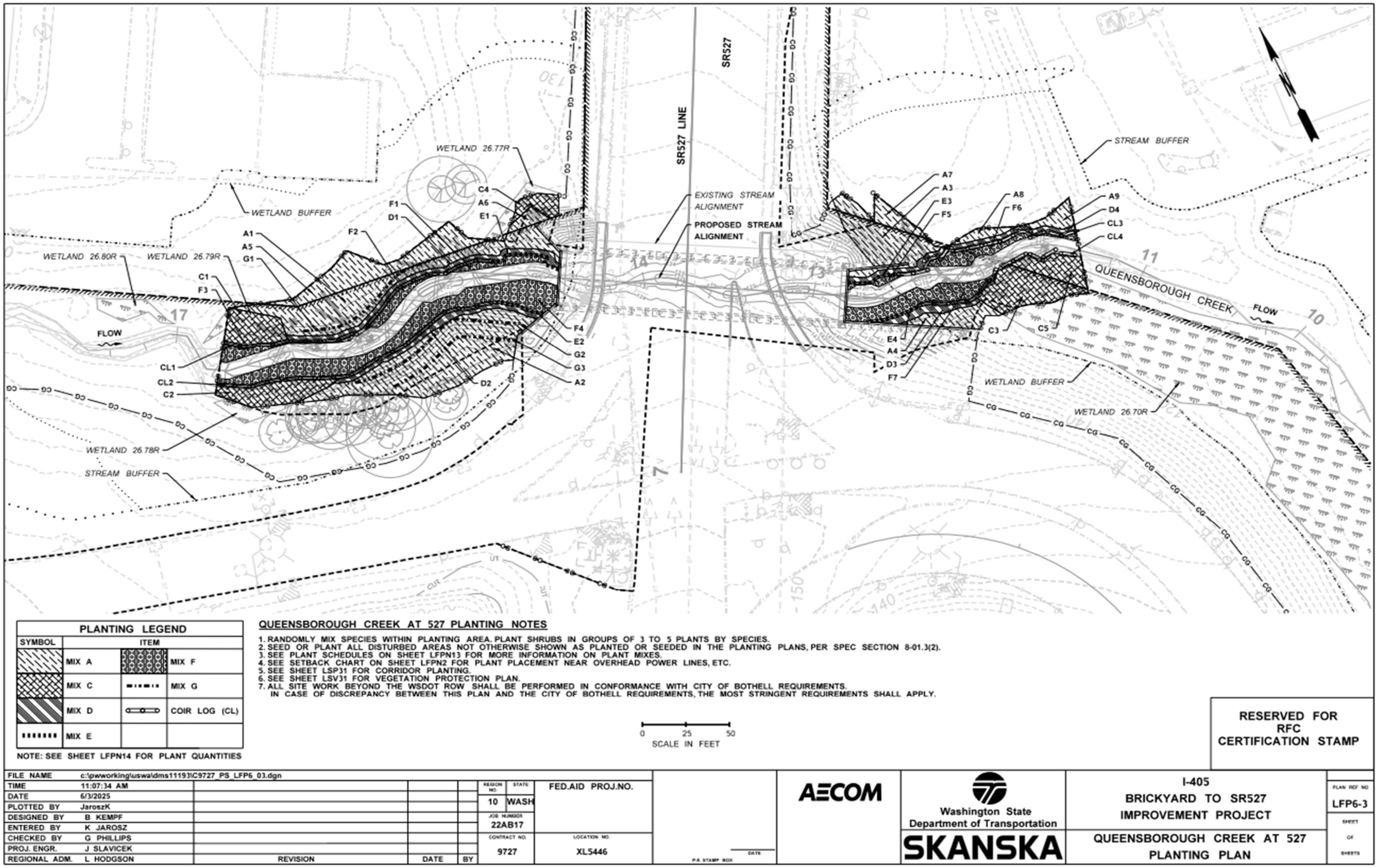


Figure 4-7: Planting plan

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 SR 527 crossing in the vicinity of Queensborough 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 (WDFW ID 993084) and proposed SR 527 Queensborough Creek crossing was performed using the United States Bureau of Reclamation's Sedimentation and River Hydraulics (SRH-2D) computer program version 3.5.0, a two-dimensional hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using the Surface-Water Modeling Systems (SMS) Version 13.2.18 (Aquaveo 2023).

Two scenarios were analyzed for determining stream characteristics for Queensborough Creek: (1) the existing condition, which included a 42-inch culvert at I-405 (WDFW ID 993109), 48-inch culvert at SR 527 (WDFW ID 993084), and 48-inch culvert under 17th Avenue (WDFW ID 102 N058), and (2) the proposed condition, which replaces the existing culverts at I-405 and SR 527 with two new fish passage structures. In accordance with the crossing design presented in Section 4 of this report and the *Final Hydraulic Design Report* for the I-405 crossing (AECOM 2024), the proposed fish passage structures at SR 527 and I-405 have a 30-foot-wide span with smooth concrete top slabs and side walls.

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 two different field survey techniques. The first captured the entire Project vicinity and was obtained from aerial LiDAR in fall of 2021. Three additional field surveys were conducted. In 2019, most of the modeling extent was surveyed by WSDOT. This data captured the stream corridor and about 40 feet on either side of the stream centerline, which includes the floodplain and overbanks. More recent supplemental field surveys were conducted by 1 Alliance Geomatics in December 2023 and March 2024 that captured open channel cross sections, culvert locations, and invert elevations. These two rounds of survey captured channel bathymetry from ~300 feet upstream of the I-405 crossing to ~100 feet downstream of the SR-527 culvert crossing. 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 information is referenced against the NAVD 88 vertical datum.

The proposed conditions SRH-2D terrain data consists of the same source files used to create the existing conditions surface with the addition of the proposed grading surface created in InRoads to model the proposed channel design as discussed in **Section 4**. These surfaces were merged to create a single DTM for use in the SRH-2D proposed conditions model.

The existing and proposed DTM surfaces were imported into SMS as rasters with 0.5-foot cells and subsequently used for mesh generation of existing and proposed conditions.

5.1.2 Model Extent and Computational Mesh

Overviews of the existing and proposed conditions SRH-2D meshes with the underlying terrain are shown in **Figure 5-1** and **Figure 5-2**, respectively. The western edge of the computational mesh (see **Figure 5-3** and **Figure 5-5**) is about 200 feet upstream of the I-405 crossing. The mesh, in-line with the creek, goes from the western edge for about 0.5 mile to the east (**Figure 5-4** and **Figure 5-6**). The mesh covers almost the entirety of the creek and ends about 300 feet upstream of the confluence of North Creek.

The mesh is a combination of patch (rectangular) and paving (triangular) elements. There are 76,716 total mesh elements in the existing condition model and 105,487 elements in the proposed condition model.

The existing condition mesh was cropped near an existing drainage ditch that routes to a series of stormwater detention ponds in the I-405/SR 527 interchange. This area was cropped to exclude the ponds and drainage infrastructure. **Section 5.1.4** fully details the reasoning for this change. Because no water drains through the ditch under proposed conditions, the pond and ditch were left in the proposed mesh.

The buildings downstream of the crossing at 527 were represented as “holes” in the computational mesh. This forces water to flow around the buildings and accounts for resulting head loss, improving accuracy of velocity and shear stress distributions.

The overall area of the existing condition mesh is approximately 24.7 acres, and the area of the proposed condition mesh is 28.6 acres.

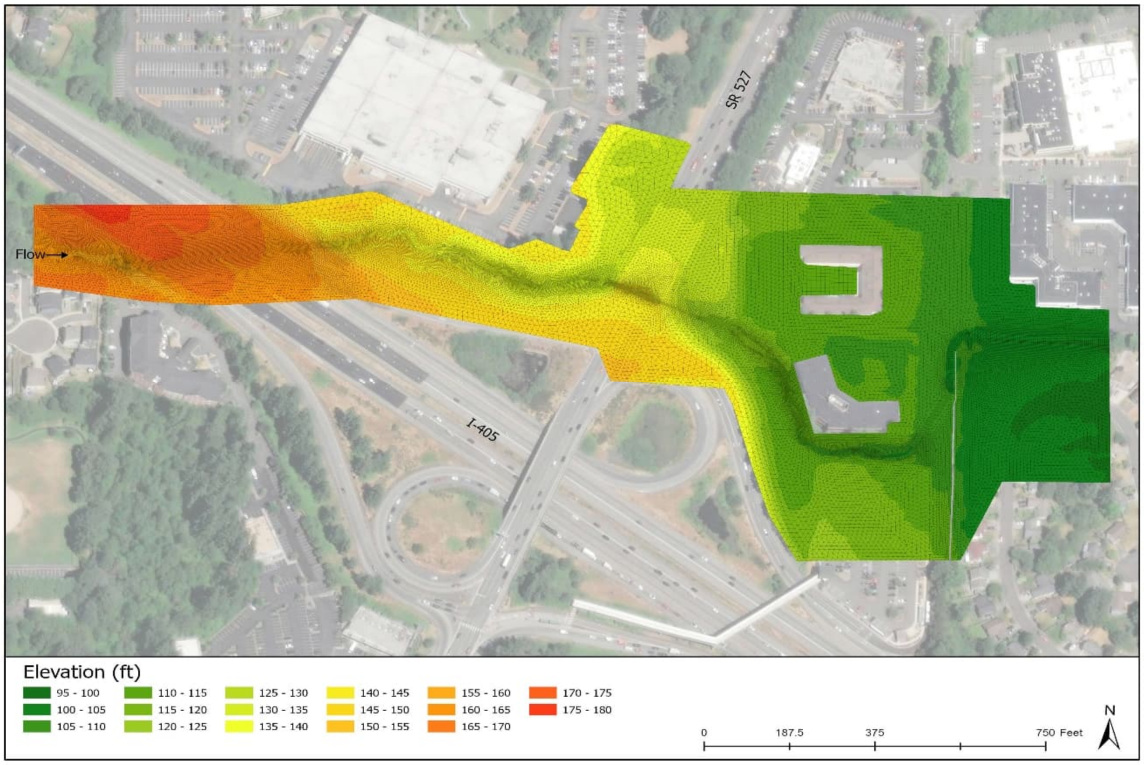


Figure 5-1: Overview of existing condition SRH-2D mesh with the underlying terrain

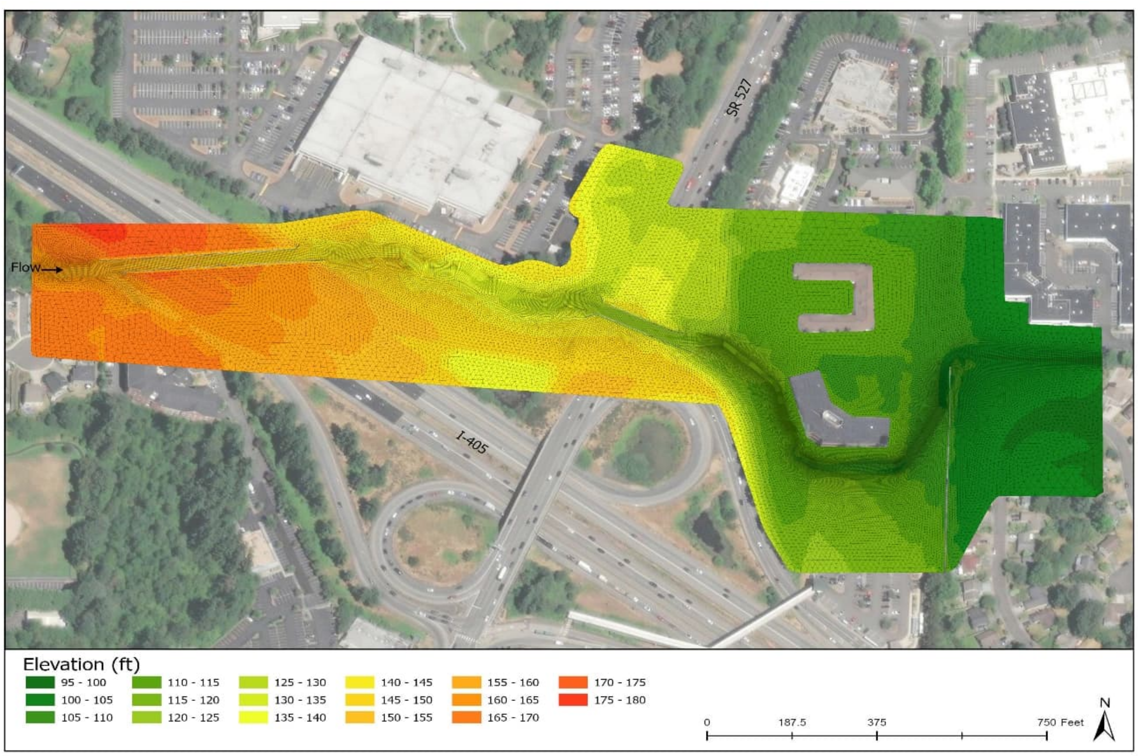


Figure 5-2: Overview of proposed condition SRH-2D mesh with the underlying terrain

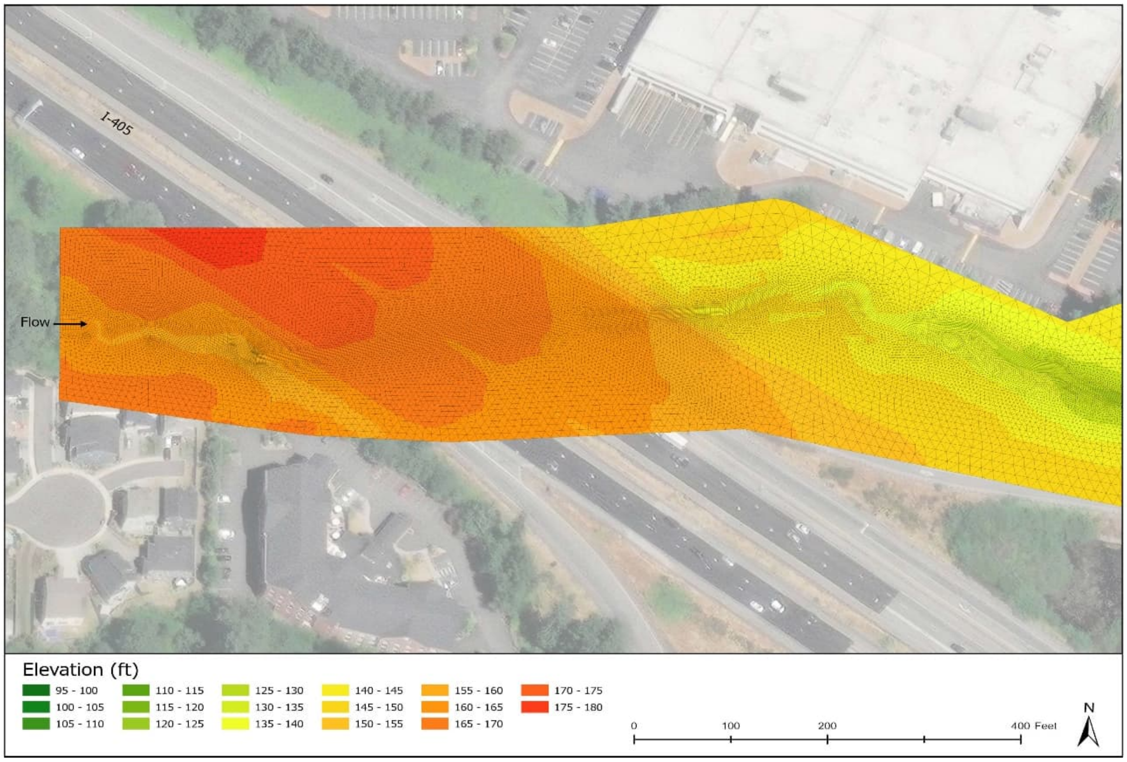


Figure 5-3: Western half of existing condition SRH-2D mesh, including I-405 crossing

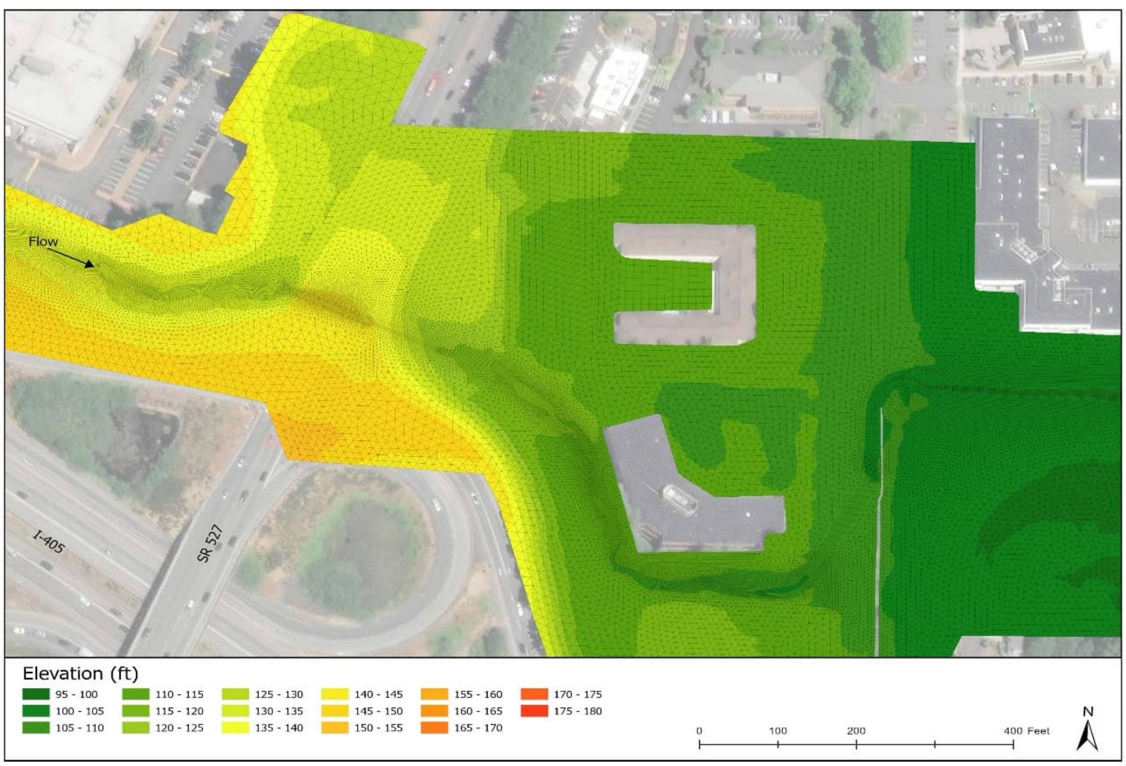


Figure 5-4: Eastern half of the existing condition SRH-2D mesh, including the crossing at SR 527

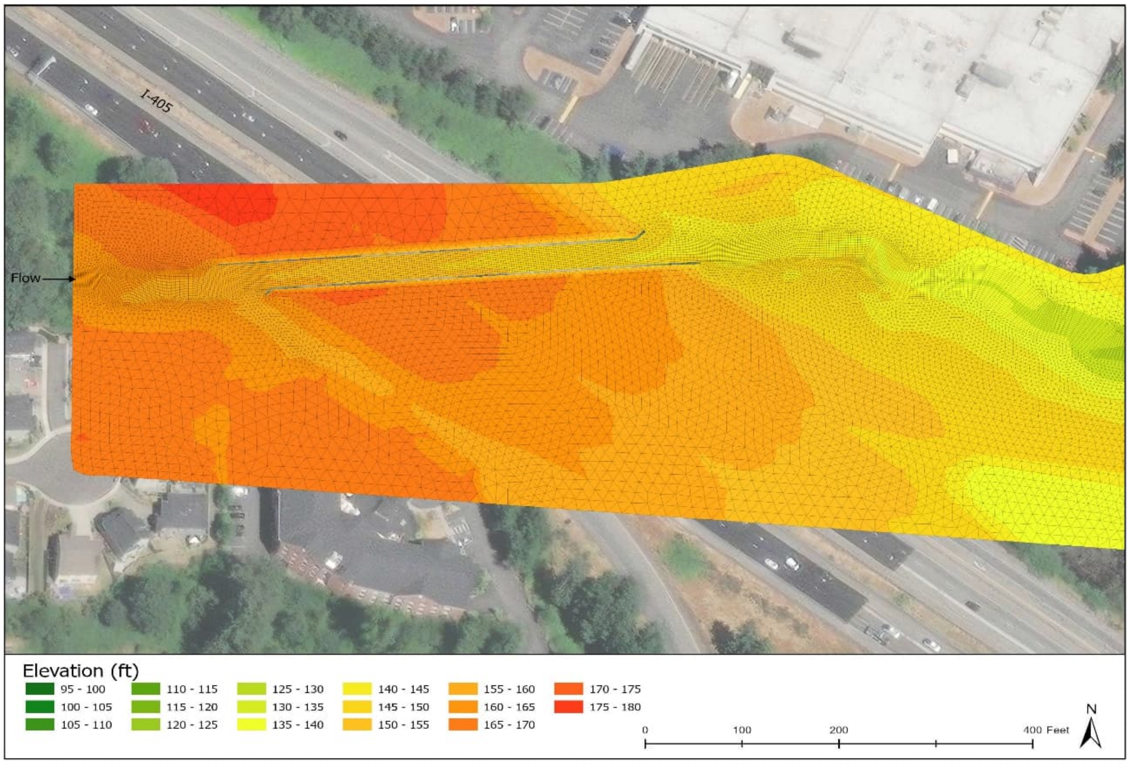


Figure 5-5: Western half of proposed condition SRH 2D mesh, including I-405 crossing

Figure 5-6: Eastern half of proposed condition SRH 2D mesh, including SR 527 crossing

5.1.3 Materials/Roughness

The Arcement and Schneider method was used to estimate Manning's n values due to the stream's dense vegetation and presence of natural obstructions like large wood. This method accounts for key roughness factors such as vegetation density, bed material, and percent obstruction, making it well suited for natural, irregular channels. It provided a more accurate and site-specific representation of flow resistance than standard reference values. Site observations, aerial topography, and standard empirical values were all used to determine the calculation parameters. The full calculations are presented in **Appendix E.**

Table 5-1 summarizes the values used in the hydraulic models. **Figure 5-7** and **Figure 5-8** depict the spatial distributions of roughness values under existing and proposed conditions, respectively.

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

Material	Manning's n
Existing channel with Mobile Woody Material	0.085
Existing channel without Mobile Wood Material	0.07
Proposed channel with Mobile Wood Material	0.0875
Roadway	0.013
Overbank vegetation	0.14
Proposed plantings	0.1
Large Woody Material	0.1125
Pond	0.02
Development (open space)	0.03
Development (low density)	0.06
Existing CSTs	0.024

To model the impacts of the proposed LWM that will be used on the upstream and downstream ends of the proposed channel regrade limits, discrete representations of LWM were incorporated into the hydraulic model. Because logs and other obstructions influence water velocities, shear stress, and other parameters beyond the exact footprint and dimensions of each feature, a buffer of 24 inches was applied to the LWM. This buffer more accurately represents the hydraulic influence these LWM structures have on the system. Discrete Manning's polygons were outlined based on the design layout, and buried portions of the logs were included for reference but are represented by the Manning's n of the classification at the finish grade surface. Detailed LWM Manning's polygons can be seen in **Figure 5-9** and **Figure 5-10.** It is worth noting that the placement of LWM is highly influenced by construction conditions, and field fitting is common; therefore, the LWM layout shown in the hydraulic model and drawings in **Appendix D** may differ from final constructed LWM, with the approval of the stream design engineer or their designee. Manning's roughness for LWM was calculated based on the Arcement and Schneider approach that applies standard increases to a base Manning's Roughness value from variations in channel and bank conditions (Arcement and Schneider 1989). Calculated values were compared to and confirmed against standards values listed in the *Hydraulics Manual* (WSDOT 2022a).

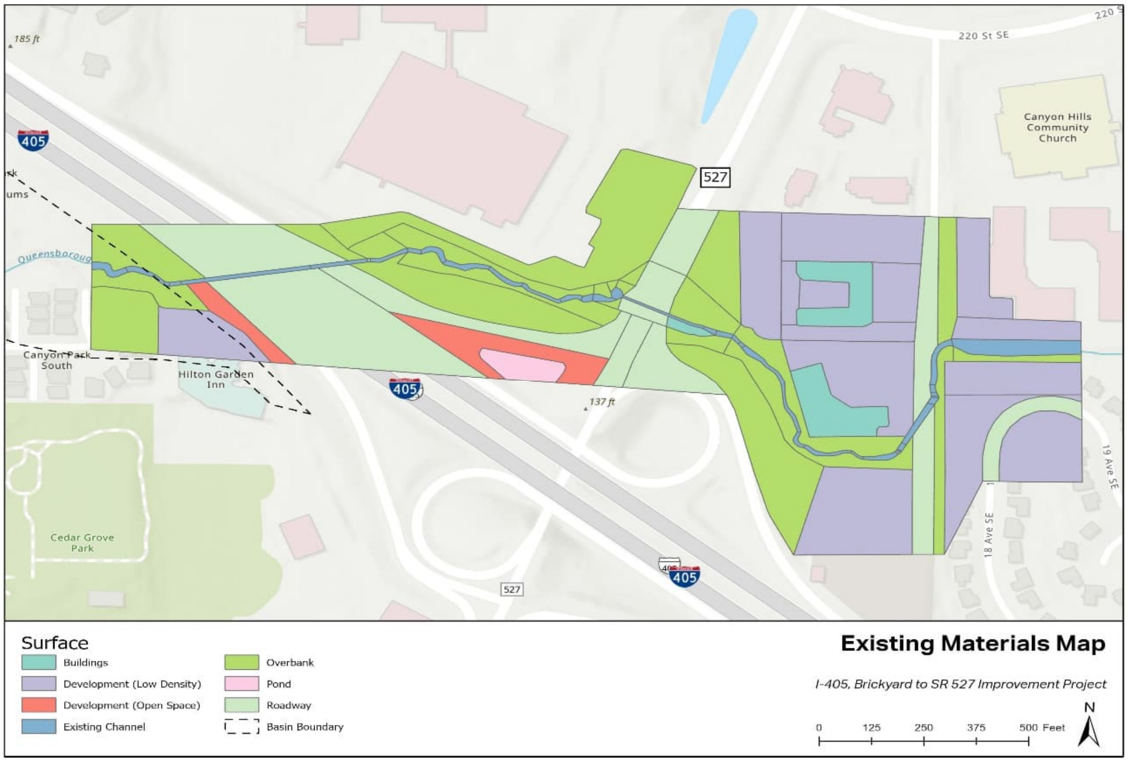


Figure 5-7: Spatial distribution of existing conditions roughness values

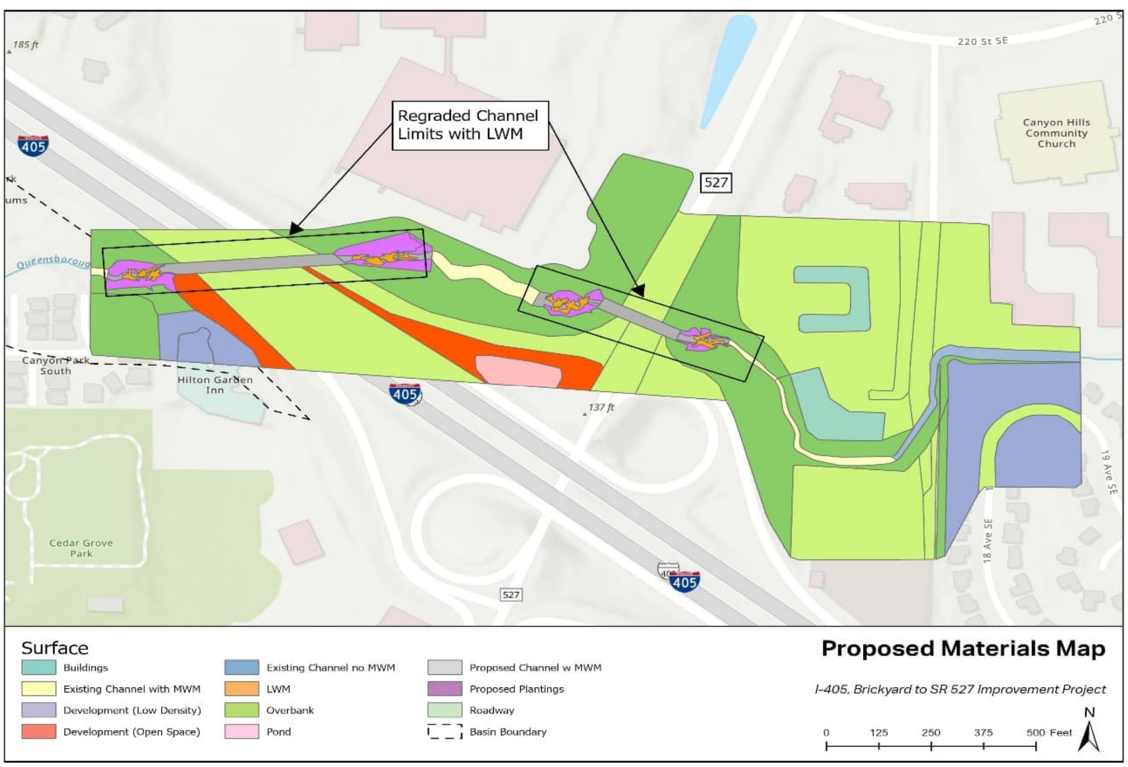


Figure 5-8: Spatial distribution of proposed conditions roughness values

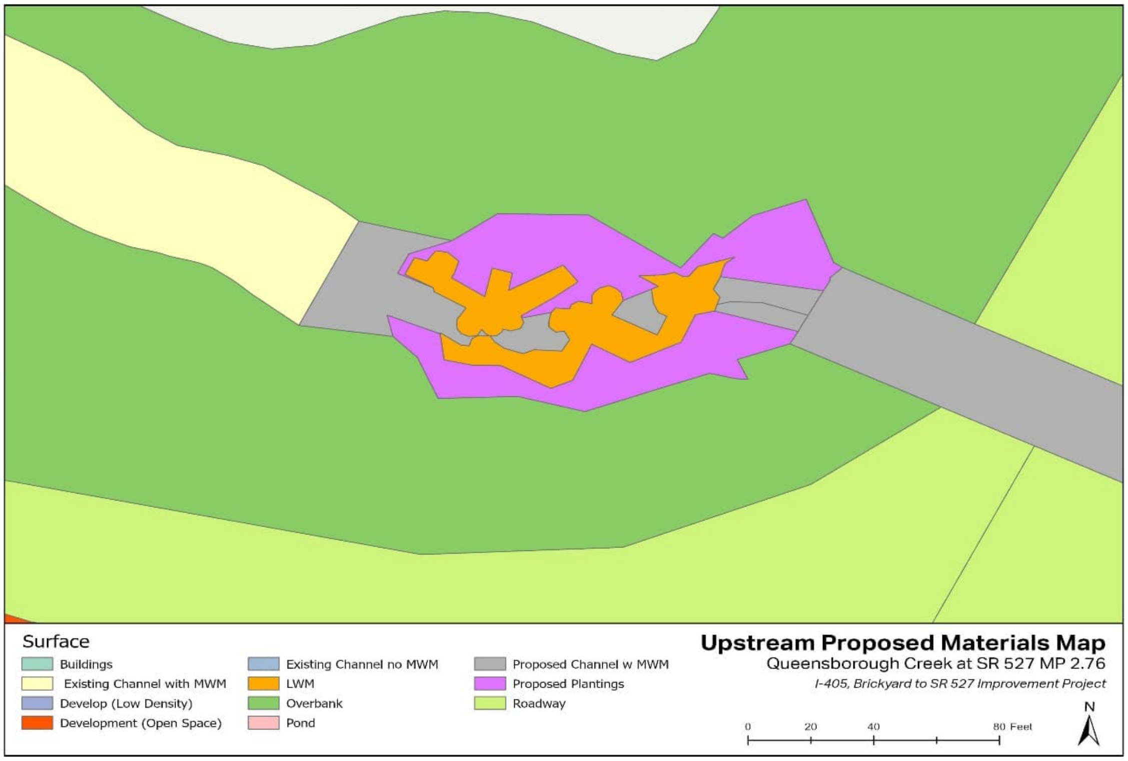


Figure 5-9: LWM polygons upstream of the proposed SR 527 fish passage structure

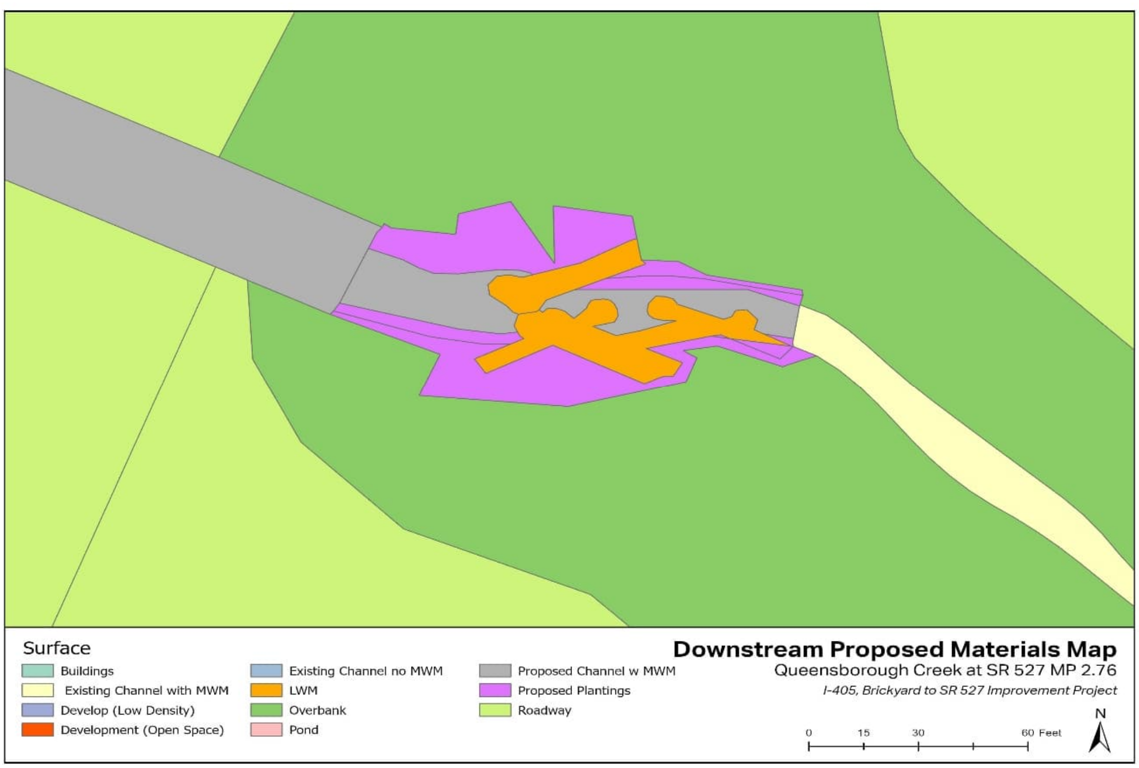


Figure 5-10: LWM polygons downstream of the proposed SR 527 fish passage structure

5.1.4 Boundary Conditions

For the existing conditions model, there are four inflow and outflow boundary condition arcs and six culvert boundary condition arcs to represent inlets and outlets for the three crossings at I-405, SR 527 and 17th Avenue. The primary inflow and outflow arcs are located at the upstream and downstream ends of the modeled reach and represent the main channel flow entering and exiting the system.

The other two inflow/outflow arcs account for flow diversion through an adjacent drainage ditch and a series of existing stormwater facilities. During storms with a return period of 25 years or greater, the undersized culvert at I-405 cannot convey the full storm and a backwater condition develops at the crossing inlet. Backwatered flow is diverted through a nearby drainage ditch, which connects to a system of stormwater facilities. This diverted flow is assumed to re-enter the system downstream of the SR 527 culvert. To model this diversion, a secondary "exit" boundary condition was placed at the point of diversion in the drainage ditch upstream of I-405, and a secondary "inlet" boundary condition was placed downstream of the SR 527 crossing, near the Park and Ride lot. The flow assigned to these auxiliary arcs was calculated by subtracting the culvert-conveyed flow at I-405 from the total flow generated by MGSFlood. Flow values for each boundary condition location are provided in **Table 5-2**.

In the proposed conditions model, the culvert at I-405 is replaced with a 30-foot-wide fish passage structure, similar to the structure at SR 527. The design of the new I-405 crossing is described in detail in a separate FHD (AECOM 2024). This new structure can convey the full flow from all modeled storm events, ranging from the 2-year to the 500-year event. As a result, no backwatering occurs, and the drainage ditch is no longer needed in the model. Accordingly, the proposed model includes only two inflow/outflow boundary condition arcs and one set of culvert arcs at the 17th Avenue crossing.

Table 5-2: Conveyance through existing culvert versus conveyance to drainage ditch and southwest ponds

Recurrence Interval	Culvert Conveyance (cfs)	Flow at Secondary Inlet (cfs)	Total Flow at the Primary Inlet (cfs)
2-year	37.4	0.00	37.4
25-year	59.1	16.0	75.1
100-year	62.0	27.0	89.0
500-year	70.0	67.0	137.0

The inflow arc at the upstream end of the modeled reach is defined as an Inlet-Q arc and applies the flow for each storm as calculated by MGSFlood. A full description of the hydrology can be found in **Section 3.1** or summarized above in **Table 5-2** as “Total Flow at the Primary Inlet”.

The downstream boundary condition is located approximately 500 feet downstream of the 17th Avenue crossing. A constant water surface elevation (WSE) boundary, calculated using the built-in WSE calculator, was applied for both existing and proposed conditions. The main channel uses a Manning’s n of 0.07 (representing the existing channel without MWM) and a slope of 0.02. The overbanks use a Manning’s n of 0.06 (representing low-density development) and a slope of 0.01.

To reflect variations in channel and overbank conditions, the boundary was divided into two segments: one for the main channel and one or two for the overbanks. This segmentation improves model stability by accounting for differences in slope, roughness, and depth. For the 500-year event under existing conditions, a third segment—a supercritical Exit-EX boundary—was added to address shallow flow and a Froude number greater than 1, which improved model performance.

A sensitivity analysis was performed to assess any impact of the downstream boundary condition on results near I-405 and SR 527. The boundary condition was tested in three different scenarios: (1) a constant WSE exit boundary of 97 feet, (2) a rating curve from the previous WSDOT modeling, and (3) a rating curve developed using the native SMS channel calculator. Across all three scenarios, there was no measurable difference in flow, WSE, or velocity near I-405 or SR 527, indicating no influence from the downstream boundary condition on the rest of the model.

The primary effect of the downstream boundary conditions was on model stability, and the boundary type was chosen to optimize model stability.

The existing condition model includes three HY-8 internal boundary conditions to represent the existing 42-inch CST at I-405, 48-inch CST at SR 527, and 48-inch CST at 17th Avenue. The existing 42-inch CST under I-405 was modeled as a circular metal pipe with no embedment and a beveled edge inlet configuration. The existing 48-inch CST under SR 527 was modeled as a circular metal pipe with no embedment and a beveled edge inlet configuration. Lastly, the culvert at 17th Avenue was modeled as a circular metal pipe with no embedment and a thin edge projecting inlet configuration. Inlet and outlet elevations correspond to the stream thalweg for continuity with the hydraulic model surface. This assumes that partial sedimentation observed in the field at culvert outlets of I-405 and SR 527 is present.

For the proposed condition model, the HY-8 culverts at I-405 and SR 527 were replaced with the proposed 30-foot fish passage structures, while the 48-inch CST at 17th Avenue remained. Existing culvert parameters are shown in **Figure 5-11**, **Figure 5-12**, and **Figure 5-13,** and associated locations for existing and proposed conditions are shown in **Figure 5-14** and **Figure 5-15**, respectively.

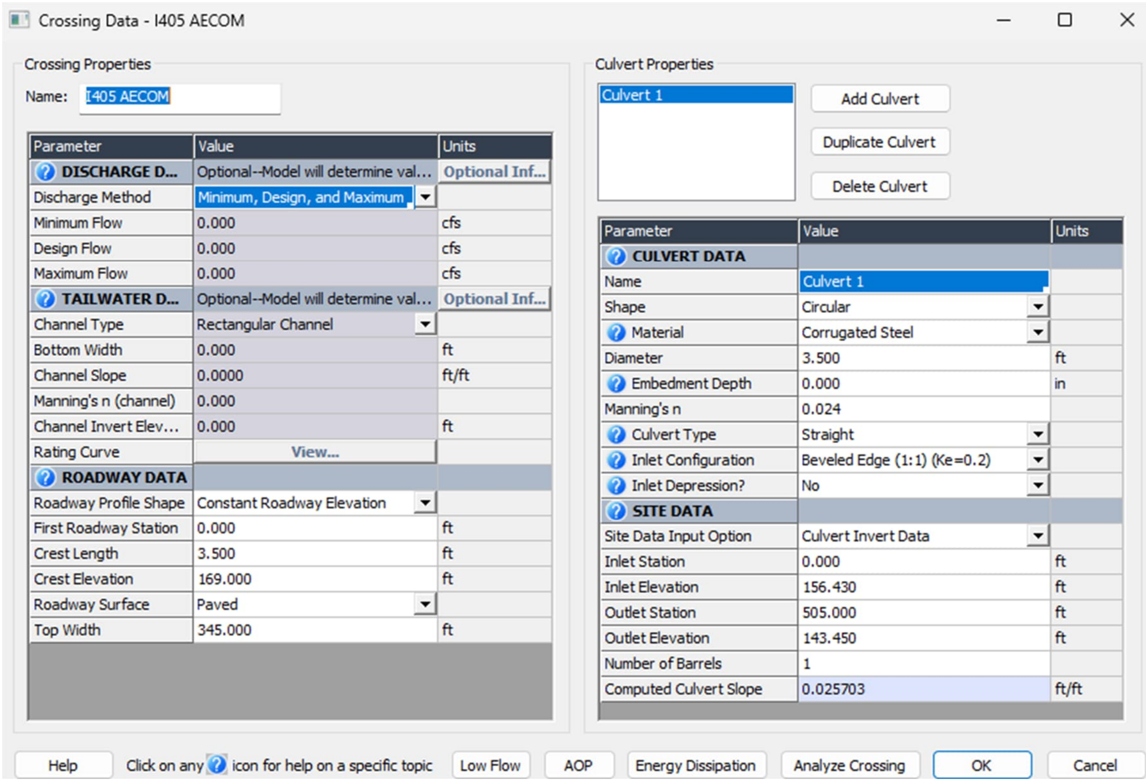


Figure 5-11: Existing I-405 HY-8 culvert parameters

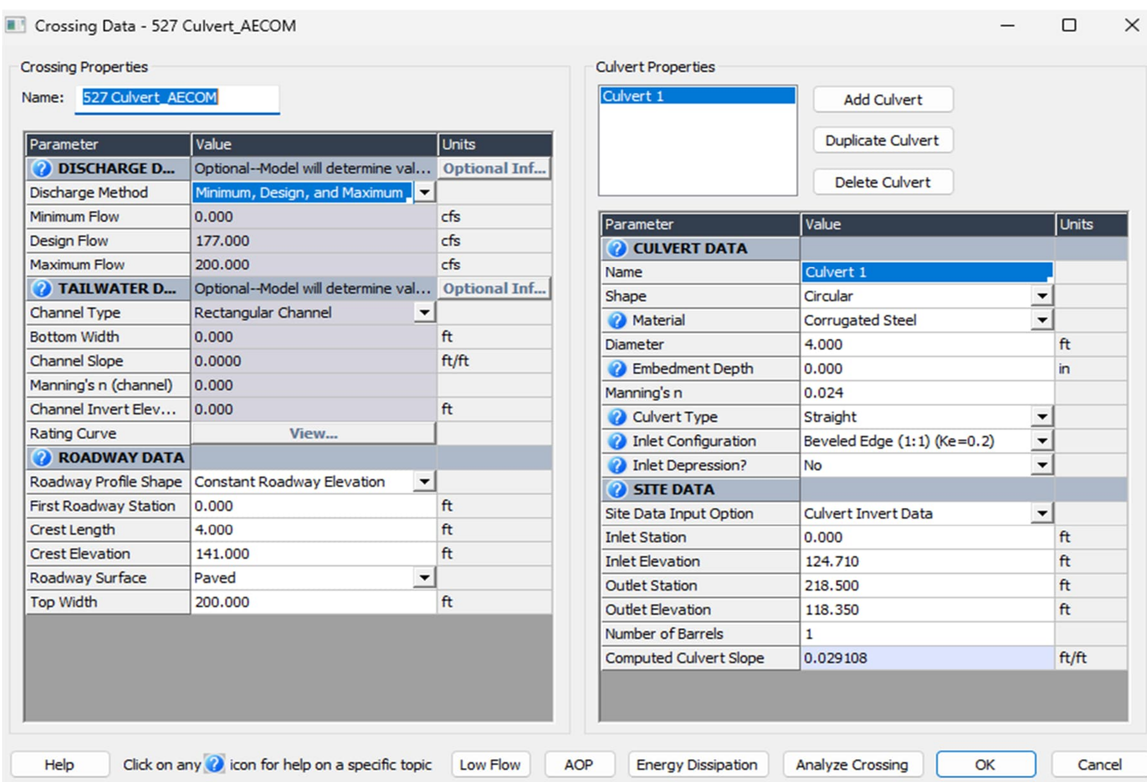


Figure 5-12: Existing SR 527 HY-8 culvert parameters

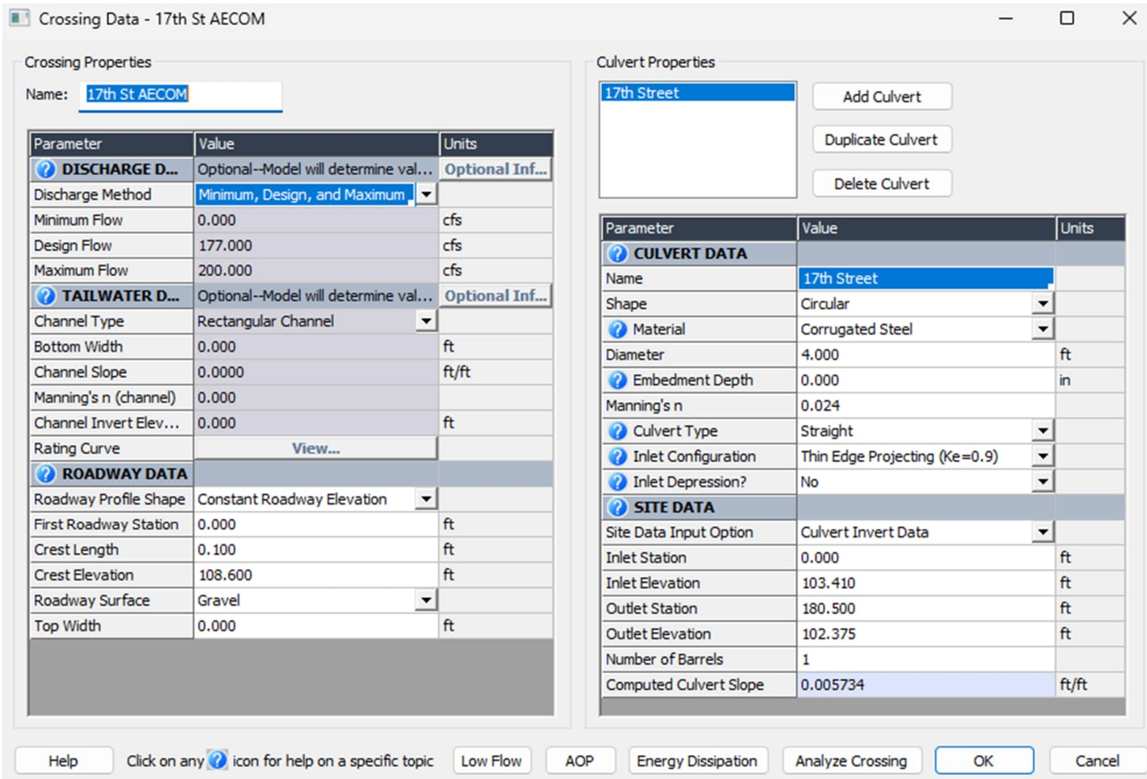


Figure 5-13: Existing 17th Avenue HY-8 culvert parameters

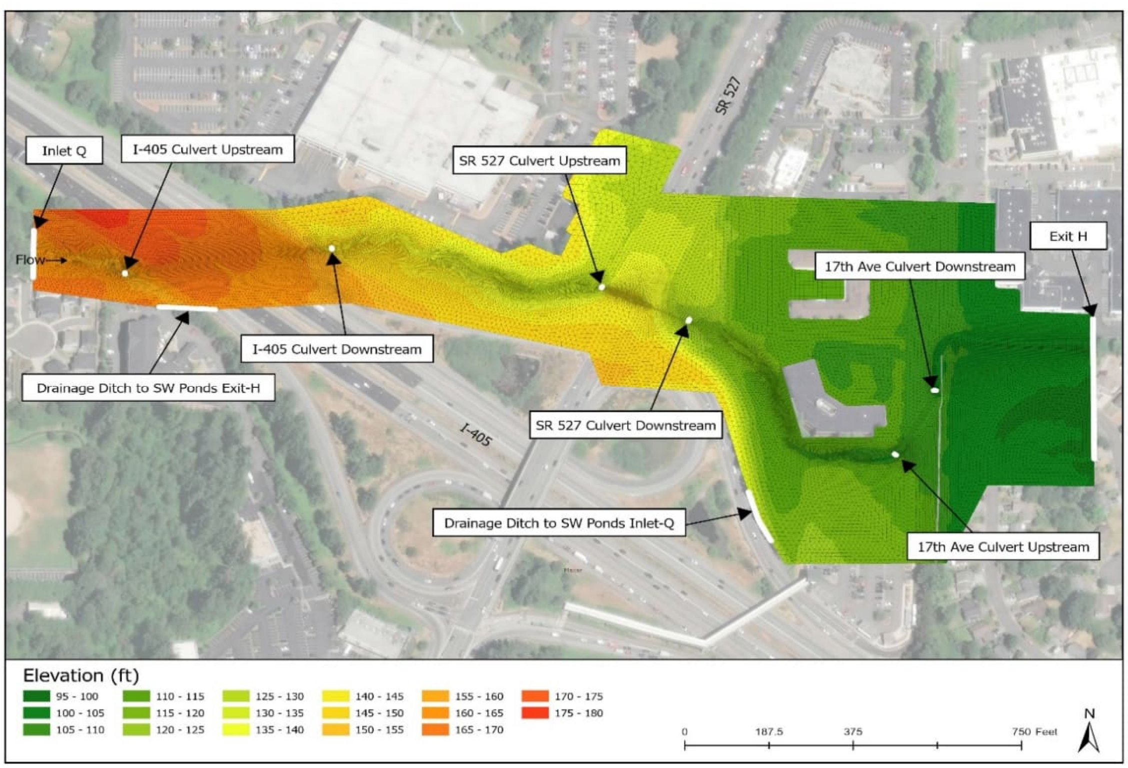


Figure 5-14: Existing conditions boundary conditions

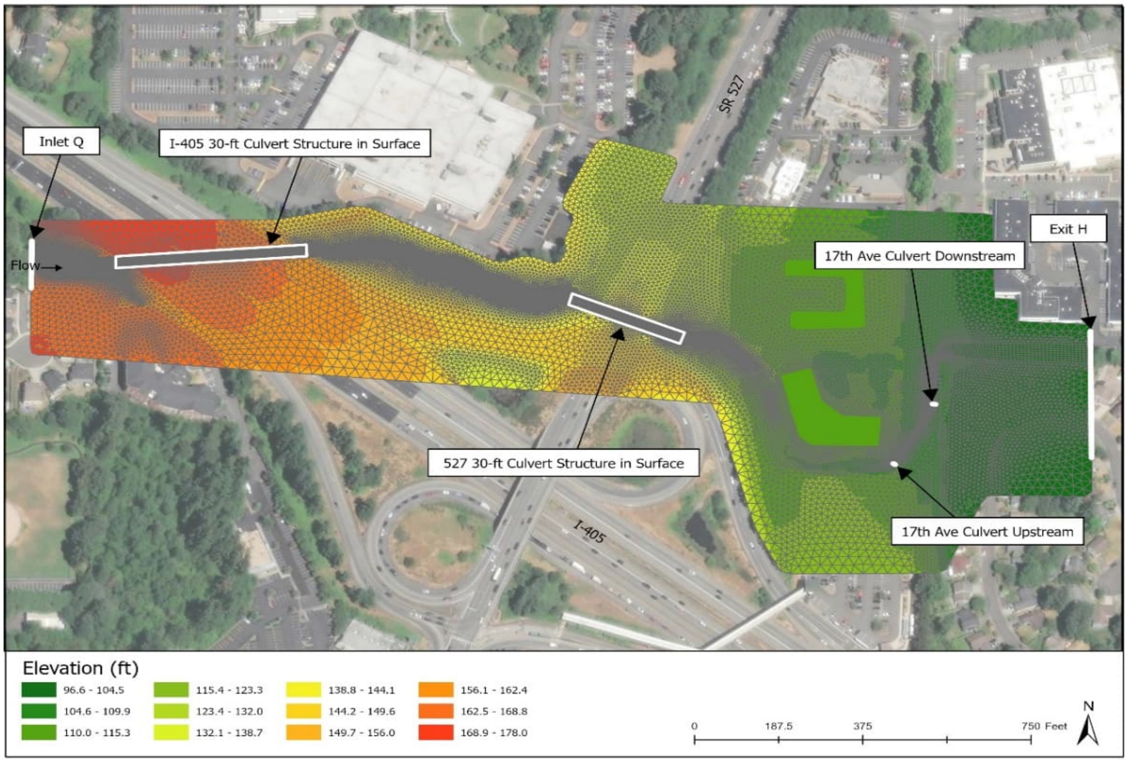


Figure 5-15: Proposed conditions boundary conditions

5.1.5 Model Run Controls

Model control for the existing and proposed conditions included a start time of 0 hours and an end time of 2 hours. Simulations were run with a 0.5-second time step and had an initial condition of dry. The output frequency was set to 6.0 minutes (0.1 hours), and the default parabolic turbulence was left as 0.7. The model was run as unsteady with three iterations per timestep.

5.1.6 Model Assumptions and Limitations

A watershed-wide longitudinal profile was not used due to the extensive survey or data collection required to incorporate this information. Additionally, it was assumed that all water that backed up at the undersized 3.5-foot CST crossing and went into the drainage ditch upstream of the I-405 crossing was then routed through the drainage system and re-entered Queensborough Creek near the park and ride parking lot downstream of the crossing at SR 527. More details on this can be found in **Section 5.1.4**. Lastly, the model is determined to be stable and continuous. The stability plots for each model run are presented in **Appendix I**.

5.2 Existing Conditions

This section presents the key results from the hydraulic analysis of the existing SR 527 Queensborough Creek crossing, modeled as a 48-inch-diameter CST. Illustrations summarizing the WSE, velocity, shear stress, and depth results under the 2-, 25-, 100-, and 500-year recurrence interval flows are provided in **Appendix H**. **Figure 5-16** depicts the SRH-2D elevation mesh of existing condition and associated cross section locations. All results are presented relative to the NAVD 88 datum. Cross-section locations were selected based on proposed conditions WSE contours and were used to analyze the existing conditions results for consistency in results reporting. Hydraulic results for all cross sections are summarized in **Table 5-3.**

The 2-, 25-,100-, and 500-year WSEs along the existing Queensborough Creek profile are shown in **Figure 5-17**. The SRH-2D model of the existing condition and the WSE in **Appendix H** indicate that the existing 48-inch-diameter CST is sufficient for passing the 2-year recurrence interval flow but causes backwater upstream for the 25-year and 100-year flows. This water backwaters upstream of the culvert inlet for approximately 150 feet.

As seen in **Figure 5-18**, upstream of the SR 527 crossing, the 2-year event is contained within the channel banks, while the 25-year event begins to inundate the floodplain. During the 100-year and 500-year events, a large portion of the adjacent undeveloped floodplain is inundated.

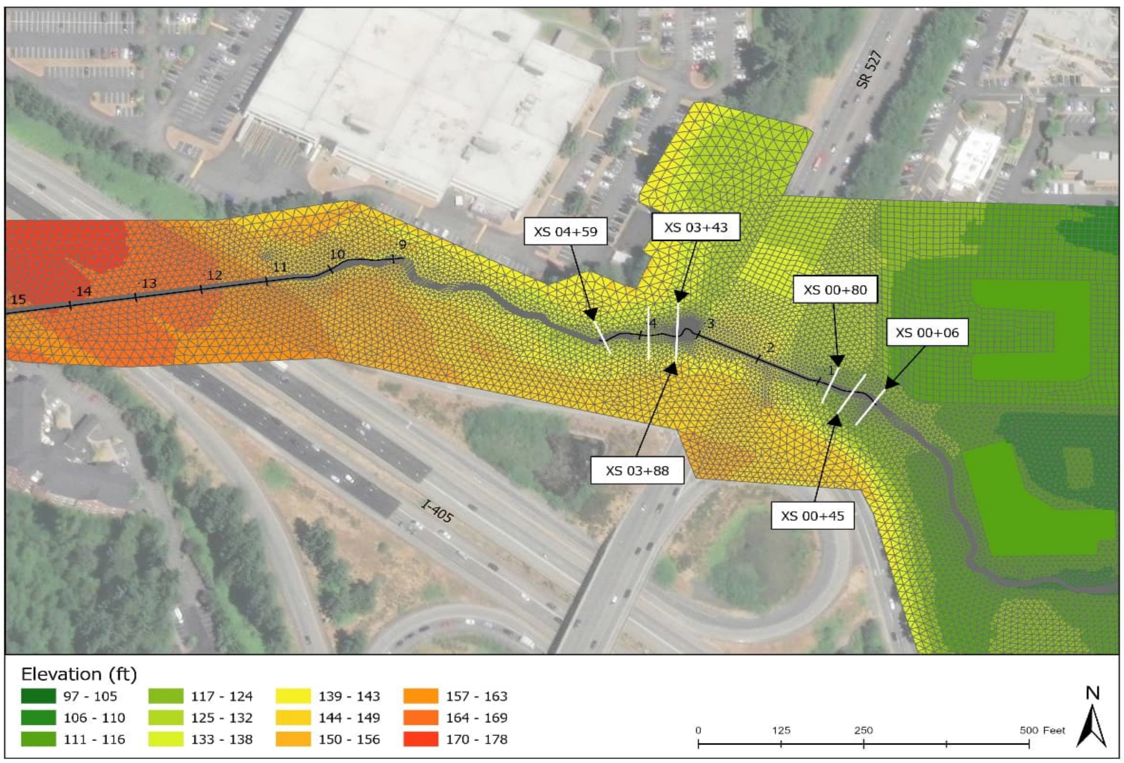


Figure 5-16: Locations of cross sections used for results reporting

Table 5-3: Average main channel hydraulic results for existing conditions

Hydraulic Parameter	Cross Section	2-year	25-year	100-year	500-year
Average WSE (ft)	US - XS 04+59	129.2	129.6	129.7	129.9
	US - XS 03+88	128.2	128.6	128.8	129.2
	US - XS 03+43	127.7	128.5	128.6	129.1
	Structure	N/A	N/A	N/A	N/A
	DS - XS 00+80	120.1	120.3	120.4	120.5
	DS - XS 00+45	119.3	119.6	119.6	119.7
	DS - XS 00+06	118.3	118.5	118.6	118.7
Maximum depth (ft)	US - XS 04+59	1.8	2.2	2.3	2.5
	US - XS 03+88	1.6	2.1	2.2	2.6
	US - XS 03+43	1.8	2.5	2.6	3.1
	Structure	N/A	N/A	N/A	N/A
	DS - XS 00+80	1.9	2.3	2.4	2.5
	DS - XS 00+45	1.4	1.6	1.7	1.8
	DS - XS 00+06	1.4	1.8	1.8	2.0
Average velocity (ft/s)	US - XS 04+59	2.3	2.1	2.1	2.2
	US - XS 03+88	1.7	1.8	1.7	1.6
	US - XS 03+43	0.9	0.8	0.8	0.8
	Structure	N/A	N/A	N/A	N/A
	DS - XS 00+80	1.4	2.1	2.0	2.3
	DS - XS 00+45	2.5	1.9	1.9	1.9
	DS - XS 00+06	1.4	1.5	1.6	1.4
Average shear (lbs/ft^2)	US - XS 04+59	1.1	1.1	1.1	1.2
	US - XS 03+88	0.7	0.7	0.6	0.5
	US - XS 03+43	0.3	0.3	0.3	0.2
	Structure	N/A	N/A	N/A	N/A
	DS - XS 00+80	0.7	1.2	1.2	1.4
	DS - XS 00+45	1.2	1.1	1.0	1.1
	DS - XS 00+06	0.7	0.9	0.9	0.9

Notes: ft = feet, s = second, lbs = pounds, US = upstream, DS = downstream, XS = cross-section, N/A = not available. Main channel extents were approximated by developing banklines within the hydraulic model. These banklines were chosen by marking the edge of the main channel based on the LiDAR topography.

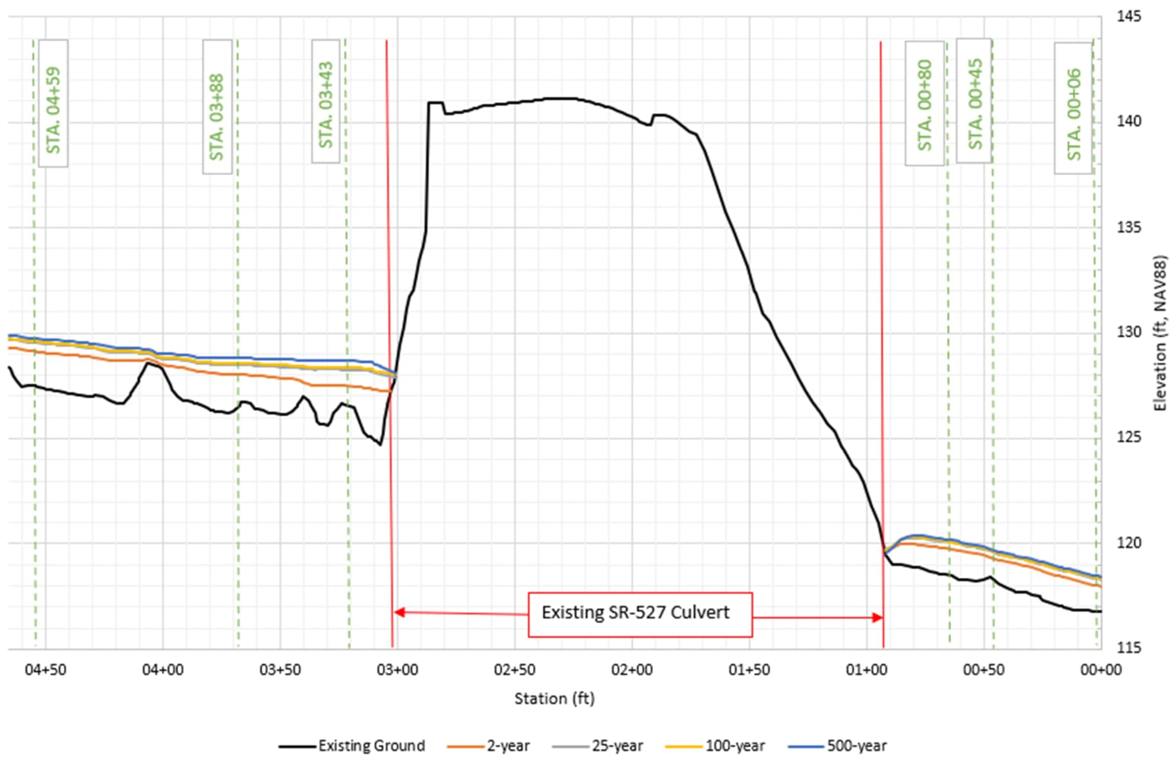


Figure 5-17: Existing conditions water surface profiles

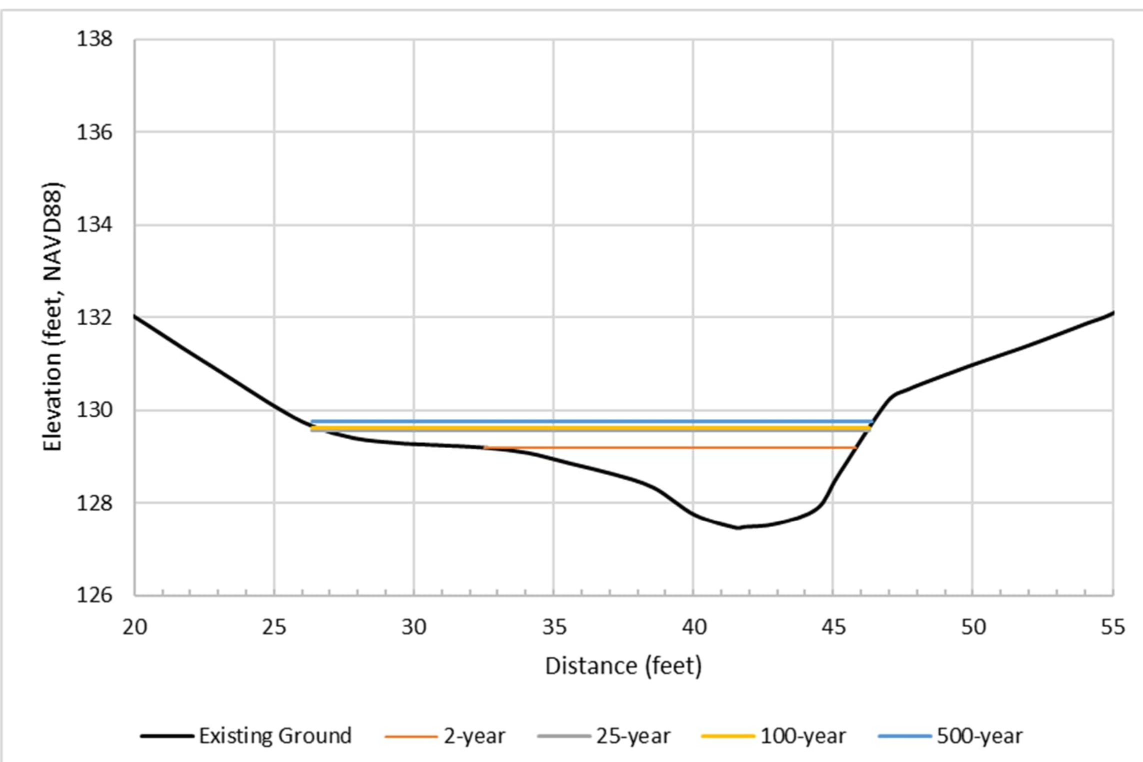


Figure 5-18: Upstream existing channel cross section (STA 04+59)

With higher flows in the floodplain during the 100-year event, water velocities are distributed across the entire inundated area. As seen in **Figure 5-19**, velocities in the majority of the floodplain are relatively low and increase in magnitude as they reach the main channel. Local increases in velocities can be seen at the inflow boundary condition due to the constant inflow condition. Velocities are greater downstream of the culvert crossings than upstream. The highest velocity adjacent to the existing crossing occurs at the outlet of the 527 culvert and flows at 6.3 ft/sec. The overall maximum velocity of 6.4 ft/s occurs at the 500-year event is found in the stretch downstream of the outlet of the I-405 crossing but upstream of the SR-527 crossing.

Main channel and floodplain velocities for the 100-year flood event can be seen in **Figure 5-19** and **Figure 5-20.** In general, the main channel velocities are greater than the left and right overbank velocities. Overbank and main channel velocities are higher downstream of the I-405 crossing. Average velocities under existing conditions are shown in **Table 5-4**.

Table 5-4: Existing conditions average channel and floodplains velocities

Cross-section Location	Q100 Average Velocities Tributary Scenario (ft/s)		
	Left Overbank [a]	Main channel	Right Overbank [a]
US - XS 04+59	1.0	3.5	1.0
US - XS 03+88	1.2	2.7	N/A
US - XS 03+43	0.7	1.5	0.3
Structure	N/A	N/A	N/A
DS - XS 00+80	1.1	3.5	0.8
DS - XS 00+45	1.0	4.0	0.9
DS - XS 00+06	1.5	3.5	0.6

Notes: ft = feet, s = second, US = upstream, DS = downstream, XS = cross-section, N/A = not available.

[a] Right and left overbank locations were approximated using the one-dimensional cross sections in SR-H2D. The banklines were drawn using the topography of the channel.

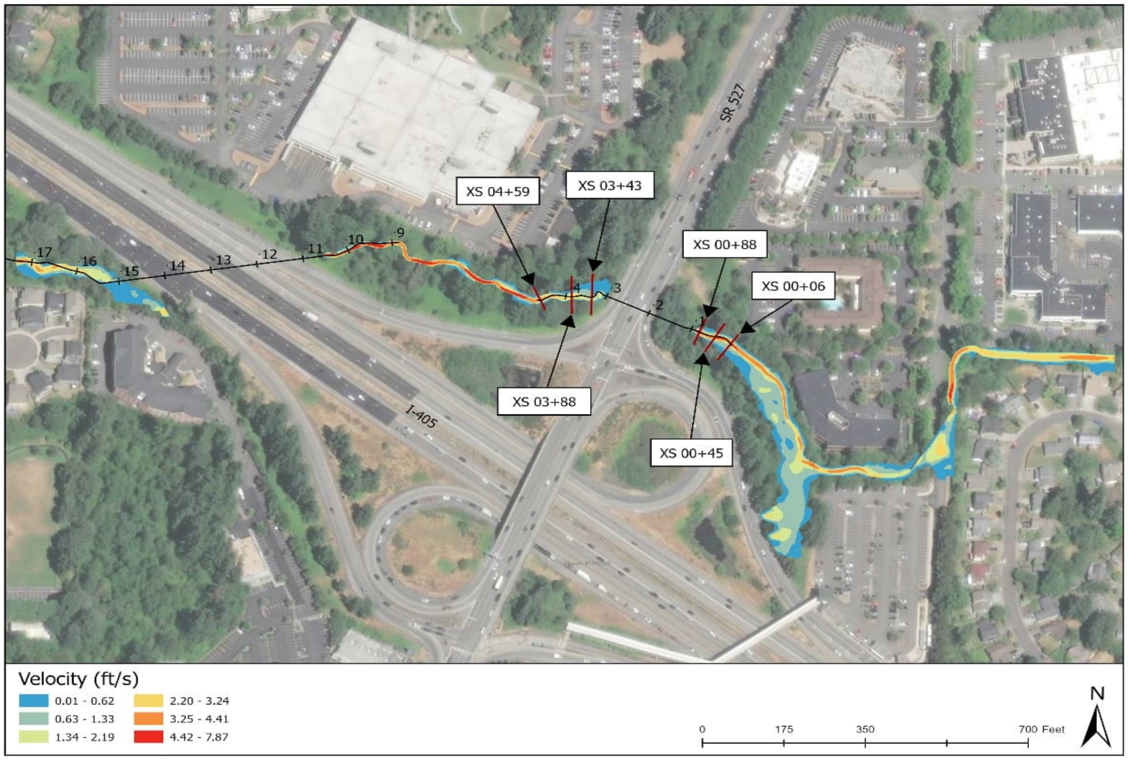


Figure 5-19: Existing conditions 100-year velocity map with cross-section locations

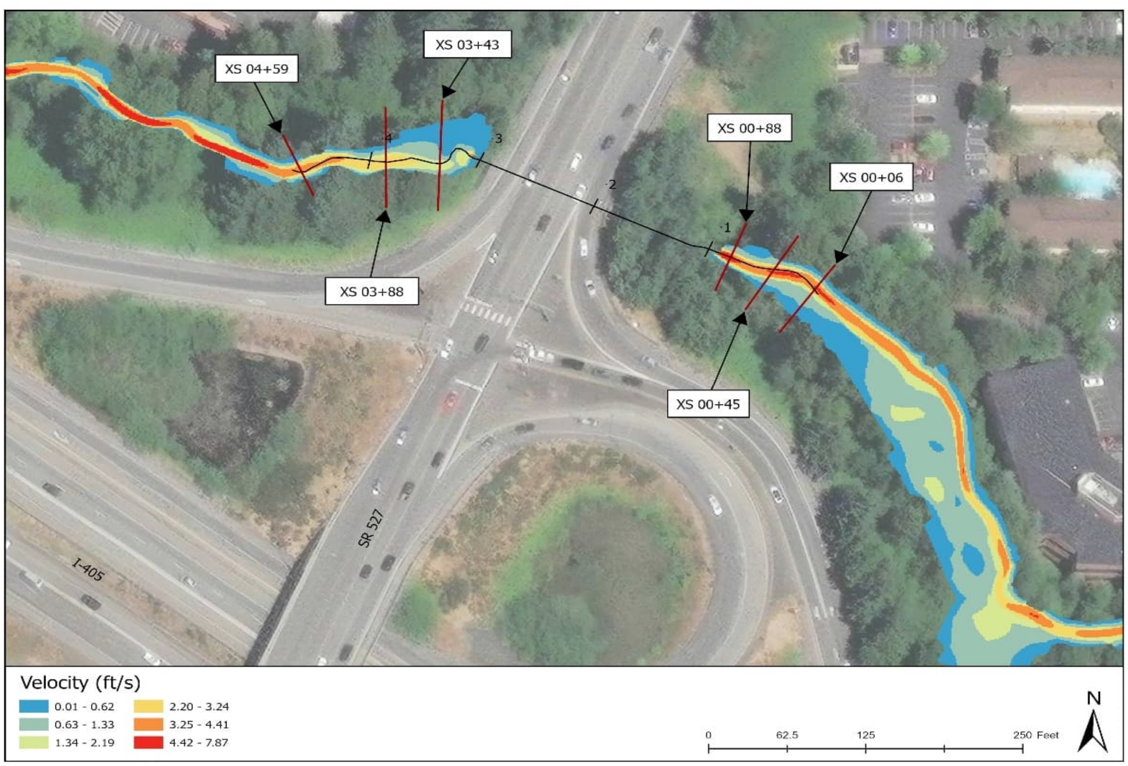


Figure 5-20: Existing conditions 100-year velocity map of SR 527 crossing

5.3 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 includes vertical walls within the structure at the edge of the SFZ, unless otherwise specified. The structure walls and wing walls were modeled as holes in the mesh that the model treats as infinitely tall vertical walls. See **Section 4.2.2** for a description of how the minimum hydraulic width and SFZ were determined.

This section presents key results from the hydraulic analysis of the proposed SR 527 Queensborough Creek crossing. Illustrations summarizing the WSE, velocity, depths, and shear stress under the 2-, 25-, 100-, 2080 projected 100-, and 500-year recurrence interval flows are provided in **Appendix H**. **Figure 5-21** depicts the SRH-2D elevation mesh of the proposed condition and associated cross sections used for reporting results. All results are presented relative to the NAVD 88 datum. Hydraulic results for all cross sections are summarized in **Table 5-5**.

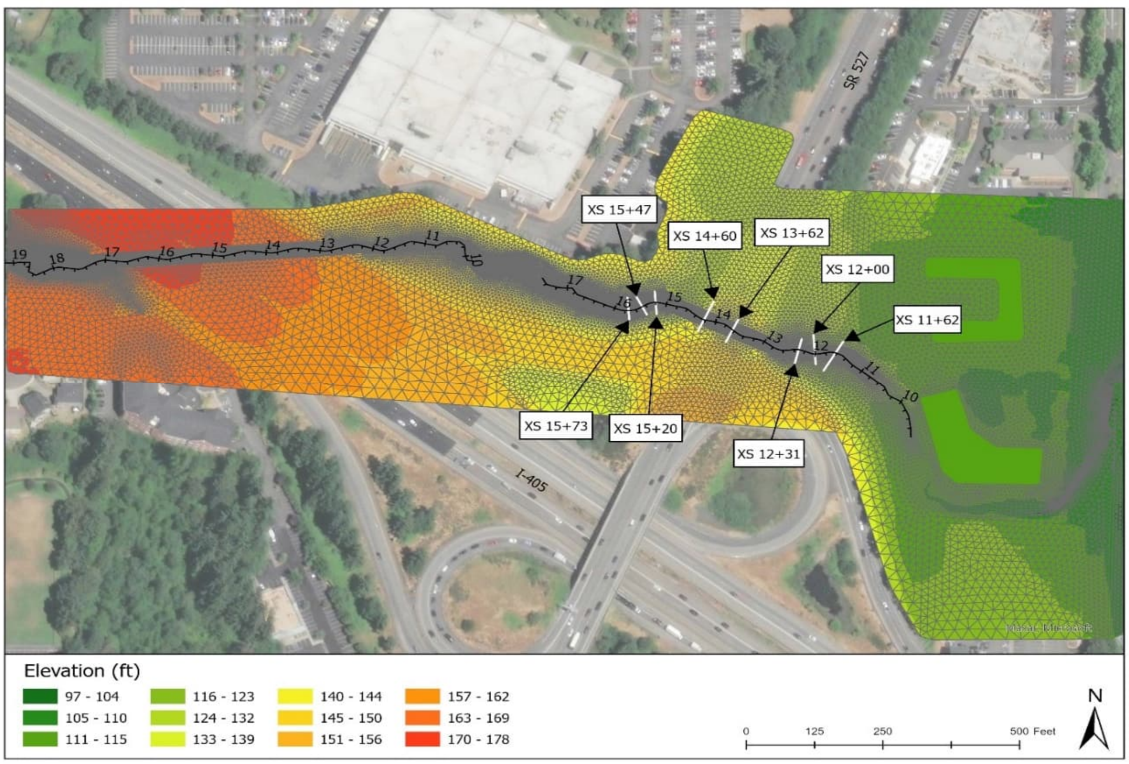


Figure 5-21: Locations of cross sections on proposed alignment used for reporting results

Table 5-5: Average main channel hydraulic results for proposed condition

Hydraulic Parameter	Cross Section	2-year	25-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	US - XS 15+73	128.3	128.8	128.9	129.1	129.4
	US - XS 15+47	127.4	127.9	128.0	128.2	128.4
	US - XS 15+20	126.9	127.5	127.6	127.8	128.0
	ST - XS 14+60	124.7	125.1	125.3	125.4	125.6
	ST – XS 13+62	123.4	123.8	123.9	124.1	124.3
	DS - XS 12+31	120.6	121.1	121.2	121.4	121.6
	DS - XS 12+00	119.9	120.4	120.5	120.7	120.9
	DS - XS 11+62	119.1	119.4	119.5	119.7	119.8
Maximum depth (ft)	US - XS 15+73	2.7	3.2	3.3	3.6	3.8
	US - XS 15+47	1.4	1.9	2.0	2.2	2.4
	US - XS 15+20	2.7	3.2	3.3	3.5	3.7
	ST - XS 14+60	2.5	3.0	3.1	3.3	3.5
	ST – XS 13+62	1.3	1.8	1.9	2.1	2.2
	DS - XS 12+31	2.6	3.1	3.3	3.5	3.7
	DS - XS 12+00	2.1	2.6	2.7	2.9	3.0
	DS - XS 11+62	1.8	2.2	2.3	2.4	2.6
Average velocity (ft/s)	US - XS 15+73	1.2	1.8	1.9	2.0	2.3
	US - XS 15+47	2.0	2.4	2.6	2.9	3.2
	US - XS 15+20	1.1	1.5	1.6	1.9	2.1
	ST - XS 14+60	1.3	1.5	1.8	2.1	2.4
	ST – XS 13+62	2.2	2.5	2.6	2.9	3.2
	DS - XS 12+31	1.2	1.7	1.8	2.1	2.2
	DS - XS 12+00	1.4	1.7	1.8	1.9	2.1
	DS - XS 11+62	1.0	1.4	1.5	1.6	1.9
Average shear stress (lbs/ft^2)	US - XS 15+73	0.5	0.9	1.0	1.2	1.5
	US - XS 15+47	1.3	1.7	1.9	2.2	2.6
	US - XS 15+20	0.4	0.7	0.8	1.1	1.2
	ST - XS 14+60	0.4	0.6	0.8	1.0	1.3
	ST – XS 13+62	1.4	1.6	1.7	2.0	2.2
	DS - XS 12+31	0.5	1.0	1.1	1.4	1.6
	DS - XS 12+00	0.6	0.8	0.9	1.0	1.2
	DS - XS 11+62	0.5	0.9	1.1	1.2	1.6

Notes: ft = feet, s = second, lbs = pounds, US = upstream, DS = downstream, XS = cross-section, ST = within structure.

The 2-, 25-, 100-, 2080 100-, and 500-year WSEs along the proposed Queensborough Creek profile are shown in **Figure 5-22**. The SRH-2D proposed condition model results indicate that the proposed 30-foot span structure better accommodates the creek flows and reduces WSEs. Flows for all frequency storms are conveyed through the 30-foot structure without overtopping the roadway. Results from the 100-year and 2080 projected 100-year events indicate that, although the 2080 projected flows are greater and result in greater WSEs and velocities, they are not excessively greater in magnitude and do not impact the conveyance of flow or inhibit the continuity of channel processes. This confirms previous WSDOT direction that using the 100-year event for design is adequate.

Model results indicate that, within the structure, all flows up to the 2-year flood are conveyed within the proposed bankfull channel; greater flood events overtop the banks and extend out to the structure walls. This is shown in the typical cross section through the structure at XS 13+50 (equivalent to STA 01+30 along the existing centerline) in **Figure 5-23.**

Velocity results for the 100-year event, as seen in **Figure 5-24** and **Figure 5-25,** indicate that faster velocities occur in the Queensborough Creek channel and are minimal in the floodplain areas. Overbank and main channel velocity values are illustrated in **Figure 5-24**. Velocities decrease as flow enters the proposed crossing because the structure is wider than the streamline just upstream. Velocities are lower downstream of the crossing than velocities upstream of the SR 527 crossing. The maximum velocity of 7.56 ft/s for the reach near SR 527 at the 100-year event occurs downstream of the I-405 fish passage structure but upstream of the SR 527 crossing culvert. The overall maximum velocity of 8.26 ft/s occurs at the 500-year event at the same location. Average velocities from the proposed condition hydraulic model are shown in **Table 5-6**.

Table 5-6: Proposed conditions average channel and floodplain velocities

Cross-section location	Q100 Average Velocities (ft/s)			2080 Q100 Average Velocity (ft/s)		
	Left Overbank[a]	Main Channel	Right Overbank[a]	Left Overbank[a]	Main Channel	Right Overbank[a]
US - XS 15+73	1.2	2.6	1.1	1.2	2.9	1.3
US - XS 15+47	1.6	3.6	1.8	1.8	3.8	2.2
US - XS 15+20	1.2	2.4	0.9	1.5	2.7	1.3
ST – XS – 14+22	1.1	2.8	1.1	1.5	3.0	1.4
ST - XS 13+62	2.1	3.7	1.5	2.4	3.9	1.9
DS - XS 12+31	1.5	2.6	1.3	1.7	2.8	1.5
DS - XS 12+00	1.4	2.9	1.2	1.3	3.1	1.4
DS - XS 11+62	0.7	3.8	1.1	0.6	3.0	1.4

Notes: ft = feet, s = second, lbs = pounds, US = upstream, DS = downstream, XS = cross-section, ST = within structure
[a] Right and left overbank locations were based on where the banklines ended in the SR-H2D model. Those banklines were approximated by observing where the main channel appeared to be in the regraded channel terrain.

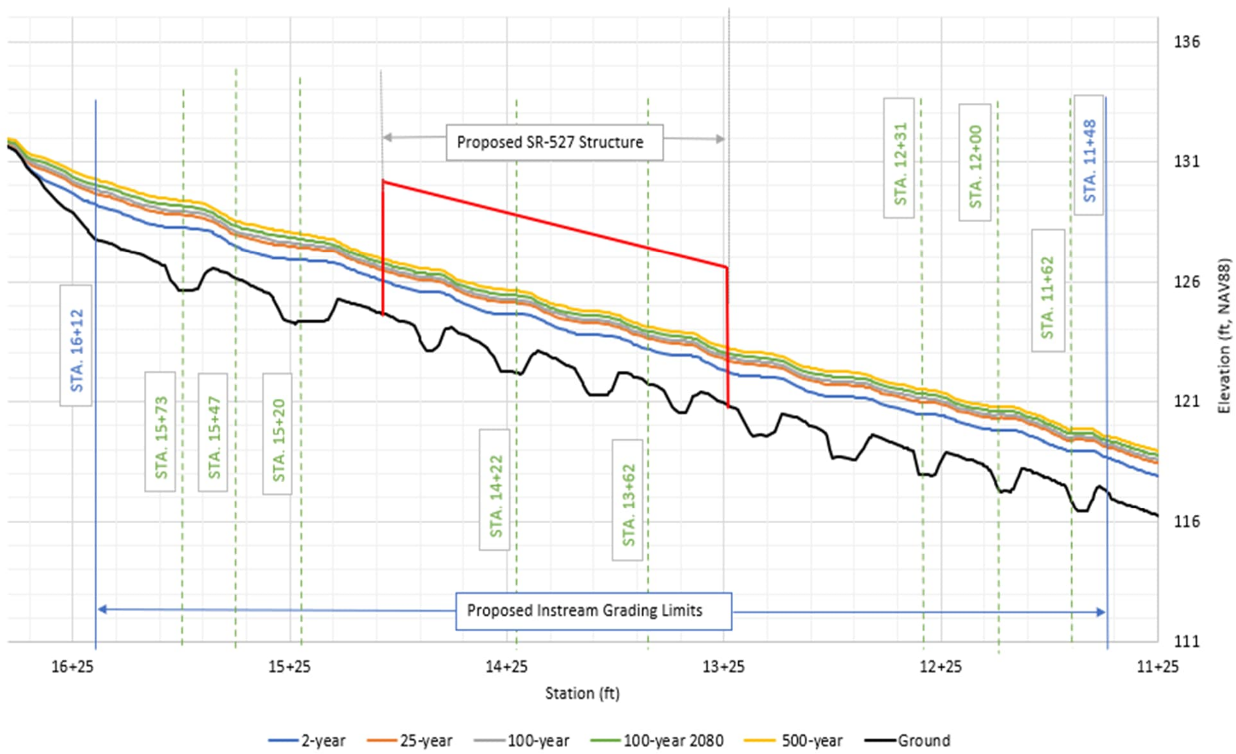


Figure 5-22: Proposed conditions water surface profiles

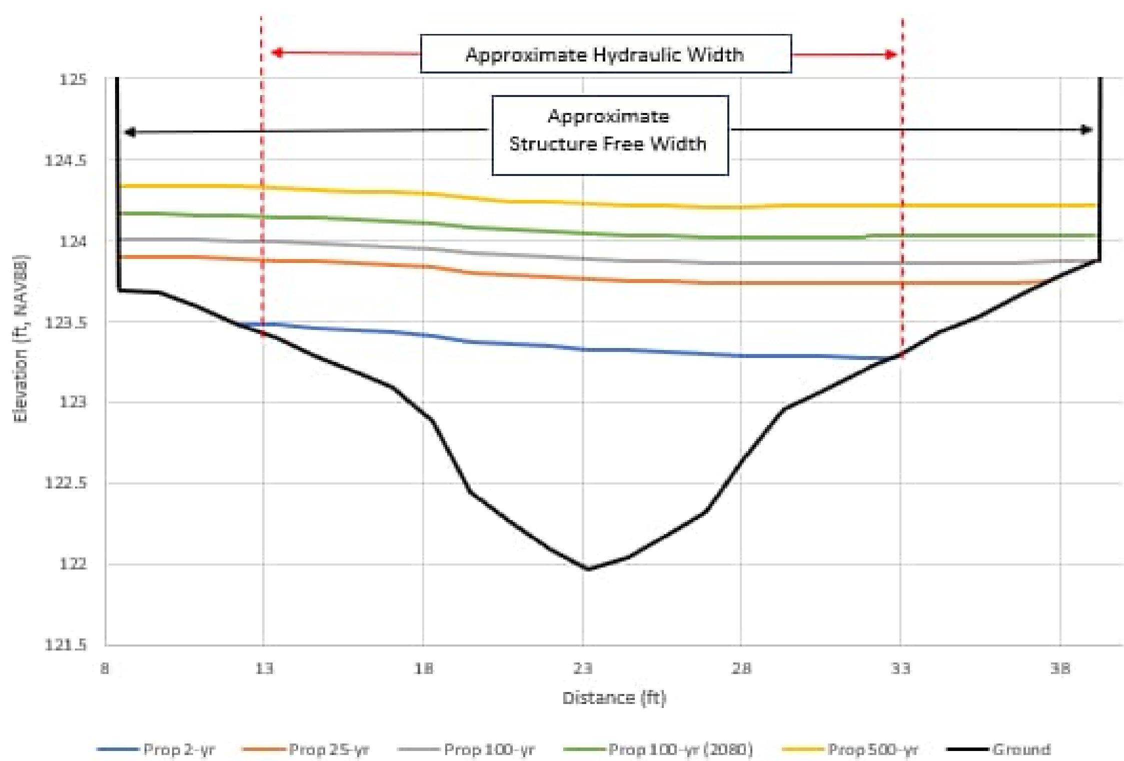


Figure 5-23: Typical riffle section through proposed structure (STA 13+62)

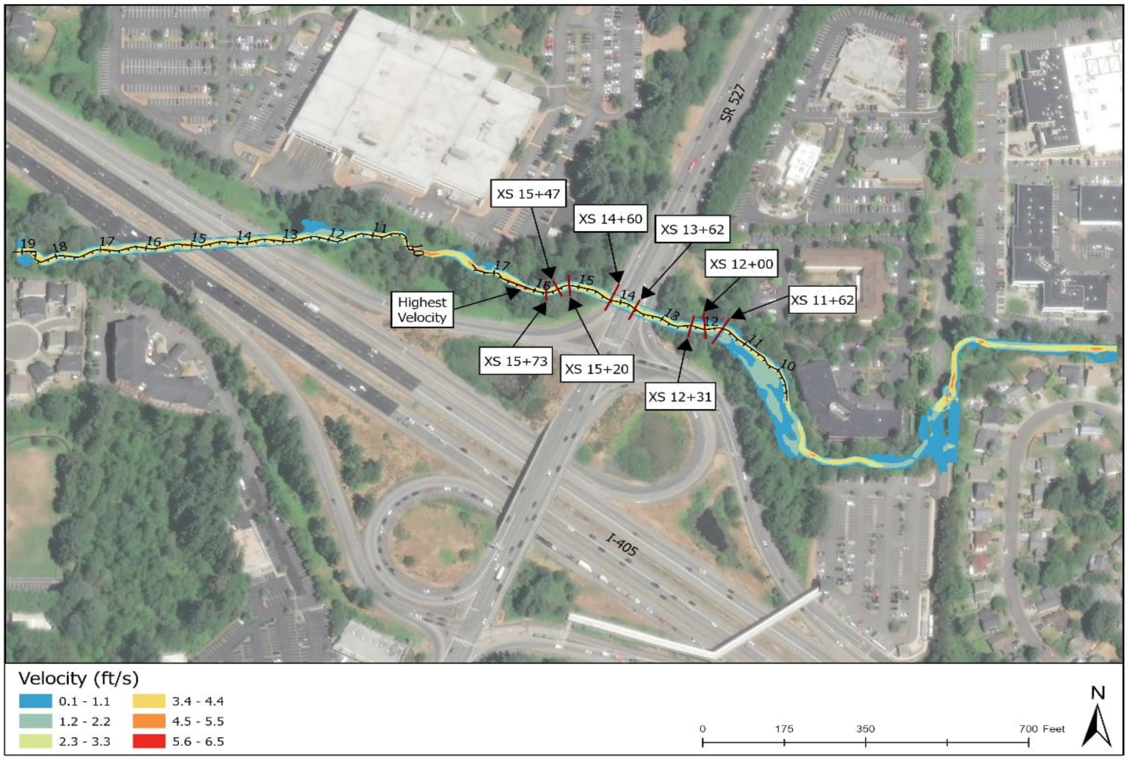


Figure 5-24: Proposed conditions 100-year velocity map

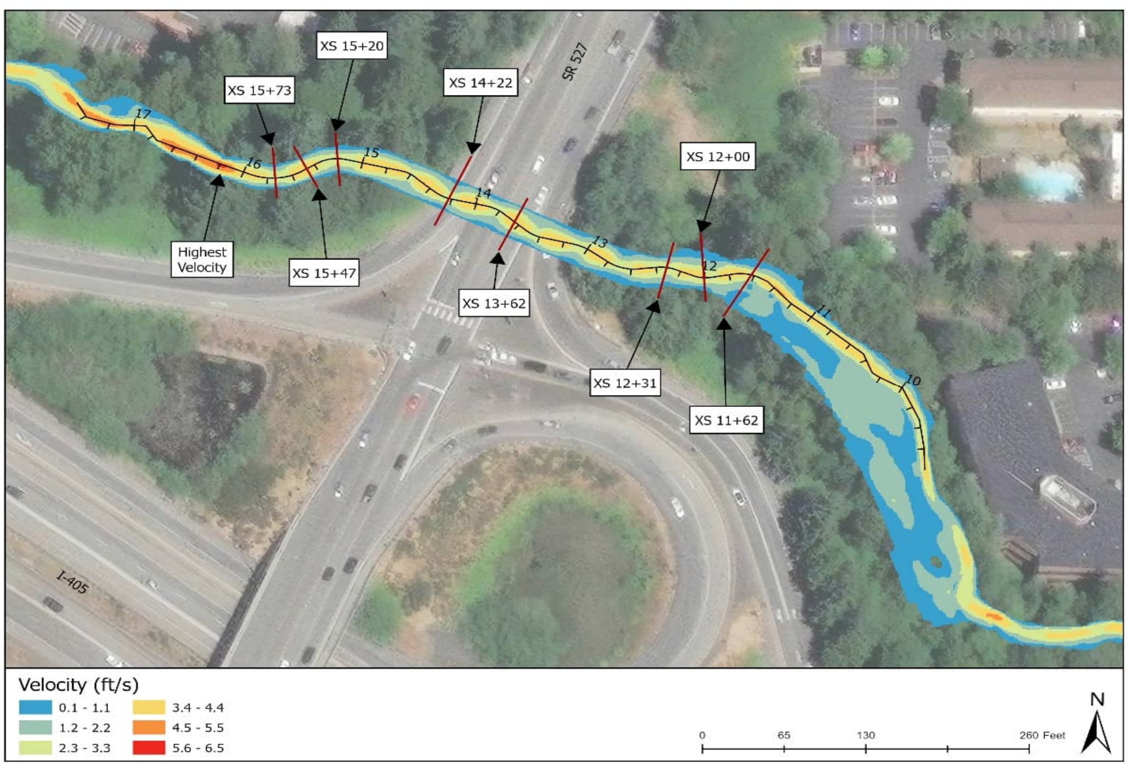


Figure 5-25: Proposed conditions 100-year velocity map of SR 527 crossing

6 Floodplain Evaluation

This project is not in a FEMA special flood hazard area. See **Appendix A** for the floodplain insurance rate map. The existing and proposed conditions were evaluated to determine whether the project would cause a change in flood risk. It was determined that the proposed SR 527 structure, with associated channel grading and habitat features, does not cause an average rise in the 1-percent AEP (100-year) WSE outside of the WSDOT ROW (**Figure 6-1**).

The 100-year WSE change from existing to proposed conditions is presented in **Figure 6-2**. The 100-year water surface profile for the existing and proposed conditions are presented along the proposed alignment in **Figure 6-3**.

To evaluate the 100-year WSE change from existing to proposed conditions, a Food Risk Assessment has been completed; see **Appendix L** for details.

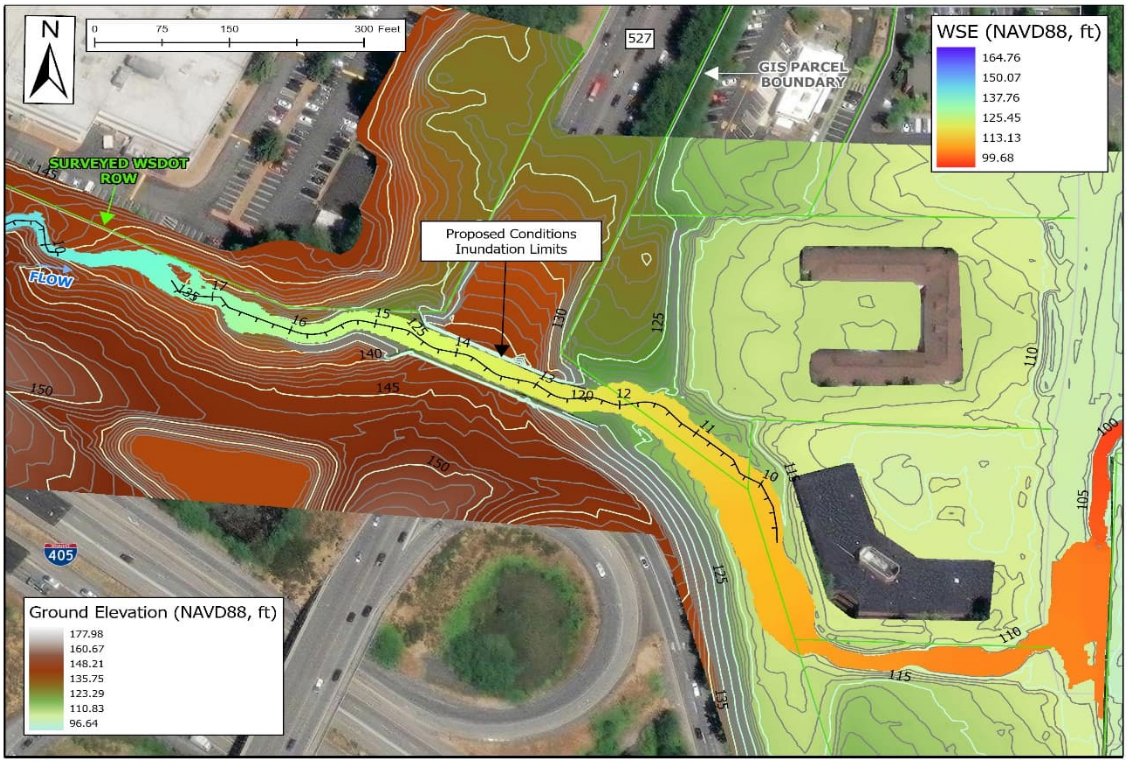


Figure 6-1: Proposed conditions 1-percent AEP (100-Year) WSE, inundation extents, and ground elevations

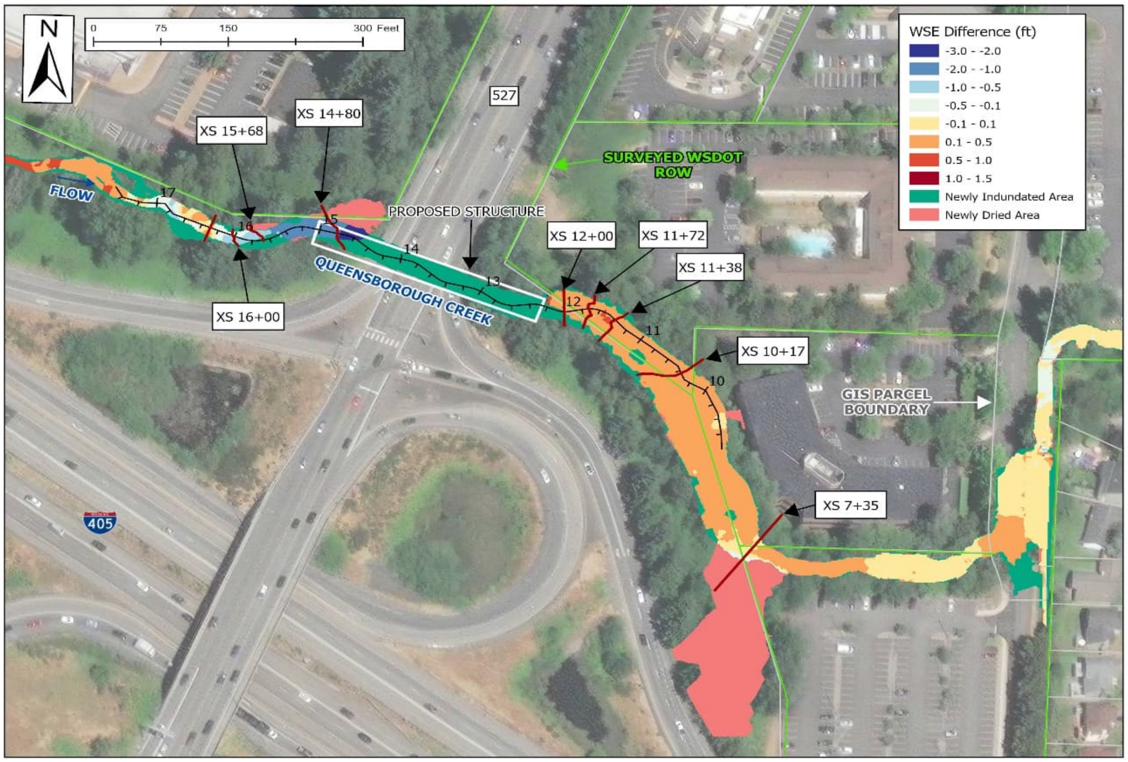


Figure 6-2: 100-year WSE change from existing to proposed conditions

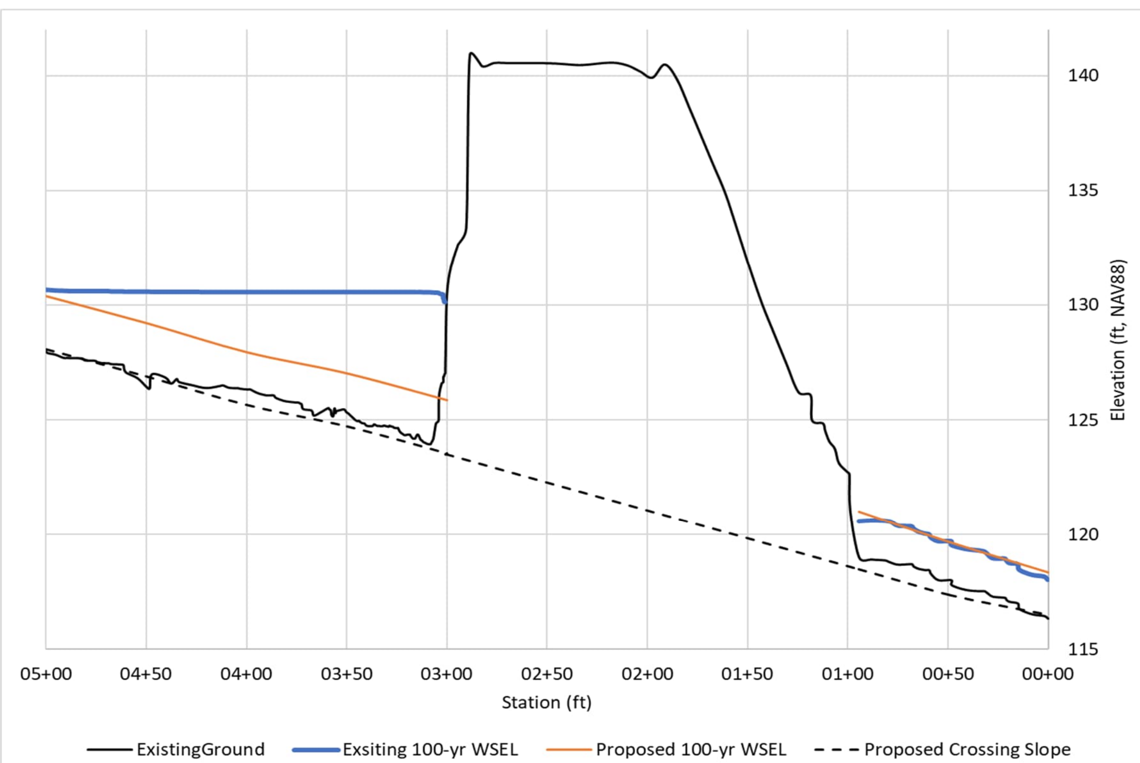


Figure 6-3: Existing and proposed conditions 100-year water surface profile comparison along proposed alignment

7 Final Scour Analysis

Using the results of the hydraulic analysis (**Section 5.3**), based on the recommended final structure, and considering the potential for lateral channel migration, final scour calculations for all flood events, including the scour design flood and scour check flood were performed following the procedures outlined in *Hydraulic Engineering Circular No. 18 - Evaluating Scour at Bridges* (HEC-18) (Arneson et al. 2012). The scour design flood is defined by the *Hydraulics Manual* (WSDOT 2022a) as the greater of the 100-year or 2080 100-year discharge; for Queensborough Creek, that is the 2080 100-year event. Similarly, the scour check flood is defined as the greater of the 2080 100-year or 500-year discharge; for Queensborough Creek, that is the 500-year event.

Scour components considered in the analysis include:

- long-term degradation,
- contraction scour,
- local scour,
- scour at LWM, and
- bend scour.

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

The risk for lateral migration, potential for long-term degradation, and evaluation of total scour rely on the final geotechnical report dated January 8, 2025 (Terracon 2025).

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 the conditions described in **Section 2.7.5**.

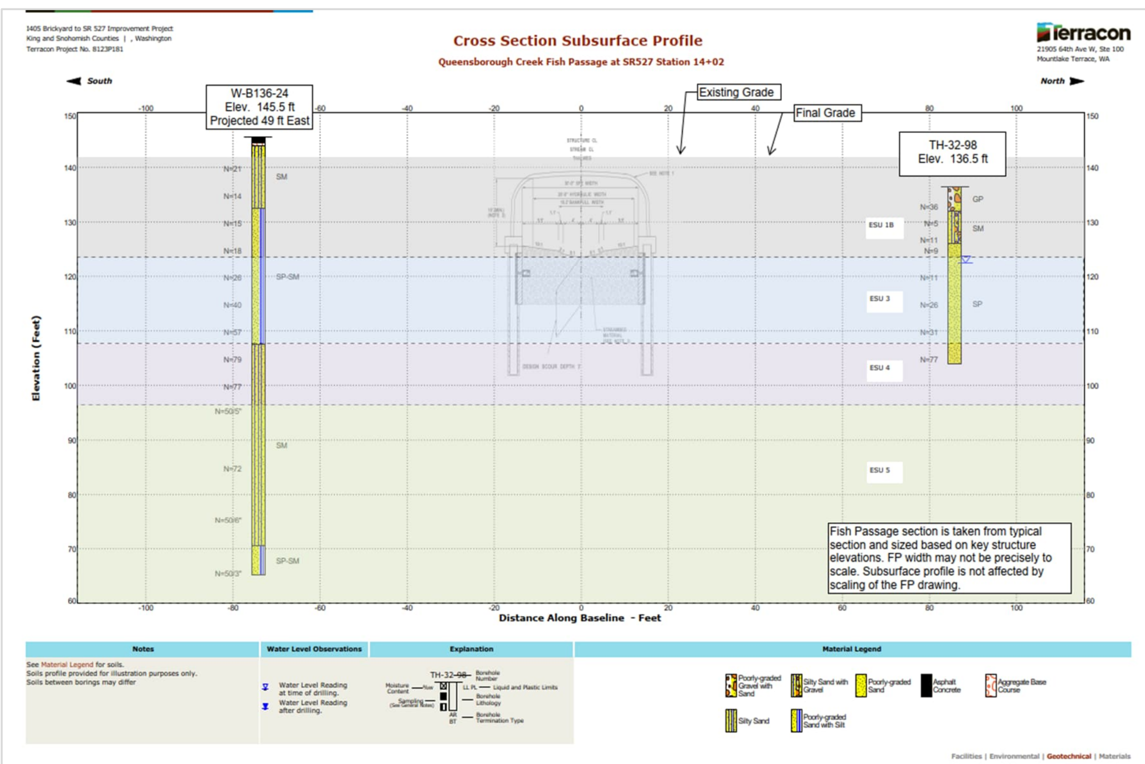
A rapid assessment of stream stability for Queensborough Creek was completed following the procedure outlined in the Federal Highway Administration's (FHWA's) *Hydraulic Engineering Circular No. 20 - Stream Stability at Highway Structures* (HEC-20) (Lagasse et al. 2012). The existing conditions were 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 the 2023 site visit was used to inform the rapid assessment scoring. The overall score of 96 indicates that Queensborough Creek has fair channel stability. A fractional score based on the vertical and lateral stability indicators is used to determine the dominant direction of instability. For Queensborough Creek, the vertical fraction of 0.71 and the lateral fraction of 0.58 indicate that vertical instability may be dominant. This is consistent with field observations, which noted that lower reaches of Queensborough Creek are incised and disconnected from the floodplain. See **Appendix P** for the scoring assessment.

Historical aerial imagery available through Google Earth Pro was reviewed for potential evidence of meander migration or channel widening. However, the resolution of available imagery is insufficient to document changes in the Queensborough Creek channel.

Geotechnical data as provided in the *RFC Geotechnical Engineering Report, Design Package 8* dated January 8, 2025, and developed by Terracon, was used in the evaluation of lateral migration potential at the fish passage structures. According to the subsurface cross sections of Queensborough Creek at SR 527 that were developed from multiple boring locations near the proposed structure, the proposed streambed, structure, and wingwalls are withing engineering stratigraphic units (ESU) 1B and 3 (**Figure 7-1**).

ESU 1B corresponds to existing fill and is generally granular, cohesionless, and loose to very dense sand with variable silt and gravel content. ESU 3 corresponds to recessional outwash (Q_{vr}) and generally consists of medium dense to dense sand with variable gravel content and minor silt and clay layers; see **Section 2.3**.

Non-erodible geologic features or cohesive materials that could limit the extents of lateral migration of the stream channel were not identified at this crossing. Although Queensborough Creek has fair channel stability, geotechnical data available at this time are not sufficient to exclude the risk of lateral migration from the scour analysis being anticipated over the life (75+ years) of the proposed structure. Lateral migration is assumed to occur for the purposes of total scour across the entire structure free zone (SFZ) width within the structure.



Source: Terracon 2025

Figure 7-1: Subsurface cross-section of the proposed Queensborough Creek fish passage at SR 527

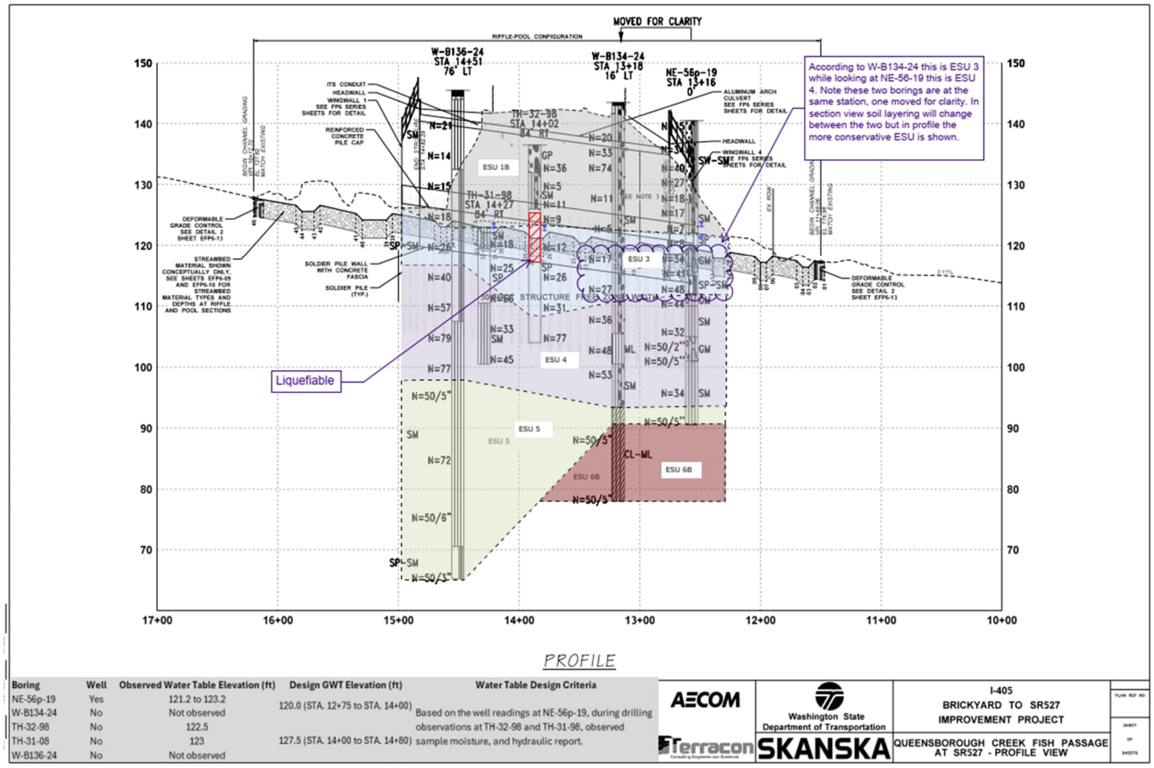
7.2 Long-Term Degradation of the Channel Bed

For Queensborough Creek, the design requires the channel to naturally regrade, which could occur in the form of long-term degradation. Long-term degradation of the channel bed was evaluated using an armor layer analysis.

Engineering stratigraphic units (ESU) 1B and 3 discussed in **Section 7.1** overlay ESU 4, which corresponds to Glacial till (Q_{vt}), also known as hardpan; see **Section 2.3**. Geotechnical borings have also identified a soil layer – ESU 6B – that includes cohesive materials. It corresponds to undisturbed transitional beds (Q_{tb}) and generally consists of very stiff to hard silt and clay with some interbedded granular material. **Figure 7-2** shows the subsurface profile at the Queensborough Creek crossing of SR 527, and the variable depth of ESU 4 and ESU 6B. These layers may be capable of slowing long-term degradation, but the spatial extents do not support a definitive vertical limit to channel degradation.

However, in situations where the streambed material contains a sufficient quantity (>10 percent) of coarse material that is not transported by normal discharge, the best approach to compute depth of degradation is to consider the development of an armor layer (Pemberton and Lara 1984), where finer material is mobilized and transported downstream, while the remaining material is coarse enough to inhibit vertical degradation of the streambed.

Following the procedures presented in *Hydraulic Engineering Circular No. 20 - Stream Stability at Highway Structures* (HEC-20) (Lagasse et al. 2012) and the source material (Pemberton and Lara 1984), the long-term degradation for Queensborough Creek has been estimated using an armor analysis under bankfull conditions. As described in **Appendix K.1**, an armor layer would form at the Queensborough Creek crossing of SR 527 after only 0.4 feet of degradation considering the proposed streambed material (see **Section 4.3.1**). This layer would likely arrest any further degradation of the streambed. Therefore, 0.4 feet is selected as the long-term degradation component of total scour.



Source: Terracon 2025

Figure 7-2: Subsurface profile of Queensborough Creek fish passage at SR 527.

7.3 Contraction Scour

The 2-year, 25-year, 100-year, 2080 project 100-year climate change, and 500-year events were evaluated for contraction scour in the proposed conditions model (**Section 5.3**). Contraction scour was calculated using clear-water conditions because the critical velocity of sediment at the approach section is greater than the average velocity at the approach section at all flood events (**Appendix K.1**). The sediment size used for contraction scour calculations in SRH-2D is the D_{50} of the existing streambed sediment.

In the SRH-2D hydraulic model, the 2-year, 25-year, 100-year, 2080 100-year, and 500-year events were evaluated by the Federal Highway Administration (FHWA) hydraulic toolbox on the same bridge scour coverage with the same scour arcs. The calculations carried out using the FHWA hydraulic toolbox showed that no contraction scour is anticipated at the SR 527 fish passage crossing for any of the evaluated storm events (**Appendix K.1**).

7.4 Local Scour

Pier and abutment scour were considered for local scour analysis per *Hydraulic Engineering Circular No. 18 - Evaluating Scour at Bridges* (HEC-18) (Arneson et al. 2012). In addition, bend scour is also considered as a component of total scour – evaluated at meander bends in the proposed alignment.

7.4.1 Pier Scour

Pier scour was considered per HEC-18 guidance, but 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.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program 24-20 approach for all flood events up to the scour design flood and scour check flood using a clear-water condition. As explained in **Section 7.3**, clear-water conditions prevail because the critical velocity of sediment at the approach section is greater than the average velocity at the approach section at all flood events (**Appendix K.1**).

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 (Arneson et al. 2012).

Abutment scour was evaluated at the entrance of the proposed culvert. Wing wall geometries were approximated and included in the mesh. Accordingly, a vertical wall abutment with wing walls was chosen as the abutment type in the FHWA hydraulic toolbox. The calculations carried out using the FHWA hydraulic toolbox showed that no abutment scour is anticipated at the SR 527 fish passage crossing for any of the evaluated storm events (see **Appendix K.1**).

7.4.3 Bend Scour

Bend scour was evaluated for all meander bends within the proposed channel grading; details are presented in **Appendix K.3**. Considering the proposed sediment gradations (**Section 4.3.1**), the two most applicable bend scour equations are the Thorne (WDFW 2012) and USACE (USBR 2015) equations for gravel-bed streams. The Maynord and Wattanabe bend scour equations apply to sand-bed channels are not utilized.

The bend scour equations are empirical and were developed based on flows at or below the bankfull condition and are generally valid up to significant interaction between main channel and overbank flows (USACE 2025; WDFW 2012). Due to this, bend scour was evaluated using the 2-year flow. **Figure 7-3** shows the location of the bend scour calculations. Bends 1, 2, 3, and 4 are downstream of the structure, bends 10 and 11 are upstream of the structure. Bends 5-9 are located within the structure.

The result of this analysis is summarized in **Table 7-1**. They represent an approximation of how deep meander bend would scour in a natural channel having a constant bankfull width. However, the proposed channel will have pre-scoured pools that dissipate hydraulic energy, resulting in a 1.0-foot residual pool depth at every meander bend. Because the scour depth estimated by the Thorne equation is less than the residual pool depth, no bend scour is anticipated.

This is supported by the USACE (1994; 2024) methodology, which directly incorporates the maximum depth at the evaluation cross-section, and predicts negative bend scour for all bends.

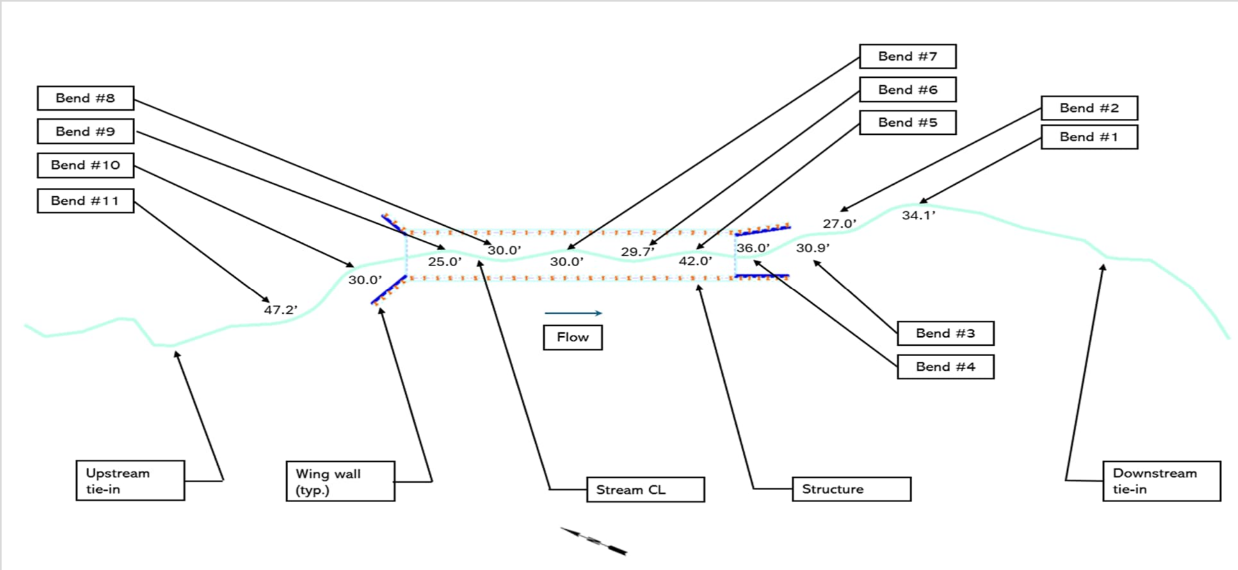


Figure 7-3: Location of meander bends evaluated for bend scour

Table 7-1: Depth of bend scour

	Thorne			**USACE**
Bend No.	**Depth of Scour Below Local Streambed Elevation (ft)**	**Residual Pool Depth (ft)**	**Estimated Scour Depth in Pre-Scoured Pool (ft)**	**Estimated Scour Depth in Pre-Scoured Pool (ft)**
1	0.6	1.0	0.0	-0.7
2	0.6	1.0	0.0	-0.8
3	0.7	1.0	0.0	-0.5
4	0.6	1.0	0.0	-0.6
5	0.5	1.0	0.0	-0.8
6	0.5	1.0	0.0	-0.8
7	0.6	1.0	0.0	-0.7
8	0.6	1.0	0.0	-0.8
9	1.0	1.0	0.0	-0.4
10	0.7	1.0	0.0	-0.5
11	0.5	1.0	0.0	-0.7

Notes: ft = feet; USACE = U.S. Army Corps of Engineers; Negative values indicate zero bend scour.

7.5 Total Scour

For Queensborough Creek, there are four components of total scour: long-term degradation, contraction scour, and local scour in the form of abutment scour and bend scour. Total depths of scour for the scour design flood and scour check flood at the proposed Queensborough Creek SR 527 crossing are summarized in **Table 7-2**. Further details for scour calculations can be found in **Appendix K**. The *Hydraulics Manual* defines a minimum total scour depth of 3.0 feet; this is considered the total design scour for Queensborough Creek. Because the risk of lateral migration of the main channel is assumed across the entire SFZ width for this scour analysis (see **Section 7.1**), the thalweg is the starting elevation for total scour depths.

Table 7-2: Scour analysis summary

Calculated scour components and total scour for SR 527 at Queensborough Creek		
Long-term degradation (feet)	0.4	
	Scour design flood (2080 100-year)	**Scour check flood (500-year)**
Contraction scour (feet)	0.0	0.0
Local abutment scour (feet)	0.0	0.0
Bend scour (feet)	0.0	0.0
Estimated depth of total scour (feet)	0.4	0.4
Minimum depth of total scour (feet)	**3.0**	**3.0**

Note: depth of total scour should be applied to the thalweg elevation of the proposed channel to determine the total scour elevation at each infrastructure component.

7.6 Other Types of Scour

Other types of scour, namely local scour caused by large woody material (LWM) was also evaluated. However, this type of scour is not a component of total scour as defined by *Hydraulic Engineering Circular No. 18 - Evaluating Scour at Bridges* (HEC-18) (Arneson et al. 2012) and is not included in the total scour determination.

7.6.1 Scour at LWM

Large woody material (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 like wing walls. Per the *Hydraulics Manual* section 10-6.6 (WSDOT 2022a), reliable methods for estimating scour at LWM 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.

To estimate the potential scour at LWM, the HEC-18 pier scour equation was used at all LWM structures. The HEC-18 pier scour equation frequently over-predicts the scour observed in laboratory studies and therefore results in maximum scour depths (Arneson et al. 2012). When using the HEC-18 equation, caution needs to be taken with the resulting scour depths when this equation is applied to geometries like LWM that are different than the pier shapes that the equation was developed for. The U.S. Bureau of Reclamation Bank Stabilization Guidelines (USBR 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 provides less conservative results than the HEC-18 method. The less conservative Julien equation (USBR 2015) was also used to evaluate potential scour at LWM.

Both methods described above are dependent on the geometry of LWM. It was assumed the upstream, or most prominent rootwad in the channel would be the main obstruction (see **Appendix K.2**).

Local scour at LWM was evaluated for the 2-year, 25-year, 100-year, projected 2080 100-year, and 500-year events in the proposed conditions model (**Section 5.3**). Results are presented in **Table 7-3**. Calculations are found in **Appendix K.2**.

The maximum scour depth for the HEC-18 equation is 3.5 feet at structure “H” under the 500-year flow and the projected 2080 100-year flow.

This type of scour is not a component of total scour as defined by HEC-18, and is not included in the total scour determination, but it is accounted for in the proposed design. The width of a pier scour hole is typically assumed to be twice the scour hole depth. To reduce risk of scour at structural elements caused by LWM, LWM rootwads nearest to the fish passage structure wing walls are placed a minimum of 7.0 feet away.

Table 7-3: Depth of local scour at LWM

Structure	25-Year Scour Depth (ft)		100-Year Scour Depth (ft)		2080 100-Year Scour Depth (ft)		500-Year Scour Depth (ft)	
-	Julien	HEC-18	Julien	HEC-18	Julien	HEC-18	Julien	HEC-18
A	1.5	2.4	1.5	2.4	1.6	2.6	1.7	2.7
B	1.5	2.7	1.6	2.9	1.6	2.9	1.7	3.0
C	1.7	2.7	1.8	2.9	1.9	2.9	2.0	3.1
D	1.6	3.0	1.6	3.1	1.8	3.3	1.9	3.4
E	1.8	2.9	1.9	3.0	2.0	3.1	2.1	3.3
F	1.8	2.8	1.9	2.9	1.9	3.0	2.1	3.2
G	1.7	2.9	1.8	3.1	1.9	3.2	2.0	3.3
H	1.6	3.1	1.7	3.3	1.8	3.4	1.9	3.5

Notes: STA = station; ft = feet; LWM = large woody material; 2-year and 10-year results omitted for clarity - see Appendix K.2.

8 Scour Countermeasures

No scour countermeasures are required or recommended for the Queensborough Creek crossing of SR 527 MP 2.76. As described in **Section 7.5**, the scour analysis shows long-term degradation limited by the formation of an armor layer, with no expected contraction scour or local abutment scour (see **Appendix K.1**), and minimal bend scour (**Appendix K.3**).

Additional scour analysis evaluated scour at LWM. To ensure scour at LWM does not undermine the crossing structure no key pieces are placed within the structure. Outside of the structure, key piece rootwads are placed a minimum of 7.0 feet away the structure wing walls (see **Appendix K.2**).

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	1,139 LF	2.1 Site Description
Bankfull width	Reference reach found?	No	2.7.1 Design Reference Reach Selection
	Design BFW	10.1 feet	2.7.2 Channel Geometry
	Concurrence BFW	10.1 feet	2.7.2 Channel Geometry
FUR	FPW	US 10.5 feet DS 23.7 feet	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	US Average 1.3 DS Average 2.6	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See section:	2.7.2 Channel Geometry
	Proposed	See section:	4.3.2 Channel Complexity
Hydrology/design flows	100-year flow	89.0 cfs	3 Hydrology and Peak Flow Estimates
	2080 100-year flow	110.1 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	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See section:	2.7.2 Channel Geometry
	Proposed	See section:	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	2.57%	2.1 Site Description
	Upstream reach	2.54%	4.1.3 Channel Gradient
	Proposed	2.32%	4.1.3 Channel Gradient
Hydraulic width	Existing	4.0 feet	2.6.2 Existing Conditions
	Proposed	20.0 feet	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Structure free zone width	Proposed	30.0 feet	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	3.0 feet	4.2.3 Vertical Clearance
	Required freeboard applied to 100-year or 2080 100-year	2080 100-year	4.2.3 Vertical Clearance
	Maintenance clearance	10.0 feet	4.2.3 Vertical Clearance
	Low chord elevation	See section:	4.2.3 Vertical Clearance
Crossing length	Existing	215.0 feet	2.1 Site Description
	Proposed	166.5 feet	4.2.4 Hydraulic Length
Structure type	Recommendation	Yes	4.2.6 Structure Type
	Type	Buried (bottomless)	4.2.6 Structure Type

Stream Crossing Category	Element	Value	Report Location
Substrate	Existing	See section:	2.7.3 Sediment
	Proposed	See section:	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	No	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	Yes – MWM only	4.3.2 Channel Complexity
	Meander bars	4	4.3.2 Channel Complexity
	Deformable grade control	Yes	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	No	2.7.5 Channel Migration
	Floodplain changes?	Yes	6 Floodplain Evaluation
Scour	Analysis	See section:	7 Final Scour Analysis
	Scour countermeasures	No	8 Scour Countermeasures
Channel degradation	Potential	0.4 feet	7.2 Long-Term Degradation of the Channel Bed
Channel degradation	Allowed	Yes, but limited via channel complexity	7.2 Long-Term Degradation of the Channel Bed

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