Washington State
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I-405 MP 20.95 Juanita Creek Tributary (WDFW ID): Draft Final Hydraulic Design Report

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I-405, NE 132nd Street Interchange Project
MP 20.95 Juanita Creek Tributary
Draft Final Hydraulic Design Report
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1 Introduction

To comply with United States of America, et al. v. State of Washington, et al. No. C70-9213 Sub proceeding 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 to 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the Interstate 405 (I-405) crossing of Juanita Creek Tributary at Mile Post (MP) 20.95. This existing structure under I-405 has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (Site ID 992654) due to slope.

Per 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. This stream simulation culvert restores stream connection under the roadway and simulates natural stream functions within the proposed structure that meets the terms of the injunction.

The structure is located in King County, approximately 0.75-mile north of Totem Lake in Kirkland, Washington, within WRIA 8. The culvert crossing at I-405 is about 3,400 feet upstream from the confluence of the main channel of Juanita Creek. Juanita Creek tributary generally flows east to west. See Figure 1 for the vicinity map.

The proposed project will replace the existing 710-foot-long, 54-inch, and 48-inch corrugated metal and concrete pipes with a series of open channel and three stream simulation structures at 114th Place NE (Culvert 1), NE 132nd Street (Culvert 2), and Totem Lake Boulevard NE (Culvert 3). Each of the three structures will provide a minimum of 17-foot clear span cross section for the restored stream section while providing a safe roadway for the traveling public. The three proposed structures will also reduce the total enclosed length by 339 feet, while increasing the total stream length within the project limits by 135 feet. These proposed structures are designed to meet the requirements of the federal injunction utilizing the stream simulation criteria outlined in the 2013 WDFW Water Crossing Design Guidelines (WCDG) and commitments made between WSDOT, WDFW, National Marine Fisheries Service (NMFS), and the Muckleshoot Indiana Tribe Fisheries Division (MITFD) during preliminary design and permitting.

Two culvert crossings (WDFW Site IDs 998979 and 998981) are located to the north, just outside the limits of work for the proposed NE 132nd Street interchange project. WDFW has identified both crossings as fish bearing, but with minimal upstream habitat gain (less than 200 meters). Correction of these two injunction barriers has therefore been deferred to future transportation projects.

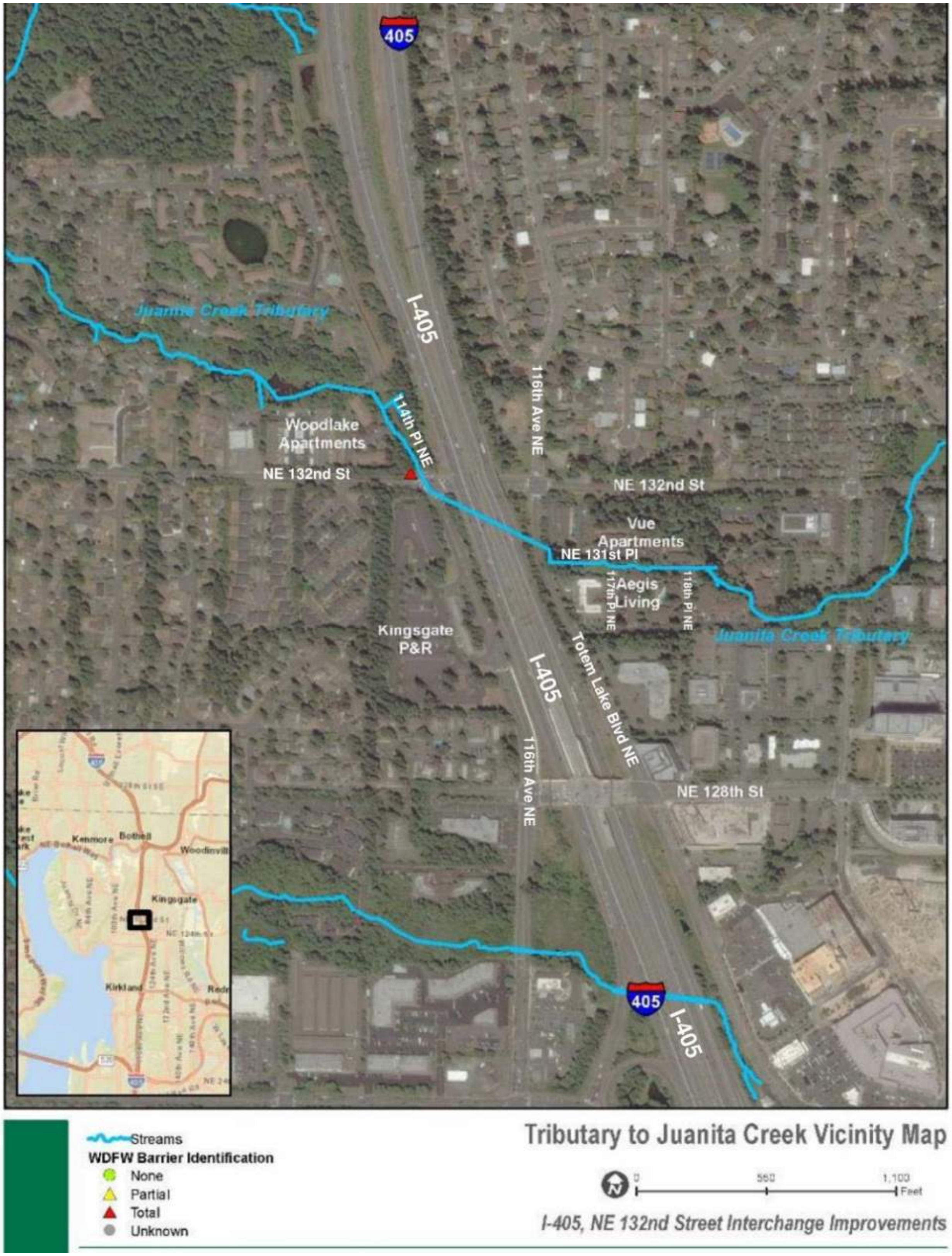

Figure 1. Vicinity Map: Juanita Creek Tributary at NE 132nd Street

2 Watershed and Site Assessment

2.1 Watershed & Landcover

Juanita Creek tributary is located within the Cedar River-Lake Washington Watershed, which is part of WRIA 8. WRIA 8 is a 692 square mile watershed that funnels all rivers, streams, and other water courses into Lake Washington and then discharges to Puget Sound via Lake Union at Shilshole Bay. The Juanita Creek tributary drainage subbasin resides almost entirely within the city of Kirkland, with the northernmost reach extending into the city of Woodinville. The subbasin area is estimated to be approximately 0.92 square mile and is upstream of the existing I-405 crossing. The average annual precipitation is estimated to be 41.6 inches, according the WSDOT's Mean Annual Precipitation Map. Appendix B.1 shows the Washington Mean Annual Precipitation Map and Appendix B.2 shows an exhibit of the Juanita Creek tributary basin compared to the larger Juanita Creek watershed.

The general topography of Juanita Creek basin slopes from northeast to southwest. The creek traverses through highly developed areas within the city of Kirkland, before discharging to Lake Washington. About 95% of the Juanita Creek tributary subbasin is zoned as residential by the City of Kirkland. The remaining area is primarily commercial and park/open space zoning, with a trace amount of industrial zoning. See Appendix B.3 for an exhibit showing the current City of Kirkland zoning within the Juanita Creek tributary subbasin.

2.2 Geology and Soils

Geology and soils at the I-405 culvert crossing were assessed using the Natural Resources Conservation Service (NRCS) Web Soil Survey. The geology of Juanita Creek tributary subbasin consists largely of glacial till soils, with few areas of outwash soils in the lower elevations near the I-405 culvert crossing. Generally, the entire subbasin contains poorly drained soils with a few small pockets of moderately drained soils. Figure 2 shows the NRCS Hydrologic Soil Map for the subbasin.

These hydrologic soil groups are based on estimates of runoff potential, as defined by NRCS. The soils are assigned to one of the four groups (A, B, C, and D), based on the bare soil's ability to infiltrate water when fully saturated during precipitation events, with Group A having the highest infiltration rate, and group D having the lowest. Table 1 presents the table provided by NRCS that summarizes the subbasin's hydrologic soil group ratings.

Additional information and data on soil characteristics within the project site can be found in the Geotechnical Baseline Report, Geotechnical Data Report, and historical documents from WSDOT records.

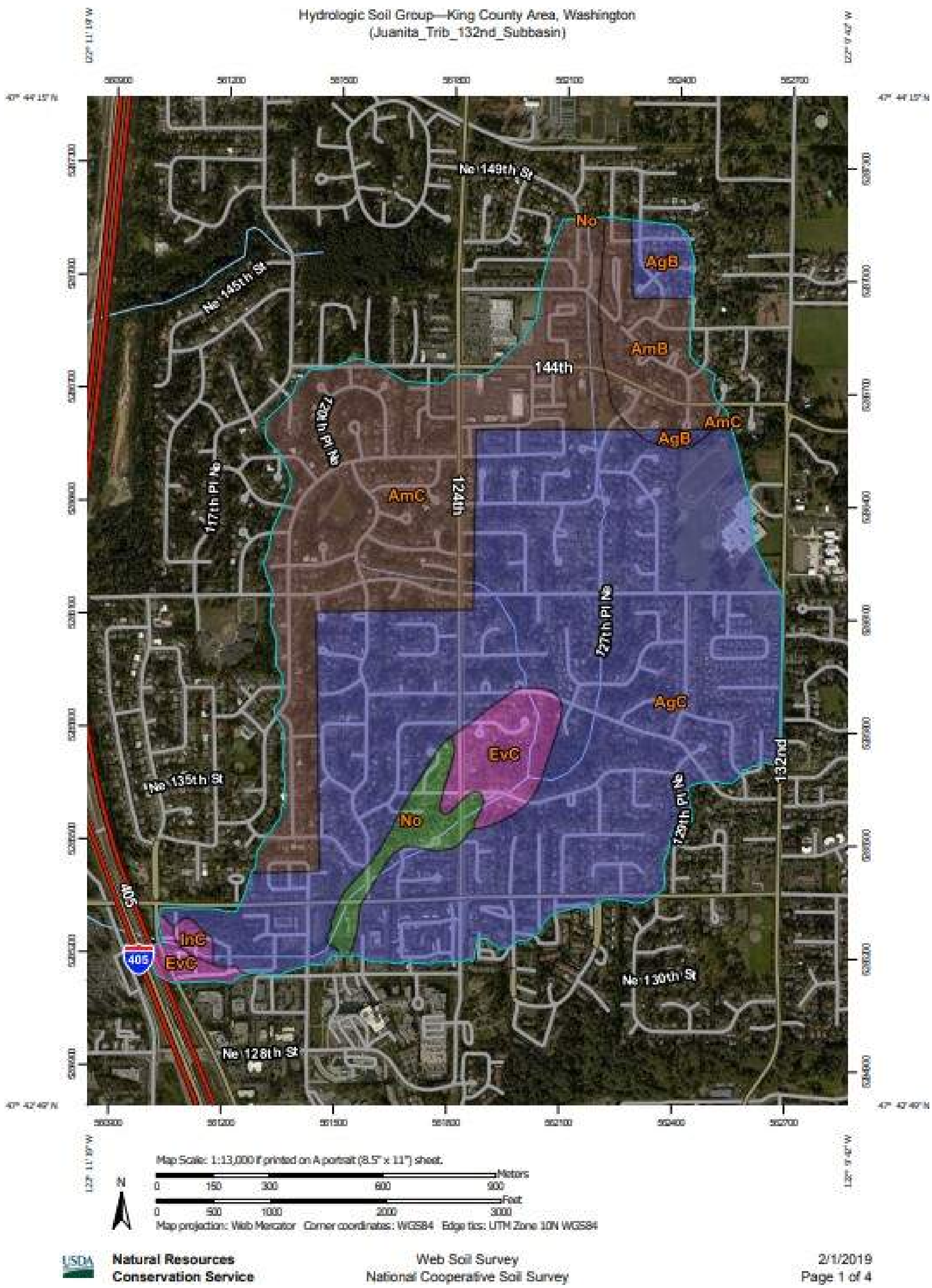

Figure 2. NRCS Hydrologic Soil Group Map for Juanita Creek Tributary

Table 1. NRCS Hydrologic Soil Group Summary Table for Juanita Creek Tributary

Hydrologic Soil Group – Summary by Map Unit – King County Area, Washington				
Map Unit Symbol	**Map Unit Name**	**Rating**	**Acres in Area of Interest**	**Percent of Area of Interest**
AgB	Alderwood gravelly sandy loam, 0 to 8% slopes	C	9.6	**1.9%**
AgC	Alderwood gravelly sandy loam, 8 to 15% slopes	C	307.7	**59.7%**
AmB	Arents, Alderwood material, 0 to 6% slopes	B	26.3	**5.1%**
AmC	Arents, Alderwood material, 6 to 15% slopes	B	133.7	**25.9%**
EvC	Everett very gravelly sandy loam, 8 to 15% slopes	A	23.1	**4.5%**
InC	Indianola loamy sand, 5 to 15% slopes	A	2.0	**0.4%**
No	Norma sandy loam	C	13.2	**2.6%**
Totals for Area of Interest			**515.6**	**100.0%**

2.3 Floodplains

This project is not located within a Federal Emergency Management Agency (FEMA) mapped floodplain. The Juanita Creek tributary floodplain is largely unnaturally confined to the channel downstream of the I-405 culvert crossing. The channel upstream of the I-405 crossing is narrow and incised and is further confined by NE 131st Place running alongside the northern embankment. This has removed natural floodplain function. The downstream channel is less confined and incised than the upstream channel, allowing for the formation of small floodplains, particularly on the west stream bank. Figure 3 shows a small floodplain along the stream bank in the downstream channel.

Figure 3. Small Floodplain Areas Along the West Bank, Looking Upstream

2.4 Site Description

The existing fish barrier is a 710-foot-long culvert that conveys flow from Juanita Creek tributary across I-405 from the intersection of NE 131st Place and Totem Lake Boulevard NE to the intersection of NE 132nd Street and 114th Place NE. See Figure 4 for the location of the existing fish barrier or culvert. The Juanita Creek tributary culvert crossing under I-405 (WDFW Culvert ID 992654) is a 48-inch-diameter concrete pipe. This feature is considered a full barrier to fish passage due to its slope. The steep culvert slope results in increased water velocities, which often exceed swimming capabilities of fish, thereby rendering the culvert a barrier to fish passage. Also, the culvert does not contain substrate throughout its length and water does not get impounded or slowed.

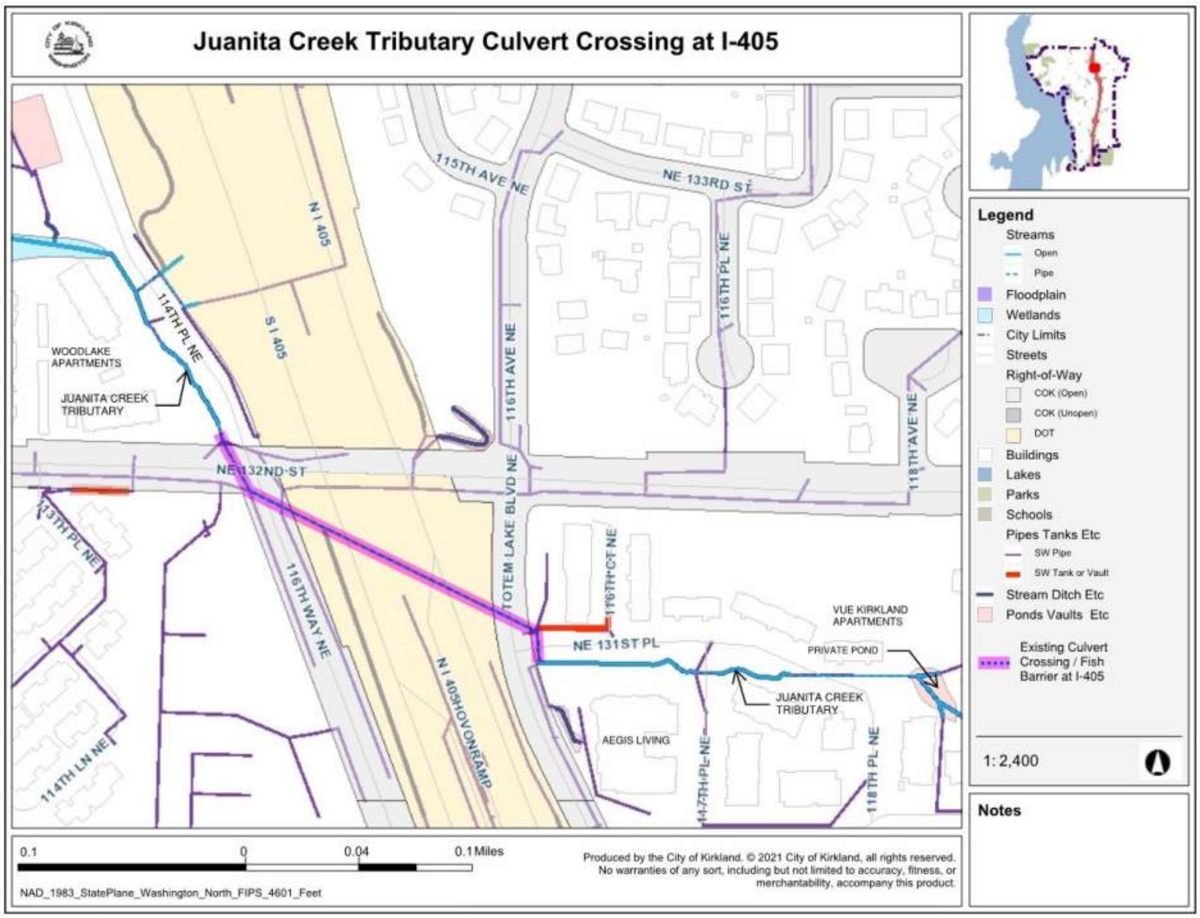

Figure 4. Juanita Creek Tributary Culvert Crossing at I-405

Large woody material (LWM) was not observed in the channel immediately upstream of the culvert opening at NE 131st Place. A private residential (Vue Apartments) pond with a vertical standpipe is located approximately 650 feet upstream of the culvert opening. The vertical standpipe, which serves as the outlet for the pond is topped with a grate that prevents the transport of LWM downstream. This vertical standpipe and the downstream culvert have been identified as fish barriers by WDFW (Site ID 932414), due to a drop in water surface elevation that exceeds the upstream swimming or leaping abilities of fish.

Between the I-405 culvert inlet and the residential pond, Juanita Creek tributary passes through two other culverts at 117th Place NE and 118th Place NE. Site investigation showed evidence of incision upstream of the I-405 culvert inlet. Several sharp bends in the channel just downstream of the culvert crossing at 117th Place NE had begun to erode into the outer banks of the steeper channel slopes. Figure 5 shows evidence of headcutting (indicated by arrows) and lack of natural vegetation and woody material downstream of the existing culvert at 117th Place NE.

Figure 5. Stream Incision of Two Banks in Upstream Channel, Looking Downstream

There is also evidence of aggradation in the downstream channel between the I-405 culvert outlet and the private driveway culvert at Woodlake Apartments. The private driveway culvert, which is 40 inches in diameter and 35 feet long, was found to be heavily clogged with debris. The velocity of the downstream channel appears to be slower than upstream, which has allowed the deposition of sediment. This velocity reduction is likely due to backwater influence from the wetland complex located just several hundred feet further downstream of the Woodlake Apartments culvert. Figure 6 shows aggradation of sediment in the downstream channel.

Figure 6. Sediment Aggradation on Inside of Stream Bend

WSDOT Area 4 Maintenance was contacted to discuss maintenance activities and no maintenance problems were indicated at the existing structure. LWM does not accumulate at the culvert opening and sedimentation does not appear to be an issue.

The WDFW habitat survey conducted in spring 2016 concluded that there was the potential for 3,363 feet (1,025 meters) of additional lineal habitat gain. This included 2,637 square feet (245 square meters) of spawning area and 43,712 square feet (4,061 square meters) of rearing area.

2.5 Fish Presence in the Project Area

The potential for fish use is based on the WDFW fish passage inventory, assessment, and prioritization protocol, as mapped on the Washington State Fish Passage mapping tool (WDFW, 2019). WDFW staff observed resident cutthroat trout and sculpin throughout the Juanita Creek tributary during a habitat survey conducted in the spring 2016. The presence of coastal cutthroat, coho salmon, winter steelhead, and river lamprey is assumed possible based on suitable physical conditions within stream system, but anadromous access to the project site is contingent on the future removal of downstream barriers within Juanita Creek tributary. The currently documented, presumed, and modeled native fish species in Juanita Creek tributary are summarized in Table 2.

Table 2. Native Fish Species Potentially Present Within the Project Area

Species	Presence (Presumed, Modeled, or Documented)	Data Source	ESA Listing
Sculpin (cottus)	Documented	*WDFW	Not Warranted
Coastal Cutthroat (Onchoryhnchusclarkii)	Presumed	*WDFW	Not Warranted
Fall Chinook (Oncorhynchustsawytscha)	Modeled	*WDFW	Threatened
Coho Salmon	Presumed	*WDFW	Not listed
Resident Trout	Documented	*WDFW	Not listed
Winter Steelhead (Oncorhynchusmykiss)	Presumed	*WDFW	Threatened
River Lamprey	Presumed	*WDFW	Not listed

*WDFW = WDFW Fish Passage and Diversion Screening Inventory Database 2019

2.6 Wildlife Connectivity

Information for this section shall be obtained from WSDOT and included in the final version of the report.

2.7 Site Assessment

The existing culvert crosses I-405 and NE 132nd Street, approximately 0.75-mile north of Totem Lake in Kirkland, Washington. The culvert crossing is within a highly developed area and is surrounded by commercial, residential, and public parking properties on either side.

2.7.1 Data Collection

The WDFW habitat survey was conducted in spring 2016. See Appendix A for the Hydraulic Field Report Form that includes the WDFW Site Assessment Report and Habitat Assessment Survey. The Reduced

Sample Full Survey (RSFS) method was used for Habitat Assessment. Below is a summary of observations from the report and survey.

The target barrier (Site ID 992654) is a 257-foot-long, 48-inch concrete culvert that conveys Juanita Creek tributary across I-405 and NE 132nd Street. The upstream end of the culvert is located at the intersection of NE 131st Place and Totem Lake Boulevard NE and the downstream end is located at the corner of NE 132nd Street and 114th Place NE. The Level A Culvert Assessment Report provided in Appendix A identifies the culvert as a fish barrier because of its slope (2.17%).

A site visit was conducted by project staff on November 30, 2018, and the preliminary bankfull width for Juanita Creek tributary was determined. The bankfull width locations and measurements are summarized in section 2.8.2.

2.7.2 Existing Conditions

The culvert (WDFW Culvert ID 992654) is a series of three individual pipe sections connected by two maintenance holes. The most upstream pipe section is a 54-inch-diameter corrugated metal pipe that extends north for approximately 45 feet across NE 131st Place. The middle 48-inch-diameter reinforced concrete pipe extends northwest approximately 570 feet across Totem Lake Boulevard NE and I-405. The most downstream 48-inch-diameter corrugated metal pipe extends north approximately 95 feet from a structure at NE 132nd Street and 114th Place NE and outlets on the west side of 114th Place NE. See Figure 4 for information and location of culvert pipes.

As-builts within the project limits were obtained from WSDOT. Based on the storm sewer as-builts and available GIS information, storm drainage from numerous city of Kirkland streets, WSDOT-owned Kingsgate Park and Ride, and nearby private storm systems discharge flows into the culvert, at the two maintenance hole junctions.

Upstream of the existing I-405 culvert inlet, Juanita Creek tributary gently meanders east, for approximately 280 feet, in a narrow, incised stream channel between NE 131st Place (see Figures 7 and 8) and the Aegis Living facility. Along this path, the channel flows across 117th Place NE and 118th Place NE, through two 40-inch-diameter corrugated metal culverts that are 45 feet and 200 feet in length respectively. The 200-foot-long culvert terminates at the vertical standpipe structure, within the private pond at Vue Apartments. The standpipe allows flows to overtop the riser unrestrained, so the pond appears to exist for aesthetic purposes and not to provide stormwater detention storage (see Figure 9). Juanita Creek tributary then continues upstream through the remainder of the Vue apartment complex and then continues into a heavily wooded area. Several storm-drain networks from the Vue apartment complex outfall directly into Juanita creek tributary or into the pond, based on available as-built information and GIS data.

Figure 7. Upstream Inlet of Existing I-405 Culvert at Totem Lake Boulevard NE, Looking Downstream

Figure 8. Incised Channel Upstream of I-405 Culvert, Looking Downstream

Figure 9. Vue Apartments Pond with Standpipe, Looking Upstream

Downstream of the existing I-405 culvert outlet (see Figure 10), Juanita Creek tributary continues north for approximately 200 feet between 114th Place NE and Woodlake Apartments (see Figure 11). Juanita Creek tributary then enters a 40-inch-diameter private driveway culvert at Woodlake Apartments that is approximately 35 feet long and heavily clogged with debris. Further downstream, Juanita Creek tributary widens and opens into a large wetland complex. In general, the downstream channel is slightly wider and less incised than the channel upstream of the I-405 culvert, which is primarily due to backwater influence from the downstream wetland complex. The downstream channel is also more heavily wooded than upstream, with numerous logs and tree stumps disturbing stream flows and creating small eddies. See Appendix A for the Hydraulic Field Report Form which includes WDFW Fish Passage Inventory Report and Habitat Assessment Survey. See Figures 10 and 11 for pictures of the downstream end of the I-405 culvert crossing.

Upstream of the I-405 culvert, the vertical standpipe which serves as the outlet for the Vue Apartments' pond is topped with a grate that prevents the transport of LWM downstream. This vertical standpipe and connecting culvert (culvert across 118th Place NE) have been identified as a fish barrier by WDFW (Site ID 932414) due to water surface elevation drop, which restricts the fish from swimming upstream. The I-405 culvert (WDFW Culvert ID 992654) has been identified as a full fish barrier because the slope (2.17%) of the culvert results in increased water velocities which impedes fish passage. Uniform culvert conditions (gradient, roughness, and depth) and absence of LWM eliminate the creation of low-velocity zones or deep pools, where fish can rest after swimming, thereby impacting fish life.

Figure 10. Downstream Outlet of Existing I-405 Culvert at 114th Place NE, Looking Upstream

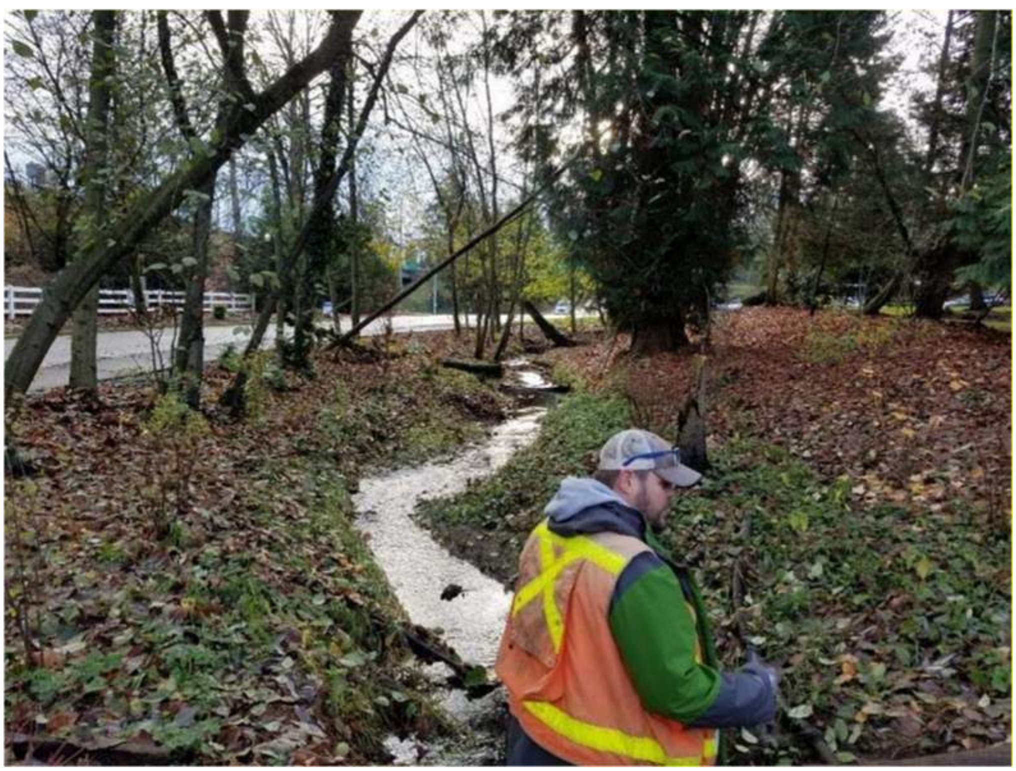

Figure 11. Downstream of Existing I-405 Structure, Looking Upstream Toward NE 132nd Street

2.7.3 Fish Habitat Character and Quality

The tributary enters the primary Juanita Creek channel approximately 0.55 mile downstream of the identified culvert barrier at the I-405 crossing. The channel immediately downstream of the project's barrier widens into wetland greenbelt located to the north of the residential development along NE 132nd Street. The velocities in the channel downstream of the I-405 culvert were lower compared to the channel velocities upstream of the culvert because of backwater effects from the downstream wetland. WDFW staff observed fish in the wetland and numerous invasive plant species in the riparian habitat. Because of the downstream fish barriers (one full and three partial barriers) located along Juanita Creek tributary, it is assumed that the coastal cutthroat and sculpin documented by WDFW are residents at all life stages and are present in the stream at all times.

According to a comprehensive Juanita Creek Basin Geomorphic Analysis prepared for the King County Department of Natural Resources (DNR) in 2010, deep pools where both adult and juvenile fish might take refuge are few in number and far between, which inhibits opportunities to take refuge during critical low-flow months. The report also describes that the presence of large woody debris is critically low within the basin, which prevents greater oxygen and nutrient transfer to the substrate.

2.8 Geomorphology

2.8.1 Reference Reach Selection

The streams surrounding the proposed crossing have been impacted by urbanization and are not suitable for use as reference reaches. Because of lack of a suitable reference reach, field measurements were used to determine bankfull width values. Figure 12 shows existing channel cross sections.

2.8.2 Channel Geometry

The existing channel characteristics were determined through field survey. Outside of the influence of the existing crossings, the channel is generally uniform straight with riffle pool geometry. The lack of sinuosity can be attributed to the close proximity of urbanization.

The existing channel grade was measured immediately upstream of the crossings listed in Table 3. WDFW's Water Crossing and Design Guidelines (WCDG) recommend that the proposed structure bed gradient not exceed a ratio of 1.25 compared to the natural stream gradient of the crossing (WCDG Equation 3.1).

Table 3. Existing Channel Grade Upstream of Crossings

Stream	Crossing	Approximate Upstream Channel Grade (%)
Juanita Creek Trib.	Totem Lake Boulevard NE	**2.00**
Juanita Creek Trib.	NE 132nd Street	**1.28**
Juanita Creek Trib.	**114th Pl NE**	**0.67**

The preliminary bankfull width for Juanita Creek tributary was determined in the field, on November 30, 2018, by project staff. In total, eight bankfull width measurements were recorded in approximately 33-feet (10-meter) intervals between the upstream inlet of the I-405 culvert and the next upstream culvert crossing at 117th Place NE. Table 4 shows a list of the bankfull width measurements and locations. Figure 13 shows bankfull width measurement locations along the existing stream alignment.

Table 4. Bankfull Width Measurements Upstream of Existing I-405 Culvert

BFW #	Bankfull Width (feet)	Included in Design Average	Location Measured	
			Latitude	Longitude
1	3.51	Yes	47.717532	**-122.186070**
2	5.51	Yes	47.717537	**-122.185949**
3	4.76	Yes	47.717532	**-122.185836**
4	5.51	Yes	47.717531	**-122.185714**
5	4.76	Yes	47.717527	**-122.185595**
6	5.81	Yes	47.717526	**-122.185476**
7	4.79	Yes	47.717523	**-122.185356**
8	5.25	Yes	47.717520	**-122.185234**
Average Width	**4.99**			

The bankfull widths reported in Table 4 are understood to reflect unnaturally confined conditions associated with the urban setting. In coordination between WSDOT, WDFW, and MITFD, a bankfull width of 9 feet has been accepted as the basis for completing the preliminary hydraulic design.

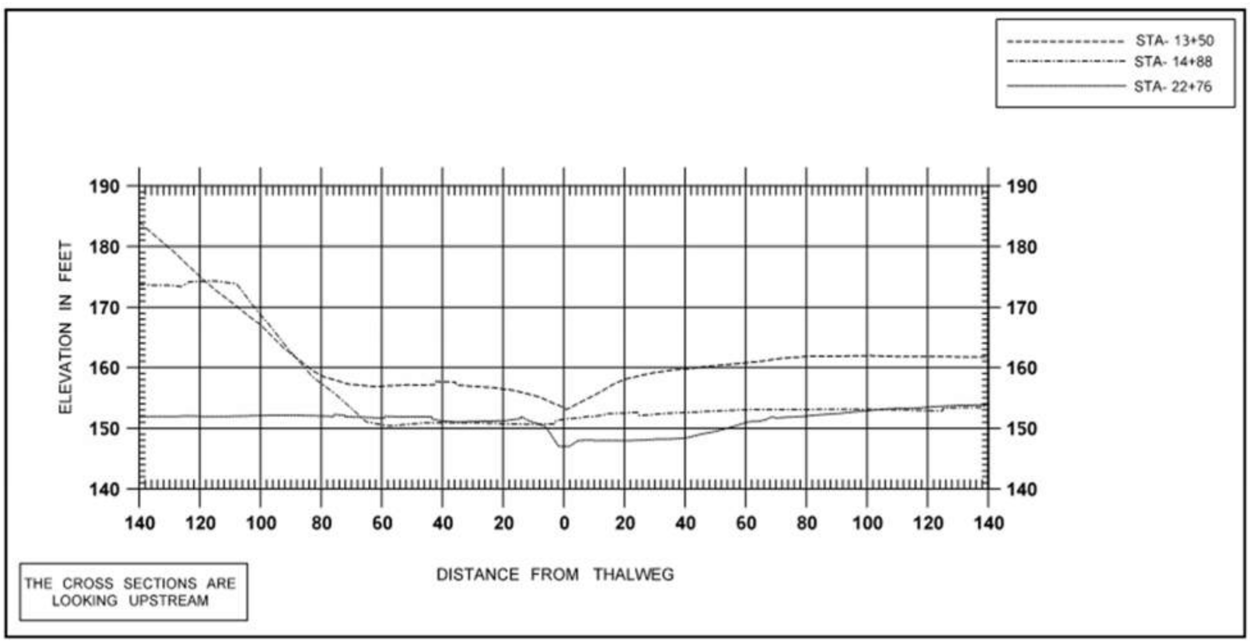

Figure 12. Existing Channel Cross-sections

2.8.3 Sediment

Wolman pebble counts were performed on Juanita Creek tributary upstream of Totem Lake Boulevard NE the morning of January 25, 2019, by three WSDOT staff members. Three counts of a minimum of 100 streambed particles were completed resulting in a minimum of 300 counts. Particles smaller than 2 millimeters (mm) were recorded as silts in the field, as the measuring device could not capture smaller grain sizes. The first and third pebble counts were performed between the I-405 culvert and the next upstream culvert at 117th Place NE, and the second count was performed in the stream channel between the 117th Place NE and the culvert outlet from the vertical standpipe. The streambed sediment

consisted primarily of gravels of various gradations, with small quantities of sand and cobbles. Areas of hardpan sediment were observed but not accounted for, downstream of the 117th Place NE culvert crossing. A few small boulders were found in all three counts; however, they were found proximally close to each other and were similar to the landscaping boulders in adjacent garden beds. These boulders were not considered to be naturally present in the stream and were not counted. Table 5 below shows cumulative results of the pebble counts. See Appendix B.5 for a more detailed record of pebble counts and sediment distribution. Approximate pebble count measurement locations are shown in Figure 13.

Table 5. Sediment Properties Upstream of I-405 Crossing

Juanita Creek Upstream of 132nd Crossing				
	Pebble Count 1 Diameter (in)	**Pebble Count 2 Diameter (in)**	**Pebble Count 3 Diameter (in)**	**Average Diameter (in)**
D_{15}	0.2	0.2	0.3	**0.24**
D_{35}	0.4	0.3	0.4	**0.39**
D_{50}	0.6	0.4	0.6	**0.51**
D_{84}	1.3	0.8	1.1	**1.03**
D_{95}	**2.1**	**1.0**	**1.8**	**1.69**

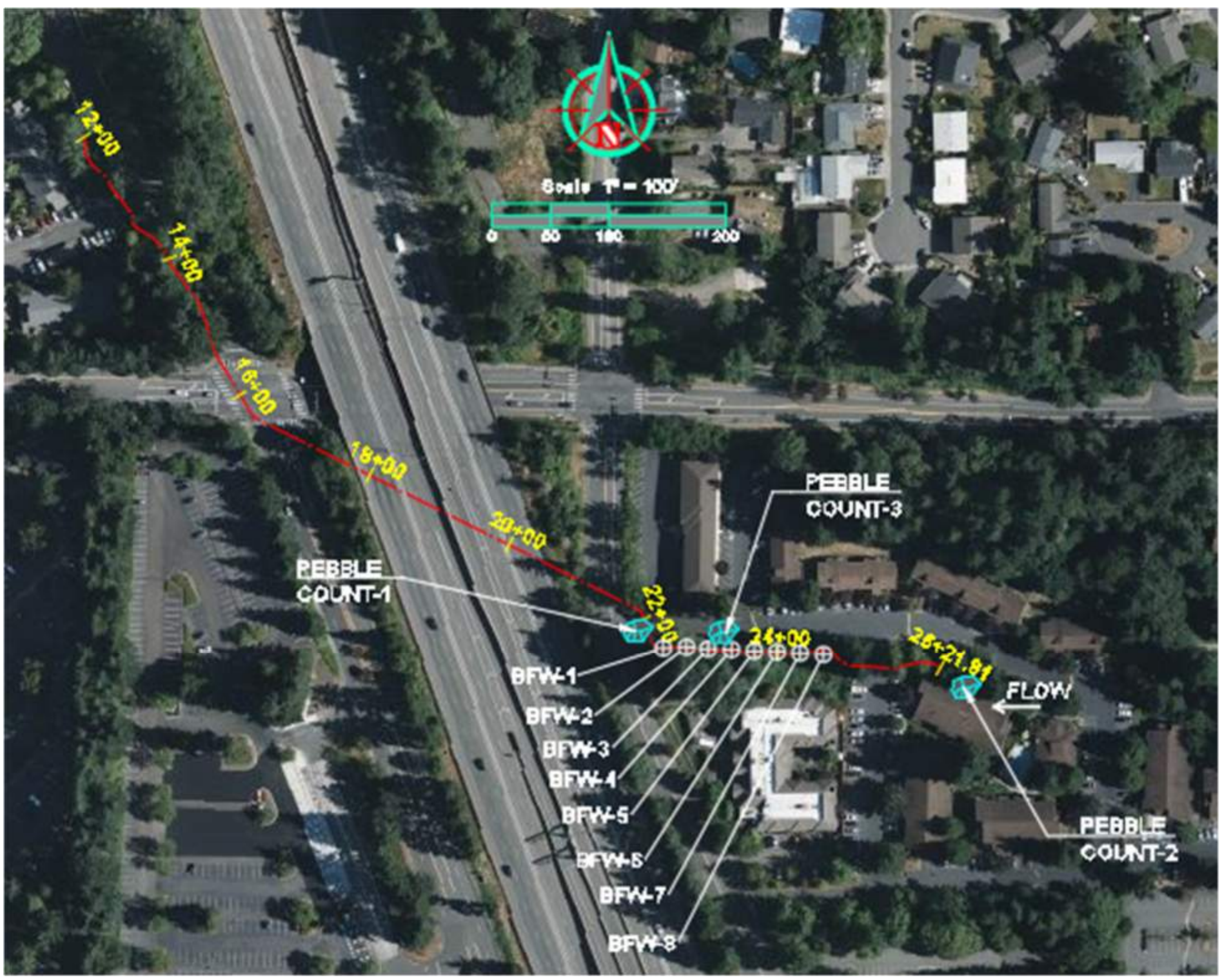

Figure 13. Pebble Count and Bankfull Width (BFW) Measurement Locations

2.8.4 Vertical Channel Stability

Upstream of the I-405 culvert, Juanita Creek tributary enters the project area through a two 40-inch metal culverts at 118th Place NE and 117th Place NE respectively, within the Vue Apartments property. These culverts, along with the Vue Apartments pond outlet standpipe, reduce flow and limit the transport of sediment to the project reach downstream. Therefore, the urban setting and presence of infrastructure limit the sediment supply that might otherwise be transported to the project site channel.

There is evidence of aggradation in the downstream channel between the I-405 culvert outlet and the private driveway culvert at Woodlake Apartments. The private driveway culvert was found to be heavily clogged with debris. The velocity of the downstream channel appears to be lower than the upstream channel velocity, which has allowed the deposition of sediment. This velocity reduction is likely due to backwater influence from the wetland complex located several hundred feet further downstream of the Woodlake Apartments culvert.

Site investigation showed evidence of incision upstream of the I-405 culvert inlet. Several sharp bends in the channel had begun to erode into the outer banks of the steeper channel slopes. Lack of natural vegetation and woody material also may have contributed to the headcutting in the channel.

2.8.5 Channel Migration

Channel migration is limited for Juanita Creek tributary. Both the upstream and downstream channels have moderate vegetation, which limits the erosive action that drives channel migration. The stream channel is also confined between city streets and private residential developments, and it is likely that the channel is managed by the landowners to prevent channel migration impacts to the property. Therefore, the channel migration risk is low.

The existing channel discussed in this report is not located within FEMA Detailed Study Zone AE floodplain areas.

2.8.6 Riparian Conditions, Large Wood, Other Habitat Features

The channel immediately upstream of the I-405 crossing features stream banks with manicured landscaping as well as unmaintained areas of dense blackberry brush.. Portions of the immediate upstream channel are wider and feature small pools; however, large woody debris remains minimal. LWM was not observed in the stream channel between the I-405 culvert crossing and the Vue Apartments pond.

Downstream habitat mostly includes greenbelt areas behind homes and apartments. This area comprises of several invasive species in riparian habitat. A small amount of LWM is present in the channel downstream of the I-405 culvert crossing. This LWM is likely not transported downstream, but rather has fallen in place from the trees surrounding the stream embankments. The LWM disturns stream flows and creates small eddies. The potential for recruitment of LWM is good in Juanita Creek tributary because of moderate flows, but is contingent upon stream buffer protection, further upstream fish barrier correction, and native tree planting.

3 Hydrology and Peak Flow Estimates

Hydrology was developed for the existing and proposed I-405 land-use conditions using the MGSFlood continuous simulation hydrologic model. Versions 4.38 and 4.54 of the program were used to generate peak flows for the existing and proposed conditions respectively. The Web Soil Survey hydrologic soil

group layer was used to determine whether surfaces were located on till or outwash soil. The modeled existing drainage basin reflects the current land use in Juanita Creek subbasin. See Appendix B for exhibits showing Juanita Creek Watershed Area and Juanita Creek Tributary Basin Area.

For the proposed drainage basin, stormwater drainage upstream of the proposed structures at Totem Lake Boulevard NE and NE 132nd Street will reflect the full build-out condition of the existing drainage subbasin. As part of the stormwater concept, portions of I-405 and adjacent residences will discharge to Juanita Creek tributary via a new outfall located just upstream of the proposed 114th Place NE structure. To incorporate this additional flow, a separate model was created for upstream of the proposed 114th Place NE structure to include additional stormwater drainage from I-405 and adjacent residences. Results of the MGSFlood modeling are provided in Appendix C and a summary of existing and proposed flows is presented in Table 6.

Table 6. Peak Flows for Juanita Creek Tributary

Mean Recurrence Interval (MRI)	Juanita Creek Tributary Peak Flow (cfs)		
		Proposed Drainage Basin	
	Existing Drainage Basin	Upstream of Totem Lake Boulevard NE (cfs)	Upstream of 114th Place NE (cfs)
2-Year	63.0	69.3	**73.9**
10-Year	96.1	106.7	**113.8**
25-Year	118.0	128.9	**137.5**
50-Year	127.0	136.1	**145.0**
100–Year	139.1	154.9	**165.1**
500-Year	168.0	211.8	**225.8**
2040 Predicted 100	188.4	177.5	**189.2**
2080 Predicted 100	**N/A**	**194.1**	**206.9**

4 Hydraulic Analysis and Design

The hydraulic analysis of the existing and proposed Juanita Creek tributary crossing at I-405 was performed using the US Bureau of Reclamation’s Sedimentation and River Hydraulics – Two-Dimensional (SRH-2D) Version 3.2 computer program, a two-dimensional hydraulic and sediment transport numerical model. The Surface-Water Modeling System (SMS) is embedded in SRH-2D to provide a full range of hydraulic modeling, which provides the user interface to develop the hydraulic models. The SRH-2D model allows for a detailed visualization of stream velocities and water surface elevations within the stream channel and in the vicinity of culverts at various time increments. Pre- and post-processing for this model was completed using SMS Version 13.1.13.

Two scenarios were analyzed for determining stream characteristics for Juanita Creek tributary with the SRH-2D models: (1) existing conditions with the existing 48-inch-diameter concrete pipe crossing, and (2) future conditions with the three proposed 17-foot clear span structures at 114th Place NE (Culvert 1), NE 132nd Street (Culvert 2), and Totem Lake Boulevard NE (Culvert 3).

A hydraulic analysis of existing and proposed conditions was performed. The model limits approximately extend from 30 feet upstream of the 117th Place NE crossing to 65 feet downstream of the Woodlake Apartment private roadway culvert crossing. The proposed channel length between the existing upstream 117th Place NE culvert crossing, and the downstream Woodlake Apartments driveway culvert

crossing is approximately 1,334 feet. The proposed channel design and layout comprises of approximately 963 feet of open channel habitat within the system, which is an increase of 474 feet from the existing condition (489 feet). Existing condition geometry was developed using survey data provided by WSDOT. King County established horizontal control in the local coordinate system. The local datum was converted to Washington State Plane Coordinate System, South Zone, NAD83. All elevations are based on the NAVD88 vertical datum.

For the purpose of preliminary hydraulic design, 17-foot span structures (measured perpendicular to the stream) with smooth concrete top slab and side walls are assumed. Agency and MITFD coordination has resulted in a WSDOT commitment for the structure to be “bottomless” (no floor or connected structure below the channel).

4.1 Model Development

4.1.1 Topographic and Bathymetric Data

The pre-developed SRH-2D terrain data were established from a combination of two field surveys. The first survey captured the entire project vicinity and was obtained from an aerial lidar survey conducted in the fall of 2017. A more detailed supplemented field survey was performed by WSDOT crew in May 2018, which more accurately captured specific open channel cross sections and culvert location and invert data. The InRoads digital terrain model (DTM) surface used as the basis of the pre-developed model is a merged version of these two surveys.

The post-developed SRH-2D terrain data primarily utilizes InRoads DTMs that were developed from proposed roadway surfaces, stream channel, and box culverts, and is supplemented by the existing merged DTM outside of the project limits. A single composite post-developed surface was created using existing survey data and the proposed fish-passage surface model, including proposed roadway corridors pasted into the existing surface. This composite post-developed surface merges the various existing and proposed DTMs for importing into SRH-2D and is the basis for fish passage open channel hydraulic and hydrologic modeling. The composite surface was imported into SMS as an XML file for SRH-2D modeling. Using the scatter data created from the imported surface, a mesh was created.

4.1.2 Model Extent and Computational Mesh

The pre-developed and post-developed composite DTM surfaces were imported into SMS (Aquaveo, 2019). Multiple DTM surfaces were used to create the mesh, which is a 3D rendering of the pre-developed and post-developed conditions. The mesh surface is developed within SRH-2D because it defines the computational boundaries of the model. The mesh generated uses patch systems for the stream main channel, and paving systems for the rest of the site features, following SRH-2D SMS best modeling practices.

SRH-2D requires a smooth surface because the model uses a finite element method on a depth average based set of equations, meaning it converges on a point for solutions. Therefore, it is important that the surface is clean and smooth, without error, before bringing it into SMS. The mesh created is a representation of the area being modeled. The proposed model has over 8,777 individual elements used in its analysis, creating a detailed model with mass balance plotting error reporting under 0.08%, per the simulation run queue screen shot in Figure 14. See section 4.1.5 for more model run control assumptions and conclusions.

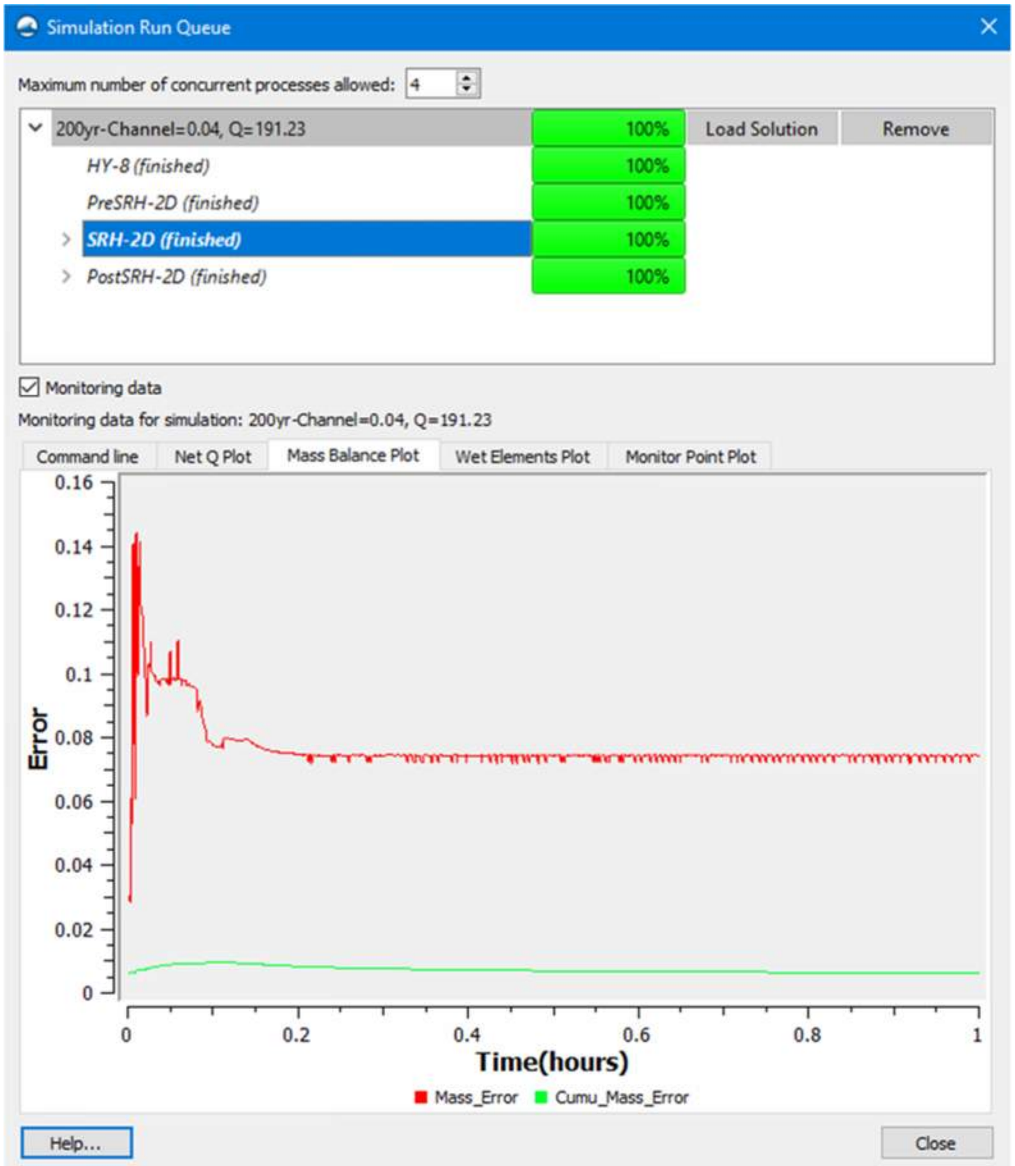

Figure 14. SRH-2D Simulation Run Queue Mass Balance Plot

The upstream and downstream boundary conditions for both models were placed at the edge of the computational mesh, several hundred feet upstream and downstream of the existing private culverts that are not being replaced as part of this project. The boundary conditions are placed far enough away from the project site to not influence the hydraulic results of the existing private road culverts and proposed stream design and crossing structures. Figures 15 and 16 depict the SRH-2D elevation meshes for existing and proposed conditions respectively. All results are presented relative to the NAVD88 datum.

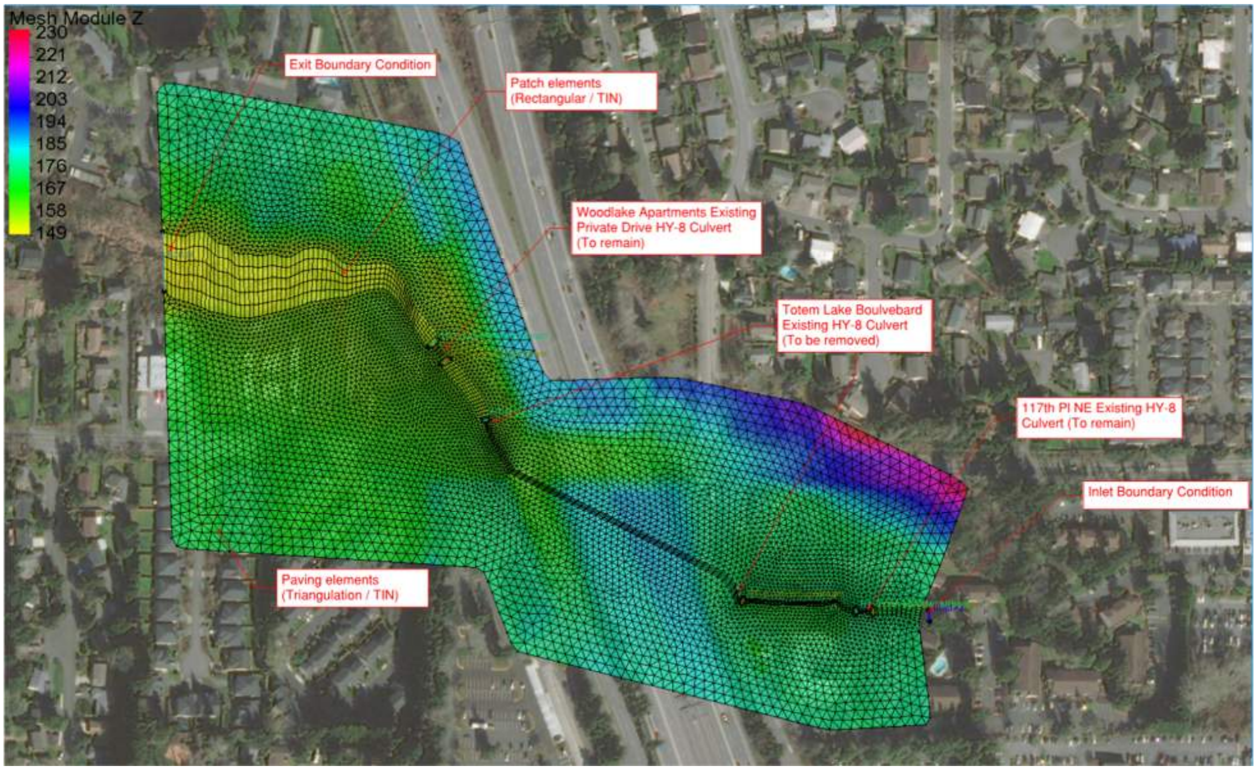

Figure 15. Existing Conditions Elemental Computational Mesh

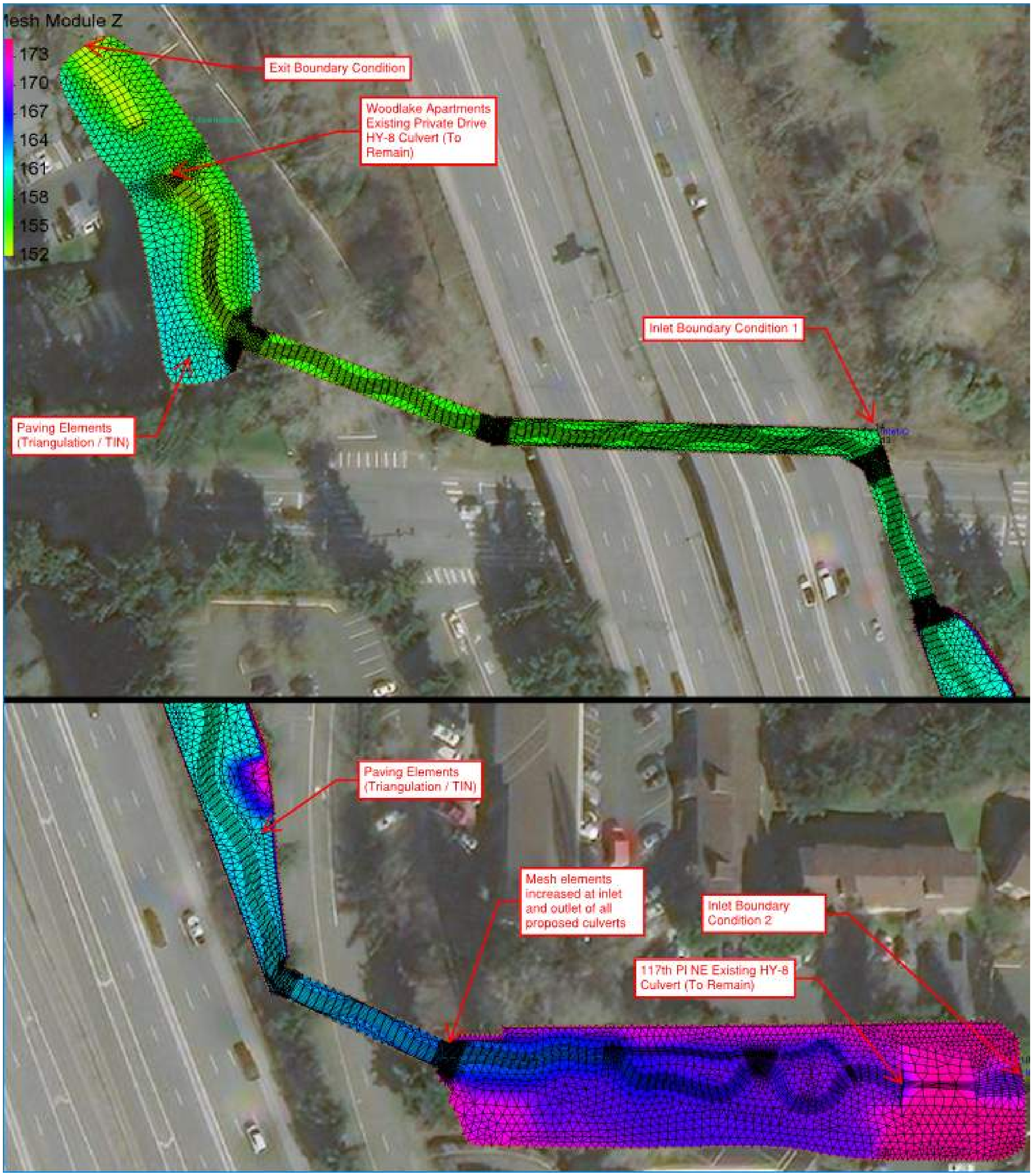

Figure 16. Proposed Conditions Elemental Computational Mesh

4.1.3 Materials/Roughness

Three Manning's roughness coefficients were used within the pre-developed model. A roughness coefficient of 0.05 was assigned for the stream channel within the prescribed 9-foot bankfull width to simulate stream embankments and bed material. Outside of the bankfull width, a roughness coefficient of 0.05 was assigned to simulate brush and other thick vegetation which may be present at the stream edge. A third roughness coefficient of 0.02 was used to simulate a pre-developed condition where the stream overtops an embankment and flows onto adjacent impervious surface. Manning's roughness

values (n) were estimated based on field observations and engineering judgment in the absence of definitive calibration data.

Two Manning's roughness coefficients were used within the post-developed model. A roughness coefficient of 0.04 was assigned for the stream channel within the proposed 9-foot bankfull width to simulate stream embankments and bed material. Outside of the bankfull width, a roughness coefficient of 0.05 was assigned to simulate live stakes and riparian embankment vegetation that are proposed at the stream edge and within the project floodplain limits. Inside the culverts, a Manning's n value of 0.1 was used to represent the smooth concrete side walls and the channel bottom lined with streambed material and meander bars that resemble gravel will be assigned a Manning's n value of 0.06 in the final SMS model. The LWM on the project was assigned a Manning's n of 0.16, and the smooth concrete walls of the open channel sections were assigned a Manning's n of 0.01. The areas outside project limits, where overtopping was observed, the roadway was assigned a composite Manning's n value of 0.015. Table 7 shows Manning's n values used for different land cover types and Figure 17 shows the spatial distribution of roughness values in the model.

Table 7. Manning's n Hydraulic Roughness Coefficient Values Used in the SRH-2D Model

Land Cover Type	Manning's n
Stream	0.04
Riparian Embankment	0.05
Meander Bars	0.06
LWM	0.16
Wall	0.01
Road	0.015

Figure 17. Spatial Distribution of Roughness Values in SRH-2D Model

4.1.4 Boundary Conditions

The upstream boundary condition defines the inflow to the model. An MGSFlood model was created for both the existing conditions and proposed conditions of the Juanita Creek tributary subbasin, to obtain peak flows for the 2, 10, 25, 10, 100, 200, 500, and 2080 Predicted 100-year design storm events (see Table 6). The upstream boundary condition was modeled as subcritical flow to match the expected flow regime at the boundary condition. The flow rate from MGSFlood was entered into the model as constant flow for the desired design storm event. For the existing culvert, boundary conditions were

specified at the existing culvert inlet and outlet and the interior hydraulics were evaluated using the embedded Federal Highway Administration (FHWA) HY-8 culvert analysis tool. Boundary conditions were similarly placed at the inlet and outlet of each proposed structure, but the interior hydraulics were instead evaluated as open channel flow.

Downstream water surface boundary conditions were computed assuming normal depth with estimated slope of 0.006 feet per foot. An initial tailwater surface elevation condition is set for each peak-flow simulation based on the peak flow event. The boundary condition tailwater elevation for the exit is calculated using the base inflow for each peak flow, slope (0.06 feet per foot for all models), and composite Manning's n value (0.05 used for all models) with a channel normal depth calculator provided in SMS to account for base flow in the model.

The 117th Place NE crossing at the upstream end of the project features a 40-foot-long, 4-foot-diameter corrugated aluminum culvert crossing. At the downstream end of the project, the Woodlake Apartments private driveway crossing features 46-foot-long, 5-foot-diameter concrete culvert. The project scope does not include improvements to the structures at these crossings; however, they are included in the hydraulic model as HY-8 files due to their proximity to the project site and influence on hydraulic modeling. See Figures 18 and 19 for downstream culvert parameters and normal depth rating curve respectively, and Figures 20 and 21 for upstream culvert parameters and normal depth rating curve respectively.

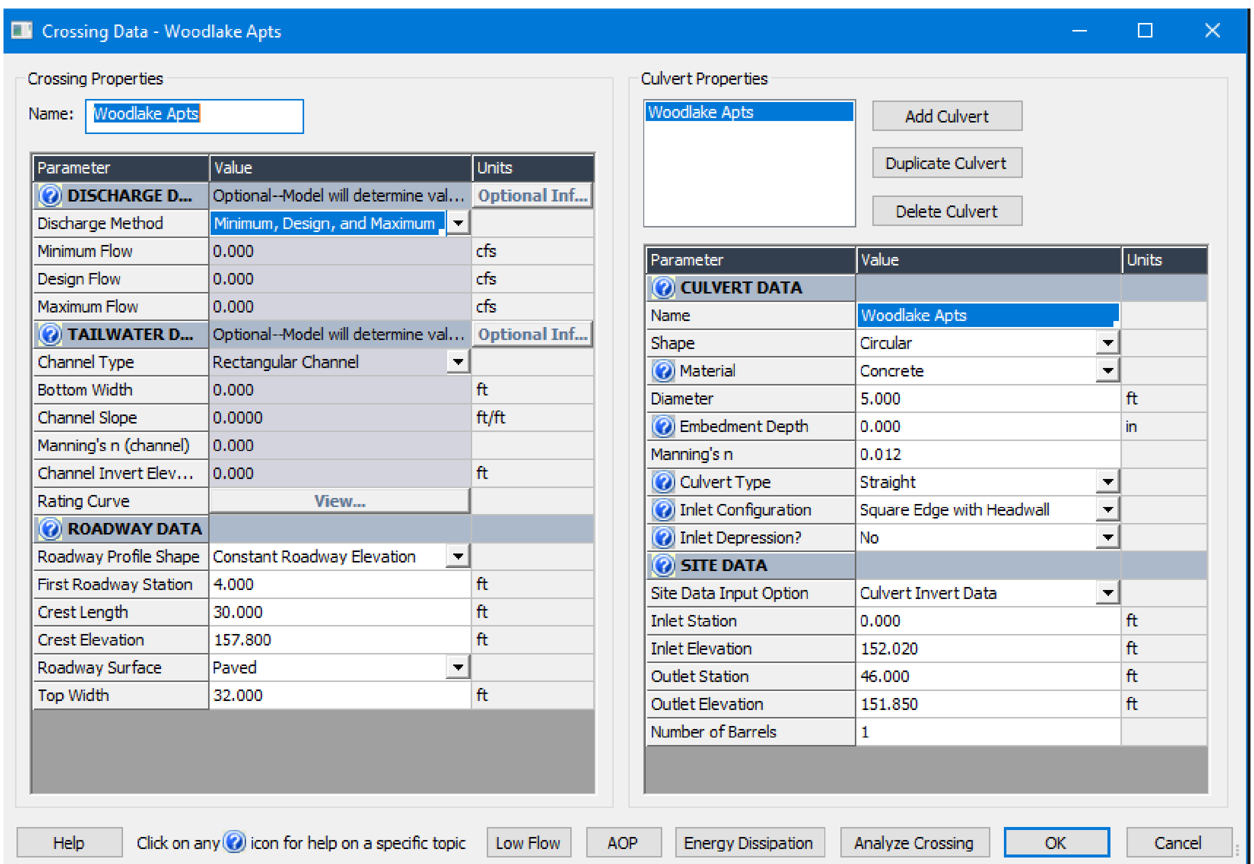

Figure 18. HY-8 Existing Woodlake Apartments Culvert Parameters

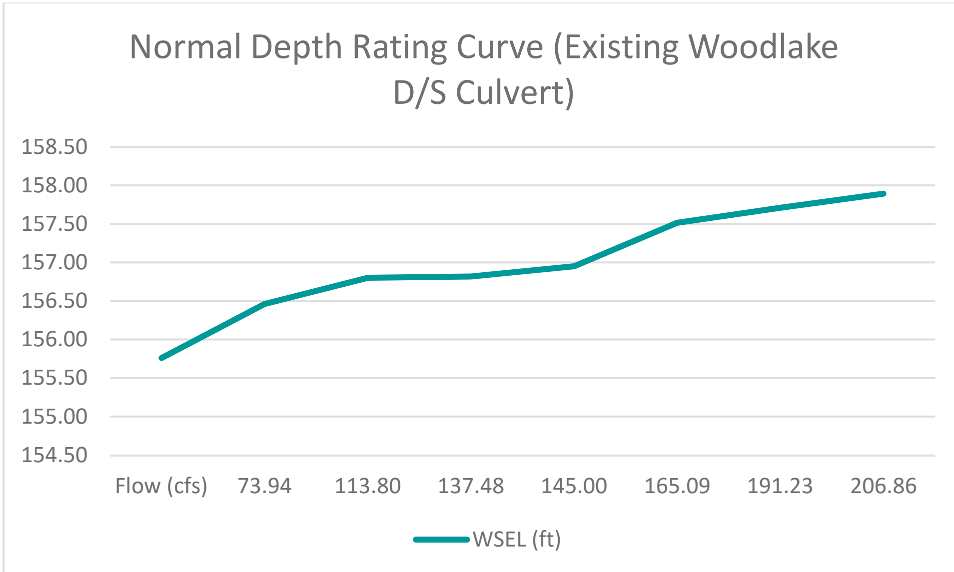

Figure 19. Downstream Normal Depth Rating Curve

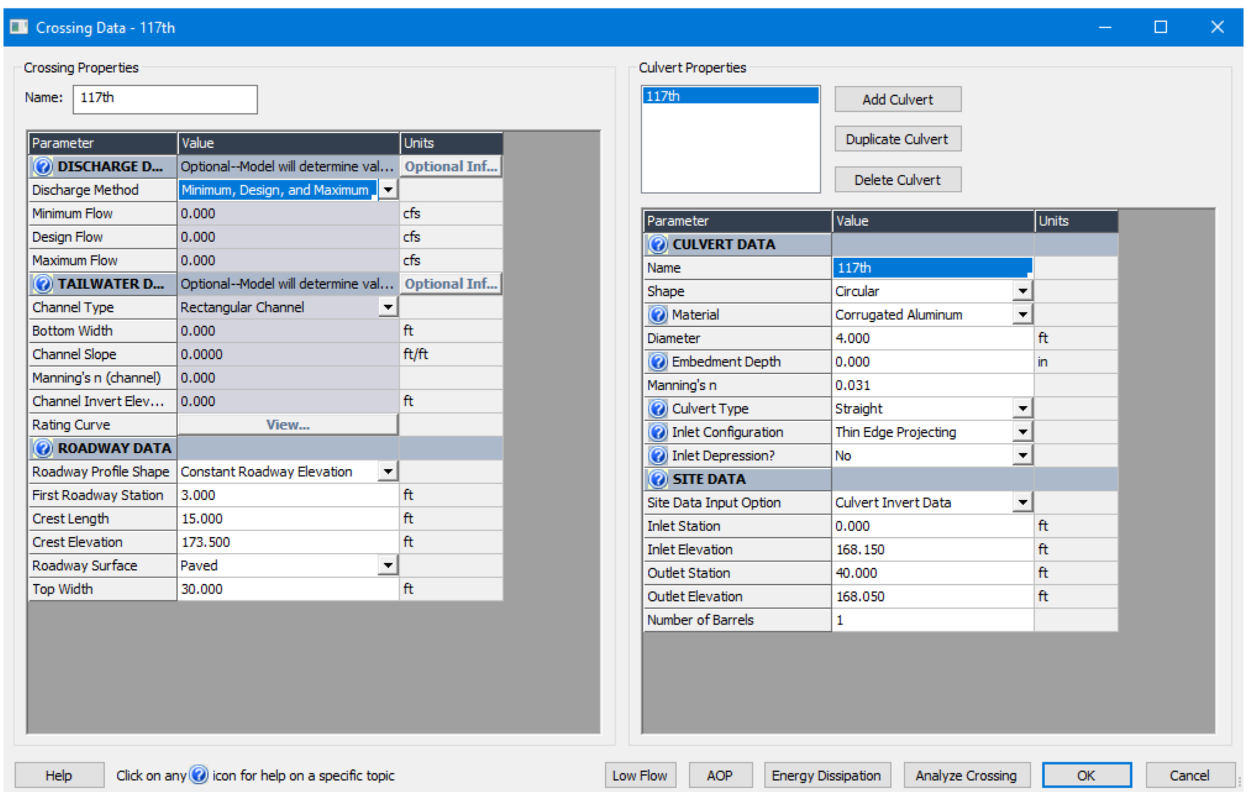

Figure 20. Upstream 117th Place NE Crossing Culvert Parameters

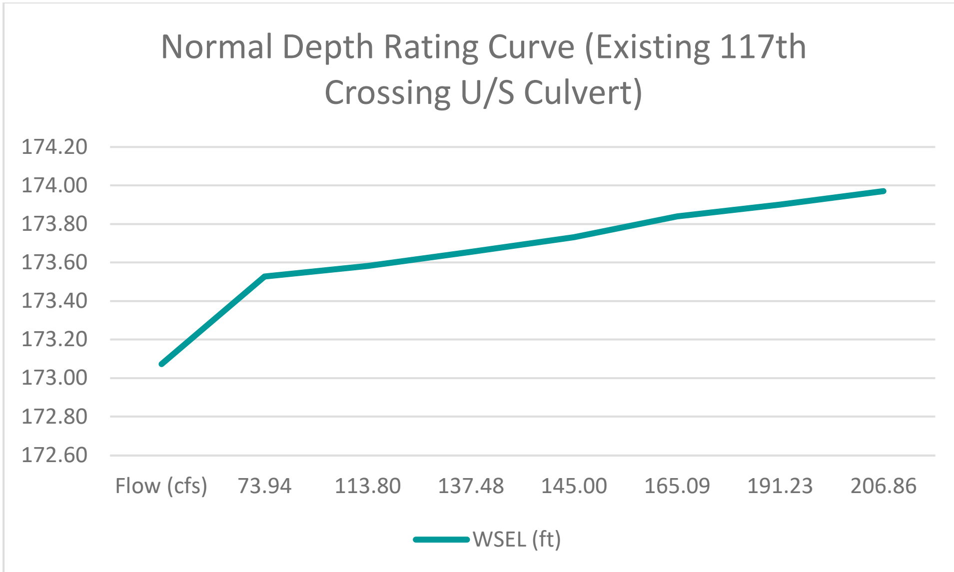

Figure 21. Upstream 117th Place NE Crossing Normal Depth Rating Curve

4.1.5 Model Run Controls

The initial model was set to run from 0 to 4 hours with a 0.05-second time step. Timesteps were determined based on the Courant Condition Equation: dt = Length / [(g)^(1/2)]. Because of the nature of the smaller mesh elements near the entrance and exits of all culverts on the project site, the model does not run with a larger time step. Therefore, the measured length (0.3 foot) of the smallest mesh element was used as the model time step.

As discussed in section 4.1.2 of the report, after running the initial model, the hydraulic mass balance plot smooths out, verifying that inflow equals outflow after only one hour. When compared, there is no difference in hydraulic model computations between the eight-hour simulation with 0% error and the hydraulic model computations from the two-hour simulation with 0.08% error. Therefore, the two-hour model duration was used to expedite the simulation process for each flow rate scenario.

4.1.6 Model Assumptions and Limitations

As described in section 4.1.3, the Manning's n values were assumed based on typical values for streams, floodplains, roadways, walls, and vegetated channels. To incorporate the proposed LWM in SRH-2D model analysis, each log shape was entered into the model as a material property and assigned a Manning's roughness coefficient of 0.16. This was done as an acceptable method of modeling LWM, as opposed to editing the surface scatter data and mesh to include logs as 2D obstructions.

The existing and proposed roadway stormwater conveyance systems enter the proposed stream channel in several locations, but not all have been included in the SMS SRH-2D model. The model includes the existing stream that flows into the project site via the existing culvert at 117th Place NE at the upstream project end, and additional stormwater input that will discharge to the stream north of the NE 132nd Street culvert crossing. However, there are additional local stormwater discharges that may need to be added to the stream hydraulic evaluation for the final design.

4.2 Existing Conditions Model Results

This section presents the key results from the hydraulic analysis of the existing I-405 Juanita Creek tributary culvert crossing, modeled as a 48-inch-diameter concrete pipe. Illustrations summarizing the water surface elevation (WSE), velocity, and depths under the 2-, 25-, and 100-year recurrence interval flows are provided in Appendix D.1. Figure 22 below shows existing and proposed stream and culvert alignments.

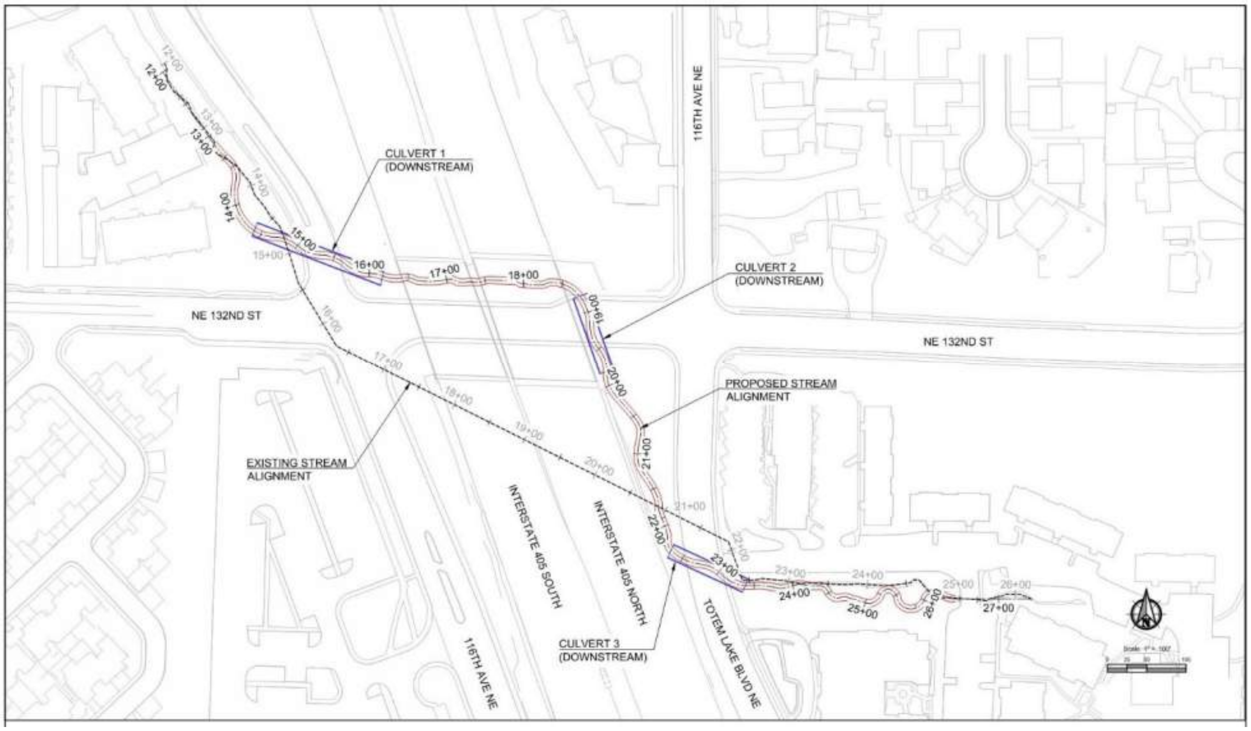

Figure 22. Longitudinal Profile Stationing for Existing and Proposed Conditions

Table 8 summarizes the average WSE, upstream channel velocity, and culvert outlet velocity for the existing I-405 culvert crossing at various design storm events. The average upstream channel velocity reduces in higher interval events because the existing stream channel overtops its banks into adjacent streets and parking lots. The existing structure outlet velocity increases with recurrence interval due to the increased hydraulic head created at the upstream inlet to the culvert.

Table 8. Average Hydraulic Results for Existing Conditions

	2-Year Flow	25-Year Flow	100-Year Flow
Water Surface Elevation at the Proposed Inlet (feet)	171.90	175.00	**176.01**
Average Upstream Channel Velocity (feet per second)	8.4	7.0	**6.8**
Existing Structure Outlet Velocity (feet per second)	**4.0**	**6.6**	**7.6**

The 2-, 25-, and 100-year WSEs along the pre-developed Juanita Creek tributary profile are shown in Figure 23. SRH-2D model illustrations summarizing the WSEs, velocities, and depths for various recurrence intervals in the pre-developed condition are provided in Appendix D. The illustrations indicate that the existing 48-inch-diameter structure is insufficient to pass even the two-year recurrence

interval flow without creating excessive headwaters that begin flooding adjacent parking lots and local streets.

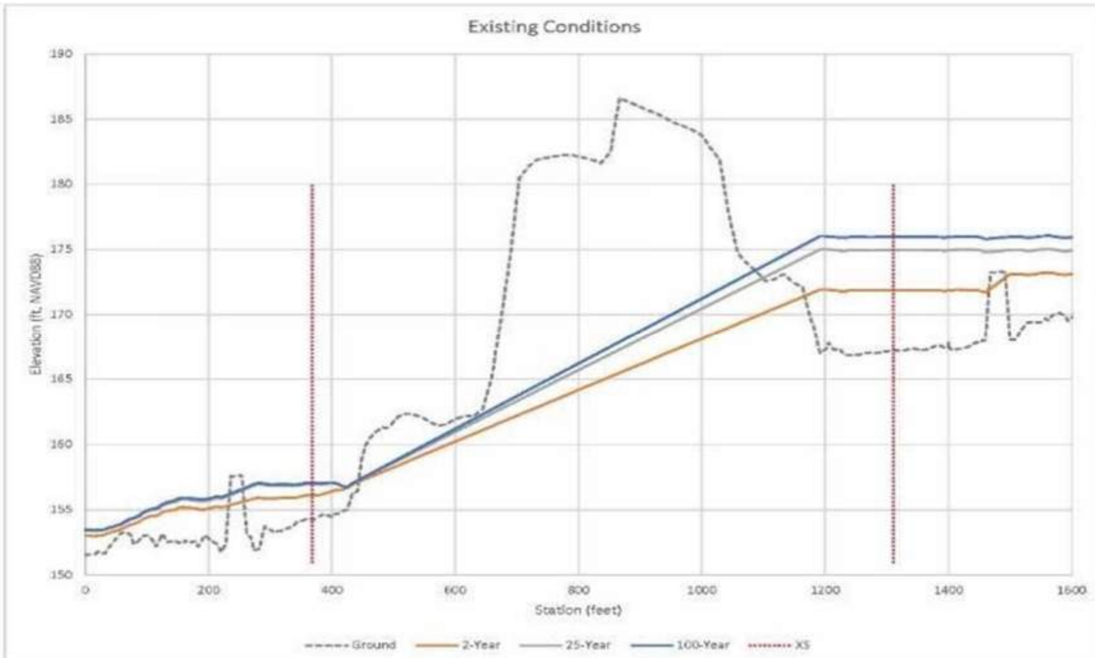

Figure 23. Existing Conditions Water Surface Profiles

4.3 Channel Design

4.3.1 Floodplain Utilization Ratio

Floodplain utilization ratio (FUR) is defined as the flood-prone width (FPW) divided by the bankfull width. The FPW is the water surface width at twice the bankfull depth, or the width at the 50-year to 100-year flood. A ratio under 3.0 is considered a confined channel and above 3.0 is considered an unconfined channel. FUR was determined using upstream and downstream measurements, at locations that outside of the culvert influence.

See Appendix B.6 for figures showing upstream and downstream FPW and bankfull width measurements. FURs of 2.7 and 2.0 were obtained at the upstream and downstream locations respectively. A FUR of 2.35, which is the average of upstream and downstream values, was used in the design of the proposed channel.

4.3.2 Channel Planform and Shape

WCDG requires that the channel planform and shape mimic conditions within a reference reach. A reference reach could not be located for this project due to the difference of slope and modifications of the channel over time. The existing channel characteristics were determined through field survey. Outside of the influence of the existing crossings, the channel is generally uniform straight with riffle pool geometry. The lack of sinuosity can be attributed to the close proximity of urbanization.

The proposed channel follows riffle pool designed geometry. The instream habitat configurations include slopes that mimic existing channel geometry previously described. The proposed channel section shown in Figure 24 was developed for use in riffle sections. Pre-formed scour pools are proposed in the streambed, around select LWM rootwads, to encourage habitat variety at the time of stream commissioning. See design plans in Appendix F.

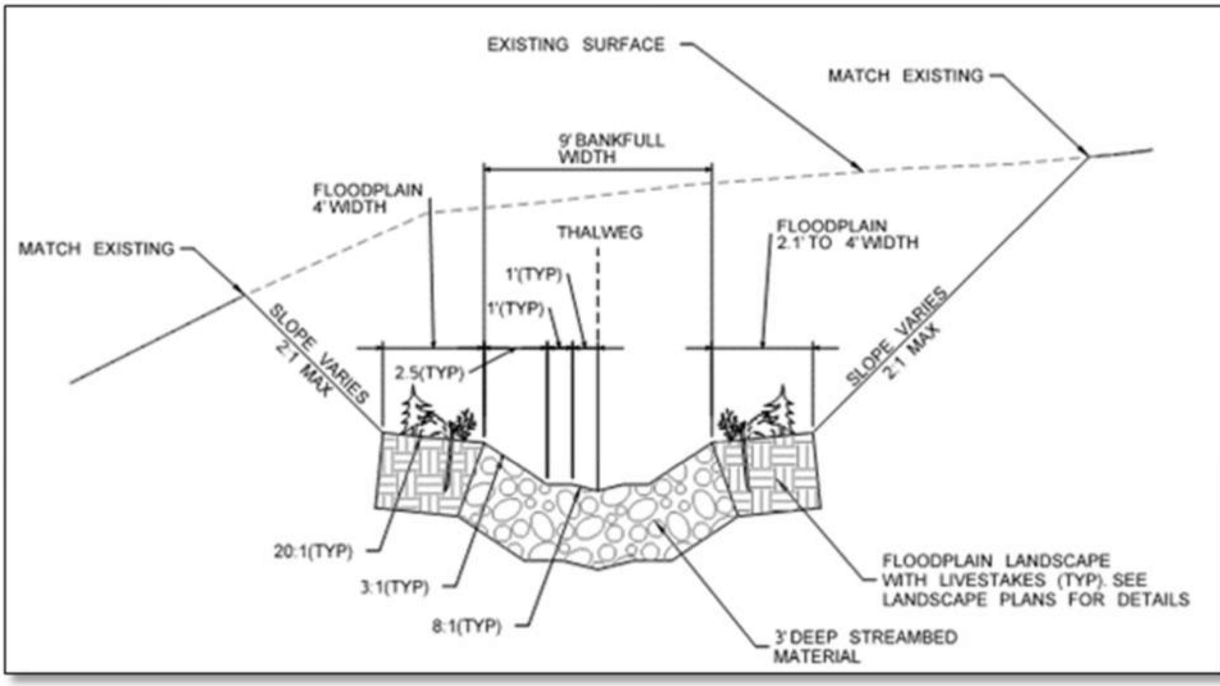

Figure 24. Design Open Channel Cross Section

4.3.3 Channel Alignment

The proposed stream channel follows the general flow direction of the existing stream channel but has been realigned primarily to maximize opportunities to reduce enclosed length and increase open channel length by 339 feet. The proposed design also adds an additional 135 feet of open channel to the total stream length, thereby resulting in a total open channel length increase of 474 feet. Proposed channel grading limits extend from the beginning of stream realignment (sta. 13+23.05) to the end of stream realignment (sta. 26+57.39).

Beginning at the upstream end of the proposed channel realignment (between 117th Place NE and Totem Lake Boulevard NE), the stream closely follows the existing horizontal channel alignment. This upstream open channel section is less constrained by adjacent roadway elements, so the design has incorporated larger, u-shaped meanders. The incorporation of these sweeping meanders increases the length of the channel and provides additional open channel habitat. This open channel also features the highest profile grade (2.25%). The large meanders within the stream channel, encourage the development of a dynamic stream system and help to reduce flow velocities through the segment (see Appendix D.2).

The two sections between Totem Lake Boulevard NE and 114th Place NE have maximized opportunities for open channel but are confined by adjacent roadway features. Through this segment, the minimum width at which the stream channel can behave as a dynamic system is no less than the 17-foot clear dimension of the proposed structures. The 17-foot minimum dimension has been applied to these open channel sections, because WSDOT has reached an agreement with the agencies and MITFD to view this series of structures and confined open channel sections as one unit. This segment incrementally reduces profile grade (1.60% to 0.68%) and the conceptual design has incorporated smaller meanders into the horizontal channel alignment to the maximum extent feasible by the adjacent roadway elements to encourage dynamic change and to reduce flow velocities.

The most downstream open channel segment between 114th Place NE and the private driveway to Woodlake Apartments closely follows the existing stream alignment and ties into the upstream invert of the existing private culvert. The stream profile grade flattens further (0.60%) as Juanita Creek tributary begins to experience some backwater influence from the downstream wetland complex. See Appendix F for proposed fish passage plans and profiles.

4.3.4 Channel Gradient

WCDG recommends that the proposed structure bed gradient not exceed a ratio of 1.25 compared to the natural stream gradient of the crossing (WCDG Equation 3.1). Slope ratios for each crossing are shown in Table 9.

Table 9. Slope Ratios Between Upstream Channel and Structure Crossings

Stream	Crossing	Approximate Upstream Channel Grade (%)	Proposed Structure Grade (%)	Slope Ratio
Juanita Creek Trib.	Totem Lake Boulevard NE	1.95	1.59	**082**
Juanita Creek Trib.	NE 132nd Street	1.32	1.25	**0.95**
Juanita Creek Trib.	**114th Place NE**	**0.68**	**0.60**	**0.88**

The proposed Juanita Creek tributary vertical profile transitions from a channel gradient of 0.75% to the downstream open channel gradient of 0.60%. The transition is accomplished in reaches of varying lengths from 30 to 50 feet with each reach having a slope ratio not exceeding 1.25. With a proposed slope ranging between 0.50% and 2.25%, the proposed stream will accommodate a riffle-pool system throughout the constructed profile. This riffle-pool system will be created and maintained through the construction of in-stream habitat features including LWM and boulder bars. See Appendix F for the proposed fish passage profile.

4.4 Design Methodology

The proposed fish passage design was developed using the 2013 WCDG and the WSDOT Hydraulics Manual. WCDG contains methodology for five different types of crossings: no-slope culverts, stream simulation crossings, bridges, temporary culverts or bridges, and hydraulic design fishways. 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 WCDG, a bridge should be considered for a site if the following conditions are met:

- The FUR is greater than 3.0;
- The stream has a bankfull width of greater than 15 feet;
- The channel is believed to be unstable as the slope ratio exceeds 1.25 between the existing channel and the new channel; or
- The culvert would be greater than 10:1 length to width ratio.

Since none of the above-mentioned criteria hold good for the existing site, the Stream Simulation design method was determined to be the most appropriate at this crossing. This method helps restore stream connection under the roadway and simulates natural stream functions within the proposed structure that meets the terms of the injunction. Consistent with WCDG recommendations, factors considered in selecting Stream Simulation as the design methodology, are listed below:

- Bankfull width – 9.0 feet (refer to section 2.8.2)
- FUR – 2.35 (refer to section 4.3.1)
- Slope ratio of proposed channel to the existing channel – 1.25 (refer to section 4.3.4)
- Length of the proposed crossing – (refer to section 4.6.2)
- Channel stability, including potential aggradation or degradation – (refer to sections 4.3.4, 5.1, and 5.2)
- Channel migration – (refer to section 2.8.5)
- Climate resiliency – (refer to section 7.0)

4.5 Future Conditions – Proposed 17-Foot Minimum Hydraulic Opening

The hydraulic opening is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic opening assumes vertical walls at the edge of the minimum hydraulic opening width unless otherwise specified.

The starting point for the design of all WSDOT structures is equation 3.2 of WCDG, rounded up to the nearest whole foot. The proposed crossing design is based on the proposed bankfull width sections. The average bankfull width proposed in the project area is 9 feet. Based on WDFW criteria and climate change considerations, a minimum 17-foot-wide crossing would be required. A 17-foot-wide structure is proposed at each of the three crossings within the project area. The channel geometry provides a 2-foot bottom width that gently slopes at 8:1 to the thalweg. A 4-foot-wide channel is provided for meander low flows, with bank slopes of 3:1, which transition to a 20:1 floodplain, toward the crossing structure's walls. The channel maintains this geometry through both open channel sections and the proposed culverts.

The three new culvert placements will significantly alter the stream alignment. While the existing alignment crosses I-405 at a 45-degree angle, the proposed alignment runs parallel to I-405 before crossing it at a 90-degree angle. See Figure 22 for existing and proposed alignments. This major realignment of the crossing is proposed to open up additional habitat and remove fish barriers. The proposed fish passable channel is constrained on all sides by roads and residential properties. Because of existing infrastructure and property ownership constraints, it is not necessary to provide hydraulic continuity between upstream and downstream reaches.

Juanita Creek will be regraded for approximately 1,334 feet between the upstream and downstream connection points of the existing and proposed alignments. . The proposed longitudinal slope of the stream will vary between 0.6% to 2.25% to match the existing stream gradient in the project vicinity.

Roughness elements such as wood, channel meanders, and large boulders are limited in the observed Juanita Creek crossing area. Limited roughness in combination with the straightened planform results in

greater scour potential at the crossings. Large woody debris elements are recommended and proposed throughout the open channel areas of the project for habitat complexity. Meander bars are proposed within the culvert crossings to prevent channel entrainment along the structure and maintain cross-sectional geometry.

The backwater conditions created by the existing undersized culverts at 117th Place NE and the private roadway for the Woodlake Apartments (upstream and downstream ends, respectively) have important implications regarding the culvert replacement. Specifically, by removing the undersized culvert within the project area and installing three stream-simulation structures (split box culvers), upstream hydraulic gradients are expected to steepen, and velocities increase during the 2-year event, thus, increasing sediment transport capacity and possibly leading to upstream channel degradation. An incipient motion analysis following Shield's methodology (USACE, 1994) suggests that under existing conditions, sediment transport upstream of the 117th Place NE crossing during a 2-year event is competent to transport large gravels. Under proposed conditions, with the hydraulic control removed, incipient motion analysis suggests large gravels would still be mobile but material in the 5-inch cobble range would be stable in up to a 100-year event, as required by the WCDG. As such, augmentation of WSDOT streambed material with 5-inch cobble-sized material would be considered appropriate to ensure streambed stability in the project vicinity. An additional consideration to inhibit channel degradation is incorporating buried and non-buried large woody debris into the channel bed near the outlet of the existing 117th Place NE crossing and through the stream simulation open channel project areas.

Removal of riparian vegetation and stabilized bank material could present future erosion issues. Roughening the channel banks with large woody debris helps reduce constriction of the channel and/or shift erosion to opposite banks and existing stream channel on the upstream reach.

In existing conditions, flow is supercritical and a small hydraulic jump forms at the outlet of the 117th Place NE culvert. When hydraulic continuity is restored through the proposed project area, a minor rise occurs at the 117th Place NE existing structure outlet. As such, comparison of existing and proposed conditions modeling using updated peak flow results shows the hydraulic jump remains in the proposed conditions. Computed proposed water surface elevations are lower than existing conditions upstream of the crossing. The simulated hydraulic jump is shown to be less than in the existing conditions. As such, no change is proposed to this culvert as part of the project requirements.

Assuming there is no debris blockage in the existing 117th Place NE culvert, overtopping at NE 131st Place is not predicted up to the 100-year return interval. However, for return intervals greater than the 100-year, flow overtops the right bank at the existing 117th Place NE culvert crossing, causing water to pool on the road near the Vue apartments. In the proposed condition, the floodplain widens, thereby providing ample storage for all flows and eliminating roadway overtopping throughout the proposed stream regraded corridor. Figure 25 depicts computed WSE profiles for proposed conditions assuming placement of the three 17-foot-wide culverts and channel regrading in the project vicinity. Figures 26 and 27 show typical sections of proposed culverts at 114th Place NE, NE 132nd Street, and Totem Lake Boulevard NE.

Average hydraulic results from the SRH-2D model, including WSE, depth, velocity, and shear stress for each proposed culvert crossing (upstream and downstream of structure and within structure) are summarized in Table 10 and the 2-, 25-, 100-, 500-year, and 2080 predicted 100-year recurrence interval storm events in Table 11. Illustrations summarizing the WSE, velocity, and depths under the 2-, 25-, 100-, 500-year, and 2080 predicted 100-year recurrence interval flows are provided in Appendix D.

The proposed channel water surface profiles in Figure 25 show that all three proposed 17-foot-span structures easily pass flow through the project site without overtopping or creating a buildup of

headwater upstream. At each culvert, WSEs increase with higher peak flow events. But the larger crossing structures do not constrict flow, which keeps the hydraulic head low at the upstream end of each culvert. This causes the stream to remain confined within the channel, which leads to a relatively linear increase in velocity with higher recurrence interval storm events. The profiles also show that WSE increases slightly toward the downstream end of the realigned stream due to backwater influence from the existing Woodlake Apartments private road culvert, located just downstream of the project site.

Table 10. Average Main Channel Hydraulic Results within Proposed Culverts

Culvert 1						
Flow Event	*WSE (ft)*	*Depth (ft)*	*Vel (ft/s)*	*Shear Stress (lb/ft2)*	*Culvert Soffit Elevation*	*Freeboard (ft)*
2-Year	156.53	2.04	2.60	0.21	161.31	4.78
25-Year	157.49	3.00	2.94	0.24	161.31	3.82
100-Year	157.70	3.21	3.28	0.29	161.31	3.61
500-Year	158.36	3.87	3.65	0.33	161.31	2.95
Year 2028 Predicted 100-Year	158.19	3.70	3.51	0.31	161.31	3.12
Culvert 2						
Flow Event	*WSE (ft)*	*Depth (ft)*	*Vel (ft/s)*	*Shear Stress (lb/ft2)*	*Culvert Soffit Elevation*	*Freeboard (ft)*
2-Year	159.34	1.29	4.40	0.73	163.27	3.93
25-Year	159.93	1.89	4.80	0.77	163.27	3.34
100-Year	160.21	2.17	4.92	0.77	163.27	3.06
500-Year	160.82	2.78	5.11	0.77	163.27	2.45
Year 2028 Predicted 100-Year	160.63	2.59	5.06	0.77	163.27	2.64

Culvert 3						
Flow Event	*WSE (ft)*	*Depth (ft)*	*Vel (ft/s)*	*Shear Stress (lb/ft2)*	*Culvert Soffit Elevation*	*Freeboard (ft)*
2-Year	163.95	1.24	4.51	1.42	168.26	4.31
25-Year	164.50	1.78	5.00	1.82	168.26	3.76
100-Year	164.75	2.03	5.14	1.93	168.26	3.51
500-Year	165.27	2.55	5.42	2.10	168.26	2.99
Year 2028 Predicted 100-Year	165.11	2.39	5.33	2.05	168.26	3.15

Table 11. Average Main Channel Hydraulic Results at Upstream and Downstream of Proposed Culverts

Culvert 1								
Flow Event	*WSE (ft)*		*Depth (ft)*		*Vel (ft/s)*		*Shear Stress (lb/ft2)*	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2-Year	156.93	156.38	1.75	2.45	3.37	1.97	1.24	0.18
25-Year	157.76	157.37	2.58	3.44	3.75	2.30	1.54	0.23
100-Year	158.00	157.56	2.82	3.63	4.04	2.61	1.79	0.29
500-Year	158.64	158.22	3.46	4.29	4.36	2.97	2.06	0.36
Year 2028 Predicted 100-Year	158.46	158.05	3.28	4.12	4.24	2.83	1.95	0.33
Culvert 2								
Flow Event	*WSE (ft)*		*Depth (ft)*		*Vel (ft/s)*		*Shear Stress (lb/ft2)*	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2-Year	160.35	158.94	1.40	1.82	3.75	2.95	0.79	0.94
25-Year	160.90	159.72	1.95	2.60	3.90	3.15	0.84	1.18
100-Year	161.14	160.03	2.19	2.91	3.90	3.29	0.84	1.31
500-Year	161.65	160.66	2.70	3.54	3.85	3.66	0.82	1.60

Year 2028 Predicted 100-Year	161.49	160.47	2.54	3.35	3.87	3.53	0.83	1.51
Culvert 3								
Flow Event	*WSE (ft)*		*Depth (ft)*		*Vel (ft/s)*		*Shear Stress (lb/ft2)*	
	US	*DS*	*US*	*DS*	*US*	*DS*	*US*	*DS*
2-Year	166.04	163.23	1.41	1.53	4.59	3.68	1.36	1.44
25-Year	166.52	163.76	1.88	2.07	5.28	4.58	1.72	2.19
100-Year	166.69	163.98	2.05	2.28	5.57	4.91	1.89	2.50
500-Year	167.04	164.40	2.41	2.71	6.02	5.54	2.14	3.12
Year 2028 Predicted 100-Year	166.93	164.28	2.30	2.58	5.88	5.36	2.06	2.93

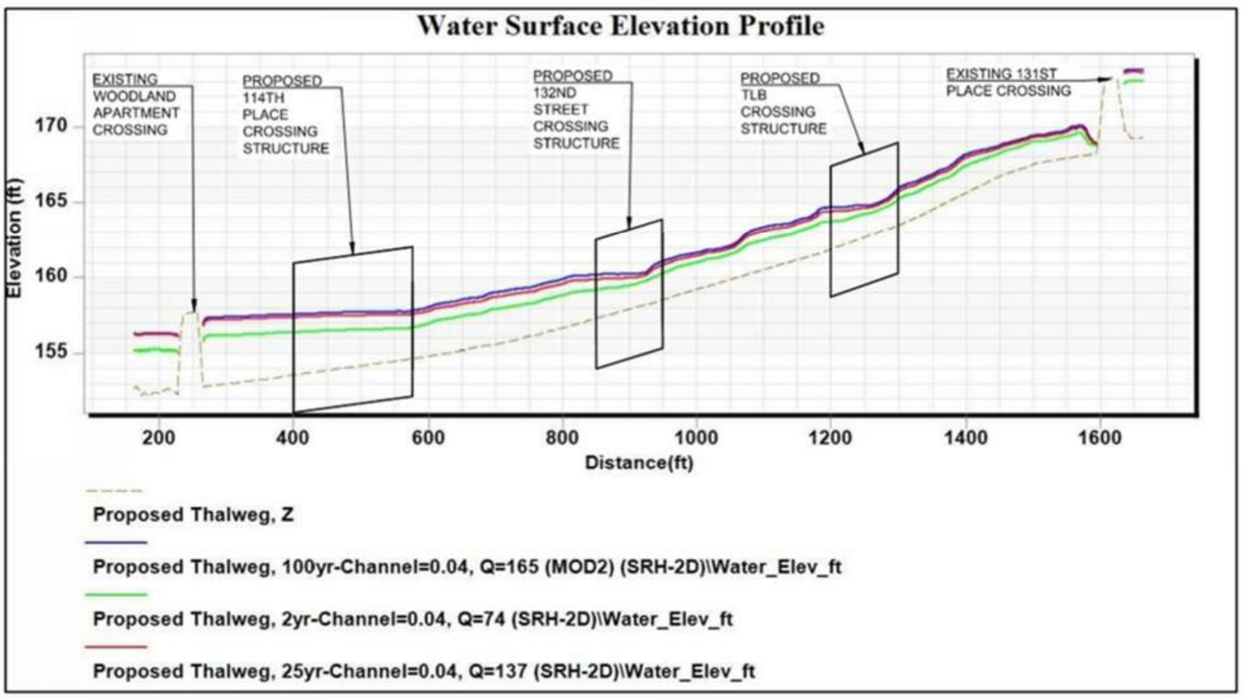

Figure 25. Proposed Condition Water Surface Profiles

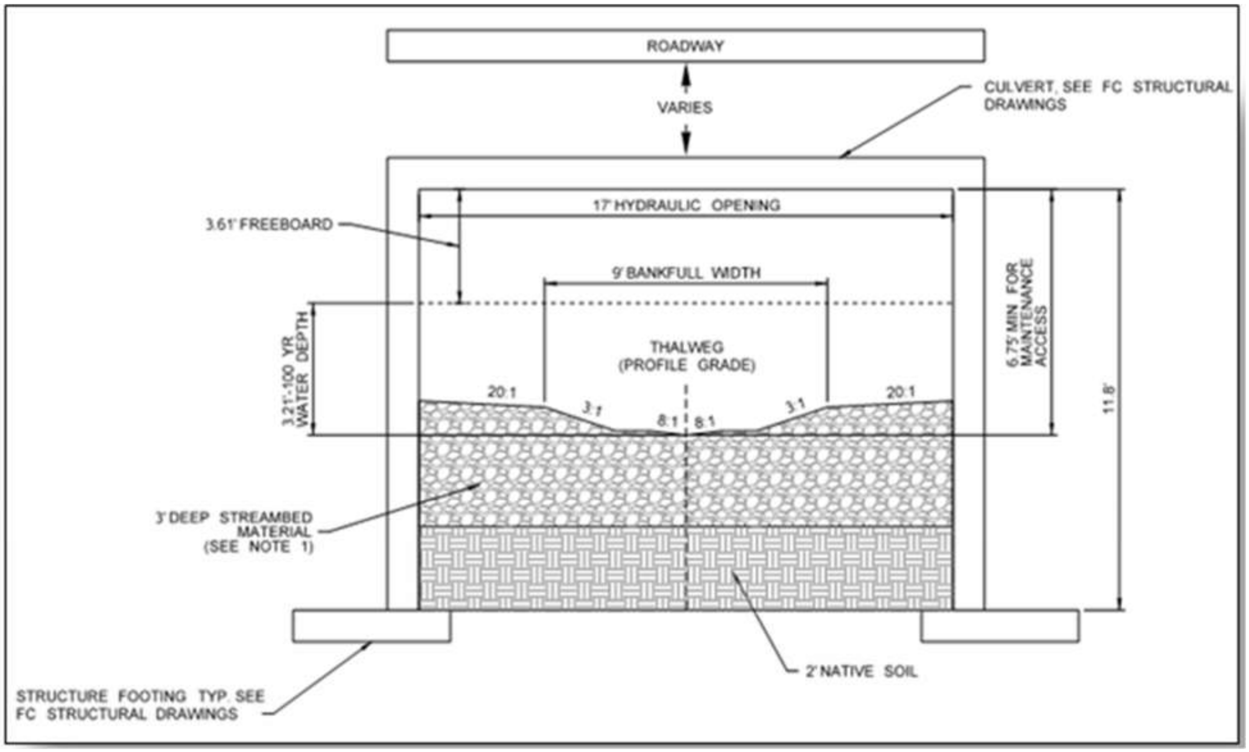

Figure 26. Typical Section Through Proposed Structure Crossing at 114th Place NE

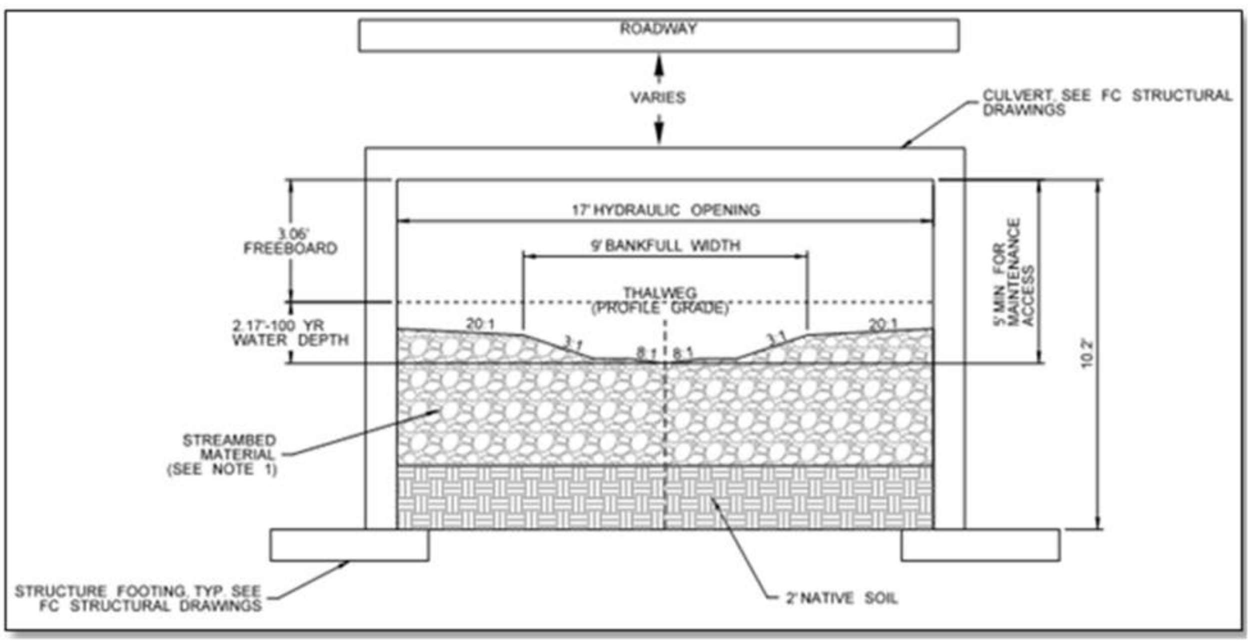

Figure 27. Typical Section Through Proposed Structure Crossings at NE 132nd Street and Totem Lake Boulevard NE

The proposed conditions SRH-2D model predicts that peak velocities will occur at the upstream and downstream of the second and third crossing structures beneath NE 132nd Street and Totem Lake Boulevard NE, respectively. Figure 28 shows the 100-year flow velocity map in the proposed condition. Meander bars and LWM are proposed in these areas to provide additional streambed stabilization and habitat features to address stream restoration through the relatively sharp bends in the channel geometry.

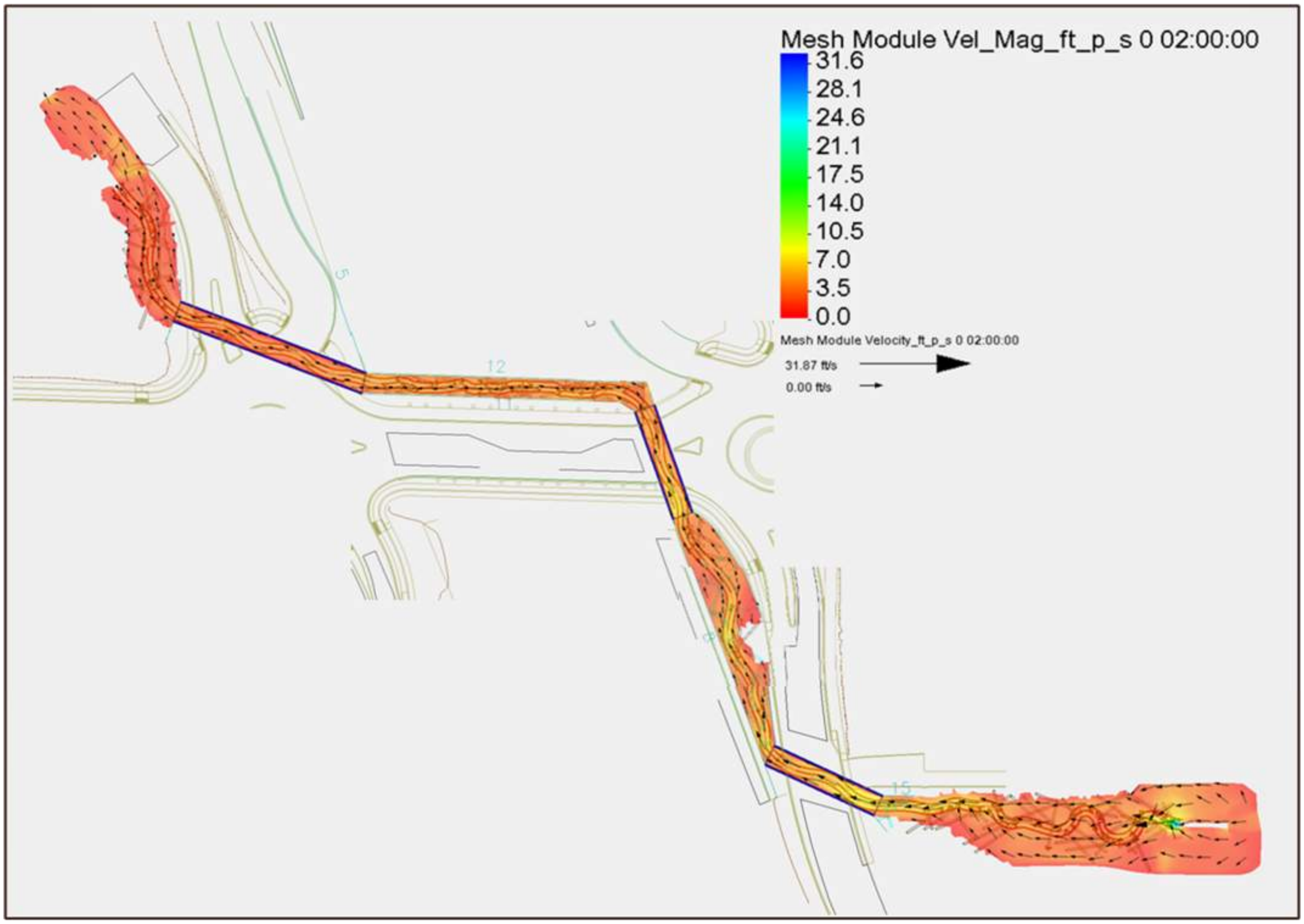

Figure 28. Proposed Conditions 100-Year Design Flow Velocity Map

4.6 Water Crossing Design

4.6.1 Structure Type

A buried structure is recommended by WSDOT's Headquarters Hydraulics Section for this crossing because a buried structure can help restore stream connection under the roadway without having to make major changes to existing infrastructure. Also, as mentioned in Section 4.4 of this report, since no extraordinary circumstances exist on the site, either the stream simulation method or bridge design method are recommended. The FUR, bankfull width, slope ratio, and length to width ratio for the proposed project are less than the threshold values, which if exceeded, would require bridge design. Therefore, a buried structure simulating natural stream functions was recommended for this project.

4.6.2 Minimum Hydraulic Opening Width and Length

WCDG recommends sizing proposed structure span based on the agreed upon bankfull width, with the span being 1.2 times the bankfull width plus 2 feet (WCDG Equation 3.2). As WCDG states in Chapter 3, culverts with a length to width ratio greater than 10 are considered long and special consideration should be given to their design. There are three alternatives proposed for long culverts, and are stated as such:

1. Increase culvert width using geomorphological features as a guide to sizing.

2. Increase culvert roughness by decreasing hydraulic radius. This corresponds to a roughly 30% increase in width, which would be added to the results given by Equation 3.2.

3. Use a bridge instead of a culvert.

Using this equation from special consideration 2, along with the measured bankfull width discussed in section 2.8.2, structure spans were calculated at the three crossings. The resulting structure spans for each crossing are shown in Table 12 The physical dimension of the individual crossing is a minimum of 17-foot clear span in all cases because WSDOT agreed with the agencies and MITFD to view the series of crossings and confined open channel sections as one unit. Therefore, the +30% added width applies to all the structures. See Appendix F for proposed fish passage plans and profiles.

Table 12. Structure Widths Based on Measured Bankfull Width

Structure Crossing	Bankfull Width (ft)	Structure Width (Eqn. 3.2) (ft)[1]	Structure Length (ft)	Length: Width Ratio	Structure Width (+30%) (ft)[2]
Totem Lake Boulevard NE	9.0	13	107	6.3	**17**
NE 132nd Street	9.0	13	104	6.2	**17**
114th Place NE	**9.0**	**13**	**176**	**10.4**	**17**

Notes:

1. Structure widths are rounded up to the nearest foot, per Chapter 3 of the 2013 WCDG.
2. This dimension is the minimum inside clear dimension inside the structure crossing measured perpendicular to the centerline of the structure.

As stated in section 2.8.5 of this report, lateral migration risk is low for Juanita Creek tributary and has not been accounted for in the determination of structure width. The projected 2080 100-year flow event was evaluated and the velocity comparisons for these flow rates can be seen in Table 13 below.

Table 13. Velocity Comparison for 17-Foot Structures, Culverts 1, 2, and 3

Culvert 1			
	Velocities (cfs)		
	100-Year	2080 Projected 100-Year	Difference
Upstream of the Structure	4.0	4.2	0.2
Through the Structure	3.3	3.5	0.2
Downstream of the Structure	2.3	2.1	-0.2
Culvert 2			

	Velocities (cfs)		
	100-Year	2080 Projected 100-Year	Difference
Upstream of the Structure	3.7	3.7	0.0
Through the Structure	4.9	5.0	0.1
Downstream of the Structure	3.9	4.0	0.2
Culvert 3			
	Velocities (cfs)		
	100-Year	2080 Projected 100-Year	Difference
Upstream of the Structure	5.5	5.7	0.2
Through the Structure	5.1	5.3	0.2
Downstream of the Structure	4.9	5.4	0.4

Replacement of the existing fish barrier culvert with multiple 17-foot-wide crossings is not expected to have a significant morphologic impact to the existing channel upstream and downstream of the project. The proposed stream simulation structures will reduce the extent of upstream floodplain inundation during all flow events. The channel may regrade through the crossings and dewater the existing pool upstream, where the stream can be expected to transition to the similar riffle-pool morphology observed downstream. Inside the proposed crossings (proposed Culverts 1, 2, and 3), meander bars will help define the channel and prevent channel entrainment along each of the structure banks.

As described in section 4.2, the existing culvert crossing creates hydraulic jumps and backwater conditions as frequently as the 2-year event. Proposed conditions modeling shows that backwater conditions are reduced and more than 2 feet of freeboard is provided at the 100-year event for all culverts. Therefore, the proposed structures will improve flood conditions and reduce risk of roadway overtopping and inundation.

The proposed streambed material and meander bar depth will aid against anticipated scour and potential channel regrading. Incorporation of LWM within each structure and upstream and downstream of the crossings will provide habitat uplift benefits. No size increase was determined to be necessary to accommodate climate change.

4.6.3 Freeboard

To allow the free passage of debris through the culverts, WCDG recommends a minimum 2-foot freeboard for streams of this size (streams with 8 to 15 feet BFW), above the 100-year water surface

elevation. Freeboard was evaluated for the 100-year WSE and the projected 2080 100-year WSE, to account for climate resiliency. Each culvert has adequate freeboard (2 feet or greater) for the 100-year water surface elevation. See Table 10 in section 4.5 for freeboard provided at each culvert.

As the site has negligible maintenance issues and no recruitable large vegetation upstream and downstream, the risk of debris impacting conveyance through the culverts is considered minimal.

4.6.3.1 Past Maintenance Records

WSDOT Area 4 Maintenance was contacted to determine whether there were ongoing maintenance problems at the existing structure due to LWM racking at the inlet or sedimentation. The maintenance representative indicated there was no record of LWM blockage and/or removal or sediment removal at this crossing. LWM does not accumulate at the culvert opening and sedimentation does not appear to be an issue. WSDOT Area 4 Maintenance was contacted to discuss maintenance activities and access. WSDOT Area 4 Maintenance indicated that access roads are not required, but 3:1 (horizontal to vertical) slopes are acceptable for equipment access as long as landscaping and LWM placement leaves a clear path for access and egress. Any maintenance access issues arising from proposed design will be discussed and resolved with Area 4 Maintenance, and incorporated into the final design plans, as needed.

4.6.3.2 Wood and Sediment Supply

As mentioned in section 3.3.5, Juanita Creek tributary has good potential for LWM and sediment transport downstream. The proposed fish passage structures will increase the potential for LWM to be recruited and transported through the channel due to the increase in structure span. This transport, however, will be limited until upstream fish passage barriers (WDFW Site ID 932414) are removed.

4.6.3.3 Flooding

The project site is not located within a FEMA mapped floodplain. The proposed structures are anticipated to improve the existing condition by reducing backwater effects caused by the existing undersized culverts.

4.6.3.4 Future Corridor Plans

The existing structures are being replaced as part of the I-405 NE 132nd Street Interchange Improvements Project. This project will construct a new half diamond interchange and adds approximately 2.8 acres of tributary impervious area to the Juanita Creek tributary subbasin upstream of the proposed structures. This impervious area will be included in the hydraulic modeling of the stream to be included in future submissions.

The lengths of all three proposed culvert crossings have been sized and located to accommodate further mainline I-405 Master Plan elements as well as anticipated future widening to Totem Lake Boulevard NE and other local streets.

5 Streambed Design

5.1 Bed Material

The proposed streambed material sizing is similar to that of the gradation provided in the pebble count. Per Chapter 7 of the WSDOT Hydraulics Manual, the combined streambed material should have a D_{50} that is within 20% of the reference reach D_{50} or be 100% streambed sediment if streambed sediment is larger than the reference reach material, unless otherwise approved by WSDOT.

Given the uniform slope of less than 4%, the Modified Shields Methodology was selected for streambed design. Analysis indicates that the reference reach sediment sample would be mobile during all flood events. This conclusion is consistent with the channel stability analysis that described the streambed sediment consisting of only gravels and smaller material. For this project, streambed material would need to have a similar resistance to scour, or it would be transported downstream. To achieve this level of resistance the bed materials must be substantially coarser than the sediment transported through the system.

To provide D_{84} stability at the 100-year flood flow, calculations indicate that the resultant D_{50} would be 2.21 inches, with the existing D_{50} of 0.51 (333% increase), and the D_{84} would be nearly 4.66 inches, with the existing D_{84} of 1.03 inches (352% increase). With this mix, the D_{50} would be mobile in events greater than the 10-year event and the D_{84} would become mobile in greater than the 100-year flow. See Appendix E for streambed material sizing calculations.

It is not desirable to increase the streambed sediment by this amount. Therefore, the streambed sediment mix will be increased by 20%, as shown in Table 14 below:

Table 14. Comparison of Observed and Proposed Streambed Material

Particle	Observed Material Diameter (inches)	Proposed Material Diameter (inches)
D_{15}	0.24	0.29
D_{50}	0.51	0.61
D_{84}	1.03	1.24
D_{95}	1.69	2.03

Thus, the proposed streambed material will be 100% streambed sediment per WSDOT standard specifications.

To provide the needed channel stability, meander bars are needed within the structures to prevent streambed sediment from being washed out. These meander bars, composed of a higher percentage of small to medium cobbles and large gravels would be placed within the structure to provide additional stability. In addition, LWM will be arranged within the structure to provide additional roughness, channel stability, and habitat variability.

The meander bar material gradation was sized using the guidance for coarse bands in Chapter 7 of the WSDOT Hydraulic Manual. The guidance states that the material is typically sized for the D_{84} to be stable at the 100-year flow event and shall not have material that is larger than twice the D_{100} of the design bed mix. The meander bar material gradation was designed using the Modified Shields Methodology with consideration that the D_{100} for streambed sediment (the design bed mix) is 2.5 inches. As previously discussed, to provide D_{84} stability at the 100-year flood flow, calculations provide that the resultant D_{50} would be 2.21 inches, and the D_{84} would be nearly 4.66 inches using a mixture of 15% streambed sediment and 85% 6-inch streambed cobbles per WSDOT standard specifications. The D_{100} for this is 6 inches, which is greater than twice the design mix D_{100} of 2.5 inches. However, this design uses WSDOT material gradations which are standard and available at local aggregate material suppliers and is generally acceptable.

5.2 Channel Complexity

LWM will be incorporated throughout the proposed design of Juanita Creek Tributary. Channel complexity within the structure will be created with the use of meander bars that partially obstruct low

flows to create habitat diversity and act to prevent the stream from entrainment along the structure walls and avoid plane-bed configurations.

LWM will be installed according to the minimum recommended by Chapter 10 of the Hydraulics Manual within the project limits as defined for permitting. Channel complexity outside of the crossing structures will include meandering, riffles, and pre-formed scour pools near select LWM root wads, and restored streambank shape generally as shown in the preliminary plans (Appendix F).

Bioengineering for bank stability immediately after construction shall comprise of live stakes within the floodplain and live fascines at the edge of floodplain embankments where the 20:1 floodplain slope will transition to 2:1 embankment slope.

5.2.1 Design Concept

The alignment for the proposed stream channel follows the general flow direction of the existing stream channel but has been realigned primarily to maximize opportunities to create open channel that is currently enclosed. See Appendix F, which details the proposed fish passage plan and profile.

Beginning at the upstream end of the proposed channel realignment (between 117th Place NE and Totem Lake Boulevard NE), the stream closely follows the existing horizontal channel alignment. This upstream open channel section is less constrained by adjacent roadway elements, so the design has incorporated larger, u-shaped meanders. The incorporation of these sweeping meanders increases the length of the channel and provides additional open channel habitat. This open channel also features the highest profile grade (2.25%). The large meanders within the stream channel, encourage the development of a dynamic stream system and help to reduce flow velocities through the segment.

The two sections between Totem Lake Boulevard NE and 114th Place NE have maximized opportunities for open channel but are confined by adjacent roadway features. Through this segment, the minimum width in which the stream channel can behave as a dynamic system is no less than the 17-foot clear dimension of the proposed structures. The 17-foot minimum dimension has been applied to these open channel sections because WSDOT has reached an agreement with the agencies and MITFD to view this series of structures and confined open channel sections as one unit. This segment incrementally reduces profile grade (1.60% to 0.67%) and the conceptual design has incorporated smaller meanders into the horizontal channel alignment to the maximum extent feasible by the adjacent roadway elements to encourage dynamic change and to reduce flow velocities.

The most downstream open channel segment between 114th Place NE and the private driveway to Woodlake Apartments closely follows the existing stream alignment and ties into the upstream invert of the existing private culvert. The stream profile grade flattens further (0.60%) as Juanita Creek tributary begins to experience some backwater influence from the downstream wetland complex.

LWM will be placed to emulate instream habitat functions in a manner to mimic natural wood loads, at the 75th percentile key-piece density levels found by Fox and Bolton (2007) in similar natural streams in the region. For the Juanita Creek tributary, 48 key pieces of LWM will be placed over the 1,344 feet of constructed channel. This exceeds the 75th percentile of 45 key pieces suggested by Fox and Bolton for the same stream length. The key pieces will be a minimum 18-inch-diameter at breast height (DBH), 35 and 40 feet long and will have root wads attached for increased instream habitat complexity. The remaining 88 pieces of LWM in the proposed design will include 73, 15-foot, 18-inch diameter logs with rootwads; 3, 20 foot, 18-inch diameter logs without rootwads; and 12, 10-foot, 12-inch diameter logs. All 18-inch diameter LWM pieces are designed to be stable at the 100-year design flow, as per WSDOT design guidance. LWM will be stabilized using various methods including burying the stem of the log, log ballasting, boulder anchors, and mechanical anchors. The 12-inch diameter logs are marginally mobile

wood pieces that are placed strategically throughout the channel to avoid downstream and in-structure racking issues and is designed to be stable at the 10-year design flow. Any larger cobbles or boulders placed within the structure will be arranged in a manner to enhance instream habitat and maintain channel sinuosity.

The LWM layout does not meet the 75th percentile quantities for wood volume and total number of pieces, due to the stream's highly urban setting and close proximity to adjacent infrastructure. However, the design does meet the requirement for total number of key pieces. This was agreed upon by WSDOT and MITFD during conceptual design and thus the design is consistent with this agreement in total number of LMW, sizes of LWM, and general LWM layout.

The placement of LWM along the stream channel will create energy breaks in which juvenile and adult fish can take refuge and encourages the creation of the pools and other habitat features associated with more complex stream morphology. Root wads are generally placed within the 2-year flow water surface elevation and at preformed scour pool locations, as shown in the Plans (Appendix F).

Design calculations indicate that the partially buried stems and wood stacking ballasting methods will provide stability to most of the LWM at the upstream of Culvert 3 (Lake Totem Boulevard) end of the channel. Partial log burial, boulder anchoring, and cable pinning logs together will be required to provide stability for logs downstream of Culvert 3 and Culvert 2. LWM stabilization downstream of Culvert 1 will include partial log burial, boulder ballasting, and mechanical anchors. Table 15 summarizes ballasting requirements. See Appendix F for plans showing the LWM layout. LWM design calculations can be found in Appendix I.

Materials for LWM and LWM anchoring follow the guidance in Chapter 10 of the WSDOT Hydraulics Manual. Log stability analysis was performed using the United States Forest Service's Computational Design Tool for Evaluating the Stability of Large Wood Structure (Rafferty, 2016). The design uses native Douglas fir trees for LWM. Log stability is evaluated using a safety factor of 1.5 for a 100-year design flow, in accordance with WSDOT's guidance.

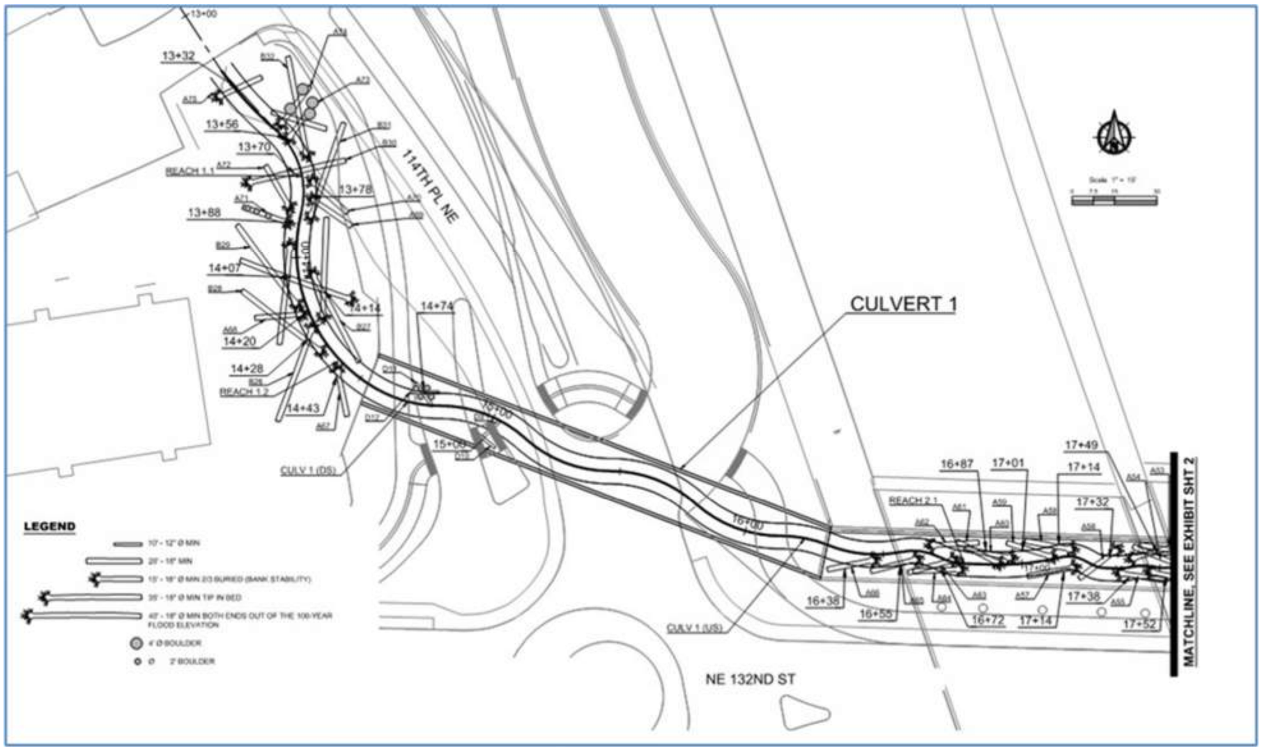

Figure 29. Conceptual Layout of Habitat Complexity - Downstream

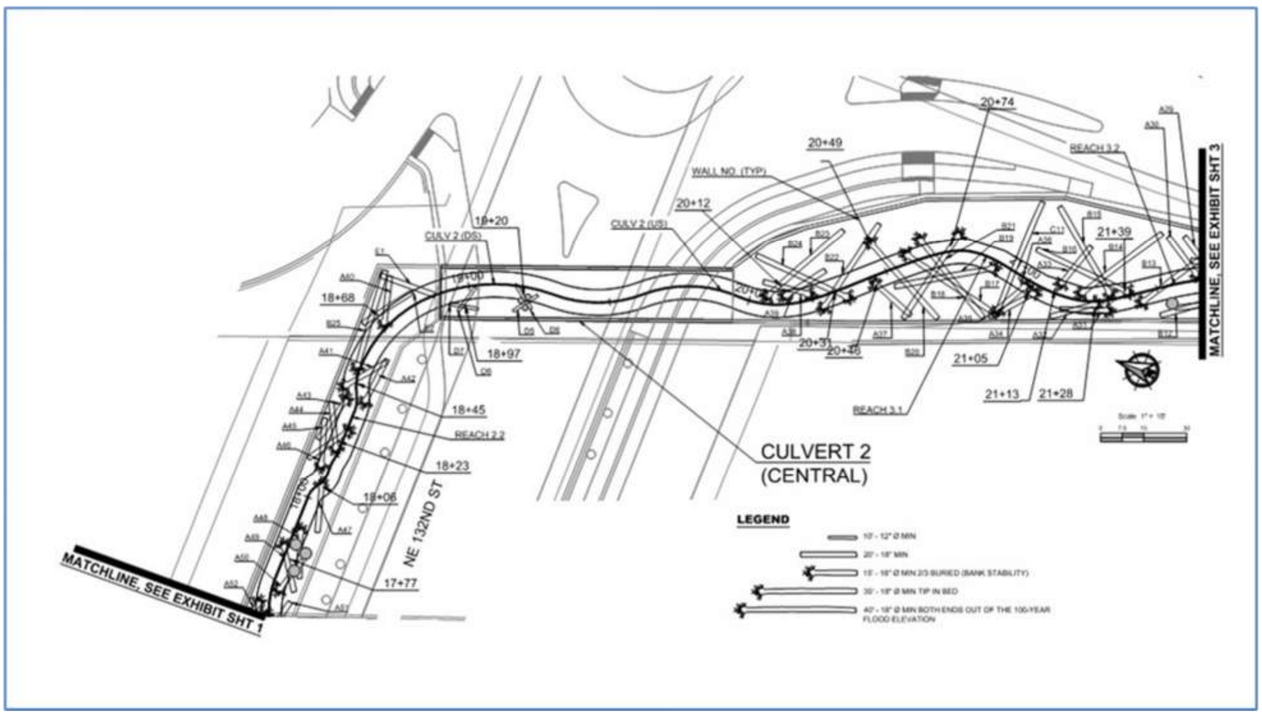

Figure 30. Conceptual Layout of Habitat Complexity - Central

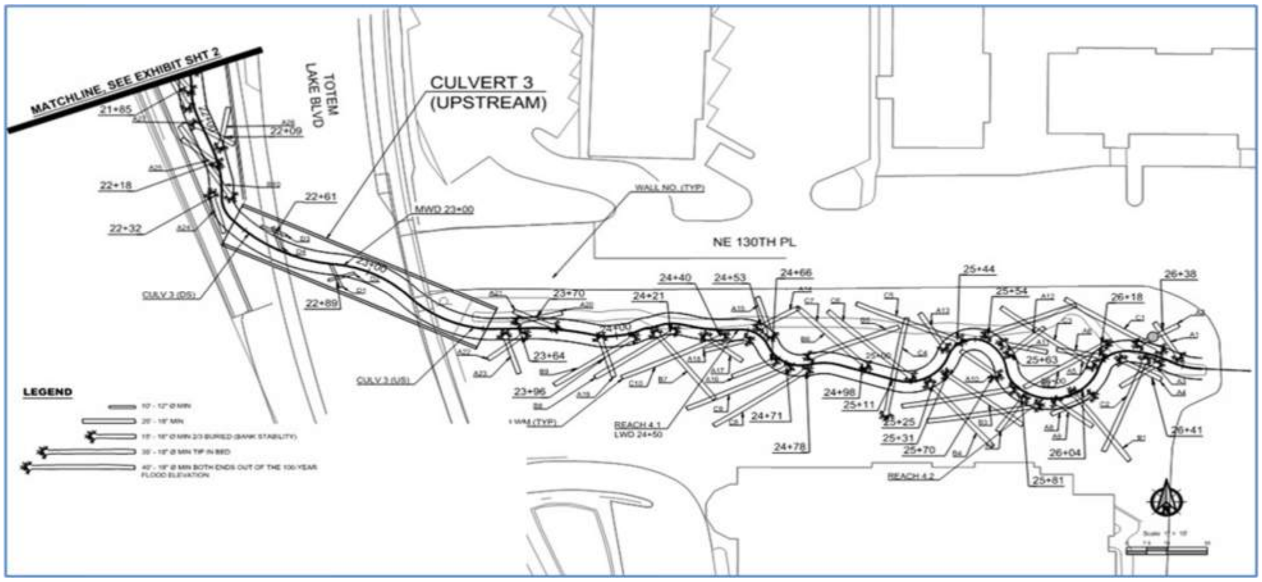

Figure 31. Conceptual Layout of Habitat Complexity - Upstream

5.2.2 Stability Analysis

A stability analysis was done for each log using the United States Forest Service's published Computational Design Tool for Evaluating the Stability of Large Wood Structures (Rafferty, 2016), as recommended by WSDOT's Hydraulic Manual Chapter 10. Per WSDOT design guidance, LWM stability was evaluated using the 100-year design flow, and a factor of safety of 1.5 applied to the stability analysis for each log, to account for vertical, horizontal, and moment forces. LWM stabilization methods include partial log burial, wood ballasting, boulder anchoring, and mechanical anchoring. Non-galvanized metal wire is used to secure LWM to boulder anchors and for pinning LWM together. Mobile Wood material was designed with wood and boulder ballasting, to be mobile at flows higher than the 10-year design flow. Therefore, a factor of safety of 1.5 at the 100-year design flow is not applicable for Mobile Wood design. The table below summarizes buoyancy, horizontal and moment factors of safety, and ballasting or anchoring requirements.

Table 15. Summary of Log Ballast Requirements

LWD STATION	LOGS ID NUMBER	LOG LENGTH (FT), DIA. (FT)	BOUYANCY FACTOR OF SAFETY	HORIZONTAL FACTOR OF SAFETY	BOUYANCY MOMENT (FT/LBS)	ANCHOR REQUIREMENTS		
						REQUIRED BALLAST (POUNDS)	LOG/BALLAST/ ANCHOR NOTES	NOTES
13+32								
13+56								
13+70								
13+78	A69	15, 1.5	1.5	37.5	7.5	2138	PARTIALLY BURIED, CABLE PINNED TO B31, MANTA RAY ANCHOR	BASELOG
	A70	15, 1.5	2.4	16.6	4.4	2095	STEM PARTIALLY BURIED; CABLE PINNED TO B31	ATTACHED
	B31	35, 1.5	2.5	35.3	1.7	4072	CABLE PINNED TO A69 AND A70	STACKED
13+88	A71	15, 1.5	1.5	11.5	1.8	1640	STEM PARTIALLY BURIED, 1-2 MAN	BASELOG

							BOULDER and 1-3 MAN BOULDER ANCHORS	
16+07								
14+14								
14+20								
14+28								
14+43								
14+74[1]	D11	10, 1.0	1.4	6.5	2.1	466	2–2 MAN BOULDER BALLASTS	BASELOG
	D12	10, 1.0	2.2	6.4	3.9	395	2–2 MAN BOULDERS BALLASTS	STACKED
15+00								
16+38								
16+55								
16+72								
16+87								
17+00								
17+14								
17+32								
17+39								
17+49								
17+52								
17+77	A49	15, 1.5	1.5	2.1	1.6	1718	1-3 MAN BURIED BOULDER ANCHOR	BASELOG
	A50	15, 1.5	2.1	1.5	5.4	-301		STACKED
	A48	15, 1.5	1.6	1.5	3.9	-63		STACKED
18+06								
18+23								
18+40								
18+68								
18+97								
19+20[1]	D5	10, 1.0	1.7	1.9	1.8	484	2–2 MAN BOULDER BALLASTS	BASELOG
	D6	10, 1.0	1.1	2.2	1.6	114	1–2 MAN BOULDER BALLASTS	STACKED
20+12								
20+31								
20+46								
20+49								
20+74								
21+05	A33	15, 1.5	1.5	2.5	1.6	1382	PARTIALLY BURIED, 1-3 MAN BURIED BOULDER ANCHOR	BASELOG
	A34	15, 1.5	1.5	2.2	1.5	1324	PARTIALLY BURIED, 1-3 MAN BURIED BOULDER ANCHOR	STACKED
	C11	40, 1.5	3.4	3.2	3.1	-1591	SPANNING ACROSS 100-FLOOD LEVEL	STACKED
21+12								

21+28									
21+39									
21+70									
21+85	B11	35, 1.5	1.5	2.7	2.1	4153	PARTIALLY BURIED AND 3-3 MAN BOULDER ANCHORS	BASELOG
	B12	35, 1.5	2.2	1.5	4.5	-755	CABLE ANCHORED TO LOG B11	STACKED
22+07									
22+18									
22+32	A-24	15, 1.5	1.5	1.6	1.5	1343	1-3 MAN BOULDER ANCHOR	BASELOG
22+60[1]	D3	10, 1.0	1.9	57.8	2.3	457	1–2 MAN BOULDER BALLAST	BASELOG
	D4	10, 1.0	2.4	2.2	1.9	321	1–2 MAN BOULDER BALLAST	STACKED
22+70									
23+64									
23+70									
24+04									
24+21									
24+40	A17	15, 1.5	2.6	2.8	2.2	1467	PARTIALLY BURIED	BASELOG
	A18	15, 1.5	9.1	2.5	16.4	2304		STACKED
	C10	40, 1.5	118.5	47.0	104.3	-2777		STACKED
24+53									
24+66									
24+71									
24+78									
24+98									
25+11									
25+25									
25+31									
25+44									
25+54									
25+63									
25+70									
25+81									
26+04	A8	15, 1.5	1.7	8.9	3.4	1787	PARTIALLY BURIED	BASELOG
	B1	35, 1.5	15.3	1204.5	70.6	-2258		STACKED
	A9	15, 1.5	5.5	7.6	14.1	-920		STACKED
26+18	A6	15, 1.5	2.3	2.9	2.5	1722	PARTIALLY BURIED	BASELOG
	B2	35, 1.5	4.1	2.3	1.6	-582		STACKED
	C3	40, 1.5	160.2	2016.0	160.2	-2786		STACKED
26+38	A2	15, 1.5	2.5	1.7	2.4	1631	PARTIALLY BURIED	BASELOG
	A1	15, 1.5	6.8	1.7	6.1	-1187		STACKED
	C1	40, 1.5	204.4	26.4	2.04.4	-2792		STACKED
26+41	A3	15, 1.5	2.2	3.1	2.6	1549		BASELOG

	A4	15, 1.5	6.0	2.3	6.4	-249		STACKED
	C2	40, 1.5	28029	1457	4216.52	-2813		STACKED

1: Mobile wood debris is designed to be stable for a 10-year event

6 Floodplain Changes

The project is not located within a designated FEMA mapped floodplain.

7 Climate Resilience

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

7.1 Climate Resilience Tools

Climate resilience is evaluated at each crossing using the Climate Impacts Vulnerability Assessment Maps created by WSDOT to assess risk level of infrastructure across the state. The Juanita Creek tributary has been evaluated and determined to be a low-risk site, based on the Climate Impacts Vulnerability Assessment Maps.

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the 2080 percent increase throughout the design of the structure. Appendix J contains the information received from WDFW for this site.

7.2 Hydrology

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

In addition to using the best available science for current site hydrology, WSDOT is evaluating all structures at the 2080 predicted 100-year flow event to check for climate resiliency. See Table 16 below for a comparison of project input flows, between the 100-year and 2080 projected 100-year design storm events.

Table 16. Design Flows in Juanita Creek Tributary

Juanita Creek Tributary Flow Rate Summary			
Design Year	Flow Input upstream of NE 132nd Place (cfs)	Flow Input upstream of 117th Place crossing (cfs)	Flow Total (cfs)
100-Year	10.2	154.9	165.1
100-Year 2080	12.8	194.1	206.9
500-Year	14.0	211.8	225.8

7.3 Climate Resilience Summary

A minimum hydraulic opening of 17 feet and a minimum freeboard of 3.07, 2.37, and 2.52 feet at Culverts 1, 2, and 3 respectively, allows the channel to behave similarly through the structure as it does in the adjacent reaches, during the projected 2080 100-year flow event. This will help ensure that the structure is resilient to climate change and the system is allowed to function naturally, including the passage of sediment, debris, and water in the future.

8 Scour Analysis

A series of scour calculations were performed utilizing the results of the hydraulic analysis to consider the depth of scour potential in the streambed channel. Scour calculations were performed following the procedures outlined in *Evaluating Scour at Bridges HEC No. 18* (Arneson et al., 2012). The scour components considered in the analysis include:

1. Lateral Migration
2. Long-Term Aggradation/Degradation
3. General Scour (i.e., contraction scour)
4. Local Scour
5. Bend Scour

Finally, the total scour evaluation at each culvert structure is summarized. In addition to the three scour components above, potential lateral migration of a channel must be assessed when evaluating total scour at highway infrastructure.

8.1 Lateral Migration

The proposed channel bottom (9 feet wide) will be lined with stream bed material and the surrounding slopes within the 100-year floodplain will be reinforced with bioengineering material such as live stakes and coir logs. The areas above the 100-year floodplain will be vegetated with native shrubs. Therefore, the risk of lateral migration is minimal and countermeasures to prevent it are not needed.

8.2 Long-Term Aggradation/Degradation of the Channel Bed

To determine the predicted long-term aggradation/degradation of the channel, a sediment transport analysis was done in the SMS model. Two soil columns were created in the model to a depth of 15 feet, one for the native soil and one for the streambed. The native soil gradation was determined by analyzing and compiling the gradation data collected through the soil borings. That data was also used in the stream bed soil column for the lower 12 feet, while the upper 3 feet the proposed streambed gradation was utilized. Table 17 depicts the soil columns' gradations that were inputted into the model for both the native soil column (a) and the streambed soil column (b).

Table 17. Soil Gradation for the Native and Proposed Streambed Soil Columns

Native Soil Column (a)							
Soil Thickness (ft)	*Soil Particle Diameters (mm)*						
	D_{95}	D_{85}	D_{60}	D_{50}	D_{30}	D_{20}	D_{15}
1 foot	-	-	1.549	-	0.177	0.105	-
14 feet	-	-	4.152	-	0.237	0.123	-
Total depth of soil column: 15 feet							
Streambed Soil Column (b)							
Depth in Soil Column (ft)	*Soil Particle Diameters (mm)*						
	D_{95}	D_{85}	D_{60}	D_{50}	D_{30}	D_{20}	D_{15}
3 feet	51.562	31.496	-	15.494	-	-	7.366
12 feet	-	-	4.152	-	0.237	0.123	-
Total depth of soil column: 15 feet							

The model inputs for the sediment transport analysis are shown in Figure 32. The specific gravity of soil in the project's location is 2.65. The particle diameter thresholds were set using the Phi Scale compiled into five groups. The Meyer-Peter Müller equation was chosen as it is a widely applied bedload transport equation, and this proposed stream comprising a gravel bed. The hiding factor was kept at 0 as there were no determined causes to change it. The temperature was kept at the default 25 degrees C (77 degrees F) based on the project's location and climate. In addition, the deposition and erosion coefficients were kept at the defaults as that is what was recommended by the user's manual—stating that "the default values are recommended as we do not have enough cases which show that using values other than the default values are advantageous." Constant length was chosen for the adaptation length mode and set to the width of the channel, 9 feet, since this is best for gravel rivers according to the user's manual. For the active layer thickness the user manual stated that thickness based on the D_{90} was the preferred option for most applications, with the thickness scale between one and three.

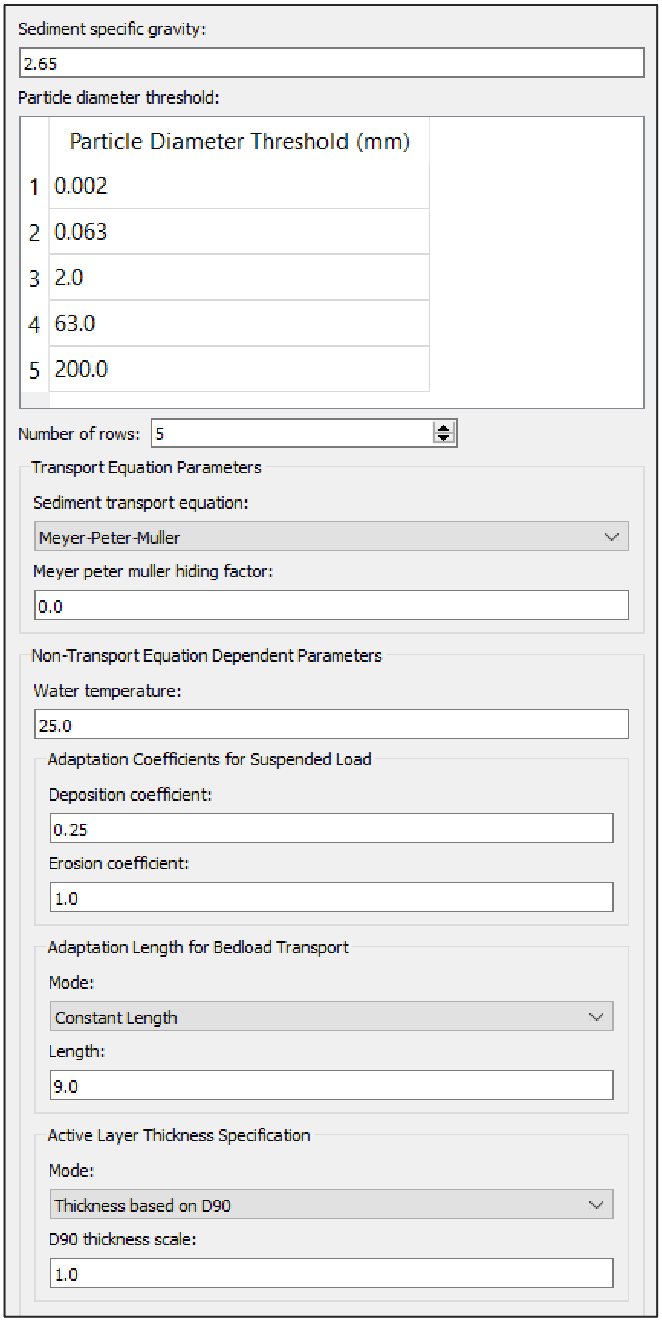

Figure 32. Sediment Transport Model Inputs

The results of the sediment transport analysis in the SMS model depicts the variation in the stream channel and floodplain from slight aggregation to low degradation. Figure 33 is the visual representation of the aggradation/degradation results from the SMS model for the 100-year flow event. Note the lower degradation to slight aggregation values found in the proximity of the LWM, demonstrating the LWM's velocity reduction potential.

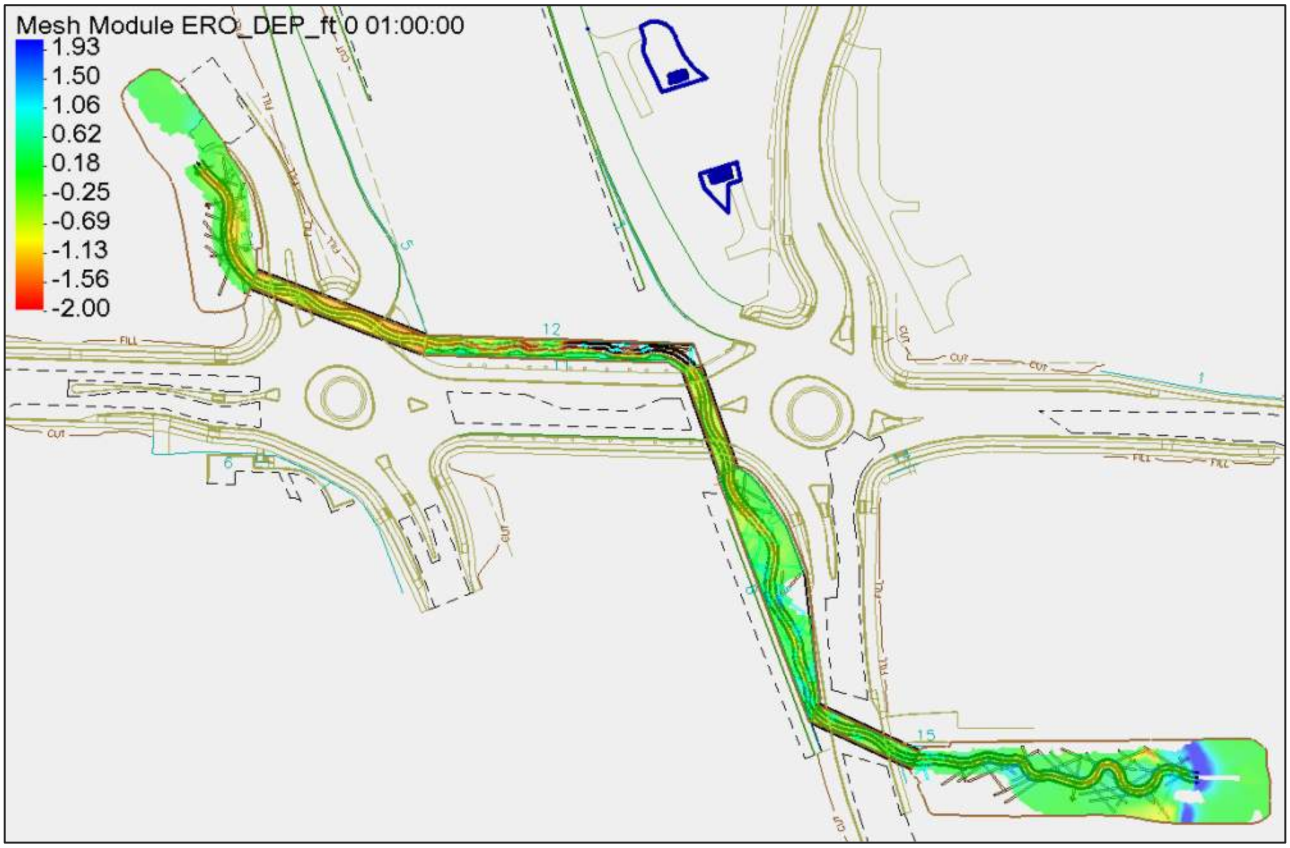

Figure 33. Aggregation/Degradation Results from the SMS Model for the 100-Year Flow Event

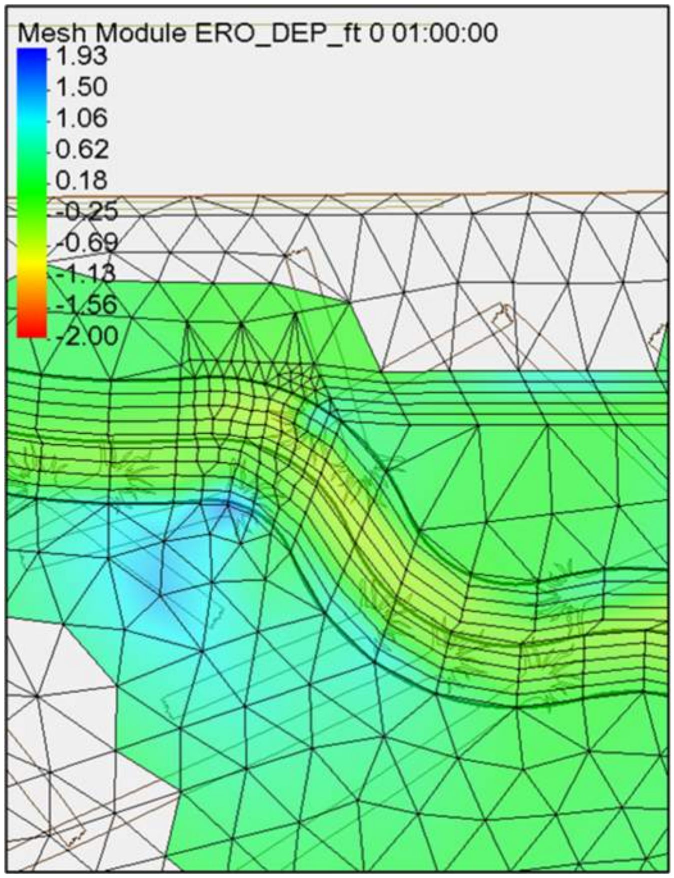

Figure 34. Section of the SMS Model Results of the Sediment Transport Analysis for the 100-Year Flow Event, Located Upstream of Culvert 3, Depicting the Erosional and Depositional Depths in the Streambed

The model results show a variation of aggradation/degradation with an overall average trend toward slight degradation for the various flow events, increasing as the event intensity increases (i.e., increased overall degradation in the 100-year flow event when compared to the 2-year flow event). The results also show that there is increased degradation in the upstream when compared to the downstream. A summary of the aggregation and degradation throughout the channel for the 2 year and 100-year flow events can be found in Table 18.

Table 18. Summary of Aggradation/Degradation Throughout the Channel

	Depth of Aggradation/Degradation (feet)	
	2-Year Flow Event	100-Year Flow Event
Culvert 1	-0.05	-0.94
Culvert 2	-0.06	-0.50
Culvert 3	-0.03	-0.14
Bend 1	-0.02	-0.58
Bend 2	-0.03	-0.67

Bend 3	-0.36	-1.15
Bend 4	0.07	-0.41
Bend 5	-0.04	-0.49
Bend 6	0.04	0.24
Bend 7	-0.04	-0.34
Bend 8	-0.01	-0.22
Bend 9	0.06	0.34
Bend 10	-0.11	-0.21
Bend 11	0.03	0.02
Bend 12	-0.02	-0.10
Bend 13	0.02	-0.10
Bend 14	0.03	-0.32
Bend 15	-0.12	-0.64
Bend 16	0.03	-0.13
Bend 17	0.25	0.10

8.3 General Scour at the Crossing Structures (i.e., contraction scour)

At each of the three proposed culverts contraction scour was calculated to determine the amount of scour in the culvert structures due to the potential for flow contraction as it enters the culverts. First a check was done directly upstream of each culvert location, per flow event analyzed, to determine if the contraction scour would be live bed or clear water so that the correct set of equations could be applied.

For each of the three culverts and for each flow event scenario analyzed—100-year, 500-year, and year 2080 predicted 100-year flow events—the critical velocity was greater than the calculated velocity in the stream bed; therefore, the HEC-18 Clear Water Contraction Scour equation was utilized for each scenario. The results of which can be found in Table 19.

Table 19. Depth of Scour Results per Culvert for the Three Flow Events Analyzed: 100-Year, 500-Year, and Year 2080 Predicted 100-Year Flow

Culverts	Depth of Contraction Scour (ft)		
	100-Year	500-Year	2080 Predicted 10-Year
Culvert 1	-1.00	-0.70	-1.07
Culvert 2	0.11	0.34	0.12
Culvert 3	0.32	0.46	0.47

Note that Culvert #1 has negative depth of scour results for the contraction scour—this indicates that no contraction scour will occur at this culvert. Since the approach stream section is confined within the 17-foot-wide section between Walls 11 and 12, prior to entering the 17-foot-wide span of Culvert 1, there is no contraction in the flow and these values validate that no contraction scour will be present. Whereas for Culverts 2 and 3 there are conditions present for contraction scour as the flow moves from a slightly larger floodplain into the respective culvert sections.

The proposed design includes retaining walls and wingwalls, thus, there are no abutments in the proposed design and abutment scour evaluation is not applicable. See Appendix G for contraction scour calculations.

8.4 Local Scour

Since there are no piers in this project, there will not be any local scour.

8.5 Bend Scour

Bend scour is not identified in the HEC-18 manual but is described in Appendix E of the Stream Habitat Restoration Guidelines (WDFW, 2012). The guidelines include three equations for calculating bend scour: Thorne, Maynord, and Wattanabe. Within the project limits, the proposed stream design includes several major and minor meander bends along the length of the channel. Based on discussions with WSDOT, Bend scour at the minor meander bends, especially within culverts, was determined to be insignificant and therefore, was not taken into consideration for design of culverts. However, there are several major bends where the open channel sections of the stream pass between proposed retaining walls. Bend scour was analyzed for these major bends, which are identified in Figure 35 below.

For this project, the Thorne method was utilized as it is most suitable for gravel-bed streams, such as the one proposed on this project. The proposed streambed has a D_{50} of 0.61 inch, which falls within the range referenced in the Stream Habitat Restoration Guidelines (WDFW, 2012) of 0.3 mm (0.012 inch) to 63 mm (2.5 inch). The other two methods are for sand-bed channels and are therefore not applicable for the proposed design.

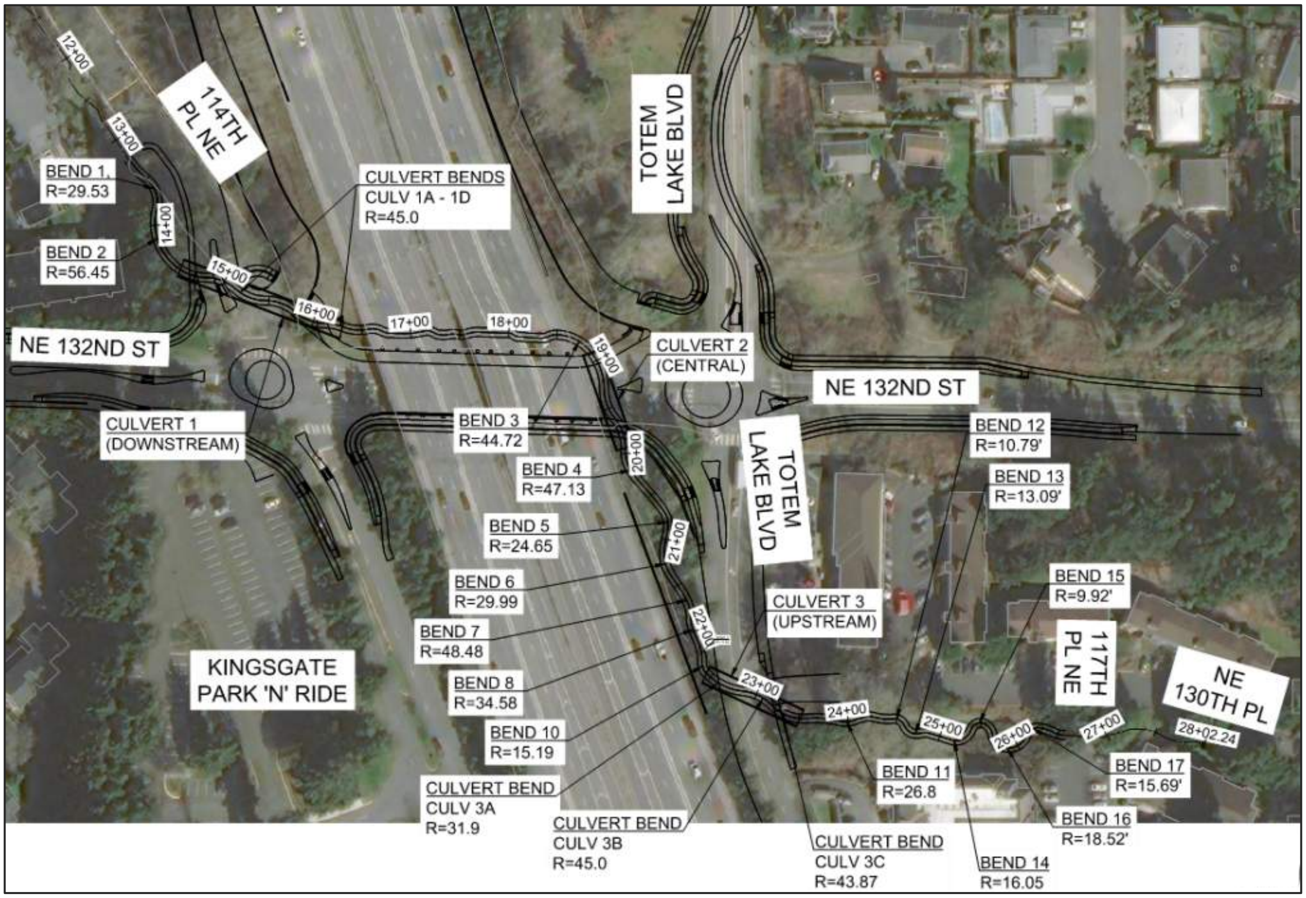

Figure 35. Location of the 17 Bends Analyzed for Bend Scour

Each of the major bends in the proposed design was analyzed for bend scour potential for the 100-year, 500-year, and the year 2080 predicted 100-year flow events. The results of this analysis can be found in Table 20. The calculated bend scour for the 17 bends ranges from depths of 1.4 feet to 4.2 feet for the 100-year flow event, with an average of 2.6 feet of scour.

Table 20. Calculated Bend Scour Depth for the 100-Year, 500-Year, and Year 2080 Predicted 100-Year Flow Events

				Depth of Scour (ft)		
Bend #	Begin STA	End STA	Radius of Curvature (ft)	100-Year	500-Year	2080 Predicted 100-Year
Bend 1	13+20	13+90	30	4.1	4.7	4.6
Bend 2	13+90	45+75	56	1.7	2.0	1.9
Bend 3	18+17	19+20	45	1.8	2.2	2.1
Bend 4	20+60	20+80	47	1.4	1.7	1.6
Bend 5	20+80	21+00	25	2.7	3.1	3.0
Bend 6	21+10	21+40	30	2.6	3.1	2.9
Bend 7	21+50	21+70	48	1.4	1.7	1.6
Bend 8	21+70	21+80	35	2.1	2.4	2.3
Bend 9	21+80	22+30	45	1.5	1.8	1.7
Bend 10	22+40	22+70	15	3.1	3.6	3.5
Bend 11	25+77	26+52	27	2.5	2.9	2.8
Bend 12	25+78	26+53	11	3.1	3.5	3.4
Bend 13	25+79	26+54	13	3.0	3.4	3.3
Bend 14	25+80	26+55	16	3.1	3.5	3.4
Bend 15	25+81	26+56	10	2.7	3.0	2.9
Bend 16	25+82	26+57	19	4.2	4.7	4.6
Bend 17	25+83	26+58	16	2.5	2.8	2.7

The proposed design employs several countermeasures to reduce scour potential within the channel such as incorporation of streambed material, bioengineering planting material across channel slopes, and the installation and placement of LWM. The streambed material, reinforced with meander bars, provides required channel stability, and prevents scouring at the bottom of the channel. The bioengineering planting materials provide channel slope stability while reducing erosion and scour potential. The LWM not only provides ecosystem habitat enhancement, but also helps to deflect stream flows, particularly around the bends, thus reducing scour potential. This is shown in Figure 36, which depicts the velocity map for the 100-year flow event.

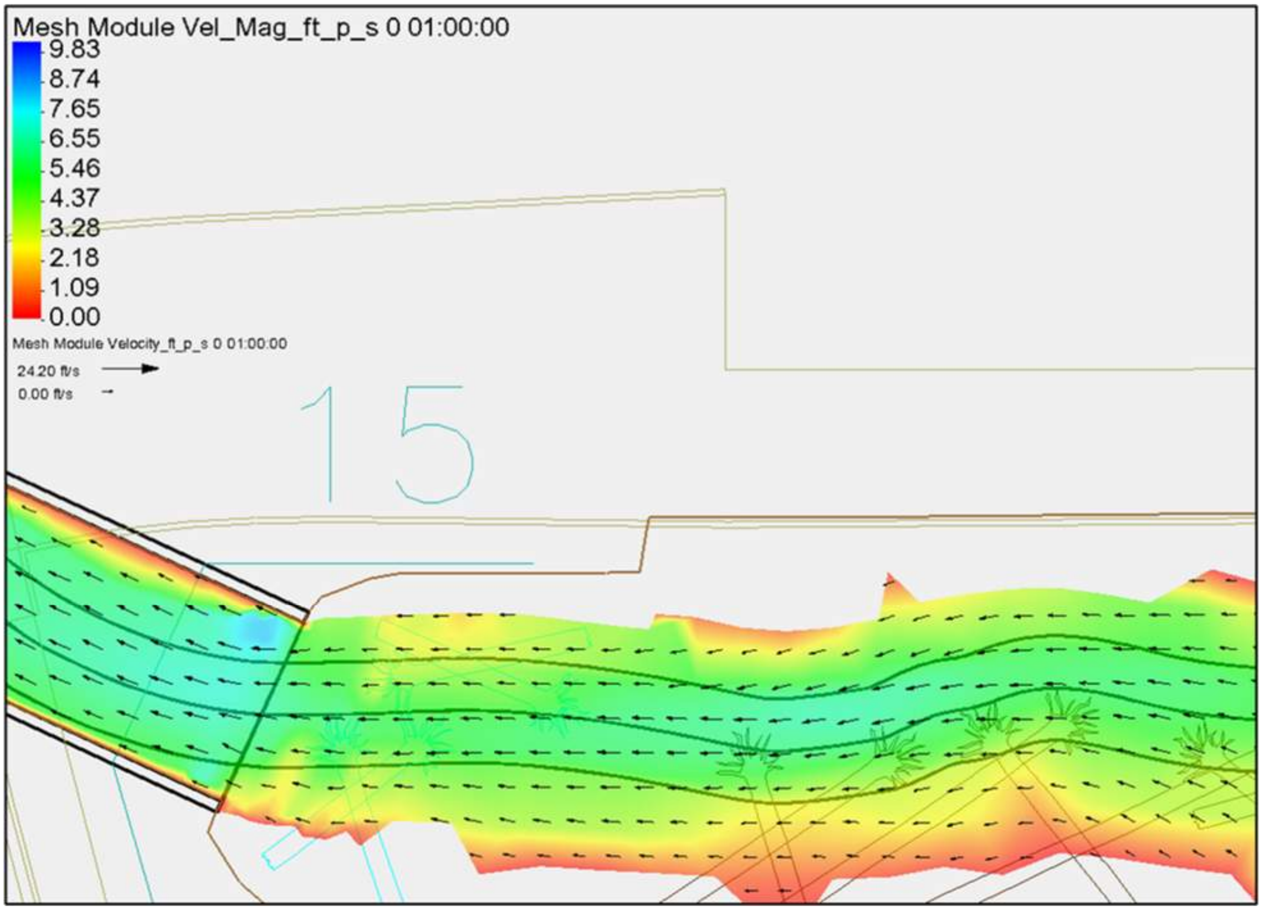

Figure 36. Section of the Velocity Map for the 100-Year Flow Event

8.6 Total Scour

Calculated total scour depths for the proposed Juanita Creek tributary structures are provided in Table 21. WSDOT's Headquarters Hydraulics Section recommends that the structure and adjacent walls be designed to account for the total scour depths to assist in providing structure stability over time. The total scour evaluation for each culvert crossing structure follows the HEC-18 guidelines as described in Chapter 7 of the WSDOT Hydraulics Manual.

The 100-year flow is used as the design event for calculating scour at each culvert. For scour evaluation, the design scour depth plus 2 feet should be deep enough to encompass the check scour depth. The check scour is calculated using the 500-year flow. This depth is used as the minimum requirement for determining the structure free zone for the culvert material depth below the channel thalweg or flow elevation.

The design includes a minimum of 3 feet of streambed material below the channel thalweg. Based on the total scour depths presented in Table 21 this material depth accommodates anticipated design scour and check scour depths. Additionally, the evaluation calculated a maximum scour depth of almost 2 feet during the projected 2080 predicted 100-year flow event, which is within the proposed 3 feet depth of streambed material.

Table 21. Scour Analysis Summary

Calculated Scour for Juanita Creek Tributary									
Scour Type (ft)	**Culvert 1**			**Culvert 2**			**Culvert 3**		
	100-Year	500-Year	2080 Predicted 100-Year	100-Year	500-Year	2080 Predicted 100-Year	100-Year	500-Year	2080 Predicted 100-Year
Lateral Migration	0	0	0	0	0	0	0	0	0
Long-Term Degradation	0.9	1.1	1.9	0.5	0.5	0.5	0.1	0.2	0.2
Contraction Scour	0	0	0	0.1	0.3	0.1	0.3	0.5	0.5
Local Scour	0	0	0	0	0	0	0	0	0
Bend Scour	0	0	0	0	0	0	0	0	0
Total Depth of Scour (ft)	0.9	1.1	1.9	0.6	0.8	0.6	0.4	0.7	0.7
Scour Elevation (NAVD88)	153.7	153.5	152.7	157.7	157.5	157.7	162.7	162.4	162.4

Summary

Table 22. Report Summary Table

Stream Crossing Category	Elements	Values	Report Location
Habitat Gain	Total Length		
Bankfull Width	Reference reach found?	N	2.8.1 Reference Reach Selection
	Design BFW		2.8.2 Channel Geometry
	Concurrence BFW		2.8.2 Channel Geometry
Channel Slope/Gradient	Existing Crossing		2.8.4 Vertical Channel Stability
	Reference Reach		2.8.2 Channel Geometry
	Proposed		4.3.2 Channel Planform and Shape
Countersink	Proposed		4.6.3 Freeboard / 8 Scour Analysis
	Added for climate resiliency		4.6.3 Freeboard / 8 Scour Analysis
Scour	Analysis		8 Scour Analysis
	Streambank protection/stabilization		8 Scour Analysis
Channel Geometry	Existing		2.8.2 Channel Geometry
	Proposed		4.3.2 Channel Planform and Shape
Channel Conditions	Dry Channel in Summer	N	2.7.2 Existing Conditions
Floodplain Continuity	FEMA mapped floodplain	N	6 Floodplain Changes
	Lateral Migration	N	2.8.5 Channel Migration
	Floodplain changes?	N	6 Floodplain Changes
Freeboard	Required Above 100 yr		4.6.3 Freeboard
	Added for climate resiliency		4.6.3 Freeboard
	Additional Recommended		4.6.3 Freeboard
Maintenance Clearance	Proposed		4.6.3 Freeboard
Substrate	Existing		2.8.3 Sediment
	Proposed		Bed Material
	Coarser than existing?	Y/N	5.1 Bed Material
Hydraulic Opening	Proposed		4.6.2 Minimum Hydraulic Opening Width and Length
	Added for climate resiliency	Y/N	4.6.2 Minimum Hydraulic Opening Width and Length
Channel Complexity	LWM for Bank Stability	Y/N	5.2 Channel Complexity
	LWM for Habitat	Y/N	5.2 Channel Complexity
	Meander Bars	#	5.2 Channel Complexity
	Boulder Clusters	#	5.2 Channel Complexity
	Coarse Bands	#	5.2 Channel Complexity
	Mobile Wood	Y/N	5.2 Channel Complexity
Crossing length	Existing		2.7.2 Existing Conditions
	Proposed		4.6.2 Minimum Hydraulic Opening Width and Length

Floodplain Utilization Ratio (FUR)	Floodprone Width		4.2 Existing Conditions Model Results
	Average FUR Upstream and DS		4.2 Existing Conditions Model Results
Hydrology/Design Flows	Existing	See Link	3 Hydrology and Peak Flow Estimates
	Climate resiliency	See Link	3 Hydrology and Peak Flow Estimates
Channel Morphology	Existing		2.8.2 Channel Geometry
	Proposed		5.2 Channel Complexity
Channel Degradation	Potential?	Range	8.2 Long-Term Aggradation/Degradation of the Channel Bed
	Allowed?	Y/N	8.2 Long-Term Aggradation/Degradation of the Channel Bed
Structure Type	Recommendation	Y/N	4.6.1 Structure Type
	Type		4.6.1 Structure Type

* This table will be updated for next submittal

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Appendices

Appendix A

Hydraulic Field Report Form

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Fish Passage and Diversion Screening Inventory Database
Report Cover Sheet

The Washington Department of Fish and Wildlife (WDFW) makes every attempt to keep these reports in sync with the fish passage data presented on the web map; however, the dynamic nature of the data and workflows associated with maintaining the Fish Passage database may result in short-term differences.

Users are encouraged to contact WDFW to discuss appropriate use of the data and how we can assist with fish passage barrier removal or inventory. Please visit the Fish Passage web site for contact information at: http://dfw.wa.gov/conservation/habitat/fish_passage/.

Disclaimer:

- WDFW makes no guarantee concerning the data's content, accuracy, completeness, or the results obtained from use of the data.
- These data are not an attempt to provide you with an official agency response as to the impacts of your project on fish and wildlife.
- WDFW makes no warranty of fitness for a particular purpose, no representation as to the quality of any data, and assumes no liability for the data represented here.
- The fish and wildlife data may not represent exhaustive inventories, but are compilations of observations from field biologists that are updated periodically as knowledge improves.
- It is important to note that fish passage features, habitats, or species may occur on the ground in areas not currently known to WDFW biologists, or in areas for which comprehensive surveys have not been conducted.
- All data presented here represent a snapshot observation of conditions in a dynamic environment that are subject to change.
- Unauthorized attempts to alter or modify the contents of these reports are strictly prohibited.

Other Notes Regarding Fish Passage Data:

- The Fish Passage and Diversion Screening Inventory (FPDSI) database often uses default values such as '-99.99' or -999 to represent null values.
- EXIF data presented with Image Reports may be erroneous due to camera battery failures and resetting of camera clock functions.
- When conducting projects or planning for fish and wildlife, please consider using additional information gathered from field investigations and consultations with WDFW or other professional biologists.
- Erroneous data may be reported directly to Fish Passage staff through the use of the Washington State Fish Passage web application at: http://apps.wdfw.wa.gov/fishpassage/.

WDFW Fish Passage and Diversion Screening Inventory Database

Site Description Report

Site ID 992654 **Project** WSDOT

Geographic Coordinates

Latitude (WGS 84):	47.71853
Longitude (WGS 84):	-122.18857
East (HARN 83)	1,224,740.6
North (HARN 83)	874,326.5

Waterbody

Stream:	unnamed
Tributary To:	Juanita Cr
WRIA:	08.0238
River Mile:	-999.99
Fish Use Potential:	Yes
FUP Criteria:	Physical

General Location

Road Name:	I-405
Mile Post:	20.95
County:	King
WDFW Region:	4

Owner

Type:	State
Name:	Washington State Department of Transportation

PI Species

- [ ] Sockeye
- [ ] Chinook
- [x] Sea Run Cutthroat
- [ ] Pink
- [x] Coho
- [x] Resident Trout
- [ ] Chum
- [ ] Steelhead
- [ ] Bull Trout

Associated Features

- [x] Culvert
- [ ] Dam
- [ ] Natural Barrier
- [ ] Diversion
- [ ] Non-Culvert Xing
- [ ] Other
- [ ] Fishway

Location/Directions

DS end located at the corner of 132nd St and 114th. US end located at 131st off of Totem Lake Drive. (2/22/07)

Site Comments

Print Date: 5/23/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Level A Culvert Assessment Report

Site ID: **992654**

Latitude: **47.71853** Stream: **unnamed** WRIA: **08.0238**

Longitude: **-122.18857** Tributary To: **Juanita Cr** Fish Use Potential: **Yes**

Data Source WDFW

Field Crew: Holowatz;Phinney;Wilson Review Date: 3/31/2016

Culvert Details / **Level A Parameters**

ID	Shape	Material	Span	Rise	Length	WDIC	Apron	WSDrop	Location	Countersunk	Backwater	Slope (%)
1.1	RND	CST	1.37	1.37	257.00	0.75	DS	0.00		No	0	2.17

All dimensions in meters

Channel Description

Toe Width (m): 0.9

Average Width (m): 2.90

Culvert/Stream Width Ratio: 0.47

Plunge Pool

Length (m): 0.00

Max Depth (m): 0.00

OHW Width (m): 0.00

Road

Fill Depth (m): 5.00

Assessment Results

Barrier: Yes Passability (%): 0 Method: Level A

Reason: Slope Fishway Present: No Recheck:

Comments

US Span/Rise 1.37m, DS Span/Rise 2.51m

Potential Habitat Gain

Survey Type: RSFS Spawning (sq m): 245 Length (m): 1,025

Significant Reach: Yes Rearing (sq m): 4,061 **PI Total** 11.98

Print Date: 5/23/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Habitat Survey Summary Report

Site ID:	**992654**				
Latitude:	**47.71853**	Longitude:	**-122.18857**	WRIA:	**08.0238**
Stream:	**unnamed**	Tributary To:	**Juanita Cr**	PI Total:	**11.98**

Survey Type RSFS

Spreadsheet File(s):

992654.xls.

Downstream Survey

Date: 8/29/2012 Crew: Gatchell; Stilwater Length (m): 835

Downstream Comments:

Downstream habitat is mostly greenbelt behind homes and apartments. Stream turns to wetland then becomes ponded at a substantial barrier. Fish observed downstream of barrier. Some areas of decent gravels, lots of invasive species in riparian habitat.

Upstream Survey

Date: 8/29/2012 Crew: Gatchell; Stilwater Length (m): 1,025

Upstream Comments:

Many areas where stream banks have been landscaped as well as unmaintained areas of dense blackberry. Several stormwater retention ponds within stream channel.

Potential Habitat Gain

Lineal (m): 1,025

Spawning Area (sq m): 245

Rearing Area (sq m): 4,061

Distribution
- (●) Anadromous
- ( ) Resident Only
- ( ) Unknown

Gain Direction (Resident Only)

Potential Species Benefit

☐ Sockeye / Kokanee	☐ Chinook	☑ Searun Cutthroat
☐ Pink	☑ Coho	☑ Resident Trout
☐ Chum	☐ Steelhead	☐ Bull Trout

Print Date: 5/23/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Barrier Priority Index Report

Site ID: **992654**

Stream	unnamed	**Trib To**	Juanita Cr	**WRIA**	08.0238
Habitat (H) Estimatiom Method	RSFS				

	B	H	M	D	C	Species PI
Sockeye			2		1	0.00
Pink			2		1	0.00
Chum			2		1	0.00
Coho	1	3,629	2	1	1	4.36
Chinook			2		1	0.00
Steelhead			2		1	0.00
Searun Cutthroat	1	3,629	2	1	1	4.05
Resident Trout	1	4,061	1	1	1	3.57
Dolly/Bull Trout					1	0.00
					TOTAL PI	**11.98**

B = proportion of fish passage improvement (1, 0.67, 0.33).

H = potential habitat gain (square meters), spawning habitat for sockeye, pink and chum, rearing habitat for the rest.

M= mobility modifier (anadromous = 2, resident = 1).

D = stock condition modifier (critical = 3, depressed = 2, not 2 or 3 = 1).

C= repair cost modifier (<$100K = 3, $100K - $500K = 2, >$500K = 1).

Print Date: 5/23/2016

WDFW Fish Passage and Diversion Screening Inventory Database
Image Report - Active

Site ID:	**992654**				
Latitude:	**47.71853**	Stream:	**unnamed**	WRIA:	**08.0238**
Longitude:	**-122.18857**	Tributary To:	**Juanita Cr**	Fish Use Potential:	**Yes**

Associated Features

☑ Culvert	☐ Dam	☐ Natural Barrier	☐ Diversion
☐ Non-Culvert Xing	☐ Other	☐ Fishway	

Image Name: 992654_1.JPG, Date/Time: 03/31/2016 13:50

Image Name: 992654_2.JPG, Date/Time: 03/31/2016 13:39

Print Date: 5/23/2016

Fish Passage and Diversion Screening Inventory Database
Report Cover Sheet

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WDFW Fish Passage and Diversion Screening Inventory Database

Site Description Report

Site ID 998979 **Project** WSDOT

Geographic Coordinates

Latitude (WGS 84):	47.723639245
Longitude (WGS 84):	-122.190368206
East (HARN 83)	1,224,337.9
North (HARN 83)	876,199.5

Waterbody

Stream:	unnamed
Tributary To:	Juanita Cr
WRIA:	08
River Mile:	-999.99
Fish Use Potential:	No
FUP Criteria:	Physical

General Location

Road Name:	I-405
Mile Post:	21.29
County:	King
WDFW Region:	4

Owner

Type:	State
Name:	Washington State Department of Transportation

PI Species

- ☐ Sockeye
- ☐ Chinook
- ☐ Sea Run Cutthroat
- ☐ Pink
- ☐ Coho
- ☐ Resident Trout
- ☐ Chum
- ☐ Steelhead
- ☐ Bull Trout

Associated Features

- ☑ Culvert
- ☐ Dam
- ☐ Natural Barrier
- ☐ Diversion
- ☐ Non-Culvert Xing
- ☐ Other
- ☐ Fishway

Location/Directions

Site Comments

Culvert was extended and connected to former WSDOT site 998980 under NB lanes.
(998980 was removed when these sites were merged)

Print Date: 8/8/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Level A Culvert Assessment Report

Site ID:	**998979**				
Latitude:	**47.723639245**	Stream:	**unnamed**	WRIA:	**08**
Longitude:	**-122.190368206**	Tributary To:	**Juanita Cr**	Fish Use Potential:	**No**

Data Source WDFW

Field Crew: Holowatz;Phinney;Wilson   Review Date: 3/30/2016

Culvert Details / **Level A Parameters**

ID	Shape	Material	Span	Rise	Length	WDIC	Apron	WSDrop	Location	Countersunk	Backwater	Slope (%)
1.1	RND	CST	0.76	0.76	-999.90	-99.99	NO	-99.99		Unknown		-99.99

All dimensions in meters

Channel Description

Toe Width (m):	-99.99
Average Width (m):	-99.99
Culvert/Stream Width Ratio:	-99.99

Plunge Pool

Length (m):	-999.99
Max Depth (m):	-99.99
OHW Width (m):	-999.99

Road

Fill Depth (m):	-999.90

Assessment Results

Barrier:	N/A	Passability (%):	N/A	Method:	N/A
Reason:	N/A	Fishway Present:	No	Recheck:	

Comments

Potential Habitat Gain

Survey Type:	TD	Spawning (sq m):	-999	Length (m):	-999
Significant Reach:	N/A	Rearing (sq m):	-999	**PI Total**	

Print Date: 8/8/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Habitat Survey Summary Report

Site ID: **998979**

Latitude: **47.723639245** Longitude: **-122.190368206** WRIA: **08**

Stream: **unnamed** Tributary To: **Juanita Cr** PI Total:

Survey Type TD

Spreadsheet File(s):

Downstream Survey

Date: 4/9/2007 Crew: Hird;Dhundale Length (m): -999

Downstream Comments:

Site is about 40m downstream of WSDOT site 998980 above which no channel was located.

Upstream Survey

Date: 4/9/2007 Crew: Hird;Dhundale Length (m): 40

Upstream Comments:

Potential Habitat Gain

Lineal (m): -999

Spawning Area (sq m): -999

Rearing Area (sq m): -999

Distribution

- Anadromous
- Resident Only
- Unknown

Gain Direction (Resident Only)

Potential Species Benefit

- ☐ Sockeye / Kokanee
- ☐ Chinook
- ☐ Searun Cutthroat
- ☐ Pink
- ☐ Coho
- ☐ Resident Trout
- ☐ Chum
- ☐ Steelhead
- ☐ Bull Trout

Print Date: 8/8/2016

Fish Passage and Diversion Screening Inventory Database
Report Cover Sheet

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WDFW Fish Passage and Diversion Screening Inventory Database

Site Description Report

Site ID 998981 **Project** WSDOT

Geographic Coordinates

Latitude (WGS 84):	47.72556628
Longitude (WGS 84):	-122.189448439
East (HARN 83)	1,224,579.3
North (HARN 83)	876,897.5

Waterbody

Stream:	unnamed
Tributary To:	Juanita Cr
WRIA:	08
River Mile:	-999.99
Fish Use Potential:	No
FUP Criteria:	Physical

General Location

Road Name:	I-405; NB
Mile Post:	21.42
County:	King
WDFW Region:	4

Owner

Type:	State
Name:	Washington State Department of Transportation

PI Species

- ☐ Sockeye
- ☐ Chinook
- ☐ Sea Run Cutthroat
- ☐ Pink
- ☐ Coho
- ☐ Resident Trout
- ☐ Chum
- ☐ Steelhead
- ☐ Bull Trout

Associated Features

- ☑ Culvert
- ☐ Dam
- ☐ Natural Barrier
- ☐ Diversion
- ☐ Non-Culvert Xing
- ☐ Other
- ☐ Fishway

Location/Directions

Site Comments

OHW < 0.61m.

Print Date: 10/3/2016

WDFW Fish Passage and Diversion Screening Inventory Database

Level A Culvert Assessment Report

Site ID: **998981**

Latitude: **47.72556628** Stream: **unnamed** WRIA: **08**

Longitude: **-122.189448439** Tributary To: **Juanita Cr** Fish Use Potential: **No**

Data Source WDFW

Field Crew: Holowatz;Phinney;Wilson Review Date: 3/30/2016

Culvert Details / **Level A Parameters**

ID	Shape	Material	Span	Rise	Length	WDIC	Apron	WSDrop	Location	Countersunk	Backwater	Slope (%)
1.1	RND	CST	0.76	0.76	-999.90	-99.99		-99.99		Unknown		-99.99

All dimensions in meters

Channel Description

Toe Width (m): -99.99

Average Width (m): -99.99

Culvert/Stream Width Ratio: -99.99

Plunge Pool

Length (m): -999.99

Max Depth (m): -99.99

OHW Width (m): -999.99

Road

Fill Depth (m): -999.90

Assessment Results

Barrier: N/A Passability (%): N/A Method: N/A

Reason: N/A Fishway Present: No Recheck:

Comments

Potential Habitat Gain

Survey Type: Spawning (sq m): Length (m):

Significant Reach: N/A Rearing (sq m): **PI Total**

Print Date: 10/3/2016

WDFW - SSHEAR
PHYSICAL HABITAT SURVEY - INPUT FILE (Ver. 4c)

Survey Method :	RSFS	Date:	8/29/2012
Stream Name:	unnamed	Observer(s):	Gatchell Stilwater
Tributary To:	Juanita Cr	Section surveyed:	From confluence with Juanita to EOPFU.
WRIA #:	08.0238		
Sample Frequency:	R/60	Filename:	992654.xls

REACH #1 Begin(m): 0 End(m): 196 Reach Length(m): 196

Quality		Position:	US of target barrier 992654.
spawning:	0.66	Instream Cover:	Low
rearing:	0.66	Juv. Abundance:	None observed.
		Canopy:	20%
T (C):		Limiting Factors:	Excess fines, gravels embedded in substrate, low instream cover.
		Barrier SiteID:	932413, 932414
T @trib:		Total culverted length:	80 m Est. Drainage Area: 0.82 mi

REACH #1 FIELD DATA

FLOW				
Time 1	Time 2	Time 3	Average	
			#DIV/0	
D(m)	L(m)	W(m)	Flow	
			#DIV/0	cms
			#DIV/0	cfs

Species Expected to Benefit (x =Yes, blank = No)

Sockeye	Chum	Pink		
Coho	SR Cutthroat	Chinook	Steelhead	
x	x			
Res CT/RB	Bull			
x				
Brook	Brown			

Spring influences are (see below): 1
(absent-0, slight-1, mod.-2, pronounced-3)
1.) relatively regular, rectangular cross-section, minor variations in depth
2.) Poorly defined bars and thalweg / very low, flat floodplain
3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks

Reg. Constant (for 60-d low flow calc.): 1.04
Olympic/Coastal = 0.49
Cascade/E. Puget = 1.04
Columbia/E. WA=0.12
Northern/NE Mts.=0.097

REACH #1 HABITAT MEASUREMENT

Type	L	W	OHW	D	Grad.	B	R	G	S	SUM BRGS
pl	3.7	0.8	1.1	0.12	0.01	0	0	20	80	100
rf	8.1	0.8	1.4	0.03		0	0	40	60	100
pl	3.3	0.8	1.3	0.13		0	5	25	70	100
rf	5	0.6	1.4	0.05		0	0	20	80	100
pl	10.9									0
rf	25.9									0
pl	3.1									0
										0
										0
										0
										0
										0
										0
										0
										0
										0

	samp L				Grad ave	B ave	R	G ave	S ave
	60	W	OHW	D	0.01	0	1	26	73
	pl L	pl ave	pl ave	pl ave		plB ave	plR ave	plG ave	plS ave
	21	0.8	1.2	0.13		0	2.5	22.5	75
	rf L	rf ave	rf ave	rf ave		rfB ave	rfR ave	rfG ave	rfS ave
	39	0.70	1.4	0.04		0	0	30	70
	rp L	rp ave	rp ave	rp ave		rpB ave	rpR ave	rpG ave	rpS ave
	-	-	-	-		-	-	-	-
	pd L	pd ave	pd ave	pd ave		pdB ave	pdR ave	pdG ave	pdS ave
	-	-	-	-		-	-	-	-
						0	1.25	26.25	72.5
						0	2.5	52.5	145

L	W	OHW	D	B	R	G	S
Type	Type	Type	Type	Type	Type	Type	Type
pl	pl	pl	pl	pl	pl	pl	pl
Type	Type	Type	Type	Type	Type	Type	Type
rf	rf	rf	rf	rf	rf	rf	rf
Type	Type	Type	Type	Type	Type	Type	Type
rp	rp	rp	rp	rp	rp	rp	rp
Type	Type	Type	Type	Type	Type	Type	Type
pd	pd	pd	pd	pd	pd	pd	pd

REACH #2 Begin(m): 196 End(m): 222 Reach Length(m): 26

Quality		Position:	Upstream of culvert a site 932415.
spawning:	0	Instream Cover:	Low
rearing:	1	Juv. Abundance:	None observed.
		Canopy:	45%
T (C):		Limiting Factors:	
		Barrier SiteID:	
T @trib:		Total culverted length:	0 Est. Drainage Area: 0.75 mi

REACH #2 FIELD DATA

FLOW				
Time 1	Time 2	Time 3	Average	
			#DIV/0	
D(m)	L(m)	W(m)	Flow	
			#DIV/0	cms
			#DIV/0	cfs

Species Expected to Benefit (x =Yes, blank = No)

Sockeye	Chum	Pink		
Coho	SR Cutthroat	Chinook	Steelhead	
x	x			
Res CT/RB	Bull			
x				
Brook	Brown			

Spring influences are (see below): 1
(absent-0, slight-1, mod.-2, pronounced-3)
1.) relatively regular, rectangular cross-section, minor variations in depth
2.) Poorly defined bars and thalweg / very low, flat floodplain
3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks

Reg. Constant (for 60-d low flow calc.): 1.04
Olympic/Coastal = 0.49
Cascade/E. Puget = 1.04
Columbia/E. WA=0.12
Northern/NE Mts.=0.097

REACH #2 HABITAT MEASUREMENT

Type	L	W	OHW	D	Grad.	B	R	G	S	SUM BRGS
pd	26	22	22	0.5	0.001	0	0	0	100	100
										0
										0
										0
										0
										0
										0

	samp L				Grad ave	B ave	R	G ave	S ave
	26	W	OHW	D	0.00	0	0	0	100
	pl L	pl ave	pl ave	pl ave		plB ave	plR ave	plG ave	plS ave
	-	-	-	-		-	-	-	-
	rf L	rf ave	rf ave	rf ave		rfB ave	rfR ave	rfG ave	rfS ave
	-	-	-	-		-	-	-	-
	rp L	rp ave	rp ave	rp ave		rpB ave	rpR ave	rpG ave	rpS ave
	-	-	-	-		-	-	-	-
	pd L	pd ave	pd ave	pd ave		pdB ave	pdR ave	pdG ave	pdS ave
	26	22	22	0.50		0	0	0	100

L	W	OHW	D	B	R	G	S
Type	Type	Type	Type	Type	Type	Type	Type
pl	pl	pl	pl	pl	pl	pl	pl
Type	Type	Type	Type	Type	Type	Type	Type
rf	rf	rf	rf	rf	rf	rf	rf
Type	Type	Type	Type	Type	Type	Type	Type
rp	rp	rp	rp	rp	rp	rp	rp
Type	Type	Type	Type	Type	Type	Type	Type
pd	pd	pd	pd	pd	pd	pd	pd

REACH #3	Begin(m):	222	End(m):	487	Reach Length(m): 265
Quality	Position:	Upstream of ponded reach.			
spawning: 0.66	Instream Cover:	Low			
rearing: 0.66	Juv. Abundance:	None observed.			
	Canopy:	60%			
T (C):	Limiting Factors:	Impacted gravels, pollution.			
	Barrier SiteID:	932415, 932416, 932417			
T @trib:	Total culverted length:	55.1 m	Est. Drainage Area:	0.74 mi	

REACH #3
FIELD DATA

FLOW

Time 1	Time 2	Time 3	Average	
			#DIV/0	
D(m)	L(m)	W(m)	Flow	
			#DIV/0	cms
			#DIV/0	cfs

Species Expected to Benefit (x =Yes, blank = No)

Sockeye	Chum	Pink		
Coho	SR Cutthroat	Chinook	Steelhead	
x	x			
Res CT/RB	Bull			
x				
Brook	Brown			

Spring influences are (see below): 1

(absent-0, slight-1, mod.-2, pronounced-3)

1.) relatively regular, rectangular cross-section, minor variations in depth
2.) Poorly defined bars and thalweg / very low, flat floodplain
3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks

Reg. Constant (for 60-d low flow calc.): 1.04

Olympic/Coastal = 0.49
Cascade/E. Puget = 1.04
Columbia/E. WA=0.12
Northern/NE Mts.=0.097

REACH #3 HABITAT MEASUREMENT

Type	L	W	OHW	D	Grad.	B	R	G	S	SUM BRGS
rf	3.2	0.9	1.1	0.05	0.02	0	10	50	40	100
pl	15	1.2	1.3	0.16		10	10	40	40	100
rf	3.9	2	2.3	0.06		30	10	30	30	100
pl	6.4	2.2	2.2	0.3		30	0	20	50	100
rf	18.2									0
pl	14									0
rf	3.2									0
										0
										0
										0
										0
										0
										0
										0
										0
										0

	samp L				Grad ave	B ave	R	G ave	S ave
	63.9	W	OHW	D	0.02	18	8	35	40
	pl L	pl ave	pl ave	pl ave		plB ave	plR ave	plG ave	plS ave
	35.4	1.7	1.75	0.23		20	5	30	45
	rf L	rf ave	rf ave	rf ave		rfB ave	rfR ave	rfG ave	rfS ave
	28.5	1.45	1.7	0.06		15	10	40	35
	rp L	rp ave	rp ave	rp ave		rpB ave	rpR ave	rpG ave	rpS ave
	-	-	-	-		-	-	-	-
	pd L	pd ave	pd ave	pd ave		pdB ave	pdR ave	pdG ave	pdS ave
	-	-	-	-		-	-	-	-

L	W	OHW	D	B	R	G	S
Type	Type	Type	Type	Type	Type	Type	Type
pl	pl	pl	pl	pl	pl	pl	pl
Type	Type	Type	Type	Type	Type	Type	Type
rf	rf	rf	rf	rf	rf	rf	rf
Type	Type	Type	Type	Type	Type	Type	Type
rp	rp	rp	rp	rp	rp	rp	rp
Type	Type	Type	Type	Type	Type	Type	Type
pd	pd	pd	pd	pd	pd	pd	pd

REACH #4	Begin(m):	487	End(m):	571	Reach Length(m): 84
Quality	Position:	Upstream of culvert at site 932419.			
spawning: 0	Instream Cover:	Low			
rearing: 1	Juv. Abundance:	None observed.			

		Canopy:		30%					
T (C):		Limiting Factors:							
		Barrier SiteID:							
T @trib:		Total culverted length:		0	m	Est. Drainage Area:		0.68	mi

REACH #4
FIELD DATA

FLOW					Species Expected to Benefit (x =Yes, blank = No)			
					Sockeye	Chum	Pink	
Time 1	Time 2	Time 3	Average		Coho	SR Cutthroat	Chinook	Steelhead
			#DIV/0		x	x		
D(m)	L(m)	W(m)	Flow		Res CT/RB	Bull		
			#DIV/0	cms	x			
			#DIV/0	cfs	Brook	Brown		

Spring influences are (see below): 1 — Reg. Constant (for 60-d low flow calc.): 1.04

(absent-0, slight-1, mod.-2, pronounced-3)

1.) relatively regular, rectangular cross-section, minor variations in depth — *Olympic/Coastal = 0.49*

2.) Poorly defined bars and thalweg / very low, flat floodplain — *Cascade/E. Puget = 1.04*

3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks — *Columbia/E. WA=0.12*; *Northern/NE Mts.=0.097*

REACH #4 HABITAT MEASUREMENT

Type	L	W	OHW	D	Grad.	B	R	G	S	SUM BRGS
pd	84	36	40	1	0.001	0	0	0	100	100
										0
										0
										0
										0
										0
										0
										0
										0
										0
										0

	samp L				Grad ave	B ave	R	G ave	S ave
	84	W	OHW	D	0.00	0	0	0	100
	pl L	pl ave	pl ave	pl ave		plB ave	plR ave	plG ave	plS ave
	-	-	-	-		-	-	-	-
	rf L	rfave	rf ave	rf ave		rfB ave	rfR ave	rfG ave	rfS ave
	-	-	-	-		-	-	-	-
	rp L	rp ave	rp ave	rp ave		rpB ave	rpR ave	rpG ave	rpS ave
	-	-	-	-		-	-	-	-
	pd L	pd ave	pd ave	pd ave		pdB ave	pdR ave	pdG ave	pdS ave
	84	36	40	1.00		0	0	0	100

L	W	OHW	D	B	R	G	S
Type	Type	Type	Type	Type	Type	Type	Type
pl	pl	pl	pl	pl	pl	pl	pl
Type	Type	Type	Type	Type	Type	Type	Type
rf	rf	rf	rf	rf	rf	rf	rf
Type	Type	Type	Type	Type	Type	Type	Type
rp	rp	rp	rp	rp	rp	rp	rp
Type	Type	Type	Type	Type	Type	Type	Type
pd	pd	pd	pd	pd	pd	pd	pd

REACH #5	Begin(m):	571	End(m):	1025	Reach Length(m):	454		
Quality	Position:	Upstream of ponded reach 3.						
spawning:	0.66	Instream Cover:	Low					
rearing:	0.66	Juv. Abundance:	None observed.					
		Canopy:	40%					
T (C):		Limiting Factors:	Impacted gravels.					
		Barrier SiteID:	932417, 932418					
T @trib:		Total culverted length:	118.3	m	Est. Drainage Area:	0.61	mi	

REACH #5
FIELD DATA

FLOW					Species Expected to Benefit (x =Yes, blank = No)			
					Sockeye	Chum	Pink	
Time 1	Time 2	Time 3	Average		Coho	SR Cutthroat	Chinook	Steelhead
			#DIV/0		x	x		
D(m)	L(m)	W(m)	Flow		Res CT/RB	Bull		
			#DIV/0	cms	x			
			#DIV/0	cfs	Brook	Brown		

Spring influences are (see below): 1 — Reg. Constant (for 60-d low flow calc.): 1.04

(absent-0, slight-1, mod.-2, pronounced-3)

1.) relatively regular, rectangular cross-section, minor variations in depth — *Olympic/Coastal = 0.49*

2.) Poorly defined bars and thalweg / very low, flat floodplain — *Cascade/E. Puget = 1.04*

3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks — *Columbia/E. WA=0.12*; *Northern/NE Mts.=0.097*

REACH #5 HABITAT MEASUREMENT

Type	L	W	OHW	D	Grad.	B	R	G	S	SUM BRGS
rf	5.5	0.6	1.6	0.1	0.02	0	0	50	50	100
pl	4.6	0.7	1	0.22		0	10	50	40	100
rf	1.5	1.1	1.2	0.09		0	0	50	50	100
pl	15.8	1	1.1	0.23		0	10	50	40	100
rf	1.7									0
pl	8.4									0
rf	5.1									0
pl	2.6									0
rf	14.8									0
										0
										0
										0
										0
										0
										0

	samp L				Grad ave	B ave	R	G ave	S ave
	60	W	OHW	D	0.02	0	5	50	45
	pl L	pl ave	pl ave	pl ave		plB ave	plR ave	plG ave	plS ave
	31.4	0.85	1.05	0.23		0	10	50	40
	rf L	rf ave	rf ave	rf ave		rfB ave	rfR ave	rfG ave	rfS ave
	28.6	0.85	1.4	0.10		0	0	50	50
	rp L	rp ave	rp ave	rp ave		rpB ave	rpR ave	rpG ave	rpS ave
	-	-	-	-		-	-	-	-
	pd L	pd ave	pd ave	pd ave		pdB ave	pdR ave	pdG ave	pdS ave
	-	-	-	-		-	-	-	-

0							
L	W	OHW	D	B	R	G	S
Type	Type	Type	Type	Type	Type	Type	Type
pl	pl	pl	pl	pl	pl	pl	pl
Type	Type	Type	Type	Type	Type	Type	Type
rf	rf	rf	rf	rf	rf	rf	rf
Type	Type	Type	Type	Type	Type	Type	Type
rp	rp	rp	rp	rp	rp	rp	rp
Type	Type	Type	Type	Type	Type	Type	Type
pd	pd	pd	pd	pd	pd	pd	pd

WDF&W - SSHEAR

PHYSICAL SURVEY OF POTENTIAL HABITAT (Ver. 4c)

Stream Name:	unnamed	**Date:**	8/29/2012
Tributary To:	Juanita Cr	**Observer(s):**	Gatchell; Stilwater
WRIA #:	08.0238	**Section surveyed:**	From confluence with Juanita to EOPFU.
Sample Frequency:	R/60		
Survey Method:	RSFS	**Filename:**	992654.xls

Summary of Information - Total Stream Length

Total Length Surveyed:	1025.00 m	Tot. Length Culverted:	253.40 m
Total Length Sampled:	293.90 m	Percent of Stream Length	
Percent Sampled:	28.67 %	Culverted:	24.72 %

Measured Pool Area:	379.49 m²
Measured Riffle Area	324.54 m²
Measured Rapid Area:	0.00 m²
Measured Pond Area:	3596.00 m²
Total Measured Stream Area:	**4300.03 m²**

Total Spawning Area:	**245.25 m²**
Total Rearing Area:	**4060.66 m²**

POOL : RIFFLE : RAPID : POND RATIO (%)

Pool= 8.83 Riffle= 7.55 Rapid= 0.00 Pond= 83.63

PRODUCTION AREA CALCULATIONS

	Sockeye	Chum	Pink	Coho	SR Cutthroa	Chinook	Steelhead	Res CT/RB	Bull	Brook	Brown
Reach 1	0.00	0.00	0.00	56.27	56.27	0.00	0.00	56.27	0.00	0.00	0.00
Reach 2	0.00	0.00	0.00	572.00	572.00	0.00	0.00	572.00	0.00	0.00	0.00
Reach 3	0.00	0.00	0.00	220.06	220.06	0.00	0.00	220.06	0.00	0.00	0.00
Reach 4	0.00	0.00	0.00	3024.00	3024.00	0.00	0.00	3024.00	0.00	0.00	0.00
Reach 5	0.00	0.00	0.00	188.33	188.33	0.00	0.00	188.33	0.00	0.00	0.00
Reach 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total area*	0.00	0.00	0.00	4060.66	4060.66	0.00	0.00	4060.66	0.00	0.00	0.00

** Spawning habitat used for sockeye, chum and pink, rearing used for all other species.*

ADJUSTED PRODUCTION AREAS

	Sockeye	Chum	Pink	Coho	SR Cutthroa	Chinook	Steelhead	Res CT/RB	Bull	Brook	Brown
Reach 1	0.00	0.00	0.00	50.29	50.29	0.00	0.00	56.27	0.00	0.00	0.00
Reach 2	0.00	0.00	0.00	511.20	511.20	0.00	0.00	572.00	0.00	0.00	0.00
Reach 3	0.00	0.00	0.00	196.67	196.67	0.00	0.00	220.06	0.00	0.00	0.00
Reach 4	0.00	0.00	0.00	2702.55	2702.55	0.00	0.00	3024.00	0.00	0.00	0.00
Reach 5	0.00	0.00	0.00	168.31	168.31	0.00	0.00	188.33	0.00	0.00	0.00
Reach 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reach 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total area*	0.00	0.00	0.00	3629.01	3629.01	0.00	0.00	4060.66	0.00	0.00	0.00

Summary of Information - Reach #1

Starting Position:	US of target barrier 992654.	Length of Reach Culve	80.00 m
Length of Reach:	196.00 m	Percent of Reach Culv	40.8 %
Length Sampled:	60.00 m	Estimated drainage are	0.82 mi²

Canopy: 0.2
Instream Cover: Low
Juv. Abundance: None observed.
Limiting Factors: Excess fines, gravels embedded in substrate, low instream cover.
Barrier Site ID: 932413, 932414

Spring influences are (see below):	1	Reg. Constant (for 60-d low flow c	1.04
(absent-0, slight-1, mod.-2, pronounced-3)		*Olympic/Coastal = 0.49*	
1.) relatively regular, rectangular cross-section, minor variations in de		*Cascade/E. Puget = 1.04*	
2.) Poorly defined bars and thalweg / very low, flat floodplain		*Columbia/E. WA=0.12*	
3.) bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks		*Northern/NE Mts.=0.097*	

Species Expected to Benefit

Sockeye	no	Coho	yes	Steelhead	no	Res CT/RB	yes	Brook	no
Chum	no	SR Cutthroa	yes			Bull	no	Brown	no
Pink	no	Chinook	no						

Pool : Riffle : Rapid : Pond Ratio (%)

Pool= 38.10 Riffle= 61.90 Rapid= 0.00 Pond= 0.00

Pool L sampled:	21.00 m	Pool Gravel %:	22.50
Riffle L sampled:	39.00 m	Riffle Gravel %:	30.00
Rapid L sampled:	0.00 m	Rapid Gravel %:	0.00
Pond L sampled:	0.00 m	Pond Gravel %:	0.00
Ave. Pool Depth:	0.13 m	Flow:	cfs
Ave. Riffle Depth:	0.040 m	Ave. Grad.	1.00 %
Ave. Rapid Depth:	0.00 m	Ave. Temp	0.0 °C
Ave. Pond Depth:	0.00 m	T @ trib.:	0.0 °C

Substrate Compositi Boulder= 0.00 Rubble= 1.25 Gravel= 26.25 Sand= 72.50

Wetted (Measured) Area

Ave. Pool Width:	0.80 m	Pool Area (W)	32.48 m²
Ave. Riffle Width:	0.700 m	Riffle Area (W):	52.78 m²
Ave. Rapid Width:	0.00 m	Rapid Area (W):	0.00 m²
Ave. Pond Width:	0.00 m	Pond Area (W):	0.00 m²
		Total Reach Area(W):	**85.26 m²**

Ordinary High Water Area

Ave. Pool W(OHW):	1.20 m	Pool Area (OHW):	48.72 m²
Ave. Riffle W(OHW):	1.40 m	Riffle Area (OHW):	105.56 m²
Ave. Rapid W(OHW):	0.00 m	Rapid Area (OHW):	0.00 m²
Ave. Pond W(OHW):	0.00 m	Pond Area (OHW):	0.00 m²
		Total Reach Area(OHW):	**154.28 m²**

60-day Low Flow Area

60-day Low Flow:	0.024 cfs	Pool Area (60dLF):	69.30 m²
Low-Flow Depth:	0.120 m	Riffle Area (60dLF):	123.52 m²

Low-Flow Width:	2.11 m	Rapid Area (60dLF):	0.00 m²	
		Pond Area (60dLF):	0.00 m²	
Pool Factor:	2.70			
Riffle/Rapid Factor:	3.01	**Total Reach Area (60dLF):**		**192.82 m²**
Pond Factor:	1.00			

QUALITY MODIFIERS:

spawning:	0.66	**Spawning Area:**	**28.14 m²**
rearing:	0.66	**Rearing Area:**	**56.27 m²**

Summary of Information - Reach #2

Starting Position:	Upstream of culvert a site 932415.	Length of Reach Culve	0.00 m
Length of Reach:	26.00 m	Percent of Reach Culv	0.0 %
Length Sampled:	26.00 m	Estimated drainage ar	0.75 mi²

Canopy:	0
Instream Cover:	Low
Juv. Abundance:	None observed.
Limiting Factors:	0
Barrier Site ID:	0

Spring influences are (see below): 1 — Reg. Constant (for 60-d low flow c 1.04

(absent-0, slight-1, mod-2, pronounced-3) — *Olympic / Coastal = 0.49*

1.)Relatively regular, rectangular cross-section, minor variations in d — *Cascade / E. Puget = 1.04*

2.)Poorly defined bars and thalweg — *Columbia / E. WA = 0.12*

3.)Bank vegetation along a distinct line, at a small distance above the H2O surface; moss on exposed surfaces of rocks — *Northern / NE Mts. = 0.097*

Species Expected to Benefit

Sockeye	no	Coho	yes	Steelhead	no	Res CT/RE	yes	Brook	no
Chum	no	SR Cutthroa	yes			Bull	no	Brown	no
Pink	no	Chinook	no						

Pool : Riffle : Rapid : Pond Ratio (%)

Pool= 0.00 Riffle= 0.00 Rapid= 0.00 Pond= 100.00

Pool L sampled:	0.00 m	Pool Gravel %:	0.00
Riffle L sampled:	0.00 m	Riffle Gravel %:	0.00
Rapid L sampled:	0.00 m	Rapid Gravel %:	0.00
Pond L sampled:	26.00 m	Pond Gravel %:	0.00
Ave. Pool Depth:	0.00 m	Flow:	cfs
Ave. Riffle Depth:	0.00 m	Ave. Grad.	0.10 %
Ave. Rapid Depth:	0.00 m	Ave. Temp	0.0 °C
Ave. Pond Depth:	0.50 m	T @ trib.:	0.0 °C

Substrate Compositi Boulder = 0.00 Rubble = 0.00 Gravel = 0.00 Sand = 100.00

Wetted (Measured) Area

Ave. Pool Width:	0.00 m	Pool Area (W)	0.00 m²	
Ave. Riffle Width:	0.00 m	Riffle Area (W):	0.00 m²	
Ave. Rapid Width:	0.00 m	Rapid Area (W):	0.00 m²	
Ave. Pond Width:	22.00 m	Pond Area (W):	572.00 m²	
		Total Reach Area (W):		**572.00 m²**

Ordinary High Water Area

Ave. Pool W(OHW):	0.00	m	Pool Area (OHW):	0.00	m²
Ave. Riffle W(OHW):	0.00	m	Riffle Area (OHW):	0.00	m²
Ave. Rapid W(OHW):	0.00	m	Rapid Area (OHW):	0.00	m²
Ave. Pond W(OHW):	22.00	m	Pond Area (OHW):	572.00	m²

Total Reach Area(OHW): **572.00 m²**

60-day Low Flow Area

60-day Low Flow:	0.022	cfs	Pool Area (60dLF):	0.00	m²
Low-Flow Depth:	#DIV/0!	m	Riffle Area (60dLF):	0.00	m²
Low-Flow Width:	#DIV/0!	m	Rapid Area (60dLF):	0.00	m²
			Pond Area (60dLF):	572.00	m²
Pool Factor	0.80				
Riffle/Rapid Factor:	0.62		**Total Reach Area (60dLF):**	**572.00**	**m²**
Pond Factor:	1.00				

QUALITY MODIFIERS:

spawning:	0.00	**Spawning Area:**	**0.00**	**m²**
rearing:	1.00	**Rearing Area:**	**572.00**	**m²**

Summary of Information - Reach #3

Starting Position:	Upstream of ponded reach.	Length of Reach Culve	55.10	m
Length of Reach:	265.00 m	Percent of Reach Culv	20.8	%
Length Sampled:	63.90 m	Estimated drainage are	0.74	mi²

Canopy:	1
Instream Cover:	Low
Juv. Abundance:	None observed.
Limiting Factors:	Impacted gravels, pollution.
Barrier Site ID:	932415, 932416, 932417

Spring influences are (see below): 1 — Reg. Constant (for 60-d low flow c 1.04

(absent-0, slight-1, mod.-2, pronounced-3) — *Olympic / Coastal = 0.49*

1.)Relatively regular, rectangular cross-section, minor variations in de — *Cascade / E. Puget = 1.04*

2.)Poorly defined bars and thalweg — *Columbia / E. WA = 0.12*

3.)Bank vegetation along a distinct line, at a small distance above the H2O distance; moss on exposed surfaces of rocks — *Northern / NE Mts. = 0.097*

Species Expected to Benefit

Sockeye	no	Coho	yes	Steelhead	no	Res CT/RE	yes	Brook	no
Chum	no	SR Cutthroa	yes			Bull	no	Brown	no
Pink	no	Chinook	no						

Pool : Riffle : Rapid : Pond Ratio (%)

Pool= 59.29 Riffle= 40.71 Rapid= 0.00 Pond= 0.00

Pool L sampled:	35.40	m	Pool Gravel %:	30.00
Riffle L sampled:	28.50	m	Riffle Gravel %:	40.00
Rapid L sampled:	0.00	m	Rapid Gravel %:	0.00
Pond L sampled:	0.00	m	Pond Gravel %:	0.00

Ave. Pool Depth:	0.23	m	Flow:		cfs
Ave. Riffle Depth:	0.06	m	Ave. Grad.	2.00	%
Ave. Rapid Depth:	0.00	m	Ave. Temp	0.0	°C
Ave. Pond Depth:	0.00	m	T @ trib.:	0.0	°C

Substrate Compositi	Boulder =	17.50	Rubble =	7.50	Gravel =	35.00	Sand =	40.00

Wetted (Measured) Area

Ave. Pool Width:	1.70	m	Pool Area (W)	197.68	m²
Ave. Riffle Width:	1.45	m	Riffle Area (W):	135.75	m²
Ave. Rapid Width:	0.00	m	Rapid Area (W):	0.00	m²
Ave. Pond Width:	0.00	m	Pond Area (W):	0.00	m²
			Total Reach Area (W):	**333.43**	**m²**

Ordinary High Water Area

Ave. Pool W(OHW):	1.75	m	Pool Area (OHW):	203.49	m²
Ave. Riffle W(OHW):	1.70	m	Riffle Area (OHW):	159.15	m²
Ave. Rapid W(OHW):	0.00	m	Rapid Area (OHW):	0.00	m²
Ave. Pond W(OHW):	0.00	m	Pond Area (OHW):	0.00	m²
			Total Reach Area(OHW):	**362.64**	**m²**

60-day Low Flow Area

60-day Low Flow:	0.022	cfs	Pool Area (60dLF):	229.55	m²
Low-Flow Depth:	0.081	m	Riffle Area (60dLF):	179.03	m²
Low-Flow Width	2.14	m	Rapid Area (60dLF):	0.00	m²
			Pond Area (60dLF):	0.00	m²
Pool Factor:	1.24				
Riffle/Rapid Factor	1.48		**Total Reach Area (60dLF):**	**408.57**	**m²**
Pond Factor:	1.00				

QUALITY MODIFIERS:				
spawning:	0.66	**Spawning Area:**	**82.31**	**m²**
rearing:	0.66	**Rearing Area:**	**220.06**	**m²**

Summary of Information - Reach #4

Starting Position:	Upstream of culvert at site 932419.		Length of Reach Culve	0.00	m
Length of Reach:	84.00	m	Percent of Reach Culv	0.0	%
Length Sampled:	84.00	m	Estimated drainage are	0.68	mi²

Canopy:	0
Instream Cover:	Low
Juv. Abundance:	None observed.
Limiting Factors:	0
Barrier Site ID:	0

Spring influences are (see below): 1 — Reg. Constant (for 60-d low flow c 1.04

(absent-0, slight-1, mod.-2, pronounced-3) — *Olympic / Coastal = 0.49*

1.)Relatively regular, rectangular cross-section, minor variations in de — *Cascade / E. Puget = 1.04*

2.)Poorly defined bars and thalweg — *Columbia / E. WA = 0.12*

3.)Bank vegetation along a distinct line, at a small distance — *Northern / NE Mts. = 0.097*

above the H2O surface; moss on exposed surfaces of rocks

Species Expected to Benefit

Sockeye	no	Coho	yes	Steelhead	no	Res CT/RB	yes	Brook	no
Chum	no	SR Cutthroa	yes			Bull	no	Brown	no
Pink	no	Chinook	no						

Pool : Riffle : Rapid : Pond Ratio (%)

Pool=	0.00	Riffle=	0.00	Rapid=	0.00	Pond=	100.00

Pool L sampled:	0.00	m	Pool Gravel %:	0.00	
Riffle L sampled:	0.00	m	Riffle Gravel %:	0.00	
Rapid L sampled:	0.00	m	Rapid Gravel %:	0.00	
Pond L sampled:	84.00	m	Pond Gravel %:	0.00	
Ave. Pool Depth:	0.00	m	Flow:		cfs
Ave. Riffle Depth:	0.00	m	Ave. Grad.	0.10	%
Ave. Rapid Depth:	0.00	m	Ave. Temp	0.0	°C
Ave. Pond Depth:	1.00	m	T @ trib.:	0.0	°C

Substrate Compositi Boulder = 0.00 Rubble = 0.00 Gravel = 0.00 Sand = 100.00

Wetted (Measured) Area

Ave. Pool Width:	0.00	m	Pool Area (W)	0.00	m²
Ave. Riffle Width:	0.00	m	Riffle Area (W):	0.00	m²
Ave. Rapid Width:	0.00	m	Rapid Area (W):	0.00	m²
Ave. Pond Width:	36.00	m	Pond Area (W):	3024.00	m²
			Total Reach Area (W):	**3024.00**	**m²**

Ordinary High Water Area

Ave. Pool W(OHW):	0.00	m	Pool Area (OHW):	0.00	m²
Ave. Riffle W(OHW):	0.00	m	Riffle Area (OHW):	0.00	m²
Ave. Rapid W(OHW):	0.00	m	Rapid Area (OHW):	0.00	m²
Ave. Pond W(OHW):	40.00	m	Pond Area (OHW):	3360.00	m²
			Total Reach Area(OHW):	**3360.00**	**m²**

60-day Low Flow Area

60-day Low Flow:	0.02	cfs	Pool Area (60-dLF):	0.00	m²
Low-Flow Depth:	#DIV/0!	m	Riffle Area (60-dLF):	0.00	m²
Low-Flow Width:	#DIV/0!	m	Rapid Area (60-dLF):	0.00	m²
			Pond Area (60-dLF):	3024.00	m²
Pool Factor:	0.80				
Riffle/Rapid Factor:	0.62		**Total Reach Area (60dLF):**	**3024.00**	**m²**
Pond Factor:	1.00				

QUALITY MODIFIERS:

spawning:	0.00	**Spawning Area:**	**0.00**	**m²**
rearing:	1.00	**Rearing Area:**	**3024.00**	**m²**

Summary of Information - Reach #5

Starting Position:	Upstream of ponded reach 3.	Length of Reach Culve	118.30	m
Length of Reach:	454.00 m	Percent of Reach Culv	26.1	%
Length Sampled:	60.00 m	Estimated drainage are	0.61	mi²

Canopy:	0
Instream Cover:	Low
Juv. Abundance:	None observed.
Limiting Factors:	Impacted gravels.
Barrier Site ID:	932417, 932418

Spring influences are (see below):	1	Reg. Constant (for 60-d low flow c 1.04
(absent-0, slight-1, mod.-2, pronounced-3)		*Olympic / Coastal = 0.49*
1.)Relatively regular, rectangular cross-section, minor variations in de		*Cascade / E. Puget = 1.04*
2.)Poorly defined bars and thalweg		*Columbia / E. WA = 0.12*
3.)Bank vegetation along a distinct line, at a small distance		*Northern / NE Mts. = 0.097*

above the H2O surface; moss on exposed surfaces of rocks

Species Expected to Benefit

Sockeye	no	Coho	yes	Steelhead	no	Res CT/RB	yes	Brook	no
Chum	no	SR Cutthroa	yes			Bull	no	Brown	no
Pink	no	Chinook	no						

Pool : Riffle : Rapid : Pond Ratio (%)

Pool= 52.33 Riffle= 47.67 Rapid= 0.00 Pond= 0.00

Pool L sampled:	31.40 m	Pool Gravel %:	50.00
Riffle L sampled:	28.60 m	Riffle Gravel %:	50.00
Rapid L sampled:	0.00 m	Rapid Gravel %:	0.00
Pond L sampled:	0.00 m	Pond Gravel %:	0.00

Ave. Pool Depth:	0.23 m	Flow:	cfs
Ave. Riffle Depth:	0.10 m	Ave. Grad.	2.00 %
Ave. Rapid Depth:	0.00 m	Ave. Temp	0.0 °C
Ave. Pond Depth:	0.00 m	T @ trib.:	0.0 °C

Substrate Compositi Boulder = 0.00 Rubble = 5.00 Gravel = 50.00 Sand = 45.00

Wetted (Measured) Area

Ave. Pool Width:	0.85 m	Pool Area (W)	149.33 m²
Ave. Riffle Width:	0.85 m	Riffle Area (W):	136.01 m²
Ave. Rapid Width:	0.00 m	Rapid Area (W):	0.00 m²
Ave. Pond Width:	0.00 m	Pond Area (W):	0.00 m²

Total Reach Area (W): 285.35 m²

Ordinary High Water Area

Ave. Pool W(OHW):	1.05 m	Pool Area (OHW):	184.47 m²
Ave. Riffle W(OHW):	1.40 m	Riffle Area (OHW):	224.02 m²
Ave. Rapid W(OHW):	0.00 m	Rapid Area (OHW):	0.00 m²
Ave. Pond W(OHW):	0.00 m	Pond Area (OHW):	0.00 m²

Total Reach Area(OHW): 408.49 m²

60-day Low Flow Area

60-day Low Flow:	0.02 cfs	Pool Area (60dLF):	167.65 m²
Low-Flow Depth:	0.115 m	Riffle Area 960dLF):	154.94 m²
Low-Flow Width:	1.03 m	Rapid Area (60dLF):	0.00 m²
		Pond Area (60dLF):	0.00 m²
Pool Factor:	1.18		
Riffle/Rapid Factor:	1.21	**Total Reach Area (60dLF):**	**322.59 m²**
Pond Factor:	1.00		

QUALITY MODIFIERS:

spawning:	0.66	**Spawning Area:**	**134.80 m²**
rearing:	0.66	**Rearing Area:**	**188.33 m²**

WDFW-SSHEAR PHYSICAL SURVEY OF POTENTIAL HABITAT
DOWNSTREAM CHECK COMMENTS

Stream Name:	unnamed	**Date:**	8/29/2012
Tributary To:	Juanita Cr	**Observer(s):**	**Gatchell; Stilwater**
WRIA #:	08.0238	**Section surveyed:**	From confluence with Juanit
Filename:	992654.xls		EOPFU.
		DS Check Length (m):	835

Hip Chain	Comment
0	Begin Downstream Check at downstream end of culvert at **Site 992654.** Suburban/urban environment.
	100 % fines for substrate.
52	Upstream end of culvert at **new Site 932411**. CST RND.
63	Downstream end of culvert. Blackberry present on both banks.
87	0.76m CST RND enters on right bank. Likely roadside collection. Water depth in culvert <0.01m.
156	Homeless person's camp with tent and mattress box spring across channel being used as a footbridge.
197	Wetland/ponded area begins.
260	Beaver dam.
270	Back to stream channel.
275	Right back to wetland.
426	Wetland starting to end, stream channel starts. 0.40m CAL RND enters from right bank hillside.
427	0.40m CAL RND enters from left bank hillside.
430	Piled up broken concrete slabs instream.
445	**Bankfull = 4.2m.**
486	Left bank seeps. Highly manicured lawns extend down to right bank of stream. Some placed rock present.
591	Pond begins.

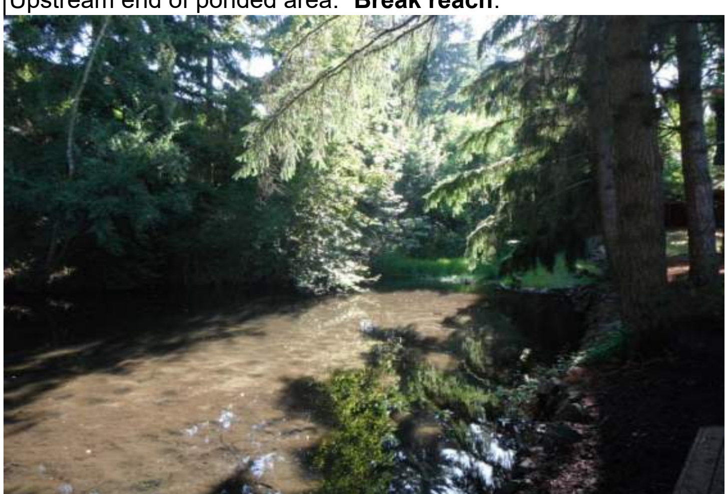
Hip Chain	Comment
635	Upstream end of **new Site 932412**. Standpipe with trash rack in pond at upstream end.
662	Downstream end of culvert that drains pond. Assessing this as a culvert per Susan Cierebiej's direction.
690	Salmonid observed.
806	Upstream end of **Site 08.0238 0.25**. PCC RND.
824	Downstream end of culvert.
835	Confluence with Juanita Creek, **End of Downstream Check**.

WDFW-SSHEAR PHYSICAL SURVEY OF POTENTIAL HABITAT
UPSTREAM SURVEY COMMENTS

Stream Name:	unnamed	**Date:**	8/29/2012
Tributary To:	Juanita Cr	**Observer(s):**	Gatchell Stilwater
WRIA #:	08.0238	**Section surveyed:**	From confluence with Juanita to EOPFU.
Sample Frequency:	R/60		
Filename:	992654.xls		

Hip Chain	Comment
Note:	Stream resides in urban/suburban setting with many businesses, single family homes, and multi-family housing. Several instream retention ponds are present, and the basin is known for being flashy due to the amount of impervious surfaces present.
Reach 1	
0	Begin survey at upstream end of target barrier **site 992654** (0% Passable). Stream flows through apartment complex and has a manicured left bank with blackberry lining the right bank.
5	**Bankfull = 3.7 m.**
80	Downstream end of culvert at **site 932413**.
92	Upstream end of culvert.
120	Both banks are manicured.
130	Downstream end of culvert at **site 932414**.
196	Upstream end of culvert. Pond begins. **Break reach**.

Reach 2	
222	Upstream end of ponded area. **Break reach**.



Reach 3	
246	Footbridge.
264	Rip rap both banks.

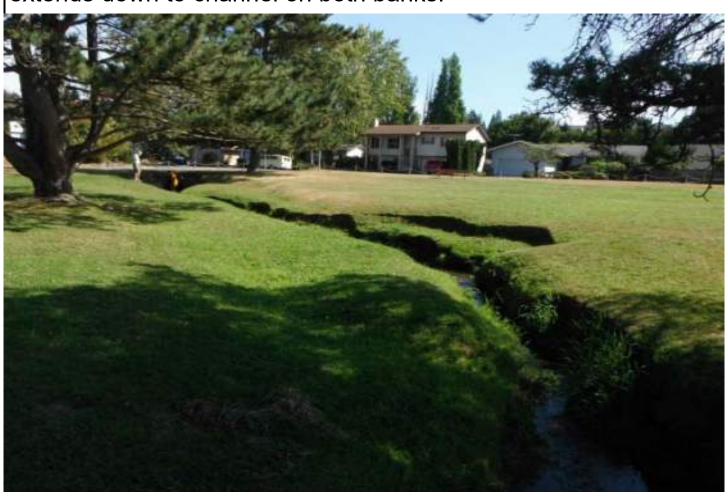
280 Footbridge.
309 Downstream end of culvert at **site 932415**.
323 Upstream end of culvert.
403 Downstream end of culvert at **site 932416**.
426 Upstream end of culvert.
470 Downstream end of culvert at **site 932419**.
487 Upstream end of culvert. Cement head wall, wing walls, and trash rack. Beginning of ponded reach. **Break reach**.

Reach 4

571 Upstream end of ponded reach. **Break reach**.

Reach 5

614 Downstream end of culvert at **site 932417**.
649 Upstream end of culvert.
659 Chainlink fence across channel. Stream flows into park. Very little instream cover, manicured lawn extends down to channel on both banks.



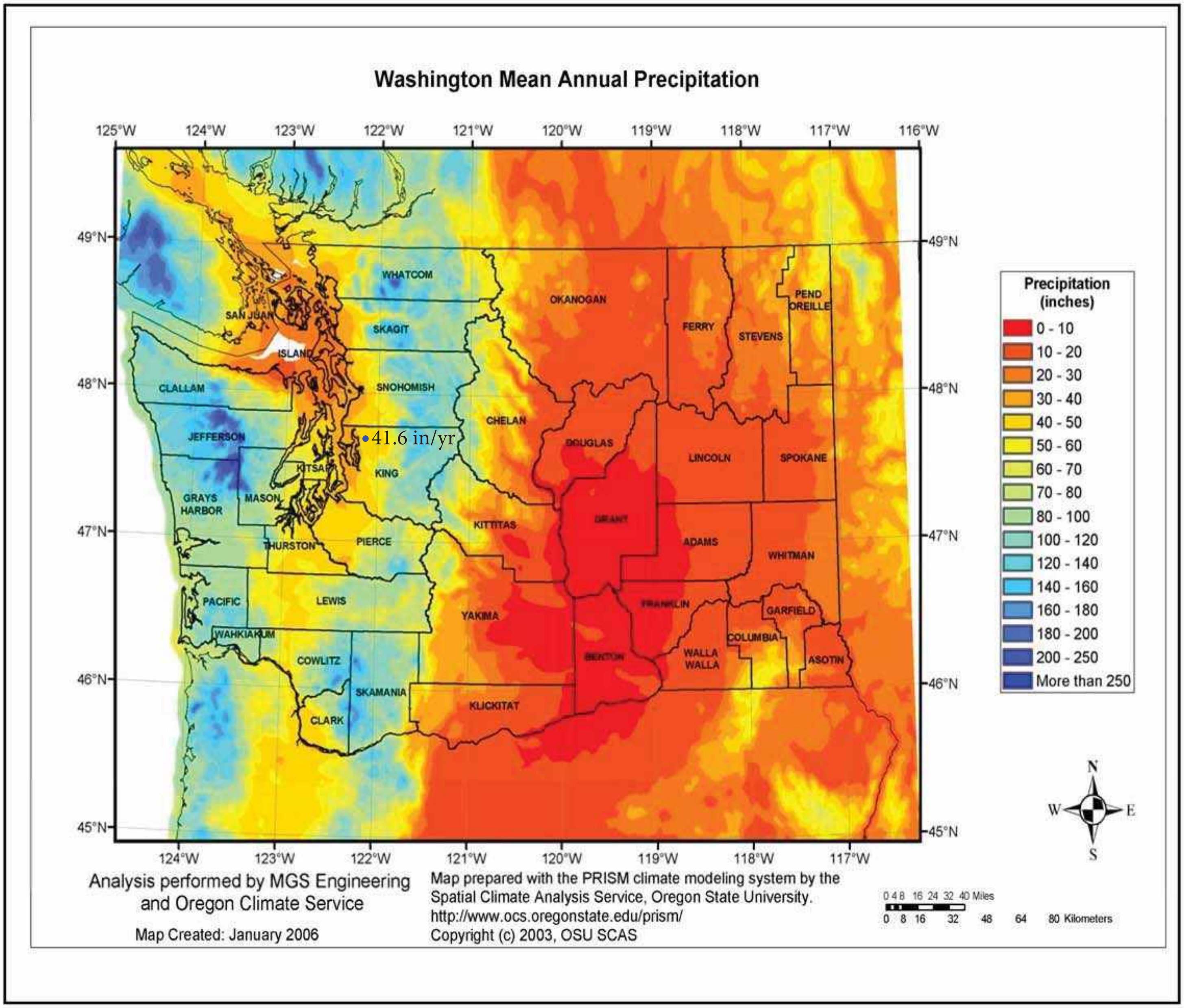
724 Roadside collection system drains into stream on right bank.
739 Downstream end of culvert at **site 932418**. **Gradient check = 2%**.
825 Upstream end of culvert.
1025 Over two hundred meters of scour line width less than 0.61 m. **End of potential fish use.**

Appendix B
Stream Design Parameter Exhibits

Appendix B.1

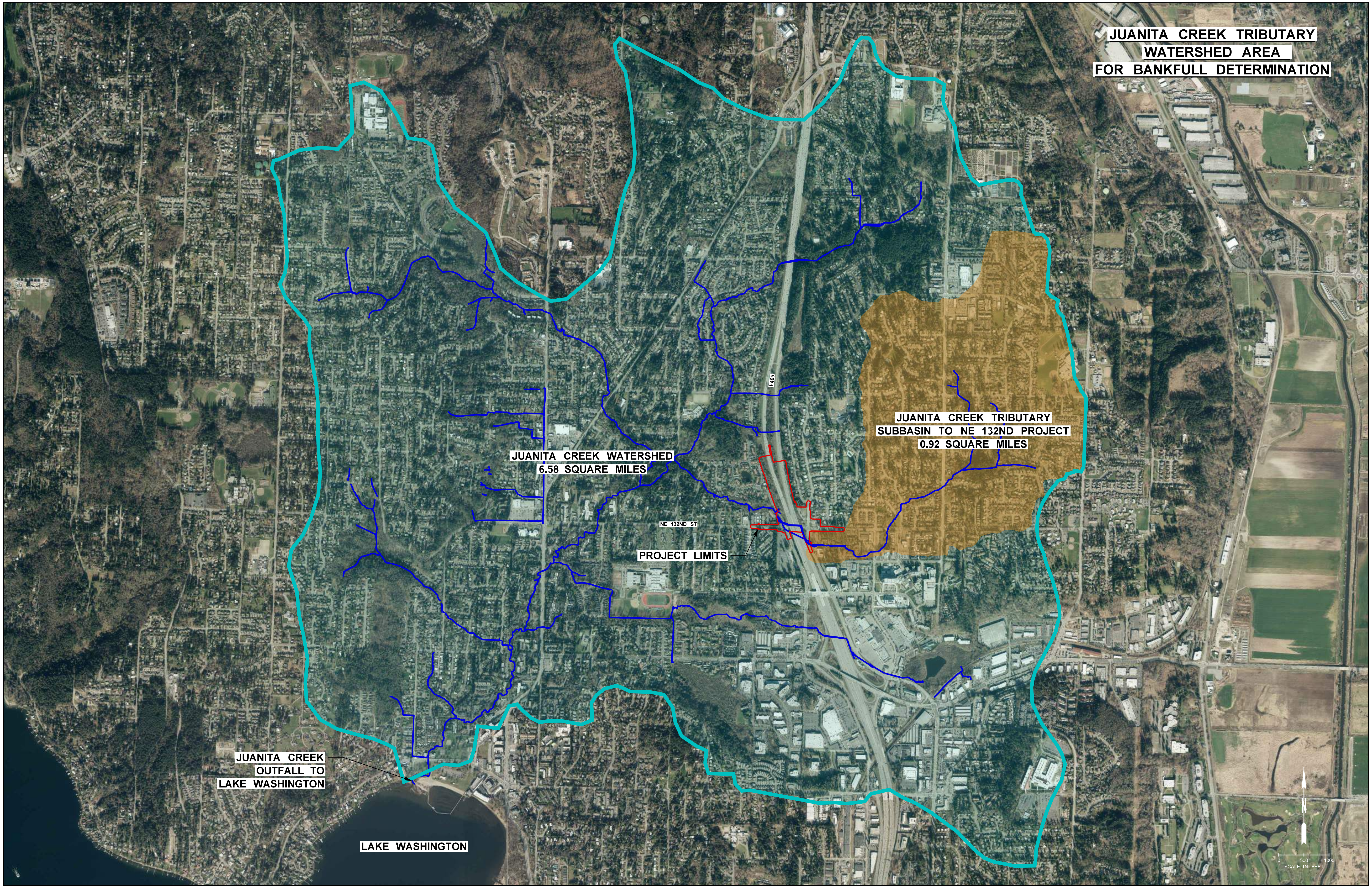
Washington Mean Annual Precipitation (MAP)

Washington Mean Annual Precipitation (MAP)
Statewide update on January 2006
Also available on the Environmental Workbench in ArcView



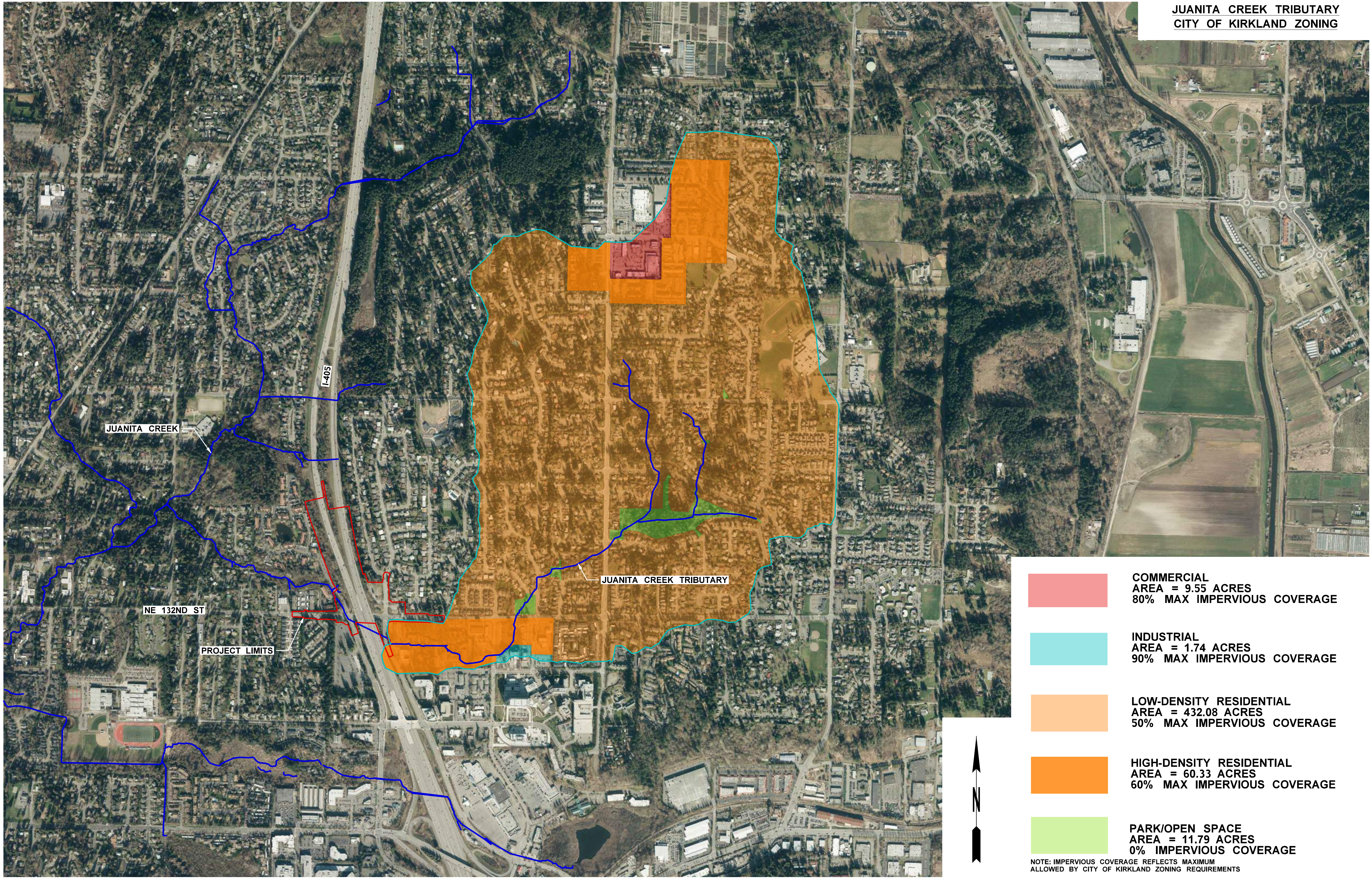
Appendix B.2

Juanita Creek Watershed Area


JUANITA CREEK TRIBUTARY
WATERSHED AREA
FOR BANKFULL DETERMINATION
JUANITA CREEK TRIBUTARY
SUBBASIN TO NE 132ND PROJECT
0.92 SQUARE MILES
JUANITA CREEK WATERSHED
6.58 SQUARE MILES
NE 132ND ST
I-405
PROJECT LIMITS
JUANITA CREEK
OUTFALL TO
LAKE WASHINGTON
LAKE WASHINGTON

Appendix B.3

Juanita Creek Tributary Basin Area


JUANITA CREEK TRIBUTARY
CITY OF KIRKLAND ZONING
I-405
JUANITA CREEK
NE 132ND ST
PROJECT LIMITS
JUANITA CREEK TRIBUTARY
COMMERCIAL
AREA = 9.55 ACRES
80% MAX IMPERVIOUS COVERAGE
INDUSTRIAL
AREA = 1.74 ACRES
90% MAX IMPERVIOUS COVERAGE
LOW-DENSITY RESIDENTIAL
AREA = 432.08 ACRES
50% MAX IMPERVIOUS COVERAGE
HIGH-DENSITY RESIDENTIAL
AREA = 60.33 ACRES
60% MAX IMPERVIOUS COVERAGE
PARK/OPEN SPACE
AREA = 11.79 ACRES
0% IMPERVIOUS COVERAGE
NOTE: IMPERVIOUS COVERAGE REFLECTS MAXIMUM ALLOWED BY CITY OF KIRKLAND ZONING REQUIREMENTS
N

Appendix B.4

Juanita Creek Tributary – Bankfull Width Determination by Regression Equation

FOR: 132nd Int. Imp.	JOB NO:	SHEET NO:
MADE BY: B. Lazzell	CHECKED BY:	BACKCHECKED BY:
DATE: 8/30/2018	DATE:	DATE:

HNTB

JUANITA CREEK TRIBUTARY
BANKFULL WIDTH DETERMINATION BY REGRESSION EQ.

2013 WDFW WATER CROSSING DESIGN GUIDELINES - APPENDIX C PROVIDES REGRESSION EQUATION RELATING BANKFULL WIDTH TO BASIN AREA AND ANNUAL PRECIPITATION.

EQUATION C.1

$W_{CH} = 0.95 \cdot WA^{0.45} \cdot AAP^{0.61}$

WHERE

W_{CH} = WIDTH OF BANKFULL CHANNEL (FT)

WA = WATERSHED AREA CONTRIBUTING (sq mi)

AAP = AVERAGE ANNUAL PRECIPITATION AT SITE (in/yr)

SEE ATTACHED EXHIBITS SHOWING CONTRIBUTING WATERSHED AREA TO 132nd AND WSDOT AVERAGE ANNUAL RAINFALL ISOPLUVIAL MAP.

$W_{CH} = 0.95 \cdot (0.92)^{0.45} \cdot (41.6)^{0.61}$

W_{CH} = 8.89 FT ROUNDED TO 9.00 FT TO BE CONSERVATIVE

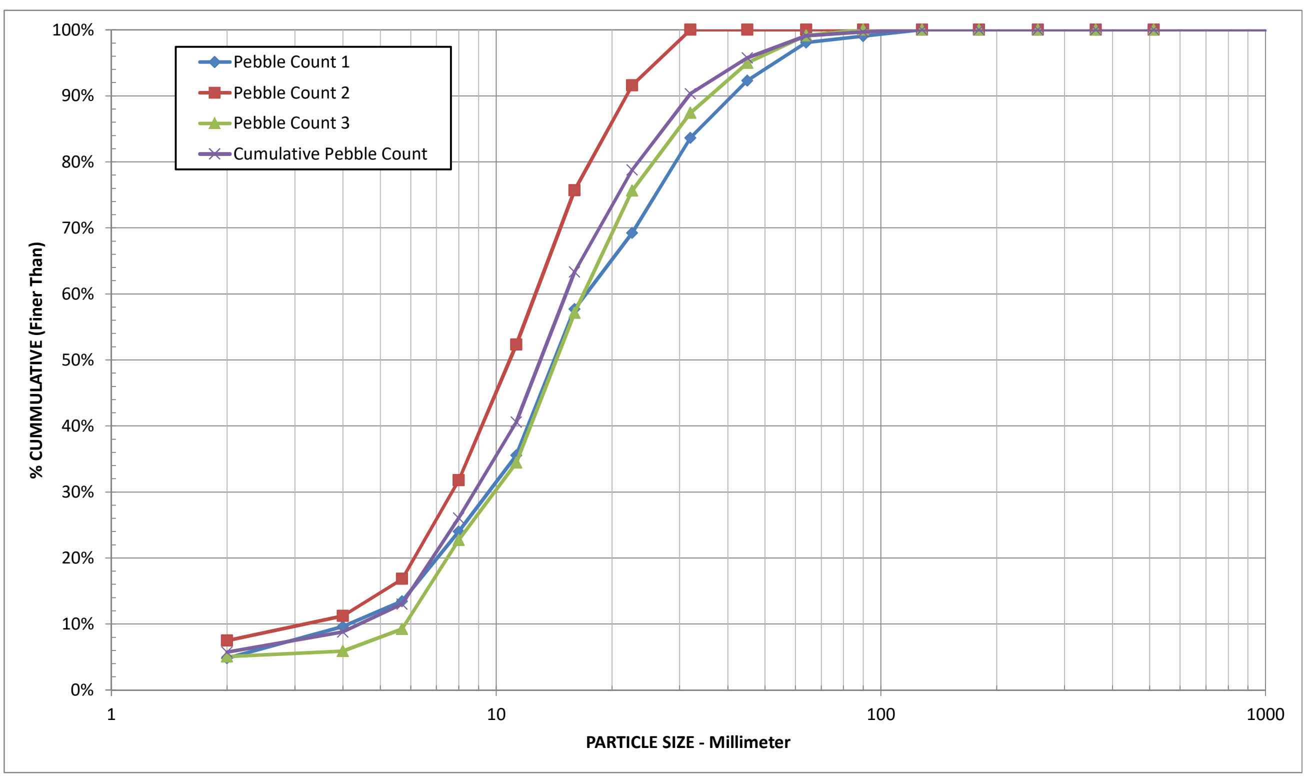
$W_{CH} = 9$ FT

ME-101-1204

Appendix B.5

Pebble Counts and Sediment Distribution

PEBBLE COUNT							Project Reach			Project Reach			Project Reach			Project Reach		
Stream: Juanita Creek		Site No:					Pebble Count #1			Pebble Count #2			Pebble Count #3			Cumulative		
Reach: Upstream of 132nd Crossing		Party:		Lazzell, Strom, Gray			Date: 1/25/2019			Date: 1/25/2019			Date: 1/25/2019			Date: 1/25/2019		
Inches	*Particle*	*Millimeters*		Particle Count 1	2	3	*Tot #*	*Item %*	*% Cum*	*Tot #*	*Item %*	*% Cum*	*Tot #*	*Item %*	*% Cum*	*Tot #*	*Item %*	*% Cum*
	Silt Clay	0.062	SILT/CLAY	0	0	2	0	0.0%	0.0%	0	0.0%	0.0%	2	1.7%	1.7%	2	0.6%	0.6%
	Very Fine	.062 - .125	SAND				0	0.0%	0.0%	0	0.0%	0.0%	0	0.0%	1.7%	0	0.0%	0.6%
	Fine	.125 - .25					0	0.0%	0.0%	0	0.0%	0.0%	0	0.0%	1.7%	0	0.0%	0.6%
	Medium	.25 - .50					0	0.0%	0.0%	0	0.0%	0.0%	0	0.0%	1.7%	0	0.0%	0.6%
	Coarse	.50 - 1.0					0	0.0%	0.0%	0	0.0%	0.0%	0	0.0%	1.7%	0	0.0%	0.6%
.04 - .08	Very Coarse	1.0 - 2		5	8	4	5	4.8%	4.8%	8	7.5%	7.5%	4	3.4%	5.0%	17	5.2%	5.8%
.08 - .16	Very Fine	2 - 4	GRAVEL	5	4	1	5	4.8%	9.6%	4	3.7%	11.2%	1	0.8%	5.9%	10	3.0%	8.8%
.16 -.22	Fine	4 - 5.7		4	6	4	4	3.8%	13.5%	6	5.6%	16.8%	4	3.4%	9.2%	14	4.2%	13.0%
.22 - .31	Fine	5.7 - 8		11	16	16	11	10.6%	24.0%	16	15.0%	31.8%	16	13.4%	22.7%	43	13.0%	26.1%
.31 - .44	Medium	8 - 11.3		12	22	14	12	11.5%	35.6%	22	20.6%	52.3%	14	11.8%	34.5%	48	14.5%	40.6%
.44 - .63	Medium	11.3 - 16		23	25	27	23	22.1%	57.7%	25	23.4%	75.7%	27	22.7%	57.1%	75	22.7%	63.3%
.63 - .89	Coarse	16 - 22.6		12	17	22	12	11.5%	69.2%	17	15.9%	91.6%	22	18.5%	75.6%	51	15.5%	78.8%
.89 - 1.26	Coarse	22.6 - 32		15	9	14	15	14.4%	83.7%	9	8.4%	100.0%	14	11.8%	87.4%	38	11.5%	90.3%
1.26 - 1.77	Very Coarse	32 - 45		9		9	9	8.7%	92.3%	0	0.0%	100.0%	9	7.6%	95.0%	18	5.5%	95.8%
1.77 - 2.5	Very Coarse	45 - 64		6		5	6	5.8%	98.1%	0	0.0%	100.0%	5	4.2%	99.2%	11	3.3%	99.1%
2.5 - 3.5	Small	64 - 90	COBBLE	1		1	1	1.0%	99.0%	0	0.0%	100.0%	1	0.8%	100.0%	2	0.6%	99.7%
3.5 - 5.0	Small	90 - 128		1			1	1.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	1	0.3%	100.0%
5.0 - 7.1	Large	128 - 180					0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
7.1 - 10.1	Large	180 - 256					0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
10.1 - 14.3	Small	256 - 362	BOULDER				0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
14.3 - 20	Small	362 - 512					0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
20 - 40	Medium	512 -1024					0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
40 - 80	Large-Very Large	1024 - 2048					0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
	Bedrock		BEDROCK				0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%	0	0.0%	100.0%
						TOTALS	104	100.0%	100.0%	107	100.0%	100.0%	119	100.0%	100.0%	330	100.0%	100.0%



Summary - Stream Simulation Bed Material Design

Project:	Juanita Creek Tributary
By:	Alex Strom

Existing Sediment Gradation:

Location:	Upstream Riffle			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.14	0.09	0.04	0.02
in	1.69	1.03	0.51	0.24
mm	43	26	13.0	6.1

Design Gradation:

Location:	Riffle			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.83	0.34	0.10	0.01
in	10.00	4.10	1.22	0.09
mm	254	104	31.0	2.3

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	95.0
32.0	813									50	95.0
28.0	711								100		95.0
23.0	584								50		95.0
18.0	457							100			95.0
15.0	381							50			95.0
12.0	305						100				95.0
10.0	254					100	80				95.0
8.0	203				100	80	68				93.0
6.0	152.4			100	80	68	57				89.8
5.0	127			80	68	57	45				86.5
4.0	102		100	71	57	45	39				83.7
3.0	76.2		80	63	45	38	34				80.5
2.5	63.5	100	65	54	37	32	28				77.8
2.0	50.8	80	50	45	29	25	22				62.2
1.5	38.1	73	35	32	21	18	16				54.4
1.0	25.4	65	20	18	13	12	11				46.6
0.75	19.1	50	5	5	5	5	5				34.0
No. 4 =	4.75	35									22.8
No. 40 =	0.425	16									10.4
No. 200 =	0.0750	7									4.6
% per category		65	5	5	10	10	0	0			--> 95%
% Cobble & Sediment		68.4	5.3	5.3	10.5	10.5	0.0	0.0	0.0	0.0	95.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

uniform bed material (Di 20-30 times D50)

Slopes less than 5%

Sand/gravel streams with high relative submergence

s	165	specific weight of sediment particle (lb/ft^3)
	62.4	specific weight of water (1b/ft^3)
D50	0.054	dimensionless Shields parameter for D50,
		use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

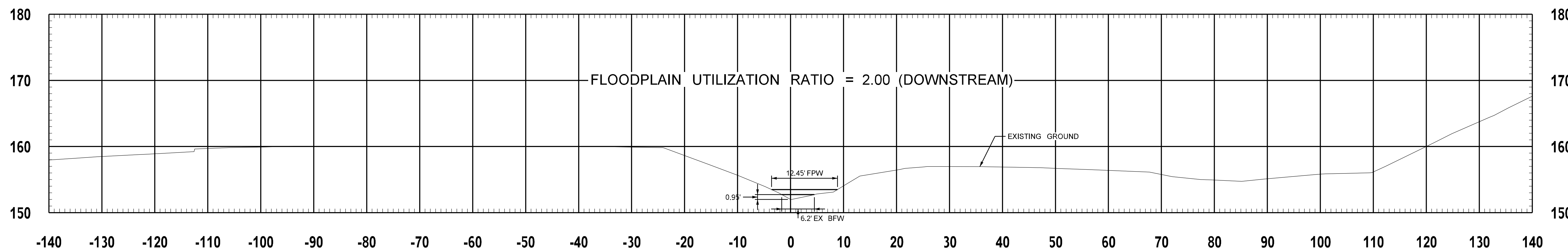
Flow	2-YR (69.2 cfs)	25-YR (128.2 cfs)	100-YR (154.2 cfs)
Average Modeled Shea	0.82	0.94	0.98
ci		Structure	
1.55	No Motion	No Motion	No Motion
1.50	No Motion	No Motion	No Motion
1.44	No Motion	No Motion	No Motion
1.36	No Motion	No Motion	No Motion
1.26	No Motion	No Motion	No Motion
1.19	No Motion	No Motion	No Motion
1.12	No Motion	No Motion	No Motion
1.06	No Motion	No Motion	No Motion
0.99	No Motion	No Motion	No Motion
0.91	No Motion	Motion	Motion
0.86	No Motion	Motion	Motion
0.80	Motion	Motion	Motion
0.74	Motion	Motion	Motion
0.70	Motion	Motion	Motion
0.65	Motion	Motion	Motion
0.60	Motion	Motion	Motion
0.53	Motion	Motion	Motion
0.49	Motion	Motion	Motion

D16	0.09	inches
D50	1.22	inches
	0.10	ft
D84	4.10	inches

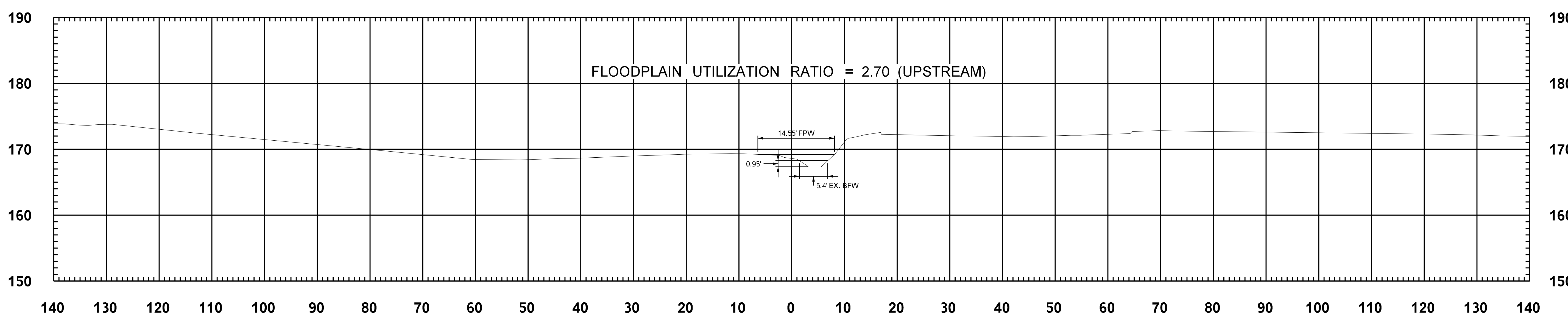
Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Appendix B.6

Floodplain Utilization Ratio



DOWNSTREAM (STA 12+00)



UPSTREAM (STA 25+50)

NOTES:
FLOODPRONE WIDTH DIMENSION CORRESPONDS TO THE STREAM WIDTH THAT OCCURS AT TWICE THE BANKFULL DEPTH.

FILE NAME	c:\users\lazzelb\pw_wsdot\d0198701\15%IR-Exhibits.dgn
TIME	11:59:00 AM
DATE	2/1/2019
DESIGNED BY	LazzelB

Informational use only
Not intended for Contract Plans

Washington State
Department of Transportation

I-405
NE 132ND STREET
INTERCHANGE IMPROVEMENTS

FLOODPLAIN UTILIZATION RATIO

Appendix C
MGSFlood Model Results

MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.54
Program License Number: 202110004
Project Simulation Performed on: 10/20/2021 6:49 PM
Report Generation Date: 10/22/2021 12:07 PM

Input File Name: EXISTING_JuanitaCreekHydrology116thWyNE-1hrTS.fld
Project Name: I-405, NE 132nd IC Improvements
Analysis Title: Juanita Creek Subbasin Model to 114th Place NE Culvert_1hr
Comments: Modeling entire Juanita Creek subbasin tributary to 114th Place NE culvert, including additional drainage area entering downstream of NE 132nd St crossing. Retrofit Ponds;1hr Timestep

PRECIPITATION INPUT

Computational Time Step (Minutes): 60

Extended Precipitation Time Series Selected
Climatic Region Number: 15

Full Period of Record Available used for Routing
Precipitation Station : 96004005 Puget East 40 in_5min 10/01/1939-10/01/2097
Evaporation Station : 961040 Puget East 40 in MAP
Evaporation Scale Factor : 0.750

HSPF Parameter Region Number: 1
HSPF Parameter Region Name : USGS Default

********** Default HSPF Parameters Used (Not Modified by User) ***************

********************** WATERSHED DEFINITION ***********************

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	458.610	499.700
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	458.610	499.700

----------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 1

---------- Subbasin : Pre-Dev Juanita Creek ----------

	-------Area (Acres) --------
Till Forest	15.960
Till Pasture	223.940

Outwash Pasture	2.860
Wetland	9.560
Green Roof	4.080
Impervious	202.210
Subbasin Total	458.610

----------------------SCENARIO: POSTDEVELOPED

Number of Subbasins: 9

---------- Subbasin : WSDOT Detained Area ----------

	-------Area (Acres) --------
Impervious	2.047
Subbasin Total	2.047

---------- Subbasin : Flow-Through WSDOT Area ----------

	-------Area (Acres) --------
Till Grass	1.152
Impervious	0.410
Subbasin Total	1.562

---------- Subbasin : Detained City of Kirkland Area ----------

	-------Area (Acres) --------
Impervious	1.375
Subbasin Total	1.375

---------- Subbasin : Flow-through City of Kirkland Area ----------

	-------Area (Acres) --------
Till Grass	1.006
Impervious	0.100
Subbasin Total	1.106

---------- Subbasin : Post-Dev Commercial ----------

	-------Area (Acres) --------
Till Pasture	1.700
Impervious	6.790
Subbasin Total	8.490

---------- Subbasin : Post-Dev Low Density Residential ----------

	-------Area (Acres) --------
Till Pasture	195.220
Outwash Pasture	16.970
Impervious	206.960
Subbasin Total	419.150

---------- Subbasin : Post-Dev Industrial ----------

	-------Area (Acres) --------
Till Pasture	0.150
Impervious	1.380
Subbasin Total	1.530

---------- Subbasin : Post-Dev High Dens Residential ----------

	-------Area (Acres) --------
Till Pasture	15.960
Outwash Pasture	5.510
Impervious	32.200
Subbasin Total	53.670

---------- Subbasin : Post-Dev Open Space/Park ----------

	-------Area (Acres) --------
Till Forest	4.350
Till Pasture	1.810
Outwash Forest	4.610
Subbasin Total	10.770

**************************** LINK DATA ********************************

----------------------SCENARIO: PREDEVELOPED
Number of Links: 0

**************************** LINK DATA ********************************

----------------------SCENARIO: POSTDEVELOPED
Number of Links: 3

--
Link Name: New Copy Lnk3
Link Type: Copy
Downstream Link: None

--
Link Name: WSDOT Detention Pond D2.1
Link Type: Structure
Downstream Link Name: New Copy Lnk3

User Specified Elevation Volume Table Used

Elevation (ft)	Pond Volume (cu-ft)
180.00	0.
180.50	1120.

181.00	2348.
181.50	3689.
182.00	5149.
182.50	6733.
183.00	8445.
183.50	10291.
184.00	12277.
184.50	14409.
185.00	16691.
185.50	19128.
186.00	21722.
186.50	24479.
187.00	27401.
187.50	30493.
188.00	33759.

Hydraulic Conductivity (in/hr) : 0.00
Massmann Regression Used to Estimate Hydralic Gradient
Depth to Water Table (ft) : 100.00
Bio-Fouling Potential : Low
Maintenance : Average or Better

Riser Geometry
Riser Structure Type : Circular
Riser Diameter (in) : 18.00
Common Length (ft) : 0.020
Riser Crest Elevation : 187.00 ft

Hydraulic Structure Geometry

Number of Devices: 3

---Device Number 1 ---
Device Type : Circular Orifice
Control Elevation (ft) : 180.00
Diameter (in) : 1.12
Orientation : Horizontal
Elbow : No

--- Device Number 2 ---
Device Type : Rectangular Weir that Intersects the Riser Top
Invert Elevation (ft) : 184.78
Length (ft) : 0.020

---Device Number 3 ---
Device Type : Circular Orifice
Control Elevation (ft) : 183.59
Diameter (in) : 0.50
Orientation : Horizontal
Elbow : Yes

--
Link Name: City of Kirkland Detention Pond D2.2
Link Type: Structure
Downstream Link Name: New Copy Lnk3

User Specified Elevation Volume Table Used

Elevation (ft)	Pond Volume (cu-ft)
180.00	0.
180.50	561.
181.00	1219.
181.50	1979.
182.00	2844.
182.50	3819.
183.00	4907.
183.50	6113.
184.00	7440.
184.50	8892.
185.00	10474.
185.50	12188.
186.00	14040.
186.50	16033.
187.00	18171.
187.50	20458.
188.00	22898.

Hydraulic Conductivity (in/hr) : 0.00
Massmann Regression Used to Estimate Hydralic Gradient
Depth to Water Table (ft) : 100.00
Bio-Fouling Potential : Low
Maintenance : Average or Better

Riser Geometry
Riser Structure Type : Circular
Riser Diameter (in) : 18.00
Common Length (ft) : 0.010
Riser Crest Elevation : 187.00 ft

Hydraulic Structure Geometry

Number of Devices: 2

---Device Number 1 ---
Device Type : Circular Orifice
Control Elevation (ft) : 180.00
Diameter (in) : 0.98
Orientation : Horizontal
Elbow : No

--- Device Number 2 ---
Device Type : Rectangular Weir that Intersects the Riser Top
Invert Elevation (ft) : 185.10
Length (ft) : 0.010

**********************FLOOD FREQUENCY AND DURATION STATISTICS*******************

---------------------SCENARIO: PREDEVELOPED
Number of Subbasins: 1
Number of Links: 0

----------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 9
Number of Links: 3

*************Groundwater Recharge Summary ***************
Recharge is computed as input to Perlnd Groundwater Plus Infiltration in Structures

Total Predeveloped Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Pre-Dev Juanita Cree	46024.510
Total:	46024.510

Total Post Developed Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: WSDOT Detained Area	0.000
Subbasin: Flow-Through WSDOT A	141.604
Subbasin: Detained City of Kir	0.000
Subbasin: Flow-through City of	123.658
Subbasin: Post-Dev Commercial	301.327
Subbasin: Post-Dev Low Density	40346.710
Subbasin: Post-Dev Industrial	26.588
Subbasin: Post-Dev High Dens R	4693.875
Subbasin: Post-Dev Open Space/	2300.761
Link: New Copy Lnk3	0.000
Link: WSDOT Detention Pond	Not Computed
Link: City of Kirkland Det	Not Computed
Total:	47934.520

Total Predevelopment Recharge is Less than Post Developed
Average Recharge Per Year, (Number of Years= 158)
Predeveloped: 291.294 ac-ft/year, Post Developed: 303.383 ac-ft/year

*************Water Quality Facility Data ***************

----------------------SCENARIO: PREDEVELOPED

Number of Links: 0

----------------------SCENARIO: POSTDEVELOPED

Number of Links: 3

********** Link: New Copy Lnk3 **********

Infiltration/Filtration Statistics--------------------
Inflow Volume (ac-ft): 142938.80
Inflow Volume Including PPT-Evap (ac-ft): 142938.80
Total Runoff Infiltrated (ac-ft): 0.00, 0.00%

Total Runoff Filtered (ac-ft): 0.00, 0.00%
Primary Outflow To Downstream System (ac-ft): 142938.80
Secondary Outflow To Downstream System (ac-ft): 0.00
Volume Lost to ET (ac-ft): 0.00
Percent Treated (Infiltrated+Filtered+ET)/Total Volume: 0.00%

*************Compliance Point Results ***************

Scenario Predeveloped Compliance Subbasin: Pre-Dev Juanita Creek

Scenario Postdeveloped Compliance Link: New Copy Lnk3

***** Point of Compliance Flow Frequency Data *****
Recurrence Interval Computed Using Gringorten Plotting Position

Predevelopment Runoff		Postdevelopment Runoff	
Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	62.997	2-Year	73.936
5-Year	79.861	5-Year	95.037
10-Year	96.107	10-Year	113.771
25-Year	118.034	25-Year	137.477
50-Year	127.017	50-Year	144.963
100-Year	139.089	100-Year	165.090
200-Year	167.972	200-Year	191.227
500-Year	206.553	500-Year	225.764

** Record too Short to Compute Peak Discharge for These Recurrence Intervals

Appendix D

SRH-2D Model Results

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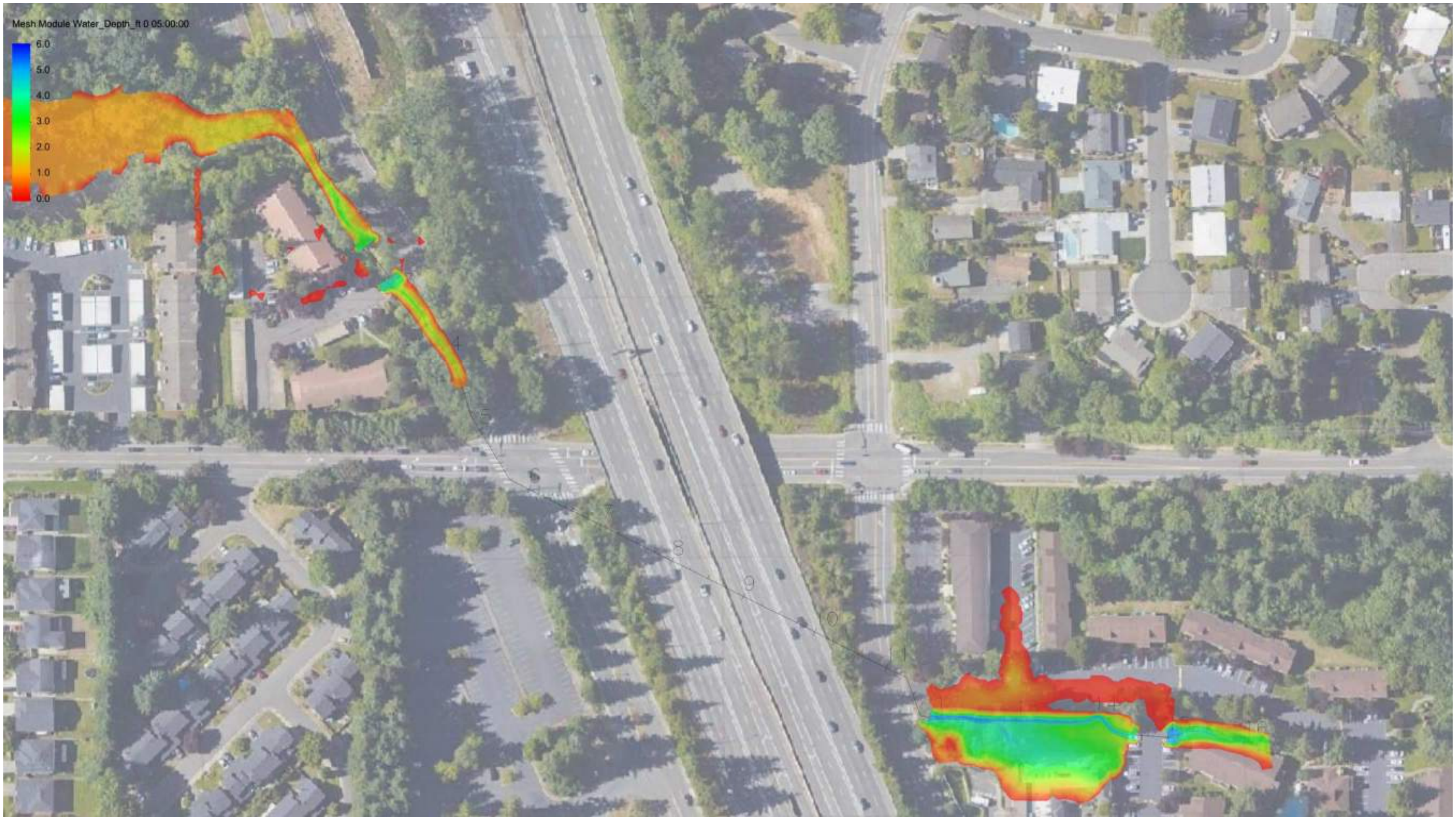
Appendix D.1

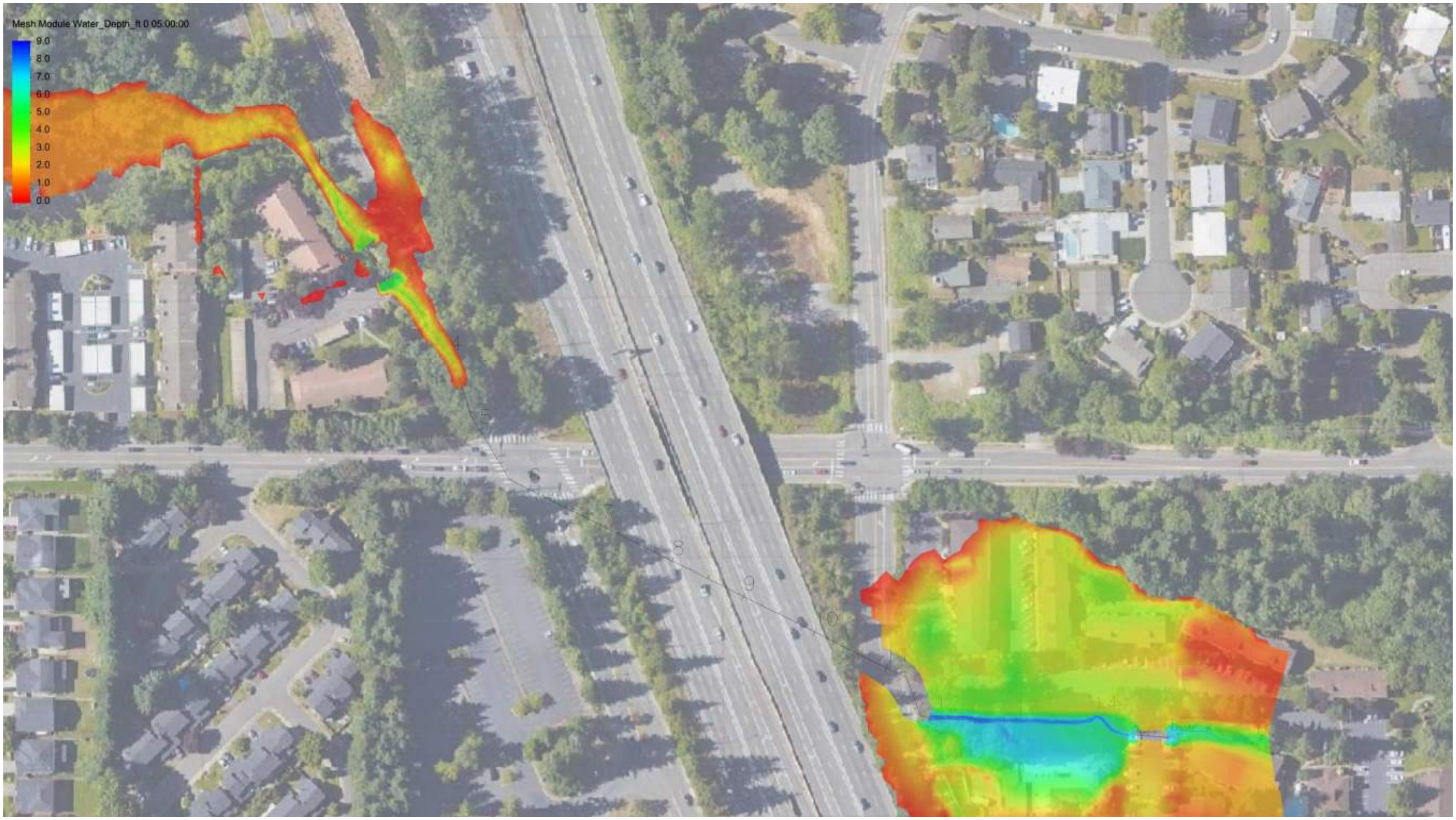
Existing Conditions



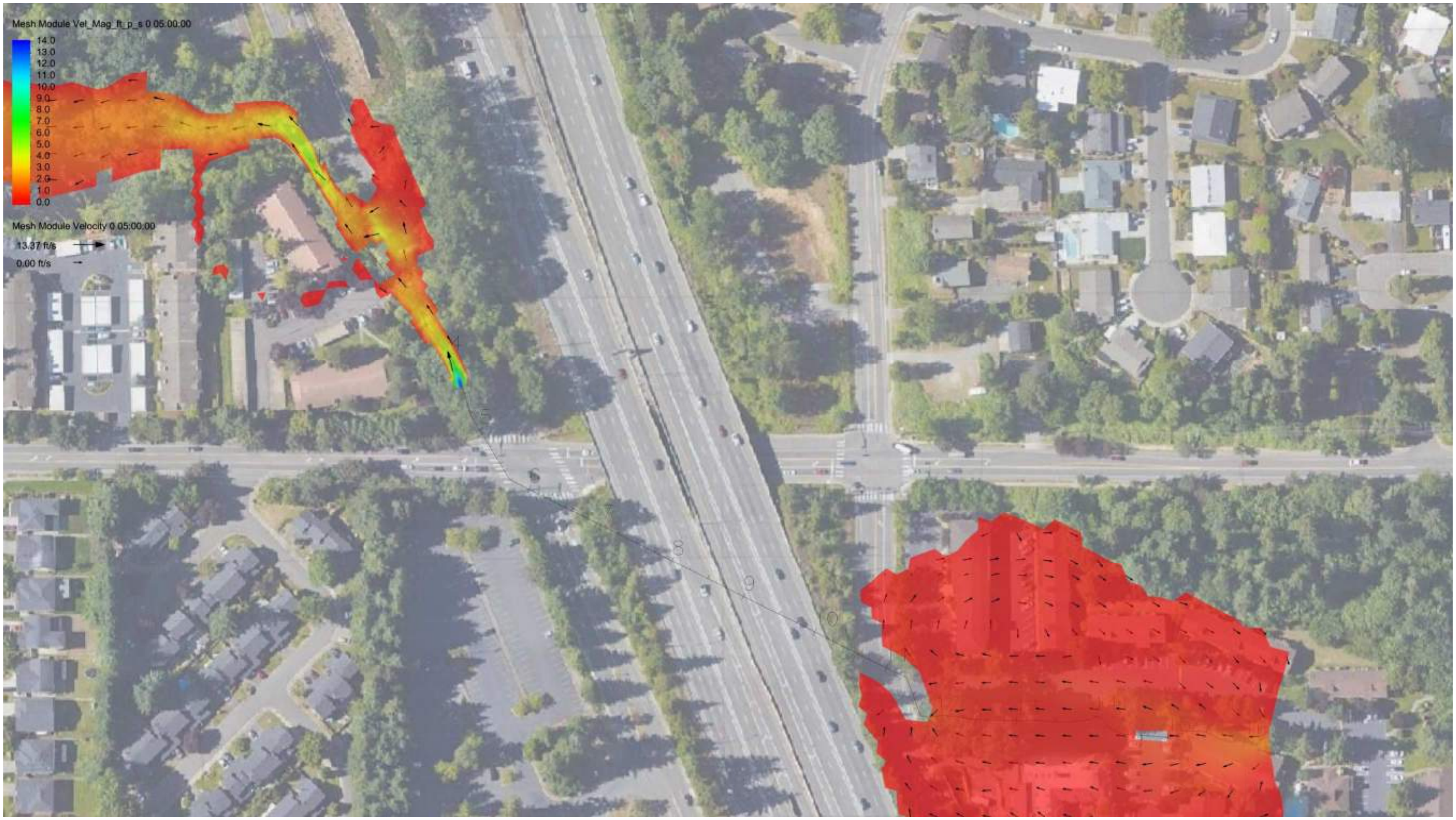
Juanita Creek Tributary Pre-Developed Conditions 2-Year Depth, USGS Regression Peak Flow

Juanita Creek Tributary Pre-Developed Conditions 2-Year Velocity, USGS Regression Peak Flow

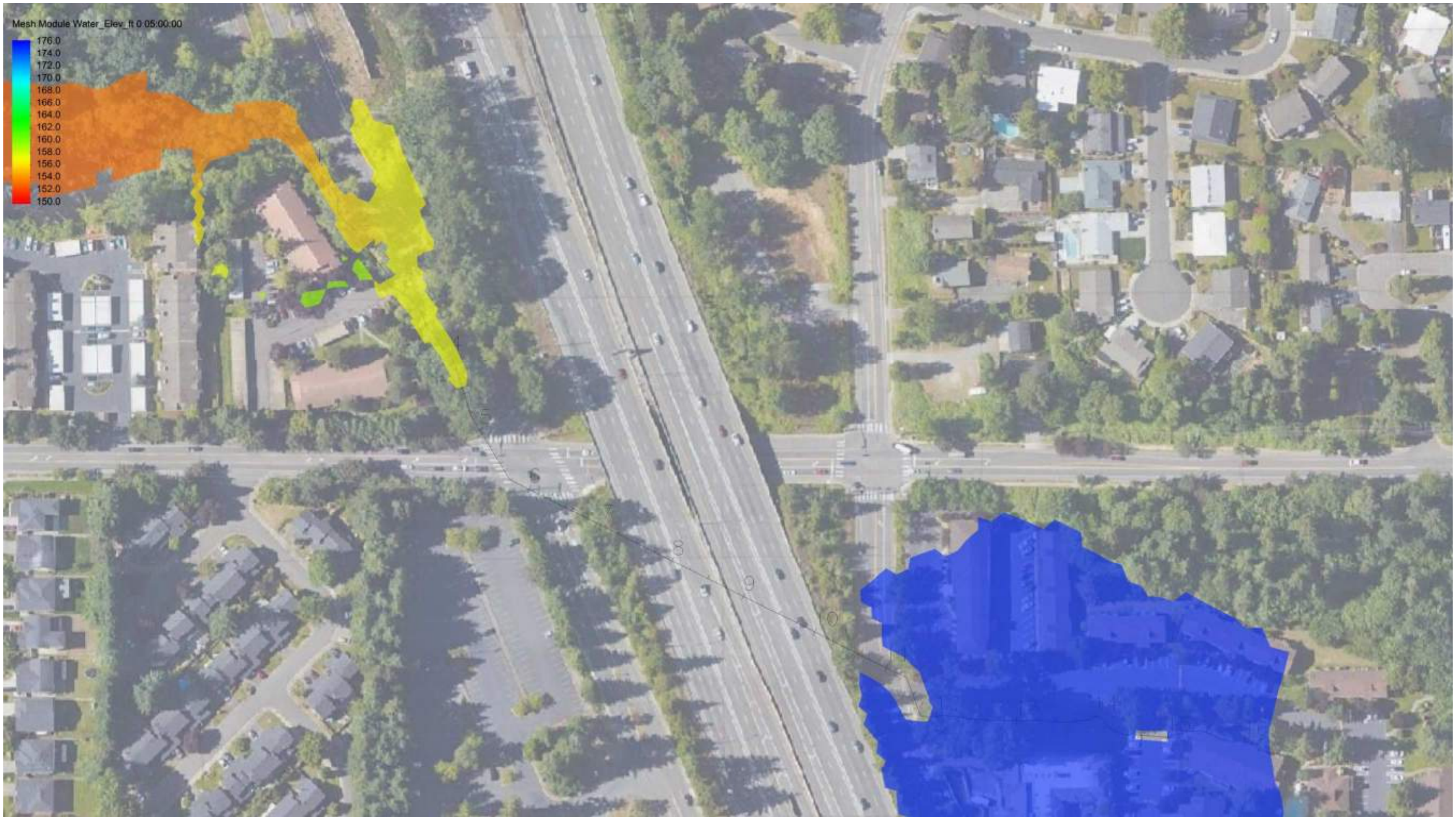
Juanita Creek Tributary Pre-Developed Conditions 2-Year Water Surface Elevation (WSE), USGS Regression Peak Flow



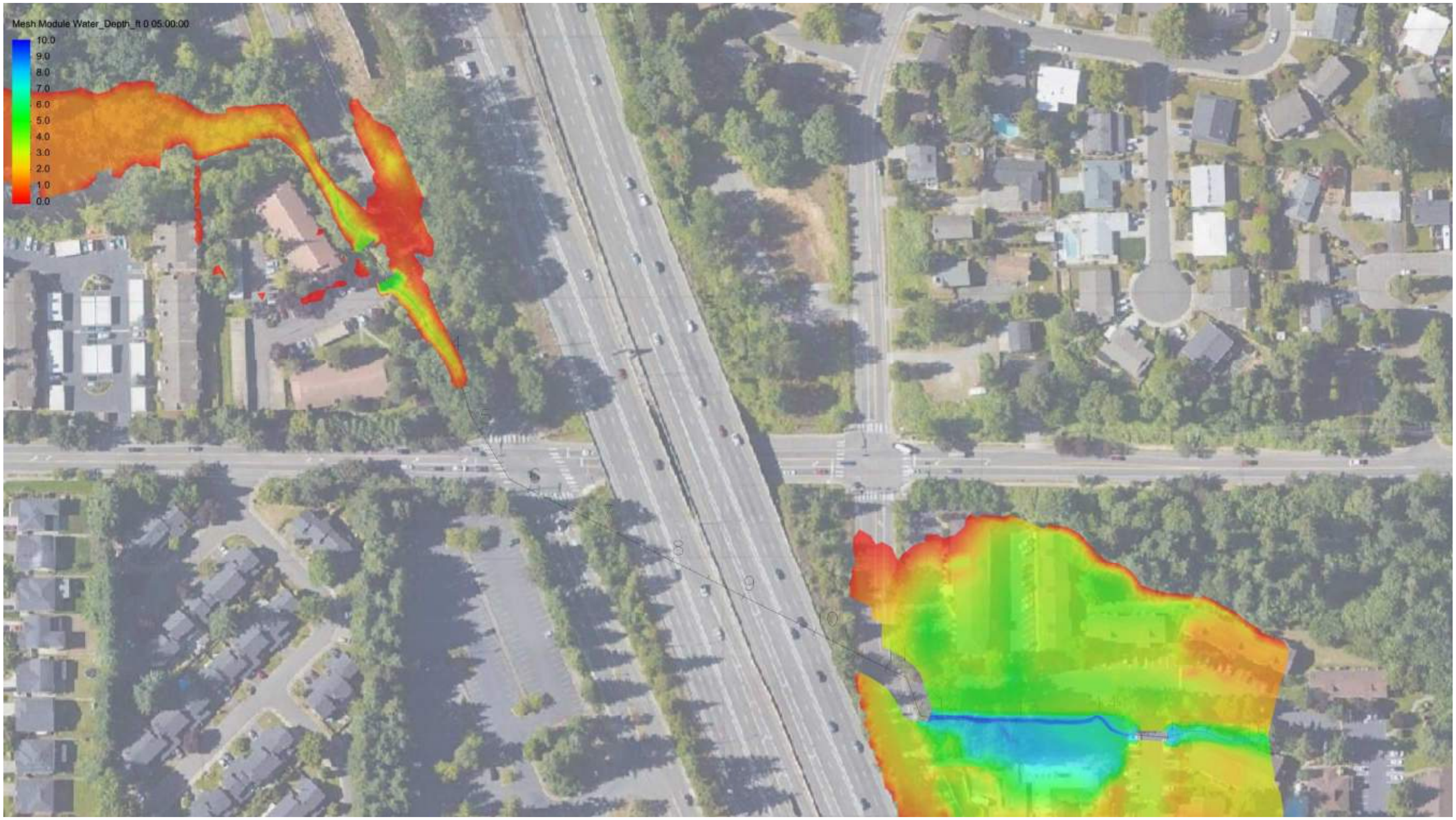
Juanita Creek Tributary Pre-Developed Conditions 25-Year Depth, USGS Regression Peak Flow



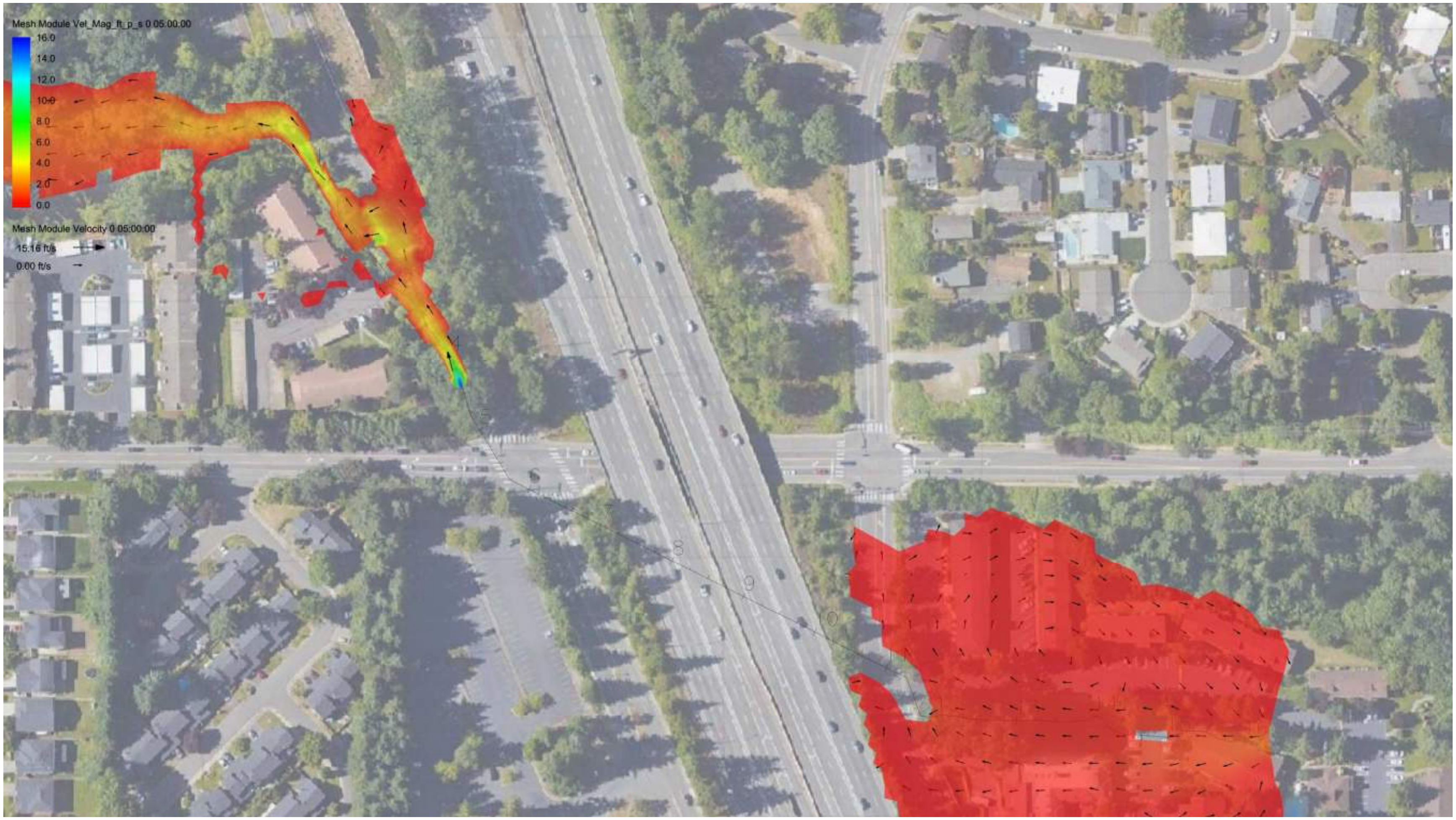
Juanita Creek Tributary Pre-Developed Conditions 25-Year Velocity, USGS Regression Peak Flow



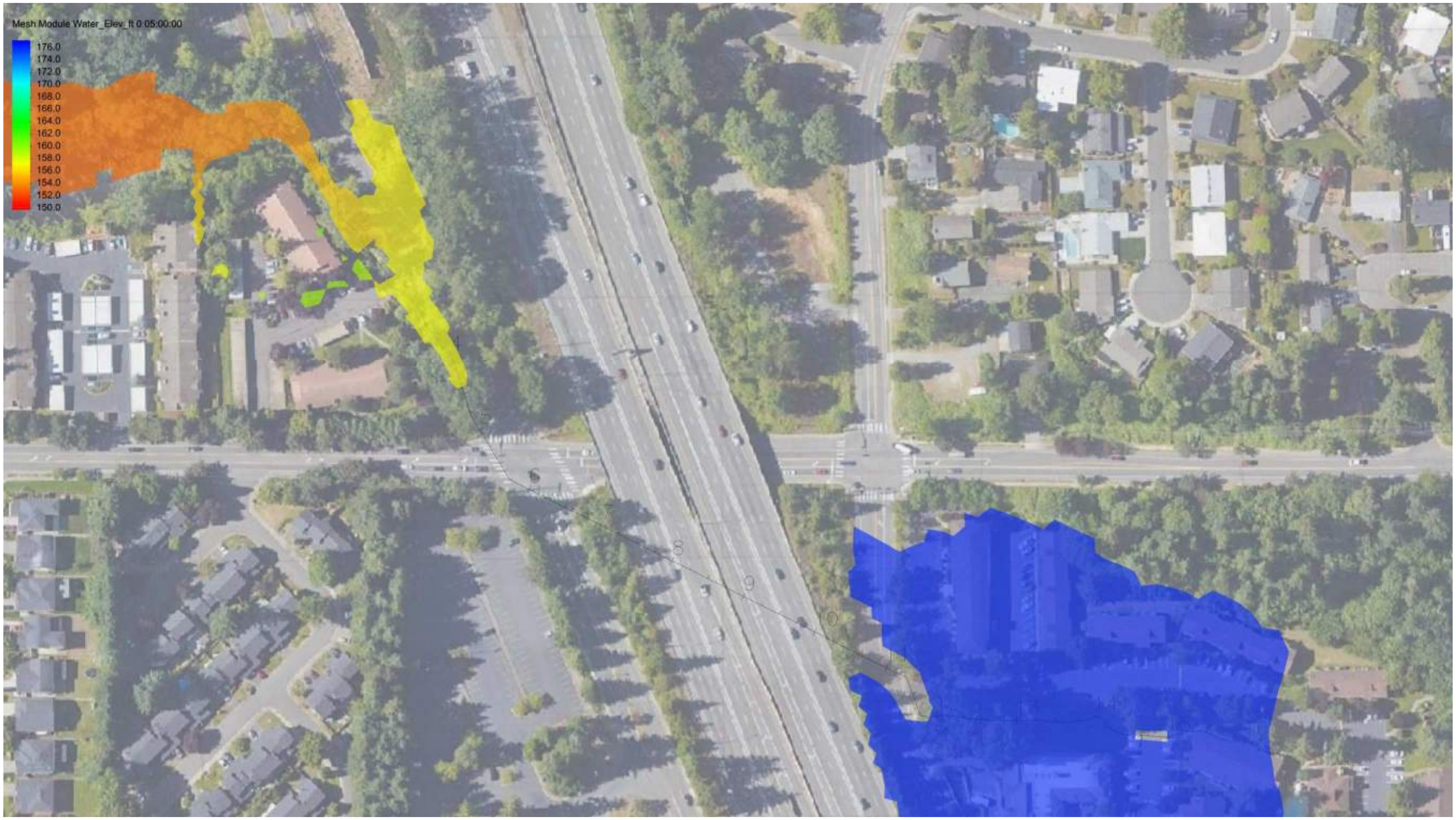
Juanita Creek Tributary Pre-Developed Conditions 25-Year Water Surface Elevation (WSE), USGS Regression Peak Flow



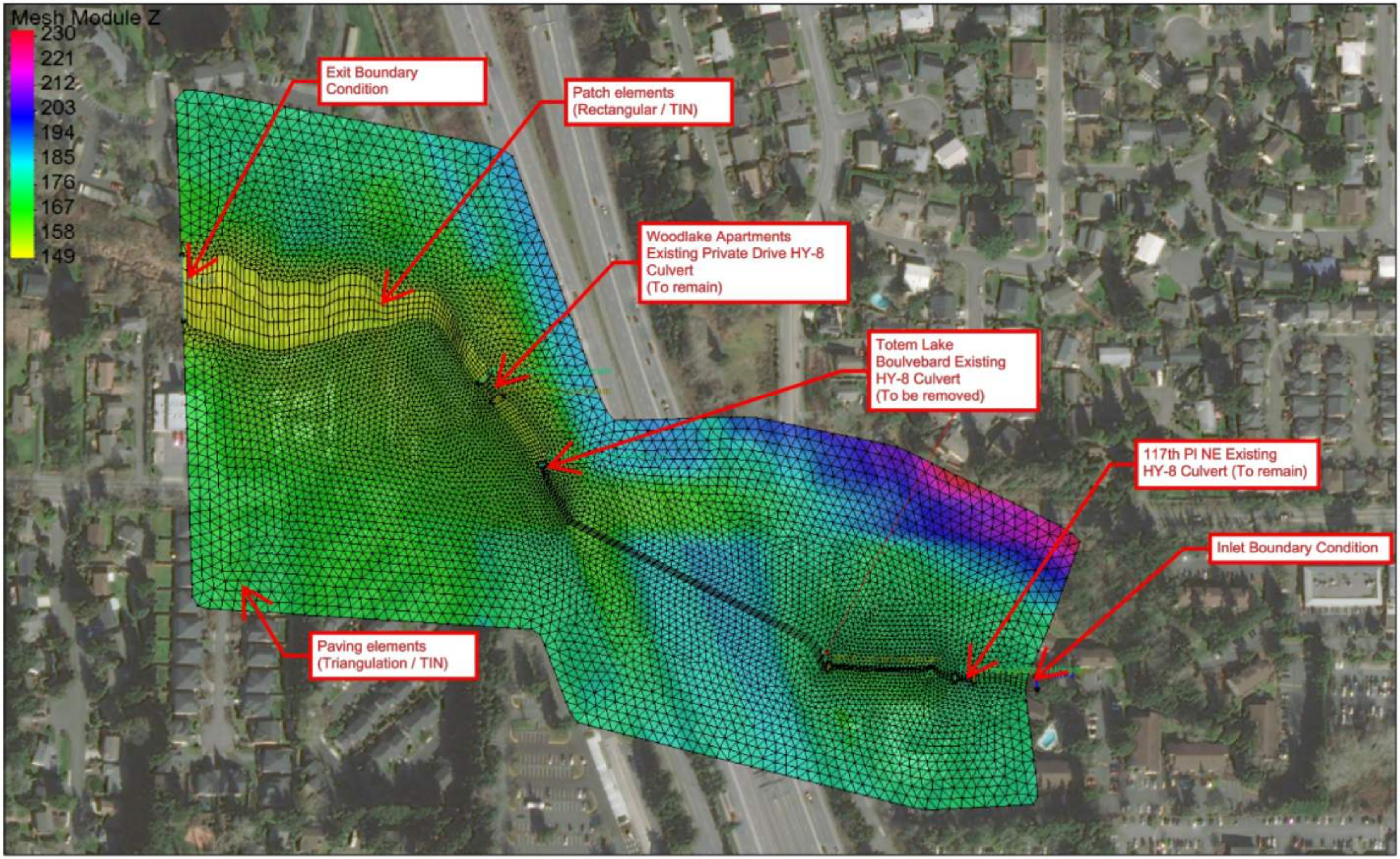
Juanita Creek Tributary Pre-Developed Conditions 100-Year Depth, USGS Regression Peak Flow



Juanita Creek Tributary Pre-Developed Conditions 100-Year Velocity, USGS Regression Peak Flow



Juanita Creek Tributary Pre-Developed Conditions 100-Year Water Surface Elevation (WSE), USGS Regression Peak Flow



Scale 1" = 200'

0 100' 200' 400'

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SRH-2D MODELING RESULTS FOR:

I-405 NE 132ND STREET INTERCHANGE PROJECT

EXISTING CONDITIONS

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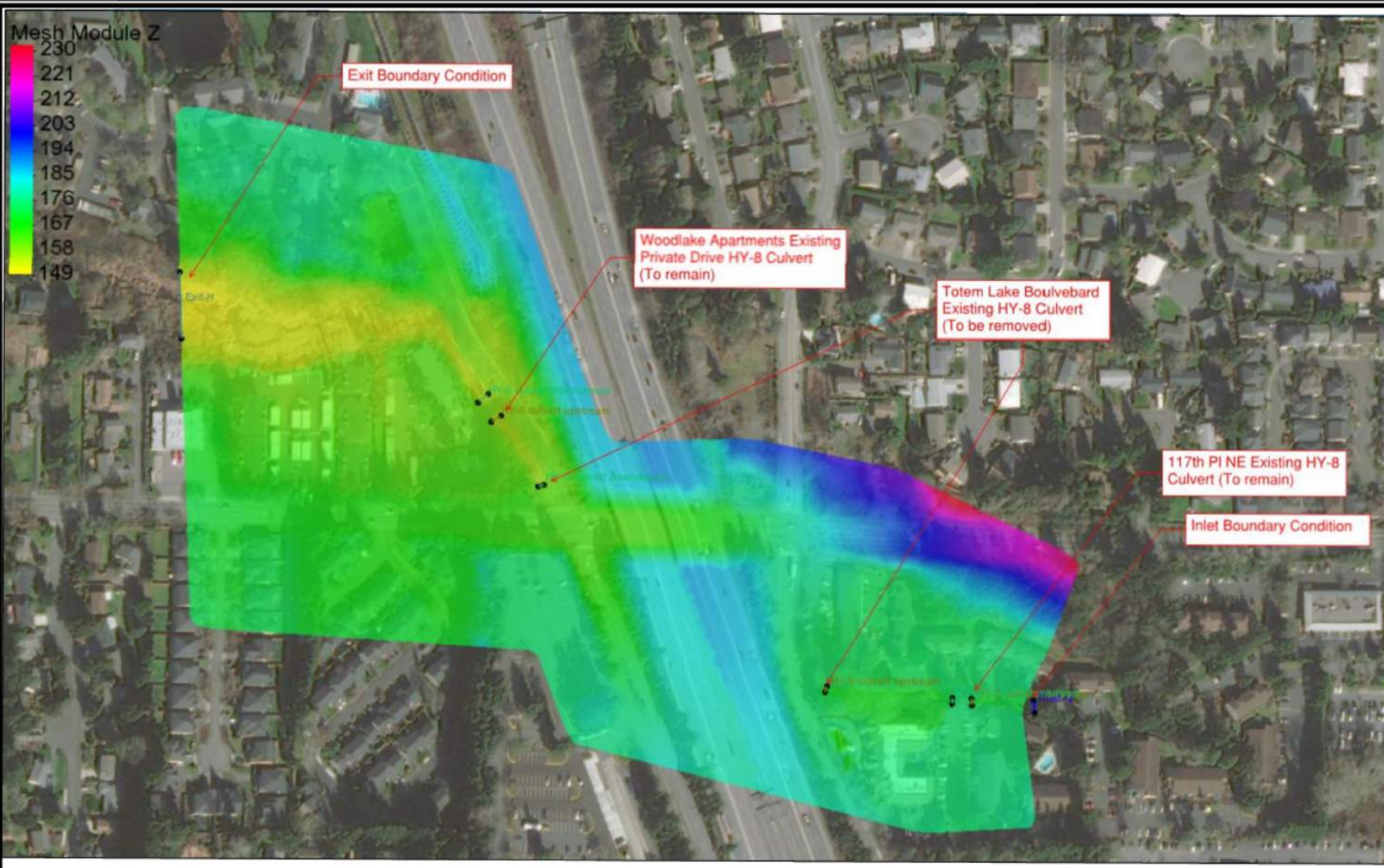

Scale 1" = 200'

0 100' 200' 400'

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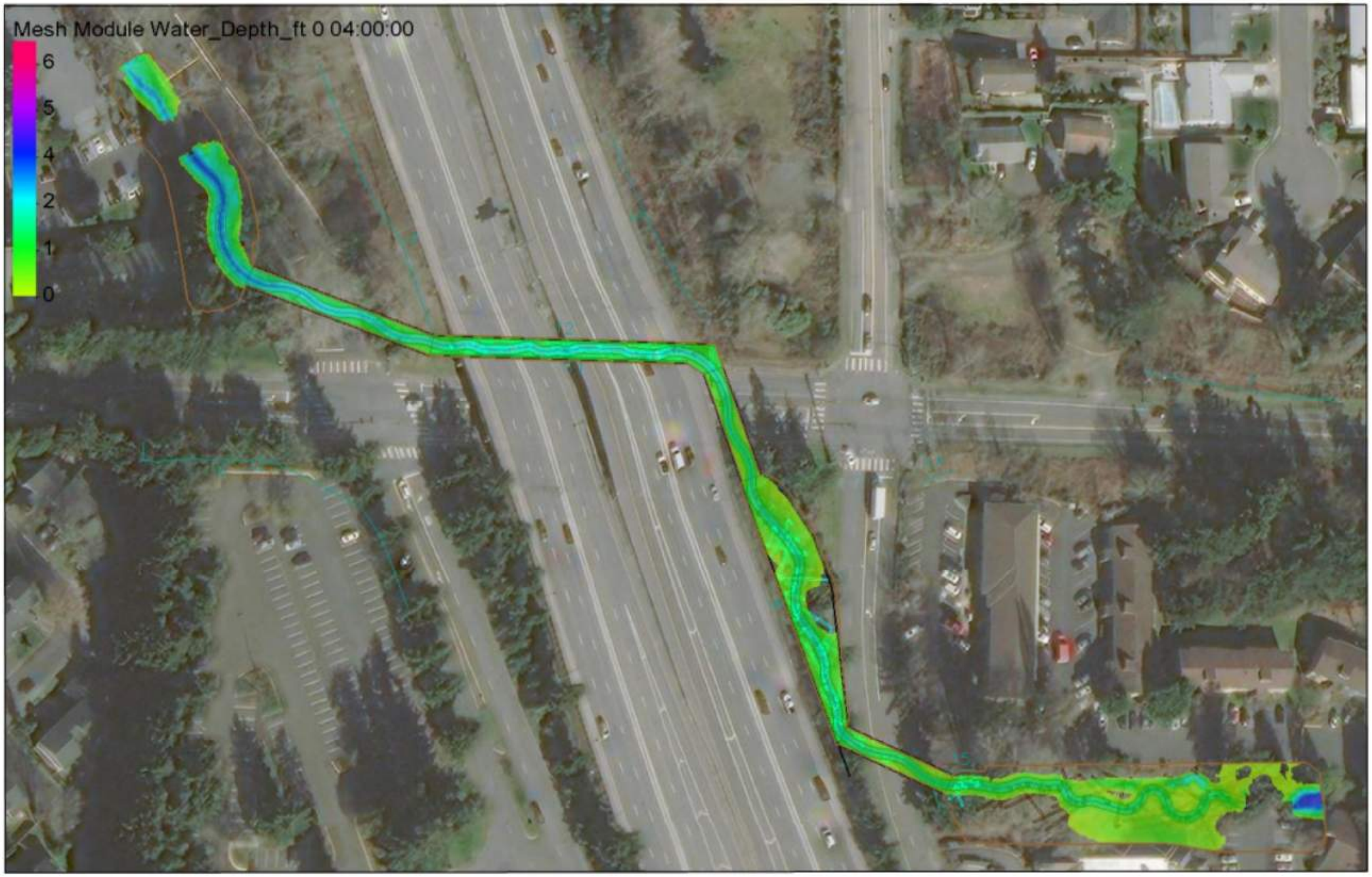
Appendix D.2

Proposed Conditions



Scale 1" = 100'

0 50' 100' 200'

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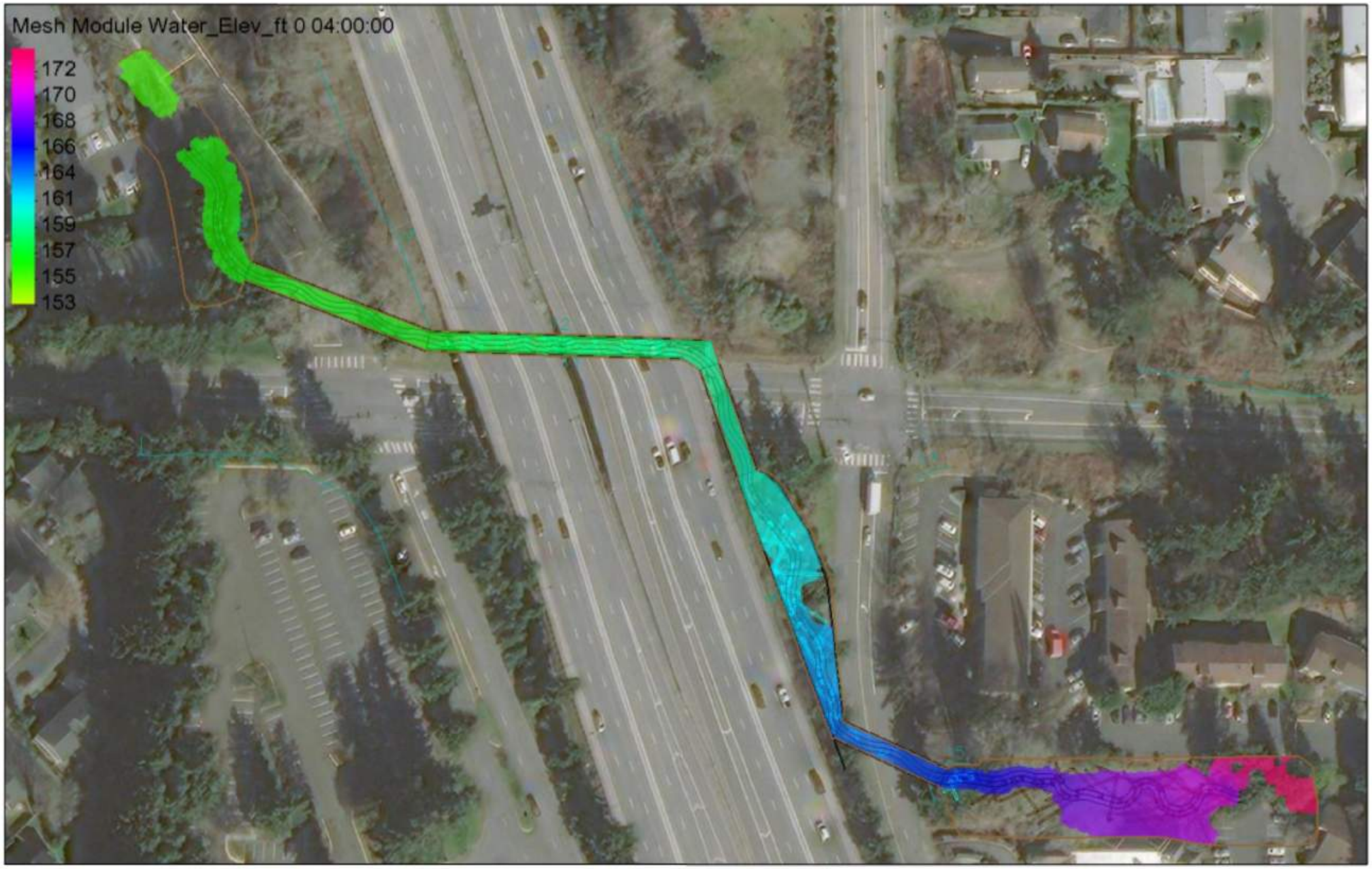

Scale 1" = 100'
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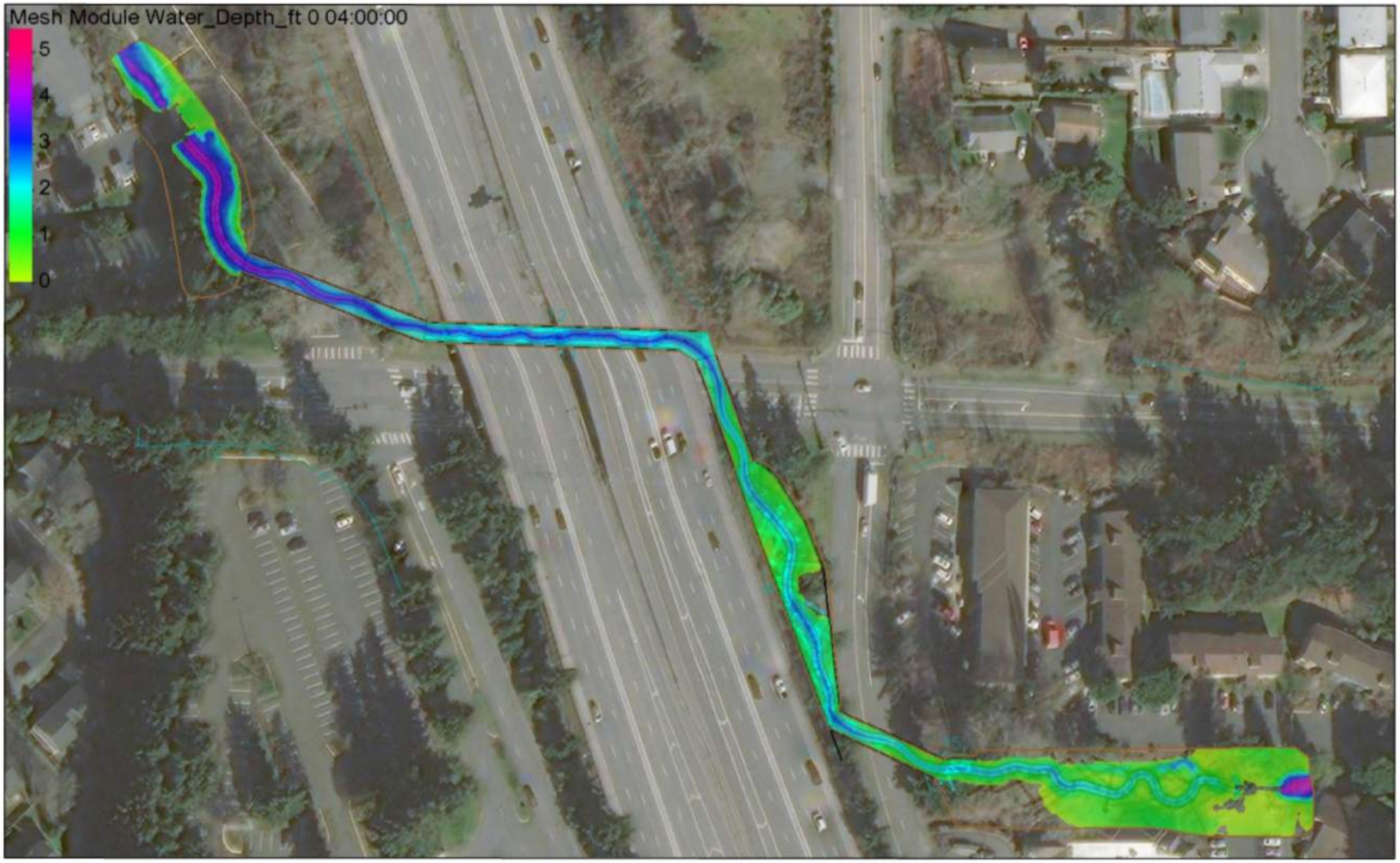

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25-YEAR RESULTS

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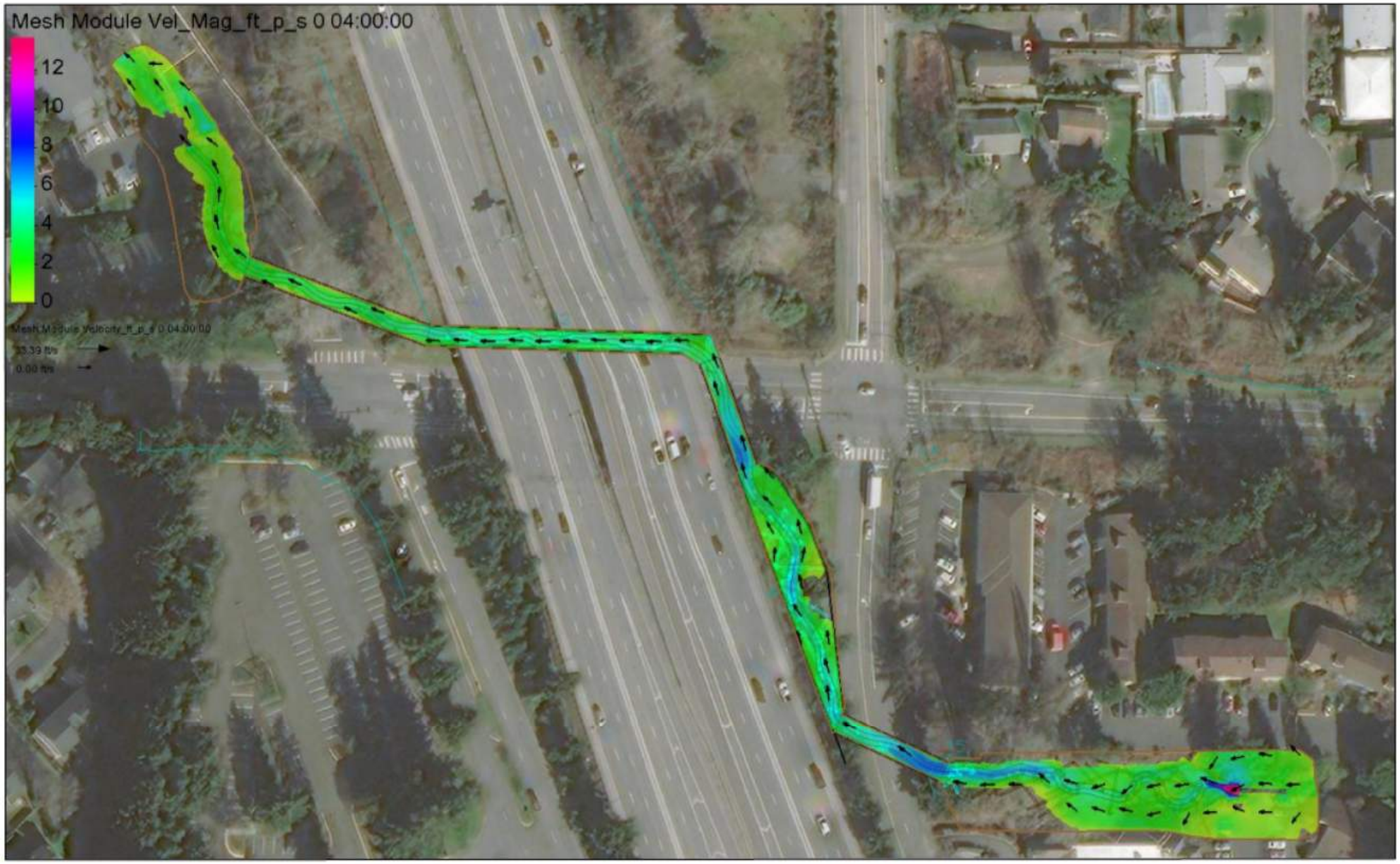

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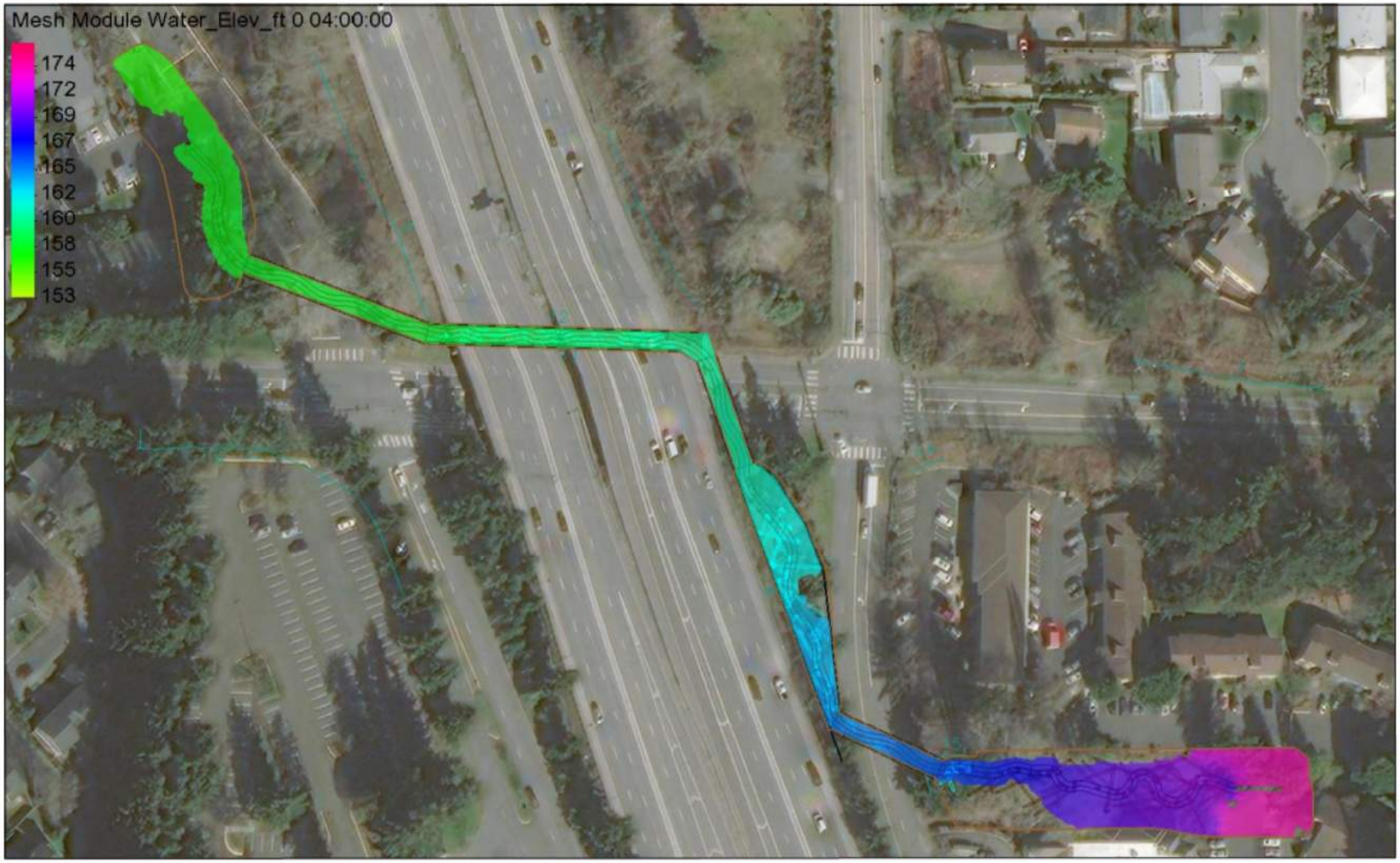

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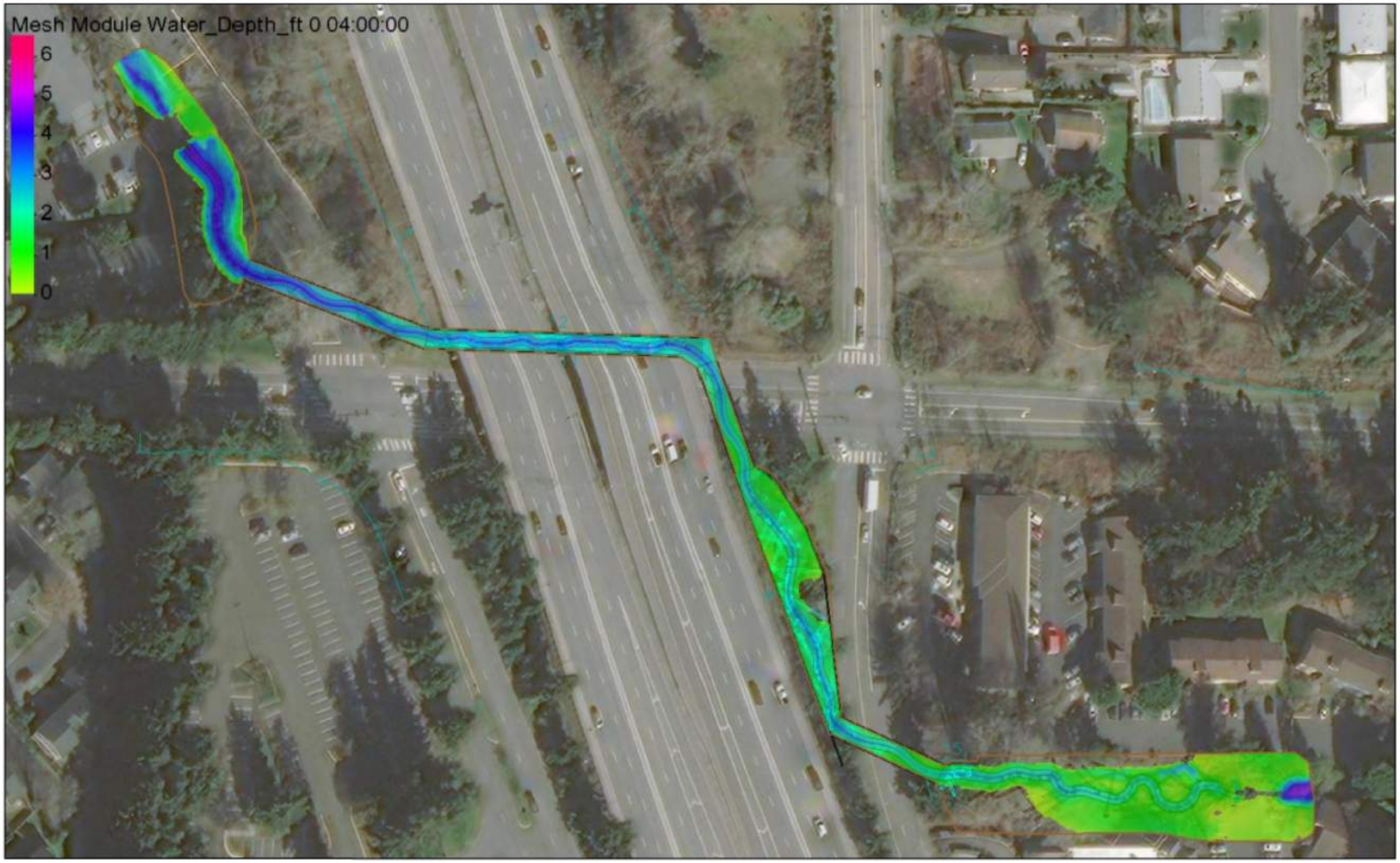

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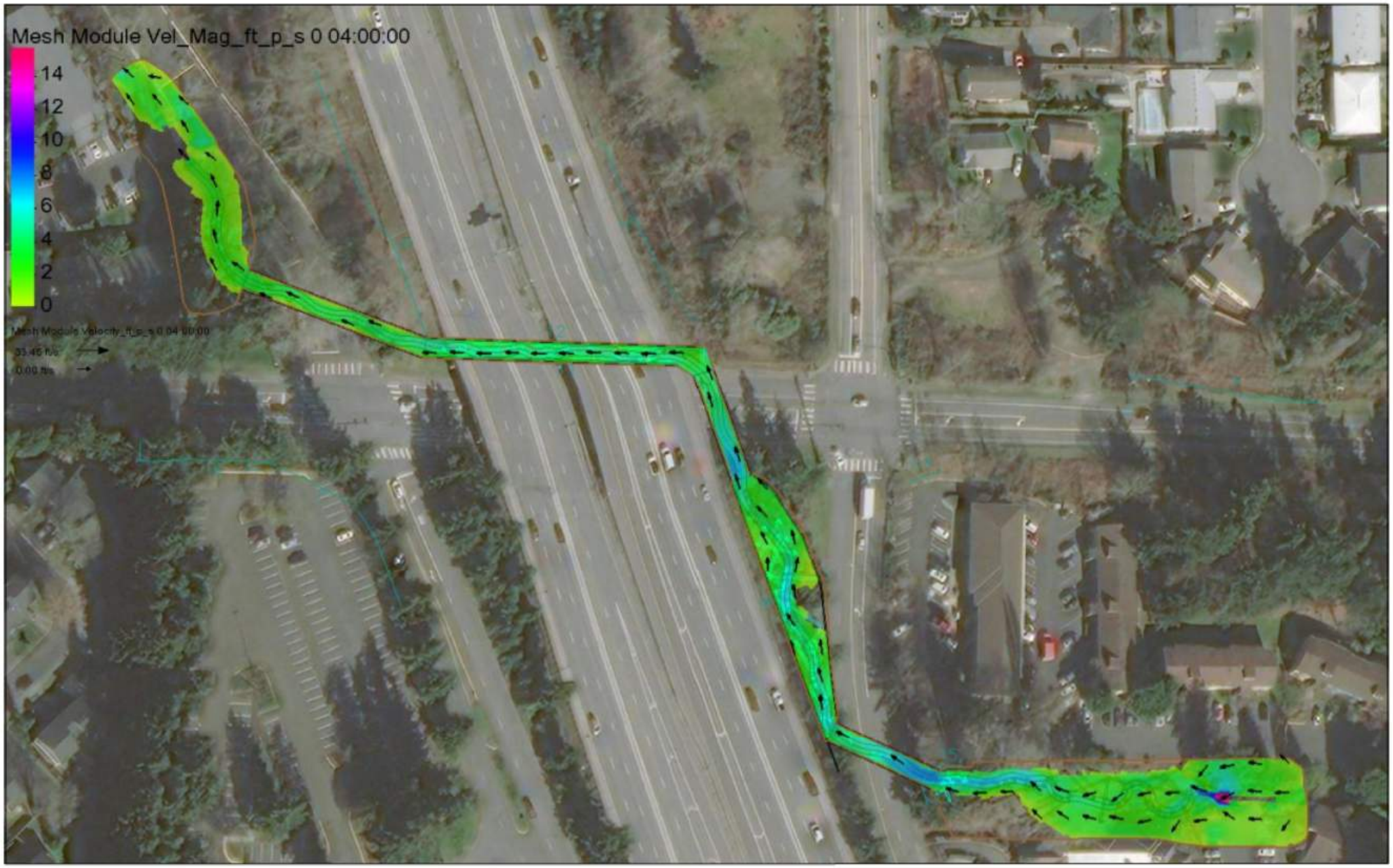

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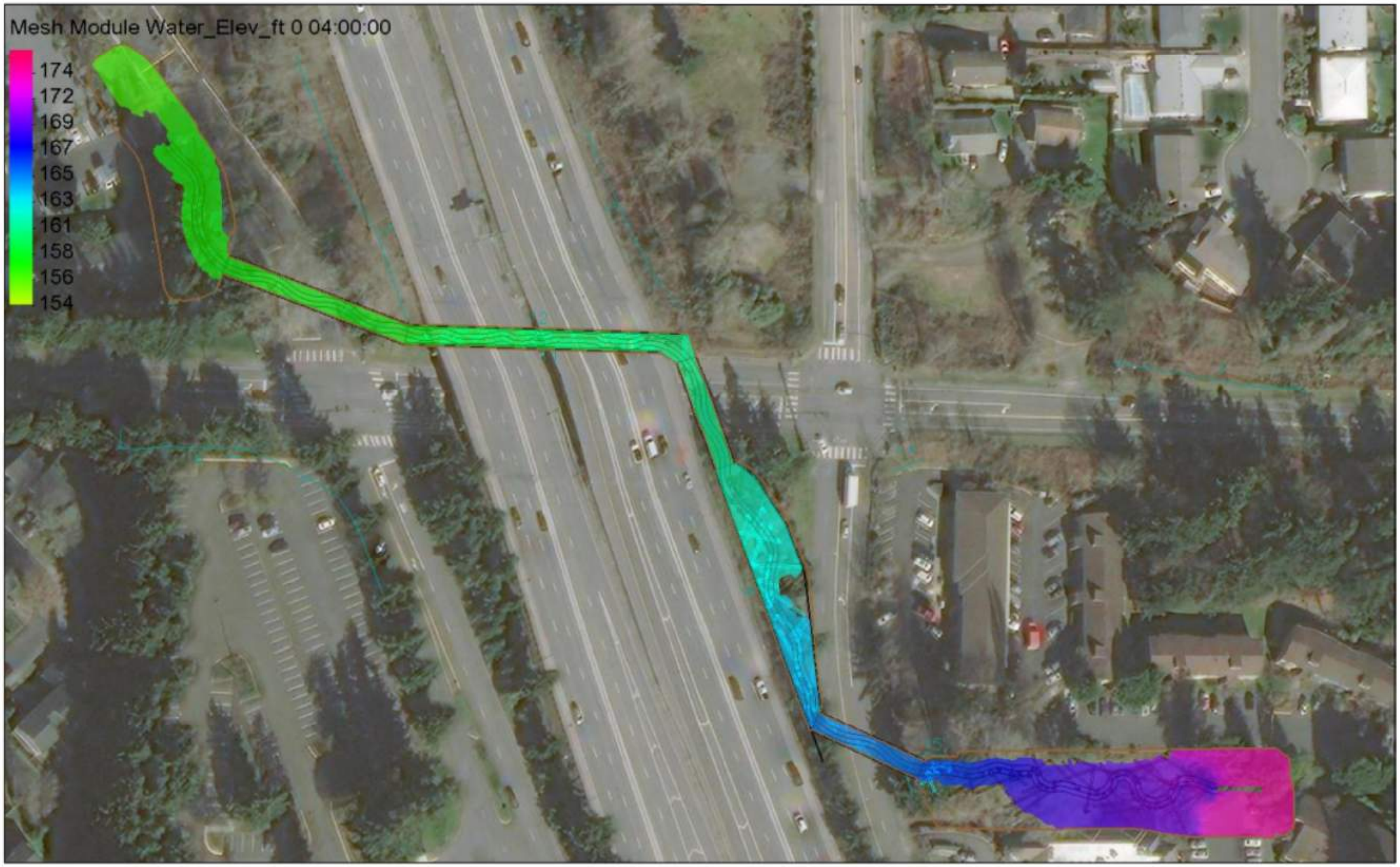

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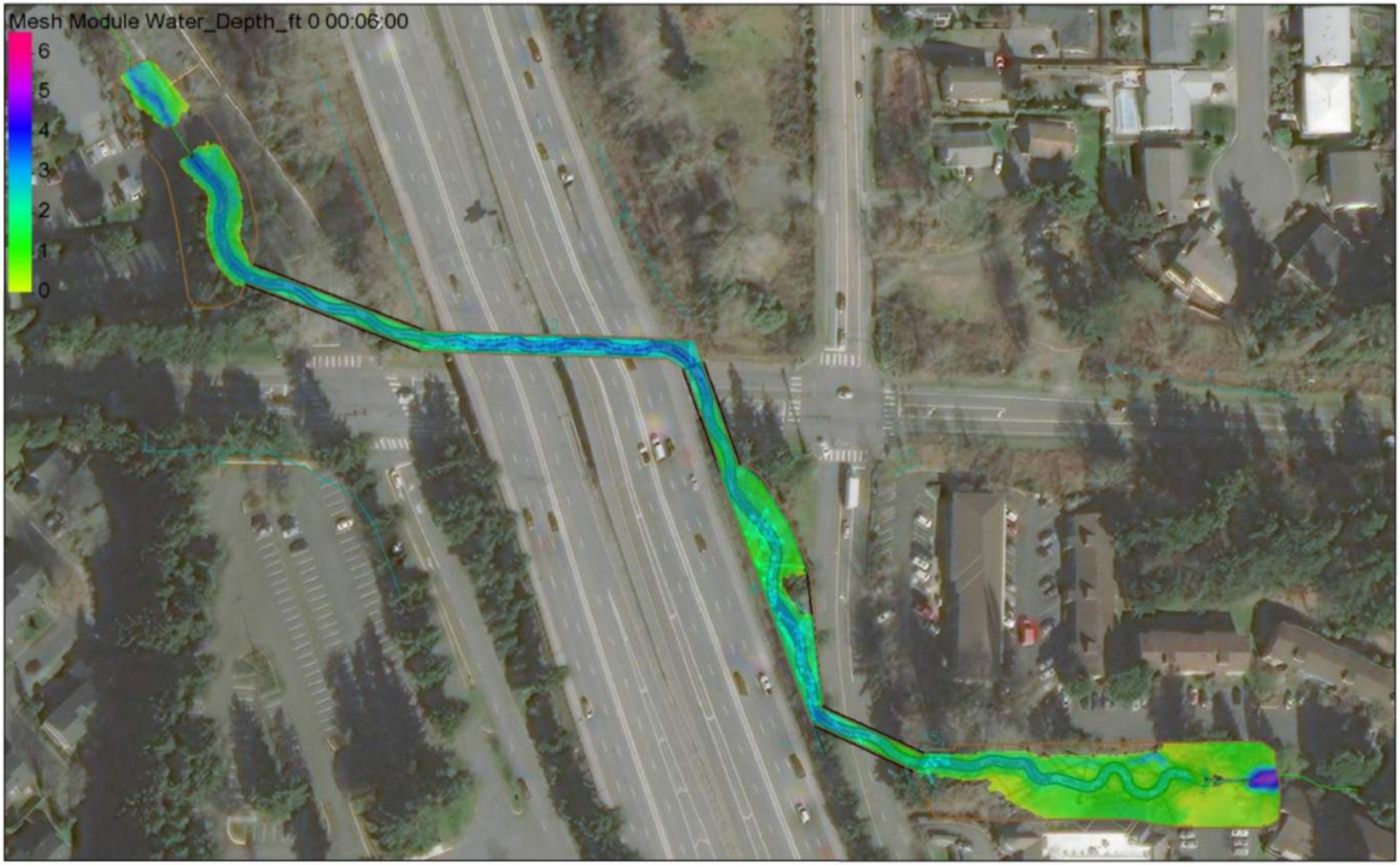

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2080-YEAR RESULTS

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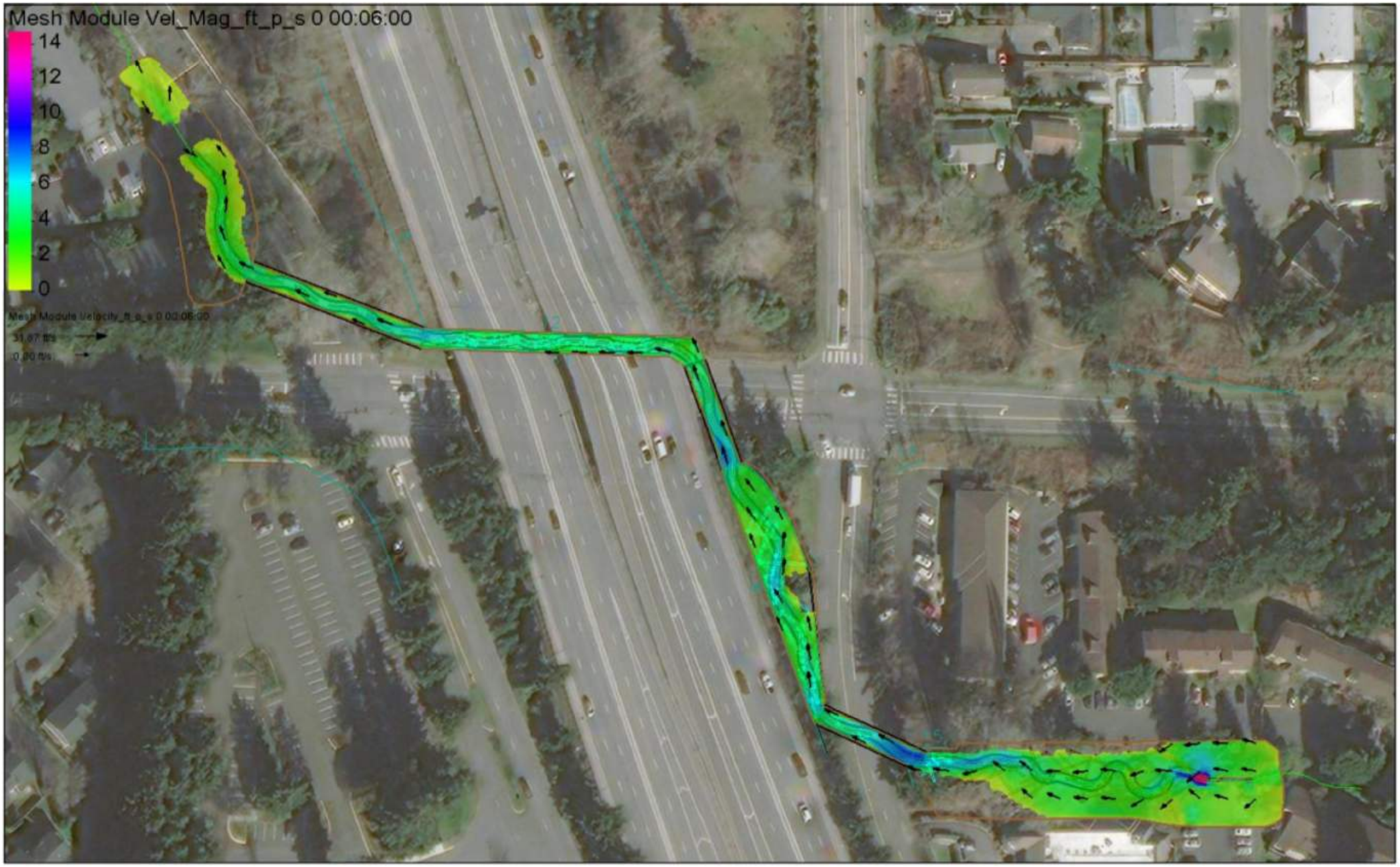

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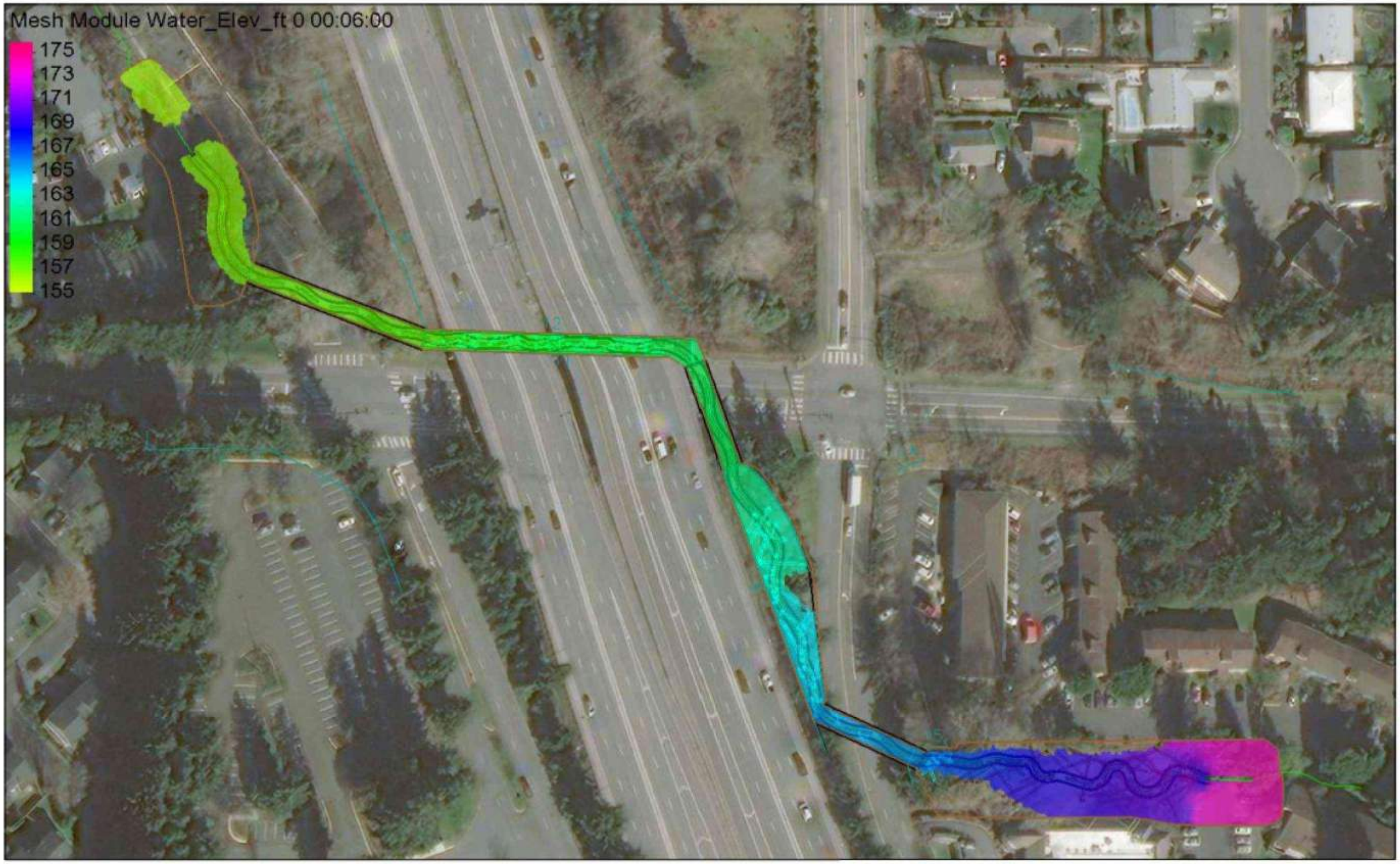

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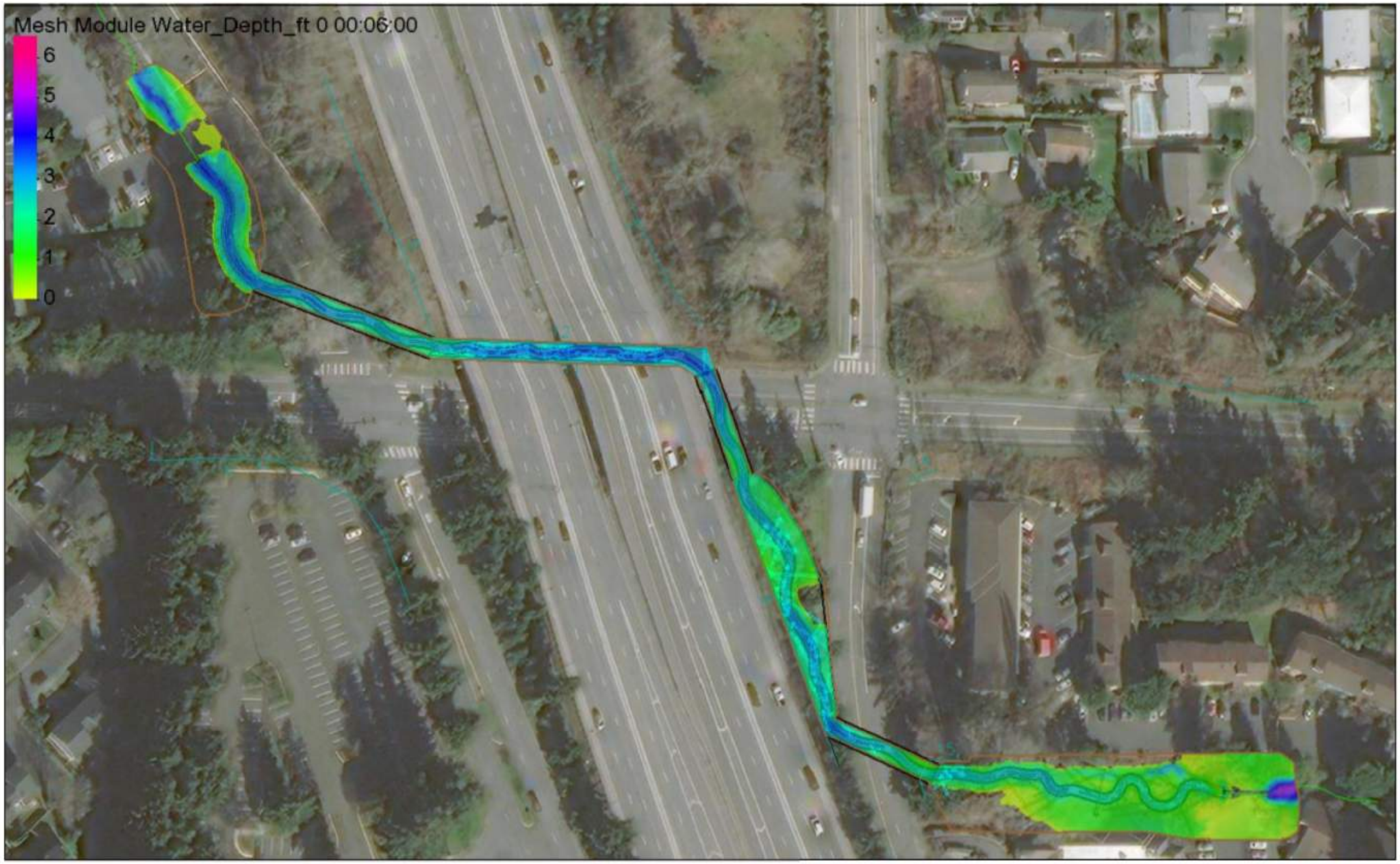

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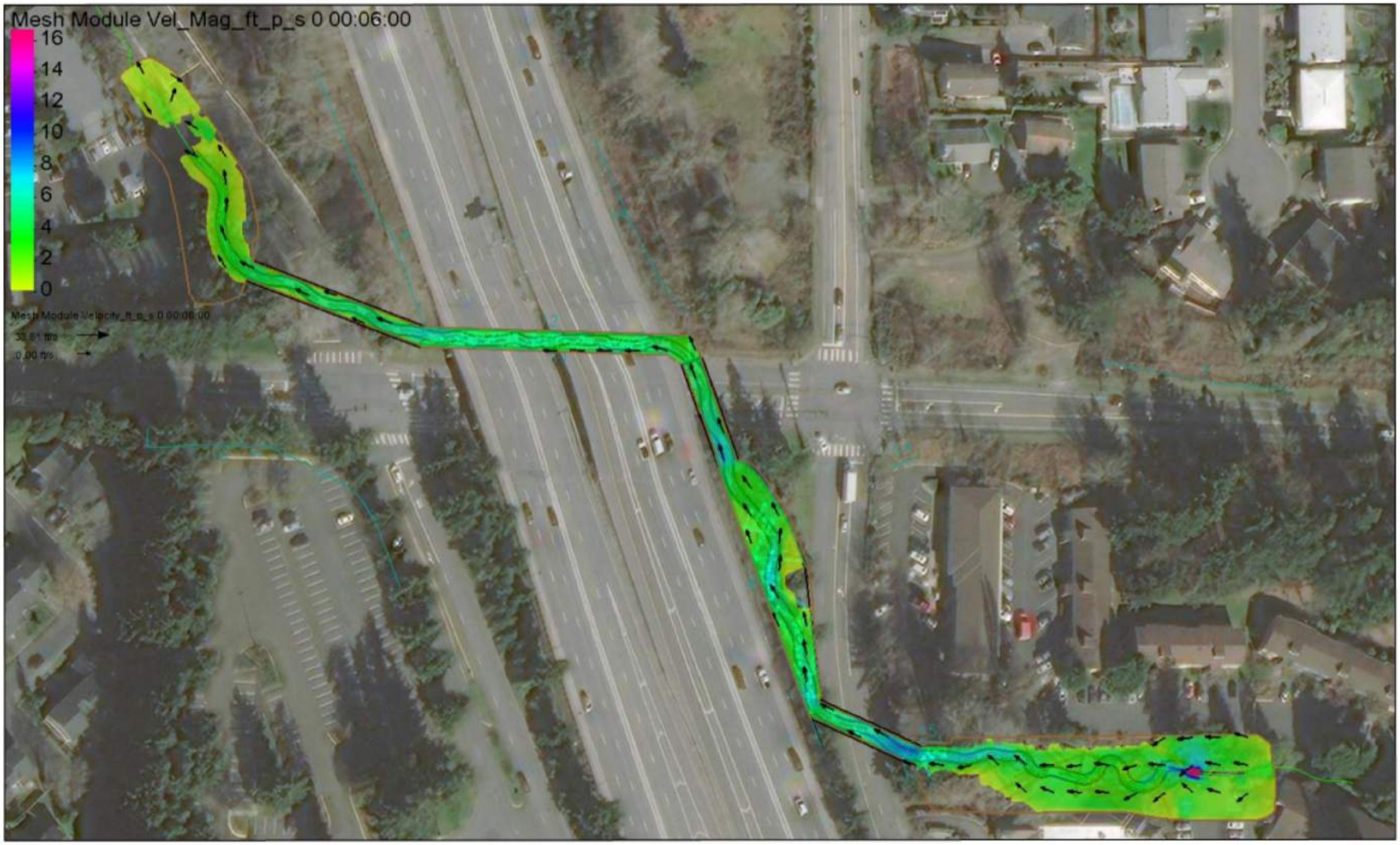

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500-YEAR RESULTS

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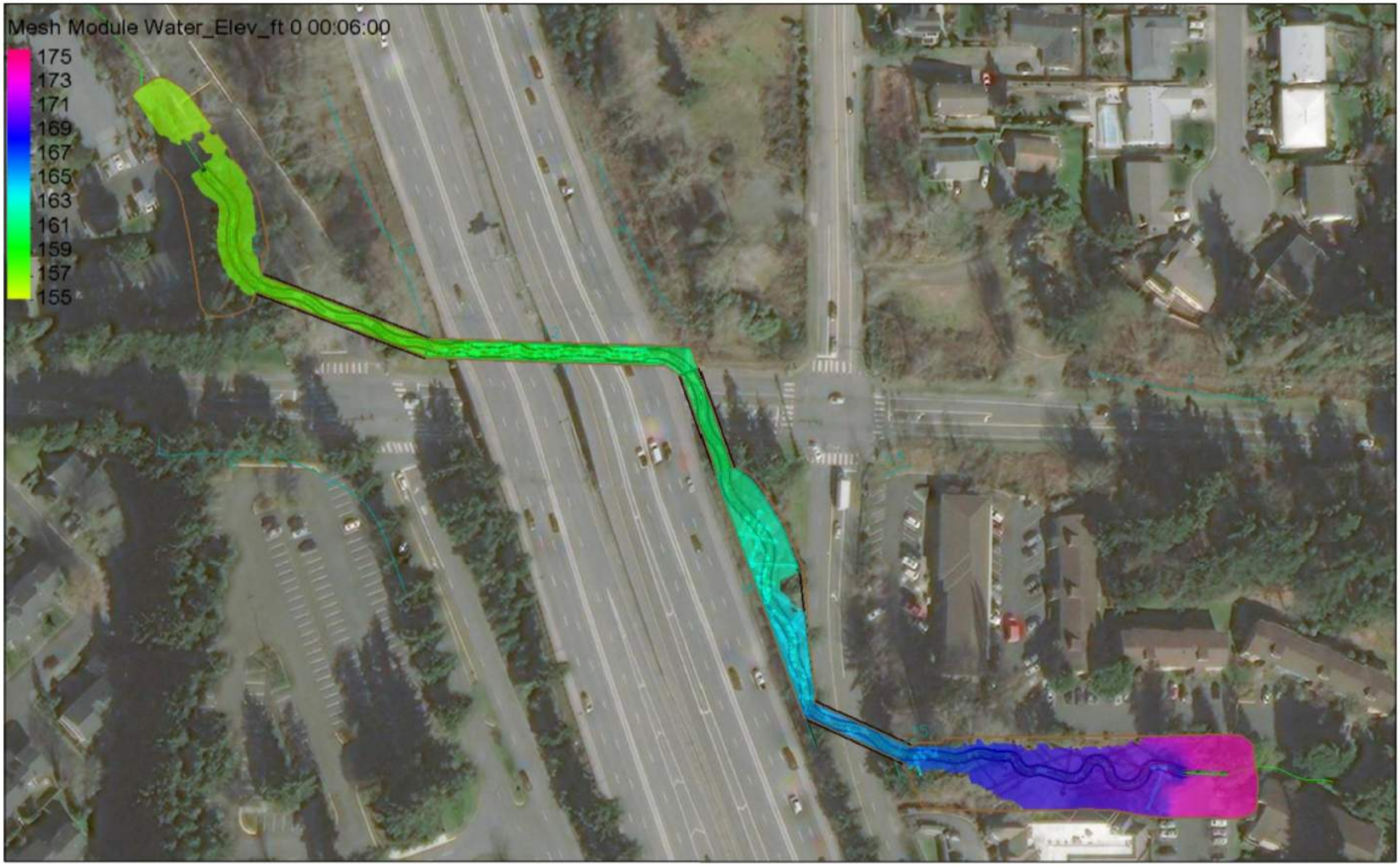

Scale 1" = 100'

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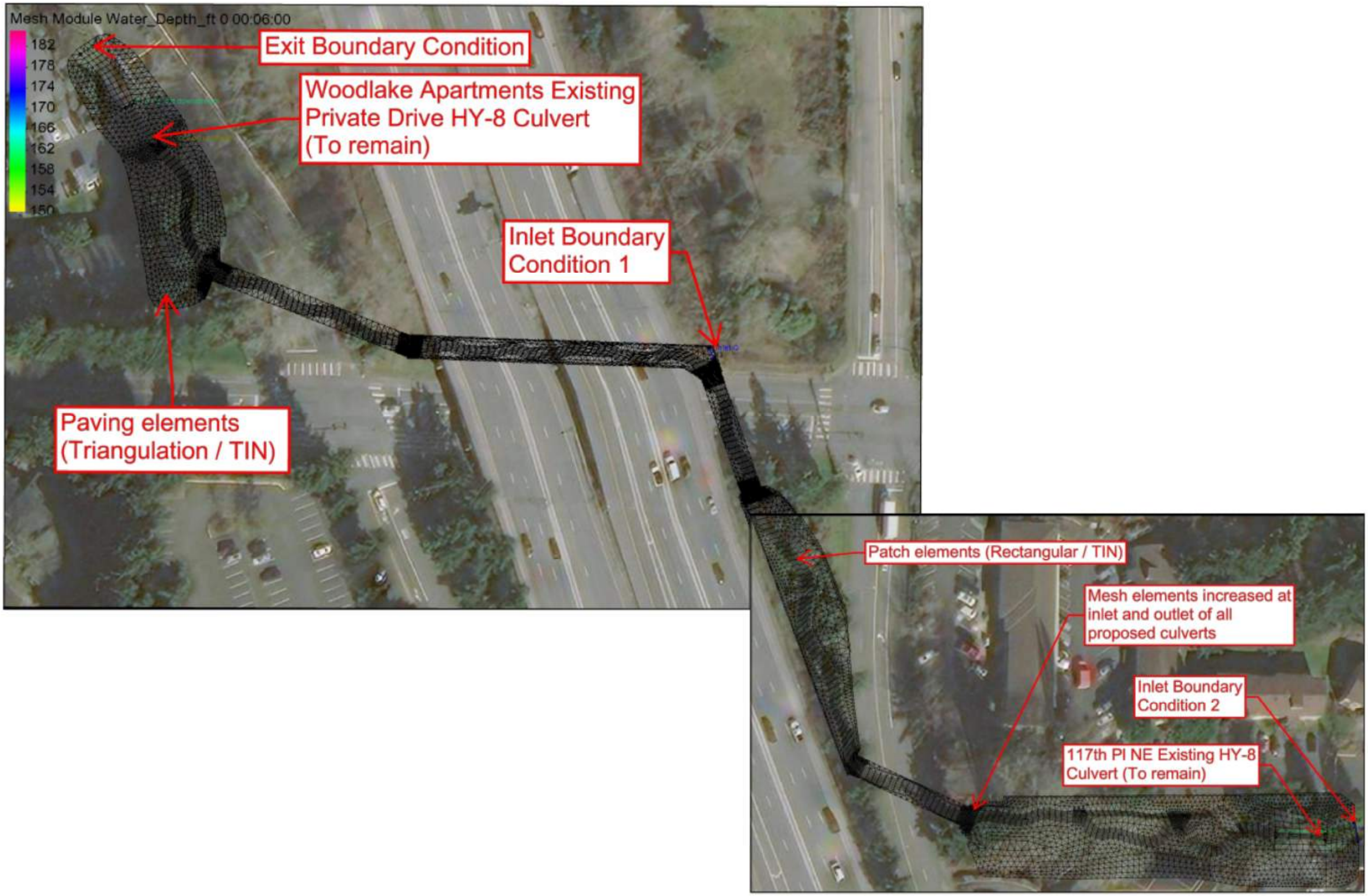
Proposed Conditions

SRH-2D Mesh Elevation, Elemental Models



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SRH-2D MODELING RESULTS FOR:
I-405 NE 132ND STREET INTERCHANGE PROJECT
EXISTING CONDITIONS

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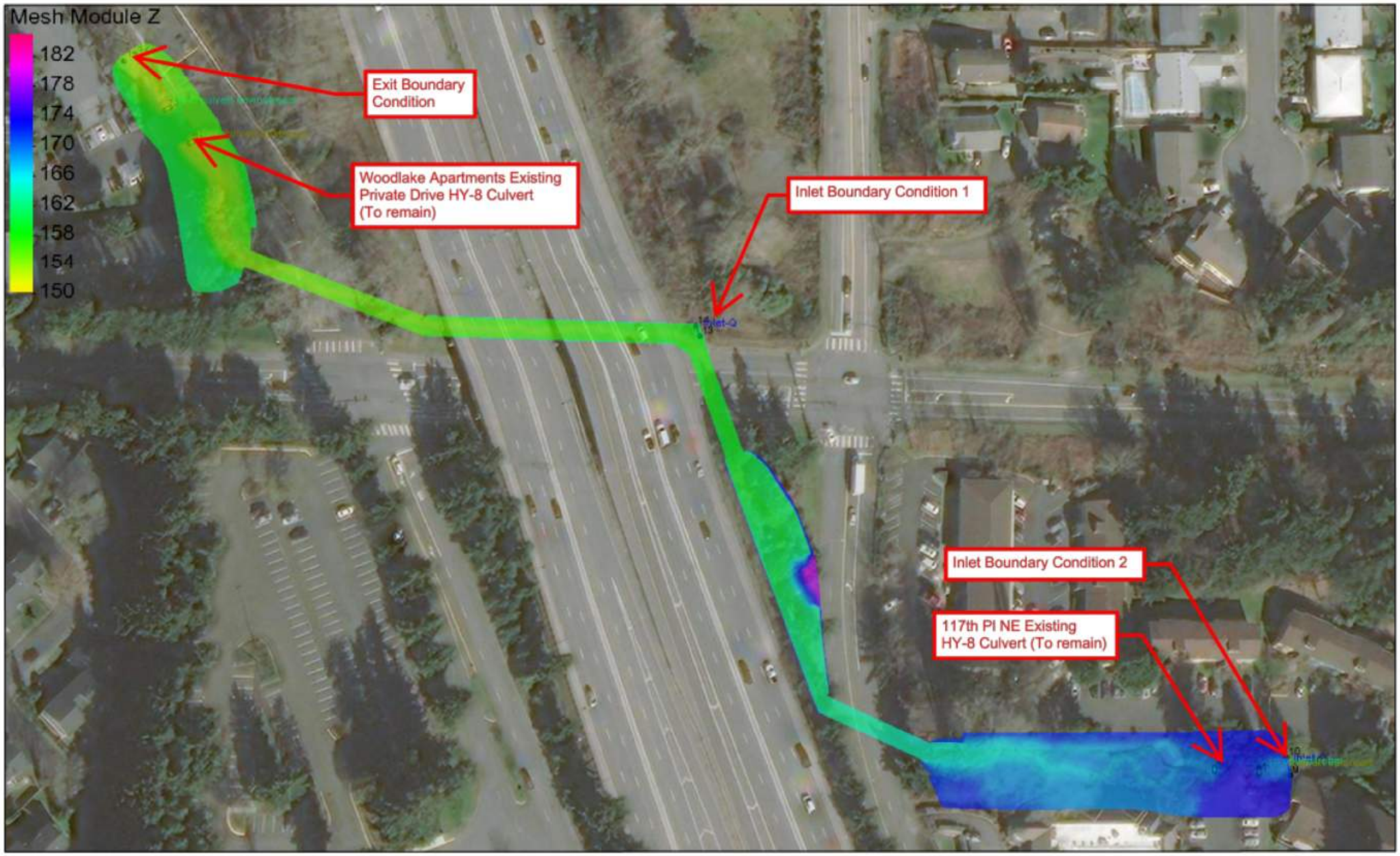
DEC, 2021
45044.001
SHEET ID
SRH-2D
SHEET - OF -



Scale 1" = 100'

0 50' 100' 200'

DRAFT FHD

PBS

SRH-2D MODELING RESULTS FOR:

I-405 NE 132ND STREET INTERCHANGE PROJECT

RPOPOSED CONDITIONS

Know what's below. Call before you dig.

DESIGNED: CNT

CHECKED: DEC

DEC, 2021

45044.001

SHEET ID

SRH-2D

SHEET - OF -

Appendix E

Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

Project:	**I-405 / 132nd Interchange Fish Passage Gradation**		
Designed By:	**CT**	**Checked By:**	**CB**
Updated:	**12/16/2021**		

OBSERVERD MATERIAL				
Location:	OBSERVED			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.14**	**0.09**	**0.04**	**0.02**
in	**1.69**	**1.03**	**0.51**	**0.24**
mm	**43**	**26**	**13.0**	**6.1**

Design Gradation:				
Location:	Coarse Bands			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.50**	**0.42**	**0.18**	**0.16**
in	**6.00**	**5.00**	**2.16**	**1.88**
mm	**152**	**127**	**55.0**	**47.8**

PROPOSED MATERIAL				
Location:	PROPOSED			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.17**	**0.10**	**0.05**	**0.02**
in	**2.03**	**1.24**	**0.61**	**0.29**
mm	**52**	**31**	**15.5**	**7.4**

Design Gradation:				
Location:	Downstream Gravel Bar			
	D_{100}	**D_{84}**	**D_{50}**	**D_{16}**
ft	**0.00**	**0.00**	**0.00**	**0.00**
in				
mm	**0**	**0**	**0.0**	**0.0**

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size		**Streambed Sediment**	**Streambed Cobbles**					**Streambed Boulders**			**D_{size}**
	[in]	**[mm]**		**4"**	**6"**	**8"**	**10"**	**12"**	**12"-18"**	**18"-28"**	**28"-36"**	
	36.0	**914**									**100**	**100.0**
	32.0	**813**									50	**100.0**
	28.0	**711**								**100**		**100.0**
	23.0	**584**								50		**100.0**
	18.0	**457**							**100**			**100.0**
	15.0	**381**							50			**100.0**
	12.0	**305**						**100**				**100.0**
	10.0	**254**					**100**	**75**				**100.0**
	8.0	**203**				**100**	**50**	70				**100.0**
	6.0	**152**			**0**	**25**	40	65				**30.0**
	5.0	**127**			**85**	18	30	**60**				**89.5**
	4.0	**102**		**100**	74	12	**20**	52				**81.6**
	3.0	**76.2**		**90**	63	**5**	18	43				**70.9**
	2.5	**63.5**	**100**	75	51	5	15	35				**58.5**
	2.0	**50.8**	**65**	59	**40**	5	13	26				**45.9**
	1.5	**38.1**	63	**44**	30	5	10	18				**34.4**
	1.0	**25.4**	**60**	20	20	5	8	9				**20.4**
	0.75	**19.1**	52	**10**	**10**	**5**	**5**	**1**				**10.4**
0.2	**No. 4 =**	**4.75**	**44**									**0.4**
	No. 40 =	**0.425**	**16**									**0.2**
	No. 200 =	**0.0750**	**9**									**0.1**
	% per category		**1**	**29**	**70**	**0**	**0**	**0**	**0**	**0**		*--> 100%*
	% Cobble & Sediment		**1.0**	**29.0**	**70.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

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

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water ($1b/ft^3$)
τ_{D50}	0.054	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Flow	2-YR (109 cfs)	2-YR (109 cfs)	10-YR (192 cfs)	25-YR (235 cfs)	50-YR (274 cfs)	100-YR (306 cfs)	500-YR (397 cfs)
Average Modeled Shear Stress (lb/ft^2)	0.5	0.7	0.86	0.97	1.00	1.02	1.15
τ_{ci}		Structure					
2.32	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.24	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.15	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.03	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.89	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.79	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.67	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.58	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.48	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.36	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.28	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.20	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
1.10	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
1.04	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	Motion
0.98	No Motion	No Motion	No Motion	No Motion	Motion	Motion	Motion
0.89	No Motion	No Motion	No Motion	Motion	Motion	Motion	Motion
0.79	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
0.73	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
D16		22.60	0.889779559				
	D50	2.16	inches				
		0.18	ft				
	D84	5.00	inches				

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

Summary - Stream Simulation Bed Material Design

Project:	I-405 / 132nd Interchange Fish Passage Gradation		
Designed By:	CT	Checked By:	CB
Updated:	10/26/2021		

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

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

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.054	dimensionless Shields parameter for D50

OBSERVERD MATERIAL

Location: OBSERVED

	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in	1.69	1.03	0.51	0.02
mm	43	26	13.0	0.5

Design Gradation:

Location: Upstream Gravel Bar

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.21	0.11	0.04	0.02
in	2.50	1.27	0.47	0.24
mm	64	32	11.9	6.0

PROPOSED MATERIAL

Location: PROPOSED

	D_{100}	D_{84}	D_{50}	D_{16}
ft				
in	2.0	1.2	0.6	0.3
mm	52	31	15.5	7.4

Design Gradation:

Location: Downstream Gravel Bar

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in				
mm	0	0	0.0	0.0

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

	Rock Size [in]	[mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
	36.0	914									100	100.0
	32.0	813									50	100.0
	28.0	711								100		100.0
	23.0	584								50		100.0
	18.0	457							100			100.0
	15.0	381							50			100.0
	12.0	305						100				100.0
	10.0	254					100	80				100.0
	8.0	203				100	80	68				100.0
	6.0	152			100	80	68	57				100.0
	5.0	127			80	68	57	45				100.0
	4.0	102		100	71	57	45	39				100.0
	3.0	76.2		80	63	45	38	34				100.0
	2.5	63.5	100	65	54	37	32	28				100.0
	2.0	50.8	95	50	45	29	25	22				95.0
	1.5	38.1	88	35	32	21	18	16				87.5
	1.0	25.4	80	20	18	13	12	11				80.0
	0.75	19.1	60	5	5	5	5	5				60.0
0.19	No. 4 =	4.75	40									40.0
0.02	No. 40 =	0.425	14									14.0
	No. 200 =	0.0750	7									7.0
	% per category		100	0	0	0	0	0	0			*--> 100%*
	% Cobble & Sediment		100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*100.0%*

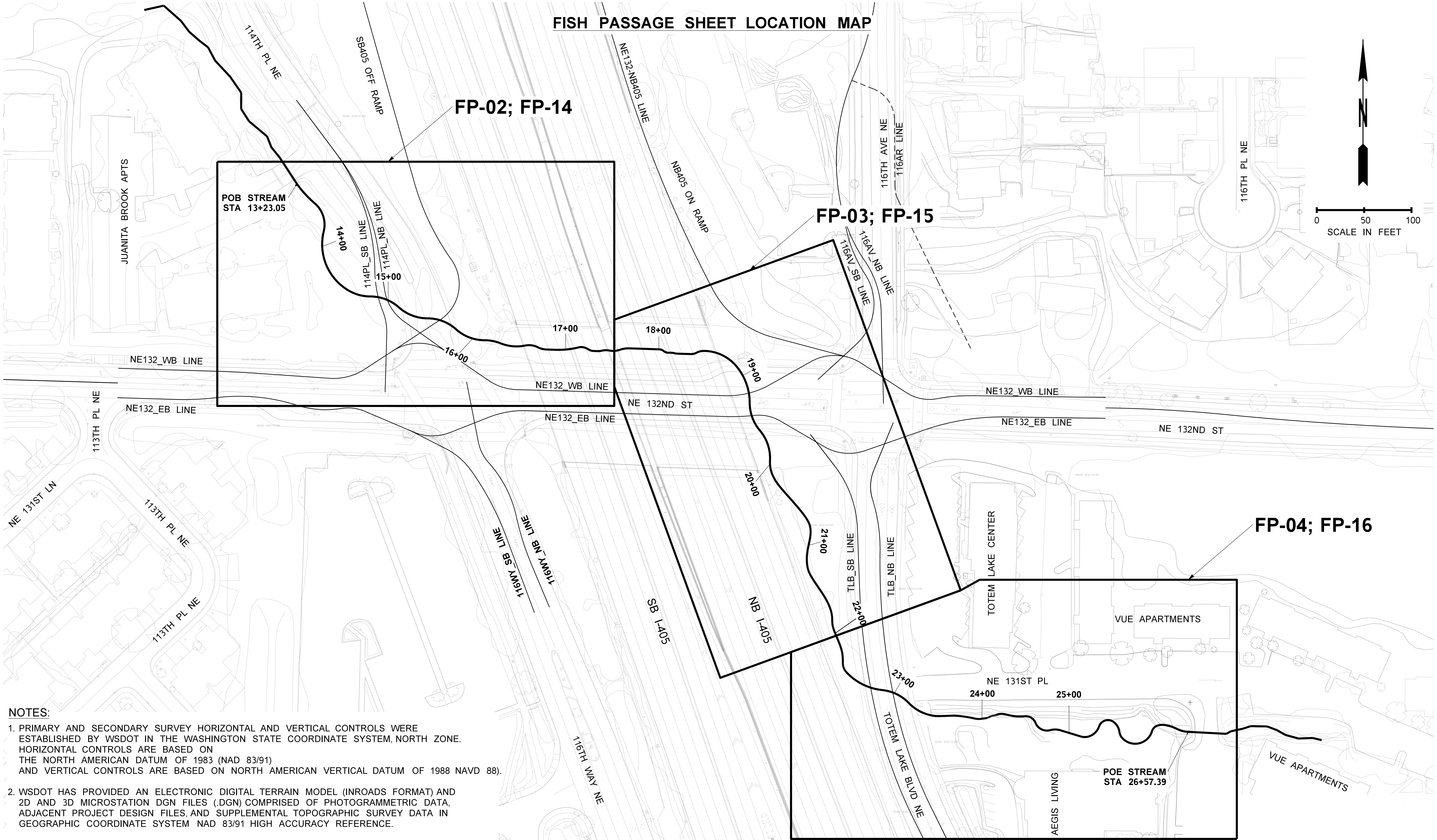
Flow	2-YR (69.2 cfs)	25-YR (137.5 cfs)	100-YR (165.1 cfs)
Average Modeled Shear Stress (lb/ft^2)	0.82	0.94	0.98
τ_{ci}		Structure	
0.80	Motion	Motion	Motion
0.77	Motion	Motion	Motion
0.74	Motion	Motion	Motion
0.70	Motion	Motion	Motion
0.65	Motion	Motion	Motion
0.61	Motion	Motion	Motion
0.57	Motion	Motion	Motion
0.54	Motion	Motion	Motion
0.51	Motion	Motion	Motion
0.46	Motion	Motion	Motion
0.44	Motion	Motion	Motion
0.41	Motion	Motion	Motion
0.38	Motion	Motion	Motion
0.36	Motion	Motion	Motion
0.33	Motion	Motion	Motion
0.31	Motion	Motion	Motion
0.27	Motion	Motion	Motion
0.25	Motion	Motion	Motion

D16	0.24	0.009277876
D50	0.47	inches
	0.04	ft
D84	1.27	

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

Appendix F
Stream Plan Sheets, Profile, Details

FISH PASSAGE SHEET LOCATION MAP



NOTES:

1. PRIMARY AND SECONDARY SURVEY HORIZONTAL AND VERTICAL CONTROLS WERE ESTABLISHED BY WSDOT IN THE WASHINGTON STATE COORDINATE SYSTEM, NORTH ZONE. HORIZONTAL CONTROLS ARE BASED ON THE NORTH AMERICAN DATUM OF 1983 (NAD 83/91) AND VERTICAL CONTROLS ARE BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988 NAVD 88).

2. WSDOT HAS PROVIDED AN ELECTRONIC DIGITAL TERRAIN MODEL (INROADS FORMAT) AND 2D AND 3D MICROSTATION DGN FILES (.DGN) COMPRISED OF PHOTOGRAMMETRIC DATA, ADJACENT PROJECT DESIGN FILES, AND SUPPLEMENTAL TOPOGRAPHIC SURVEY DATA IN GEOGRAPHIC COORDINATE SYSTEM NAD 83/91 HIGH ACCURACY REFERENCE.

   BASIS OF BEARING: WASHINGTON STATE PLANE COORDINATE SYSTEM NORTH ZONE (NAD 83/91).

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ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

PRELIMINARY
NOT FOR CONSTRUCTION

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER
CONTRACT NO. | LOCATION NO. XL-5464

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

Washington State Department of Transportation
GRAHAM
wsp
1001 Fourth Ave, Suite 3100, Seattle, WA 98154
Tel: (206) 382-5200

I-405
NE 132ND STREET INTERCHANGE PROJECT

FISH PASSAGE SHEET LOCATION MAP

PLAN REF NO FP01
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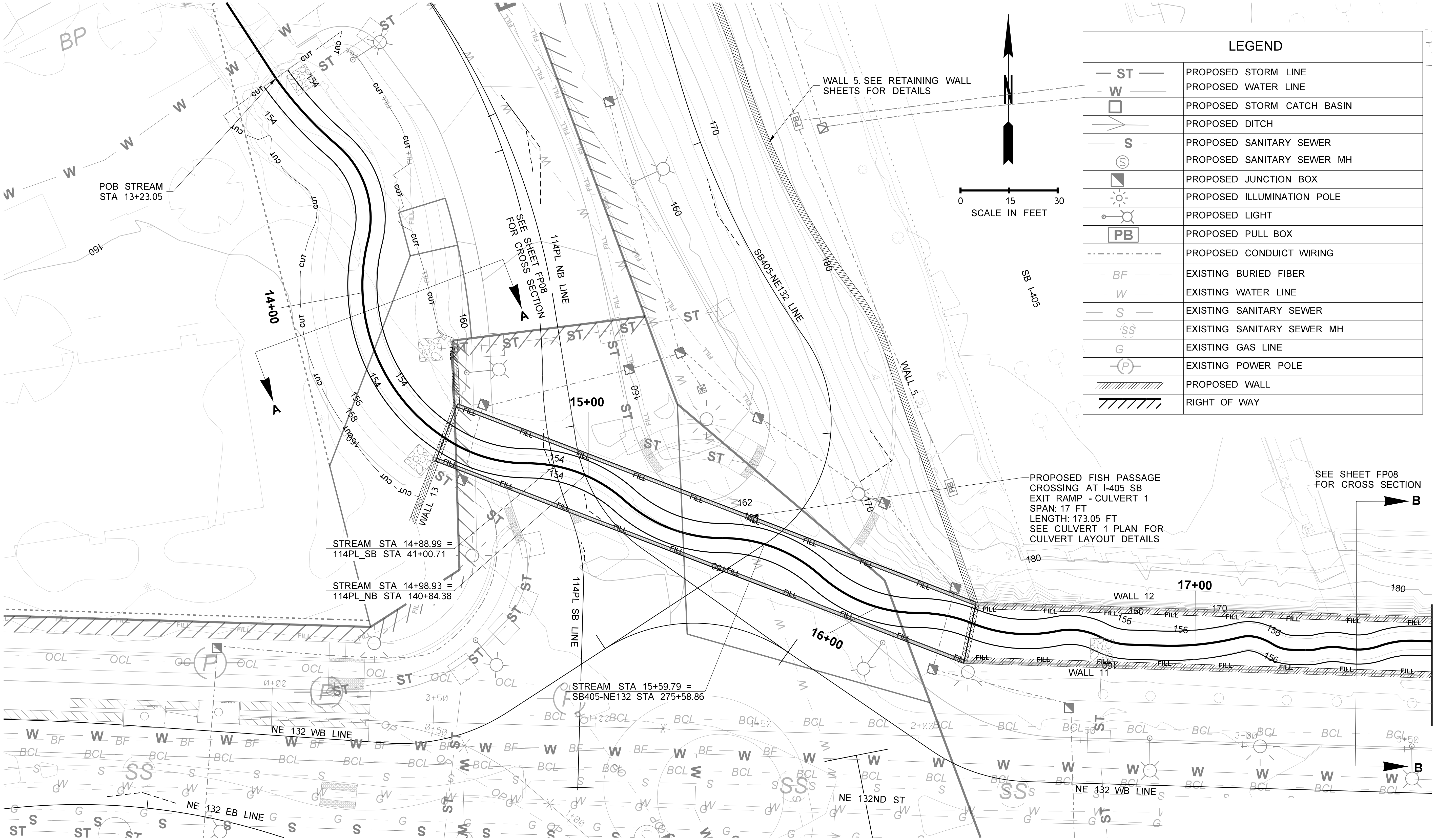

LEGEND

— ST —	PROPOSED STORM LINE
W	PROPOSED WATER LINE
☐	PROPOSED STORM CATCH BASIN
—>	PROPOSED DITCH
S	PROPOSED SANITARY SEWER
(S)	PROPOSED SANITARY SEWER MH
◩	PROPOSED JUNCTION BOX
☼	PROPOSED ILLUMINATION POLE
○—☼	PROPOSED LIGHT
PB	PROPOSED PULL BOX
- · - · -	PROPOSED CONDUIT WIRING
BF	EXISTING BURIED FIBER
W	EXISTING WATER LINE
S	EXISTING SANITARY SEWER
SS	EXISTING SANITARY SEWER MH
G	EXISTING GAS LINE
(P)	EXISTING POWER POLE
▨	PROPOSED WALL
//////	RIGHT OF WAY

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PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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10	WASH	

JOB NUMBER

CONTRACT NO.

LOCATION NO. XL-5464

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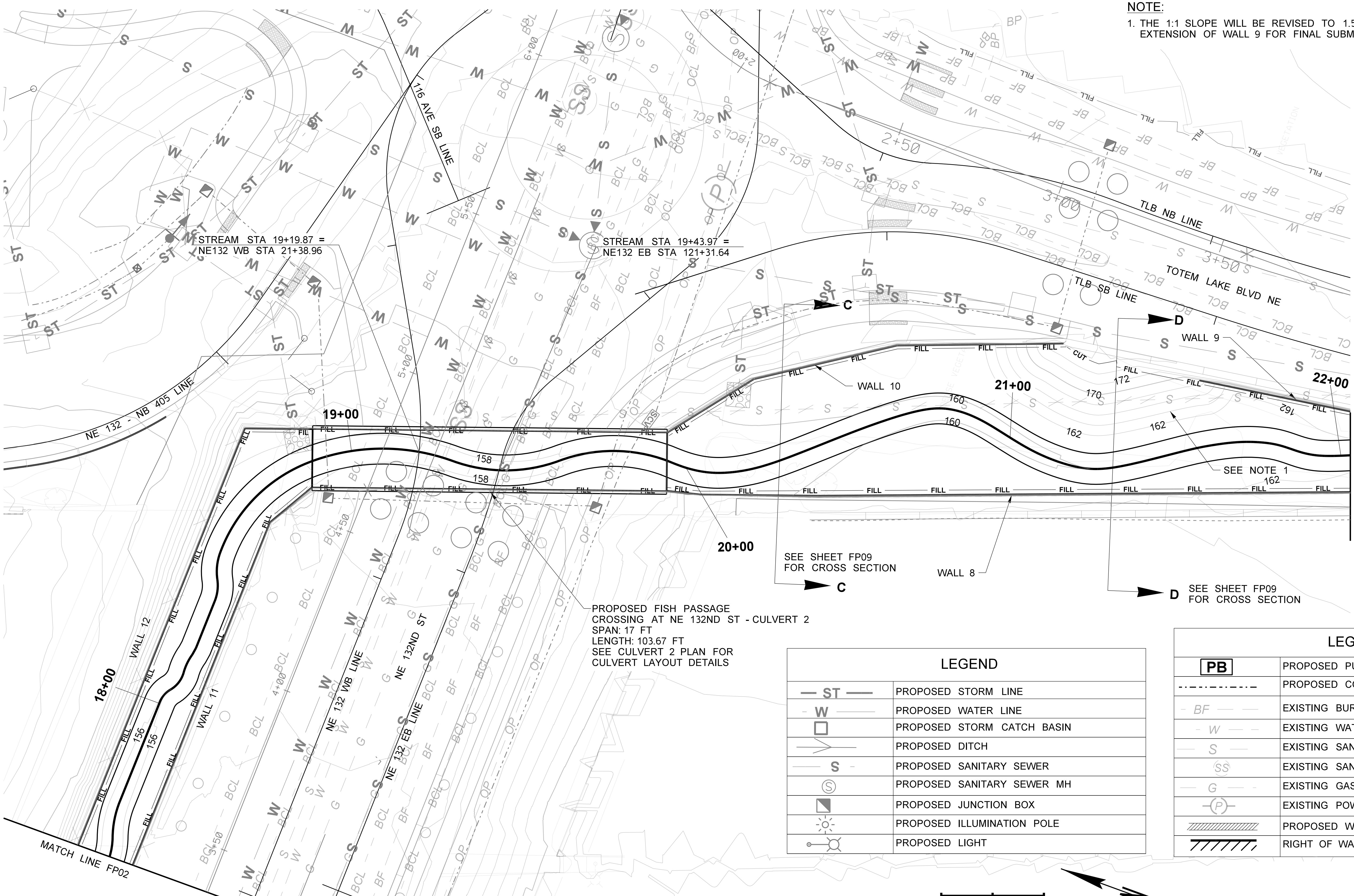
STREAM ALIGNMENT AND GRADING PLAN

PLAN REF NO FP02

SHEET OF SHEETS

NOTE:

1. THE 1:1 SLOPE WILL BE REVISED TO 1.5:1 SLOPE, FOLLOWING PROPOSED EXTENSION OF WALL 9 FOR FINAL SUBMITTAL.



LEGEND	
— ST —	PROPOSED STORM LINE
- W —	PROPOSED WATER LINE
☐	PROPOSED STORM CATCH BASIN
—>—	PROPOSED DITCH
— S -	PROPOSED SANITARY SEWER
Ⓢ	PROPOSED SANITARY SEWER MH
◪	PROPOSED JUNCTION BOX
☼	PROPOSED ILLUMINATION POLE
o—☼	PROPOSED LIGHT

LEGEND	
PB	PROPOSED PULL BOX
-·-·-·-·-	PROPOSED CONDUIT WIRING
BF	EXISTING BURIED FIBER
W	EXISTING WATER LINE
S	EXISTING SANITARY SEWER
SS	EXISTING SANITARY SEWER MH
G	EXISTING GAS LINE
(P)	EXISTING POWER POLE
//////	PROPOSED WALL
//////	RIGHT OF WAY

0 15 30
SCALE IN FEET

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CONTRACT NO. | LOCATION NO. XL-5464

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STREAM ALIGNMENT AND GRADING PLAN

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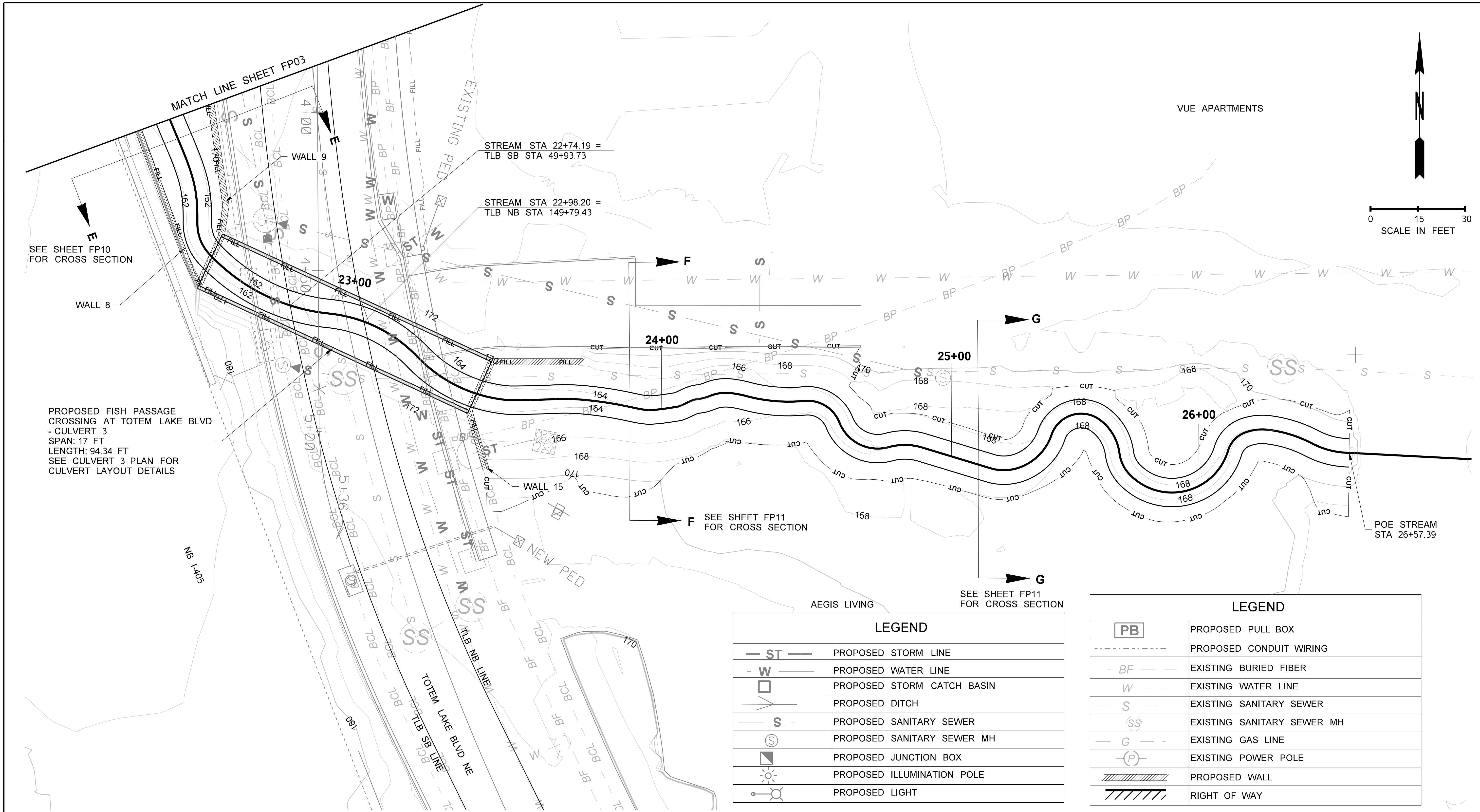

LEGEND

— ST —	PROPOSED STORM LINE
— W —	PROPOSED WATER LINE
☐	PROPOSED STORM CATCH BASIN
	PROPOSED DITCH
— S —	PROPOSED SANITARY SEWER
Ⓢ	PROPOSED SANITARY SEWER MH
	PROPOSED JUNCTION BOX
	PROPOSED ILLUMINATION POLE
	PROPOSED LIGHT

LEGEND

PB	PROPOSED PULL BOX
	PROPOSED CONDUIT WIRING
— BF —	EXISTING BURIED FIBER
— W —	EXISTING WATER LINE
— S —	EXISTING SANITARY SEWER
SS	EXISTING SANITARY SEWER MH
— G —	EXISTING GAS LINE
—(P)—	EXISTING POWER POLE
	PROPOSED WALL
	RIGHT OF WAY

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CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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JOB NUMBER

CONTRACT NO. | LOCATION NO. XL-5464

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State
Department of Transportation
GRAHAM
WSP
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PROJECT

STREAM ALIGNMENT AND
GRADING PLAN

PLAN REF NO
FP04
SHEET
OF
SHEETS

CURVE AND TANGENT DATA

P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH	NORTHING	EASTING
13+23.05					265214.83	1306763.86
13+37.16	13°51'00.70" LT	116.21	14.11	28.09	265203.35	1306772.07
13+51.14					265194.16	1306782.79
13+69.40	63°24'08.50" RT	29.57	18.27	32.72	265182.28	1306796.66
13+83.86					265164.56	1306792.25
14+26.87	74°32'06.03" LT	56.52	43.00	73.52	265122.83	1306781.86
14+57.39					265101.69	1306819.31
14+69.24	29°31'32.36" LT	45.00	11.86	23.19	265095.86	1306829.63
14+80.58					265095.87	1306841.49
14+97.88	42°04'44.18" RT	45.00	17.31	33.05	265095.90	1306858.80
15+13.62					265084.31	1306871.66
15+30.93	42°04'44.18" LT	45.00	17.31	33.05	265072.73	1306884.53
15+46.67					265072.75	1306901.84
15+63.98	42°04'44.18" RT	45.00	17.31	33.05	265072.78	1306919.15
15+79.72					265061.20	1306932.01
15+97.03	42°04'44.18" LT	45.00	17.31	33.05	265049.61	1306944.87
16+12.77					265049.64	1306962.18
16+21.54	22°03'34.51" RT	45.00	8.77	17.33	265049.65	1306970.95
16+30.10					265046.36	1306979.09
16+43.67	33°34'37.93" LT	45.00	13.58	26.37	265041.28	1306991.68
16+56.47					265044.01	1307004.98
16+63.74	38°57'24.80" RT	20.57	7.28	13.99	265045.47	1307012.10
16+70.46					265042.13	1307018.57
16+75.07	25°32'23.17" LT	20.36	4.62	9.08	265040.01	1307022.67
16+79.53	S 88°10'40.05" E			10.35	265039.86	1307027.28
16+89.89					265039.53	1307037.63
17+02.01	15°58'14.65" LT	86.44	12.13	24.09	265039.15	1307049.74
17+13.98					265042.11	1307061.50
17+17.09	31°31'00.36" RT	11.04	3.11	6.07	265042.87	1307064.52
17+20.05					265041.94	1307067.49
17+22.36	15°01'29.72" RT	17.54	2.31	4.60	265041.25	1307069.70
17+24.65					265040.01	1307071.65
17+27.72	30°34'15.43" LT	11.24	3.07	6.00	265038.37	1307074.25
17+30.65	S 88°10'40.05" E			4.49	265038.27	1307077.32
17+35.13					265038.13	1307081.81
17+37.16	15°50'15.55" LT	14.59	2.03	4.03	265038.06	1307083.83
17+39.17					265038.55	1307085.80
17+43.42	25°34'32.41" RT	18.73	4.25	8.36	265039.58	1307089.93
17+47.53					265038.73	1307094.09
17+53.04	30°50'46.13" LT	19.98	5.51	10.76	265037.63	1307099.50
17+58.29					265039.35	1307104.70
17+63.74	21°13'20.01" RT	29.09	5.45	10.78	265041.25	1307109.84
17+69.06	S 88°03'49.31" E			31.42	265041.06	1307115.29
18+00.49					265040.00	1307146.70
18+02.96	37°55'16.46" RT	7.21	2.48	4.77	265039.92	1307149.17
18+05.26					265038.33	1307151.07
18+08.67	44°22'04.45" LT	8.37	3.41	6.48	265036.14	1307153.69
18+11.74					265036.31	1307157.09
18+14.58	19°49'34.74" RT	16.25	2.84	5.62	265036.64	1307159.92
18+17.36	S 74°41'02.56" E			0.25	265035.89	1307162.66
18+17.61	S 81°01'07.08" E			2.19	265035.82	1307162.90
18+19.80	S 88°10'40.05" E			14.80	265035.48	1307165.07
18+34.60					265035.01	1307179.86
18+37.88	30°09'42.64" LT	12.16	3.28	6.40	265034.90	1307183.14
18+41.00					265036.46	1307186.02
18+45.03	28°28'44.42" RT	15.88	4.03	7.89	265038.37	1307189.57
18+48.90					265038.36	1307193.60
18+69.51	49°13'34.78" RT	45.00	20.62	38.66	265038.31	1307214.21
18+87.56					265022.67	1307227.64
19+09.80	40°40'32.21" RT	60.00	22.24	42.60	265005.79	1307242.12
19+30.15					264983.55	1307242.10

CURVE AND TANGENT DATA

P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH	NORTHING	EASTING
19+46.76	40°30'08.71" LT	45.00	16.60	31.81	264966.95	1307242.09
19+61.97					264954.32	1307252.87
19+80.10	43°53'37.07" RT	45.00	18.13	34.47	264940.52	1307264.63
19+96.44					264922.42	1307263.55
20+04.42	27°20'00.23" LT	32.82	7.98	15.66	264914.45	1307263.07
20+12.10					264907.16	1307266.30
20+16.54	10°47'32.36" LT	47.08	4.45	8.87	264903.09	1307268.10
20+20.96					264899.44	1307270.64
20+25.97	6°46'49.56" LT	84.52	5.01	10.00	264895.32	1307273.49
20+30.96	S 41°28'25.06" E			18.51	264891.57	1307276.80
20+49.48					264877.70	1307289.06
20+56.49	3°26'08.52" RT	233.79	7.01	14.02	264872.45	1307293.70
20+63.50					264866.92	1307298.03
20+68.00	6°42'39.33" RT	76.87	4.51	9.00	264863.37	1307300.80
20+72.50					264859.52	1307303.15
20+79.51	33°55'25.04" RT	23.00	7.02	13.62	264853.53	1307306.79
20+86.12					264846.52	1307306.47
20+90.44	9°32'53.70" RT	51.82	4.33	8.64	264842.20	1307306.28
20+94.75	S 12°08'41.53" W			7.28	264837.97	1307305.37
21+02.03					264830.85	1307303.84
21+10.54	15°43'59.37" LT	61.56	8.51	16.91	264822.53	1307302.05
21+18.94					264814.05	1307302.58
21+25.52	25°51'25.58" LT	28.68	6.58	12.94	264807.48	1307302.99
21+31.88					264801.74	1307306.23
21+37.62	4°54'45.58" LT	133.92	5.75	11.48	264796.74	1307309.05
21+43.36	S 34°21'28.99" E			9.68	264792.00	1307312.29
21+53.04					264784.01	1307317.76
21+60.97	9°23'06.54" RT	96.61	7.93	15.83	264777.46	1307322.23
21+68.87					264770.27	1307325.58
21+72.97	9°17'26.29" RT	50.47	4.10	8.18	264766.52	1307327.24
21+77.05					264762.55	1307328.27
21+80.30	12°46'55.66" RT	28.99	3.25	6.47	264759.41	1307329.09
21+83.52	S 1°46'37.96" E			4.06	264756.16	1307329.19
21+87.58					264752.10	1307329.31
21+89.71	9°46'38.39" LT	24.85	2.13	4.24	264749.98	1307329.38
21+91.82					264747.90	1307329.81
21+93.10	5°15'26.73" LT	27.79	1.28	2.55	264746.65	1307330.06
21+94.37					264745.42	1307330.43
21+97.30	4°41'56.32" LT	71.41	2.93	5.86	264742.63	1307331.32
22+00.23	S 22°51'02.29" E			4.17	264739.92	1307332.44
22+04.40					264736.08	1307334.06
22+08.85	1°25'35.75" RT	357.32	4.45	8.90	264731.98	1307335.78
22+13.29					264727.84	1307337.41
22+21.81	21°37'43.79" RT	44.56	8.51	16.82	264719.92	1307340.52
22+30.12	S 0°12'17.25" W			2.89	264711.40	1307340.49
22+33.01					264708.52	1307340.48
22+38.41	42°53'07.46" LT	13.76	5.41	10.30	264703.11	1307340.46
22+43.31					264699.14	1307344.12
22+66.06	41°32'13.80" LT	60.00	22.75	43.50	264682.41	1307359.55
22+86.80					264680.12	1307382.19
23+03.41	40°30'08.71" RT	45.00	16.60	31.81	264678.44	1307398.70
23+18.61					264666.44	1307410.18
23+35.92	42°04'44.18" LT	45.00	17.31	33.05	264653.93	1307422.14
23+51.66					264652.66	1307439.40
23+56.36	1°56'23.99" LT	277.40	4.70	9.39	264652.66	1307444.10
23+61.06	N 87°47'13.98" E			5.72	264652.81	1307448.79
23+66.77					264653.03	1307454.50
23+70.30	6°43'34.25" RT	60.00	3.53	7.04	264653.17	1307458.03
23+73.81					264652.89	1307461.54
23+81.45	7°21'47.28" RT	118.68	7.64	15.25	264652.29	1307469.15
23+89.07	S 78°07'24.50" E			3.95	264650.72	1307476.63

CURVE AND TANGENT DATA

P.I. STATION	DELTA	RADIUS	TANGENT	LENGTH	NORTHING	EASTING
23+93.01					264649.91	1307480.49
23+95.62	17°38'54.81" LT	16.78	2.60	5.17	264649.37	1307483.04
23+98.18					264649.63	1307485.63
24+00.50	3°09'01.34" LT	84.35	2.32	4.64	264649.87	1307487.94
24+02.82	N 81°04'39.35" E			2.53	264650.23	1307490.23
24+05.35					264650.62	1307492.72
24+06.10	7°26'40.35" LT	11.56	0.75	1.50	264650.85	1307493.44
24+06.85	N 64°51'46.92" E			2.64	264651.17	1307494.12
24+09.49					264652.29	1307496.51
24+10.92	18°56'36.93" RT	8.59	1.43	2.84	264652.90	1307497.81
24+12.33					264653.05	1307499.23
24+13.43	10°45'23.69" LT	11.74	1.11	2.20	264653.17	1307500.33
24+14.53					264653.49	1307501.39
24+15.36	5°06'16.19" LT	18.71	0.83	1.67	264653.74	1307502.19
24+16.20					264654.05	1307502.96
24+19.47	28°06'50.50" RT	13.09	3.28	6.42	264655.28	1307506.00
24+22.62					264654.94	1307509.26
24+25.24	9°00'24.70" RT	33.22	2.62	5.22	264654.66	1307511.86
24+27.84					264653.98	1307514.38
24+37.23	20°35'19.00" LT	51.69	9.39	18.57	264651.54	1307523.45
24+46.42					264652.44	1307532.79
24+54.56	74°06'34.74" RT	10.79	8.15	13.95	264653.23	1307540.90
24+60.37					264645.64	1307543.88
24+72.18	84°09'04.50" LT	13.09	11.82	19.22	264634.64	1307548.19
24+79.59					264637.81	1307559.57
24+85.05	32°26'46.92" RT	18.78	5.46	10.64	264639.28	1307564.83
24+90.22	S 73°07'02.57" E			22.65	264637.69	1307570.06
25+12.88					264631.11	1307591.74
25+17.55	35°25'46.76" LT	14.63	4.67	9.05	264629.76	1307596.21
25+21.92					264631.24	1307600.64
25+30.16	52°44'57.09" LT	16.61	8.24	15.30	264633.86	1307608.45
25+37.22					264641.67	1307611.09
25+50.65	107°05'59.85"RT	9.92	13.43	18.55	264654.39	1307615.40
25+55.76					264646.53	1307626.29
25+62.53	47°03'33.83" RT	15.54	6.77	12.76	264642.57	1307631.78
25+68.52					264635.86	1307632.62
25+72.24	35°18'01.38" LT	11.67	3.71	7.19	264632.17	1307633.08
25+75.72					264629.43	1307635.59
26+08.44	120°58'33.79"LT	18.52	32.72	39.11	264605.28	1307657.67
26+14.82					264636.64	1307667.01
26+19.35	53°46'44.25" RT	8.92	4.52	8.37	264640.98	1307668.30
26+23.20					264642.50	1307672.56
26+26.87	26°22'40.40" RT	15.69	3.68	7.22	264643.73	1307676.02
26+30.42					264643.30	1307679.67
26+37.86	21°00'10.10" RT	40.15	7.44	14.72	264642.43	1307687.06
26+45.13					264638.96	1307693.65
26+51.38	27°09'50.34" LT	25.86	6.25	12.26	264636.05	1307699.18
26+57.39					264635.99	1307705.43

FILE NAME	XL5464_PS_FP_05.dgn
TIME	7:31:12 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

PRELIMINARY

NOT FOR CONSTRUCTION

REVISION | DATE | BY

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

JOB NUMBER

CONTRACT NO. | LOCATION NO. XL-5464

DATE P.E. STAMP BOX

DATE P.E. STAMP BOX

Washington State Department of Transportation

GRAHAM

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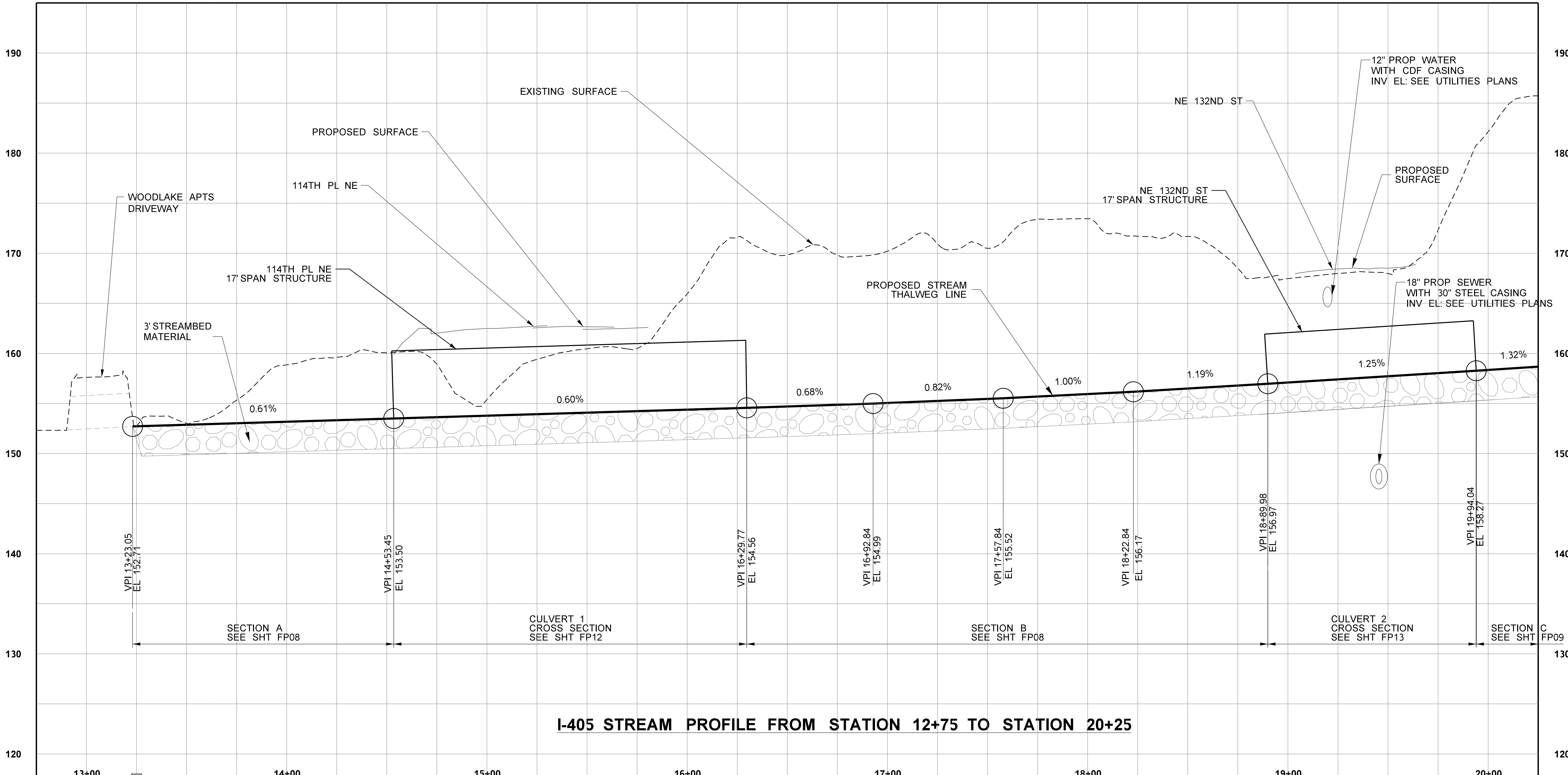
I-405
NE 132ND STREET INTERCHANGE PROJECT

I-405 STREAM ALIGNMENT GEOMETRY TABLE

PLAN REF NO FP05

SHEET OF SHEETS



I-405 STREAM PROFILE FROM STATION 12+75 TO STATION 20+25

DATUM
(NAVD) 88

NOTES:

1. STREAMBED MATERIAL SHALL BE STREAMBED SEDIMENT PER WSDOT STANDARD SPECIFICATIONS 9-03.11. OR SIMILAR SPECIFICATION MATERIAL AS APPROVED BY THE ENGINEER.
2. STREAMBED CONSTRUCTION THROUGH CULVERT CROSSINGS SHALL INCUDE MEANDER BARS. SEE SHEETS FP12 AND FP13 FOR CULVERT SECTIONS AND MEANDER BAR DETAILS.

FILE NAME	XL5464_PS_FP_06.dgn
TIME	12:41:37 AM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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JOB NUMBER
CONTRACT NO. | LOCATION NO. XL-5464

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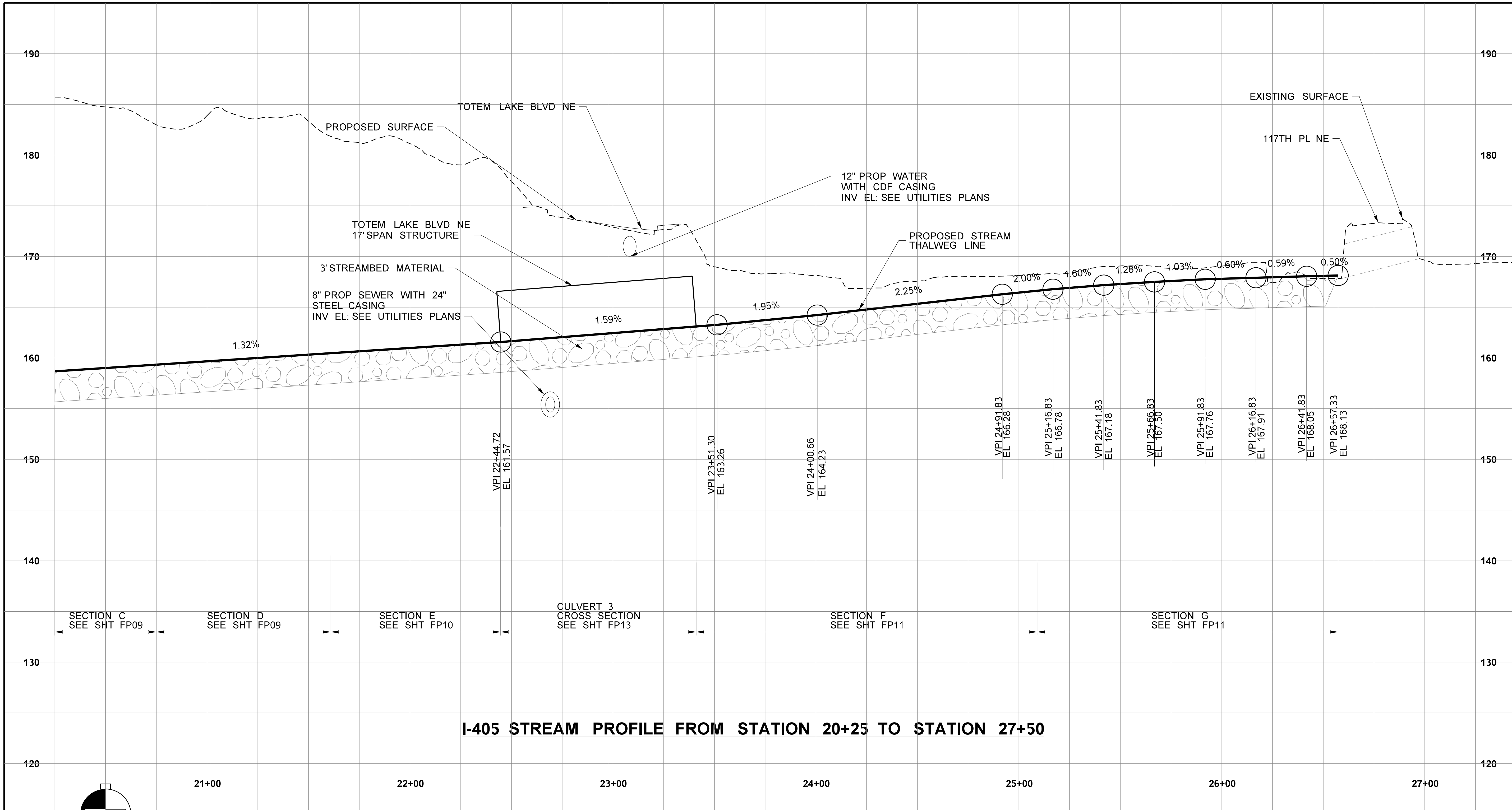
I-405 STREAM PROFILE

PLAN REF NO FP06
SHEET
OF
SHEETS



I-405 STREAM PROFILE FROM STATION 20+25 TO STATION 27+50

NOTES:

1. STREAMBED MATERIAL SHALL BE STREAMBED SEDIMENT PER WSDOT STANDARD SPECIFICATIONS 9-03.11. OR SIMILAR TO SPECIFICATION MATERIAL AS APPROVED BY THE ENGINEER.
2. STREAMBED CONSTRUCTION THROUGH CULVERT CROSSINGS SHALL INCUDE MEANDER BARS. SEE SHEETS FP12 AND FP13 FOR CULVERT SECTIONS AND MEANDER BAR DETAILS.

FILE NAME	XL5464_PS_FP_07.dgn
TIME	12:41:38 AM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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JOB NUMBER		
CONTRACT NO.		LOCATION NO. XL-5464

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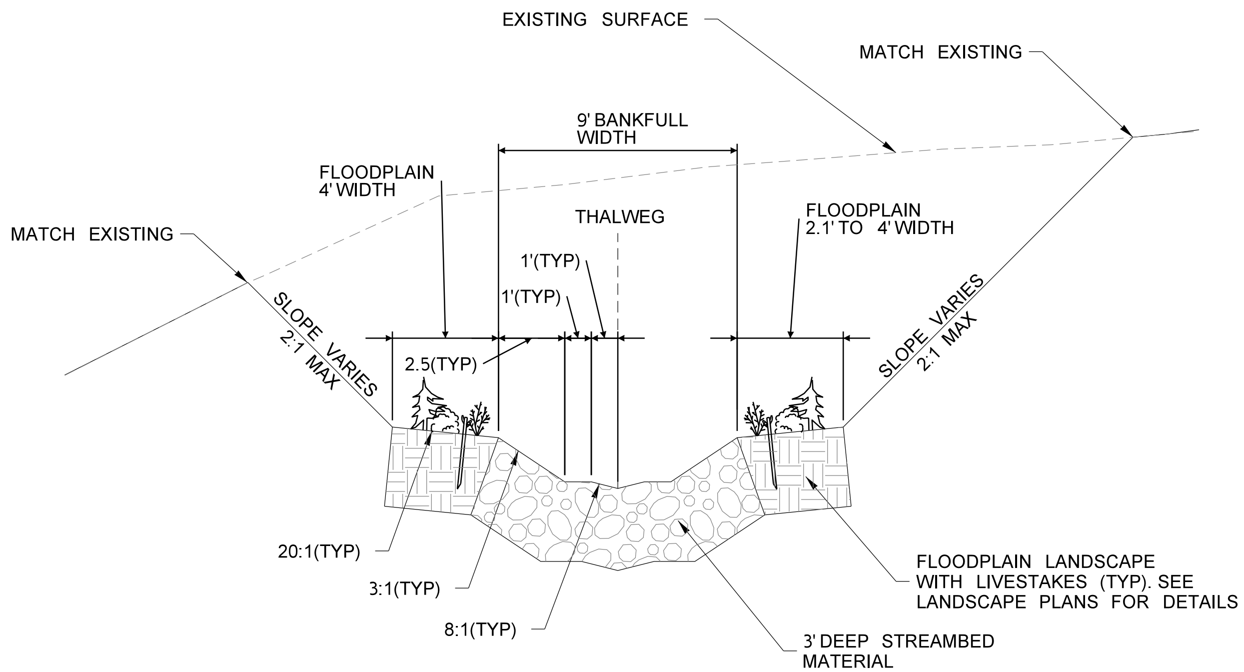
I-405
NE 132ND STREET INTERCHANGE PROJECT

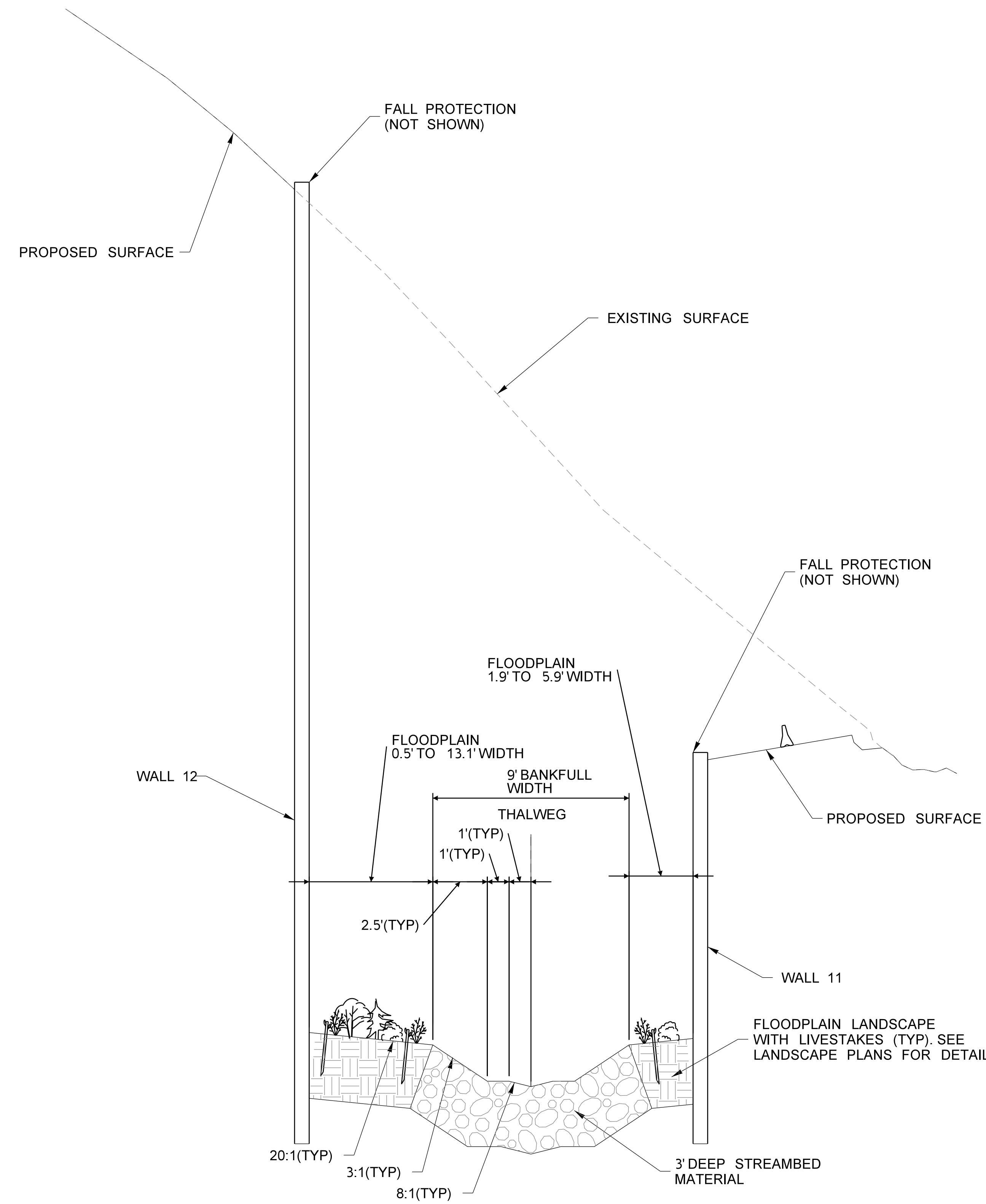
I-405 STREAM PROFILE

PLAN REF NO FP07

SHEET OF SHEETS



TYPICAL SECTION-A
STATION 13+23 TO STATION 14+53



TYPICAL SECTION-B
STATION 16+30 TO STATION 18+88

FILE NAME	XL5464_PS_FP_08.dgn
TIME	7:30:46 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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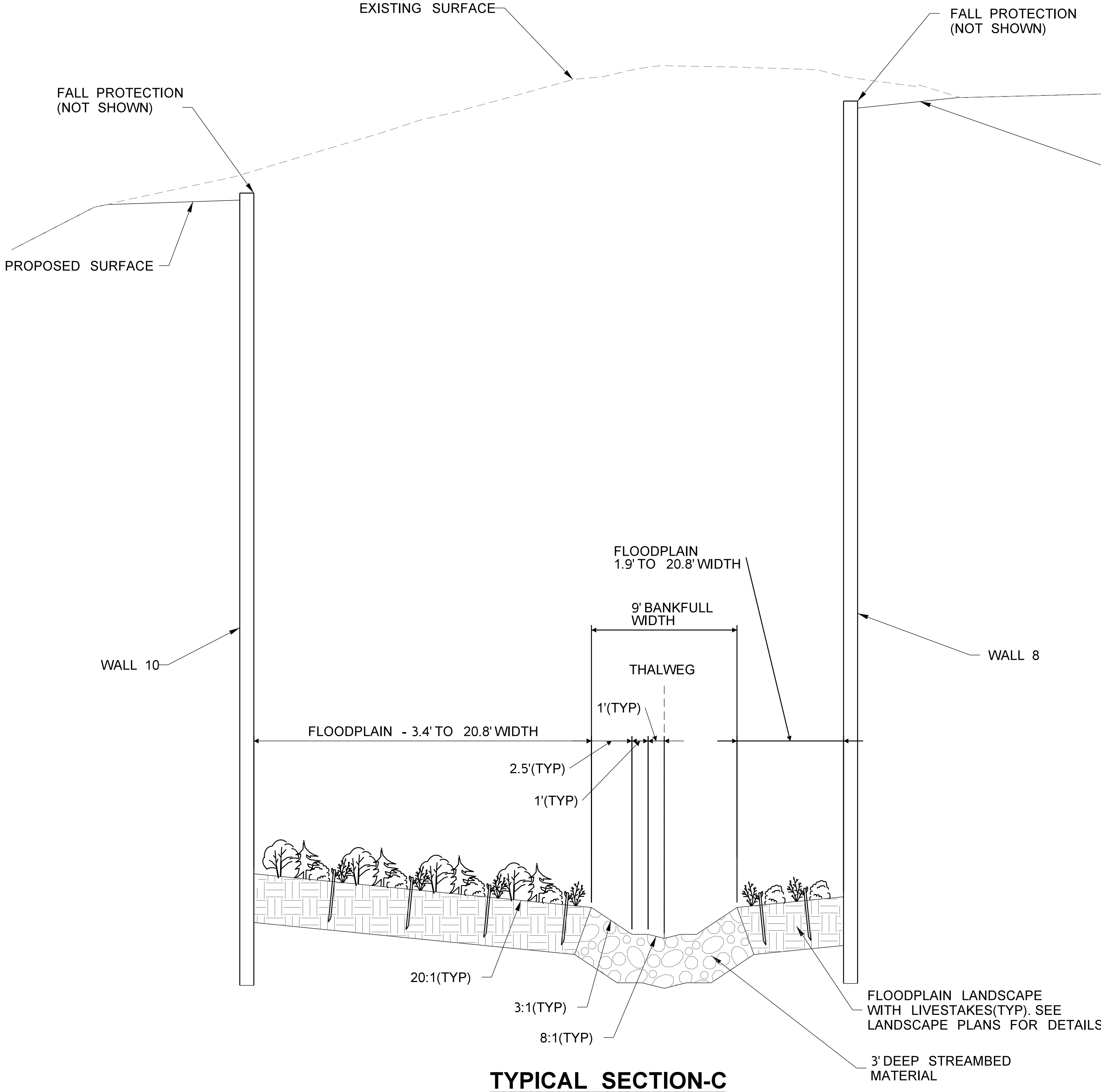
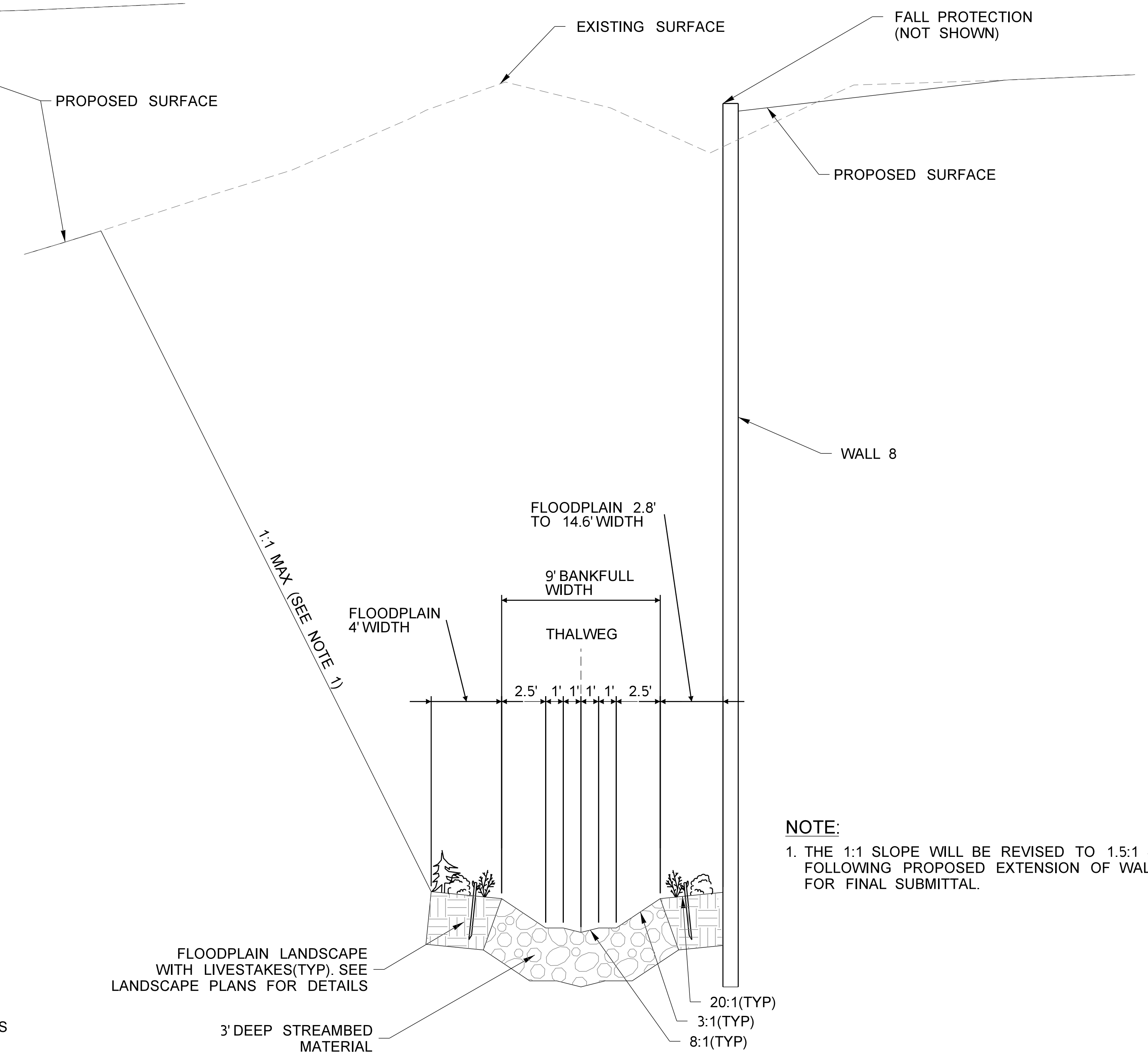
I-405
NE 132ND STREET INTERCHANGE PROJECT

I-405 STREAM CROSS SECTIONS

PLAN REF NO FP08
SHEET
OF
SHEETS



TYPICAL SECTION-C
STATION 19+94 TO STATION 20+99



NOTE:

1. THE 1:1 SLOPE WILL BE REVISED TO 1.5:1 SLOPE, FOLLOWING PROPOSED EXTENSION OF WALL 9 FOR FINAL SUBMITTAL.

TYPICAL SECTION-D
STATION 20+99 TO STATION 21+61

FILE NAME	XL5464_PS_FP_09.dgn
TIME	10:34:39 PM
DATE	1/10/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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CONTRACT NO. | LOCATION NO. XL-5464

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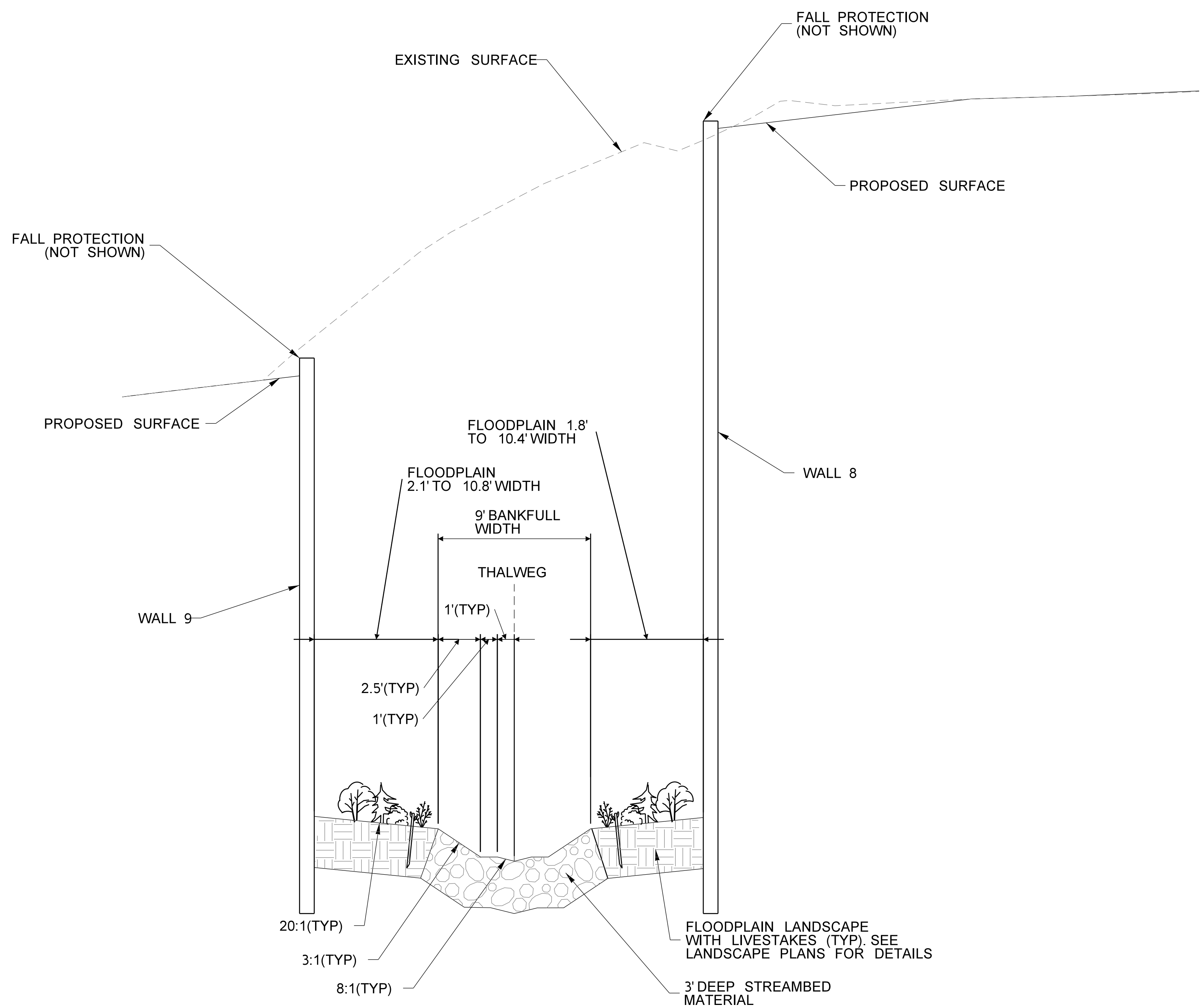
NE 132ND STREET INTERCHANGE PROJECT

I-405 STREAM CROSS SECTIONS

PLAN REF NO FP09
SHEET
OF
SHEETS



TYPICAL SECTION-E
STATION 21+61 TO STATION 22+45

FILE NAME	XL5464_PS_FP_10.dgn
TIME	7:31:11 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO. XL-5464

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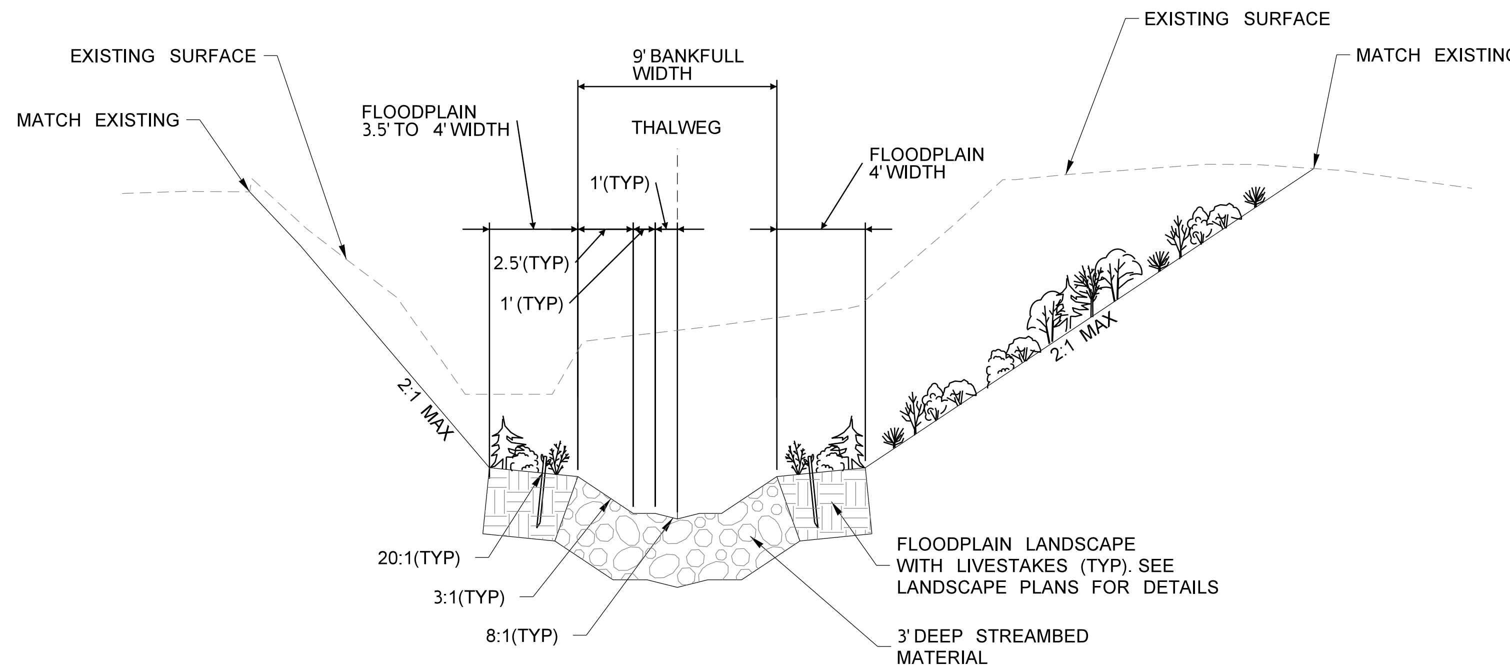
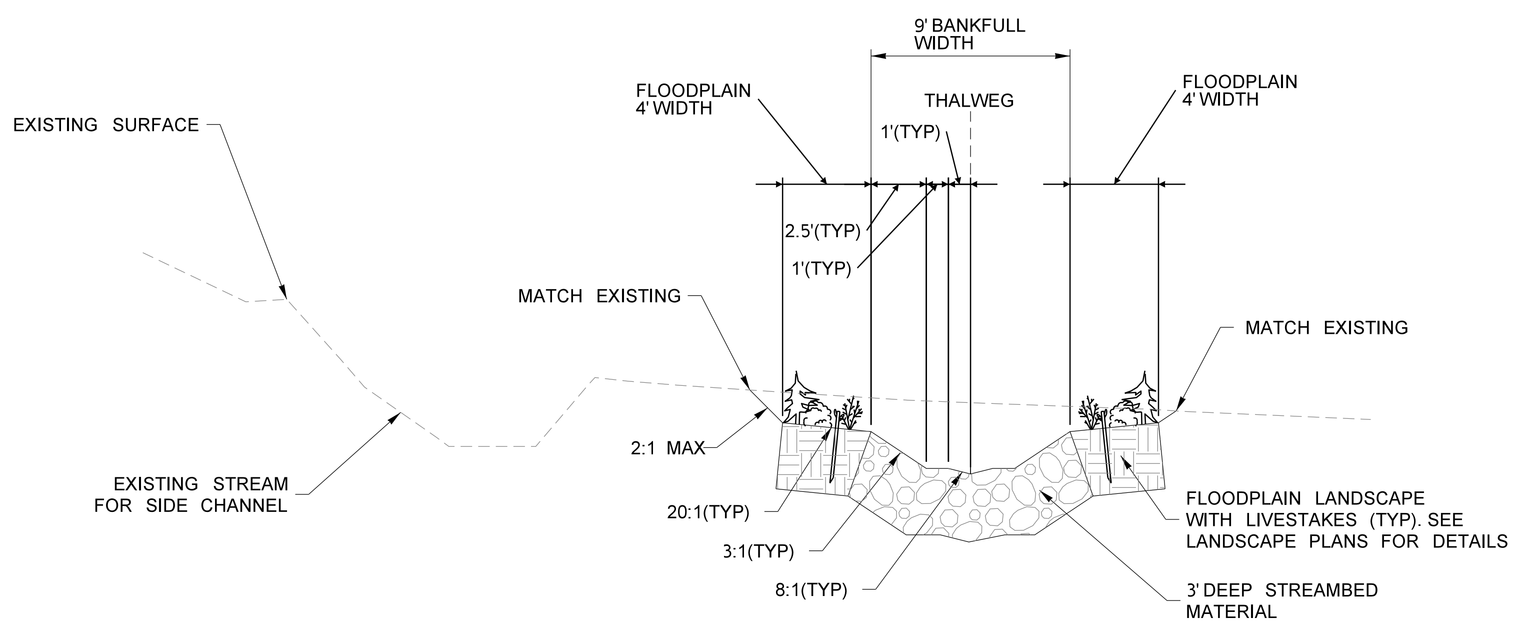
NE 132ND STREET INTERCHANGE
PROJECT

I-405 STREAM CROSS SECTION

PLAN REF NO
FP10
SHEET
OF
SHEETS



TYPICAL SECTION-F
STATION 23+41 TO STATION 24+56



TYPICAL SECTION-G
STATION 24+56 TO STATION 26+57

FILE NAME	XL5464_PS_FP_11.dgn
TIME	7:30:48 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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JOB NUMBER
CONTRACT NO. | LOCATION NO. XL-5464

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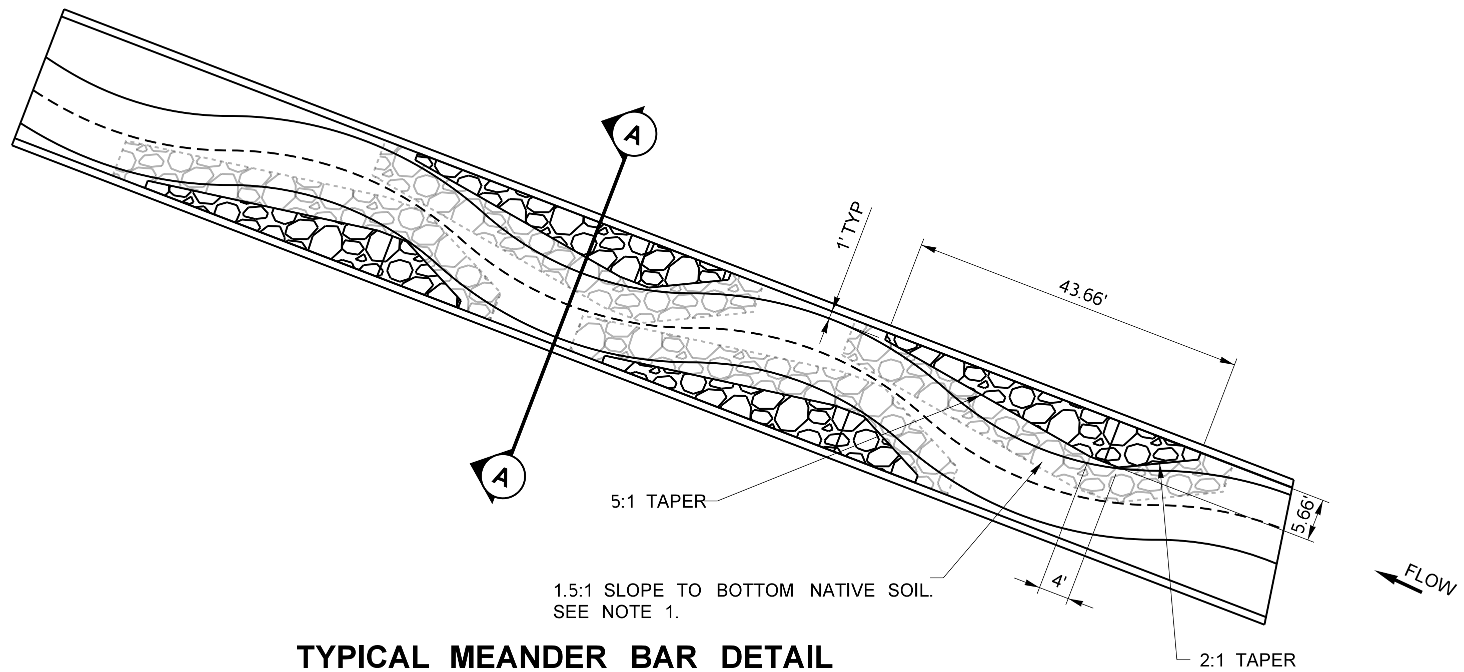
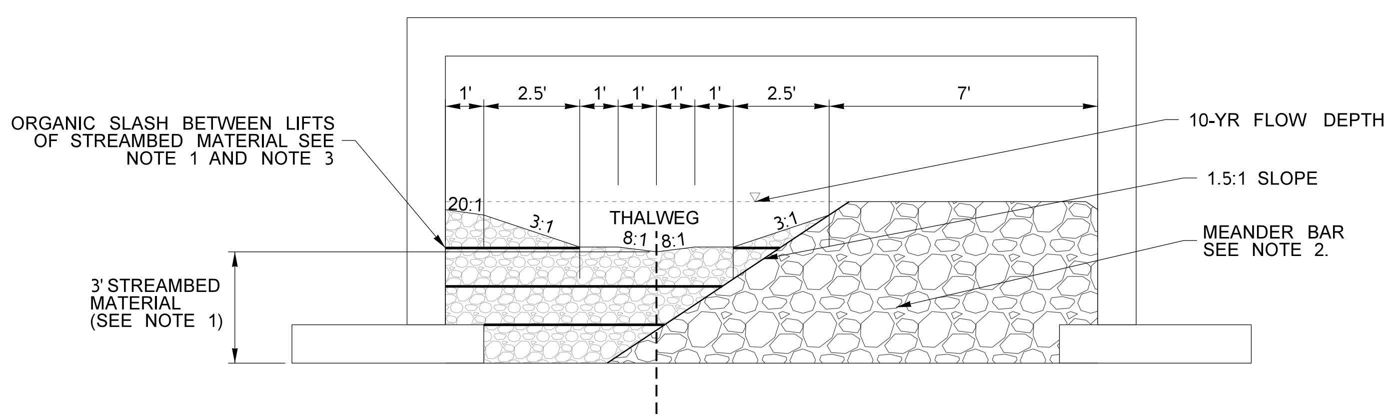
I-405
NE 132ND STREET INTERCHANGE PROJECT

I-405 STREAM CROSS SECTIONS

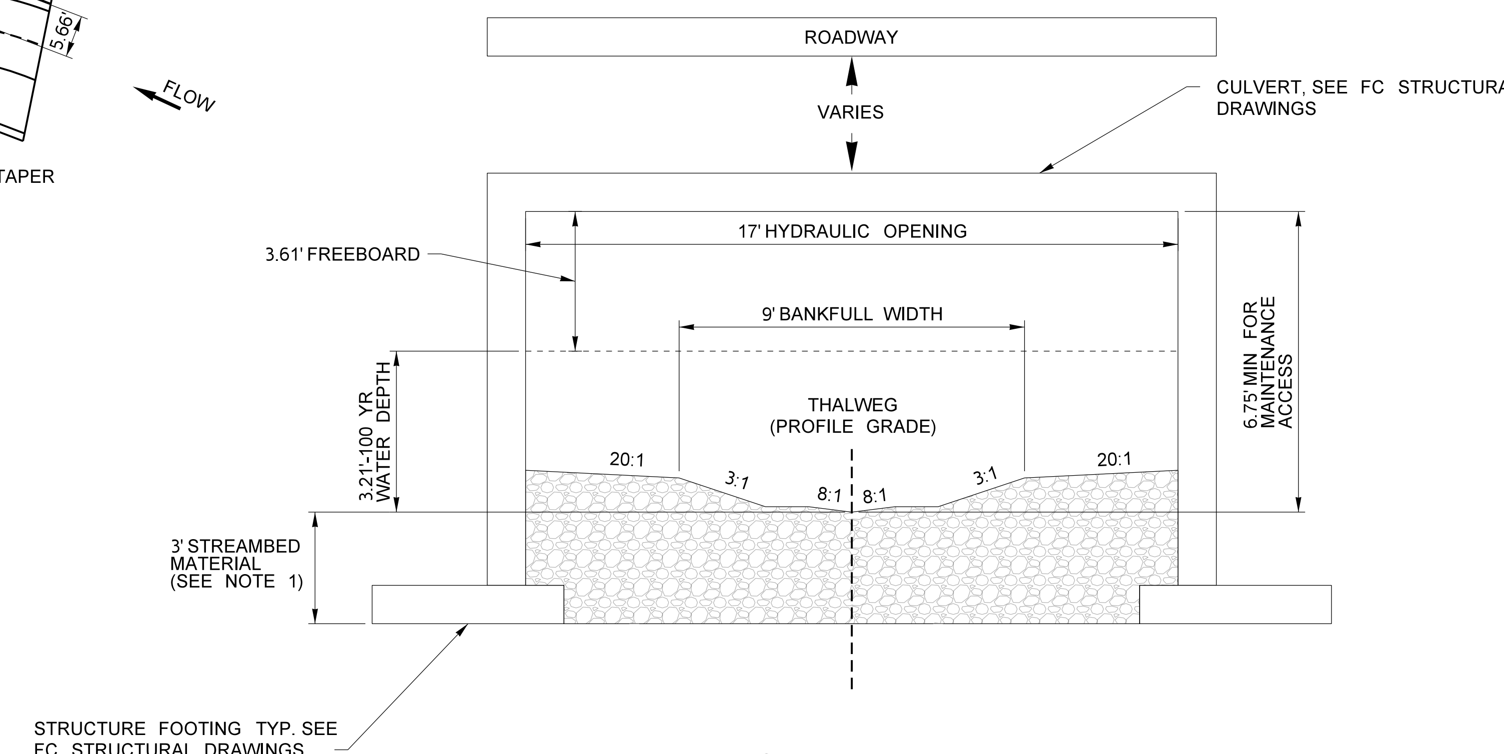
PLAN REF NO FP11
SHEET
OF
SHEETS



TYPICAL MEANDER BAR DETAIL
N.T.S.



SECTION A-A
N.T.S.



CULVERT 1
TYPICAL CROSS-SECTION
(114TH PLACE NE)
N.T.S.

NOTES:

1. PLACE MEANDER BAR AND STREAMBED MATERIAL IN 12" LIFTS. ORGANIC SLASH TO BE ADDED TO STREAMBED MATERIAL BETWEEN EACH LIFT. THOROUGHLY WASH STREAMBED WITH A PRESSURIZED HOSE AT EACH LIFT TO SEAL THE BED.
2. MEANDER BAR: 9 PARTS 6-INCH STREAMBED COBBLES SHALL BE MIXED THOROUGHLY WITH 1-PART STREAMBED SEDIMENT, IN 12-INCH LIFTS.
3. MATERIAL SHALL BE STREAMBED SEDIMENT PER WSDOT STANDARD SPECIFICATIONS SECTION 9-03.11. OR SIMILAR TO SPECIFICATION MATERIAL AS APPROVED BY THE ENGINEER.
4. ORGANIC SLASH SHALL BE LIVE FASCINES (RED OSIER DOGWOOD AND/OR SITKA WILLOW) AND DEAD TREE BRANCHES. DEAD BRANCHES CAN BE FROM ANY WOODY NATIVE, NON-INVASIVE PLANT SUCH AS CEDAR OR DOUGLAS FIR. THERE SHALL BE A MINIMUM OF 8 LIVE BRANCHES AND DEAD BRANCHES SHALL COMPRISE OF NO MORE THAN 40% OF TOTAL FASCINE COUNT.
5. SEE FC STRUCTURAL PLANS FOR THE 3 SIDED CULVERT PLAN PROFILE AND DETAILS.

FILE NAME	XL5464_PS_FP_12.dgn
TIME	4:39:03 PM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	OWEN PORKKA
ENTERED BY	OWEN PORKKA
CHECKED BY	C. BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.	LOCATION NO. XL-5464	

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

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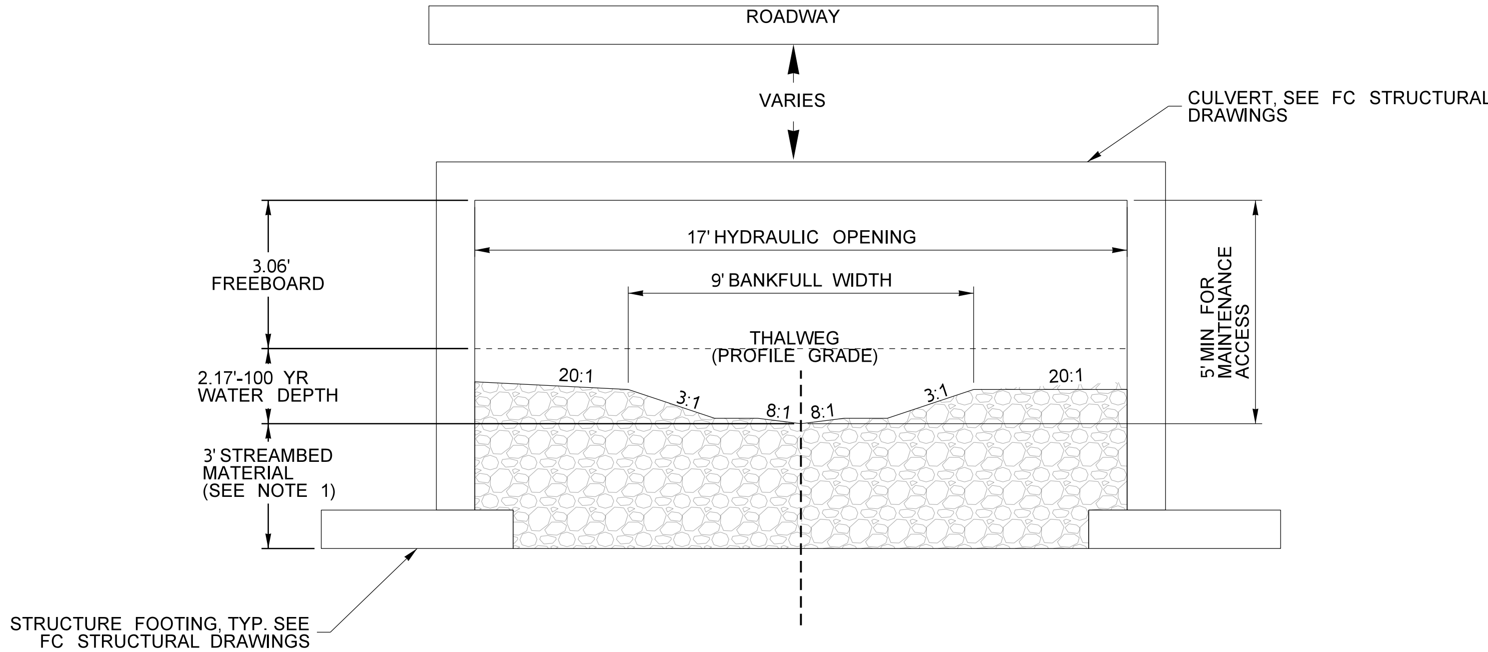
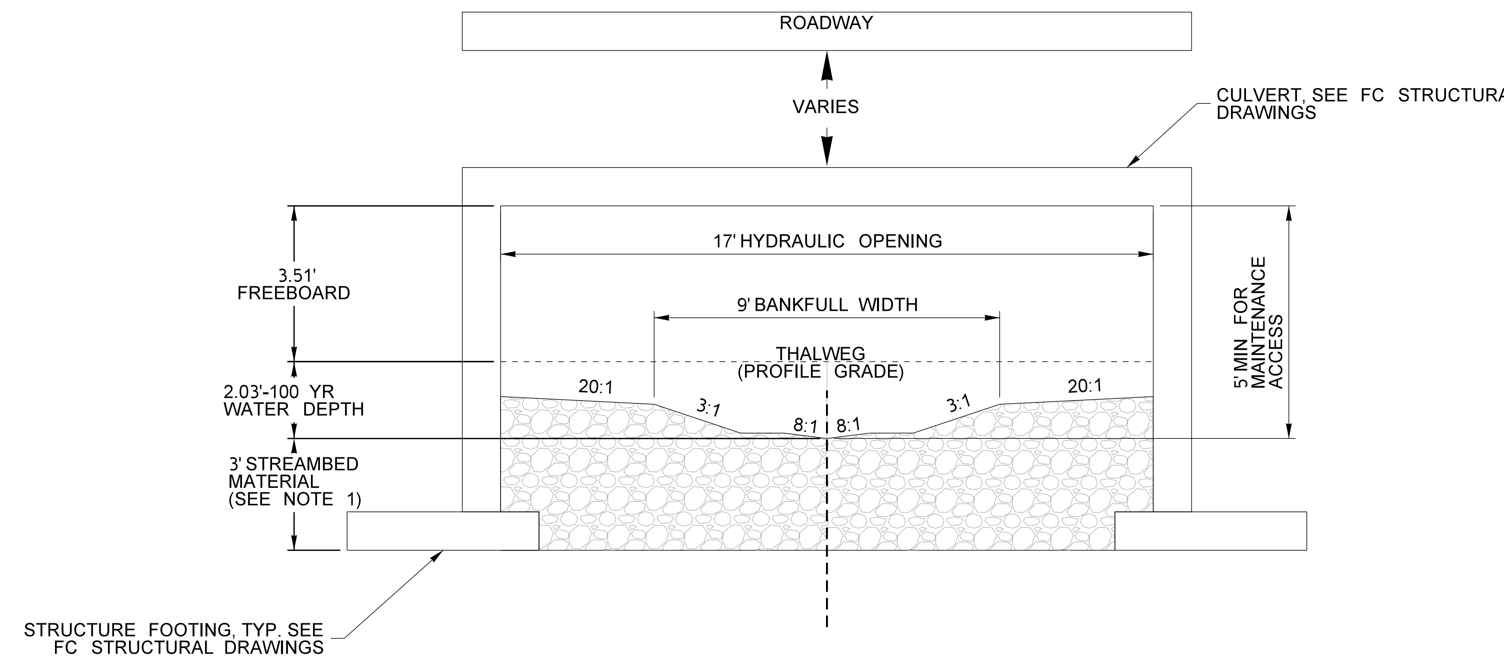
I-405
NE 132ND STREET INTERCHANGE PROJECT

CULVERT SECTIONS AND MEANDER BAR DETAILS

PLAN REF NO FP12
SHEET
OF
SHEETS



CULVERT 2 - TYPICAL CROSS-SECTION (NE 132ND ST)
N.T.S.



CULVERT 3 - TYPICAL CROSS-SECTION (TOTEM LAKE BLVD NE)
N.T.S.

NOTES:

1. PLACE MEANDER BAR AND STREAMBED MATERIAL IN 12" LIFTS. ORGANIC SLASH TO BE ADDED TO STREAMBED MATERIAL BETWEEN EACH LIFT. THOROUGHLY WASH STREAMBED WITH A PRESSURIZED HOSE AT EACH LIFT TO SEAL THE BED.
2. MEANDER BAR: 9 PARTS 6-INCH STREAMBED COBBLES SHALL BE MIXED THOROUGHLY WITH 1-PART STREAMBED SEDIMENT, IN 12-INCH LIFTS.
3. MATERIAL SHALL BE STREAMBED SEDIMENT PER WSDOT STANDARD SPECIFICATIONS SECTION 9-03.11. OR SIMILAR TO SPECIFICATION MATERIAL AS APPROVED BY THE ENGINEER.
4. ORGANIC SLASH SHALL BE LIVE FASCINES (RED OSIER DOGWOOD AND/OR SITKA WILLOW) AND DEAD TREE BRANCHES. DEAD BRANCHES CAN BE FROM ANY WOODY NATIVE, NON-INVASIVE PLANT SUCH AS CEDAR OR DOUGLAS FIR. THERE SHALL BE A MINIMUM OF 8 LIVE BRANCHES AND DEAD BRANCHES SHALL COMPRISE OF NO MORE THAN 40% OF TOTAL FASCINE COUNT.
5. SEE FC STRUCTURAL PLANS FOR THE 3 SIDED CULVERT PLAN PROFILE AND DETAILS.

FILE NAME	XL5464_PS_FP_13.dgn
TIME	4:39:00 PM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	O. PORKKA
ENTERED BY	O. PORKKA
CHECKED BY	C. BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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REVISION	DATE	BY

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

JOB NUMBER

CONTRACT NO. | LOCATION NO. XL-5464

P.E. STAMP BOX DATE

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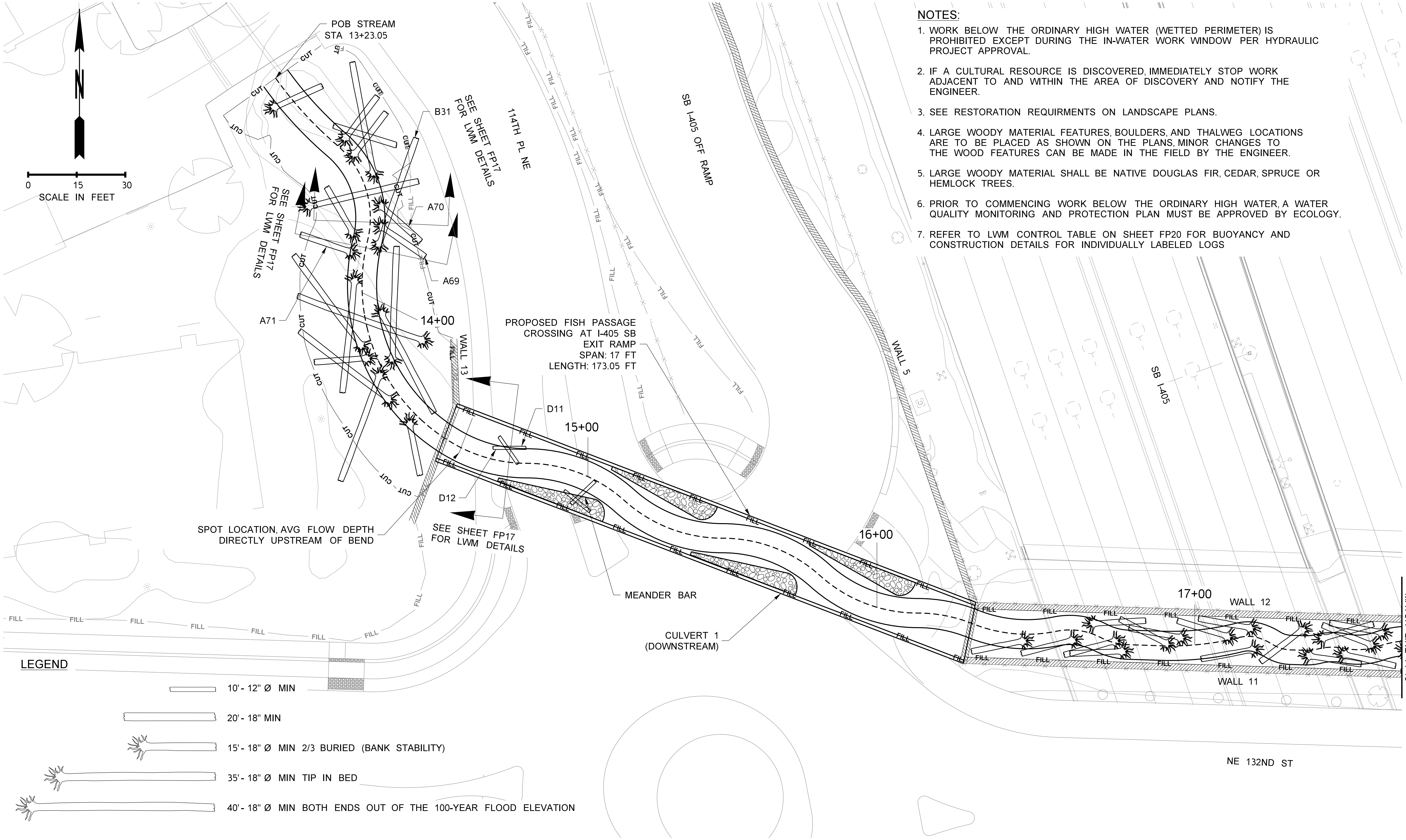
GRAHAM
WSP
1001 Fourth Ave, Suite 3100, Seattle, WA 98154
Tel: (206) 382-5200

I-405
NE 132ND STREET INTERCHANGE PROJECT

CULVERT SECTIONS AND MEANDER BAR DETAILS

PLAN REF NO **FP13**

SHEET OF SHEETS



NOTES:

1. WORK BELOW THE ORDINARY HIGH WATER (WETTED PERIMETER) IS PROHIBITED EXCEPT DURING THE IN-WATER WORK WINDOW PER HYDRAULIC PROJECT APPROVAL.
2. IF A CULTURAL RESOURCE IS DISCOVERED, IMMEDIATELY STOP WORK ADJACENT TO AND WITHIN THE AREA OF DISCOVERY AND NOTIFY THE ENGINEER.
3. SEE RESTORATION REQUIRMENTS ON LANDSCAPE PLANS.
4. LARGE WOODY MATERIAL FEATURES, BOULDERS, AND THALWEG LOCATIONS ARE TO BE PLACED AS SHOWN ON THE PLANS, MINOR CHANGES TO THE WOOD FEATURES CAN BE MADE IN THE FIELD BY THE ENGINEER.
5. LARGE WOODY MATERIAL SHALL BE NATIVE DOUGLAS FIR, CEDAR, SPRUCE OR HEMLOCK TREES.
6. PRIOR TO COMMENCING WORK BELOW THE ORDINARY HIGH WATER, A WATER QUALITY MONITORING AND PROTECTION PLAN MUST BE APPROVED BY ECOLOGY.
7. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS

LEGEND

- 10' - 12" Ø MIN
- 20' - 18" MIN
- 15' - 18" Ø MIN 2/3 BURIED (BANK STABILITY)
- 35' - 18" Ø MIN TIP IN BED
- 40' - 18" Ø MIN BOTH ENDS OUT OF THE 100-YEAR FLOOD ELEVATION

FILE NAME	XL5464_PS_FP_14.dgn
TIME	7:30:39 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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CONTRACT NO. | LOCATION NO. XL-5464

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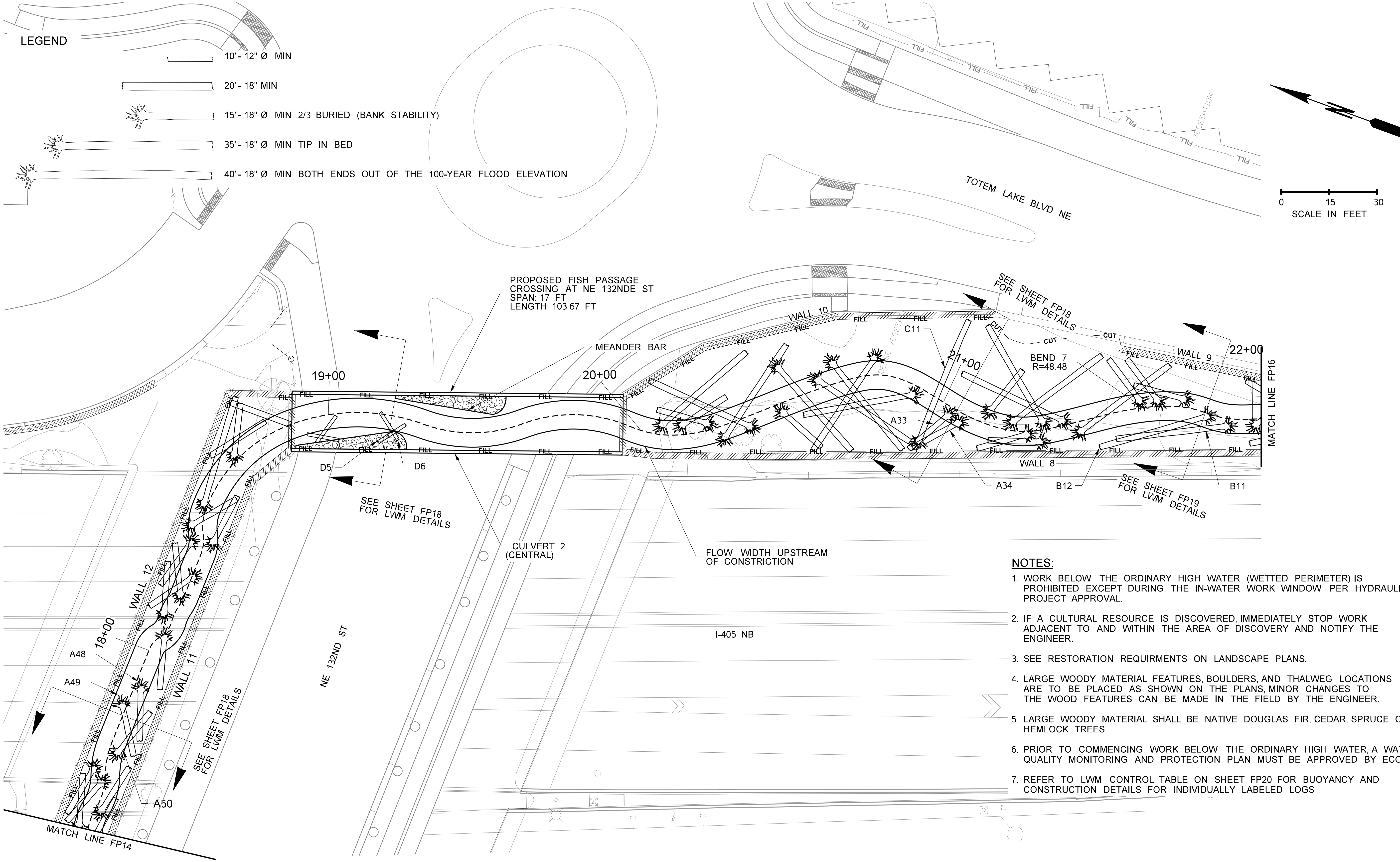
STREAM LWM AND HABITAT FEATURES PLAN

PLAN REF NO FP14
SHEET
OF
SHEETS



NOTES:

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2. IF A CULTURAL RESOURCE IS DISCOVERED, IMMEDIATELY STOP WORK ADJACENT TO AND WITHIN THE AREA OF DISCOVERY AND NOTIFY THE ENGINEER.
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4. LARGE WOODY MATERIAL FEATURES, BOULDERS, AND THALWEG LOCATIONS ARE TO BE PLACED AS SHOWN ON THE PLANS, MINOR CHANGES TO THE WOOD FEATURES CAN BE MADE IN THE FIELD BY THE ENGINEER.
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7. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS

FILE NAME	XL5464_PS_FP_15.dgn
TIME	7:30:39 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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JOB NUMBER		
CONTRACT NO.	LOCATION NO. XL-5464	

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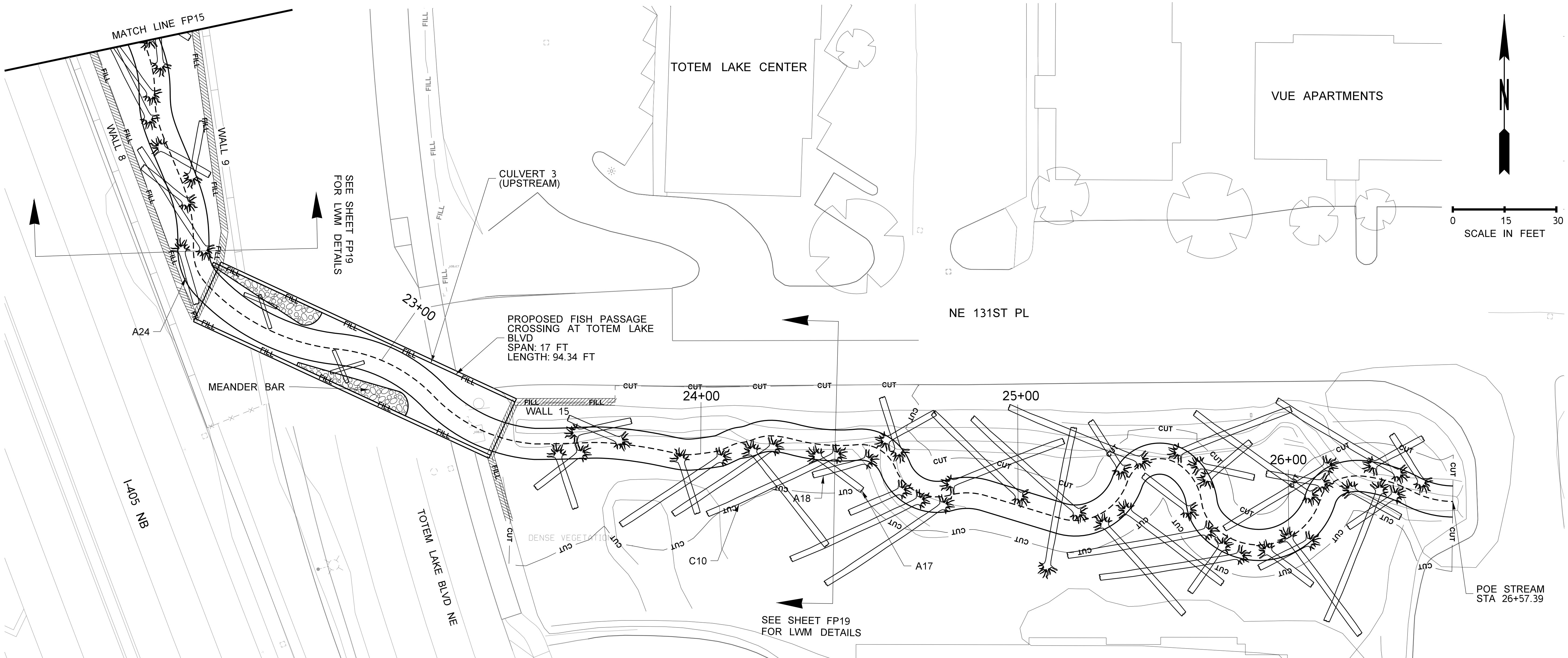
STREAM LWM AND HABITAT FEATURES PLAN

PLAN REF NO FP15
SHEET OF SHEETS



NOTES:

1. WORK BELOW THE ORDINARY HIGH WATER (WETTED PERIMETER) IS PROHIBITED EXCEPT DURING THE IN-WATER WORK WINDOW PER HYDRAULIC PROJECT APPROVAL.
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6. PRIOR TO COMMENCING WORK BELOW THE ORDINARY HIGH WATER, A WATER QUALITY MONITORING AND PROTECTION PLAN MUST BE APPROVED BY ECOLOGY.
7. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS

AEGIS LIVING

LEGEND

- 10' - 12" Ø MIN
- 20' - 18" MIN
- 15' - 18" Ø MIN 2/3 BURIED (BANK STABILITY)
- 35' - 18" Ø MIN TIP IN BED
- 40' - 18" Ø MIN BOTH ENDS OUT OF THE 100-YEAR FLOOD ELEVATION

FILE NAME	XL5464_PS_FP_16.dgn
TIME	7:30:46 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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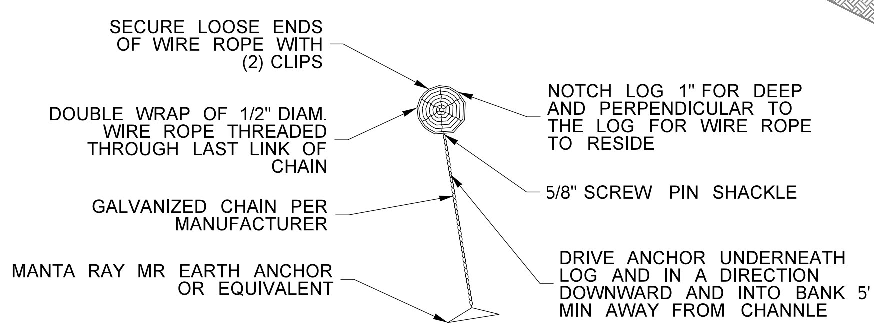
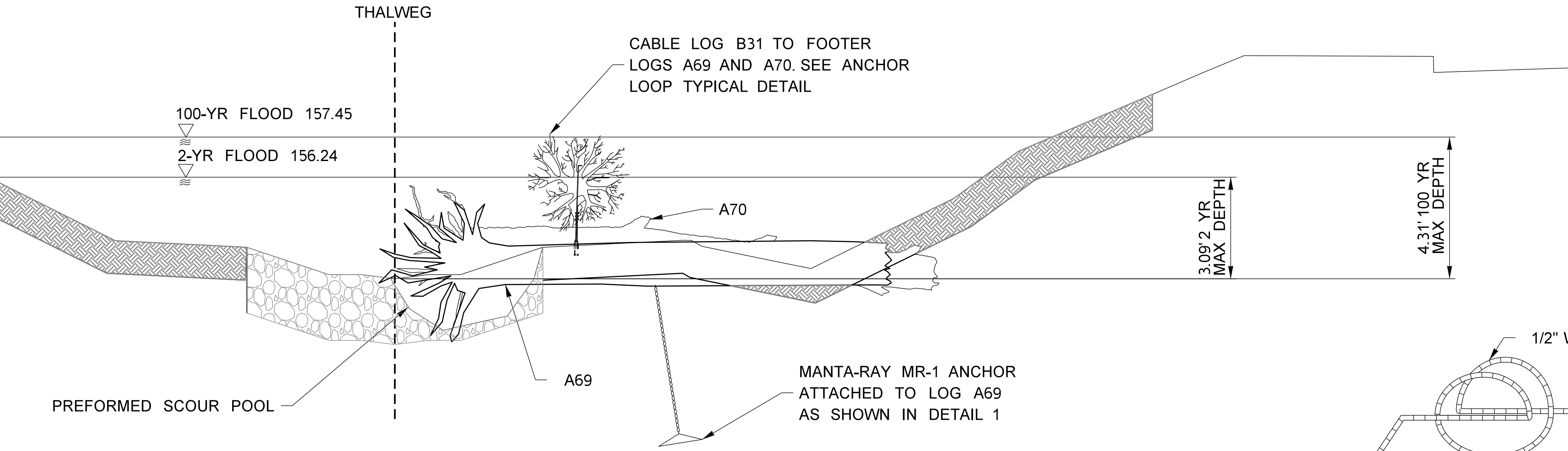
STREAM LWM AND HABITAT FEATURES PLAN

PLAN REF NO FP16
SHEET OF SHEETS



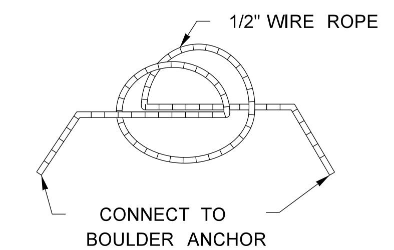
DETAIL 1: LARGE WOODY DEBRIS EARTH ANCHOR

NOT TO SCALE



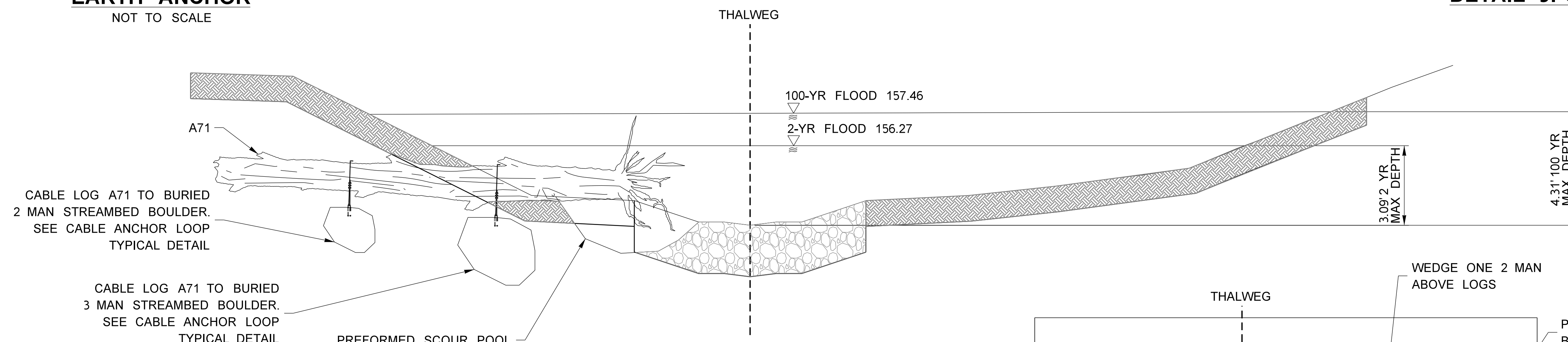
STATION 13+78

SEE SHEET FP14 FOR PLAN VIEW



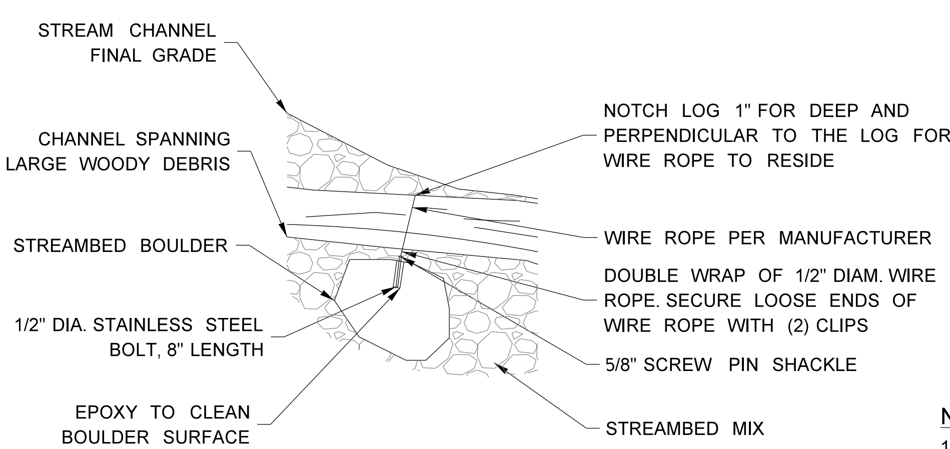
DETAIL 3: CABLE ANCHOR LOOP

NOT TO SCALE



STATION 13+88

SEE SHEET FP14 FOR PLAN VIEW

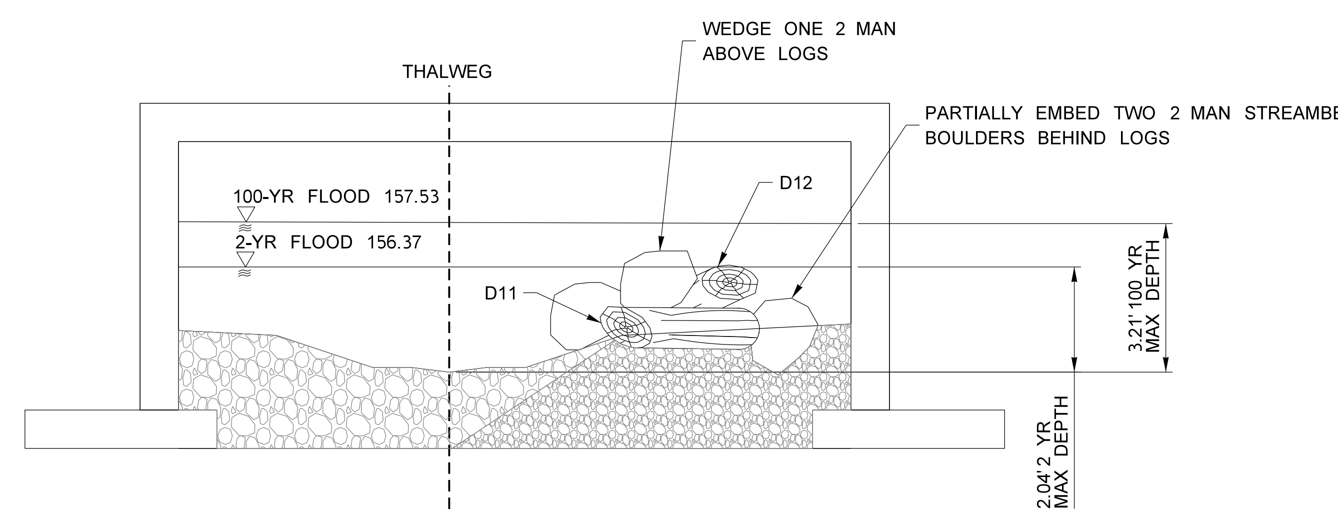


DETAIL 2: STREAMBED BOULDER ANCHOR

NOT TO SCALE

NOTES:

1. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS.
2. REFER TO STREAMBED BOUDER TABLE ON SHEET FP20 FOR DIMENSION AND SIZING.



STATION 14+74

SEE SHEET FP14 FOR PLAN VIEW

FILE NAME	XL5464_PS_FP_17.dgn
TIME	4:38:59 PM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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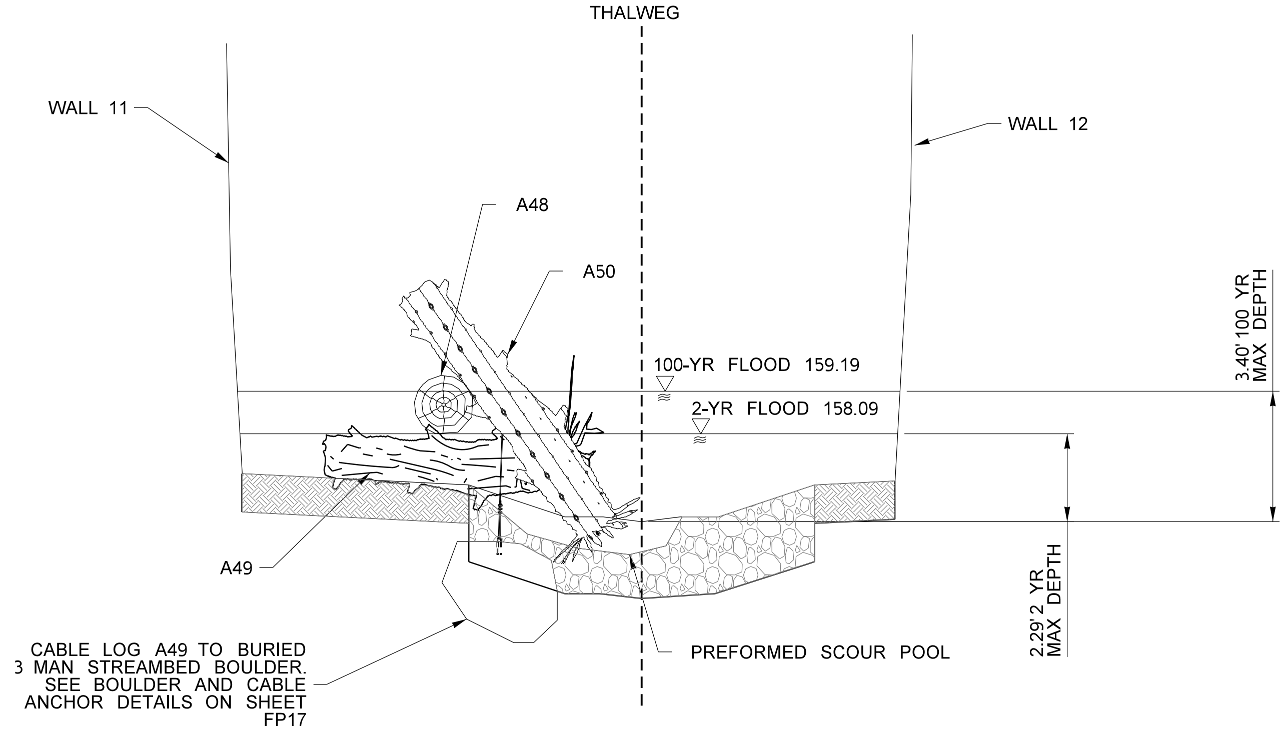
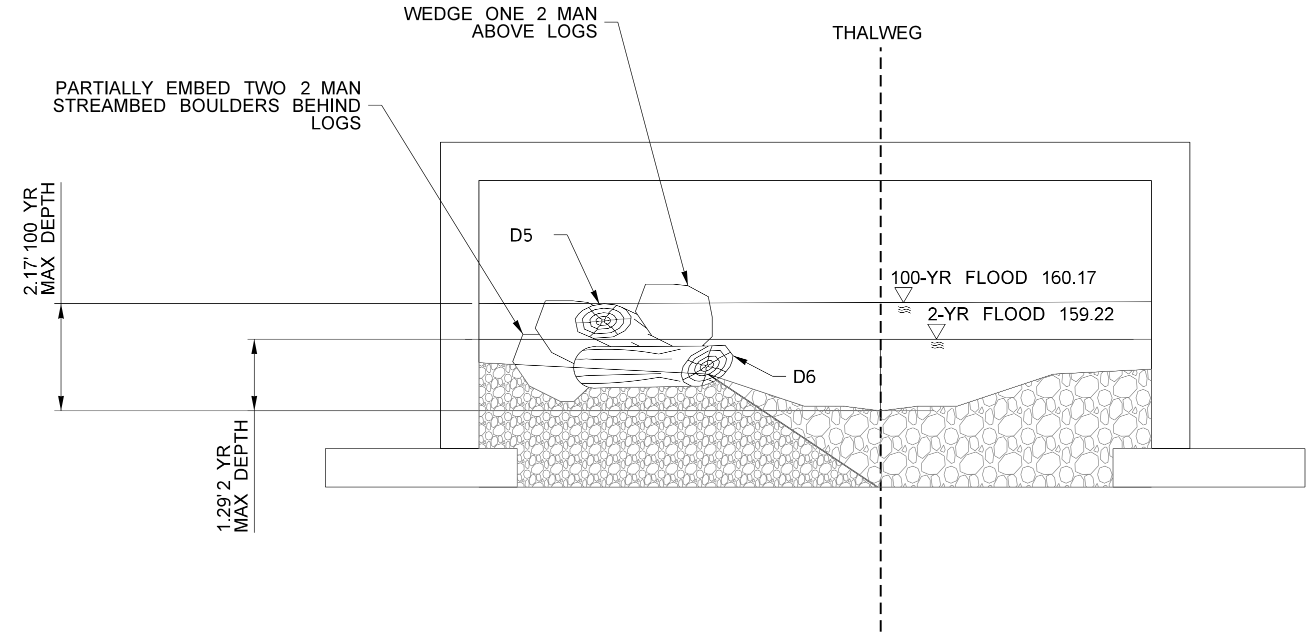
I-405 LWM DETAILS

PLAN REF NO FP17

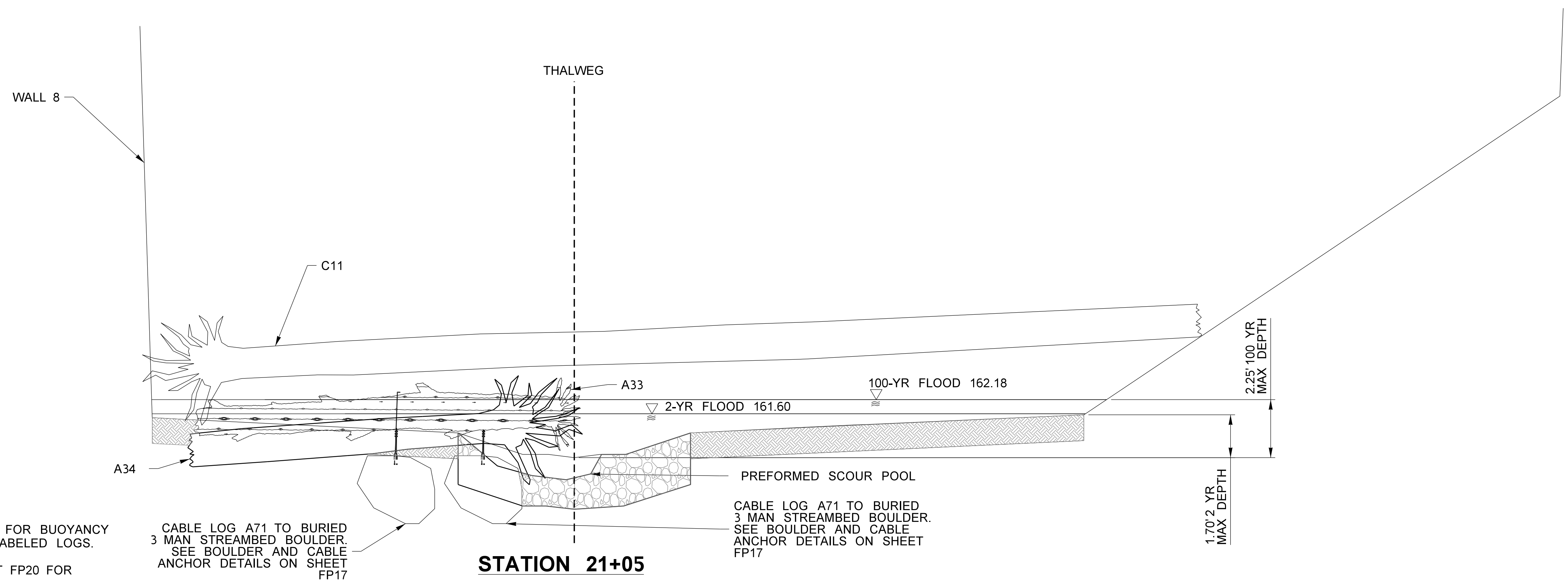
SHEET OF SHEETS



STATION 17+77
SEE SHEET FP15 FOR PLAN VIEW



STATION 19+20
SEE SHEET FP15 FOR PLAN VIEW



STATION 21+05
SEE SHEET FP15 FOR PLAN VIEW

NOTES:

1. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS.
2. REFER TO STREAMBED BOUDER TABLE ON SHEET FP20 FOR DIMENSION AND SIZING.

FILE NAME	XL5464_PS_FP_18.dgn
TIME	4:38:58 PM
DATE	1/11/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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I-405
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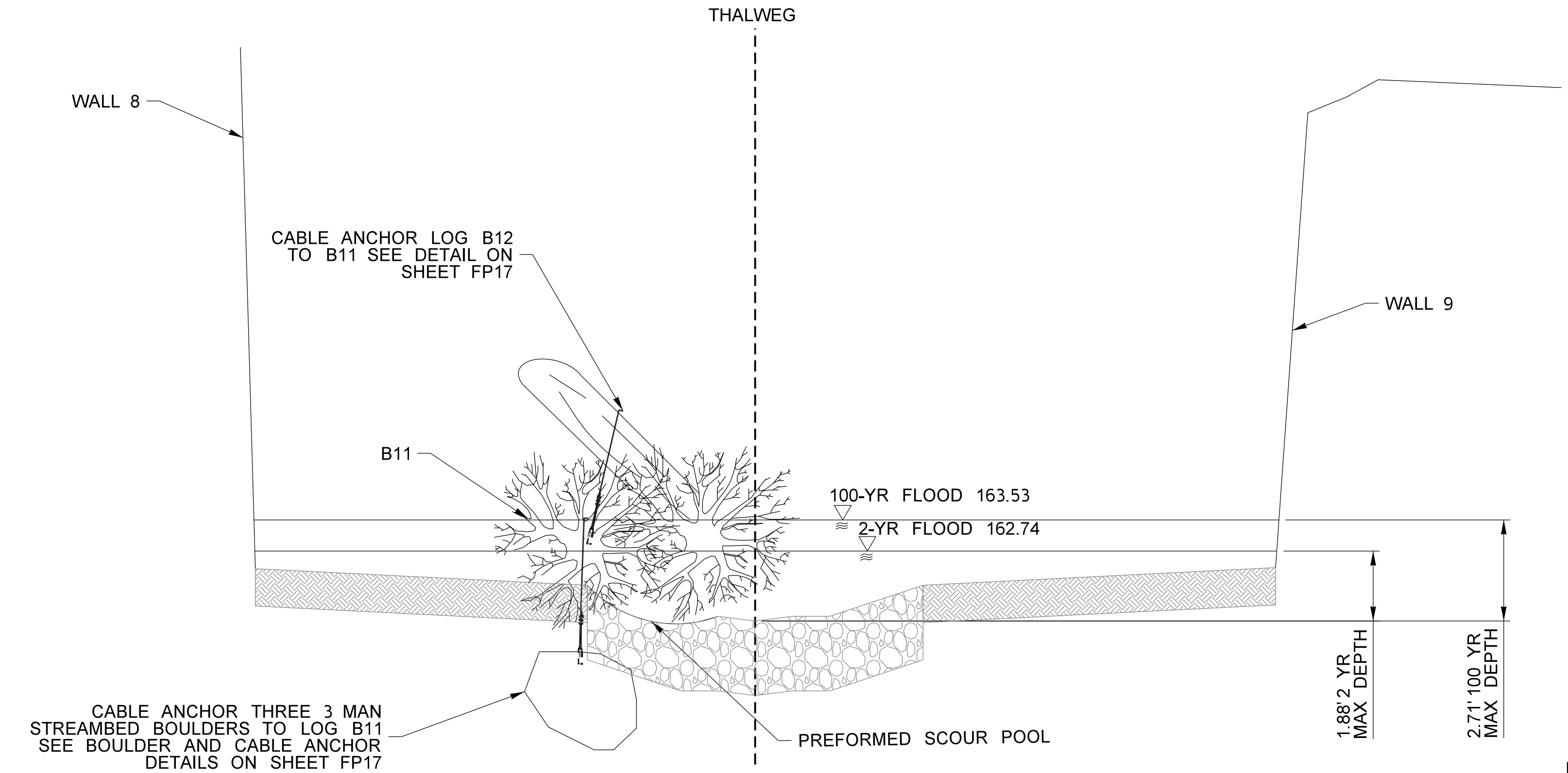
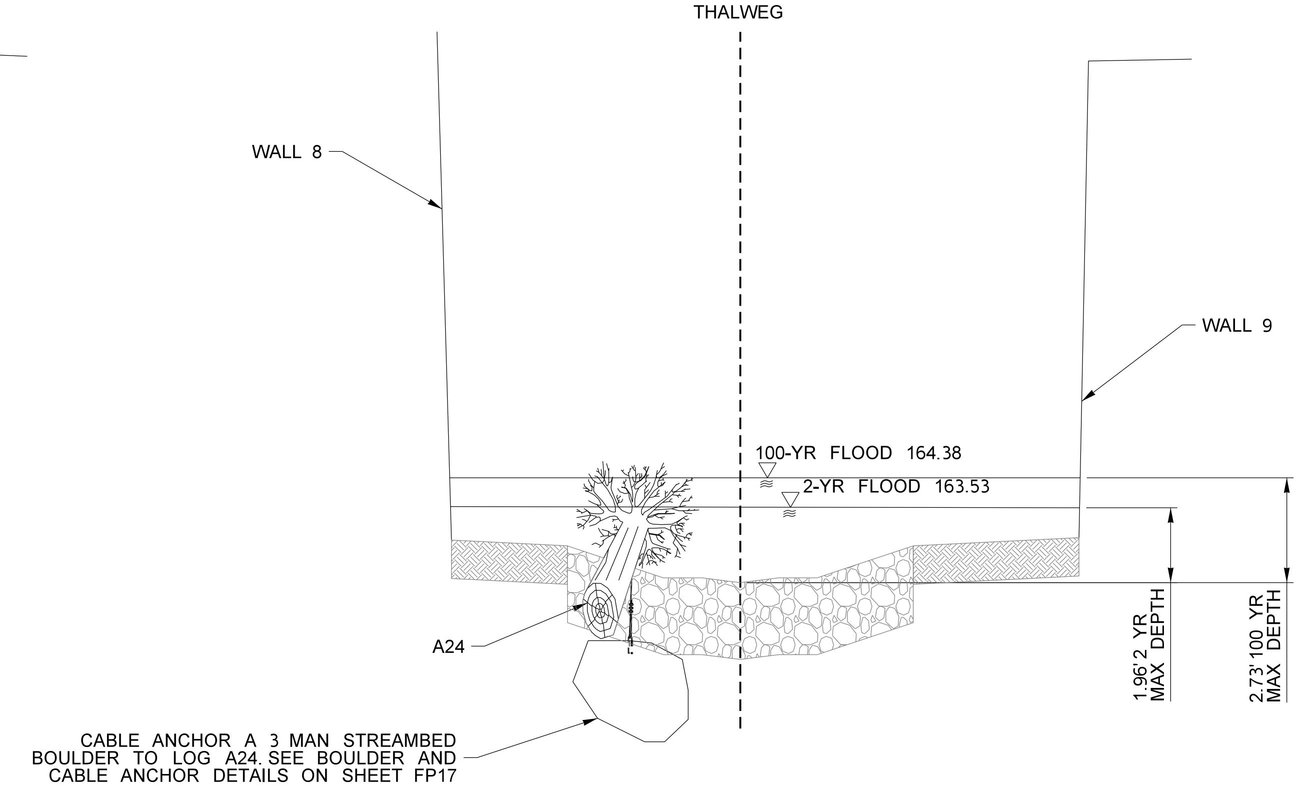
I-405 LWM DETAILS

PLAN REF NO FP18

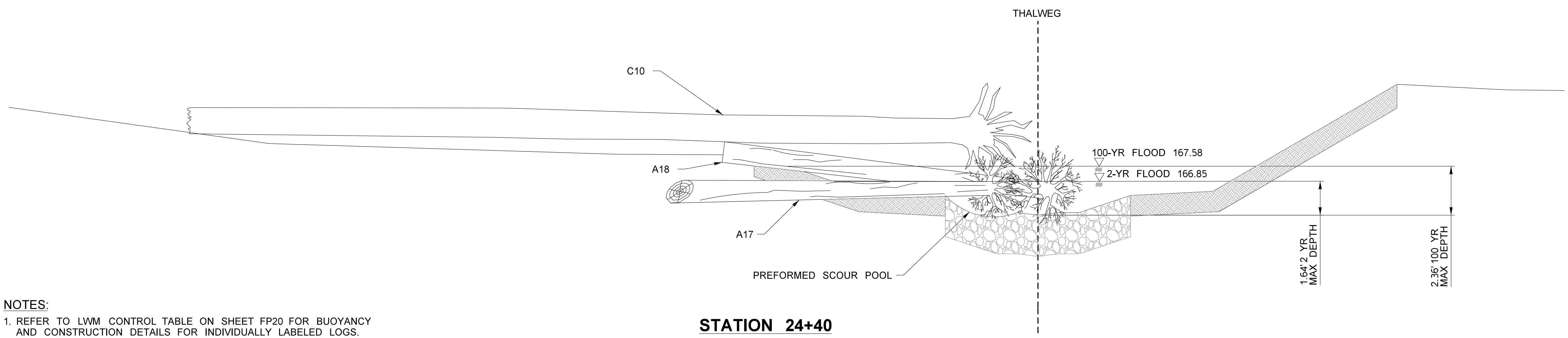
SHEET OF SHEETS



STATION 21+85
SEE SHEET FP15 FOR PLAN VIEW



STATION 22+32
SEE SHEET FP16 FOR PLAN VIEW



STATION 24+40
SEE SHEET FP16 FOR PLAN VIEW

NOTES:

1. REFER TO LWM CONTROL TABLE ON SHEET FP20 FOR BUOYANCY AND CONSTRUCTION DETAILS FOR INDIVIDUALLY LABELED LOGS.
2. REFER TO STREAMBED BOUDER TABLE ON SHEET FP20 FOR DIMENSION AND SIZING.

FILE NAME	XL5464_PS_FP_19.dgn
TIME	7:30:46 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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REGION NO.	STATE	FED.AID PROJ.NO.
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CONTRACT NO.		LOCATION NO. XL-5464

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I-405 LWM DETAILS

PLAN REF NO FP19

SHEET OF SHEETS

LWM CONTROL TABLE

LWD STATION	LOGS ID NO.	BUOYANCY FACTOR OF SAFETY	HORIZ. FACTOR OF SAFETY	BUOYANCY MOMENT (FT/LBS)	ANCHOR REQUIREMENTS: REQUIRED VERTICAL BALLAST (LBS)	ANCHOR REQUIREMENTS: LOG/BALLAST/ANCHOR NOTES	ANCHOR REQUIREMENTS: NOTES
13+32							TBD
13+56							TBD
13+70							TBD
13+78	A69	1.5	37.52	7.47	2138	STEM PARTIALLY BURIED, CABLE PINNED TO B31, MANTA RAY ANCHOR	BASELOG
	A70	2.42	16.59	4.44	2095	STEM PARTIALLY BURIED, CABLE PINNED TO B31	ATTACHED
13+88	B31	2.45	35.27	1.68	4072	CABLE PINNED TO A69 AND A70	STACKED
	A71	1.5	11.45	1.79	1640	STEM PARTIALLY BURIED, 1-2 MAN BOULDER & 1-3 MAN BOULDER ANCHORS	BASELOG
16+07							TBD
14+14							TBD
14+20							TBD
14+28							TBD
14+43							TBD
14+74 (SEE NOTE 1)	D11	1.44	6.5	2.11	466	2-MAN BOULDER BALLASTS	BASELOG
	D12	2.16	6.4	3.89	395	2-MAN BOULDERS BALLASTS	STACKED
15+00							TBD
16+38							TBD
16+55							TBD
16+72							TBD
16+87							TBD
17+00							TBD
17+14							TBD
17+32							TBD
17+39							TBD
17+49							TBD
17+52							TBD
17+77	A49	1.5	2.06	1.55	1718	1-3 MAN BURIED BOULDER ANCHOR	BASELOG
	A50	2.06	1.47	5.38	-301		STACKED
	A48	1.58	1.49	3.86	-63		STACKED
18+06							TBD
18+23							TBD
18+40							TBD
18+68							TBD
18+97							TBD
19+20 (SEE NOTE 1)	D5	1.67	1.93	1.84	484	2-2 MAN BOULDER BALLASTS	BASELOG
	D6	1.06	2.23	1.61	114	1-2 MAN BOULDERS BALLASTS	STACKED
20+12							TBD
20+31							TBD
20+46							TBD
20+49							TBD
20+74							TBD
21+05	A33	1.5	1.91	1.41	1382	PARTIALLY BURIED, 1-3 MAN BURIED BOULDER ANCHOR	KEYLOG
	A34	1.5	2.2	1.48	1324	PARTIALLY BURIED, 1-3 MAN BURIED BOULDER ANCHOR	STACKED
	C11	3.45	3.23	3.13	-1591	SPANNING ACROSS 100-FLOOD LEVEL	STACKED
21+12							TBD
21+28							TBD
21+39							TBD
21+70							TBD
21+85	B11	1.5	2.65	2.09	4153	PARTIALLY BURIED AND 3-3 MAN BOULDER ANCHORS	KEYLOG
	B12	2.15	1.48	4.5	-755	CABLE ANCHORED TO LOG B11	STACKED
22+07							TBD
22+18							TBD
22+32	A24	1.5	1.59	1.41	1343	1-3 MAN BOULDER ANCHOR	BASELOG
22+60 (SEE NOTE 1)	D3	1.93	57.84	2.29	457	1-2' BOULDER BALLAST	STACKED
	D4	2.38	2.24	1.91	321	1-2' BOULDER BALLAST	STACKED
22+70							TBD

LWM CONTROL TABLE

LWD STATION	LOGS ID NO.	BUOYANCY FACTOR OF SAFETY	HORIZ. FACTOR OF SAFETY	BUOYANCY MOMENT (FT/LBS)	ANCHOR REQUIREMENTS: REQUIRED VERTICAL BALLAST (LBS)	ANCHOR REQUIREMENTS: LOG/BALLAST/ANCHOR NOTES	ANCHOR REQUIREMENTS: NOTES
23+64							TBD
23+70							TBD
24+04							TBD
24+21							TBD
24+40	A17	2.55	2.8	2.17	1467	STEM PARTIALLY BURIED	KEYLOG
	A18	9.13	2.45	16.44	2304		STACKED
	C10	118.54	47	104.32	-2777		STACKED
24+53							TBD
24+66							TBD
24+71							TBD
24+78							TBD
24+98							TBD
25+11							TBD
25+25							TBD
25+31							TBD
25+44							TBD
25+54							TBD
25+63							TBD
25+70							TBD
25+81							TBD
26+04	A8	1.73	8.89	3.43	1787	PARTIALLY BURIED	KEYLOG
	B1	15.26	1204.5	70.6	-2258		STACKED
	A9	5.45	7.56	14.09	-920		STACKED
26+18	A6	2.25	2.9	2.5	1722	PARTIALLY BURIED	KEYLOG
	B2	4.13	2.34	1.6	-582		STACKED
	C3	160.17	2016	160.17	-2786		STACKED
26+38	A2	2.52	1.35	2.13	-90	PARTIALLY BURIED	KEYLOG
	A1	6.76	1.66	6.14	-1187		STACKED
	C1	204.38	26.43	204.38	-2792		STACKED
26+41	A3	2.2	2.2	1.9	1549		KEYLOG
	A4	6	2.13	5.66	-249		STACKED
	C2	28029	1457	4216.52	-2813		STACKED

LOG SCHEDULE

LOG NUMBER	LOG LENGTH	LOG DIAMETER	ROOTWAD
A	15	1.5	YES
B	35	1.5	YES
C	40	1.5	YES
D	10	1.0	NO
E	20	1.5	NO

STREAMBED BOULDERS

BOULDER NAME	APPROXIMATE SIZE	APPROXIMATE WEIGHT (lbf) BELOW WSE*
ONE MAN	12"-18"	54
TWO MAN	18"-28"	430
THREE MAN	28"-36"	1450

* WEIGHT DETERMINED FROM RAFFERTY (2016) COMPUTATIONAL DESIGN TOOL. ONE, TWO, AND THREE MAN BOULDERS WERE DESIGNED TO BE 1', 2', AND 3' DIAMETER BOULDERS, RESPECTIVELY.

NOTES:

1. MOBILE WOOD DEBRIS. DESIGNED TO BE STABLE FOR A 10 YEAR FLOOD EVENT.
2. TBD = VALUES TO BE DETERMINED AT A LATER DATE.

FILE NAME	XL5464_PS_FP_20.dgn
TIME	7:31:18 PM
DATE	1/4/2022
PLOTTED BY	wsppw14ics02$
DESIGNED BY	A.SHANMUGHAM
ENTERED BY	A.SHANMUGHAM
CHECKED BY	C.BUITRAGO
PROJ. ENGR.	E. PAO
REGIONAL ADM.	

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NE 132ND STREET INTERCHANGE PROJECT

LWM CONTROL TABLE AND LOG SCHEDULE

PLAN REF NO FP20

SHEET OF SHEETS

Appendix G

Scour Calculations

Cumulative Culvert Scour

Project name :	I-405 / 132ND INTERCHANGE FISH PASSAGE SCOUR CALCULATIONS	
UPDATED	12.17.2021	Update By: CS
Fish Passage Scour Review		Checked CB

Culvert 1 Scour Review, (100-Year, LWM Materials SMS Model)		
0.9	ft	Long-term Degradation
0.0	ft	Contraction Scour
0.9	ft	Total Design Scour Depth
2.9	ft	Total Design Scour Depth + 2 feet
Culvert 1 Scour Review, (500-Year, LWM Materials SMS Model)		
1.1	ft	Long-term Degradation
0.0	ft	Contraction Scour
1.1	ft	Total Check Scour Depth

Culvert 2 Scour Review, (100-Year, LWM Materials SMS Model)		
0.5	ft	Long-term Degradation
0.1	ft	Contraction Scour
0.6	ft	Total Design Scour Depth
2.6	ft	Total Design Scour Depth + 2 feet
Culvert 2 Scour Review, (500-Year, LWM Materials SMS Model)		
0.5	ft	Long-term Degradation
0.3	ft	Contraction Scour
0.8	ft	Total Check Scour Depth

Culvert 3 Scour Review, (100-Year, LWM Materials SMS Model)		
0.1	ft	Long-term Degradation
0.3	ft	Contraction Scour
0.5	ft	Total Design Scour Depth
2.5	ft	Total Design Scour Depth + 2 feet
Culvert 3 Scour Review, (500-Year, LWM Materials SMS Model)		
0.2	ft	Long-term Degradation
0.5	ft	Contraction Scour
0.6	ft	Total Check Scour Depth

Bend Scour

WDFW - Stream Habitat Restoration Guidelines - Appendix E Hydraulics - Section 4.3.3.2 - Gravel Bed Streams

Thorne Equation

Hoffmans and Verheij[20] presented the following equation developed by Thorne based on flume and large river experiments. The mean bed particle size varied from 0.3 to 63 mm. This equation is applicable to gravel-bed streams. Metric or English units may be used.

$$d/y_1 = 1.07 - log(R_c/W - 2) \text{ for } 2 < R_c/W < 22 \qquad \text{(Equation 14)}$$

Where: d = maximum depth of scour below local streambed elevation (m or ft)
y_1 = average flow depth directly upstream of the bend (m or ft)
W = width of flow (m or ft)
R_c = channel radius of curvature at channel centerline (m or ft)

The width of flow (W) in Equation (14) corresponds to the width of active flow. This width is subject to engineering judgment, however, this width often corresponds to the bankfull top width for streams that are flowing near or above bankfull stage.

THORNE EQUATION - BEND SCOUR CALCULATIONS PER BEND LOCATION							
100-YR STORM EVENT - LWM Materials model							
BEND NO.	**BEGIN STA**	**END STA**	**Rc (ft)**	**Rc/W**	y1 (ft)*	W (ft)	**d SCOUR**
BEND 1	13+20	13+90	29.53	3.28	4.246835	9	4.087
BEND 2	13+90	45+75	56.45	6.27	3.912819	9	1.719
BEND 3	18+17	19+20	44.72	4.97	3.082189	9	1.841
BEND 4	20+60	20+80	47.13	5.24	2.547356	9	1.426
BEND 5	20+80	21+00	24.65	2.74	2.241086	9	2.692
BEND 6	21+10	21+40	29.99	3.33	2.785665	9	2.634
BEND 7	21+50	21+70	48.48	5.39	2.663414	9	1.439
BEND 8	21+70	21+80	34.58	3.84	2.549052	9	2.051
BEND 9	21+80	22+30	44.62	4.96	2.580824	9	1.546
BEND 10	22+40	22+70	15.19	3.04	2.910706	5	3.067
BEND 11	25+77	26+52	26.8	2.98	2.330306	9	2.516
BEND 12	25+78	26+53	10.79	2.70	2.503492	4	3.070
BEND 13	25+79	26+54	13.09	2.62	2.32355	5	2.972
BEND 14	25+80	26+55	16.05	2.29	1.943511	7	3.116
BEND 15	25+81	26+56	9.92	2.48	1.94281	4	2.698
BEND 16	25+82	26+57	18.52	2.06	1.802029	9	4.160
BEND 17	25+83	26+58	15.69	2.62	1.953137	6	2.502

*from python

THORNE EQUATION - BEND SCOUR CALCULATIONS PER BEND LOCATION							
500-YR STORM EVENT - LWM Materials Model							
BEND NO.	**BEGIN STA**	**END STA**	**Rc (ft)**	**Rc/W**	y1 (ft)*	W (ft)	**d SCOUR**
BEND 1	13+20	13+90	29.53	3.28	4.928099	9	4.743
BEND 2	13+90	45+75	56.45	6.27	4.574497	9	2.010
BEND 3	18+17	19+20	44.72	4.97	3.716551	9	2.220
BEND 4	20+60	20+80	47.13	5.24	3.020695	9	1.691
BEND 5	20+80	21+00	24.65	2.74	2.614857	9	3.142
BEND 6	21+10	21+40	29.99	3.33	3.227196	9	3.051
BEND 7	21+50	21+70	48.48	5.39	3.126528	9	1.689
BEND 8	21+70	21+80	34.58	3.84	2.983593	9	2.401
BEND 9	21+80	22+30	44.62	4.96	2.981838	9	1.786
BEND 10	22+40	22+70	15.19	3.04	3.437309	5	3.622
BEND 11	25+77	26+52	26.8	2.98	2.686265	9	2.901
BEND 12	25+78	26+53	10.79	2.70	2.858227	4	3.505
BEND 13	25+79	26+54	13.09	2.62	2.653656	5	3.394
BEND 14	25+80	26+55	16.05	2.29	2.206855	7	3.538
BEND 15	25+81	26+56	9.92	2.48	2.172418	4	3.017
BEND 16	25+82	26+57	18.52	2.06	2.048043	9	4.727
BEND 17	25+83	26+58	15.69	2.62	2.202249	6	2.821

*from python

THORNE EQUATION - BEND SCOUR CALCULATIONS PER BEND LOCATION							
2080 Year 100-YR STORM EVENT - LWM Materials model							
BEND NO.	**BEGIN STA**	**END STA**	**Rc (ft)**	**Rc/W**	y1 (ft)*	W (ft)	**d SCOUR**
BEND 1	13+20	13+90	29.53	3.28	4.762048	9	4.583
BEND 2	13+90	45+75	56.45	6.27	4.407793	9	1.937
BEND 3	18+17	19+20	44.72	4.97	3.52037	9	2.103
BEND 4	20+60	20+80	47.13	5.24	2.870153	9	1.607
BEND 5	20+80	21+00	24.65	2.74	2.496018	9	2.999
BEND 6	21+10	21+40	29.99	3.33	3.091705	9	2.923
BEND 7	21+50	21+70	48.48	5.39	2.984165	9	1.612
BEND 8	21+70	21+80	34.58	3.84	2.850369	9	2.294
BEND 9	21+80	22+30	44.62	4.96	2.860286	9	1.713
BEND 10	22+40	22+70	15.19	3.04	3.276872	5	3.453
BEND 11	25+77	26+52	26.8	2.98	2.57831	9	2.784
BEND 12	25+78	26+53	10.79	2.70	2.751133	4	3.374
BEND 13	25+79	26+54	13.09	2.62	2.554451	5	3.267
BEND 14	25+80	26+55	16.05	2.29	2.126334	7	3.409
BEND 15	25+81	26+56	9.92	2.48	2.101283	4	2.918
BEND 16	25+82	26+57	18.52	2.06	1.971522	9	4.551
BEND 17	25+83	26+58	15.69	2.62	2.123244	6	2.720

*from python

Contraction Scour

Critical Velocity

$$V_c = K_u\, y^{1/6}\, D^{1/3} \tag{6.1}$$

where:

V_c	=	Critical velocity above which bed material of size D and smaller will be transported, ft/s (m/s)
y	=	Average depth of flow upstream of the bridge, ft (m)
D	=	Particle size for V_c, ft (m)
D_{50}	=	Particle size in a mixture of which 50 percent are smaller, ft (m)
K_u	=	6.19 SI units
K_u	=	11.17 English units

Clear Water Contraction Scour

6.4 CLEAR-WATER CONTRACTION SCOUR

The recommended clear-water contraction scour equation is based on a development suggested by Laursen (1963) (presented in the Appendix C). The equation is:

$$y_2 = \left[\frac{K_u\, Q^2}{D_m^{2/3}\, W^2}\right]^{3/7} \tag{6.4}$$

$$y_s = y_2 - y_o = \text{(average contraction scour depth)} \tag{6.5}$$

where:

y_2	=	Average equilibrium depth in the contracted section after contraction scour, ft (m)
Q	=	Discharge through the bridge or on the set-back overbank area at the bridge associated with the width W, ft^3/s (m^3/s)
D_m	=	Diameter of the smallest nontransportable particle in the bed material (1.25 D_{50}) in the contracted section, ft (m)
D_{50}	=	Median diameter of bed material, ft (m)
W	=	Bottom width of the contracted section less pier widths, ft (m)
y_o	=	Average existing depth in the contracted section, ft (m)
K_u	=	0.0077 English units
K_u	=	0.025 SI units

Contraction Scour

100 yr

Culvert 1			
See Equation 6.4	y2	1.9162366	Water depth after contraction scour (ft)
	Q2	165.1	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	27258.01	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**-0.9970564**	Depth of scour (ft)
	y2	1.9162366	Water depth after contraction scour (ft)
	y0	2.913293	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	2.6	Water depth upstream of structure (ft)
	Vc	4.8	Critical velocity (ft/s)
	V US	3.9	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 2			
See Equation 6.4	y2	1.8143037	Water depth after contraction scour (ft)
	Q2	154.9	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	23994.01	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.1109493**	Depth of scour (ft)
	y2	1.8143037	Water depth after contraction scour (ft)
	y0	1.7033544	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	1.9	Water depth upstream of structure (ft)
	Vc	4.6	Critical velocity (ft/s)
	V US	3.5	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 3			
See Equation 6.4	y2	1.8143037	Water depth after contraction scour (ft)
	Q2	154.9	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	23994.01	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.3240021**	Depth of scour (ft)
	y2	1.8143037	Water depth after contraction scour (ft)
	y0	1.4903016	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	1.9	Water depth upstream of structure (ft)
	Vc	4.6	Critical velocity (ft/s)
	V US	3.8	Average velocity upstream of structure (ft/s)

Contraction Scour

500 yr

Culvert 1			
See Equation 6.4	y2	2.5057329	Water depth after contraction scour (ft)
	Q2	225.76	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	50967.578	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**-0.7003952**	Depth of scour (ft)
	y2	2.5057329	Water depth after contraction scour (ft)
	y0	3.2061281	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	3.2	Water depth upstream of structure (ft)
	Vc	5.0	Critical velocity (ft/s)
	V US	4.2	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 2			
See Equation 6.4	y2	2.3724194	Water depth after contraction scour (ft)
	Q2	211.81	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	44863.476	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.3361009**	Depth of scour (ft)
	y2	2.3724194	Water depth after contraction scour (ft)
	y0	2.0363184	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	2.5	Water depth upstream of structure (ft)
	Vc	4.8	Critical velocity (ft/s)
	V US	3.5	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 3			
See Equation 6.4	y2	2.3724194	Water depth after contraction scour (ft)
	Q2	211.81	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	44863.476	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.4550052**	Depth of scour (ft)
	y2	2.3724194	Water depth after contraction scour (ft)
	y0	1.9174142	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	2.5	Water depth upstream of structure (ft)
	Vc	4.8	Critical velocity (ft/s)
	V US	4.0	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Contraction Scour

2080 yr

Culvert 1			
See Equation 6.4	y2	2.3252017	Water depth after contraction scour (ft)
	Q2	206.9	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	42807.61	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**-1.0746724**	Depth of scour (ft)
	y2	2.3252017	Water depth after contraction scour (ft)
	y0	3.3998741	Origional water depth, before scour (ft)
See Equation 6.1	y1 US	3.1	Water depth upstream of structure (ft)
	Vc	5.0	Critical velocity (ft/s)
	V US	4.1	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 2			
See Equation 6.4	y2	2.2013435	Water depth after contraction scour (ft)
	Q2	194.1	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	37674.81	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.1218847**	Depth of scour (ft)
	y2	2.2013435	Water depth after contraction scour (ft)
	y0	2.0794587	Origional water depth, before scour (ft)
			Closer to culvert, near tighter mesh
See Equation 6.1	y1 US	2.3	Water depth upstream of structure (ft)
	Vc	4.8	Critical velocity (ft/s)
	V US	3.5	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Culvert 3			
See Equation 6.4	y2	2.2013435	Water depth after contraction scour (ft)
	Q2	194.1	Flow through the structure (ft3/s)
	Ku	0.0077	English Units constant
	D50	0.050833	Median diaameter of bed material (ft)
	W2	17	Top width in the contracted section (ft)
	Dm	0.0635417	Dia of the smallest nontransportable particle (ft)
	Q2^2	37674.81	
	W2^2	289	
	Dm^(2/3)	0.1592352	
See Figure 6.5	ys	**0.4743297**	Depth of scour (ft)
	y2	2.2013435	Water depth after contraction scour (ft)
	y0	1.7270138	Origional water depth, before scour (ft)
			Closer to culvert, near tighter mesh
See Equation 6.1	y1 US	2.3	Water depth upstream of structure (ft)
	Vc	4.7	Critical velocity (ft/s)
	V US	3.9	Average velocity upstream of structure (ft/s)
	Vc > V : Clear		

Appendix H
Manning's 'n' Values

OPEN CHANNEL MANNNINGS N VALUE

Appendix 4A Manning's Roughness Coefficients (n)

Figure 4A-1 References for Manning's Roughness Coefficients

Category of Surface	Surfaces Included	Source
Open Channel and Pipe	Closed Conduits Pipes Pavement Gutter Manmade Channels	HEC 22
River, Stream, and Culvert Design for Aquatic Organism Passage	Rigid Channel Minor Streams Floodplains Major Streams Alluvial Beds Sand Beds Gravel Beds Cohesive Soils Composite Roughness Value	HDS 6 HEC 26 (when required for Aquatic Organism Passage) HEC 22 Chow V.T. 1959(1)
Channel Lining	Rigid Channel Unlined Channel Grass Gravel Riprap Gabion	HEC 15
Storm Sewer Conduit(2)	Concrete Pipe Metal Pipe Polyethylene Pipe PVC Pipe	HEC 22
Street and Gutter	Concrete Gutter Asphalt Concrete Pavement	HEC 22
Maintained Vegetation	Grass	HEC 15 Chow V.T. 1959(3)

Notes:
(1)See Figure 4A-2 on following page.
(2)For storm sewer pipes 24 inches or less in diameter, use n = 0.013.
(3)See Figure 4A-3 on following page.

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

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

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

Figure 4A-3 Manning's Roughness Coefficients for Highway Channels and Swales with Maintained Vegetation

Surface	Manning's n	
	Manning's n at Depth of flow <0.7 feet	Manning's n Depth of flow 0.7-1.5 feet
Bermudagrass, Kentucky bluegrass, buffalo grass:		
Mowed to 2 inches	0.07-0.045	0.05-0.035
Length 4 to 6 inches	0.09-0.05	0.06-0.04
Good stand, any grass:		
Length about 12 inches	0.18-0.09	0.12-0.07
Length about 24 inches	0.30-0.15	0.20-0.10
Fair stand, any grass:		
Length about 12 inches	0.14-0.08	0.10-0.06
Length about 24 inches	0.25-0.13	0.17-0.09

Note:
Values shown are for velocities of 2 and 6 feet per second.

HEC 22 - 3RD EDITION

Table 4-3. Manning's n for Street and Pavement Gutters.

Type of Gutter or Pavement	Manning's n		
Concrete gutter, troweled finish	0.012		
Asphalt Pavement:			
Smooth texture	0.013	0.015	Roadway
Rough texture	0.016		
Concrete gutter-asphalt pavement:			
Smooth	0.013		
Rough	0.015		
Concrete pavement:			
Float finish	0.014		
Broom finish	0.016		
For gutters with small slope, where sediment may accumulate, increase above values of "n" by	0.002		
Reference: USDOT, FHWA, HDS-3[36]			

Chart 1 can be used for direct solution of gutter flow where the Manning's n value is 0.016. For other values of n, divide the value of Qn by n. Instructions for use and an example problem solution are provided on the chart.

HEC 22 - 3RD EDITION

Table 7-1. Manning's Coefficients for Storm Drain Conduits.*[(2)]

Type of Culvert	Roughness or Corrugation	Manning's n
Concrete Pipe	Smooth	0.010-0.011
Concrete Boxes	Smooth	0.012-0.015
Spiral Rip Metal Pipe	Smooth	0.012-0.013
Corrugated Metal Pipe, Pipe-Arch and Box (Annular or Helical Corrugations -- see Figure B-3 in Reference 2, Manning's n varies with barrel size)	68 by 13 mm 2-2/3 by 1/2 in Annular	0.022-0.027
	68 by 13 mm 2-2/3 by 1/2 in Helical	0.011-0.023
	150 by 25 mm 6 by 1 in Helical	0.022-0.025
	125 by 25 mm 5 by 1 in	0.025-0.026
	75 by 25 mm 3 by 1 in	0.027-0.028
	150 by 50 mm 6 by 2 in Structural Plate	0.033-0.035
	230 by 64 mm 9 by 2-1/2 in Structural Plate	0.033-0.037
Corrugated Polyethylene	Smooth	0.009-0.015
Corrugated Polyethylene	Corrugated	0.018-0.025
Polyvinyl chloride (PVC)	Smooth	0.009-0.011

*NOTE: Manning's n values indicated in this table were obtained in the laboratory and are supported by the provided reference. Actual field values for culverts may vary depending on the effect of abrasion, corrosion, deflection, and joint conditions.

CONCRETE WALL

References

Washington State Department of Transportation (April 2019). *Hydraulics Manual*. Olympia, WA. Publication Number M 23-03.06

Hec-22 Urban Drainage Design Manual, (2009). 3rd Edition

Appendix I

Large Woody Material Calculations

I-405 MP 20.95 JUANITA CREEK TRIBUTARY DRAFT FHD

Large Wood Structure Stability Analysis

TABLE OF CONTENTS

Date of Last Revision: January 7, 2016

Designer:
Kaylan Smyth, EIT
1/4/2022

Reviewed by:
N/A

Large Wood Structure Stability Analysis Spreadsheet was developed by Michael Rafferty, P.E.
Version 1.1

Reference for Companion Paper:

Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center.

I-405 MP 20.95 JUANITA CREEK TRIBUTARY DRAFT FH
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

Symbol	Description	Value
FS_V	Factor of Safety for Vertical Force Balance	**1.50**
FS_H	Factor of Safety for Horizontal Force Balance	**1.50**
FS_M	Factor of Safety for Moment Force Balance	**1.50**

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.50
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
100yr	13+78	165	4.31	2.05	9.0	99	57

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
100yr	13+78	**31.00**	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
100yr	13+78	Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

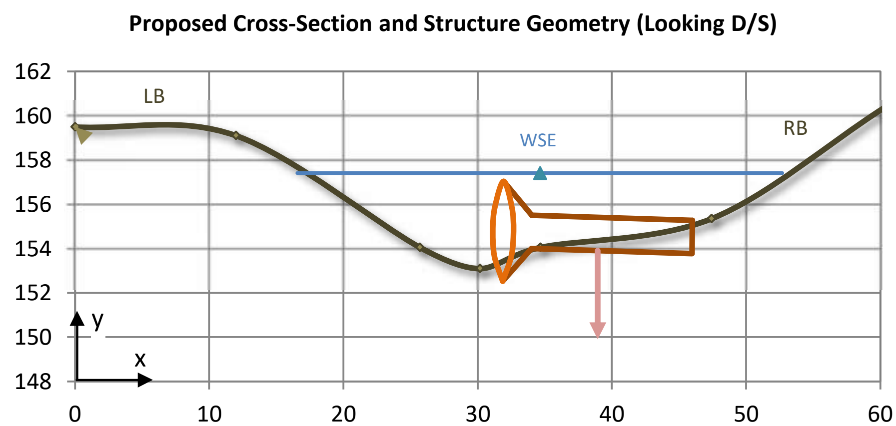
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Flow Deflection	Right bank	Outside	13+78	4.31	6.28	2.72

Multi-Log Structures	Layer	Log ID
	Key Log	A69

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	159.49
Top LB	11.98	159.10
Toe LB	25.67	154.06
Thalweg	30.17	153.10
Toe RB	34.68	154.06
Top RB	47.42	155.35
Fldpln RB	60.20	160.33

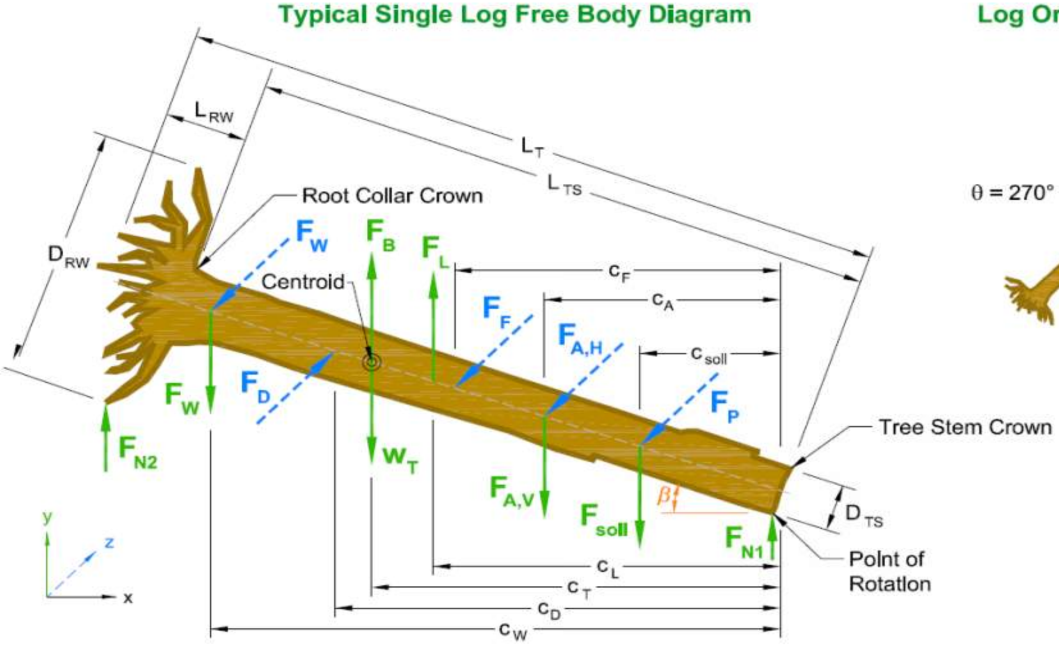


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

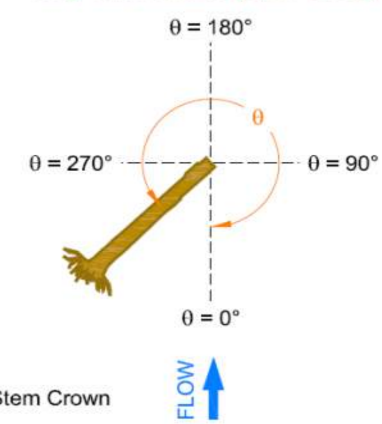
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	250.0	-1.0	Root collar: Bottom	34.00	154.00	152.54	157.04	17.63

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	22.5	13.5	36.0	1,258	2,247
↓Thalweg	0.0	0.3	0.3	12	19
Total	22.5	13.8	36.3	1,270	2,266

Lift Force

C_{LT}	0.05
F_L (lbf)	6

Vertical Force Balance

F_B (lbf)	2,266	↑
F_L (lbf)	6	↑
W_T (lbf)	1,270	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	4,072	↑
$F_{A,V}$ (lbf)	8,246	↓
ΣF_V (lbf)	3,172	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.18	0.39	1.10	0.22	1.97	248

Horizontal Force Balance

F_D (lbf)	248	→
F_P (lbf)	0	
F_F (lbf)	2,554	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	6,754	←
ΣF_H (lbf)	9,060	←
FS_H	37.52	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.30	0.78	398
Bank	4.40	0	12.04	0.81	2,157
Total	-	0	14.34	-	2,554

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	13.7	7.5	9.4	0.0	6.2	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	22,795
M_r (lbf)	170,320
FS_M	7.47 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
MR-1	7.50		15,000
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
						0		0
B31	Above	Pinned	13.0	4,072		4,072	↑	0
						0		0
						0		0

Sample Multi-Log Structure

Spreadsheet developed by Michael Rafferty, P.E.

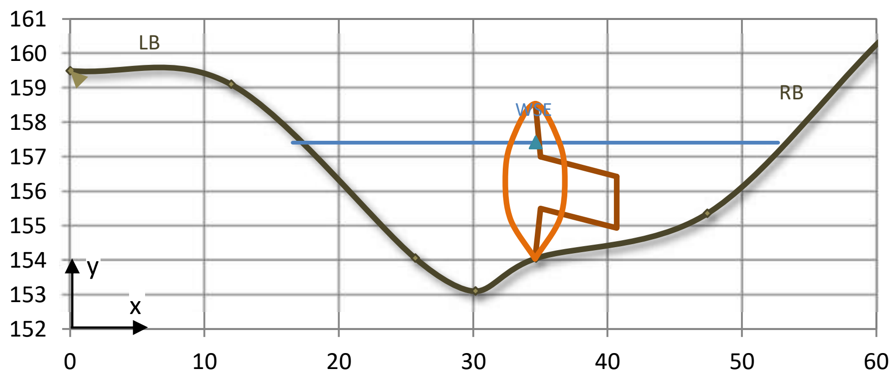
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Flow Deflection	Right bank	Outside	13+78	4.31	6.28	2.72

Multi-Log Structures	Layer	Log ID
	Stacked	B31

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	159.49
Top LB	11.98	159.10
Toe LB	25.67	154.06
Thalweg	30.17	153.10
Toe RB	34.68	154.06
Top RB	47.42	155.35
Fldpln RB	60.20	160.33

Proposed Cross-Section and Structure Geometry (Looking D/S)

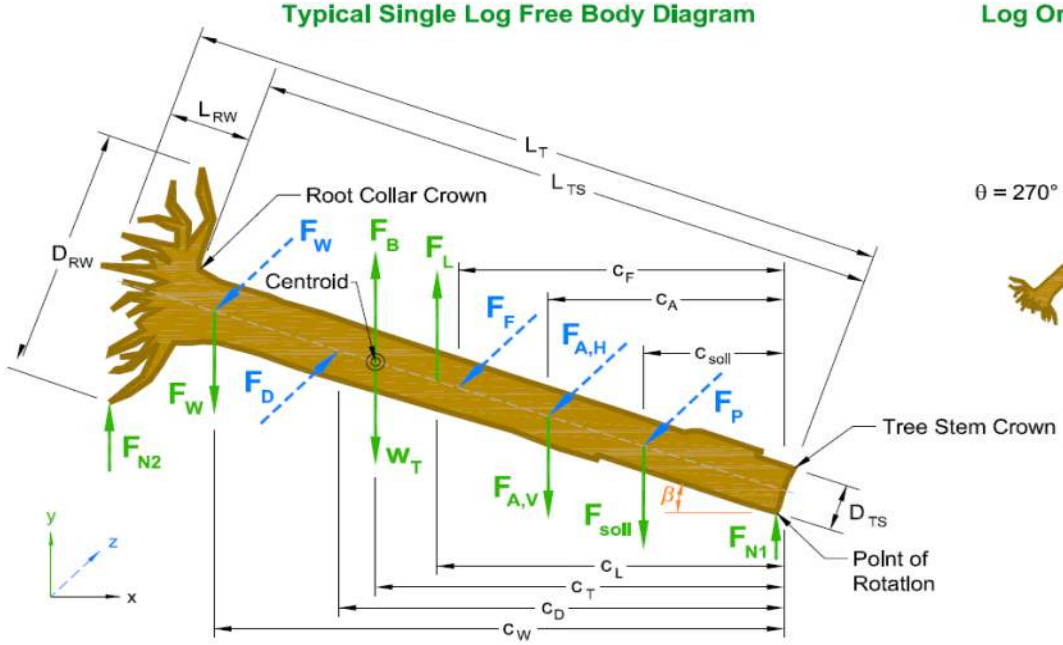


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	35.0	1.50	2.25	4.50	34.9	39.0

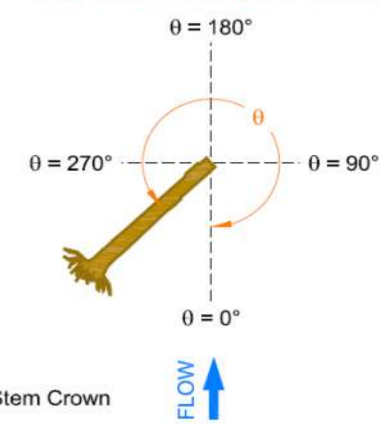
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	350.0	-1.0	Root collar: Bottom	35.00	155.50	154.04	158.54	21.70

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	1.6	1.6	54	0
↓WS↑Thw	57.9	12.2	70.1	2,450	4,375
↓Thalweg	0.0	0.0	0.0	0	0
Total	57.9	13.8	71.7	2,504	4,375

Lift Force

C_{LT}	0.06
F_L (lbf)	9

Vertical Force Balance

F_B (lbf)	4,375	↑
F_L (lbf)	9	↑
W_T (lbf)	2,504	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	8,246	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	6,366	↓
FS_V	2.45	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.22	0.39	1.10	0.43	2.54	394

Horizontal Force Balance

F_D (lbf)	394	→
F_P (lbf)	0	
F_F (lbf)	4,974	←
$F_{W,H}$ (lbf)	8,936	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	13,515	←
FS_H	35.27	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	4,974
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	4,974

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
19.8	6.9	17.5	19.8	0.0	35.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	73,609
M_r (lbf)	123,933
FS_M	1.68 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)	
A69	Below	Pinned	30.0	-8,246		8,246	↓	0	
A69	Below	Pinned	30.0		-8,936	0		8,936	←
						0		0	
						0		0	

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

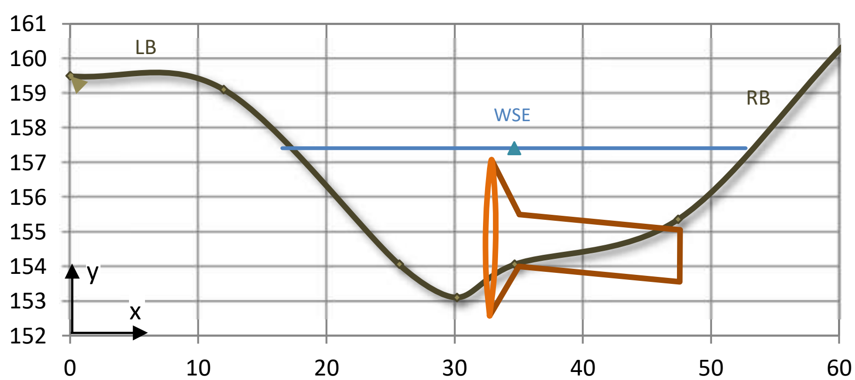
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Rootwad	Left bank	Outside	13+78	4.31	6.28	2.72

Multi-Log Structures	Layer	Log ID
	Footer	A70

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	159.49
Top LB	11.98	159.10
Toe LB	25.67	154.06
Thalweg	30.17	153.10
Toe RB	34.68	154.06
Top RB	47.42	155.35
Fldpln RB	60.20	160.33

Proposed Cross-Section and Structure Geometry (Looking D/S)

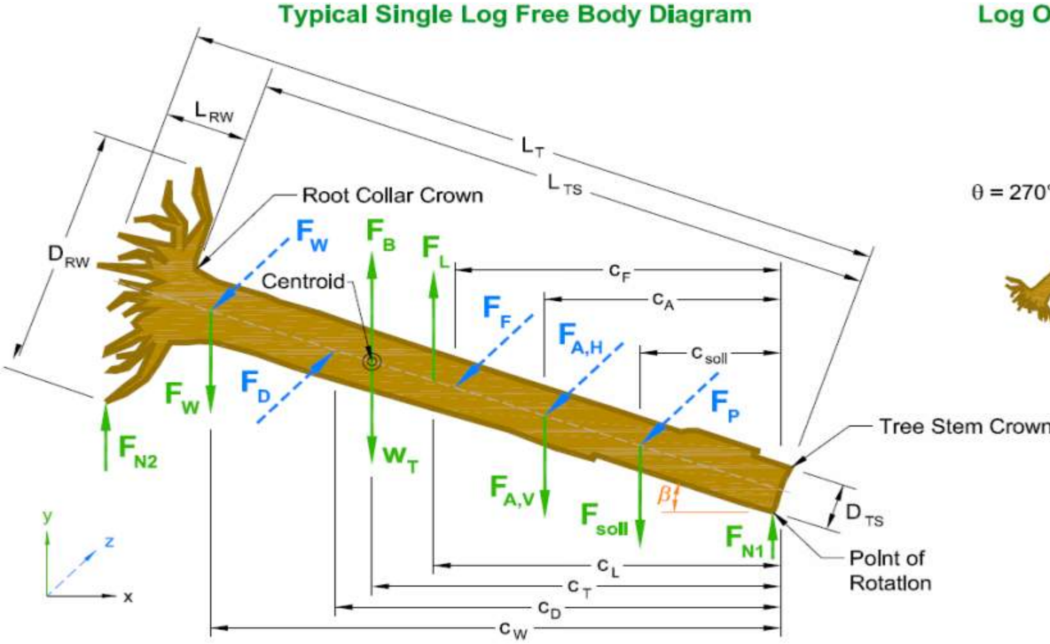


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

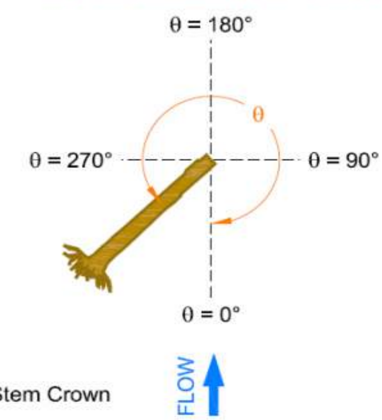
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	260.0	-2.0	Root collar: Bottom	35.00	154.00	152.58	157.08	13.02

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	2.36	0.37	0.16

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	22.5	13.5	36.1	1,260	2,250
↓Thalweg	0.0	0.3	0.3	10	16
Total	22.5	13.8	36.3	1,270	2,266

Lift Force

C_{LT}	0.04
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	2,266	↑
F_L (lbf)	4	↑
W_T (lbf)	1,270	↓
F_{soil} (lbf)	40	↓
$F_{W,V}$ (lbf)	4,174	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	3,214	↓
FS_V	2.42	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.6	0.6	40
Total	0.0	0.6	0.6	40

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.13	0.39	1.10	0.20	1.73	161

Horizontal Force Balance

F_D (lbf)	161	→
F_P (lbf)	87	←
F_F (lbf)	2,590	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,515	←
FS_H	16.59	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.15	0.78	353
Bank	4.40	87	13.16	0.81	2,237
Total	-	87	15.31	-	2,590

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	14.2	8.7	9.4	1.2	6.6	1.6

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	22,652
M_r (lbf)	100,611
FS_M	4.44 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
100yr	13+88	165	4.31	2.29	9.0	99	57

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
100yr	13+88	31.00	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
100yr	13+88	Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	Common Name	Scientific Name		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs		
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
b31	Above	Pinned	12.0	-4,174		4,174	↓	0
						0		0
						0		0
						0		0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

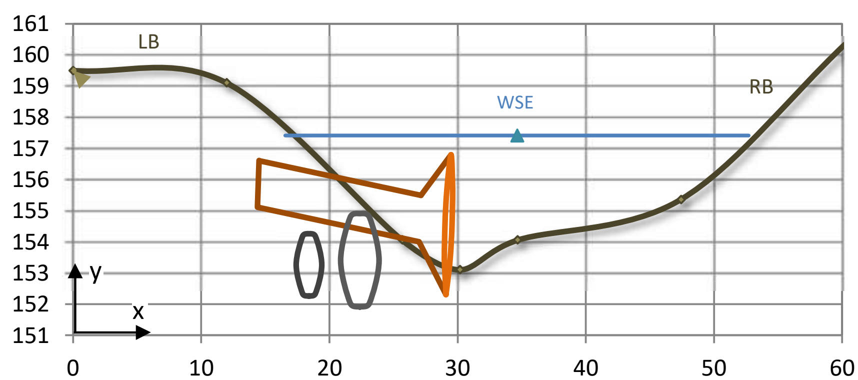
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Rootwad	Left bank	Outside	13+88	4.31	6.28	3.03

Multi-Log Structures	Layer	Log ID
	Footer	A71

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	159.49
Top LB	11.98	159.10
Toe LB	25.67	154.06
Thalweg	30.17	153.10
Toe RB	34.68	154.06
Top RB	47.42	155.35
Fldpln RB	60.20	160.33

Proposed Cross-Section and Structure Geometry (Looking D/S)

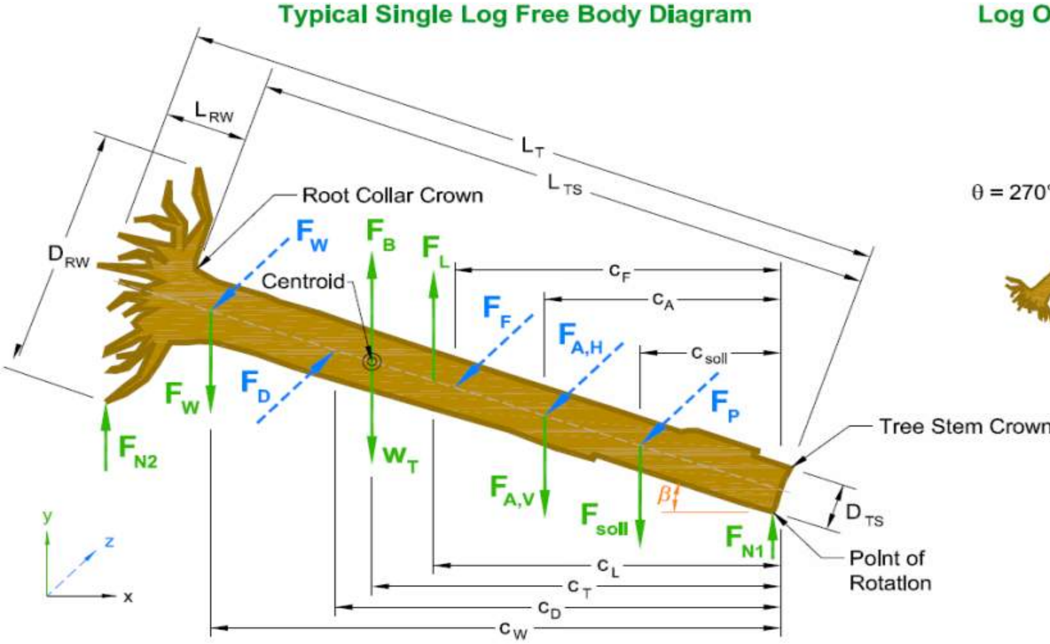


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

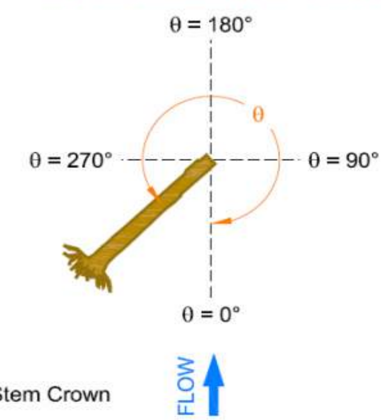
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	9-Jul	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	83.0	5.0	Root collar: Bottom	27.00	154.00	152.31	156.79	11.65

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	5.62	1.56	0.79

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	22.5	13.2	35.7	1,248	2,228
↓Thalweg	0.0	0.6	0.6	24	38
Total	22.5	13.8	36.3	1,271	2,266

Lift Force

C_{LT}	0.12
F_L (lbf)	12

Vertical Force Balance

F_B (lbf)	2,266	↑
F_L (lbf)	12	↑
W_T (lbf)	1,271	↓
F_{soil} (lbf)	506	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	1,640	↓
ΣF_V (lbf)	1,139	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	1.2	5.4	6.6	506
Total	1.2	5.4	6.6	506

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.12	0.44	1.05	0.43	1.91	198

Horizontal Force Balance

F_D (lbf)	198	→
F_P (lbf)	1,112	←
F_F (lbf)	918	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	240	←
ΣF_H (lbf)	2,071	←
FS_H	11.45	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	137
Bank	4.40	1,112	10.99	0.81	780
Total	-	1,112	12.99	-	918

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	13.0	10.3	9.4	2.8	5.5	3.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	23,334
M_r (lbf)	41,846
FS_M	1.79 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	2.00	4.0	0.0	4.2	430	0	0	375	55
Deadman	3.00	8.0	0.0	14.1	1,450	0	0	1,265	185
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 10 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
10.00	14+74	74	3.43	2.36	9.0	36	45

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	10	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
10	14+74	**15.49**	Medium gravel	5	122.2	76.1	36

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
10	14+74	Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
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Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				
Tree Type #3:				

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

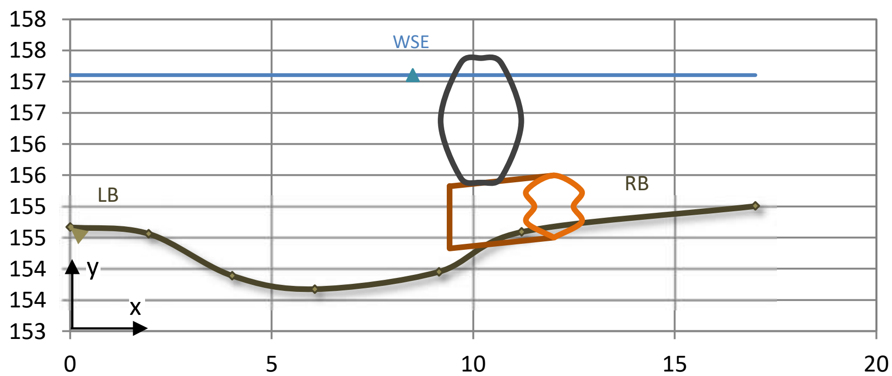
10

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10	Log Weir	Left bank	Outside	14+74	3.43	5.00	3.25

Multi-Log Structures	Layer	Log ID
	Footer	D11

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	154.67
Top LB	1.94	154.56
Toe LB	4.02	153.89
Thalweg	6.07	153.67
Toe RB	9.14	153.95
Top RB	11.19	154.59
Fldpln RB	17.00	155.01

Proposed Cross-Section and Structure Geometry (Looking D/S)

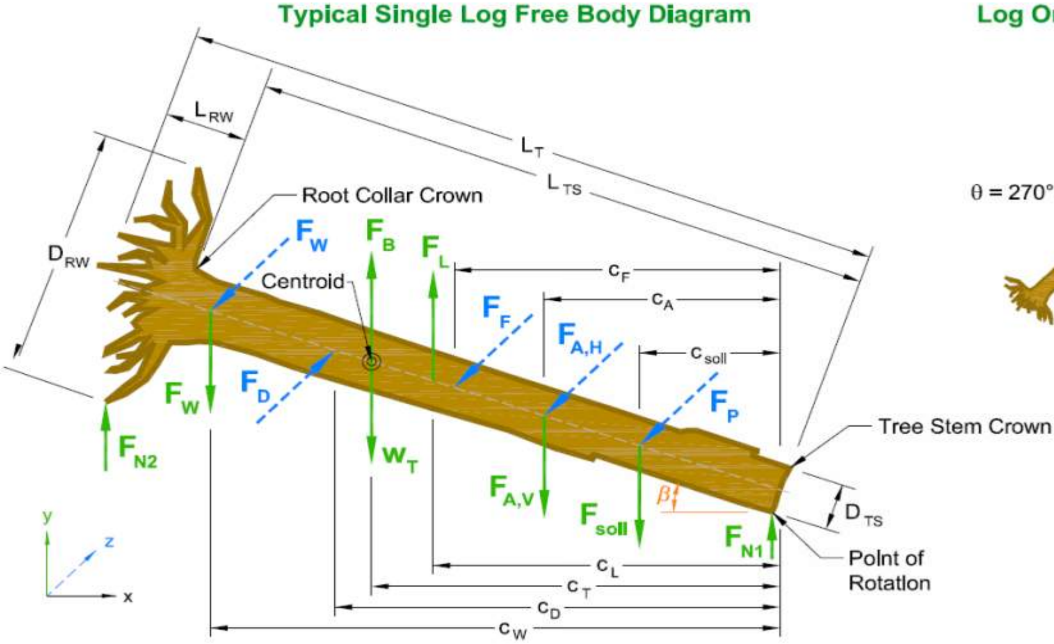


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

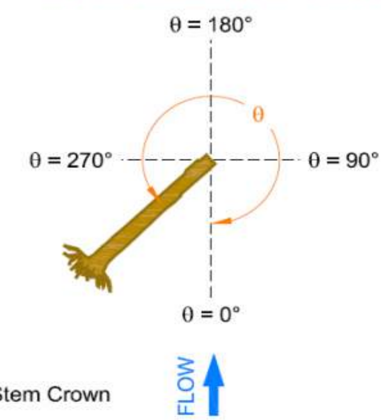
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	15.0	-1.0	Root collar: Crown	12.00	155.50	154.33	155.50	2.43

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	7.9	0.0	7.9	274	490
↓Thalweg	0.0	0.0	0.0	0	0
Total	7.9	0.0	7.9	274	490

Lift Force

C_{LT}	0.15
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	490	↑
F_L (lbf)	4	↑
W_T (lbf)	274	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	438	↓
ΣF_V (lbf)	219	↓
FS_V	1.44	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.07	0.57	0.62	0.31	1.07	27

Horizontal Force Balance

F_D (lbf)	27	→
F_P (lbf)	0	
F_F (lbf)	172	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	146	←
FS_H	6.50	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	43
Bank	4.40	0	5.42	0.81	130
Total	-	0	7.42	-	172

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	2.3	5.0	5.0	0.0	7.3	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	2,611	↻
M_r (lbf)	5,496	↺
FS_M	2.11	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Above	2.00	3.0	0.2	4.0	443	5	25	438	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

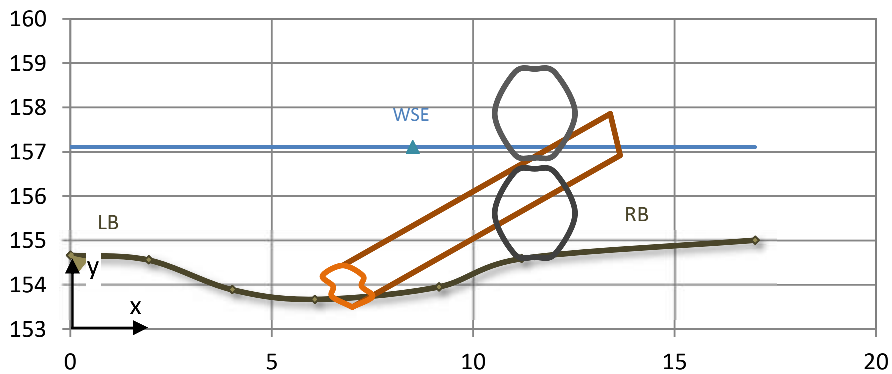
10

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10	Flow Deflection	Left bank	Outside	14+74	3.43	5.00	3.25

Multi-Log Structures	Layer	Log ID
	Key Log	D12

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	154.67
Top LB	1.94	154.56
Toe LB	4.02	153.89
Thalweg	6.07	153.67
Toe RB	9.14	153.95
Top RB	11.19	154.59
Fldpln RB	17.00	155.01

Proposed Cross-Section and Structure Geometry (Looking D/S)



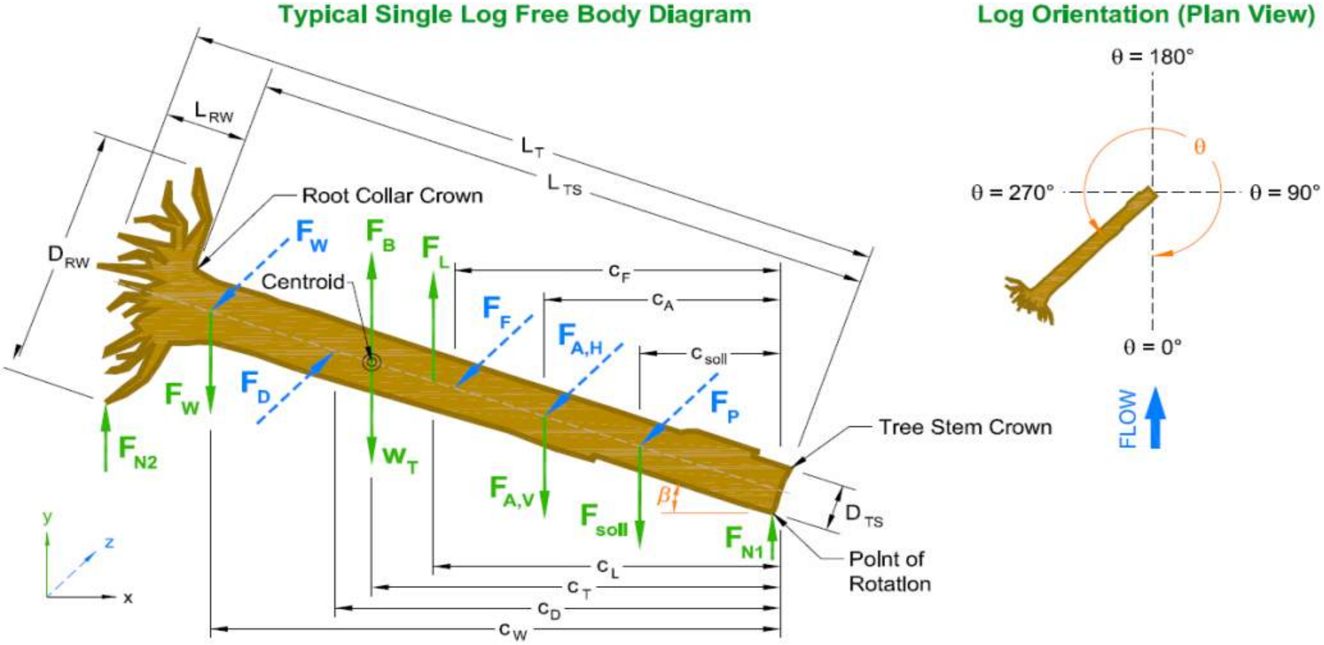
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	20.0	Root collar: Bottom	7.00	153.50	153.50	157.86	6.41

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram

Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.7	0.0	0.7	26	0
↓WS↑Thw	7.1	0.0	7.1	248	442
↓Thalweg	0.0	0.0	0.0	1	1
Total	7.9	0.0	7.9	275	443

Lift Force

C_{LT}	0.04
F_L (lbf)	3

Vertical Force Balance

F_B (lbf)	443	↑
F_L (lbf)	3	↑
W_T (lbf)	275	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	680	↓
ΣF_V (lbf)	509	↓
FS_V	2.14	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.18	0.57	0.76	0.43	1.79	117

Horizontal Force Balance

F_D (lbf)	117	→
F_P (lbf)	0	
F_F (lbf)	370	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	332	←
ΣF_H (lbf)	584	←
FS_H	5.98	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.83	0.73	370
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.83	-	370

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	8.3	5.0	5.0	0.0	9.6	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	2,640
M_r (lbf)	8,281
FS_M	3.14 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Behind	2.00	3.0	0.0	4.2	430	3	14	0	332
Above	2.00	3.0	4.0	0.2	681	0	2	680	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
17+77	17+77	165	3.40	3.84	9.0	49	386

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
17+77	17+77	**31.00**	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
17+77	17+77	**Gravel/cobble**	4	137.0	85.3	41

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				
Tree Type #3:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by Michael Rafferty, P.E.

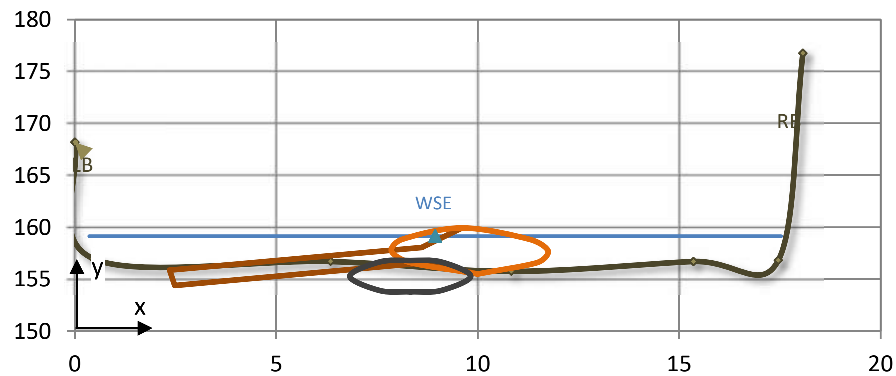
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
17+77	Rootwad	Mid-channel	Straight	17+77	3.40	42.94	3.84

Multi-Log Structures	Layer	Log ID
	Key Log	A49

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.17
Top RB	0.44	157.00
Toe LB	6.34	156.70
Thalweg	10.83	155.74
Toe RB	15.35	156.70
Top Rb	17.46	156.80
Fldpln RB	18.07	176.73

Proposed Cross-Section and Structure Geometry (Looking D/S)

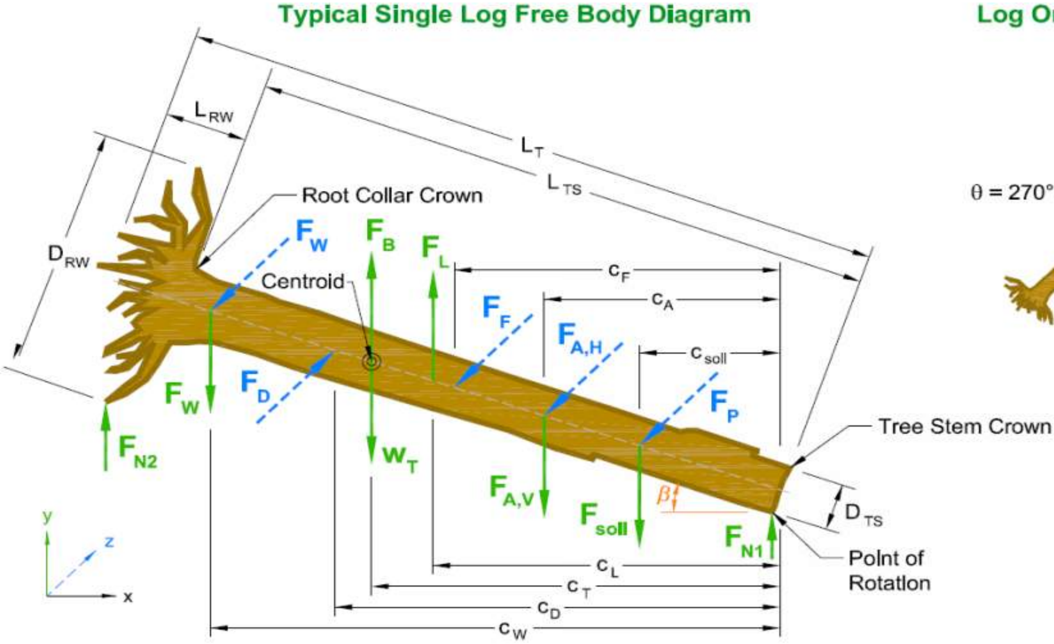


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

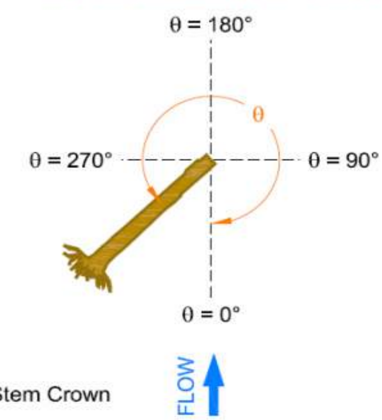
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	30.0	-10.0	Rootwad: Bottom	10.00	155.50	154.37	159.93	16.73

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	5.30	1.05	0.53

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.5	0.5	19	0
↓WS↑Thw	16.1	13.2	29.3	1,023	1,827
↓Thalweg	6.4	0.1	6.5	253	405
Total	22.5	13.8	36.3	1,295	2,232

Lift Force

C_{LT}	0.06
F_L (lbf)	14

Vertical Force Balance

F_B (lbf)	2,232
F_L (lbf)	14
W_T (lbf)	1,295
F_{soil} (lbf)	356
$F_{W,V}$ (lbf)	364
$F_{A,V}$ (lbf)	1,354
ΣF_V (lbf)	1,123
FS_V	1.50

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	4.2	4.2	356
Total	0.0	4.2	4.2	356

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.34	0.55	1.21	0.43	3.84	919

Horizontal Force Balance

F_D (lbf)	919
F_P (lbf)	858
F_F (lbf)	937
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	96
ΣF_H (lbf)	972
FS_H	2.06

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	5.38	0.78	351
Bank	4.81	858	8.06	0.87	586
Total	-	858	13.44	-	937

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	12.8	10.2	9.3	2.6	5.7	3.5

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	29,813
M_r (lbf)	46,235
FS_M	1.55

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.00	12.0	0.0	14.1	1,450	0	0	1,354	96
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
a50	Above	Gravity	5.0	-364		364	↓	0
						0		0
						0		0
						0		0

Sample Multi-Log Structure

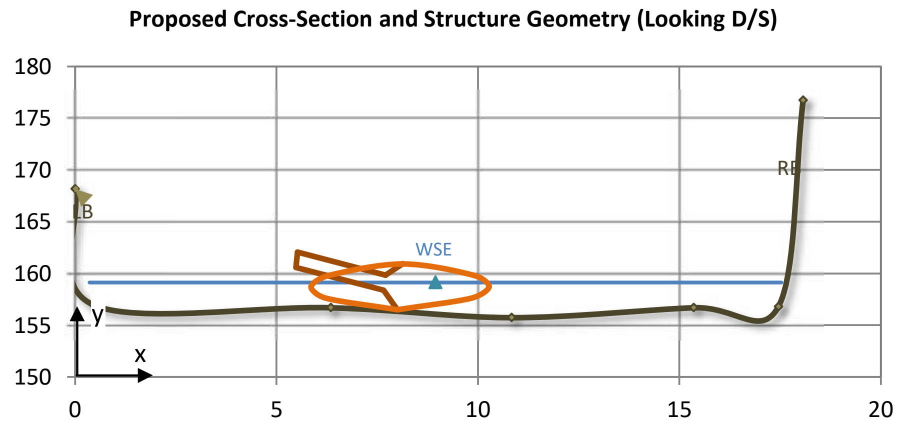
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
17+77	Rootwad	Left bank	Straight	17+77	3.40	42.94	3.84

Multi-Log Structures	Layer	Log ID
	Stacked	A50

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.17
Top LB	0.44	157.00
Toe LB	6.34	156.70
Thalweg	10.83	155.74
Toe RB	15.35	156.70
Top RB	17.46	156.80
Fldpln RB	18.07	176.73

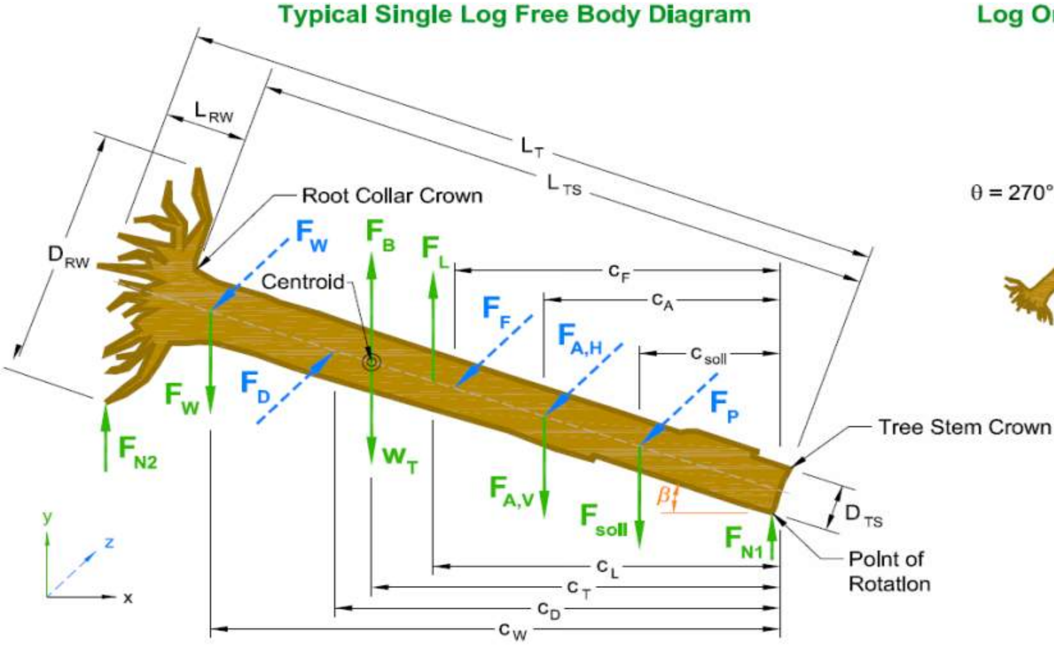


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

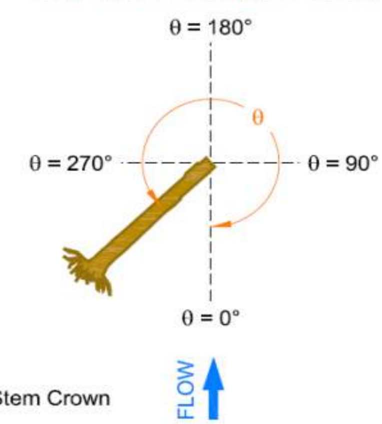
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	170.0	10.0	Rootwad: Bottom	8.00	156.50	156.50	162.06	13.77

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	20.7	5.2	26.0	908	0
↓WS↑Thw	1.8	8.6	10.3	361	645
↓Thalweg	0.0	0.0	0.0	0	0
Total	22.5	13.8	36.3	1,269	645

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	645	↑
F_L (lbf)	0	
W_T (lbf)	1,269	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	63	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	687	↓
FS_V	2.06	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.28	0.55	0.94	0.00	1.85	365

Horizontal Force Balance

F_D (lbf)	365	→
F_P (lbf)	0	
F_F (lbf)	537	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	172	←
FS_H	1.47	✗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	537
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	537

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	11.7	9.4	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	4,786	
M_r (lbf)	25,751	
FS_M	5.38	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
A48	Above	Gravity	5.0	-63		63	↓	0
						0		0
						0		0
						0		0

Sample Multi-Log Structure

Spreadsheet developed by Michael Rafferty, P.E.

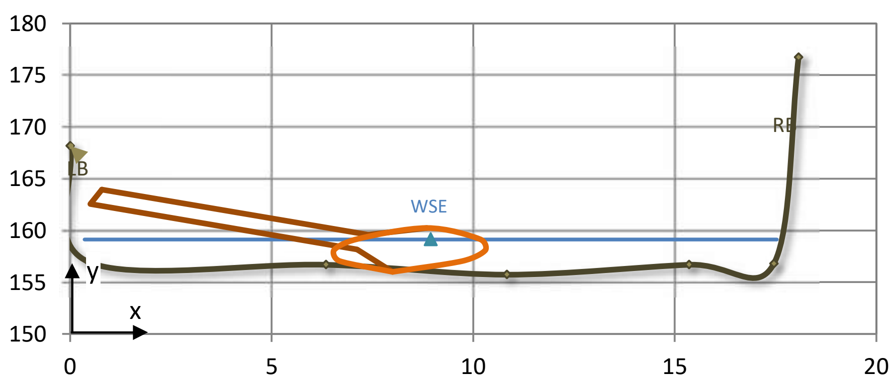
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
17+77	Rootwad	Left bank	Straight	17+77	3.40	42.94	3.84

Multi-Log Structures	Layer	Log ID
	Stacked	A48

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.17
Top LB	0.44	157.00
Toe LB	6.34	156.70
Thalweg	10.83	155.74
Toe RB	15.35	156.70
Top RB	17.46	156.80
Fldpln RB	18.07	176.73

Proposed Cross-Section and Structure Geometry (Looking D/S)

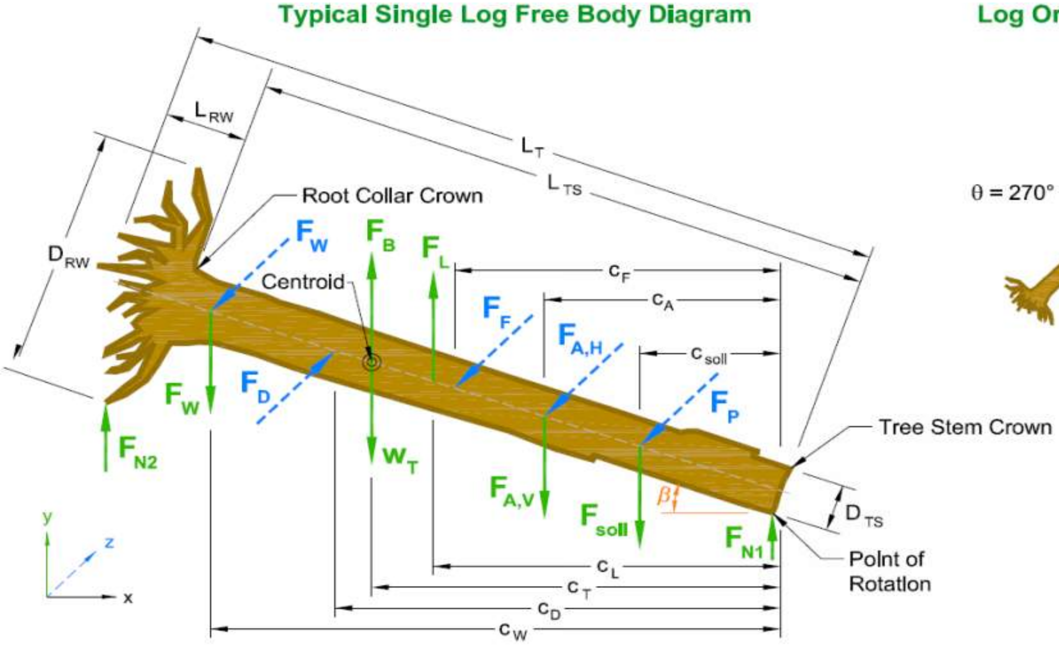


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

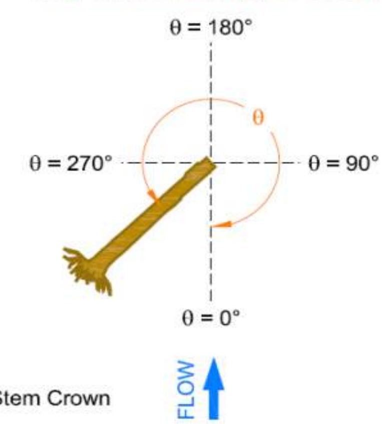
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	33.5	20.0	Rootwad: Bottom	8.00	156.00	156.00	163.95	13.29

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/cobble	137.0	85.3	41.0	4	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	20.9	2.5	23.4	819	0
↓WS↑Thw	1.6	11.3	12.9	450	804
↓Thalweg	0.0	0.0	0.0	0	0
Total	22.5	13.8	36.3	1,269	804

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	804	↑
F_L (lbf)	0	
W_T (lbf)	1,269	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	465	↓
FS_V	1.58	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.27	0.55	1.19	0.43	3.08	586

Horizontal Force Balance

F_D (lbf)	586	→
F_P (lbf)	0	
F_F (lbf)	363	←
$F_{W,H}$ (lbf)	512	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	290	←
FS_H	1.49	✗

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	363
Bank	4.81	0	0.00	0.87	0
Total	-	0	2.00	-	363

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	12.5	9.4	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	5,649	
M_r (lbf)	21,777	
FS_M	3.86	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
A49	Behind	Gravity	8.0		-512	0	512 ←
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 10 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
10yr	19+00	114	2.84	4.02	9.0	28	75

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
10yr	19+00	**15.49**	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
10yr	19+00	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

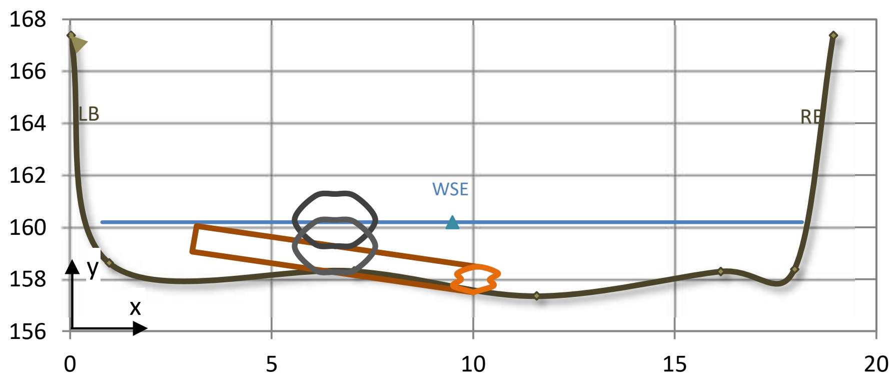
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10yr	Log Weir	Left bank	Outside	19+00	2.84	8.36	5.07

Multi-Log Structures	Layer	Log ID
	Footer	D5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.02	167.37
Top LB	0.97	158.63
Toe LB	7.05	158.31
Thalweg	11.57	157.35
Toe RB	16.14	158.30
Top RB	17.97	158.38
Fldpln RB	18.93	167.37

Proposed Cross-Section and Structure Geometry (Looking D/S)

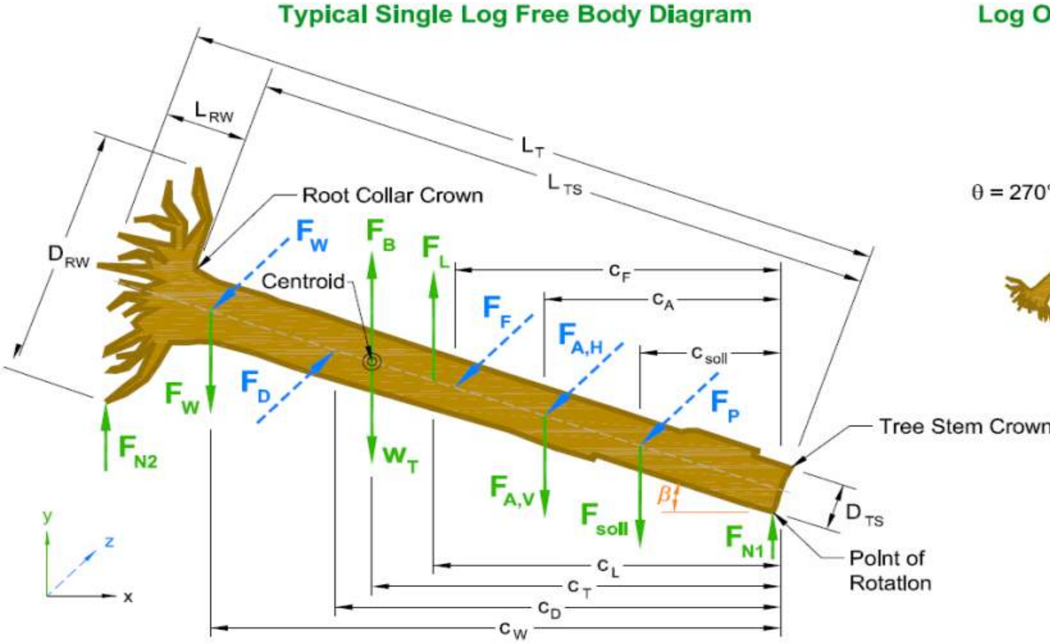


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

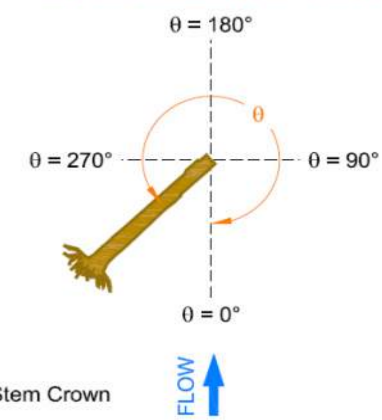
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	44.9	9.0	Root collar: Bottom	10.00	157.50	157.50	160.05	6.57

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	7.9	0.0	7.9	274	490
↓Thalweg	0.0	0.0	0.0	0	0
Total	7.9	0.0	7.9	274	490

Lift Force

C_{LT}	0.09
F_L (lbf)	15

Vertical Force Balance

F_B (lbf)	490	↑
F_L (lbf)	15	↑
W_T (lbf)	274	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	572	↓
ΣF_V (lbf)	341	↓
FS_V	1.67	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.24	0.89	0.76	0.26	1.79	292

Horizontal Force Balance

F_D (lbf)	292	→
F_P (lbf)	0	
F_F (lbf)	252	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	311	←
ΣF_H (lbf)	271	←
FS_H	1.93	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	6.37	0.73	213
Bank	4.40	0	1.05	0.81	39
Total	-	0	7.42	-	252

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	2.5	5.0	5.0	0.0	7.3	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	3,975
M_r (lbf)	7,296
FS_M	1.84

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Above	2.00	5.0	2.4	1.8	577	6	30	572	0
Behind	2.00	5.0	0.0	4.2	431	6	32	0	311
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs $F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
Top#2	Above	Gravity	4.0	50		0	0
Top#2	Above	Gravity	3.0		101	0	0
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

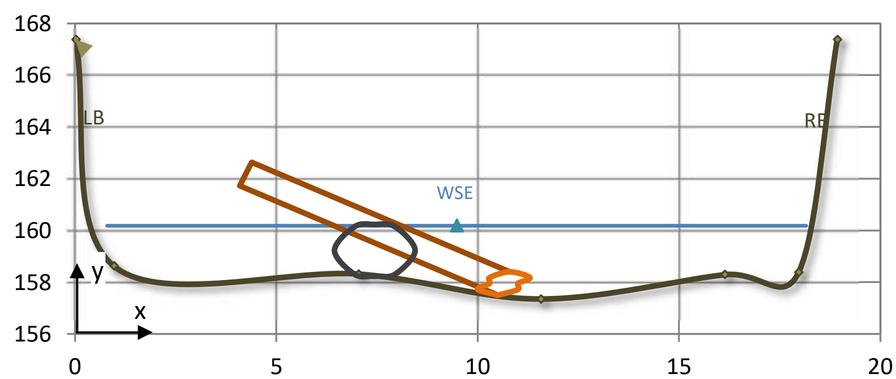
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10yr	Flow Deflection	Left bank	Outside	19+00	2.84	8.36	5.07

Multi-Log Structures	Layer	Log ID
	Key Log	D6

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.02	167.37
Top LB	0.97	158.63
Toe LB	7.05	158.31
Thalweg	11.57	157.35
Toe RB	16.14	158.30
Top RB	17.97	158.38
Fldpln RB	18.93	167.37

Proposed Cross-Section and Structure Geometry (Looking D/S)

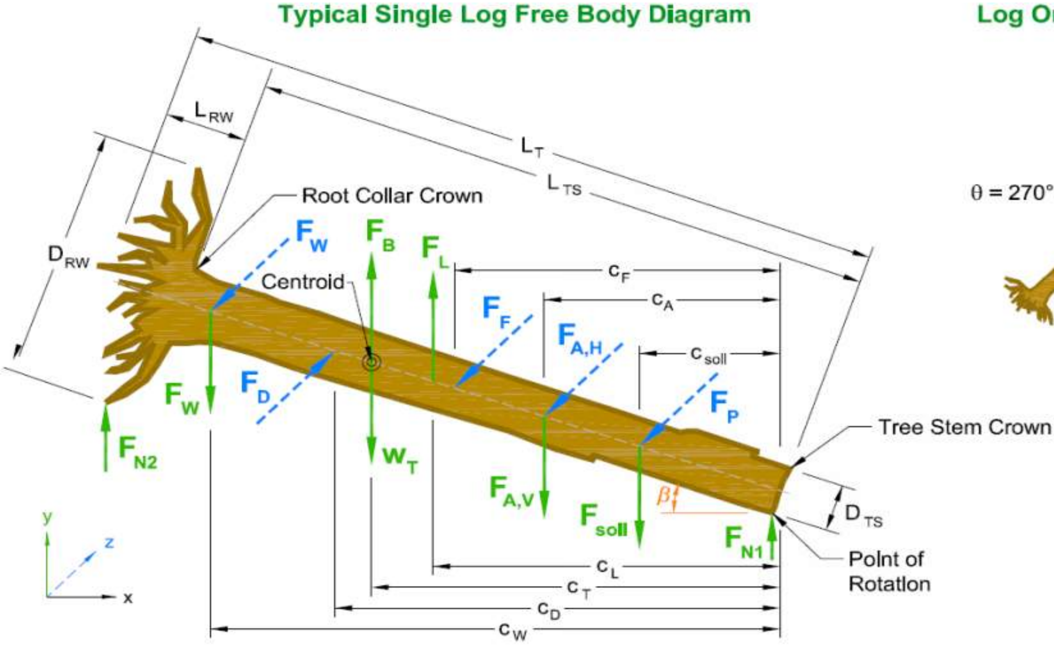


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

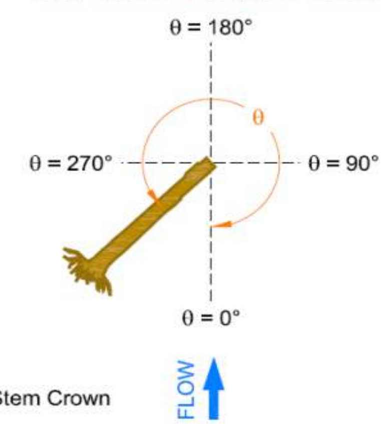
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	25.0	Root collar: Bottom	10.50	157.50	157.50	162.63	3.74

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	3.7	0.0	3.7	129	0
↓WS↑Thw	4.2	0.0	4.2	145	259
↓Thalweg	0.0	0.0	0.0	0	0
Total	7.9	0.0	7.9	274	259

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	259	↑
F_L (lbf)	0	
W_T (lbf)	274	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	15	↓
FS_V	1.06	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.14	0.89	0.76	0.26	1.38	128

Horizontal Force Balance

F_D (lbf)	128	→
F_P (lbf)	0	
F_F (lbf)	11	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	275	←
Σ F_H (lbf)	157	←
FS_H	2.23	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.03	0.73	11
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.03	-	11

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	0.0	6.8	5.0	0.0	10.0	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	1,544	
M_r (lbf)	2,488	
FS_M	1.61	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Behind	2.00	5.0	0.0	4.2	430	7	33	0	275
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs: $F_{W,V}$ (lbf)	Applied Forces from other Logs: $F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
100yr	21+05	165	2.31	5.31	9.0	48	45

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
100yr	21+05	**31.00**	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
100yr	21+05	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

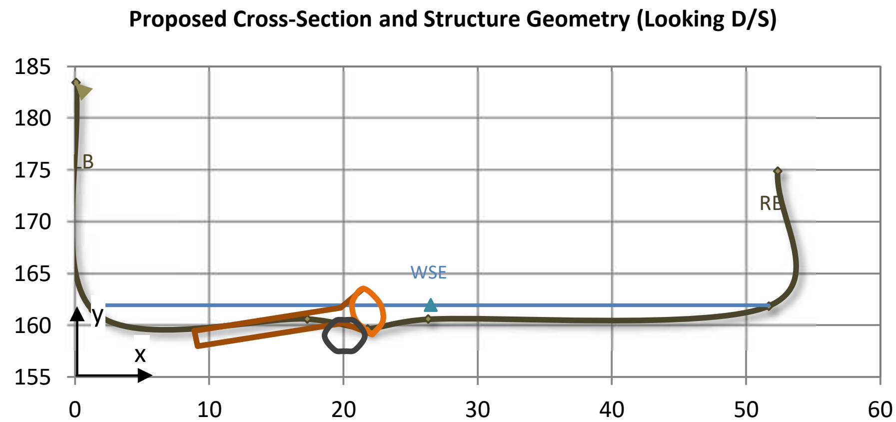
Spreadsheet developed by Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Mid-channel	Outside	21+05	2.31	4.98	7.31

Multi-Log Structures	Layer	Log ID
	Stacked	A33

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.07	183.43
Top LB	1.34	161.40
Toe LB	17.29	160.60
Thalweg	21.80	159.63
Toe RB	26.31	160.59
Top RB	51.67	161.84
Fldpln RB	52.35	174.88

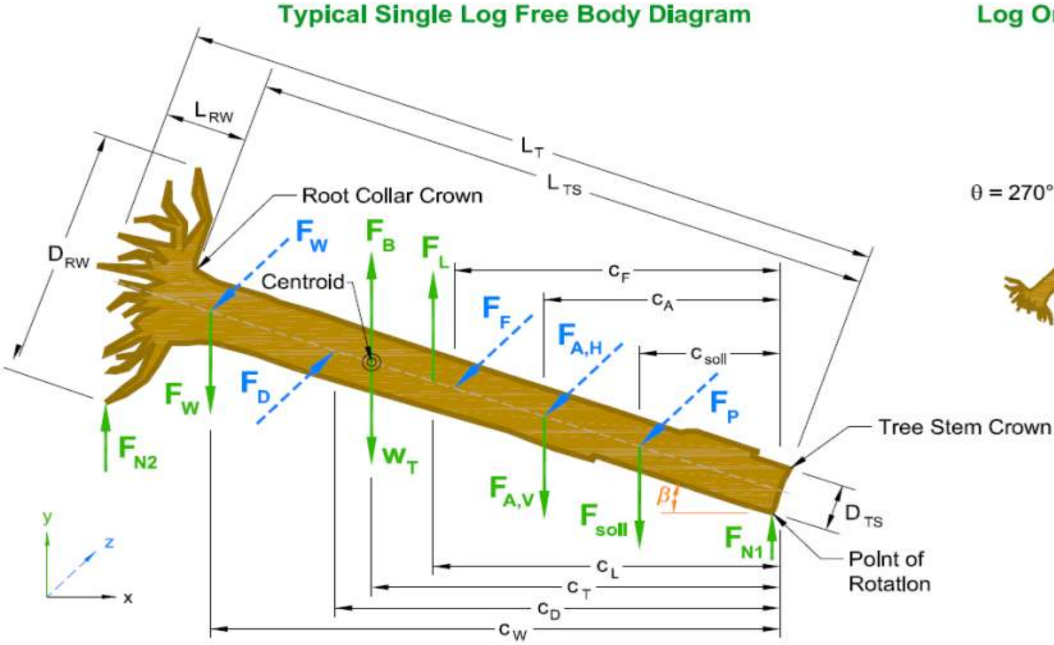


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

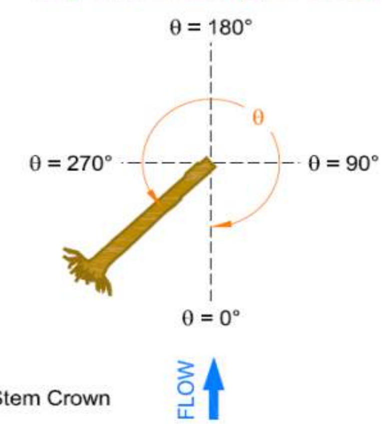
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	60.0	-10.0	Root collar: Bottom	20.00	160.20	157.99	163.55	11.39

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	7.18	1.56	0.78

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	2.9	2.9	100	0
↓WS↑Thw	13.3	10.6	23.9	834	1,490
↓Thalweg	9.3	0.3	9.6	374	598
Total	22.5	13.8	36.3	1,308	2,088

Lift Force

C_{LT}	0.06
F_L (lbf)	37

Vertical Force Balance

F_B (lbf)	2,088	↑
F_L (lbf)	37	↑
W_T (lbf)	1,308	↓
F_{soil} (lbf)	583	↓
$F_{W,V}$ (lbf)	795	↓
$F_{A,V}$ (lbf)	501	↓
Σ F_V (lbf)	1,062	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	8.4	8.4	583
Total	0.0	8.4	8.4	583

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.24	1.05	1.19	0.15	2.34	1,385

Horizontal Force Balance

F_D (lbf)	1,385	→
F_P (lbf)	1,281	←
F_F (lbf)	851	←
$F_{W,H}$ (lbf)	424	←
$F_{A,H}$ (lbf)	949	←
Σ F_H (lbf)	2,120	←
FS_H	2.53	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	4.48	0.78	259
Bank	4.40	1,281	9.86	0.81	592
Total	-	1,281	14.34	-	851

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	13.4	11.1	9.3	3.6	6.2	4.8

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	34,691
M_r (lbf)	53,739
FS_M	1.55

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.00	13.0	0.0	14.1	1,450	0	0	501	949
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)	
C11	Above	Gravity	3.0	-795		795	↓	0	
C11	Behind	Gravity	3.0		-424	0		424	←
						0		0	
						0		0	

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

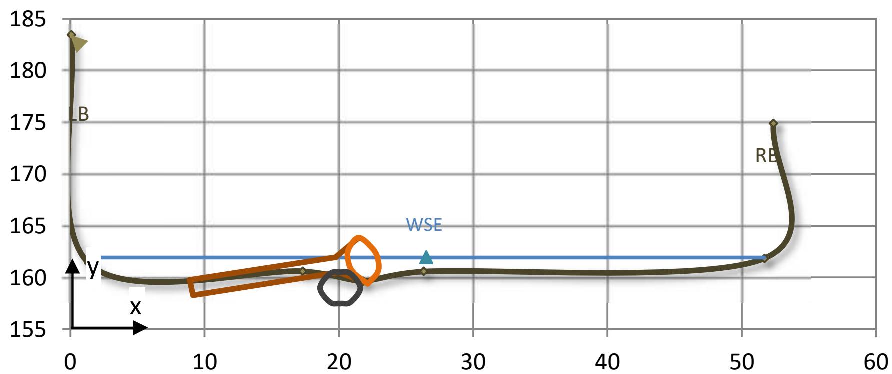
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Mid-channel	Outside	21+05	2.31	4.98	7.31

Multi-Log Structures	Layer	Log ID
	Stacked	A33

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.07	183.43
Top LB	1.34	161.40
Toe LB	17.29	160.60
Thalweg	21.80	159.63
Toe RB	26.31	160.59
Top RB	51.67	161.84
Fldpln RB	52.35	174.88

Proposed Cross-Section and Structure Geometry (Looking D/S)

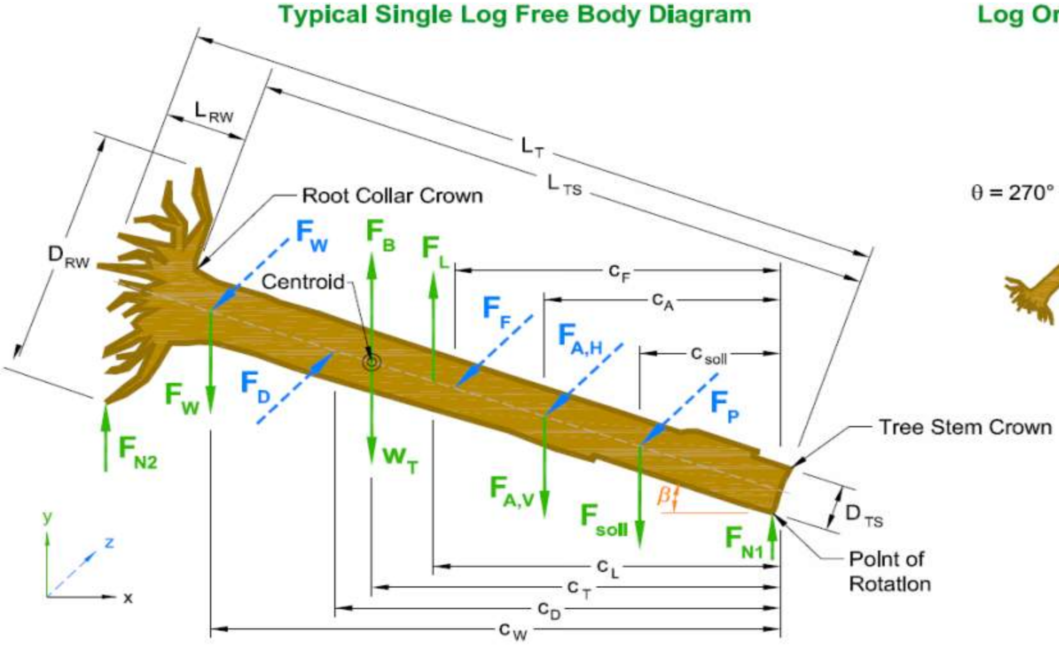


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

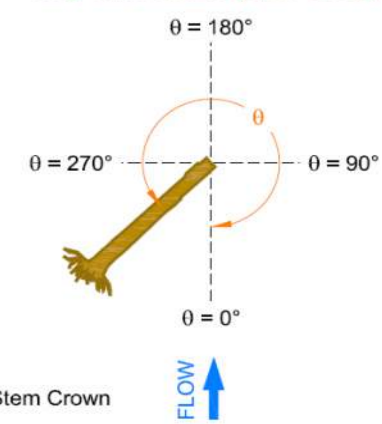
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	60.0	-10.0	Root collar: Bottom	20.00	160.50	158.29	163.85	12.11

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	5.80	1.26	0.63

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	4.2	4.2	146	0
↓WS↑Thw	16.3	9.6	25.9	904	1,614
↓Thalweg	6.2	0.0	6.3	244	391
Total	22.5	13.8	36.3	1,294	2,005

Lift Force

C_{LT}	0.05
F_L (lbf)	33

Vertical Force Balance

F_B (lbf)	2,005	↑
F_L (lbf)	33	↑
W_T (lbf)	1,294	↓
F_{soil} (lbf)	380	↓
$F_{W,V}$ (lbf)	795	↓
$F_{A,V}$ (lbf)	587	↓
Σ F_V (lbf)	1,019	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	5.5	5.5	380
Total	0.0	5.5	5.5	380

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.25	1.05	1.19	0.15	2.45	1,536

Horizontal Force Balance

F_D (lbf)	1,536	→
F_P (lbf)	835	←
F_F (lbf)	817	←
$F_{W,H}$ (lbf)	424	←
$F_{A,H}$ (lbf)	863	←
Σ F_H (lbf)	1,403	←
FS_H	1.91	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	3.65	0.78	215
Bank	4.40	835	9.86	0.81	602
Total	-	835	13.51	-	817

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	12.6	10.4	9.3	2.9	5.7	3.9

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	34,530	
M_r (lbf)	48,640	
FS_M	1.41	✗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.00	13.0	0.0	14.1	1,450	0	0	587	863
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
C11	Above	Gravity	3.0	-795		795	0
C11	Behind	Gravity	3.0		-424	0	424
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

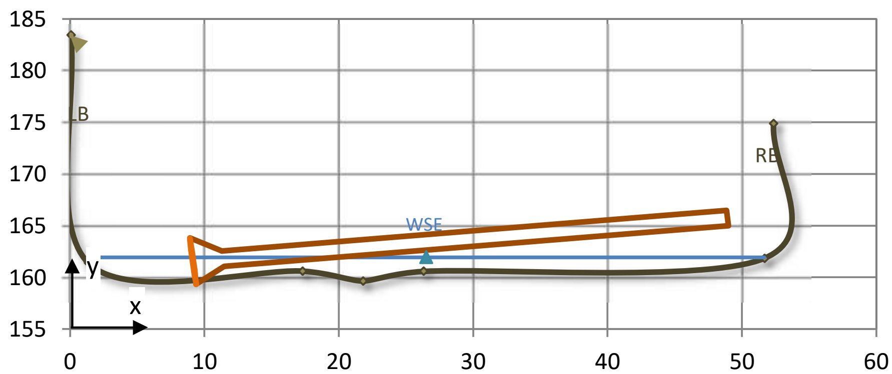
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Left bank	Outside	21+05	2.31	4.98	7.31

Multi-Log Structures	Layer	Log ID
	Stacked	C11

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.07	183.43
Top LB	1.34	161.40
Toe LB	17.29	160.60
Thalweg	21.80	159.63
Toe RB	26.31	160.59
Top RB	51.67	161.84
Fldpln RB	52.35	174.88

Proposed Cross-Section and Structure Geometry (Looking D/S)

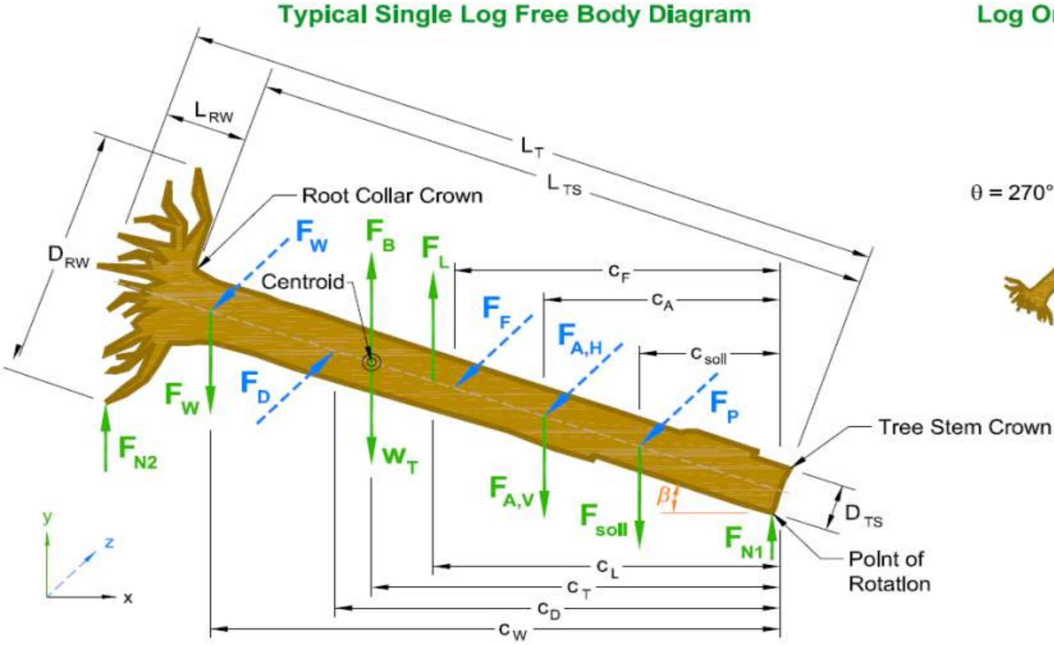


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	40.0	1.50	2.25	4.50	34.9	39.0

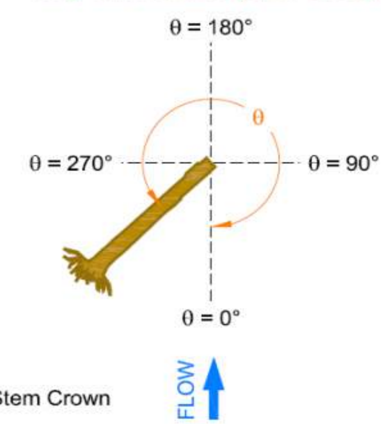
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	269.0	6.0	Stem tip: Bottom	49.00	165.00	159.33	166.49	6.40

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	62.7	5.3	68.0	2,375	0
↓WS↑Thw	4.0	8.4	12.5	436	778
↓Thalweg	0.0	0.1	0.1	2	4
Total	66.7	13.8	80.5	2,813	782

Lift Force

C_{LT}	0.10
F_L (lbf)	33

Vertical Force Balance

F_B (lbf)	782	↑
F_L (lbf)	33	↑
W_T (lbf)	2,813	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,998	↓
FS_V	3.45	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.13	1.05	1.10	0.00	1.48	491

Horizontal Force Balance

F_D (lbf)	491	→
F_P (lbf)	0	
F_F (lbf)	1,584	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,093	←
FS_H	3.23	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	946
Bank	4.40	0	1.30	0.81	637
Total	-	0	3.30	-	1,584

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.4	36.3	34.7	22.4	0.0	39.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	16,427	
M_r (lbf)	51,485	
FS_M	3.13	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
100yr	21+85	165	2.71	3.68	9.0	49	45

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
100yr	21+85	**31.00**	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
100yr	21+85	Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

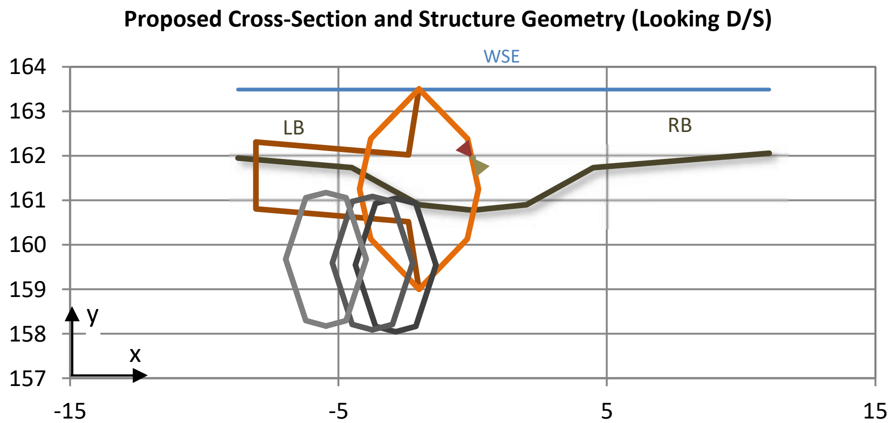
Spreadsheet developed by Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Full span	Outside	21+85	2.71	4.98	5.07

Multi-Log Structures	Layer	Log ID
	Key Log	B11

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-8.74	161.95
Top LB	-4.50	161.73
Toe LB	-2.00	160.90
Thalweg	0.00	160.77
Toe RB	2.00	160.90
Top RB	4.50	161.73
Fldpln RB	11.05	162.06

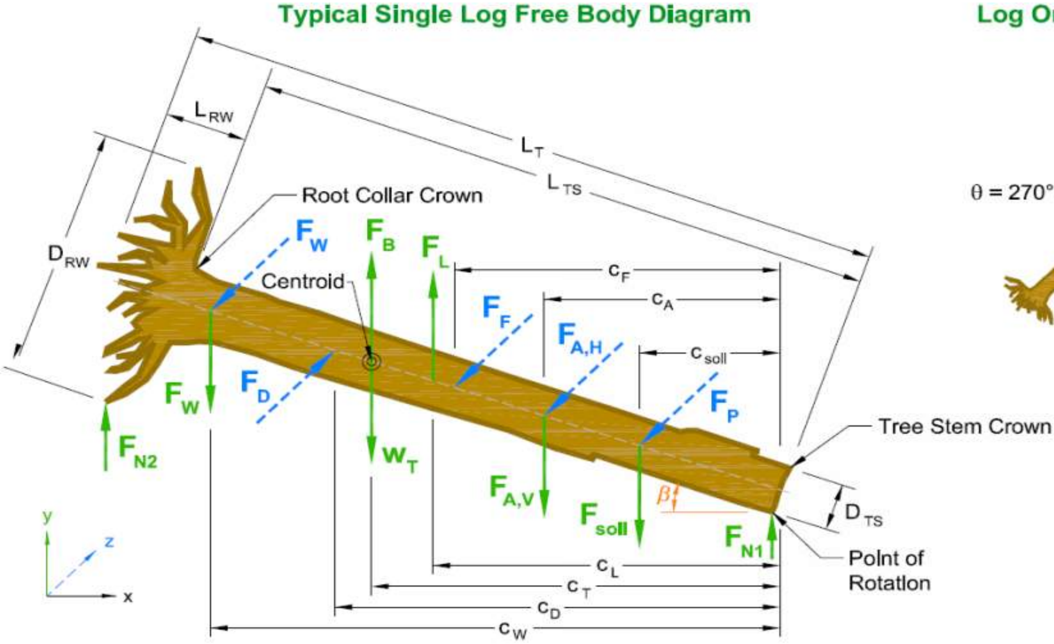


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	35.0	1.50	2.25	4.50	34.9	39.0

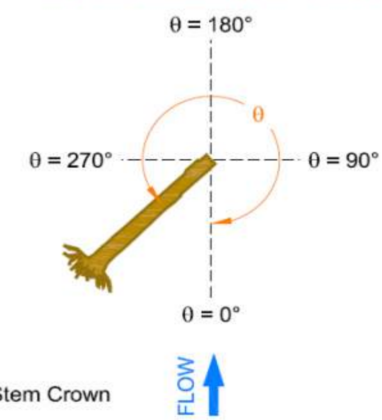
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	10.0	0.5	Rootwad: Bottom	-2.00	159.00	159.00	163.50	13.17

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	0	0
↓WS↑Thw	55.5	9.5	65.0	2,270	4,053
↓Thalweg	2.4	4.3	6.7	262	419
Total	57.9	13.8	71.7	2,531	4,471

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	4,471 ↑
F_L (lbf)	0
W_T (lbf)	2,531 ↓
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	755 ↓
$F_{A,V}$ (lbf)	3,421 ↓
ΣF_V (lbf)	2,236 ↓
FS_V	1.50 ✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.27	0.73	1.22	0.43	3.15	1,035

Horizontal Force Balance

F_D (lbf)	1,035 →
F_P (lbf)	0
F_F (lbf)	1,807 ←
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	930 ←
ΣF_H (lbf)	1,703 ←
FS_H	2.65 ✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.09	0.78	99
Bank	4.40	0	34.91	0.81	1,708
Total	-	0	37.00	-	1,807

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
19.9	0.0	17.5	19.9	0.0	17.5	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	85,647
M_r (lbf)	178,614
FS_M	2.09 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.00	30.0	0.0	14.1	1,450	0	0	1,140	310
Deadman	3.00	25.0	0.0	14.1	1,450	0	0	1,140	310
Deadman	3.00	15.0	0.0	14.1	1,450	0	0	1,140	310

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
B12	Above	Pinned	10.0	-755		755	↓	0
						0		0
						0		0
						0		0

Sample Multi-Log Structure

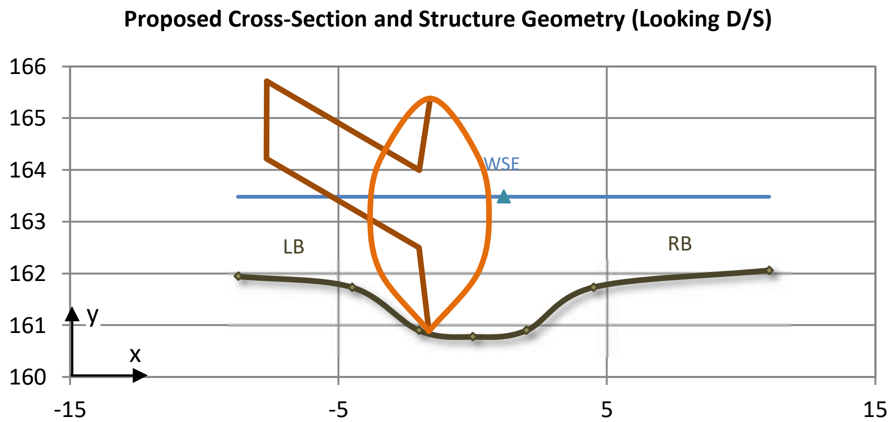
Spreadsheet developed by Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Mid-channel	Outside	21+85	2.71	4.98	5.07

Multi-Log Structures	Layer	Log ID
	Stacked	B12

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-8.74	161.95
Top LB	-4.50	161.73
Toe LB	-2.00	160.90
Thalweg	0.00	160.77
Toe RB	2.00	160.90
Top RB	4.50	161.73
Fldpln RB	11.05	162.06

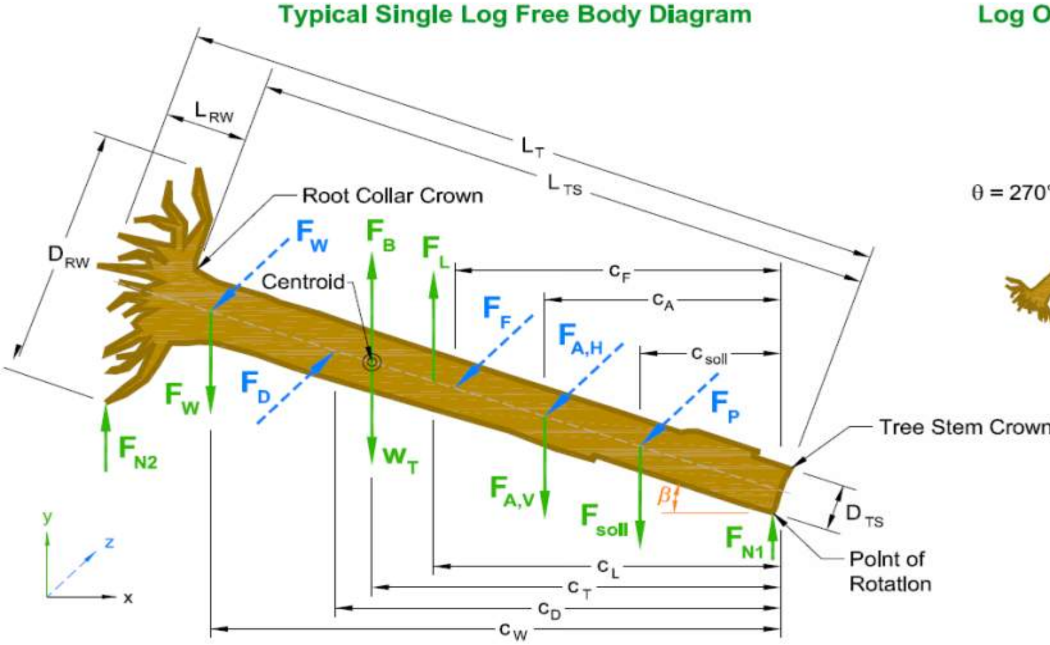


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	35.0	1.50	2.25	4.50	34.9	39.0

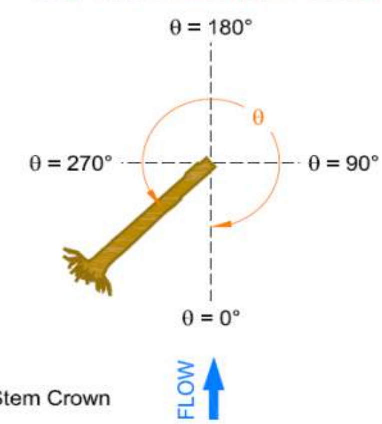
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	10.0	3.0	Root collar: Bottom	-2.00	162.50	160.88	165.71	18.52

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	47.7	5.2	53.0	1,851	0
↓WS↑Thw	10.1	8.5	18.7	653	1,166
↓Thalweg	0.0	0.0	0.0	0	0
Total	57.9	13.8	71.7	2,504	1,166

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,166
F_L (lbf)	0
W_T (lbf)	2,504
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,338
FS_V	2.15

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.38	0.73	1.22	0.00	3.27	1,507

Horizontal Force Balance

F_D (lbf)	1,507
F_P (lbf)	0
F_F (lbf)	1,045
$F_{W,H}$ (lbf)	1,185
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	723
FS_H	1.48

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	1,045
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	1,045

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
19.8	0.0	24.5	19.8	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	33,498
M_r (lbf)	150,862
FS_M	4.50

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
B12	Above	Pinned	10.0		-1,185	0	1,185
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
100yr	22+32	165	2.73	4.91	9.0	34	45

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
100yr	22+32	**31.00**	Coarse gravel	5	127.8	79.6	38

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
100yr	22+32	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:	22+32	#N/A	#N/A	#N/A

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

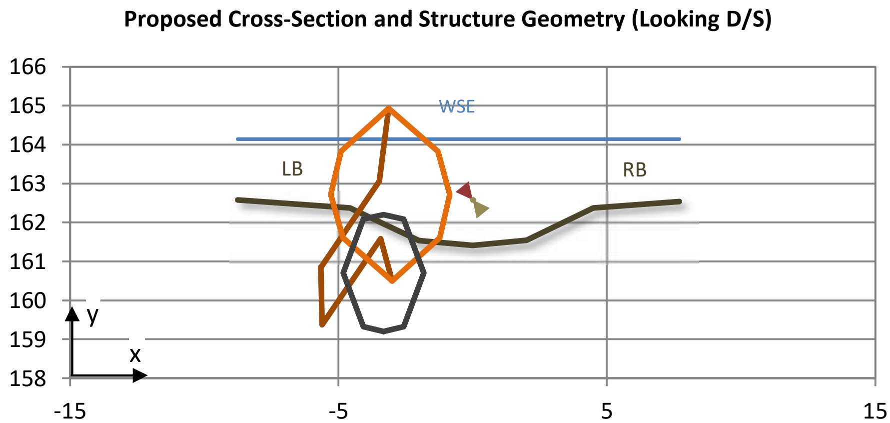
Spreadsheet developed by Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
100yr	Mid-Channel	Full span	Outside	22+32	2.73	4.98	6.76

Multi-Log Structures	Layer	Log ID
	22+32	A24

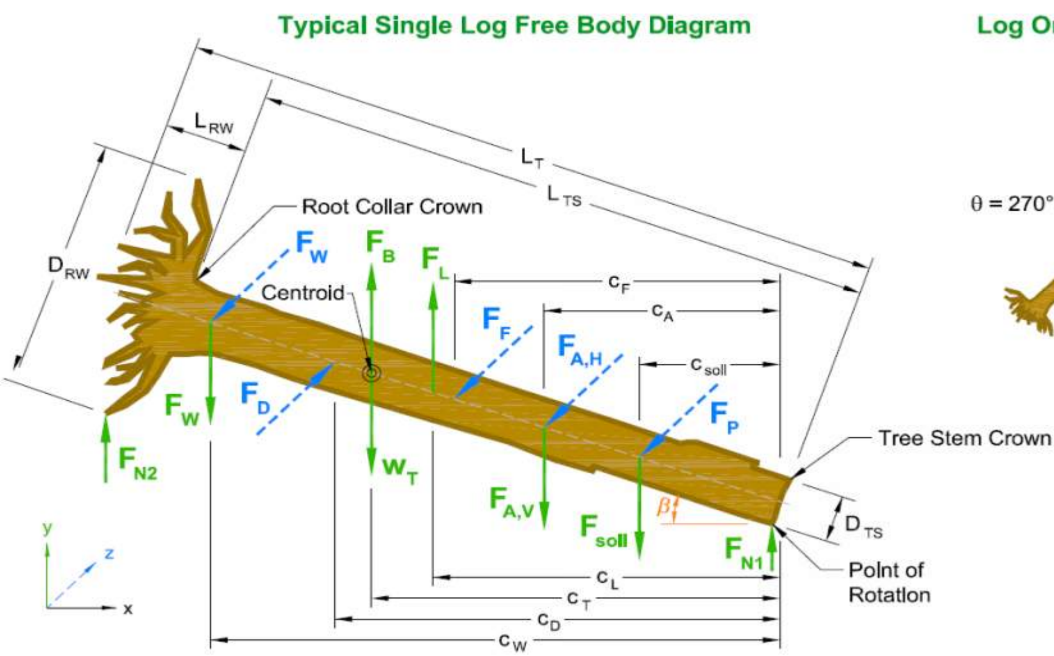
Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-8.75	162.58
Top LB	-4.57	162.37
Toe LB	-2.00	161.54
Thalweg	0.00	161.41
Toe RB	2.00	161.54
Top RB	4.50	162.37
Fldpln RB	7.70	162.53

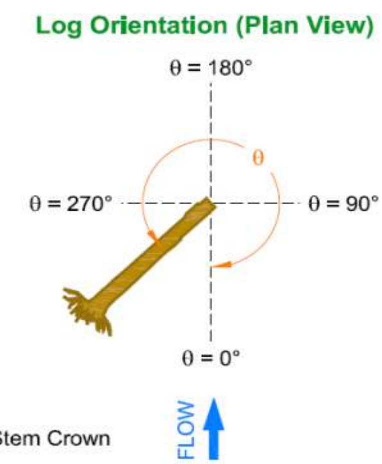


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	170.0	-10.0	Rootwad: Bottom	-3.00	160.50	159.37	164.93	12.51

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Coarse gravel	127.8	79.6	38.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	8.18	1.58	0.82





Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.5	0.5	19	0
↓WS↑Thw	9.3	12.0	21.3	743	1,327
↓Thalweg	13.2	1.3	14.5	566	906
Total	22.5	13.8	36.3	1,328	2,232

Lift Force

C_{LT}	0.03
F_L (lbf)	16

Vertical Force Balance

F_B (lbf)	2,232	↑
F_L (lbf)	16	↑
W_T (lbf)	1,328	↓
F_{soil} (lbf)	701	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	1,343	↓
ΣF_V (lbf)	1,124	↓
FS_V	1.50	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	10.1	10.1	701
Total	0.0	10.1	10.1	701

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.37	0.97	0.94	0.18	2.90	1,607

Horizontal Force Balance

F_D (lbf)	1,607	→
F_P (lbf)	1,540	←
F_F (lbf)	906	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	107	←
ΣF_H (lbf)	946	←
FS_H	1.59	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.20	0	2.00	0.78	106
Bank	4.40	1,540	14.59	0.81	800
Total	-	1,540	16.59	-	906

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	14.8	11.6	9.3	4.1	7.3	5.5

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	38,967	↻
M_r (lbf)	57,015	↺
FS_M	1.46	✗

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Deadman	3.00	13.5	0.0	14.1	1,450	0	0	1,343	107
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 10 yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
10yr	22+60	114	2.39	3.52	9.0	39	45

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
10yr	22+60	**15.49**	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
10yr	22+60	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	Common Name	Scientific Name		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

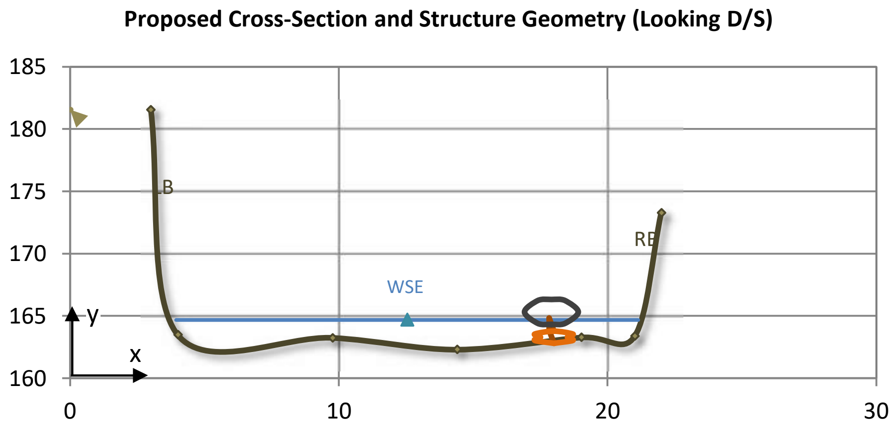
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10yr	Log Weir	Left bank	Outside	22+60	2.39	5.00	4.85

Multi-Log Structures	Layer	Log ID
	Footer	D3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	3.00	181.54
Top LB	4.01	163.49
Toe LB	9.76	163.24
Thalweg	14.41	162.30
Toe RB	19.02	163.28
Top RB	21.01	163.38
Fldpln RB	22.00	173.28

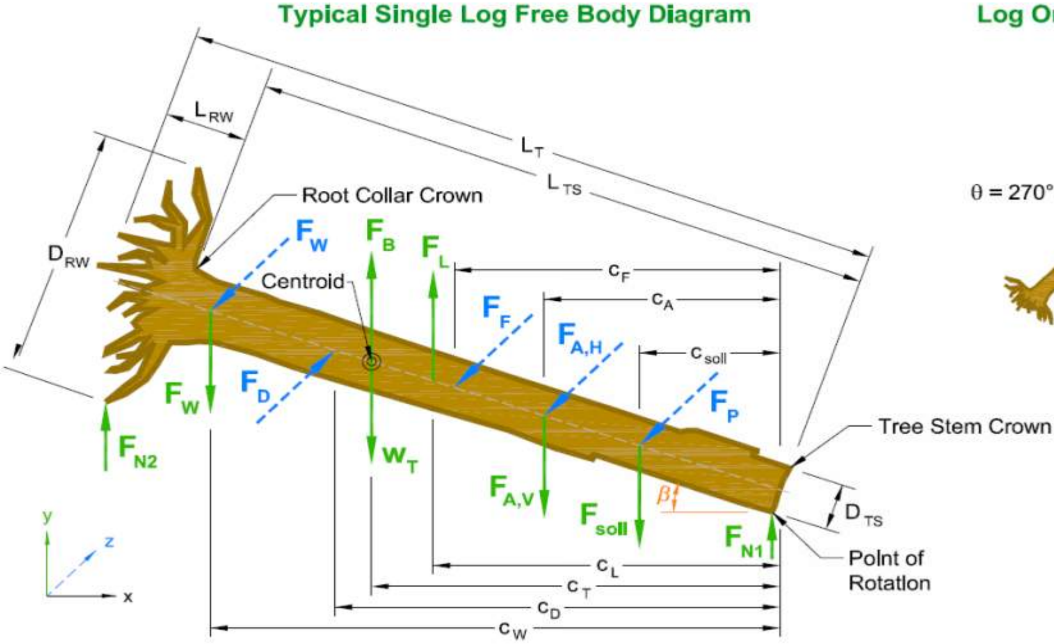


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft³)	γ_{Tgr} (lb/ft³)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

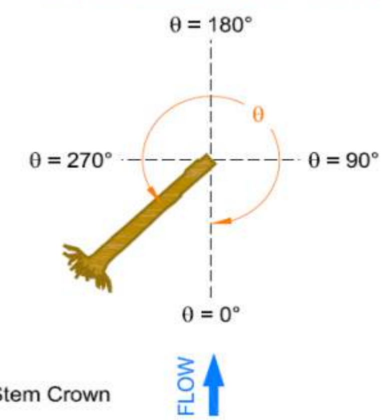
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft²)
	179.0	6.0	Root collar: Bottom	18.00	162.80	162.80	164.84	0.17

Soils	Material	γ_s (lb/ft³)	γ'_s (lb/ft³)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	0.0	0.0	2	0
↓WS↑Thw	7.8	0.0	7.8	273	487
↓Thalweg	0.0	0.0	0.0	0	0
Total	7.9	0.0	7.9	274	487

Lift Force

C_{LT}	0.10
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	487
F_L (lbf)	0
W_T (lbf)	274
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	666
Σ F_V (lbf)	453
FS_V	1.93

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.85	1.07	0.42	1.49	6

Horizontal Force Balance

F_D (lbf)	6
F_P (lbf)	0
F_F (lbf)	329
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
Σ F_H (lbf)	323
FS_H	57.84

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	4.43	0.73	329
Bank	4.40	0	0.00	0.81	0
Total	-	0	4.43	-	329

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	5.3	5.0	5.0	0.0	8.8	0.0

*Distances are from the stem tip

Point of Rotation:	Root Collar

Moment Force Balance

M_d (lbf)	2,453
M_r (lbf)	5,608
FS_M	2.29

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Above	2.00	5.0	3.8	0.4	667	2	8	666	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs $F_{W,V}$ (lbf)	Applied Forces from other Logs $F_{W,H}$ (lbf)
Top#2	Above	Gravity	3.0			0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

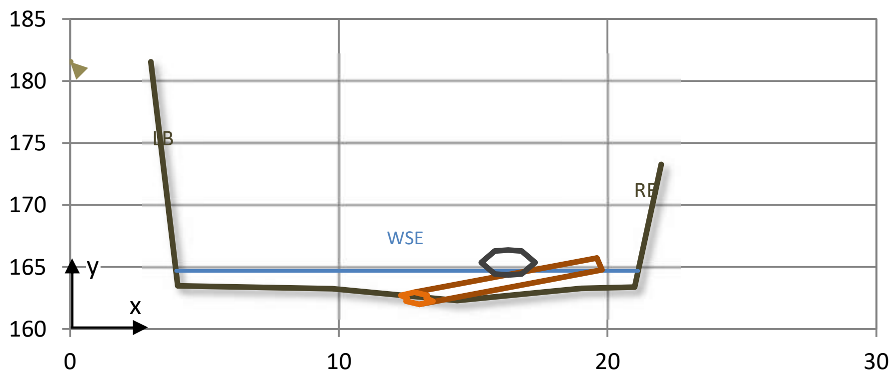
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
10yr	Flow Deflection	Left bank	Outside	22+60	2.39	5.00	4.85

Multi-Log Structures	Layer	Log ID
	Key Log	D4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	3.00	181.54
Top LB	4.01	163.49
Toe LB	9.76	163.24
Thalweg	14.41	162.30
Toe RB	19.02	163.28
Top RB	21.01	163.38
Fldpln RB	22.00	173.28

Proposed Cross-Section and Structure Geometry (Looking D/S)

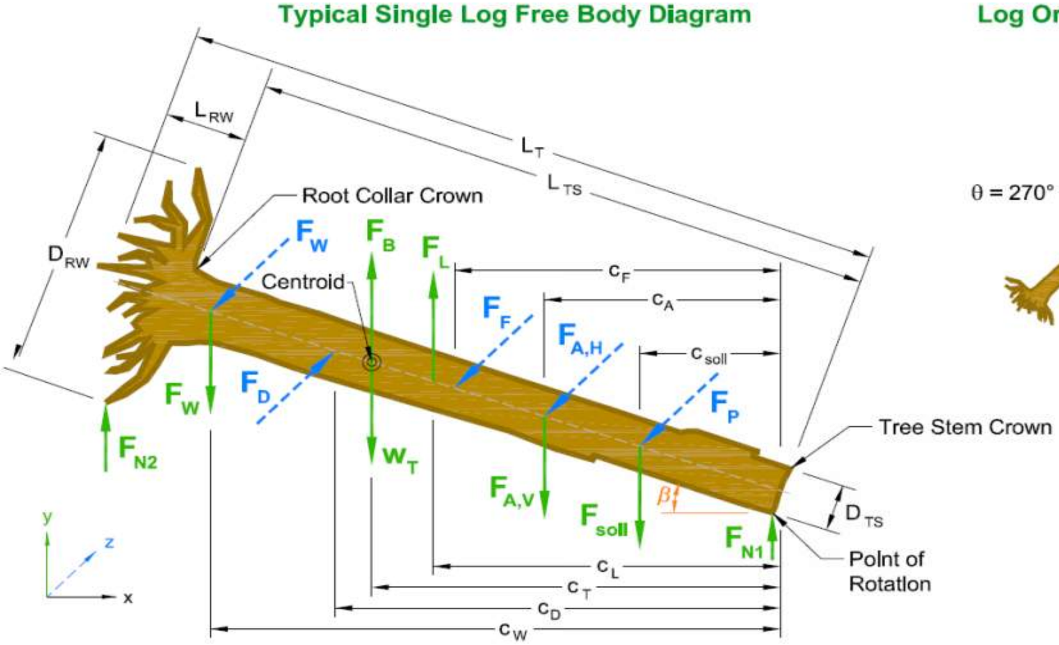


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	No	10.0	1.00	-	-	34.9	39.0

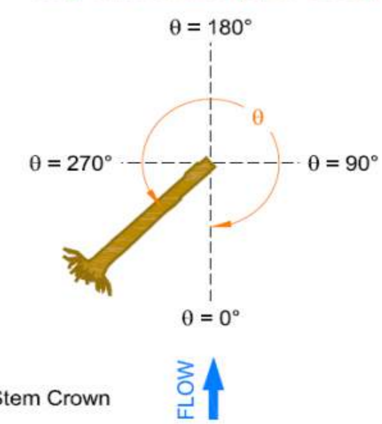
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	16.0	Root collar: Bottom	13.00	162.00	162.00	165.72	5.33

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	1.6	0.0	1.6	54	0
↓WS↑Thw	6.2	0.0	6.2	217	387
↓Thalweg	0.1	0.0	0.1	4	6
Total	7.9	0.0	7.9	275	393

Lift Force

C_{LT}	0.03
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	393	↑
F_L (lbf)	4	↑
W_T (lbf)	275	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	670	↓
Σ F_V (lbf)	548	↓
FS_V	2.38	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.14	0.85	0.76	0.32	1.47	178

Horizontal Force Balance

F_D (lbf)	178	→
F_P (lbf)	0	
F_F (lbf)	398	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	220	←
FS_H	2.24	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	3.53	0.73	398
Bank	4.40	0	0.00	0.81	0
Total	-	0	3.53	-	398

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
5.0	7.5	5.1	5.0	0.0	9.3	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	2,733	↻
M_r (lbf)	5,226	↺
FS_M	1.91	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Above	2.00	5.0	3.9	0.3	672	1	7	670	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100yr yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
24+40	24+40	165	2.36	5.50	9.0	57	52

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
24+40	24+50	**15.49**	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
24+40	24+50	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Interior west	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by Michael Rafferty, P.E.

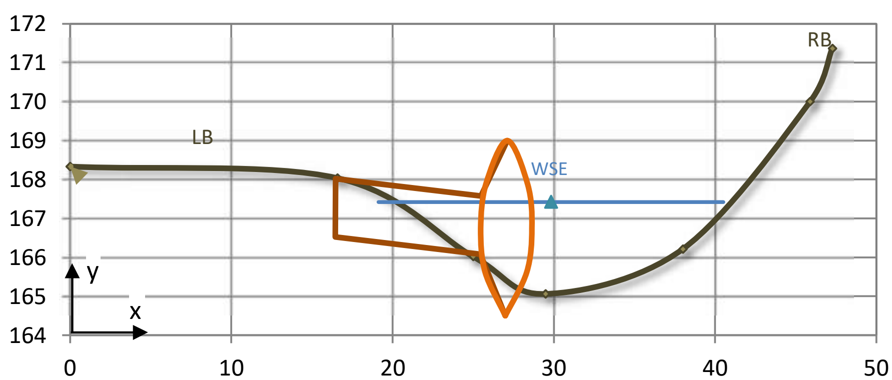
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
24+40	Rootwad	Left bank	Outside	24+40	2.36	5.74	7.40

Multi-Log Structures	Layer	Log ID
	Key Log	A17

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.33
Top LB	16.57	168.04
Toe LB	24.99	166.02
Thalweg	29.49	165.06
Toe RB	38.00	166.21
Top RB	45.89	170.00
Fldpln RB	47.27	171.37

Proposed Cross-Section and Structure Geometry (Looking D/S)

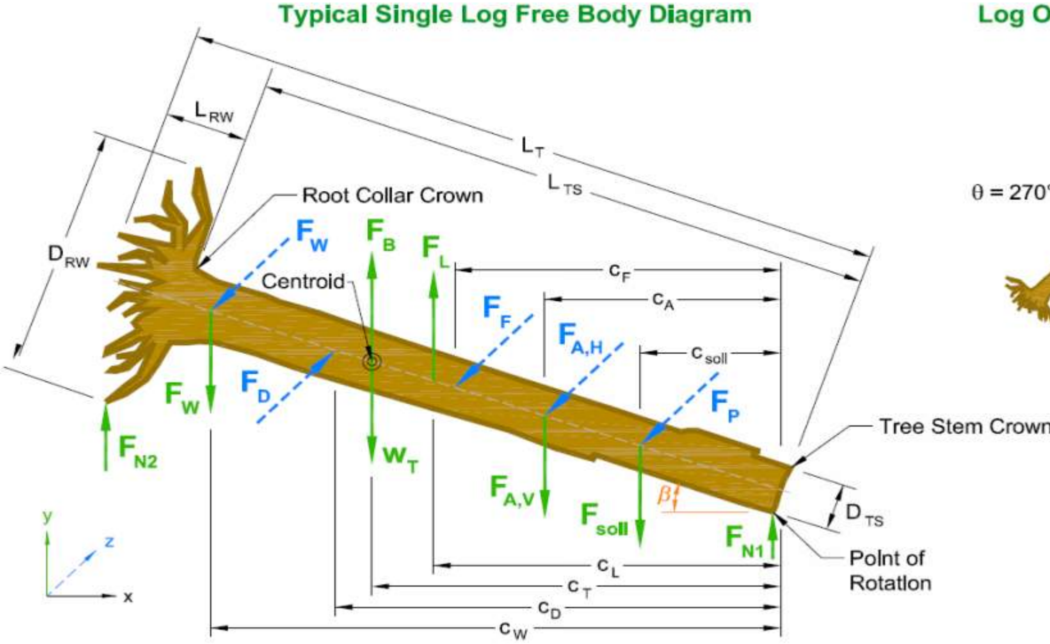


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

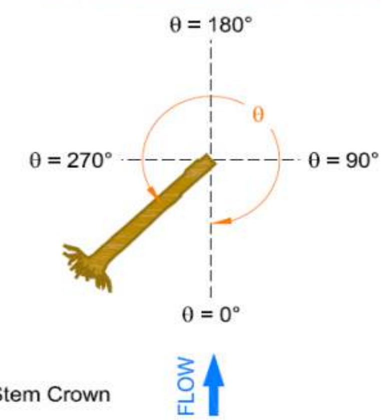
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	2.0	Rootwad: Bottom	27.00	164.50	164.50	169.00	13.84

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.26	0.02	0.01

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	4.4	3.5	8.0	279	0
↓WS↑Thw	18.1	10.0	28.0	980	1,750
↓Thalweg	0.0	0.3	0.3	11	18
Total	22.5	13.8	36.3	1,270	1,768

Lift Force

C_{LT}	0.08
F_L (lbf)	57

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	1
Total	0.0	0.0	0.0	1

Vertical Force Balance

F_B (lbf)	1,768	↑
F_L (lbf)	57	↑
W_T (lbf)	1,270	↓
F_{soil} (lbf)	1	↓
$F_{W,V}$ (lbf)	3,381	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	2,826	↓
FS_V	2.55	✓

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.24	1.06	1.12	0.00	1.99	1,459

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	306
Bank	4.40	1	11.44	0.81	1,948
Total	-	1	13.44	-	2,254

Horizontal Force Balance

F_D (lbf)	1,459	→
F_P (lbf)	1	←
F_F (lbf)	2,254	←
$F_{W,H}$ (lbf)	1,830	←
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,626	←
FS_H	2.80	✓

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	13.2	7.7	9.4	0.1	5.7	0.2

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	28,449	↻
M_r (lbf)	61,649	↺
FS_M	2.17	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)	
A18	Above	Gravity	4.0	-3,381	0	3,381	↓	0	
A18	Behind	Gravity	4.0		-1,830	0		1,830	←
						0		0	
						0		0	

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

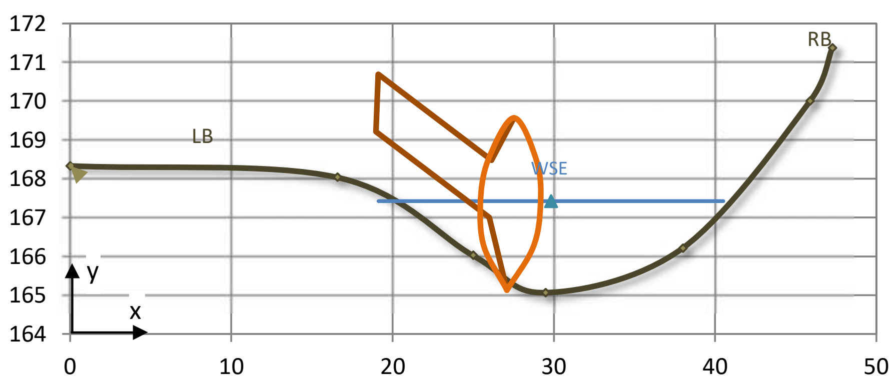
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
24+40	Flow Deflection	Left bank	Outside	24+40	2.36	5.74	7.40

Multi-Log Structures	Layer	Log ID
	Stacked	A18

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.33
Top LB	16.57	168.04
Toe LB	24.99	166.02
Thalweg	29.49	165.06
Toe RB	38.00	166.21
Top RB	45.89	170.00
Fldpln RB	47.27	171.37

Proposed Cross-Section and Structure Geometry (Looking D/S)

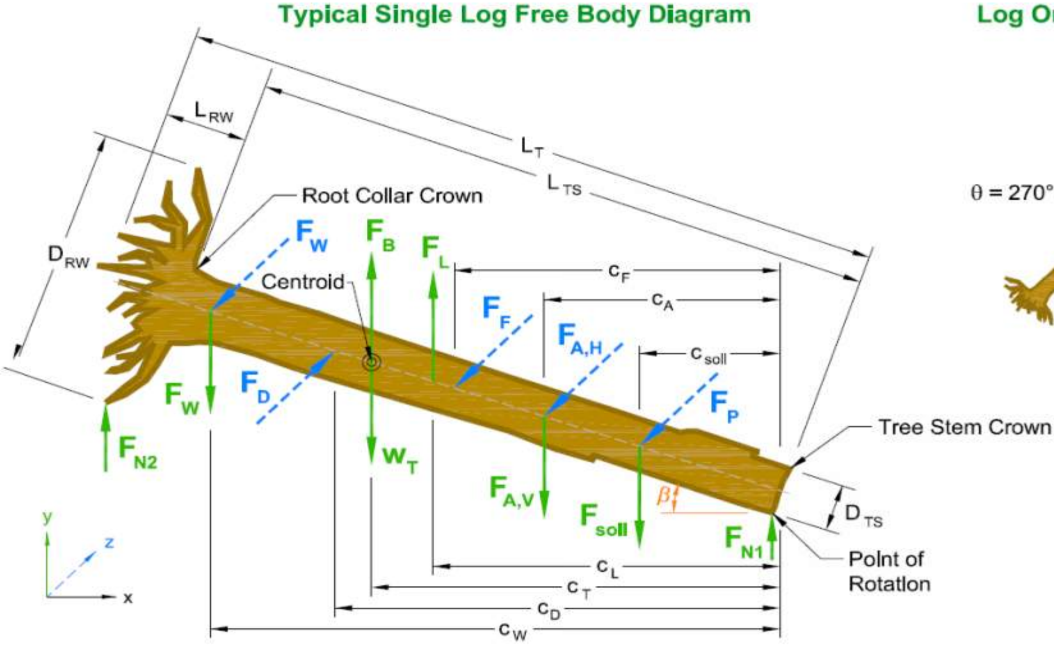


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

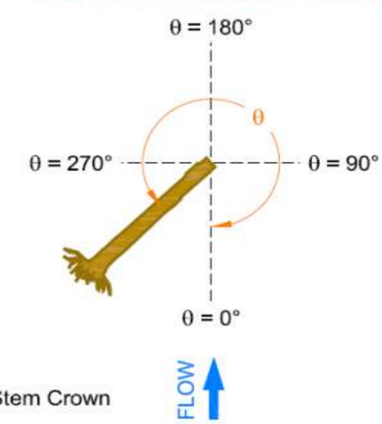
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	146.0	10.0	Root collar: Bottom	26.00	167.00	165.13	170.69	19.59

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	22.1	7.1	29.2	1,021	0
↓WS↑Thw	0.4	6.7	7.1	248	443
↓Thalweg	0.0	0.0	0.0	0	0
Total	22.5	13.8	36.3	1,269	443

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	443	↑
F_L (lbf)	0	
W_T (lbf)	1,269	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	2,777	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	3,603	↓
FS_V	9.13	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.35	1.06	0.78	0.00	1.86	1,936

Horizontal Force Balance

F_D (lbf)	1,936	→
F_P (lbf)	0	
F_F (lbf)	2,617	←
$F_{W,H}$ (lbf)	2,117	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,798	←
FS_H	2.45	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	2,617
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	2,617

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	12.7	9.4	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	6,898
M_r (lbf)	113,401
FS_M	16.44 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

						Applied Forces from other Logs	
Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
C10	Above	Gravity	12.0	-2,777		2,777 ↓	0
C10	Behind	Gravity	12.0		-2,117	0	2,117 ←
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

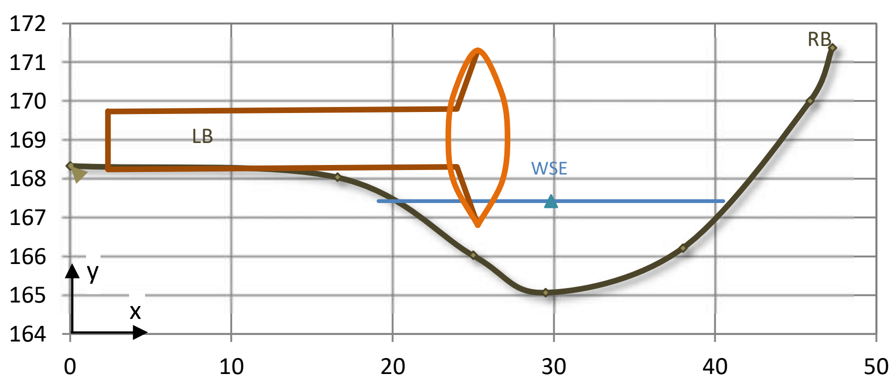
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
24+40	Rootwad	Left bank	Outside	24+40	2.36	5.74	7.40

Multi-Log Structures	Layer	Log ID
	Stacked	C10

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	0.00	168.33
Top LB	16.57	168.04
Toe LB	24.99	166.02
Thalweg	29.49	165.06
Toe RB	38.00	166.21
Top RB	45.89	170.00
Fldpln RB	47.27	171.37

Proposed Cross-Section and Structure Geometry (Looking D/S)

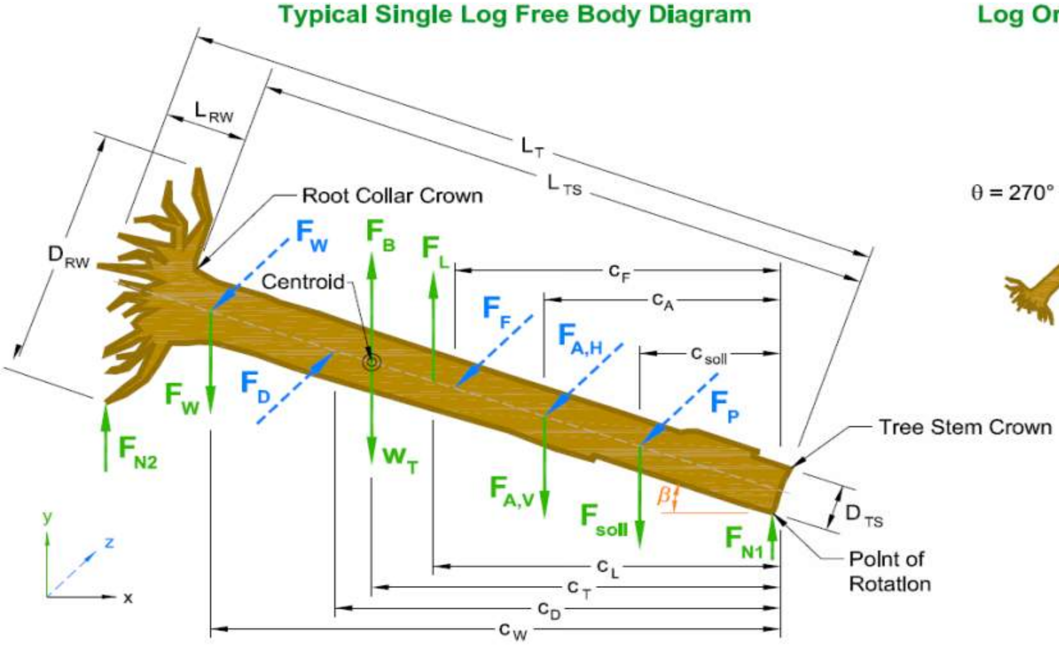


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	40.0	1.50	2.25	4.50	34.9	39.0

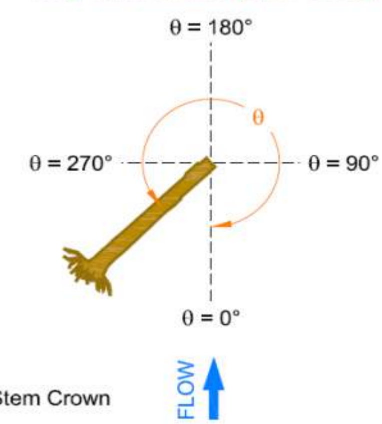
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	145.0	-0.1	Root collar: Bottom	24.00	168.30	166.80	171.30	1.08

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	66.7	13.4	80.1	2,799	0
↓WS↑Thw	0.0	0.4	0.4	13	24
↓Thalweg	0.0	0.0	0.0	0	0
Total	66.7	13.8	80.5	2,813	24

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	24	↑
F_L (lbf)	0	
W_T (lbf)	2,813	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,789	↓
FS_V	118.54	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.02	1.06	0.78	0.00	0.81	47

Horizontal Force Balance

F_D (lbf)	47	→
F_P (lbf)	0	
F_F (lbf)	2,187	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,141	←
FS_H	47.03	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	623
Bank	4.40	0	4.50	0.81	1,564
Total	-	0	6.50	-	2,187

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.4	0.0	0.0	22.4	0.0	2.2	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	2,279	
M_r (lbf)	237,717	
FS_M	104.32	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100yr yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
26+08	26+08	165	1.60	2.85	9.0	48	19

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
26+08	24+50	**15.49**	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
26+08	24+50	**Gravel/sand**	5	111.7	69.5	39
		Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

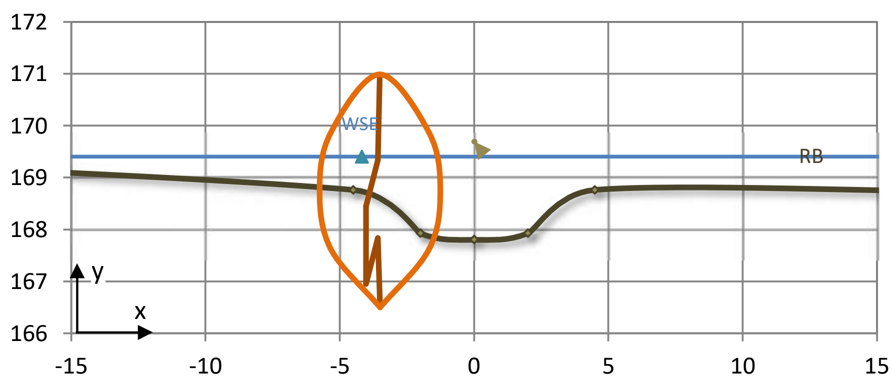
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+08	Rootwad	Right bank	Outside	26+08	1.60	2.06	4.49

Multi-Log Structures	Layer	Log ID
	Key Log	A8

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.11	169.69
Top LB	-4.50	168.76
Toe LB	-2.00	167.93
Thalweg	0.00	167.80
Toe RB	1.99	167.93
Top RB	4.49	168.76
Fldpln RB	20.72	168.71

Proposed Cross-Section and Structure Geometry (Looking D/S)

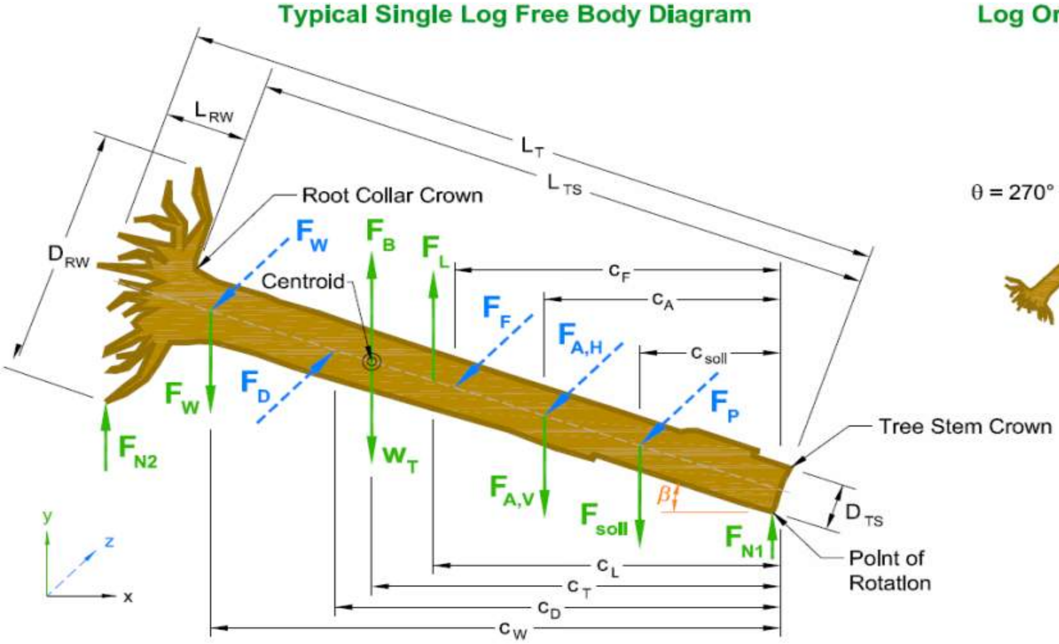


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

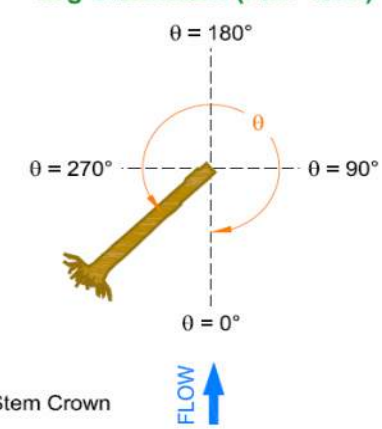
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	2.0	-4.0	Rootwad: Bottom	-3.50	166.50	166.50	170.99	7.31

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	1.92	0.16	0.08

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	3.2	3.2	110	0
↓WS↑Thw	17.1	8.2	25.3	882	1,576
↓Thalweg	5.5	2.4	7.9	308	493
Total	22.5	13.8	36.3	1,301	2,069

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,069	↑
F_L (lbf)	0	
W_T (lbf)	1,301	↓
F_{soil} (lbf)	16	↓
$F_{W,V}$ (lbf)	2,258	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,506	↓
FS_V	1.73	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.2	0.2	16
Total	0.0	0.2	0.2	16

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.15	0.65	1.20	0.43	2.29	328

Horizontal Force Balance

F_D (lbf)	328	→
F_P (lbf)	34	←
F_F (lbf)	1,205	←
$F_{W,H}$ (lbf)	1,678	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,589	←
FS_H	8.89	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	129
Bank	4.40	34	15.00	0.81	1,076
Total	-	34	17.00	-	1,205

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	0.0	8.5	9.3	0.9	7.5	1.3

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	22,048	
M_r (lbf)	75,648	
FS_M	3.43	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)	
Top#2	Above	Gravity	11.0	-2,258		2,258	↓	0	
Top#2	Behind	Gravity	11.0		-1,678	0		1,678	←
						0		0	
						0		0	

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

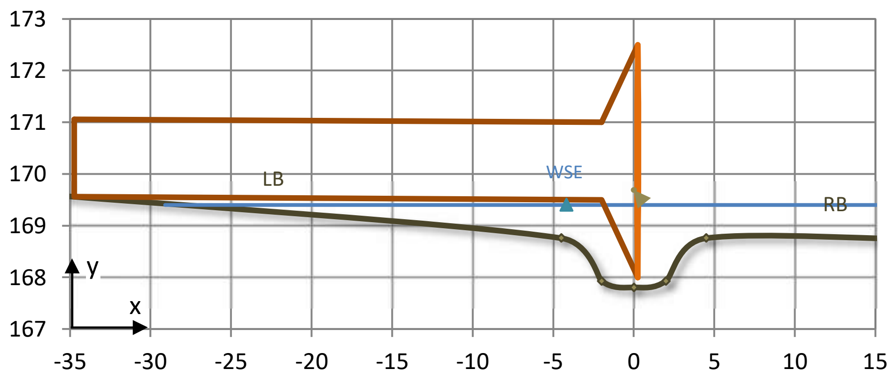
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+08	Rootwad	Left bank	Outside	26+08	1.60	2.06	4.49

Multi-Log Structures	Layer	Log ID
	Stacked	B1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.11	169.69
Top LB	-4.50	168.76
Toe LB	-2.00	167.93
Thalweg	0.00	167.80
Toe RB	1.99	167.93
Top RB	4.49	168.76
Fldpln RB	20.72	168.71

Proposed Cross-Section and Structure Geometry (Looking D/S)

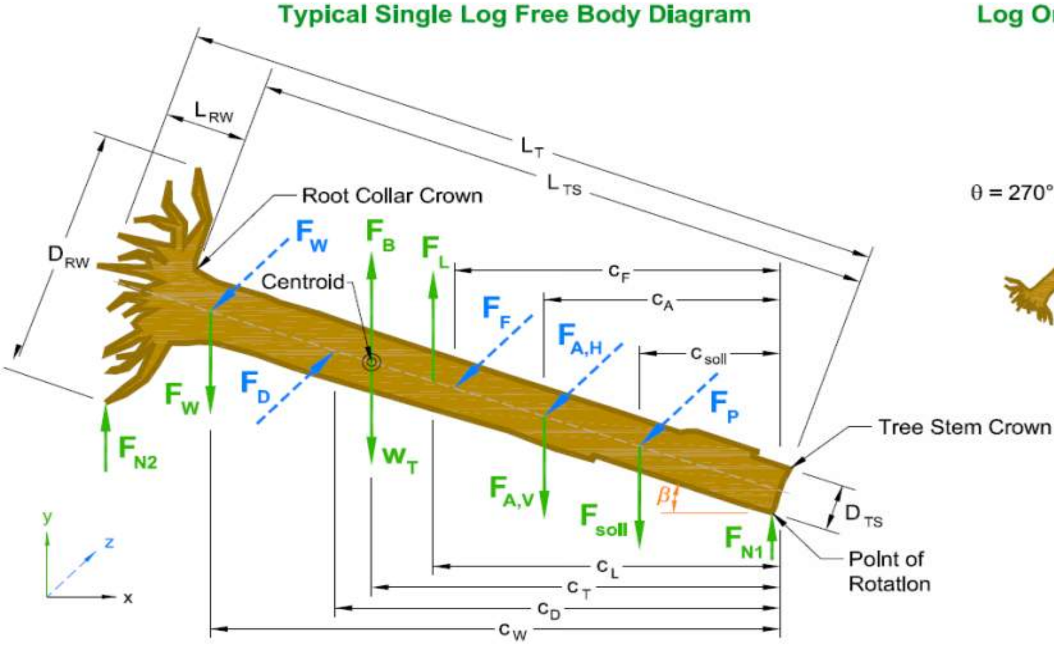


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	35.0	1.50	2.25	4.50	34.9	39.0

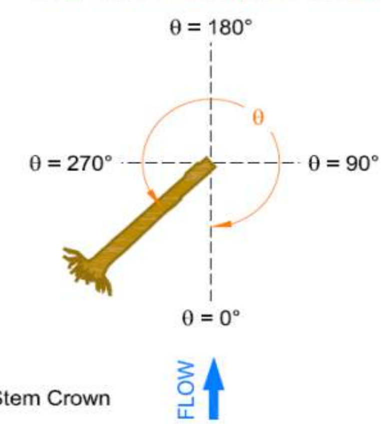
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	91.0	0.1	Root collar: Bottom	-2.00	169.50	168.00	172.50	0.07

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	57.9	11.2	69.0	2,412	0
↓WS↑Thw	0.0	2.6	2.6	92	164
↓Thalweg	0.0	0.0	0.0	0	0
Total	57.9	13.8	71.7	2,504	164

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	164
F_L (lbf)	0
W_T (lbf)	2,504
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	2,340
FS_V	15.26

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	0.65	0.97	0.00	0.97	1

Horizontal Force Balance

F_D (lbf)	1
F_P (lbf)	0
F_F (lbf)	1,700
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	1,699
FS_H	1,204.50

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	1,700
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	1,700

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
19.8	0.0	0.0	19.8	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	2,542
M_r (lbf)	179,443
FS_M	70.60

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs $F_{W,V}$ (lbf)	Applied Forces from other Logs $F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

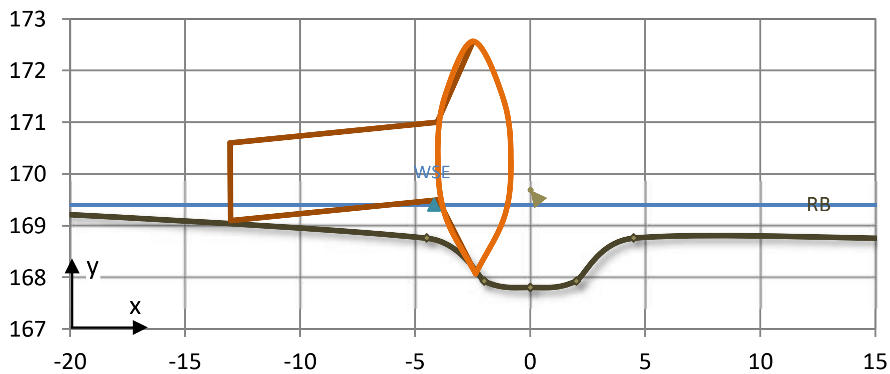
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+08	Rootwad	Left bank	Outside	26+08	1.60	2.06	4.49

Multi-Log Structures	Layer	Log ID
	Stacked	A9

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-40.11	169.69
Top LB	-4.50	168.76
Toe LB	-2.00	167.93
Thalweg	0.00	167.80
Toe RB	1.99	167.93
Top RB	4.49	168.76
Fldpln RB	20.72	168.71

Proposed Cross-Section and Structure Geometry (Looking D/S)

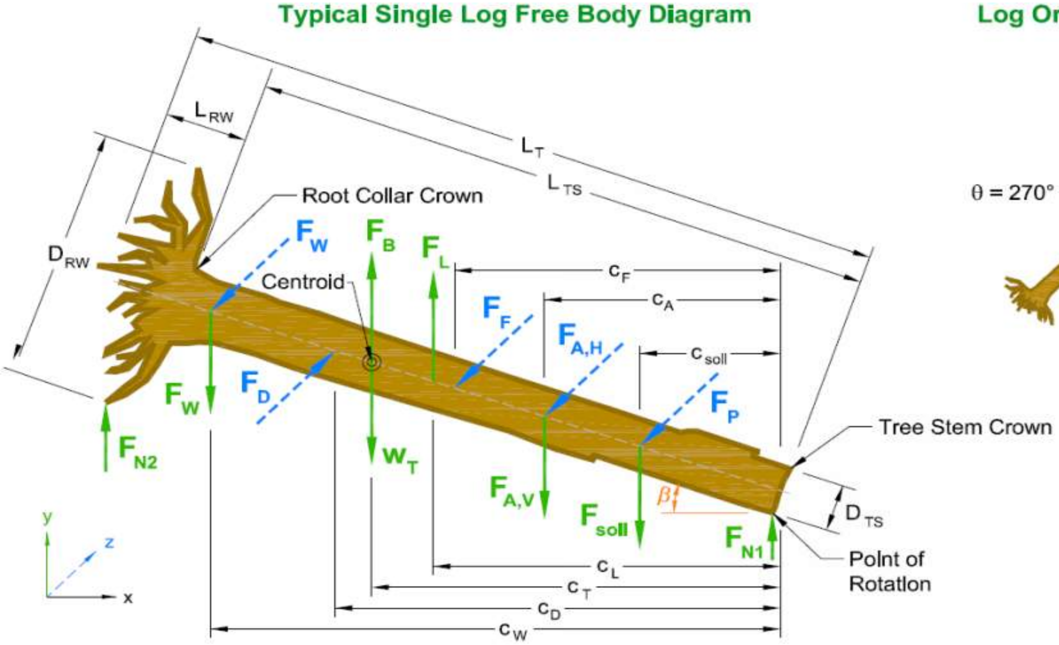


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

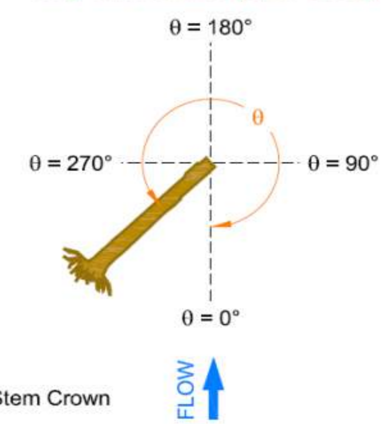
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	-1.8	Root collar: Bottom	-4.00	169.50	168.07	172.57	3.84

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	21.5	11.3	32.9	1,149	0
↓WS↑Thw	1.0	2.4	3.4	120	215
↓Thalweg	0.0	0.0	0.0	0	0
Total	22.5	13.8	36.3	1,269	215

Lift Force

C_{LT}	0.24
F_L (lbf)	18

Vertical Force Balance

F_B (lbf)	215	↑
F_L (lbf)	18	↑
W_T (lbf)	1,269	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,036	↓
FS_V	5.45	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.08	0.65	1.12	0.00	1.33	100

Horizontal Force Balance

F_D (lbf)	100	→
F_P (lbf)	0	
F_F (lbf)	753	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	653	←
FS_H	7.56	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	753
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	753

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	4.8	4.8	9.4	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	2,411
M_r (lbf)	33,981
FS_M	14.09 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs $F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100yr yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
26+18	26+18	165	1.60	4.00	9.0	16	9

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
26+18	24+50	**15.49**	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
26+18	24+50	Gravel/sand	5	111.7	69.5	39
		Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**	Pseudotsuga menziesii var. glauca	34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

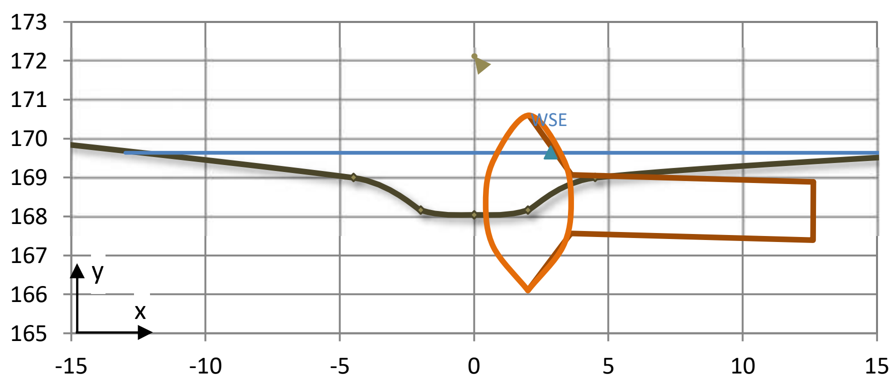
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+18	Rootwad	Right bank	Outside	26+18	1.60	0.99	6.97

Multi-Log Structures	Layer	Log ID
	Key Log	165

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

Proposed Cross-Section and Structure Geometry (Looking D/S)

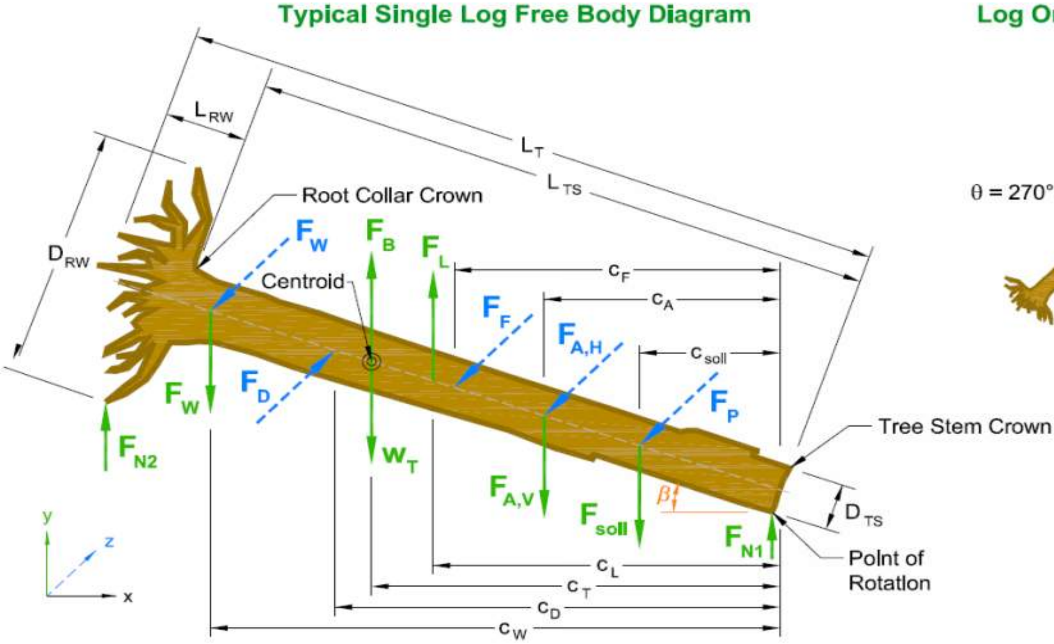


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

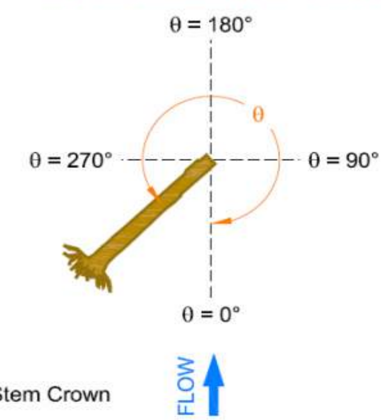
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	-0.8	Rootwad: Bottom	2.00	166.10	166.10	170.60	6.03

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	10.33	0.48	0.24

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	1.1	1.1	37	0
↓WS↑Thw	14.9	7.4	22.3	778	1,390
↓Thalweg	7.7	5.3	13.0	506	810
Total	22.5	13.8	36.3	1,322	2,200

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,200	↑
F_L (lbf)	0	
W_T (lbf)	1,322	↓
F_{soil} (lbf)	256	↓
$F_{W,V}$ (lbf)	3,368	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,746	↓
FS_V	2.25	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	3.7	3.7	256
Total	0.0	3.7	3.7	256

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.37	1.00	1.10	0.20	3.36	954

Horizontal Force Balance

F_D (lbf)	954	→
F_P (lbf)	563	←
F_F (lbf)	2,197	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,805	←
FS_H	2.89	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	235
Bank	4.40	563	15.00	0.81	1,962
Total	-	563	17.00	-	2,197

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	12.7	9.4	5.1	7.5	6.9

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	32,684
M_r (lbf)	81,549
FS_M	2.50 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)
B2	Above	Gravity	8.0	-3,368		3,368	↓	0
						0		0
						0		0
						0		0

Sample Multi-Log Structure

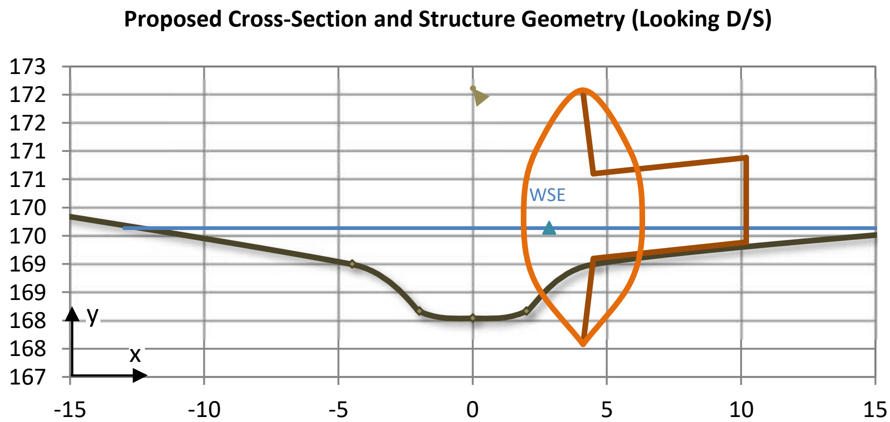
Spreadsheet developed by Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+18	Rootwad	Left bank	Outside	26+18	1.60	0.99	6.97

Multi-Log Structures	Layer	Log ID
	Stacked	165

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

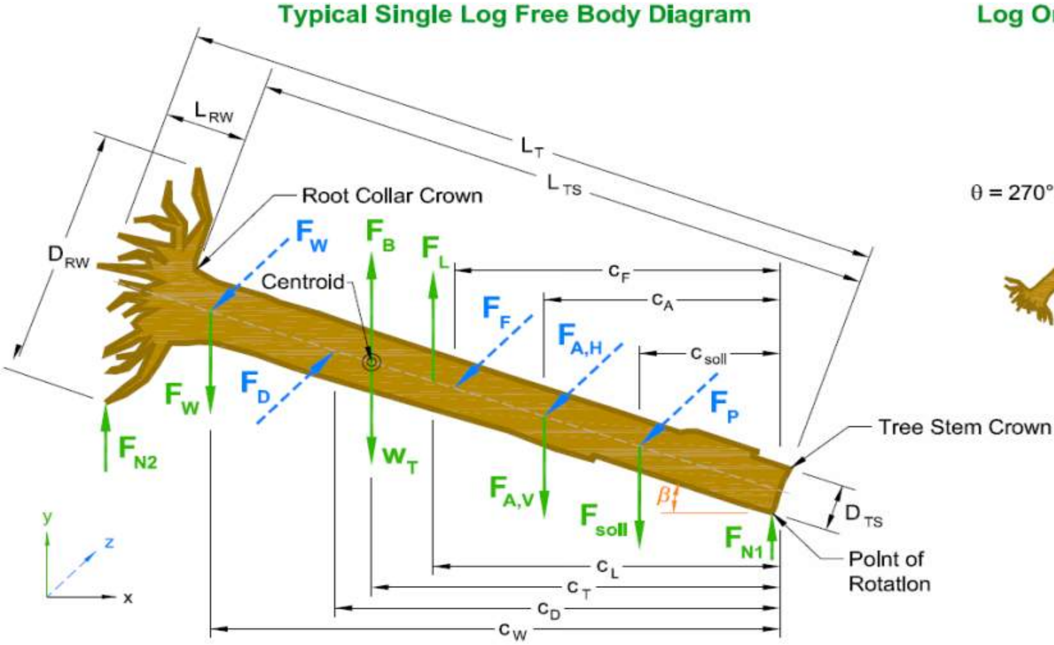


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	35.0	1.50	2.25	4.50	34.9	39.0

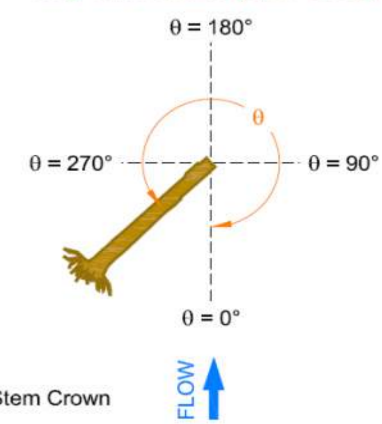
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	350.0	0.5	Root collar: Bottom	4.50	169.10	167.58	172.08	8.62

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	45.6	8.0	53.6	1,872	0
↓WS↑Thw	12.3	5.6	17.9	625	1,117
↓Thalweg	0.0	0.2	0.2	7	11
Total	57.9	13.8	71.7	2,505	1,128

Lift Force

C_{LT}	0.38
F_L (lbf)	153

Vertical Force Balance

F_B (lbf)	1,128
F_L (lbf)	153
W_T (lbf)	2,505
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	2,786
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	4,009
FS_V	4.13

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.53	1.00	1.10	0.00	5.21	2,113

Horizontal Force Balance

F_D (lbf)	2,113
F_P (lbf)	0
F_F (lbf)	2,913
$F_{W,H}$ (lbf)	2,029
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	2,829
FS_H	2.34

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	2,913
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	2,913

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
19.8	17.5	17.5	19.8	0.0	35.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	56,793
M_r (lbf)	91,004
FS_M	1.60

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
Behind								0	0
Behind								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs: $F_{W,V}$ (lbf)	Applied Forces from other Logs: $F_{W,H}$ (lbf)
C3	Above	Gravity	24.0	-2,786		2,786	0
Log#3	Behind	Gravity	24.0		-2,029	0	2,029
						0	0
						0	0

Sample Multi-Log Structure

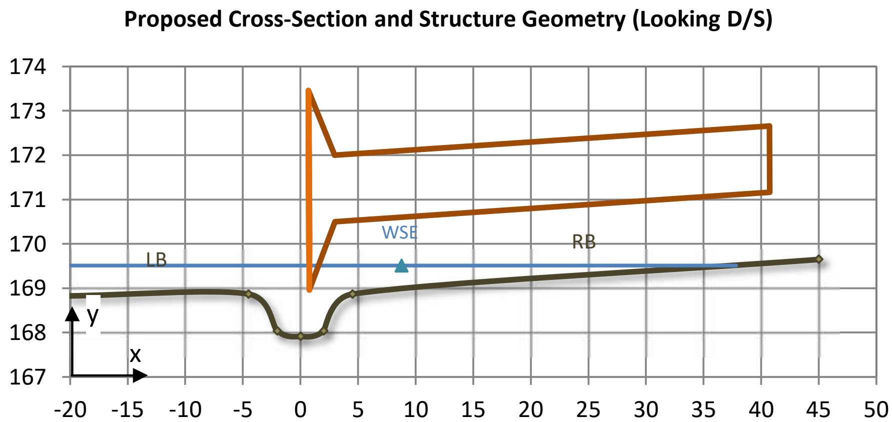
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+18	Rootwad	Left bank	Outside	26+18	1.60	0.99	6.97

Multi-Log Structures	Layer	Log ID
	Stacked	165

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-20.28	168.83
Top LB	-4.51	168.87
Toe LB	-2.01	168.04
Thalweg	0.00	167.91
Toe RB	2.00	168.04
Top RB	4.50	168.87
Fldpln RB	45.00	169.65

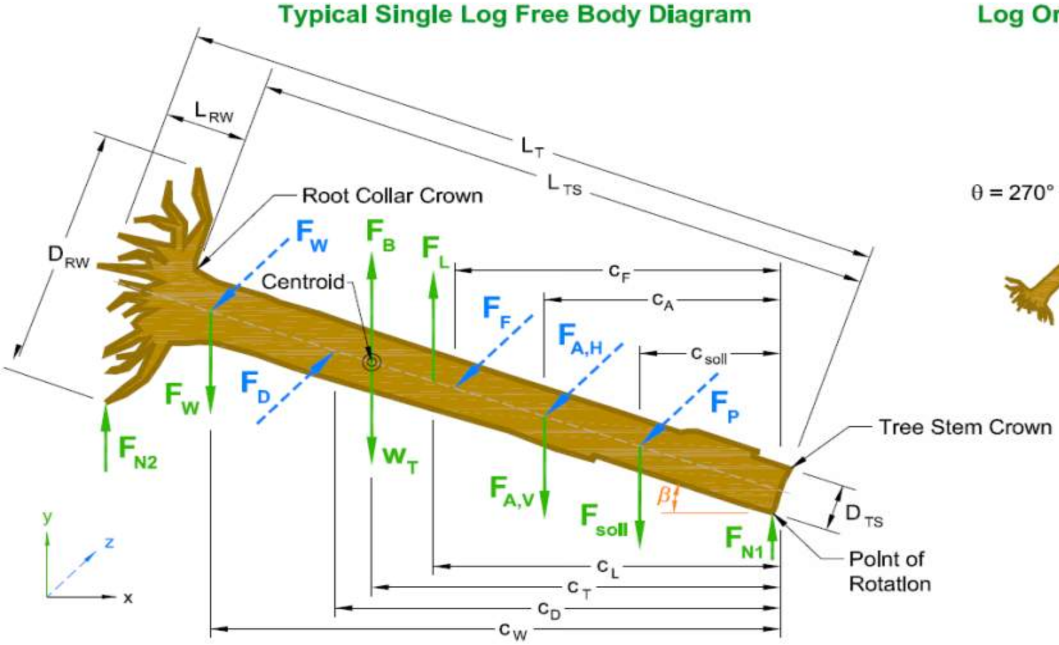


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	40.0	1.50	2.25	4.50	34.9	39.0

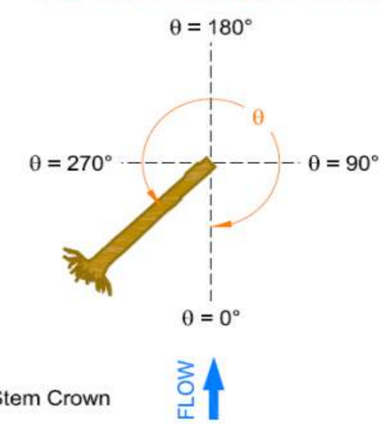
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	271.0	1.0	Root collar: Bottom	3.00	170.50	168.96	173.46	0.02

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	66.7	13.5	80.2	2,803	0
↓WS↑Thw	0.0	0.3	0.3	10	18
↓Thalweg	0.0	0.0	0.0	0	0
Total	66.7	13.8	80.5	2,813	18

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	18	↑
F_L (lbf)	0	
W_T (lbf)	2,813	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	2,795	↓
FS_V	160.17	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	1.00	1.10	0.00	1.10	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	2,031	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,030	←
FS_H	2,016.78	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	2,031
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	2,031

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.4	0.0	40.0	22.4	0.0	40.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	310	
M_r (lbf)	49,612	
FS_M	160.17	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
						0	0
						0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100yr yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
26+38	26+38	165	1.50	6.00	9.0	14	40

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
26+38	26+38	15.49	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
26+38	26+38	Gravel/sand	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	Douglas-fir, Interior west		34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight, γ_{Td}** = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).
[2] **Green unit weight, γ_{Tgr}** = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

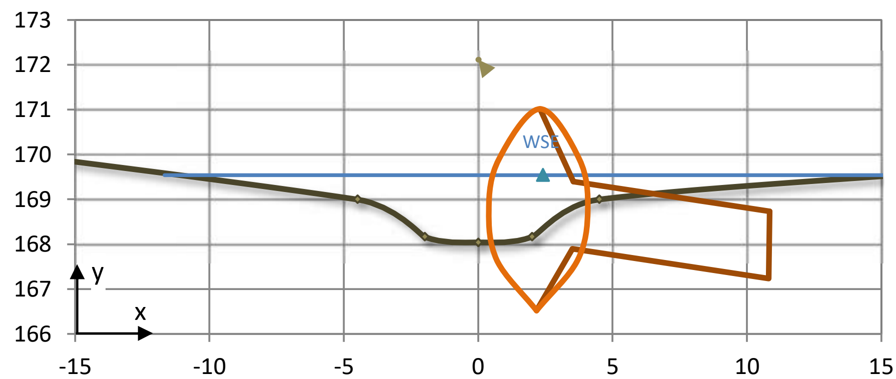
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+38	Rootwad	Right bank	Outside	26+38	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Stacked	A2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

Proposed Cross-Section and Structure Geometry (Looking D/S)

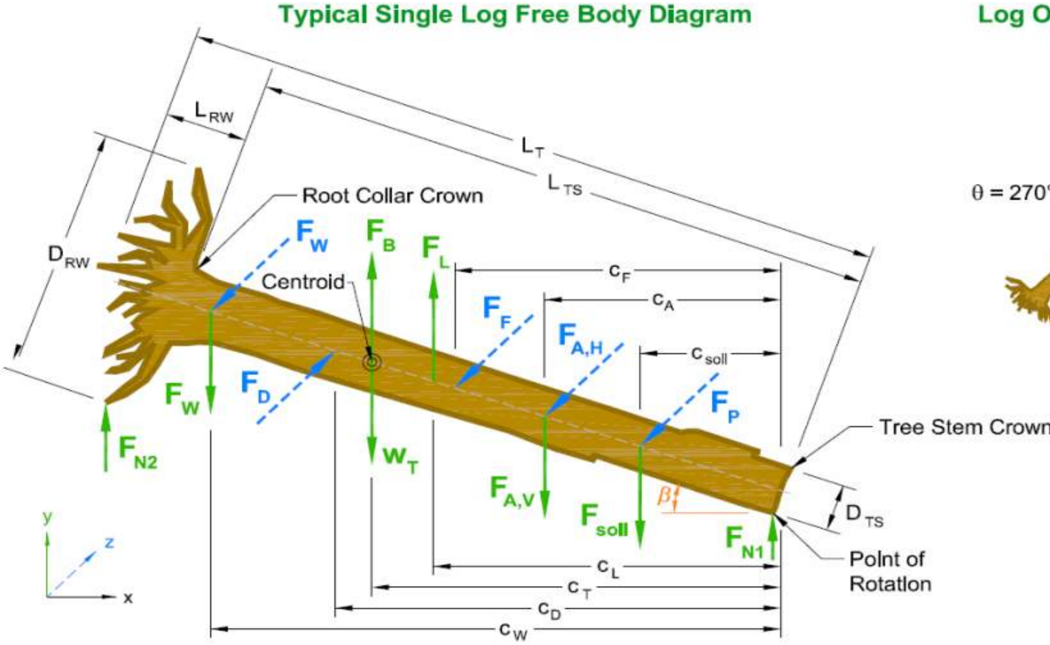


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

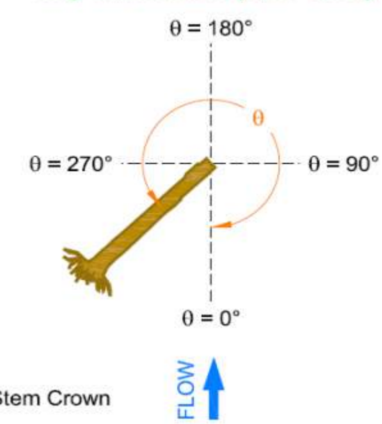
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	215.0	-3.0	Root collar: Bottom	3.50	167.90	166.52	171.01	7.56

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	7.07	0.55	0.28

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	2.7	2.7	96	0
↓WS↑Thw	16.4	7.7	24.1	843	1,505
↓Thalweg	6.1	3.3	9.5	369	590
Total	22.5	13.8	36.3	1,307	2,095

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,095	↑
F_L (lbf)	0	
W_T (lbf)	1,307	↓
F_{soil} (lbf)	204	↓
$F_{W,V}$ (lbf)	3,779	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	3,195	↓
FS_V	2.53	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	2.9	2.9	204
Total	0.0	2.9	2.9	204

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.53	1.21	1.10	0.08	5.58	2,900

Horizontal Force Balance

F_D (lbf)	2,900	→
F_P (lbf)	449	←
F_F (lbf)	2,556	←
$F_{W,H}$ (lbf)	1,995	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,101	←
FS_H	1.72	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	273
Bank	4.40	449	15.00	0.81	2,283
Total	-	449	17.00	-	2,556

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.3	0.0	11.1	9.3	3.5	7.5	4.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	51,591
M_r (lbf)	121,989
FS_M	2.36 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	
C1	Above	Gravity	12.0	-2,792		2,792	0	
C1	Behind	Gravity	12.0		-1,918	0	1,918	←
A1	Above	Gravity	7.0	-987		987	0	
A1	Behind	Gravity	7.0		-77	0	77	←

Sample Multi-Log Structure

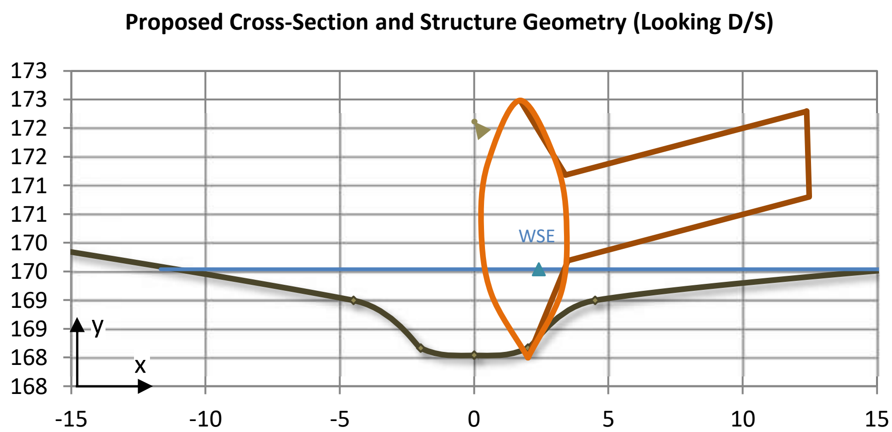
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+38	Rootwad	Right bank	Outside	26+38	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Key Log	A1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

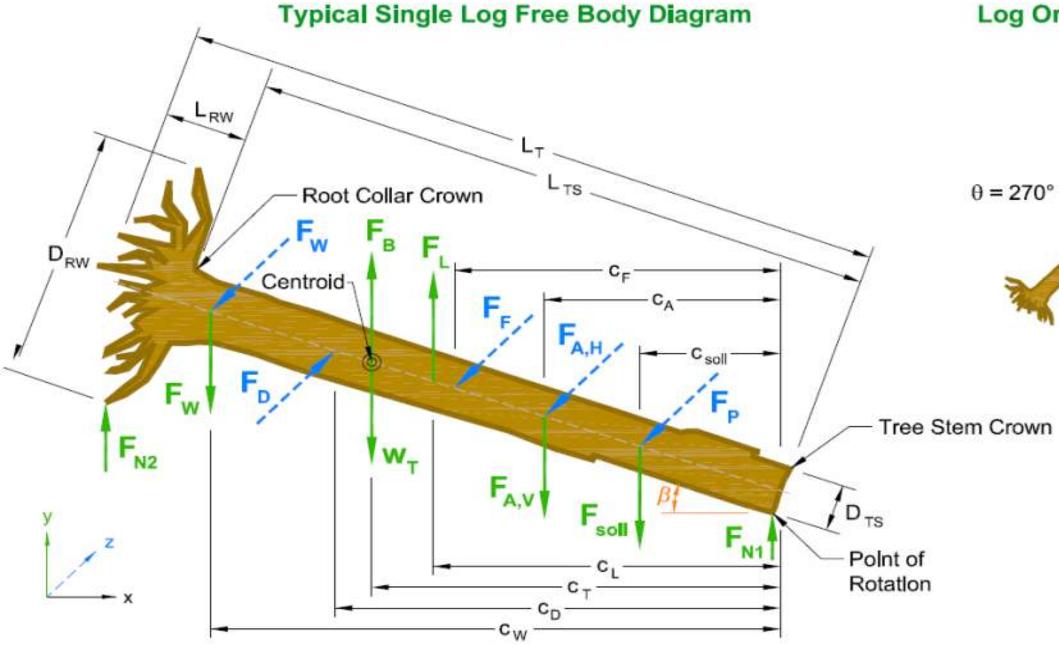


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

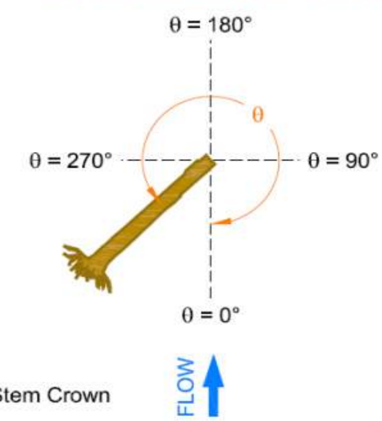
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	5.0	Rootwad: Bottom	2.00	168.00	168.00	172.48	3.51

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	22.5	10.8	33.3	1,164	0
↓WS↑Thw	0.0	3.0	3.0	105	188
↓Thalweg	0.0	0.0	0.0	0	0
Total	22.5	13.8	36.3	1,269	188

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	188	↑
F_L (lbf)	0	
W_T (lbf)	1,269	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,081	↓
FS_V	6.76	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.25	1.21	1.10	0.00	1.96	472

Horizontal Force Balance

F_D (lbf)	472	→
F_P (lbf)	0	
F_F (lbf)	785	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	313	←
FS_H	1.66	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	785
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	785

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	14.8	9.4	0.0	15.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	1,163
M_r (lbf)	7,139
FS_M	6.14 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{Wl} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
C1			12.0	-2,792		0	0
C1			12.0		-1,918	0	0
						0	0
						0	0

Sample Multi-Log Structure

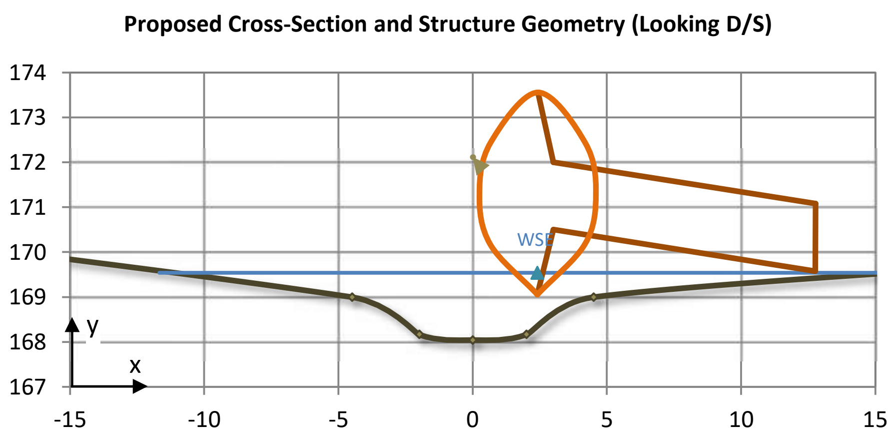
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+38	Rootwad	Left bank	Outside	26+38	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Stacked	C1

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

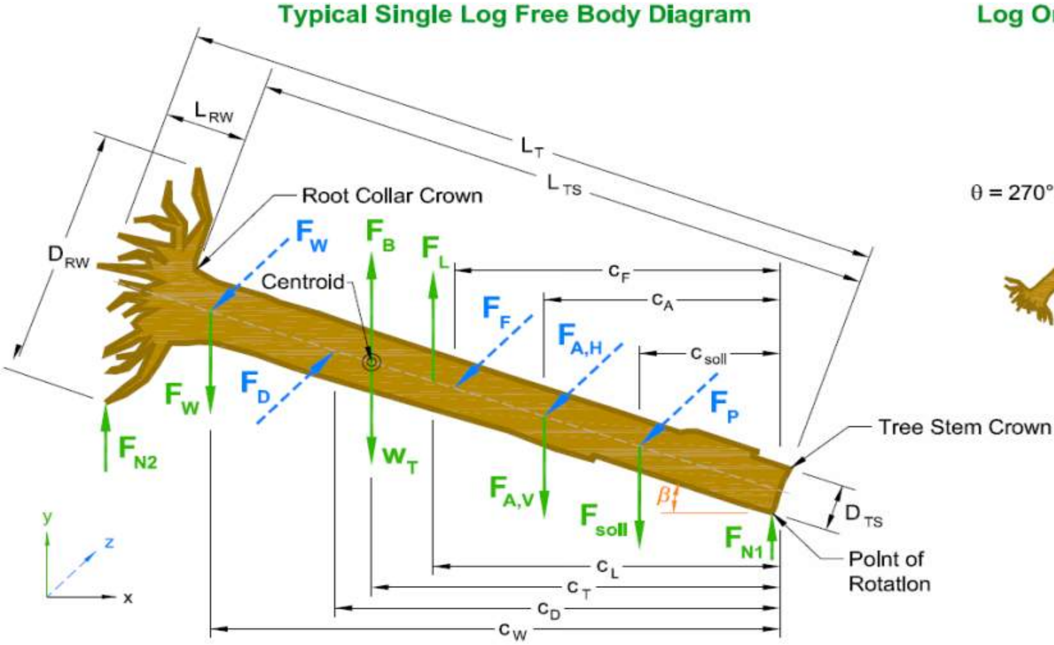


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	40.0	1.50	2.25	4.50	34.9	39.0

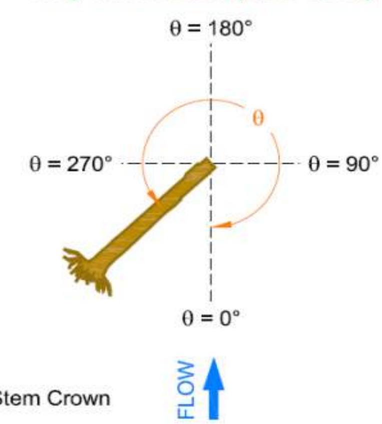
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	345.0	-1.4	Root collar: Bottom	3.00	170.50	169.06	173.55	0.89

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	66.7	13.6	80.3	2,805	0
↓WS↑Thw	0.0	0.2	0.2	8	14
↓Thalweg	0.0	0.0	0.0	0	0
Total	66.7	13.8	80.5	2,813	14

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	14	↑
F_L (lbf)	0	
W_T (lbf)	2,813	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,799	↓
FS_V	204.38	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.06	1.21	1.10	0.00	1.25	77

Horizontal Force Balance

F_D (lbf)	77	→
F_P (lbf)	0	
F_F (lbf)	2,034	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,957	←
FS_H	26.43	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	2,034
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	2,034

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.4	0.0	40.0	22.4	0.0	40.0	0.0
*Distances are from the stem tip			Point of Rotation:		Rootwad	

Moment Force Balance

M_d (lbf)	243	↻
M_r (lbf)	49,605	↺
FS_M	204.38	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
C1			12.0	-2,792		0	0
C1			12.0		-1,918	0	0
						0	0
						0	0

Sample Multi-Log Structure
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

Average Return Interval (ARI) of Design Discharge: 100yr yr

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
26+41	26+41	165	1.50	6.00	9.0	14	40

Sample Multi-Log Structure
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
26+41	26+41	15.49	Medium gravel	5	122.2	76.1	36

Source: Compiled from Julien (2010) and Shen and Julien (1993); soil classes from NRCS Table TS14E–2 Soil classification

[1] γ_{bed} (kg/m^3) = 1,600 + 300 log D_{50} (mm) (from Julien 2010)

1 kg/m^3 = 0.062 1 lb/ft^3

Sample Multi-Log Structure
Bank Soil Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
26+41	26+41	**Gravel/sand**	5	111.7	69.5	39

Sample Multi-Log Structure
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: **West Coast**

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Douglas-fir, Interior west**		34.9	39.0
Tree Type #2:				

[1] **Air-dried unit weight,** γ_{Td} = Average unit weight of wood after exposure to air on a 12% moisture content volume basis. Air-dried unit weight is used in the force balance calculations for the portion of wood that is above the proposed thalweg elevation (assuming unsaturated conditions).

[2] **Green unit weight,** γ_{Tgr} = Average unit weight of freshly sawn wood when the cell walls are completely saturated with water. Green unit weight is used in the force balance calculations as a conservative estimate of the unit weight for the portion of wood that is below the proposed thalweg elevation (assuming saturated conditions). For comparison, Thevenet, Citterio, & Piegay (1998) determined wood unit weight typically increases by more than 100% after less than 24 hours exposure to water.

Source for timber unit weights:

U.S. Department of Agriculture, U.S. Forest Service. (2009) Specific Gravity and Other Properties of Wood and Bark for 156 Tree Species Found in North America. Research Note NRS-38. Table 1A.

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

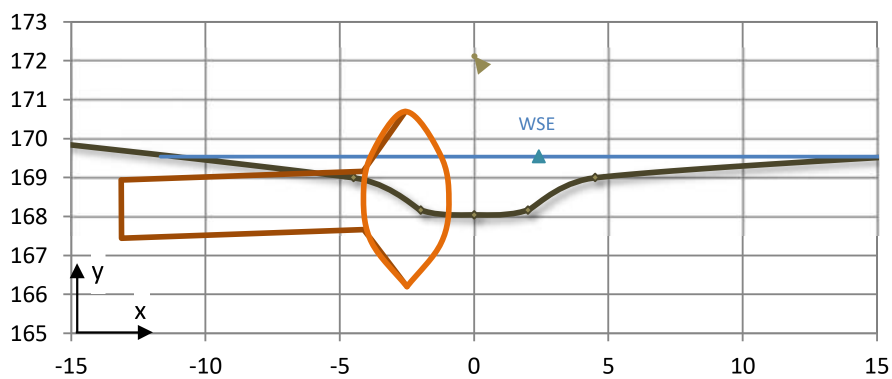
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+41	Rootwad	Left bank	Outside	26+41	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Key Log	A3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

Proposed Cross-Section and Structure Geometry (Looking D/S)

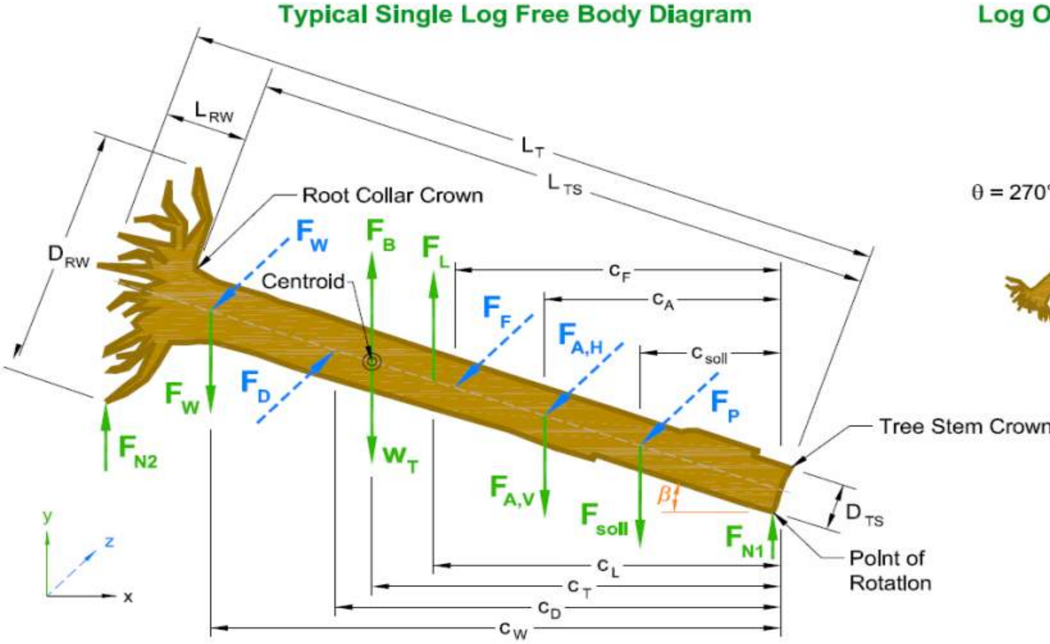


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

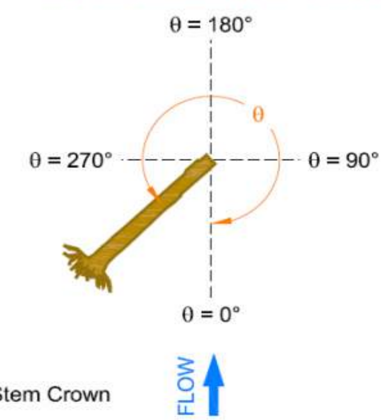
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	-1.0	Rootwad: Bottom	-2.50	166.20	166.20	170.70	5.68

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	10.05	0.71	0.36

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	1.7	1.7	58	0
↓WS↑Thw	16.1	7.3	23.5	820	1,464
↓Thalweg	6.4	4.8	11.2	437	699
Total	22.5	13.8	36.3	1,314	2,163

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,163	↑
F_L (lbf)	0	
W_T (lbf)	1,314	↓
F_{soil} (lbf)	381	↓
$F_{W,V}$ (lbf)	3,062	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,595	↓
FS_V	2.20	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.2	5.2	5.4	381
Total	0.2	5.2	5.4	381

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.40	1.21	1.12	0.08	3.40	1,325

Horizontal Force Balance

F_D (lbf)	1,325	→
F_P (lbf)	838	←
F_F (lbf)	2,076	←
$F_{W,H}$ (lbf)	1,175	←
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,764	←
FS_H	3.09	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	222
Bank	4.40	838	15.00	0.81	1,854
Total	-	838	17.00	-	2,076

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	0.0	12.6	9.4	5.0	7.5	6.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	36,901
M_r (lbf)	97,228
FS_M	2.63 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Applied Forces from other Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	$F_{W,V}$ (lbf)		$F_{W,H}$ (lbf)	
A4	Above	Gravity	10.0	-3,062		3,062	↓	0	
A4	Behind	Gravity	10.0		-1,175	0		1,175	←
						0		0	
						0		0	

Sample Multi-Log Structure

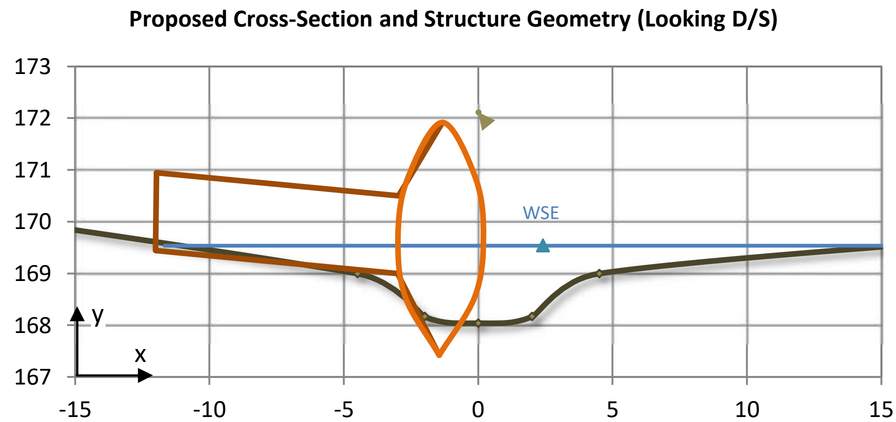
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+41	Rootwad	Left bank	Outside	26+41	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Stacked	A4

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

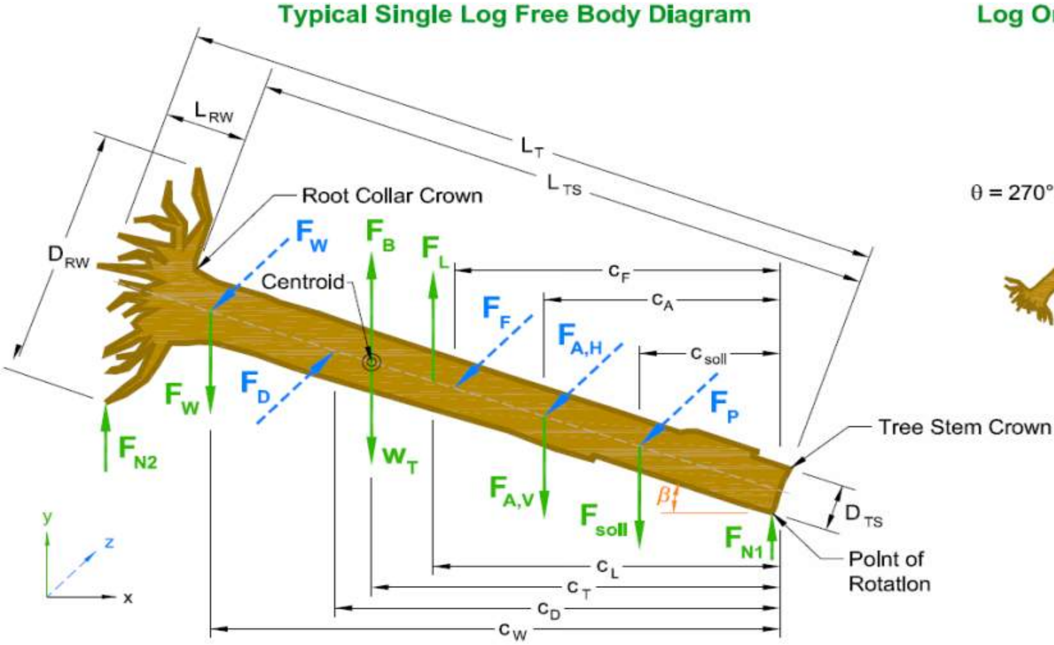


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	15.0	1.50	2.25	4.50	34.9	39.0

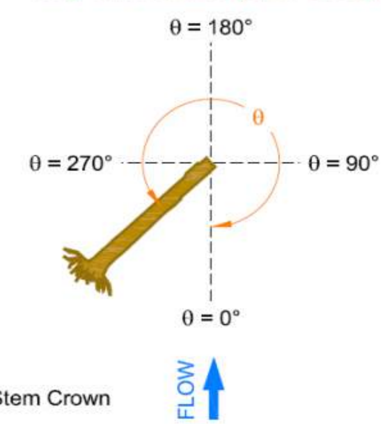
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	135.0	2.0	Root collar: Bottom	-3.00	169.00	167.42	171.92	7.81

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	19.1	7.8	26.8	937	0
↓WS↑Thw	3.5	5.7	9.1	319	570
↓Thalweg	0.0	0.4	0.4	14	22
Total	22.5	13.8	36.3	1,270	593

Lift Force

C_{LT}	0.16
F_L (lbf)	88

Vertical Force Balance

F_B (lbf)	593	↑
F_L (lbf)	88	↑
W_T (lbf)	1,270	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	2,813	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	3,402	↓
FS_V	6.00	✓

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.55	1.21	0.81	0.00	4.15	2,222

Horizontal Force Balance

F_D (lbf)	2,222	→
F_P (lbf)	0	
F_F (lbf)	2,687	←
$F_{W,H}$ (lbf)	2,401	←
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,866	←
FS_H	2.29	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	593
Bank	4.40	0	6.34	0.81	2,094
Total	-	0	8.34	-	2,687

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.4	10.1	7.5	9.4	0.0	3.2	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	20,428
M_r (lbf)	131,389
FS_M	6.43 ✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)	Applied Forces from other Logs: $F_{W,V}$ (lbf)		Applied Forces from other Logs: $F_{W,H}$ (lbf)	
C2	Above	Gravity	5.0	-2,813		2,813	↓	0	
C2	Behind	Gravity	5.0		-2,401	0		2,401	←
						0		0	
						0		0	

Sample Multi-Log Structure

Spreadsheet developed by
Michael Rafferty, P.E.

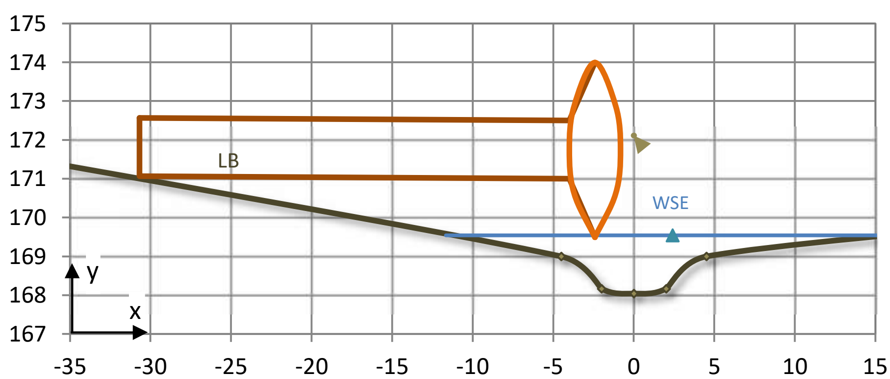
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
26+41	Rootwad	Left bank	Outside	26+41	1.50	4.46	8.41

Multi-Log Structures	Layer	
	Stacked	C2

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-45.68	172.11
Top LB	-4.50	169.00
Toe LB	-2.00	168.16
Thalweg	0.00	168.04
Toe RB	2.00	168.16
Top RB	4.50	169.00
Fldpln RB	25.57	169.95

Proposed Cross-Section and Structure Geometry (Looking D/S)

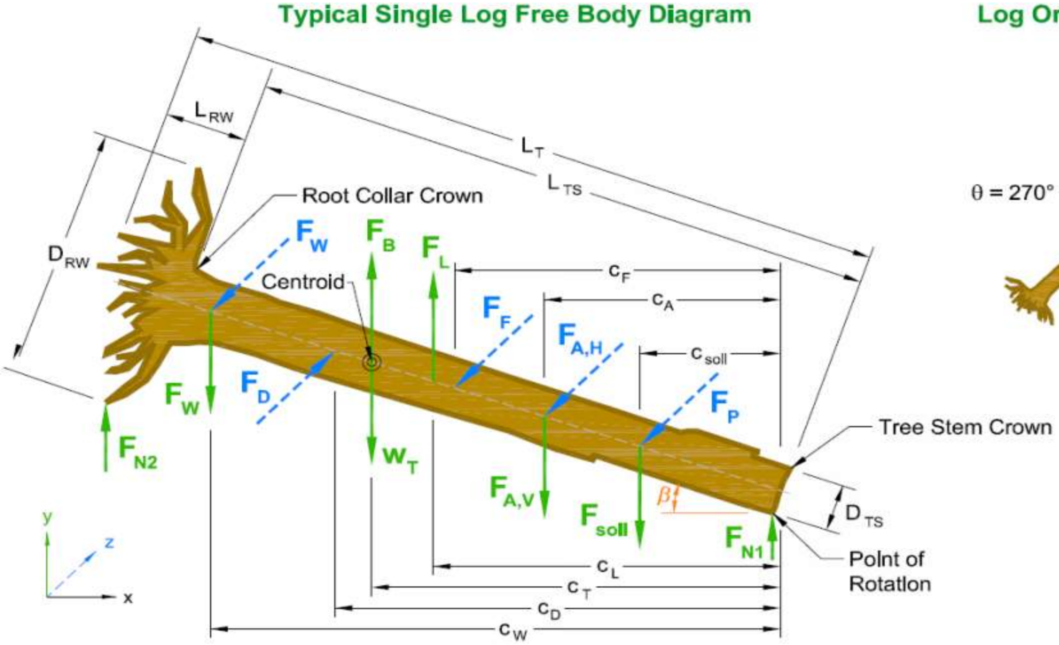


Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Interior west	Yes	40.0	1.50	2.25	4.50	34.9	39.0

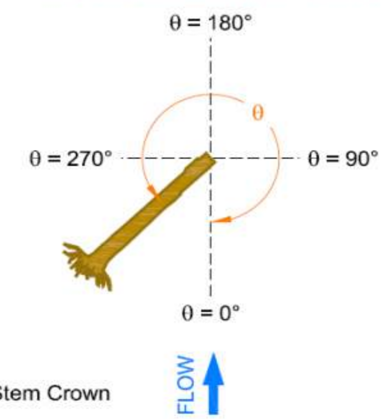
Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	0.1	Root collar: Bottom	-4.00	171.00	169.50	174.00	0.02

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Medium gravel	122.2	76.1	36.0	5	0.00	0.00	0.00
Bank	Gravel/sand	111.7	69.5	39.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	66.7	13.8	80.5	2,813	0
↓WS↑Thw	0.0	0.0	0.0	0	0
↓Thalweg	0.0	0.0	0.0	0	0
Total	66.7	13.8	80.5	2,813	0

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	0	↑
F_L (lbf)	0	
W_T (lbf)	2,813	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,813	↓
FS_V	28,029.68	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.0	0.0	0.0	0
Total	0.0	0.0	0.0	0

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.00	1.21	1.12	0.00	1.12	1

Horizontal Force Balance

F_D (lbf)	1	→
F_P (lbf)	0	
F_F (lbf)	2,044	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,042	←
FS_H	1,457.94	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	3.85	0	2.00	0.73	2,044
Bank	4.40	0	0.00	0.81	0
Total	-	0	2.00	-	2,044

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
22.4	0.0	0.0	22.4	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	58	
M_r (lbf)	243,867	
FS_M	4,216.52	✓

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft^3)	V_{Awet} (ft^3)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)
			0	0

Mechanical Anchors

Type	c_{Am} (ft)	Soils	F_{Am} (lbf)
			0
			0

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft^3)	$V_{r,wet}$ (ft^3)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

Interaction Forces with Adjacent Logs

Log ID	Position	Link	c_{WI} (ft)	$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)

Applied Forces from other Logs

$F_{W,V}$ (lbf)	$F_{W,H}$ (lbf)
0	0
0	0
0	0
0	0

Appendix J
Climate Resilience Output Report

Future Projections for Climate-Adapted Culvert Design

Project Name: I-405/NE 132nd St. IC

Stream Name: Juanita Creek Tributary

Drainage Area: 444 ac

Projected mean percent change in bankfull flow:

2040s: 10.4%

2080s: 13.5%

Projected mean percent change in bankfull width:

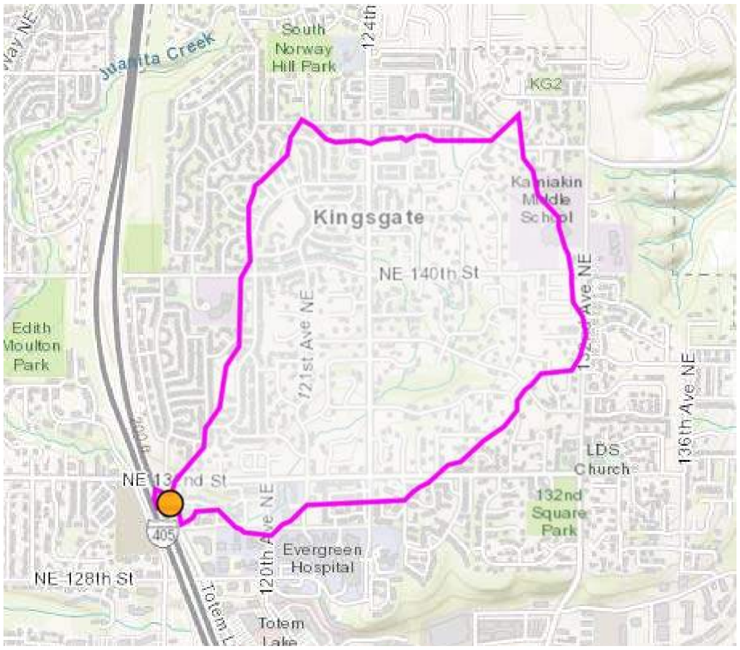
2040s: 5.1%

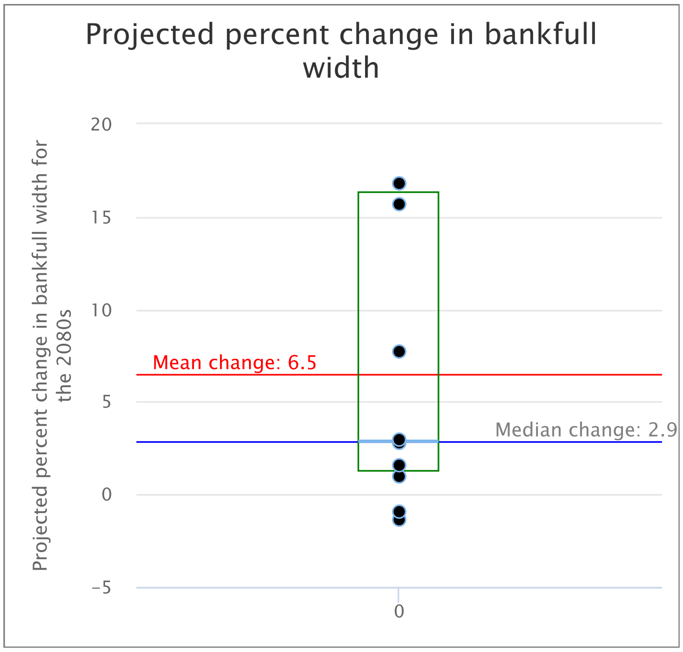
2080s: 6.5%

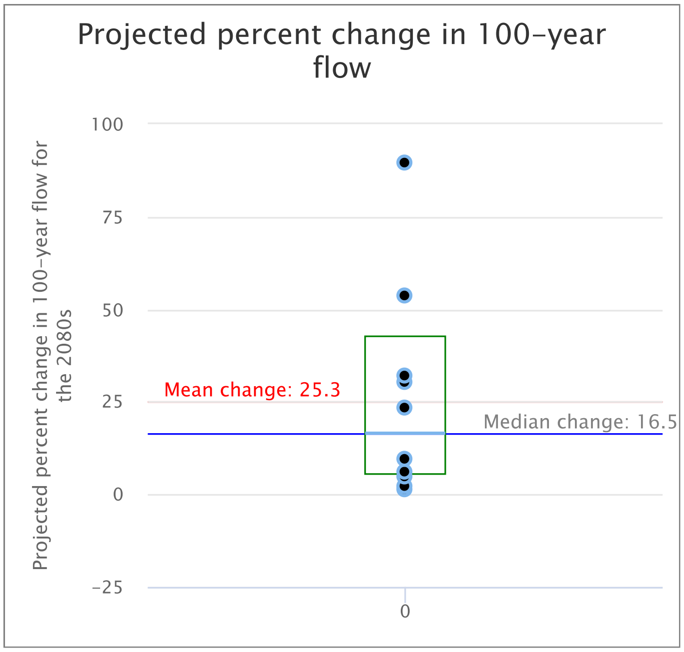
Projected mean percent change in 100-year flood:

2040s: 14.6%

2080s: 25.3%







Black dots are projections from 10 separate models