I-5 MP 211.7 Secret Creek (WDFW ID 990623): Preliminary Hydraulic Design Report

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Southbound I-5 Secret Creek – Remove Fish Barrier
MP 211.7 Secret Creek
Preliminary Hydraulic Design Report
December 2021

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Acronyms and Abbreviations

ADA – Americans with Disabilities Act

BFW – Bankfull width

cfs – cubic feet per second

Ecology – Washington State Department of Ecology

EPA – Environmental Protection Agency

ESO – Environmental Services Office

FEMA – Federal Emergency Management Agency

FIRM – Flood Insurance Rate Maps

FIS – Flood Insurance Study

FPW – Flood-prone width

FUR – Floodplain utilization ratio

ft – feet

ft/s – feet per second

HPSF – Hydrological Simulation Program

I-5 – Interstate 5

LWM – large woody material

MP – Milepost

MRI – Mean Recurrence Interval

MWM – Mobile woody material

NB – Northbound

NB I-5 offramp – Northbound Interstate 5 offramp

NEP – National Estuary Protection

NRCS – National Resource Conservation Service

OEO – Office of Equal Opportunity

SB – Southbound

SCD – Snohomish Conservation District

SR – State Route

SWIFD – Statewide integrated fish distribution

TMDL – Total daily maximum load

USGS – United States Geological Survey

WCDGs – Water Crossing Design Guidelines

WDFW – Washington Department of Fish and Wildlife

WDNR – Washington Department of Natural Resources

WRIAs – Water Resource Inventory Areas

WSCC – Washington State Conservation Commission

WSDOT – Washington State Department of Transportation

WWTIT – Western Washington Treaty Indian Tribes

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1.0 Introduction and Purpose

The Washington State Department of Transportation (WSDOT) proposes a project to provide fish passage at the Southbound (SB) Interstate 5 (I-5) crossing of Secret Creek (Site ID 990623) at Milepost (MP) 211.7. This crossing also conveys Secret Creek beneath Old Highway 99 (also known as Pacific Highway). The purpose of this project is to comply with a federal injunction requiring the state of Washington to correct fish barriers in Water Resource Inventory Areas (WRIAs) 1 through 23 (*United States et al. vs. Washington et al. No. C70-9213 Subproceeding No. 01-1*, dated March 29, 2013). The existing structure on I-5 has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and the WSDOT Environmental Services Office (ESO) (Site ID 990623) due to high velocity, resulting in a fish pass-ability of 67 percent. Once corrected, the potential fish habitat gain is 7,376 meters. This report documents the site and reference reach assessment, geomorphic analysis, hydrologic and hydraulic analyses, fish passage design, streambed material design, and climate change analysis Parametrix performed in coordination with WSDOT Headquarters Hydraulics and the WSDOT Project Office located in Mount Vernon, Washington.

In accordance with the injunction and in order of preference, fish passage should be achieved by (a) avoiding the necessity for the roadway to cross the stream, (b) using a full span bridge, or (c) using the stream simulation methodology. Avoidance of the stream crossing was determined not viable given the location of the highway and the need to maintain this critical transportation corridor. WSDOT proposes to replace the existing crossing structure with a structure designed using the unconfined bridge design methodology. This method was selected primarily because the floodplain utilization ratio is greater than 3.0, and the proposed replacement structure could be up to 368 feet long.

The structure is in Snohomish County 4 miles north of Arlington, Washington, in WRIA 5. The highway runs northwest to southeast at this location. The inlet of the existing SB I-5 culvert is about 0.10 miles upstream from the confluence with a minor unnamed tributary that discharges to Secret Creek through an unknown size culvert. A further 0.5 miles downstream, Secret Creek joins Pilchuck Creek. Secret Creek generally flows northwest to southeast, beginning approximately 3 miles upstream of the NB I-5 crossing. (Figure 1.1, Vicinity Map.)

The proposed project will replace the existing 7-foot-tall, 5-foot-wide, 366-foot-long concrete box culvert with minimum 40-foot span structures to improve fish passage while providing a safe roadway for the traveling public. The proposed design also includes the crossing of Old Highway 99 due to the proximity to SB I-5 and the depth of Secret Creek below both roadway surfaces. These proposed crossings are designed to meet the requirements of the federal injunction using the bridge design methodology outlined in the 2013 Water Crossing Design Guidelines (WCDGs) (Barnard et al. 2013). Preliminary Hydraulic Design reports are being developed concurrently for both the Northbound (NB) I-5 (999622) and the Southbound (SB) I-5 (990623) crossings of Secret Creek. Due to the proximity of these two barriers, portions of this report will include analyses of both barriers.

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Source: WA DNR, ESRI, WSDOT, Snohomish County

Figure 1.1 Vicinity Map

I-5 Secret Creek

Secret Creek Culverts at I-5

Watercourse

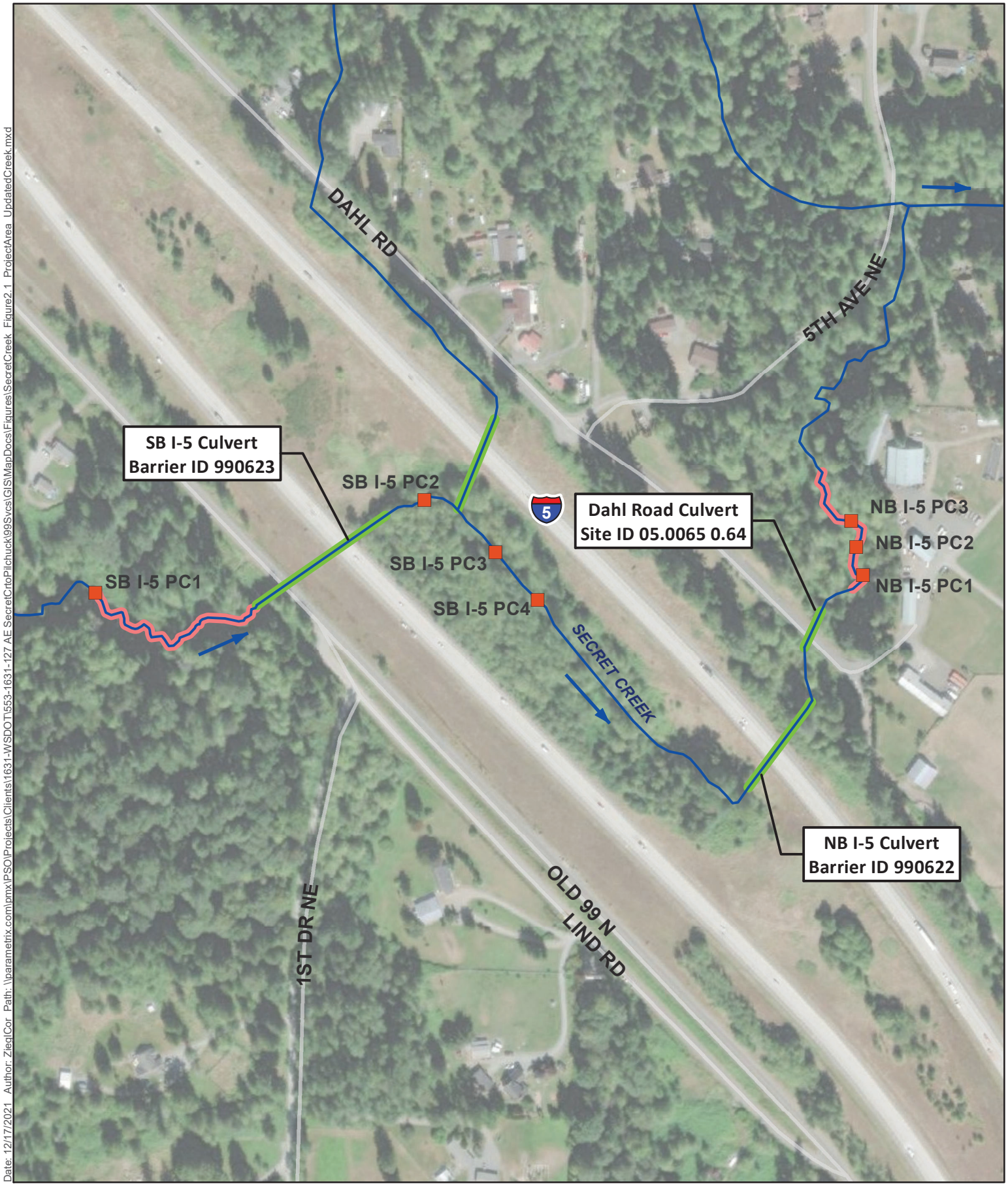
0 750 1,500 3,000 Feet

Snohomish County, WA

2.0 Site Assessment

The primary site investigation was conducted on July 30, 2019, by Parametrix surface water engineers and a fisheries biologist. The team recorded site observations and measurements at the crossings 470 feet downstream of the SB I-5 culvert outlet and approximately 515 feet upstream of the SB I-5 culvert inlet. Data collection included site photographs, bankfull width (BFW) measurements, record of large woody material (LWM) in the channel and recruitment potential, pebble counts, fish habitat assessment, record of pool and riffle dimensions if applicable, record of rocks and other key features, and records of overbank vegetation and soil types. To aid in recording the location of observations, the team extended a tape measure along the stream thalweg upstream and downstream of both barriers. Figure 2.1 displays the extents of the site investigation, including locations of pebble counts taken and potential reference reaches identified. A WSDOT Field Report is available in Appendix A.

A stakeholder site visit was performed on August 27, 2019, with representatives from WSDOT, the Stillaguamish Tribe, the Tulalip Tribe, the Skagit River System Cooperative, and Parametrix. The purpose of this site visit was for stakeholders to corroborate the BFW measurements taken during the previous site visit by Parametrix. No agreement with attendees was made on BFW, as additional analysis was needed.



Date: 12/17/2021 Author: ZieglCor Path: \\parametrix.com\pmx\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\GIS\MapDocs\Figures\SecretCreek Figure2.1 ProjectArea UpdatedCreek.mxd

Source: ESRI, WSDOT, StreamStats, WA DNR, Snohomish County

Figure 2.1 Project Area
Secret Creek I-5

Culvert
Reference Reach
Watercourse
Pebble Count Locations

0 125 250 500 Feet

Snohomish County, WA

The site assessment began at the culvert inlet (Figure 2.2). Distances in this reach were measured from the SB I-5 culvert inlet. The culvert is a 7-foot-tall by 5-foot-wide, 366-foot-long concrete box culvert at a 0.64 percent slope according to WSDOT survey. The WDFW Site Assessment (WDFW 2019) reports a culvert length of 386 feet. This report will recognize the surveyed length. There are no wingwalls or other structures at the culvert inlet. At 36 feet upstream, there is an 18-inch-diameter by 20-foot-long piece of LWM (Figure 2.3).

Figure 2.2. Culvert Inlet

Figure 2.3. 18-inch-diameter, 20-foot-long LWM at 36 feet Upstream

At 43 feet upstream, several pieces of woody material are jammed in-stream. The jam includes 4-inch-diameter, 8-foot-long piece of mobile woody material (MWM), an 18-inch-diameter by 12-foot-long piece of LWM, and a 6-inch-diameter by 15-foot-long piece of LWM (Figures 2.4 and 2.5).

Figure 2.4. Wood Pileup at 43 Feet Upstream, Looking Downstream

Figure 2.5. Wood Jam Looking Upstream

At 59 feet upstream, woody debris is present in-channel and channel spanning (Figure 2.6). The channel bottom consists of silty sand and fine gravel in this area, and the banks are overgrown with tall vegetation. A BFW measurement of 12.3 feet was taken at 90 feet upstream. At 95 feet upstream, the banks are overgrown, and they exhibit some undercutting (Figure 2.7).

Figure 2.6. LWM at 59 Feet Upstream

Figure 2.7. Vegetated Banks at 95 Feet Upstream, Some Bank Undercutting

At 124 feet upstream, multiple pieces of MWM are located within the main channel, and the banks exhibit undercutting greater than 1-foot into the bank. (Figure 2.8). At 154 feet upstream, a 40-inch-diameter by 60-foot-long LWM (cottonwood) spans the channel (Figure 2.9).

Figure 2.8. Bank Undercutting at 124 Feet Upstream

Figure 2.9. 40-inch-diameter by 60-foot-long LWM, 154 Feet Upstream

The channel bottom in this area is mucky with a clay/silt content (Figures 2.10 and 2.11).

Figure 2.10. Channel at 154 Feet Upstream

Figure 2.11. Bed Material at 154 Feet Upstream

At 167 feet upstream, there is a pool with an approximate 6-inch residual depth. From 167 to 180 feet upstream, there is a riffle section. There is a pool at 182 feet upstream with an approximate 1-foot residual depth. At 194 feet upstream, there is an 18-inch-diameter by 25-foot-long channel spanning piece of LWM. At 230 feet upstream there is a tree fall providing LWM to the channel. A BFW measurement of 11.8 feet was taken at 244 feet upstream. At 315 feet upstream, several stream meanders relatively shorter than others in the vicinity were observed. The banks in this area are dominated by reed canary grass and stinging nettle. Some lateral scour and bank undercutting occur in this area. MWM is prevalent in this area. Figure 2.12 shows the medium gravel bed material in this area. The stream exhibits an alternating pool and riffle sequence in this area, with residual pool depths between 6 and 24 inches. Figure 2.13 shows the sediment taken from the bottom of one of these pools.

Figure 2.12. Medium Gravel Bed Material

Figure 2.13. Sediment from Bottom of Pool

At 335 feet upstream, there are two 12-inch-diameter pieces of LWM. At 384 feet upstream, several large cobbles between 4 to 6-inches in diameter were noted. At 419 feet upstream, a BFW measurement of 9.3 feet was taken. At 469 feet upstream, a BFW measurement of 9.2 feet was taken. At 514 feet upstream, a BFW measurement of 16.0 feet was taken. Pebble Count 1 was also taken at 514 feet upstream.

The team then began the assessment of Secret Creek downstream of the SB I-5 culvert. Figure 2.14 shows the culvert outlet and associated wingwalls, which have a span opening of 9 feet, 7-inches. Sediment was observed at the culvert outlet ranging between 0.5 and 5 millimeters (0.02 and 0.2 inches). A BFW of 11.2 feet was taken at 28 feet downstream. A 1.4-foot-diameter by 9-foot-long piece of LWM was observed at 42 feet downstream. At 44 feet downstream, a 2-foot by 4-foot boulder was observed. At 47 feet downstream two pieces of LWM were noted; a 24-inch-diameter by 29-foot-long channel-spanning log and a 30-inch-diameter by 30-foot-long log in the channel (Figure 2.15).

Figure 2.14. SB I-5 Culvert Outlet

Figure 2.15. LWM at 47 Feet Downstream, Looking Downstream

Figure 2.16 shows this LWM looking upstream. Pebble Count 2 was taken at 82 feet downstream, shown in Figure 2.17.

Figure 2.16. LWM at 47 Feet Downstream, Looking Upstream

Figure 2.17. Pebble Count 2 at 82 Feet Downstream

A riffle section is present between 82 and 95 feet downstream. A BFW measurement of 15 feet was taken at 93 feet downstream. A large pool is present between 95 and 121 feet downstream. Between 121 and 148 feet downstream is a riffle section with cobbles present (Figures 2.18 and 2.19).

Figure 2.18. Riffle Section, 95 to 121 Feet Downstream

Figure 2.19. Closeup of Bed Material

From 128 to 174 feet downstream, boulders approximately 3 feet in diameter provide armoring along the left bank (Figure 2.20). From 148 to 174 feet downstream is a pool section (Figure 2.21).

Figure 2.20. Boulder Armoring on Left Bank

Figure 2.21. Pool Section, 148 to 174 Feet Downstream

A 6-inch-diameter by 12-foot-long piece of LWM is present at 187 feet downstream (Figure 2.22). Approximately 18-inch boulders provide armoring on the right bank from 197 to 217 feet downstream. An 8- to 12-inch-diameter willow log was noted at 236 feet downstream. A 6- to 10-inch-wide by 30-foot-long channel spanning alder was observed at 248 feet downstream. Between 238 and 249 feet downstream is a riffle section. A 10-inch-diameter, 15-foot-long channel spanning log is present at 259 feet downstream (Figure 2.23).

Figure 2.22. 6-inch-diameter by 12-foot-long LWM at 187 Feet Downstream

Figure 2.23. 10-inch-long by 15-foot-long Channel Spanning LWM at 259 Feet Downstream

At 267 feet downstream is a 6-inch-diameter by 15-foot-long LWM, and at 269 feet downstream is a 4-inch-diameter by 15-foot-long log. Pebble Count 3 was performed at 301 feet downstream (Figure 2.24). Between 323 and 352 feet downstream is a pool with boulder armoring on both banks (Figure 2.25).

Figure 2.24. Pebble Count 3 at 301 Feet Downstream

Figure 2.25. Pool Section, Boulder Armoring on Left and Right Banks

Another pool section was encountered from 358 to 390 feet downstream (Figure 2.26). At 344 feet downstream is a 16-inch-diameter by 60-foot-long channel-spanning cottonwood log. There was evidence of beaver activity at this location. At 358 feet downstream is a 16-inch-diameter by 16-foot-long alder log. Pebble Count 4 was performed at 469 feet downstream (Figure 2.27).

Figure 2.26. Pool at 358 to 390 Feet Downstream

Figure 2.27. Pebble Count 4 Location, 469 Feet Downstream

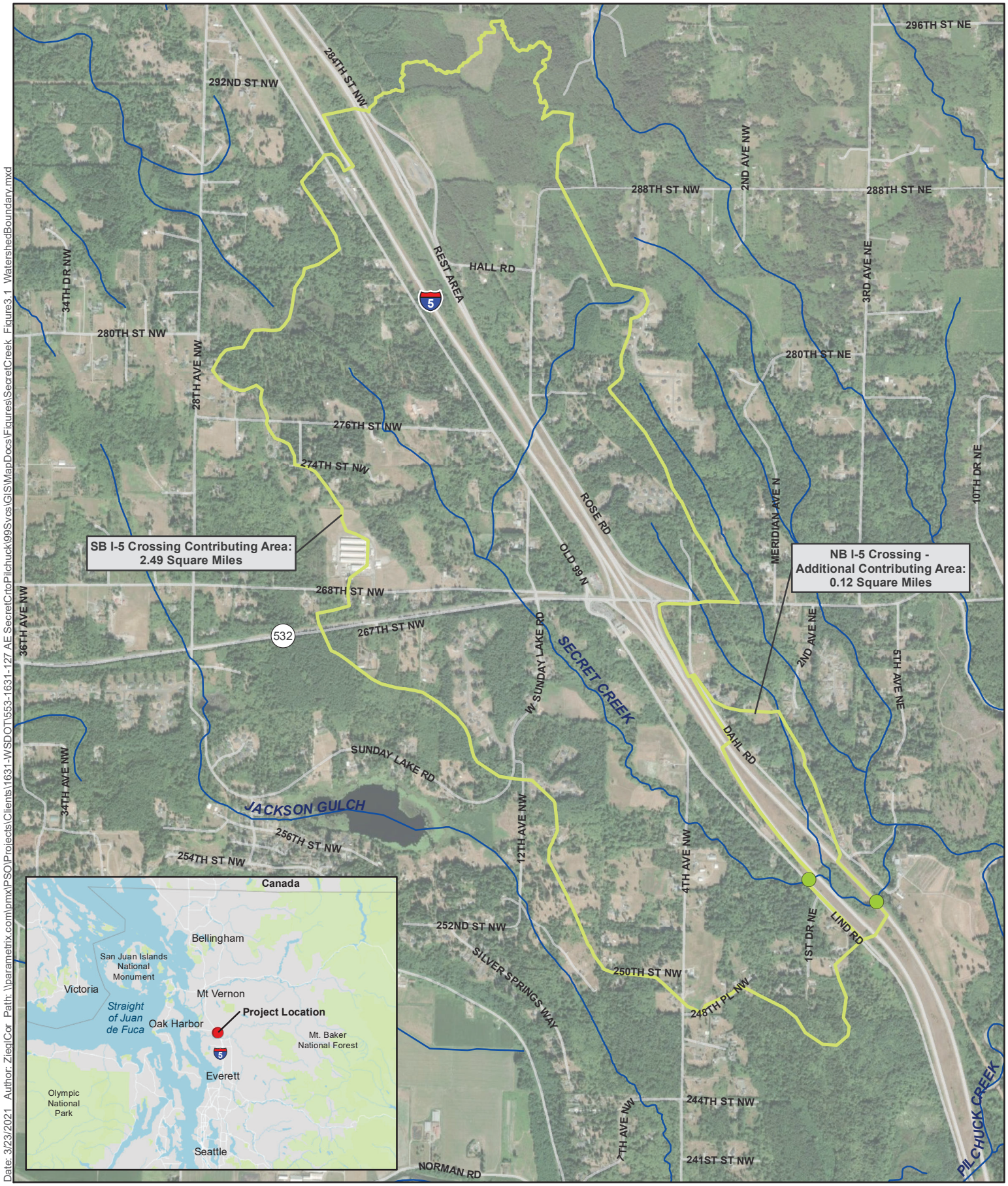
3.0 Watershed Assessment

3.1 Watershed & Landcover

The contributing watershed basin to the SB I-5 crossing of Secret Creek was first obtained using the United States Geological Survey (USGS) StreamStats delineation tool. The delineations were then verified using 2017 LiDAR data captured by Quantum Spatial, provided by the Washington Department of Natural Resources (WDNR) (Quantum Spatial, 2017). The drainage basin comprises an area of 2.49 square miles or 1,596 acres. Downstream of the SB I-5 crossing and unassociated with the hydrology at the crossing documented in this report is an unnamed tributary with a 0.12 square mile contributing area that collects runoff from I-5 and along the east side of NB I-5. The unnamed tributary crosses NB I-5 and drains into Secret Creek via a 3-foot-diameter corrugated steel culvert pipe (Site ID 996069).

The highest elevation in the watershed reaches approximately 495 feet, and the elevation of the channel at the inlet to the NB I-5 crossing is approximately 124 feet (NAVD88). The basin receives a mean annual precipitation of 36.8 inches as obtained from the National Hydrography Dataset and reported by USGS StreamStats, while the PRISM Climate Group reports a mean annual precipitation of 46.2 inches obtained from data between 1981 and 2010.

Secret Creek begins in the northwest portion of the watershed, approximately 3 miles from the I-5 crossings. The creek generally flows northwest to southeast beginning 0.25 mile north of 276th St NW. The watershed landcover in the upper western portion of the watershed consists primarily of forest and pasture, while the land cover in the eastern portion of the watershed has a greater degree of developed impervious area from I-5. Land cover types were manually delineated in GIS using ESRI World Imagery (ESRI 2019). The combined watershed consists of forest (49.9 percent), grass (35.9 percent), impervious area (9.6 percent), and wetland (4.6 percent). Figure 3.1 depicts the watershed boundary.



Date: 3/23/2021 Author: ZieglCor Path: \\parametrix.com\pmx\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\GIS\MapDocs\Figures\SecretCreek Figure3.1 WatershedBoundary.mxd

Source: Snohomish County, ESRI, WSDOT, StreamStats

Figure 3.1 Watershed Boundary

I-5 Secret Creek

Secret Creek Culverts at I-5

Watercourse

Secret Creek Watershed Boundary

0 750 1,500 3,000 Feet

Snohomish County, WA

According to Snohomish County zoning, the watershed is designated primarily as Rural 5-Acre (95.1 percent), which serves to maintain rural character in areas that lack urban services (Snohomish County 2020). The remainder consists of Rural Freeway Service (2.3 percent), Forestry (1.9 percent), and tribal land (0.7 percent).

3.2 Mapped Floodplains

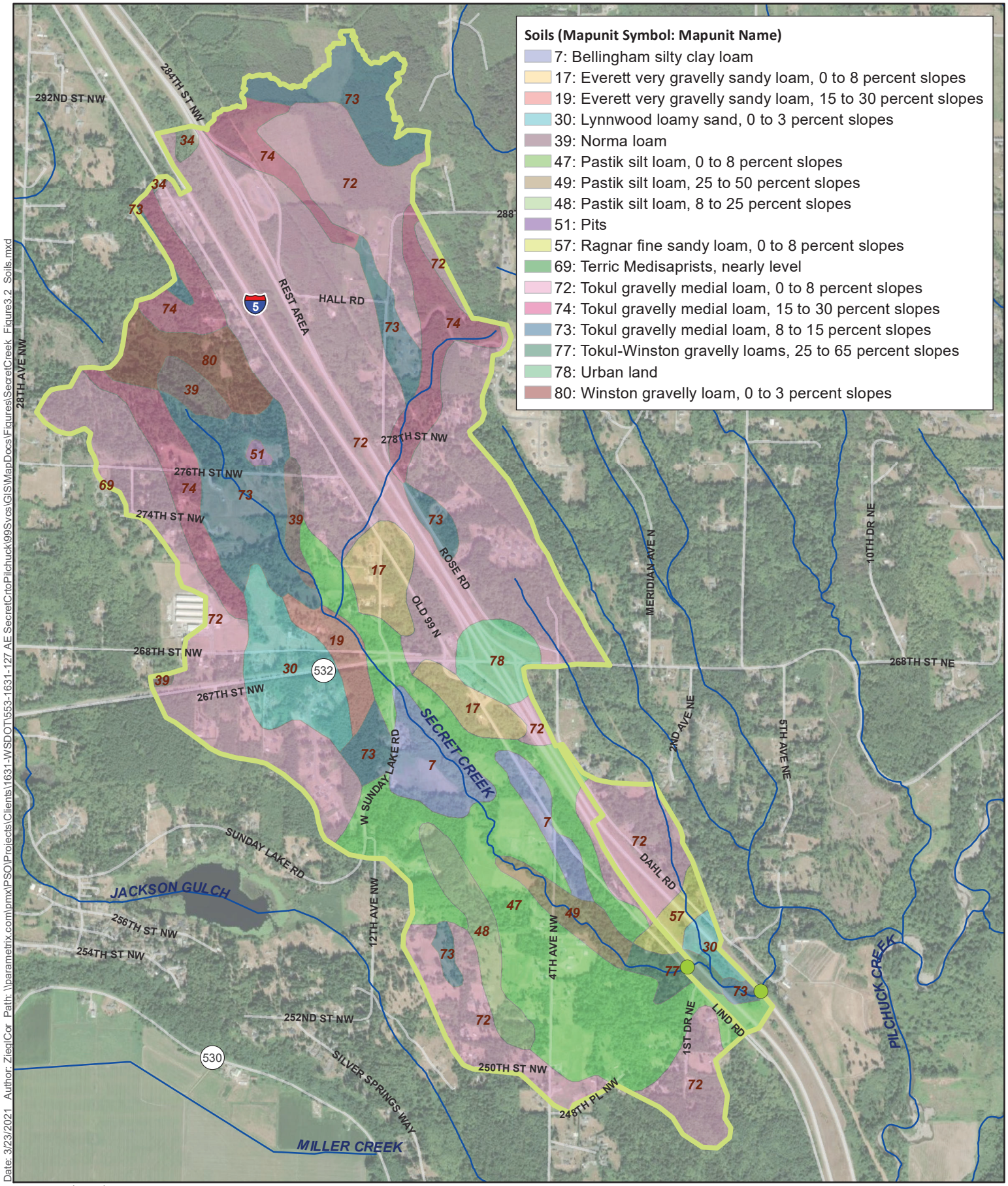
Flood Insurance Rate Maps (FIRM) showing floodplain mapping as established by the Federal Emergency Management Agency (FEMA) were reviewed for the project location. This project is not within a mapped floodplain.

The project is within an area identified as Zone X on the FIRM Number 53061C0380E (Appendix B). This zoning is associated with flood mapping of Pilchuck Creek and this indicates that the project area is determined to be outside of the 500-year floodplain of Pilchuck Creek (FEMA 1999).

3.3 Geology & Soils

The surficial geology of the Secret Creek watershed consists mainly of deposits from the Vashon Glaciation between 19,000 and 16,000 years before the present. Most of the watershed (78 percent) is underlain with Vashon Till (geologic unit Qvt) (Pessl et al. 1989). This material contains poorly sorted rock fragments that are firmly embedded in a matrix of finer components including silt, sand, and clay in variable amounts. This geologic unit is mainly found in the outer reaches of the watershed. The surficial geology of the stream corridor consists of advance outwash deposits from the Vashon glacier meltwater (geologic unit Qva). This material mainly consists of sand, gravel, silt, and clay, and it covers 13 percent of the watershed. The remaining 10 percent of the watershed is recessional-continental deposits (geologic unit Qvrc) consisting of sand, gravel, and silt.

The watershed-specific soils were identified using the National Resource Conservation Service (NRCS) Soil Survey Geographic Database. A graphic representation of the findings is presented in Figure 3.2. The watershed is mainly composed of Tokul Gravelly Medial Loam (63.1 percent) and Pastik Silt Loam (19.4 percent), with the remainder consisting of various sandy and silty loams (NRCS). Tokul Gravelly Medial Loam is prominent in the northern part of the watershed, and it resembles a dark brown gravelly loam with a depth to hardpan ranging from 20 to 40 inches. It is of moderately well drained class above the hardpan layer, and it has poor permeability through the hardpan. This soil has a moderate capacity for water storage and is classified in hydrologic soil group B. Pastik silt loam is prominent in the southern portion of the watershed, and it consists of ashy and regular silt loam. The silty loam is of poorly drained class, has a high capacity for water storage, and is categorized in hydrologic soil group C. Figure 3.2 depicts the watershed soil types.



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Source: Snohomish County, ESRI, WSDOT, SSURGO Soils Database, StreamStats

Secret Creek Culverts at I-5

Watercourse

Secret Creek Drainage Basin

0 750 1,500 3,000 Feet

Figure 3.2 Soils

I-5 Secret Creek

Snohomish County, WA

3.4 Geomorphology

3.4.1 Channel Geometry

The channel geometry of Secret Creek was evaluated upstream and downstream of the I-5 crossings using both the DNR-sourced LiDAR topography produced in 2017, as well as the surfaces created from the WSDOT and Parametrix site surveys. Two site surveys were performed, one for the NB I-5 crossing that Parametrix performed in November 2019 and one that WSDOT performed for the SB I-5 crossing in July 2019. Field observations recorded during the site visits on July 30, 2019, and March 20, 2020, were used to further evaluate the channel geometry. The channel profile, cross-section geometry, and planform are discussed in that order in the following section.

Upstream and downstream profile gradients were assessed using 2017 LiDAR data to provide an understanding of the overall longitudinal profile of the stream outside the vicinity of the I-5 crossings. The profile begins at the downstream confluence of Secret Creek and an unnamed tributary to Pilchuck Creek, and it ends at approximately 2,760 feet upstream of the inlet to the SB I-5 culvert inlet. The channel gradient is approximately 1.53 percent for 1,150 feet between the downstream confluence and Dahl Road. The channel gradient is approximately 2.85 percent for 102 feet between Dahl Road and NB I-5. The reach between Dahl Road and NB I-5 has been retrofitted with a series of five log grade control structures. The channel gradient is approximately 1.25 percent for the 1,150 feet between NB and SB I-5. The channel gradient is approximately 1.11 percent for the 2,760 feet upstream of the SB I-5 culvert. Figure 3.3 depicts the LiDAR longitudinal profile.

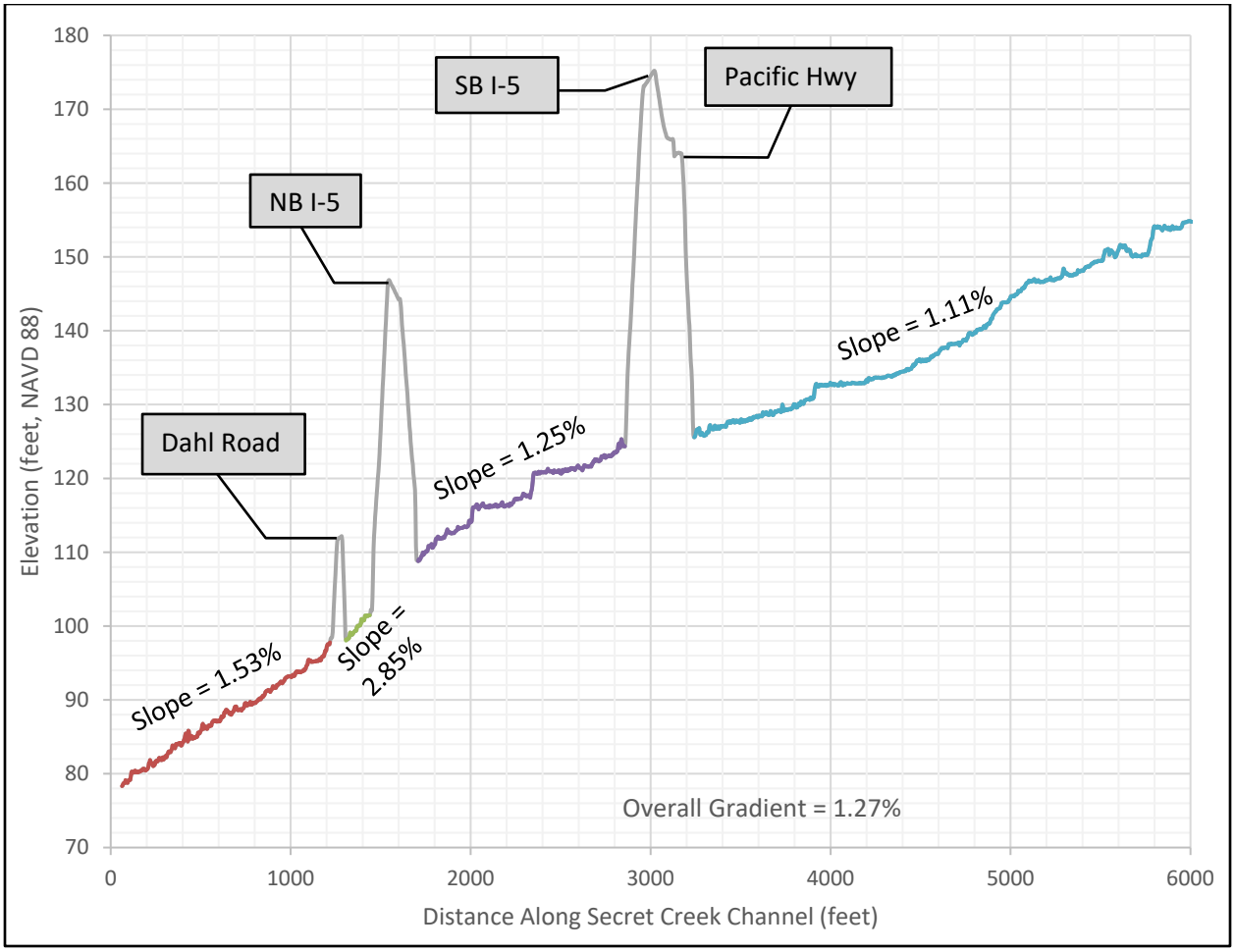


Figure 3.3. Longitudinal Profile of Secret Creek (LiDAR)

Upstream and downstream channel gradients were also assessed using WSDOT and Parametrix site survey data, which provide a more detailed and current understanding of the longitudinal profile of the stream in the immediate vicinity of the I-5 crossings. The surveyed profile begins approximately 212 feet downstream of the Dahl Road culvert outlet and ends at approximately 208 feet upstream of the inlet to the SB I-5 culvert inlet. The channel gradient is approximately 1.30 percent for the 125 feet of channel between the downstream survey limit and the most downstream log grade control structure below the Dahl Road culvert and is considered a part the reference reach for purposes of assessing existing channel gradient. Survey indicates that the channel gradient through a series of five log grade controls downstream of Dahl Road is an average of 7.20 percent as measured from upstream to downstream log grade controls, or 3.36 percent measured between the most downstream log grade control and the outlet of the Dahl Road culvert. The channel gradient is approximately 2.29 percent for the 145 feet of channel between Dahl Road and NB I-5. This reach has also been retrofitted with a series of five log grade control structures to help stabilize the steep grade in this section. The channel gradient is approximately 1.26 percent for the 1,170 feet between NB and SB I-5. The channel gradient is approximately 0.59 percent for the 208 feet upstream of the SB I-5 culvert. According to the WSDOT survey, the NB I-5 culvert has a slope of 2.77 percent, and the SB I-5 culvert has a slope of 0.64 percent. The culvert beneath Dahl Road has no slope. Figure 3.4 depicts the WSDOT Survey longitudinal profile.

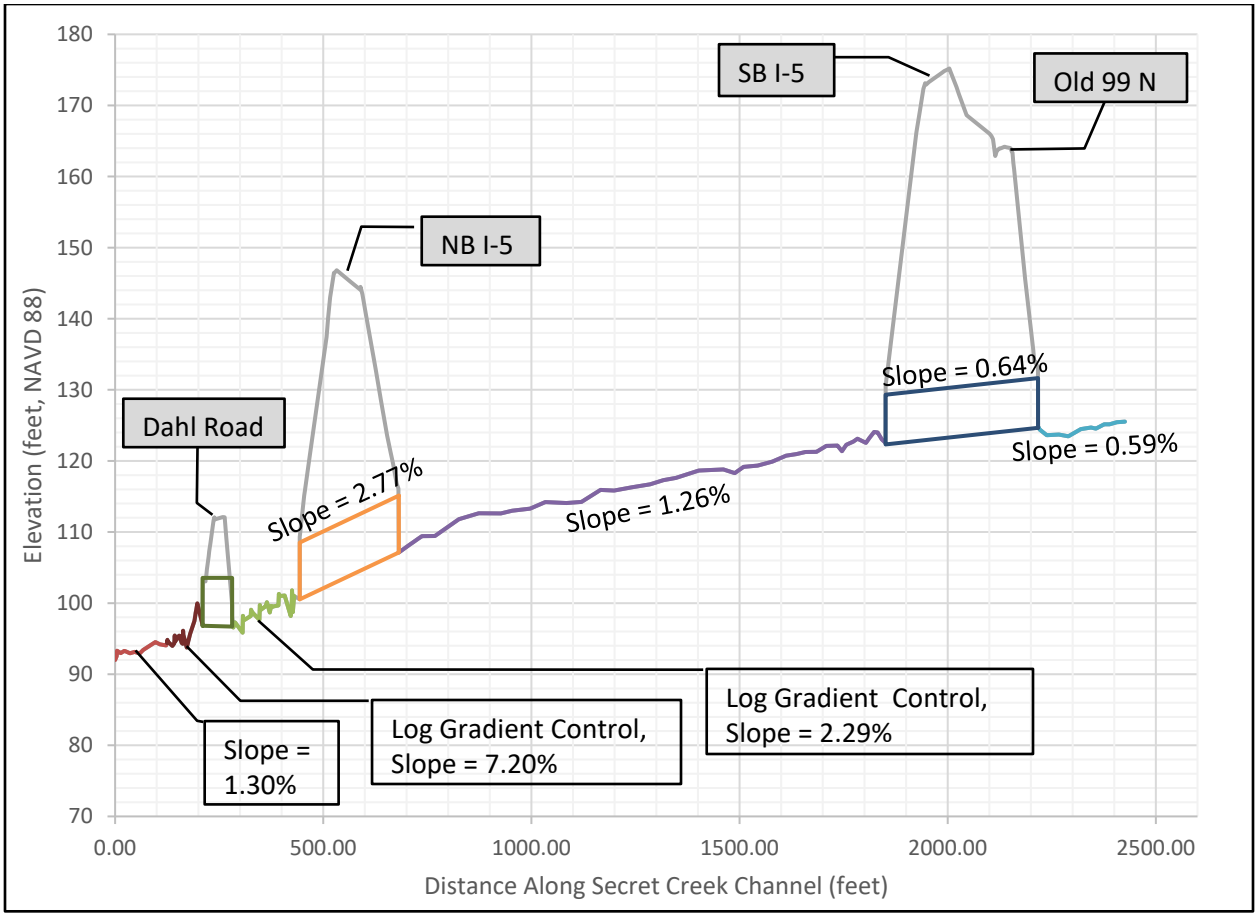


Figure 3.4. Longitudinal Profile of Secret Creek (Site Survey)

The average BFW in the vicinity of the SB I-5 crossing is 12.1 feet, as obtained during the July 30th, 2019, site visit. Seven BFW measurements were taken during the site visit, varying between 9.2 and 15 feet. A reference reach downstream of Dahl Road, assessed later for the NB I-5 crossing, was found to have an average BFW of 12.0 feet and was used a basis in the design of the proposed channel geometry through both the NB and SB I-5 crossings.

The cross-sectional geometry of Secret Creek varies depending on location. Analysis of cross-sectional geometry will be performed for each of the four distinct reaches in this order: 1) downstream of Dahl Road, 2) between Dahl Road and NB I-5, 3) between NB and SB I-5, and 4) upstream of SB I-5. This analysis was primarily performed using WSDOT survey data and LiDAR where survey data were not available.

The reach downstream of Dahl Road extends from the downstream end of the Dahl Road culvert to just upstream of culvert Site ID 991975, which is just upstream of the confluence between Secret Creek and the unnamed tributary to Pilchuck Creek. A portion of this reach from 85 feet to 500 feet downstream of the Dahl Road culvert outlet was identified as a reference reach for the NB I-5 crossing. Here, Secret Creek is confined within a low-relief valley, with a top width of approximately 280 feet at the downstream end of the reach and 210 feet at the upstream end. Valley depth from crest to trough varies from approximately 50 feet at the downstream end of the reach to 35 feet at the upstream end. The main channel is set within a flat, well-defined floodplain that modeling indicates becomes engaged during two-year flow events in many areas. Evidence of an active side channel was also observed

downstream of the installed log grade control structures at the upstream limit of the reference reach. The flood-prone width (FPW), measured as the 100-year flow width from the existing conditions model, varies between 48 and 62 feet, with a reach average value of 56.7 feet, which also well represents the average valley bottom width. See Section 7.0 for additional model discussion. The floodplain utilization ratio (FUR) is defined as the FPW divided by the BFW, resulting in a FUR of 4.7 for this reach. Since the FUR for this reach is greater than 3.0, this reach is considered unconfined. Bankfull depth measurements varied between 1 foot and 2 feet at locations of BFW measurement through the reference reach.

In the short reach between Dahl Road and NB I-5, the confining valley becomes narrower and shallower, width a top width of 170 feet and a depth of 30 feet. The main channel becomes significantly wider and deeper compared to the downstream reach. The 100-year flow is mostly contained within the main channel, and it does not significantly engage the floodplain, resulting in an FPW of 32.3 feet. Using the average BFW of 12.0 feet, this results in a FUR of 2.7, suggesting that the channel is confined in this reach. The confined nature of this channel is due to encroachment caused by the construction of the I-5 and Dahl Road embankments, as well as the channel widening that resulted from the installation of five log-grade control structures in this reach, as discussed in Section 2.0. This encroachment by roadway embankment and main channel widening leads to less floodplain activation, resulting in a narrower FPW and a lower FUR relative to the other stream reaches.

In the reach between the NB and SB I-5 culverts, the valley is deeper and more constrained relative to downstream of Dahl Road. The main channel runs along the east side of the valley, along the toe of the embankment of the NB I-5 lanes. This embankment has a steep and continuous slope up to the roadway of 2(H): 2.5(V). The channel has a trapezoidal shape with no well-defined floodplain in this reach, and it is armored in large riprap material. Near the NB I-5 crossing, the valley is the deepest and most narrow. At 300 feet upstream of the NB I-5 crossing, the channel exhibits an FPW of 28.0 feet and a FUR of 2.3. Moving upstream from the NB I-5 crossing, the embankment slopes lessen as the streambed elevation increases, decreasing the separation between the streambed and the I-5 roadway surface. At 800 feet upstream of the NB I-5 crossing, the channel exhibits an FPW of 61.8 feet and a FUR of 5.1.

In the reach upstream of the SB I-5 culvert, the valley geometry more closely resembles the reach downstream of Dahl Road, though the main channel bankfull depth is greater and channel banks are stepper, especially in the immediate vicinity of the SB I-5 culvert. An additional reference reach was identified from immediately upstream of the SB I-5 culvert inlet to 500 feet upstream of the inlet. The confining valley is 40 to 50 feet deep, and it has a 250-foot top width, with a well-defined floodplain and main channel. Here, BFW measurements averaged approximately 12.1 feet, like the reference reach identified downstream of Dahl Road. Bankfull depths measured between 3 and 3.5 feet in this reach, which results in a BFW-to-depth ratio of approximately 4. This ratio is lower than in the downstream reference reach. The channel geometry appears to have been influenced by historical beaver activity. Evidence of relic beaver dams with upstream sedimentation were observed during the visit with stakeholders, and this activity may have influenced the low BFW-to-depth ratio observed here. Modeling of this reach indicates the observed geometry has not resulted in a disconnected floodplain, with two-year water surface elevations occurring near the main channel breakover and flows over the two-year event reaching well across the valley floodplain. This reach has an average FPW of 71.8 feet, resulting in a FUR of 6.0, suggesting that the channel is unconfined. Figure 3.5 shows existing channel cross-sections taken upstream of SB I-5 (in the reference reach), and in the median between NB and SB I-5.

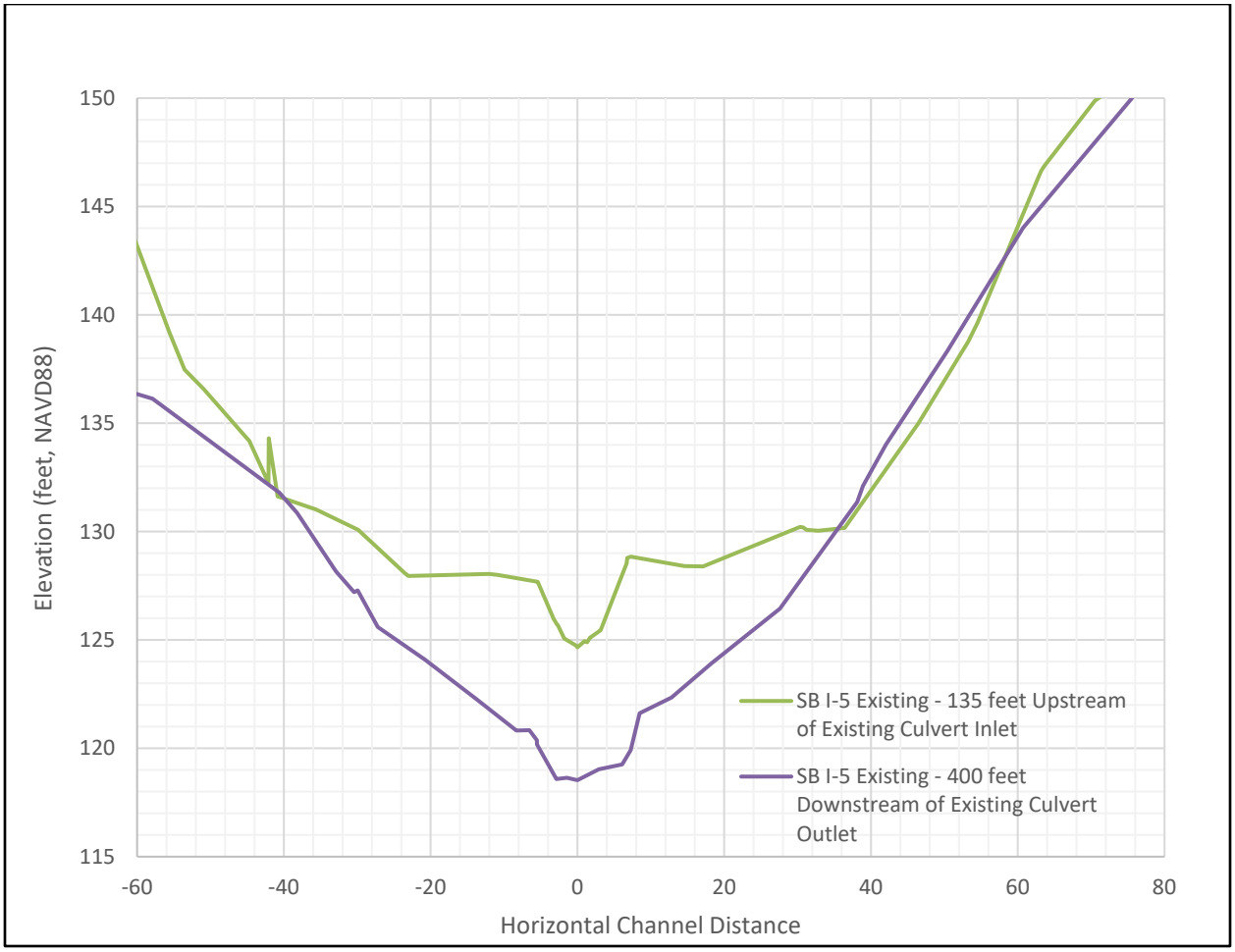


Figure 3.5. Existing Cross-sections Upstream and Downstream of the Existing SB I-5 Culvert

The planform of Secret Creek in between the I-5 crossings and near the NB I-5 crossing is generally straight and follows the centerline of the confining valley. This is due to the construction of roadway embankments and channel modifications protected by riprap armoring as seen in the reach between NB and SB I-5, and the installation of log-grade controls between the NB I-5 and Dahl Road culverts and within 150 feet downstream of the Dahl Road culverts. Secret Creek takes a 90-degree bend as it exits the SB I-5 culvert, and another as it enters the NB I-5 culvert, but these bends are artificial, and they are reinforced with armored banks.

Upstream of SB I-5 and downstream of Dahl Road, Secret Creek is sinuous. Sinuosity, approximate average meander radii, and approximate average meander belt width measurements were made at the reference reaches upstream of the SB I-5 crossing and downstream of the Dahl Road crossing. These planform measurements were performed in MicroStation using land survey and LiDAR data, and they formed the basis for the proposed planform and are presented in Section 9.

3.4.2 Potential for Aggradation, Incision and Headcutting

A comparison of the upstream LiDAR gradient value of 1.11 percent to the 1.25 percent stream gradient downstream does not suggest a significant risk of incision or headcutting.

As depicted in Figure 3.4, the gradient of 0.59 percent surveyed upstream of the SB I-5 culvert is relatively lower than the 1.26 percent stream gradient surveyed downstream of the SB I-5 culvert. This greater difference does suggest a risk of incision or channel degradation following removal of the culvert.

In the proposed condition, grading will occur from downstream of the NB I-5 crossing to upstream of the SB I-5 crossing, which includes restoration of the channel between the NB and SB roadways. The channel will be profiled to best match the prevailing upstream and downstream gradients, which will reduce the amount of potential channel degradation following construction. The proposed gradient is 1.37 percent, which is still greater than the channel upstream of the SB I-5 crossing. This suggests that incision and degradation is a risk at this crossing. Efforts to limit the rate and magnitude of channel degradation such as strategic LWM placement will be made to limit reduction in habitat quality in the reach upstream of the SB I-5 crossing.

The watershed has a moderate sediment supply. Evidence of moderate channel migration was observed during the site visit; see Section 3.4.4 for additional detail. As the channel continues to meander within its floodplain, sediment pulses may be encountered as channel avulsions lead to erosion. It is not anticipated that this moderate sediment supply will have a significant effect of aggradation, incision, or headcutting.

3.4.3 Floodplain Flow Paths

As discussed in Section 3.4.1, the channel upstream of the SB I-5 crossing has a well-defined, flat, floodplain. It is possible that multiple flow paths occur within the floodplain, but the flows are confined to the larger confining valley. No well-defined flat floodplain exists for the section of Secret Creek between NB I-5 and SB I-5, but water is still contained within the confining valley and the I-5 embankments.

3.4.4 Channel Migration

Lateral channel migration is a medium risk at this site. Evidence of channel migration including bank erosion and undercutting at meander bends was observed during the site visit. This channel migration is primarily limited to within the existing floodplain and confining valley walls, and it is unlikely to result in notable expansion of the floodplain. Vegetative growth on most of the meander point bars suggests that lateral migration may not be rapidly occurring and is more likely limited to occurrences when LWM and beaver activity force an avulsion.

3.4.5 Existing LWM and Potential for Recruitment

LWM was documented throughout all reaches of Secret Creek during the site visit. The stream corridor of Secret Creek is heavily wooded, and there is a significant potential for additional recruitment of LWM.

Upstream of the SB I-5 culvert, LWM was present both in-channel and channel spanning. Tree species are predominantly deciduous in this reach, but coniferous species were present. In the reach between the NB and SB I-5 culverts, the LWM encountered was primarily channel-spanning tree fall, and trees in this reach are primarily deciduous species. These species include red alder, black cottonwood, cascara, mountain ash, Pacific willow, and big-leaf maple.

Large riprap and boulders were also noted throughout the site visit, especially between the NB and SB I-5 crossings. See Figure 2.20.

3.4.6 Sediment Size Distribution

To evaluate the natural sediment size distribution in the vicinity of the SB I-5 crossing of Secret Creek, four Wolman pebble counts were conducted, one upstream and three downstream of the SB I-5 culvert following standard Wolman pebble count procedures (USDA 2001). Figure 3.6 depicts the results of pebble counts performed for the NB I-5 and SB I-5 crossings. Table 3.1 shows the sediment properties of the pebble counts.

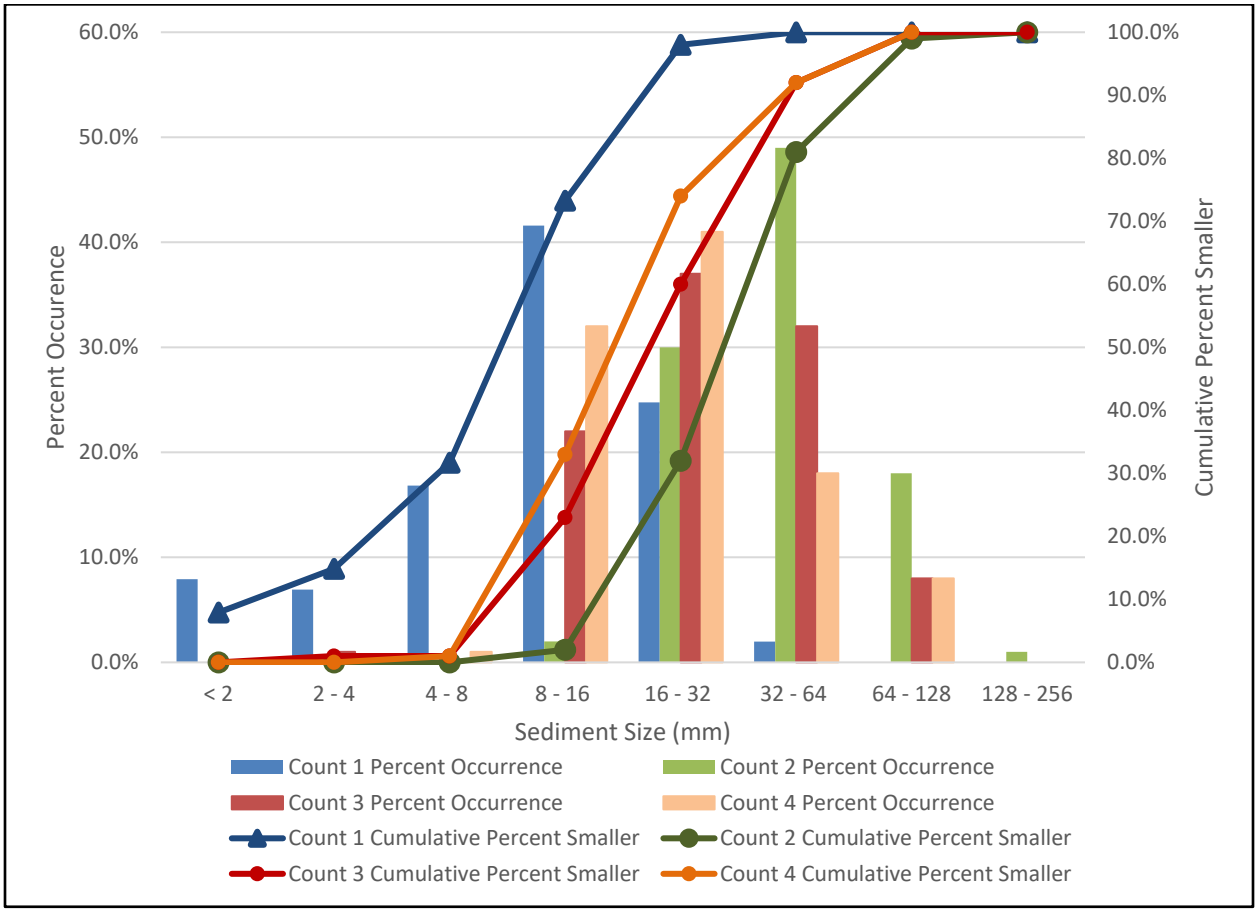


Figure 3.6. SB I-5 Pebble Count Results

Table 3.1. SB I-5 Sediment Properties of Pebble

	SB I-5 Pebble Count 1 Diameter (mm) (in)	SB I-5 Pebble Count 2 Diameter (mm) (in)	SB I-5 Pebble Count 3 Diameter (mm) (in)	SB I-5 Pebble Count 4 Diameter (mm) (in)
D_{16}	4.3 (0.17)	23.5 (0.92)	12.2 (0.48)	11.8 (0.46)
D_{50}	11.5 (0.45)	43.8 (1.72)	27.7 (1.09)	22.6 (0.89)
D_{84}	22.9 (0.90)	74.7 (2.94)	56.0 (2.20)	49.8 (1.96)
D_{100}	40.0 (1.57)	180.0 (7.09)	90.0 (3.54)	65.0 (2.56)

SB I-5 Pebble Count 1 was taken approximately 514 feet upstream of the SB I-5 culvert inlet. The Wolman analysis results show that the streambed material is composed of medium gravel (41 percent of the total), coarse gravel (27 percent of the total), fine gravel (24 percent of total), and sand (8 percent of total).

SB I-5 Pebble Count 2 was taken approximately 82 feet downstream of the SB I-5 culvert outlet at the location shown in Figure 3.7. The Wolman analysis results show that the streambed material is composed of coarse gravel (79 percent of the total), cobbles (19 percent of the total), and medium gravel (2 percent of the total).

Figure 3.7. SB I-5 Pebble Count 2 at 82 Feet downstream of SB I-5 Culvert Inlet

SB I-5 Pebble Count 3 was taken approximately 301 feet downstream of the SB I-5 culvert outlet at the location shown in Figure 3.8. The Wolman analysis results show that the streambed material is composed of coarse gravel (69 percent of the total), medium gravel (22 percent of the total), cobbles (8 percent of total), and fine gravel (1 percent of total).

Figure 3.8. SB I-5 Pebble Count 3 at 301 Feet downstream of SB I-5 culvert outlet

SB I-5 Pebble Count 4 was taken approximately 469 feet downstream of the SB I-5 culvert outlet at the location shown in Figure 3.9. The Wolman analysis results show that the streambed material is composed of coarse gravel (59 percent of the total), medium gravel (32 percent of the total), cobbles (8 percent of total), and fine gravel (1 percent of total).

Figure 3.9. SB I-5 Pebble Count 4 at 469 Feet Downstream of the SB I-5 Culvert Outlet

The proposed streambed mix was ultimately determined by matching the pebble counts performed downstream of Dahl Road. Please see Section 9.3 Bed Material for additional information and the PHD report for the I-5 NB crossing of Secret Creek for detail on the pebble counts performed downstream of NB I-5 and Dahl Road.

3.5 Groundwater

No evidence of groundwater impact was noted during the site visit, though the presence of and impacts on construction should be investigated by geotechnical engineers as the design progresses.

4.0 Fish Resources and Site Habitat Assessment

4.1 Fish Use

Native fish potentially found in the project area include chum salmon, coho salmon, sea-run and resident coastal cutthroat trout, resident rainbow trout, and steelhead, Of these, steelhead trout are threatened species under the Endangered Species Act of 1973. In Washington, chum salmon, coho salmon, sea-run and resident coastal cutthroat trout, resident rainbow trout, and steelhead are on WDFW's Priority Habitats and Species List (WDFW 2008).

The statewide integrated fish distribution (SWIFD) webmap identifies the reach upstream and downstream of the culvert as spawning habitat for coho salmon (SWIFD 2020). Steelhead have been documented upstream to the NB I-5 crossing and upstream areas are identified as gradient accessible to steelhead (SWIFD 2020). Chum salmon have been observed in the lower reaches downstream of I-5, but habitats through the subject culvert and upstream are identified as gradient accessible to chum salmon (SWIFD 2020). SWIFD, indicates that resident rainbow trout have not been documented as occurring within Secret Creek; however, they have been documented in the mainstem Pilchuck Creek and the mainstem Stillaguamish River. Therefore, it is likely that resident rainbow trout could be present in Secret Creek. Resident rainbow trout are more prevalent upstream in the North and South Fork Stillaguamish River and its tributaries, while cutthroat trout are more prevalent in the lower mainstem Stillaguamish and its tributaries (WSCC 1999). Coastal cutthroat trout are presumed to be present throughout all accessible reaches of Secret Creek. Both juvenile coho salmon and cutthroat trout were observed while conducting field surveys for this project.

Coho typically begin their upstream migrations in the Stillaguamish River system in September and October, and they generally spawn from mid-November through January (WDFW and Western Washington Treaty Indian Tribes [WWTIT] 1992). Coho fry emerge in March and April and spend a full year rearing in the watershed before migrating to the marine waters of Puget Sound (Miller and Somers 1989). Outmigration of smolts typically occurs between mid-March and the end of June (Washington State Conservation Commission [WSCC] 1999).

Chum salmon begin their upstream migrations in the Stillaguamish River system in September and migration continues through December. Spawning occurs from mid- to late October through December. Chum fry emerge in March through May, and they leave the freshwater system almost immediately to rear in the lower estuary (Miller and Somers 1989).

Steelhead that use tributaries in the lower Stillaguamish River system are winter-run steelhead. Adult winter steelhead begin their upstream migrations in early November through April with spawning occurring from March through mid-June (WSCC 1999). Juvenile steelhead typically rear in freshwater for over a year before they begin their seaward outmigration between April and June (WSCC 1999).

Sea-run coastal cutthroat begin entering the Stillaguamish River system in late July. Spawning occurs from mid-February through mid-May (WSCC 1999). Sea-run coastal cutthroat typically rear from two to four years in freshwater before migrating to the marine waters of Puget Sound, where they spend approximately two to five months before returning to the Stillaguamish watershed (Spence et al. 1995). Resident adult and juvenile cutthroat are expected in Secret Creek year-round.

4.2 Existing Habitat

Roadways, low-density residential development, and some small hobby farms are the primary factors affecting habitat and access to that habitat within the Secret Creek drainage. In general, the riparian corridor is more than 150 feet wide; however, the forested stands are young and dominated by deciduous species. Reed canarygrass is also prevalent along much of Secret Creek, which has resulted in significant sediment retention and degradation of spawning habitat. Secret Creek is not identified on the 303(d) list of impaired waterbodies for any water quality parameter; however, Pilchuck Creek

downstream of the confluence with Secret Creek has a total maximum daily load (TMDL) in place for dissolved oxygen, temperature, and bacteria (Washington State Department of Ecology [Ecology] 2020).

4.2.1 Immediate Crossing

The current crossing (Site ID 990623) is identified as a partial barrier to fish passage. This designation is due to excessive water velocity through the culvert during higher flows (WDFW 2018; WDFW 2020).

The reach downstream of the culvert outlet is located within a forested median between the northbound and southbound lanes of I-5. Current habitat includes alternating pools and riffles with alternating bank armoring. Typically, the banks and the channel opposite the armoring showed evidence of scour and undercutting. Riparian vegetation is dominated by deciduous species including red alder, black cottonwood, cascara, mountain ash, Pacific willow, and big-leaf maple with an understory of Indian plum, twinberry, red-twig dogwood, salmonberry, sword fern, and Himalayan blackberry. Reed canarygrass, horsetail, and jewelweed were common along both banks. Large woody debris was mostly absent from the channel. Where present, it was typically channel-spanning and it consisted of deciduous tree material. Substrates consisted of a mixture of cobble and large gravel, heavily embedded with fines. At the time of the survey, the riffle portion of the reach was dry with some limited water volume remaining in the pools. Juvenile coho salmon and cutthroat trout were observed within all the pools.

The channel upstream of the culvert inlet contained more sinuosity, and the riparian vegetation contained a higher conifer species component that included western red cedar and western hemlock; however, deciduous species-maintained dominance throughout the reach. Understory vegetation was more diverse than downstream, and it included salmonberry, stink currant, red elderberry Indian plum, red-twig dogwood slough sedge, lady fern, horsetail, and creeping buttercup. Reed canarygrass was significantly denser upstream of the culvert. As such, the natural process of sediment sorting has been altered, and there is a significant increase in fine sediment bedload upstream of the culvert as opposed to downstream. While fine sediment dominated much of the reach, areas of suitable spawning gravel were observed. Areas of bank erosion and undercutting were observed, particularly closer to the culvert inlet. LWM was more abundant than downstream and typically within the active channel, but still primarily deciduous material.

Overall, there was some suitable spawning and rearing habitat within the assessed reaches; however, the quality of this habitat was reduced by fine sediment inputs, limited cover and LWM within the channel, limited channel capacity due to reed canarygrass growth, and altered flow regime.

4.2.2. Quality Within Reach

WDFW conducted habitat surveys upstream of the subject crossing in April and May of 1997. The surveys were conducted to determine the quality of upstream habitat and to get an overall estimate of available spawning and rearing area that would be accessible to salmonids if the barrier were made 100 percent passable (WDFW 2018). The following is a summary of that information.

Riparian cover within the reach consists primarily of deciduous species, including red alder and black cottonwood with dense understory vegetation with some interspersion of coniferous species. The coniferous species include western red cedar and Sitka spruce. Overall canopy cover estimates are good and range between 80 and 90 percent. Instream cover was also abundant throughout the reach, which

improves the quality of the reach for rearing habitat. Overall, substrates are dominated by gravel with sand being subdominant throughout the assessed reaches. While gravels are the dominant substrate, sand accounts for a large percentage of substrate composition within each reach, and this likely limits the ability of upstream reaches to provide high quality spawning habitat.

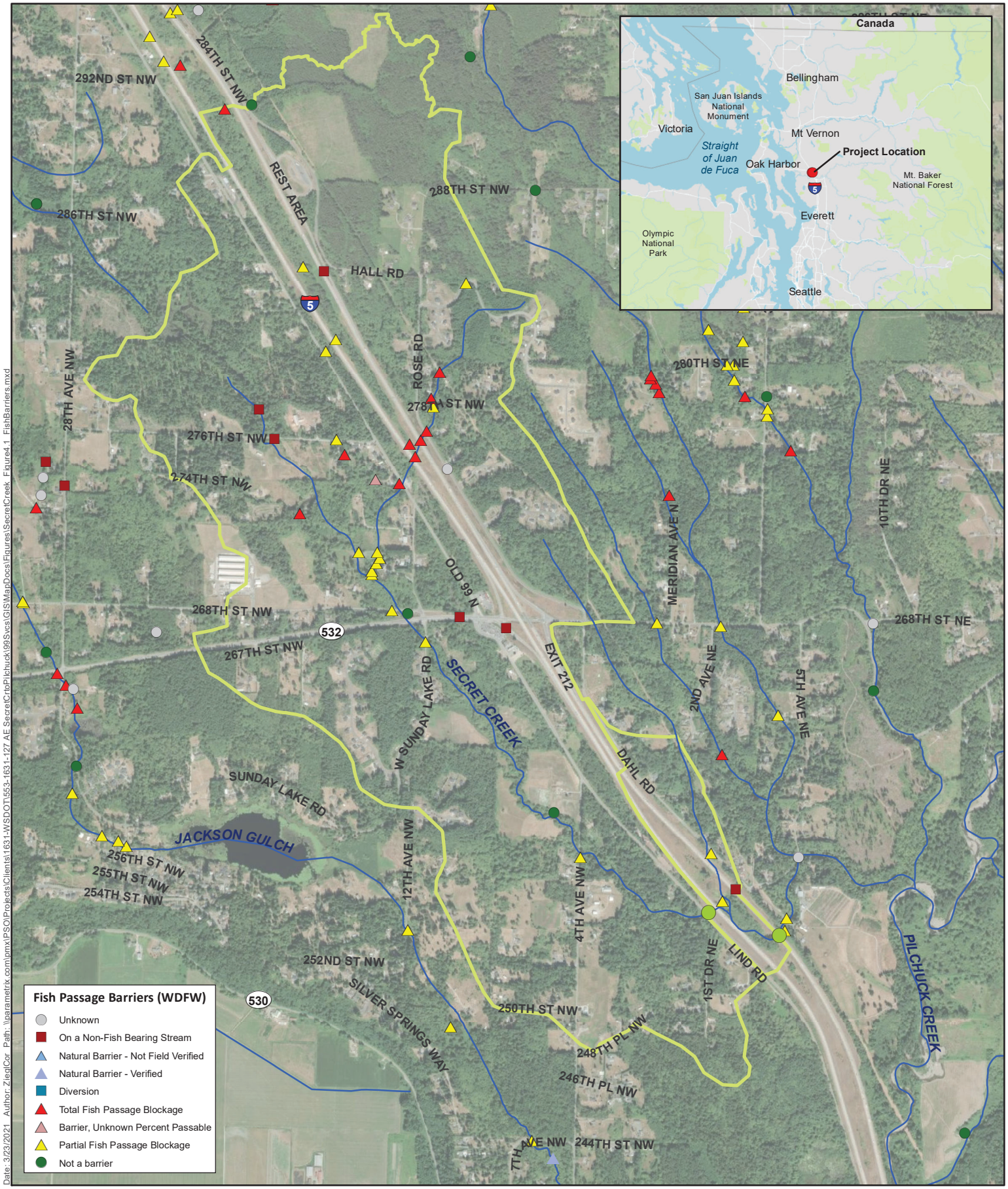
Pools and riffles dominate the habitat types throughout the reach. Pool habitats accounted for 50 percent of all habitat types, followed by riffles at 31 percent, and ponded areas at 19 percent. Pool habitat quality is improved by both abundant instream and good canopy cover. Pool quality would be much higher if the pools were deeper and if volumes were not reduced by fine sediment inputs. The reach provides some suitable spawning gravels; however, like pools, the quality has been reduced by fine sediment. The limiting factor with the highest degree of impact on suitability of the habitat for salmonid use is low summer flows followed by lack of suitable spawning gravels.

4.2.3 Length of Potential Gain

WDFW (2018) performed a habitat survey upstream from the culvert and reported 4.6 miles of potential fish habitat upstream of the culvert at I-5 and Old Highway 99 North. Of that habitat gain, 47,641 square feet/1.1 acres is spawning habitat, and 177,723 square feet/4.1 acres is rearing habitat. Habitat gain includes the mainstem.

4.2.4 Other Barriers in System

WDFW (2018) reported three downstream barriers that were corrected in 2000. The barriers are identified as currently passable, but the percent passage is listed as unknown (Figure 4.1, Secret Creek Fish Barriers). Upstream barriers include four partial barriers on the mainstem Secret Creek; a tributary to Secret Creek containing two partial barriers, two corrected barriers that are currently not passable, and a barrier with unknown passage status; there is one other tributary with an impassable barrier (Figure 4.1). Numerous barriers are reported in the Pilchuck Creek watershed, but there are no impassable barriers downstream of the confluence with the mainstem Pilchuck Creek. The partial barrier immediately downstream (Site ID 990622) and beneath the NB lanes of I-5 is also currently being evaluated for replacement with a fish passable culvert.



Date: 3/23/2021 Author: ZleqlCor Path: \\parametrix.com\pmx\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrk\Pilchuck\99Svcs\GIS\MapDocs\Figures\SecretCreek Figure4.1 FishBarriers.mxd

Source: Snohomish County, ESRI, WSDOT, WDFW

Secret Creek Culverts at I-5

Watercourse

Secret Creek Watershed Boundary

0 750 1,500 3,000 Feet

Figure 4.1 Fish Barriers

I-5 Secret Creek

Snohomish County, WA

4.2.5 Other Restoration Efforts in System

The larger Stillaguamish watershed has been identified as a high priority for salmon recovery in the Puget Sound region, particularly for restoration of several habitat factors that limit salmon productivity, including the restoration of riparian habitat, floodplain habitats, and large wood (SIRC 2005). The Lower Pilchuck Creek sub-basin and tributaries, including Secret Creek, have been identified as a riparian priority sub-basin due to high use by Chinook salmon or proximity to areas of high use (SCD 2017). The riparian corridor within the lower Pilchuck Creek sub-basin has been identified as 67 percent functional with a goal of 80 percent. The creation of pool scour in flow-gaining reaches and riparian plantings to provide temperature and salmon habitat benefits are current priorities (SWC 2015). Conservation actions important for salmon recovery in the sub-basin include invasive vegetation control, riparian reforestation, exclusion fencing, and protection of existing riparian forest habitats.

The National Estuary Protection (NEP) funded by the Environmental Protection Agency (EPA) and administered by Ecology in cooperation with the National Oceanographic and Atmospheric Administration's National Marine Fisheries Division, Snohomish County, and the Snohomish Conservation District (SCD), are currently seeking opportunities to work with property owners to purchase permanent easements along Secret Creek and lower Pilchuck Creek to meet the riparian restoration goals set forth for the subbasin.

5.0 Reference Reach Selection

The basis of the analysis and design considered two reference reaches, one upstream and adjacent to the SB I-5 crossing and the other downstream of NB I-5 and Dahl Road and associated log grade controls. Observed similarities in the channel and valley geometry characteristics upstream of the SB I-5 crossing and the reference reach downstream of the Dahl Road crossing, the relatively less managed condition of these reaches, and modeling which indicates the upstream channel floodplain is not disconnected all provided validation for the selected reference reaches. See Figure 2.1, Project Area, for the locations of the reference reaches and pebble counts.

As reported in Section 3.4.1 – Channel Geometry, average stream gradients vary slightly based on source (either the site survey from 2019, or the LiDAR imagery from 2017) and the extents of the profile analyzed. Within the limits of the WSDOT site survey, an average gradient of 1.30 percent exists through the reference reach downstream of the Dahl Road culvert and associated log grade controls, and an average gradient of 0.59 percent exists upstream of SB I-5. This length of survey is not sufficient to average out the effect of the large pool directly upstream of the culvert inlet on the gradient, therefore, the surveyed gradient of 0.59 percent does not well represent the reference reach gradient. According to LiDAR analyzed, the reach downstream of Dahl Road averages 1.53 percent and the reach upstream of SB I-5 averages 1.11 percent. The proposed gradient of 1.37 percent matches closest to the reach downstream of Dahl Road per site survey and is an average of the upper and lower reference reaches per LiDAR analysis. Therefore, the downstream reference reach was selected as the primary reference for the design.

The three pebble counts performed downstream of the NB I-5 crossing in the downstream reference reach will be used as reference for the design since the stream gradient and confinement in the downstream reference reach more closely match proposed channel conditions. Figure 2.1 depicts the locations of the pebble counts. Figure 5.1 depicts the results of the NB I-5 pebble counts. Table 5.1 shows the sediment properties of the NB I-5 pebble counts. Photographs of the streambed material of NB I-5 Pebble Count 1, NB I-5 Pebble Count 2, and NB I-5 Pebble Count 3 are depicted in Figure 5.2, Figure 5.3, and Figure 5.4, respectively.

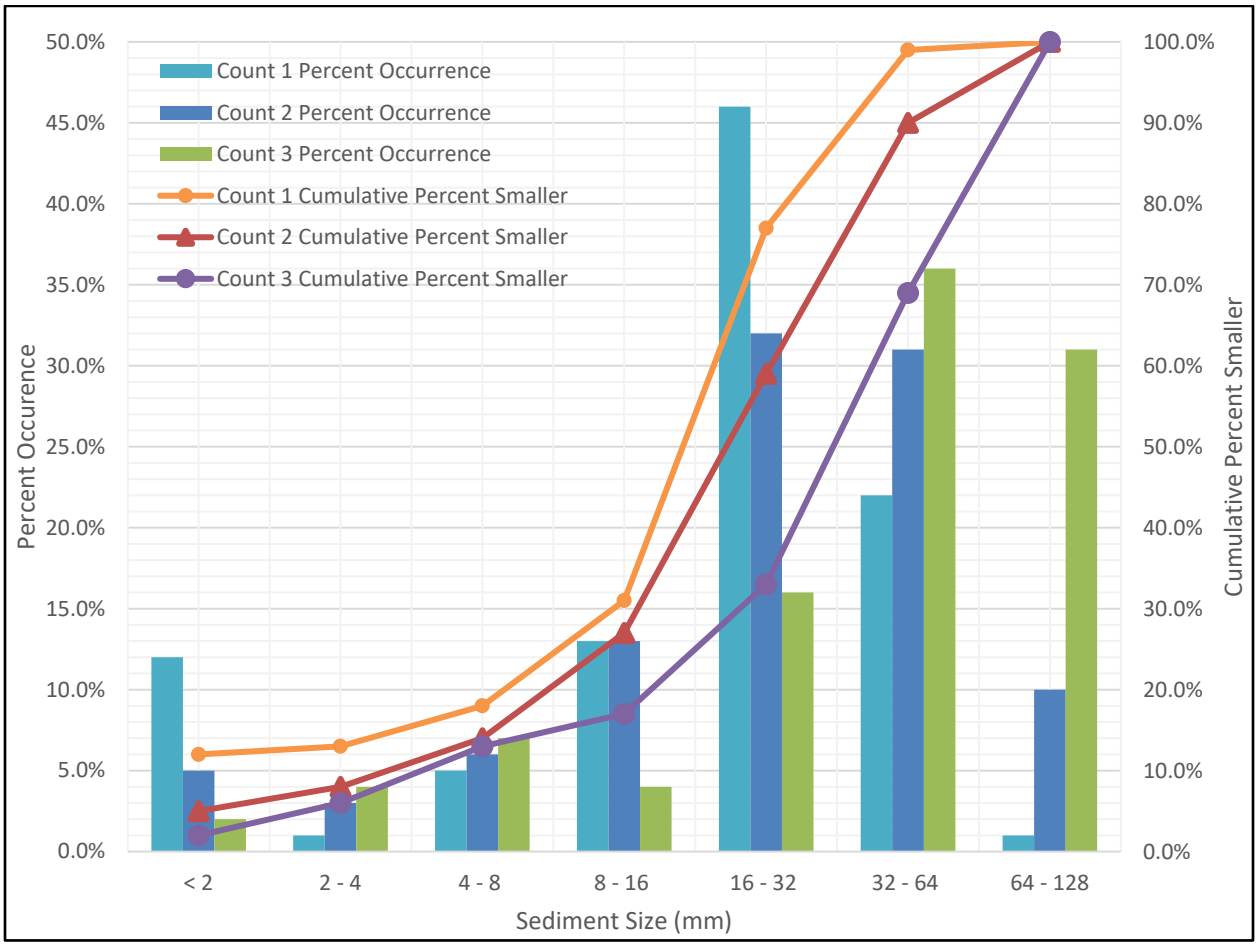


Figure 5.1. NB I-5 Pebble Count Results

Table 5.1. Sediment Properties of NB I-5 Pebble Counts

	Pebble Count 1 Diameter (mm) (in)	Pebble Count 2 Diameter (mm) (in)	Pebble Count 3 Diameter (mm) (in)
D_{16}	6.4 (0.25)	9.2 (0.36)	14.0 (0.55)
D_{50}	22.6 (0.89)	27.5 (1.08)	47.1 (1.85)
D_{84}	42.2 (1.66)	57.8 (2.28)	95.0 (3.74)
D_{100}	70.0 (2.76)	120.0 (4.72)	128.0 (5.04)

Pebble Count 1 was taken approximately 14 to 41 feet downstream of the beginning of the reference reach as determined during the field assessment, which begins 150 feet downstream of the Dahl Road culvert outlet, shown in Figure 3.9. The Wolman analysis results show that the streambed material is primarily composed of coarse gravel (68 percent of the total), medium gravel (13 percent of the total), sand (12 percent of total), and fine gravel (6 percent of total).

Figure 5.2. Pebble Count 1 at 14 to 41 Feet Downstream of the Beginning of the Reference Reach

Pebble Count 2 was taken approximately 112 feet downstream of the beginning of the reference reach, shown in Figure 3.7. The Wolman analysis results show that the streambed material is composed of coarse gravel (63 percent of the total), medium gravel (13 percent of the total), cobbles (10 percent of total), and fine gravel (9 percent of total).

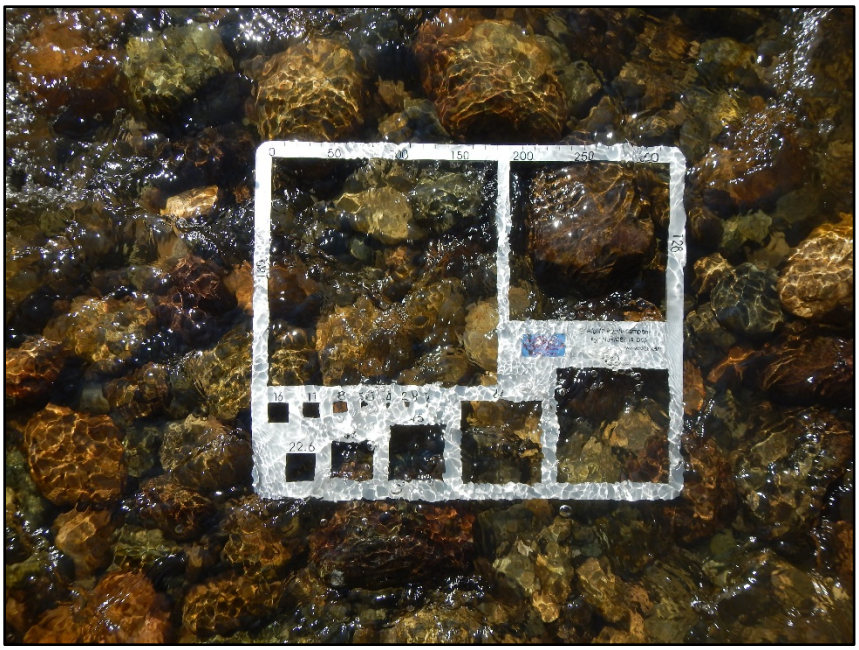


Figure 5.3. Pebble Count 2 at 112 Feet Downstream of the Beginning of the Reference Reach

Pebble Count 3 was taken approximately 204 feet downstream of the beginning of the reference reach, shown in Figure 3.8. The Wolman analysis results show that the streambed material is composed of coarse gravel (52 percent of the total), cobbles (31 percent of total), fine gravel (11 percent of the total), and medium gravel (4 percent of total).

Figure 5.4. Pebble Count 3 at 204 Feet Downstream of the Beginning of the Reference Reach

6.0 Hydrology and Peak Flow Estimates

The basin receives a mean annual precipitation of 36.8 inches as obtained from the National Hydrography Dataset and reported by USGS StreamStats. The PRISM Climate Group reports a mean annual precipitation of 46.2 inches obtained from data between 1981 and 2010.

The WDFW Water Crossings manual (2013) recommends four methods for determining hydrology in the design of culverts for fish passage. The four methods are, in order of preference, stream gauging, continuous-simulation modeling, local-regression models, and regional-regression models. Neither stream gauging nor local-regression models are available for Secret Creek.

A continuous-simulation hydrologic model based upon the Hydrological Simulation Program (HSPF) was developed for the Secret Creek watershed. The modeling software MGSFlood was used to produce this model. It incorporates land use conditions and underlying soil types to produce calculated peak flow rates. The latest USGS regional regression equation for Region 3 in Washington was also applied to the watershed with results reported below (Mastin et al. 2016). The regression equations provided by Mastin et al. apply to watersheds with impervious areas of 5 percent or less. Secret Creek has an impervious percentage of 9.0 percent; therefore, the USGS regression equations are likely to underestimate peak flow values. Due to the high percentage of impervious area and because they provide a more conservative estimate, the peak flow values from the MGSFlood continuous-simulation model will be used for the hydraulic analysis of Secret Creek. Additionally, Figure 2.14 shows the culvert outlet and wingwalls with a moss line evident. Based on scaling the photograph, the moss line appears about 3.3 feet below the soffit, or 3.7 feet above the invert of the culvert at the outlet. Hydraulic modeling of the existing conditions indicates that the 2-year water depth at the outlet is 3.5 feet. The similarity in data supports the selection for the hydrology at this crossing.

As discussed in Section 3.1, runoff from a basin of 2.49 square miles flows to the SB I-5 culvert. MGSFlood peak flow results, as well as regression equation results for the basin are presented below in Table 6.1.

Table 6.1. Peak flows for Secret Creek at SB I-5 Crossing

Mean Recurrence Interval (MRI)	HSPF-based Continuous-Simulation Model (cubic feet per second [cfs])	USGS Regression Equation (Region 3) (cfs)
2	**67**	54
10	**128**	107
25	**160**	135
50	**203**	156
100	**259**	179
200	**276**	202
500	**298**	234

7.0 Hydraulic Analysis

The hydraulic analysis of the existing flow conditions and the preliminary design of the SB I-5 Secret Creek crossing was performed using the U.S. Bureau of Reclamation's SRH-2D computer program—a two-dimensional numerical hydraulic model. Two scenarios were analyzed for determining stream characteristics for Secret Creek with the SRH-2D models: 1) existing conditions with a 366-foot-long, 7-foot-tall, by 5-foot-wide concrete box culvert; and 2) future conditions with a crossing with a minimum hydraulic opening of 40 feet.

7.1 Existing Conditions — 366-foot-long, 7-foot tall by 5-foot wide Concrete Box Culvert

The existing channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the project engineer's office. The data were developed from topographic surveys performed by WSDOT and Parametrix surveyors. 2017 LiDAR data were used as necessary where survey data were not available. The model extends 1,000 feet downstream of the Dahl Road culvert outlet and 1,200 feet upstream of the SB I-5 culvert inlet.

The SMS SRH-2D model incorporates a channel roughness in the two-dimensional mesh representation of space. Roughness values were determined based upon field observations of the channel and overbank surface material, surface irregularity, variation in channel section size and shape, physical obstruction including boulders and woody material, and live vegetation. A roughness coefficient for the channel and overbanks was then computed based on the criteria Chow (1959) developed. Table 7.1 documents the roughness coefficients in terms of Manning's n value.

Table 7.1. Manning's Roughness Coefficients Used in Existing Conditions Model

	Left Overbank Area	Main Channel	Right Overbank Area	Existing Baffled NB I-5 Culvert
Manning's 'n' Value	0.065	0.046	0.065	0.035

The project channel and surrounding area, including the NB I-5, SB I-5, and Dahl Road crossings, were imported into SRH-2D. Using the surveyed surface and supplemental LiDAR data as needed, a mesh was created to represent the existing condition. A mesh is a group of building blocks that is used to calculate depth, velocity, and other hydraulic parameters at each block.

The mesh density consists of approximately 34,500 elements. The elements along the stream and floodplain have approximately 2- to 5-foot vertex spacing. The existing culvert was represented in the HY-8 culvert analysis software (FHWA 2016) to calculate the hydraulics through the crossing. Appendix C contains the HY-8 report and the SRH-2D model results of the existing stream and crossing.

Two upstream boundary conditions were implemented in this model. The first boundary condition was approximately 1,300 feet upstream of the SB I-5 culvert inlet along the main channel of Secret Creek. This boundary condition location was placed far enough from the project site so that it would not

influence hydraulic results at the crossing. The second upstream boundary condition was placed at the north end of the reach of Secret Creek within the median of NB and SB I-5. This is where an unnamed tributary crosses beneath NB I-5 and drains into Secret Creek. The upstream boundary conditions define inflows (see Section 6.0 for peak flow rates). The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes. The model was run in steady-state mode for all modeled simulations.

The downstream boundary condition location was placed approximately 1,000 feet downstream of the Dahl Road Culvert outlet, far enough from the project site so that it would not influence the hydraulic results at the crossing. The downstream boundary condition estimated the water surface elevations using normal depth at the average gradient and corresponding peak flow being modeled.

Table 7.2 shows the water surface elevations at the existing culvert inlet, the channel velocity 5 feet downstream of the culvert outlet, and the average channel velocity approximately 400 feet upstream of the existing culvert inlet. Average upstream channel velocities were taken so that they would not be affected by any backwater occurring at the SB I-5 culvert inlet. Figure 7.1 depicts the water surface elevation profile of the existing Secret Creek I-5 crossing.

Table 7.2. Water Surface Elevations and Velocities for Existing Conditions at SB I-5 Crossing

	2-Year Flow	25-Year Flow	100-Year Flow
Water Surface Elevation at the Existing Inlet (feet [ft])	127.5	129.8	131.8
Existing Structure Outlet Velocity (ft per second [ft/s])	3.15	6.51	23.40
Average Upstream Channel Velocity (ft/s)	0.6	0.79	0.92

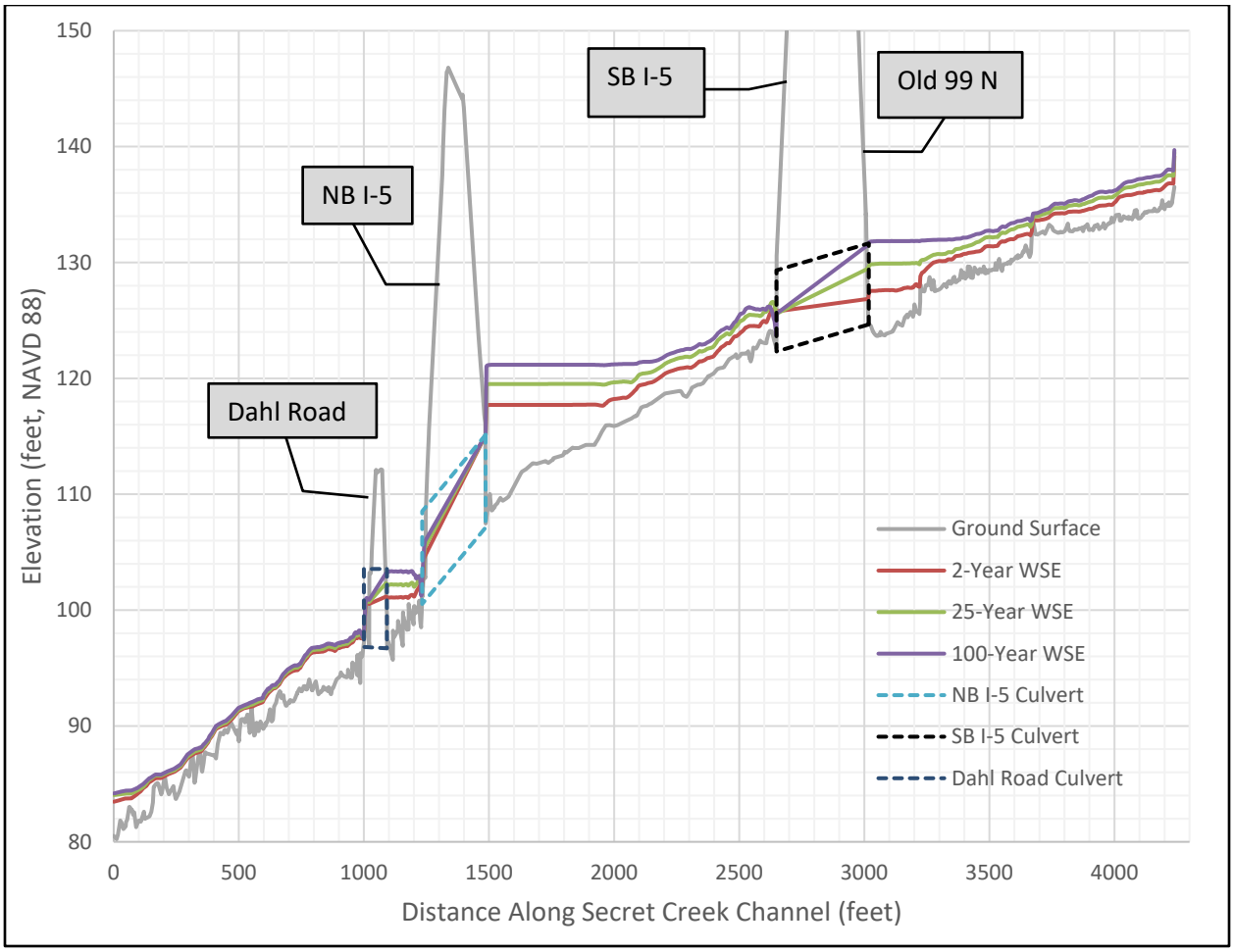


Figure 7.1. Water Surface Elevations at Existing NB and SB I-5 Crossings

7.2 Future conditions – Proposed 40-foot Span Structures

The preliminary design proposes a minimum hydraulic opening of 40 feet at the crossings of Old 99 North and SB I-5. The proposed stream corridor through the crossings was designed to accommodate channel meander by mimicking relatively less managed conditions identified upstream and downstream of the crossing, and this formed the basis of a natural conditions model. The corridor width of the natural conditions model is 64 feet wide to accommodate stream meanders designed to mimic the reference reaches. To evaluate the bridge design criteria, the model was then modified by encroaching into the floodplain by selectively removing portions of the mesh and replacing them with vertical walls beneath the footprints of both the Old 99 North and SB I-5 pavements. Based on the velocity results from this encroachment testing, a minimum hydraulic opening of 40 feet is proposed. Section 8.2.1 describes the analysis in determining the minimum hydraulic opening in more detail, and Sections 8.2.3 and 9.1 describe the design in more detail.

The roughness coefficients for the channel and overbanks were computed based on criteria Chow (1959) developed for the future condition. Table 7.3 documents the roughness coefficients in terms of Manning's n value.

Table 7.3. Manning's Roughness Coefficients Used in Proposed Conditions Model

Value Used	Left Overbank Area	Main Channel	Right Overbank Area
Manning's 'n' Value	0.070	0.056	0.070

The proposed channel and surrounding area, including the NB I-5, SB I-5, and Dahl Road crossings, were imported from Microstation InRoads into SRH-2D. Using the surveyed surface and supplemental LiDAR data as needed, a mesh was created to represent the proposed condition. The mesh density of this scenario consists of approximately 36,400 elements. The elements along the stream and floodplain have approximately 2-foot to 5-foot vertex spacing. Hydraulic results for the proposed model are summarized in Table 7.4 and Table 7.5. Water surface elevations are reported at the inlet to the proposed crossings. Average channel velocity and average channel shear stress are reported at the middle of the proposed crossings and water surface elevations are reported from the upstream face of each crossing.

Table 7.4. Water Surface Elevations and Velocities at Proposed Old 99 North Crossing

Elevations, Velocities, and Shear Stress	2-year Flow	100-year Flow	500-year Flow	100-year (2080) Flow
Water Surface Elevation at Upstream of Crossing (ft)	124.6	125.9	126.1	126.2
Average Channel Velocity Within Crossing (ft/s)	3.3	4.5	4.7	4.9
Average Channel Shear Stress within Crossing (lb/ft^2)	0.9	1.4	1.5	1.6

Table 7.5. Water Surface Elevations and Velocities at Proposed SB I-5 Crossing

Elevations, Velocities, and Shear Stress	2-year Flow	100-year Flow	500-year Flow	100-year (2080) Flow
Water Surface Elevation at Upstream of Crossing (ft)	122.4	123.8	123.9	124.1
Average Channel Velocity Within Crossing (ft/s)	3.3	4.7	4.9	5.0
Average Channel Shear Stress within Crossing (lb/ft^2)	0.9	1.5	1.6	1.7

The model's upstream and downstream boundary conditions remained the same as in the existing conditions model. The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes and the model was run in steady-state mode for all modeled simulations. Appendix D contains the SRH-2D model results of the proposed conditions. Figure 7.2 depicts the water surface elevation profile of the proposed crossing. Figure 7.3 depicts the water surface elevations relative to a section within the proposed SB I-5 crossing. The cross section was taken perpendicular to the main channel which meanders at varying skew angles to the opening, which makes the opening appear wider than it is.

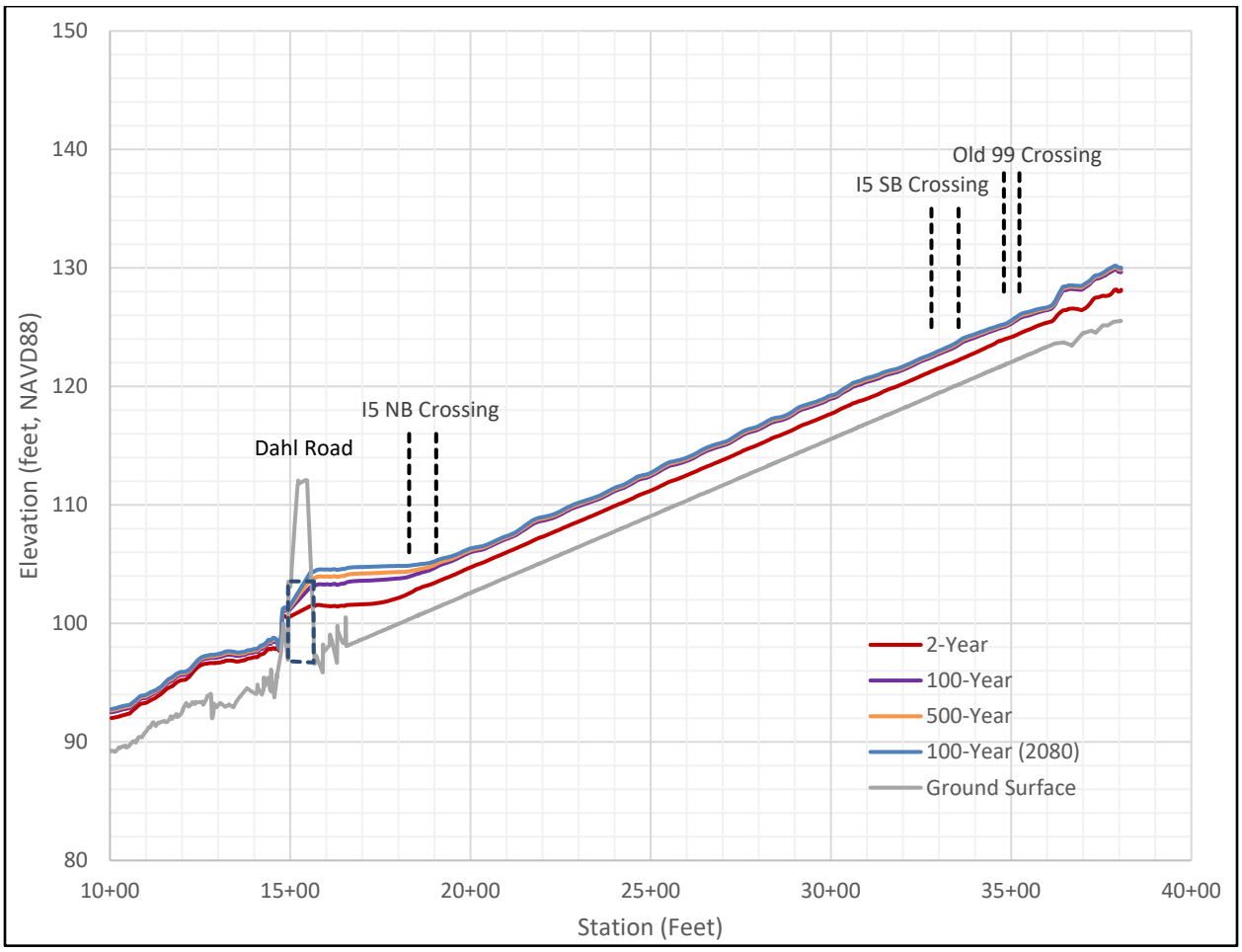


Figure 7.2. Water Surface Profile at Proposed NB I-5, SB I-5, and Old Highway 99 Crossings

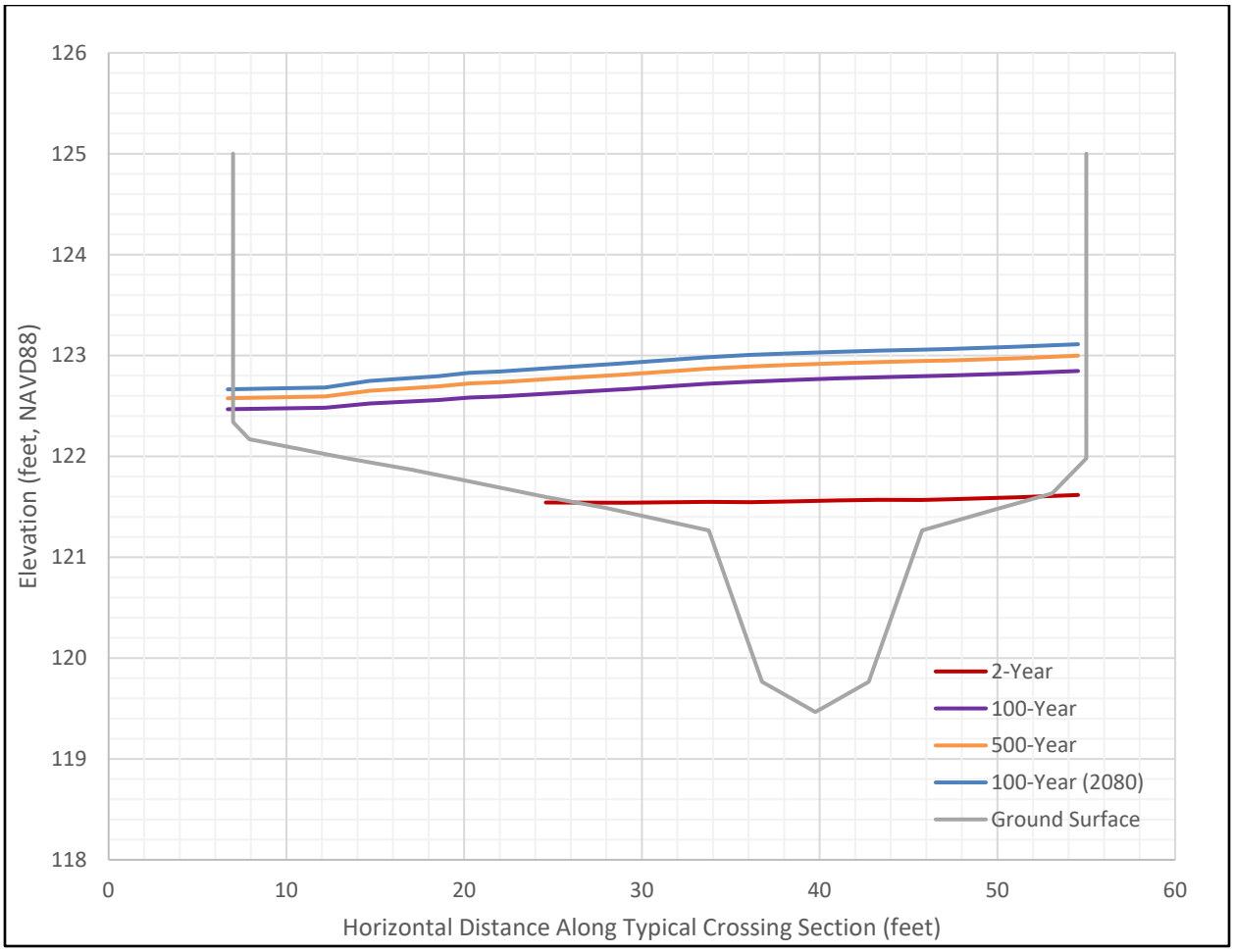


Figure 7.3. Proposed Secret Creek Typical Section with 40-foot Minimum Hydraulic Opening

8.0 Fish Passage Design Methods Selection

8.1 Design Methodology Selection

The WCDGs contain methodology for five different types of crossings: no-slope culverts, stream simulation culverts, 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 the site. According to the WCDG, a bridge should be considered for a site if the FUR is greater than 3.0, the stream has a BFW greater than 15 feet, the channel is believed to be unstable, the slope ratio exceeds 1.25 between the existing channel and the new channel, or the culvert would be very long. The bridge design method was selected primarily because the FUR is greater than 3.0, and a proposed replacement culvert could be up to 368 feet long.

8.2 Bridge Design Criteria

The 2013 WCDGs present two methodologies for designing a bridge crossing: confined bridge design and unconfined bridge design. The method to be used is defined by the FUR. The FUR is defined as the FPW divided by the BFW. 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 a ratio above 3.0 is considered an unconfined channel.

The FUR was determined by comparing the 100-year water surface from the existing conditions model to the agreed-upon BFWs measured outside of the influence of the existing crossing. FPW values were taken upstream of the SB I-5 culvert, within the reference reach. The average 100-year water surface was determined to be approximately 71.8 feet wide. Dividing this value by the BFW of 12.1 feet results in an average FUR of 5.9. The FUR is above the threshold of 3.0, supporting an unconfined bridge design approach as described in the WCDG.

8.2.1 Unconfined Bridge Design Width Criteria

For unconfined systems, the minimum hydraulic opening is defined by a ratio of the average main channel velocity within the proposed crossing to the average main channel velocity immediately upstream in a natural conditions model where the roadway fill is completely removed from the model. Unconfined bridge designs limit the encroachment of crossing structure on floodplain by targeting a maximum velocity ratio of 1.1.

A proposed corridor, based off the morphology and hydraulics of the reference reaches, formed the basis for a natural conditions model in which no roadway embankment encroaches on the stream corridor. See Sections 8.2.3 and 9.0 for additional discussion on channel geometry. To determine the minimum hydraulic clear span, a sensitivity analysis was conducted on the effect that encroachment has on the velocity ratio. Encroachment on the floodplain was applied beneath the Old 99 North pavement limit and SB I-5 pavement limits separately in the SRH-2D model. It was observed that the average main channel velocity in the natural conditions model at the location of the proposed SB I-5 crossing was higher than the average main channel velocity in the natural conditions model immediately upstream of the proposed SB I-5 crossing, creating a natural velocity ratio that exceeds 1.1 at the location of the proposed crossing. This relationship skews the evaluation of velocity ratios as defined above and does not well represent the intent of the evaluation, since no amount of encroachment can be removed from the model to bring the velocity ratio to 1.1 or below. Therefore, the velocity ratios presented here compare the average main channel velocity within the proposed crossing encroachment to the average main channel velocity at the location of the proposed crossing in the natural conditions model. For consistency, this approach was also applied to the Old 99 North crossing as well. Table 8.1 and Table 8.2 below present both current 100-year and projected year 2080 100-year flow velocities and velocity ratios.

Table 8.1. Velocity Comparison for 40-foot Span at Old 99 North

Locations	100-year Velocity (cfs)	Projected 2080 100-year Velocity (cfs)	Difference (cfs)
Natural Conditions (at Crossing Location)	4.2	4.3	0.1
Through 40-foot Span Crossing	4.5	4.8	0.3
Velocity Ratio	1.1	1.1	-

Table 8.2. Velocity Comparison for 40-foot Span at SB I-5

Locations	100-year Velocity (cfs)	Projected 2080 100-year Velocity (cfs)	Difference (cfs)
Natural Conditions (at Crossing Location)	4.8	5.0	0.2
Through 40-foot Span Crossing	4.8	5.1	0.3
Velocity Ratio	1.0	1.0	-

The results indicate that flow velocities and velocity ratios differ slightly between the two crossings. The Old Highway 99 crossing presents a velocity ratio of 1.1 for the current 100-year flow event, and 1.1 for the 2080 100-year event. The SB I-5 presents a velocity ratio of 1.0 for the current 100-year flow event, and 1.0 for the 2080 100-year event. Therefore, the proposed 40-foot minimum opening satisfies unconfined bridge design criteria. It is proposed that the SB I-5 crossing minimum opening also be 40 feet for consistency.

Structure width must also consider the free passage of LWM. Per the WSDOT HM Section 10-8.1, if the length of wood with root wads is less than 75 percent the span of the downstream crossing, or if the length of wood without root wads is less than 100 percent the span of the downstream crossing, then it is assumed that the risk of the wood lodging on the crossing is low. With a proposed minimum span of 40 feet, it could be expected to pass wood with root wads up to 30 feet in length or wood with no root wads up to 40 feet. Most of the wood observed upstream of the SB crossing was 25 feet or less in length. Placement of LWM under the crossing structure will require approval by HQ Hydraulics, but it is assumed that logs 30 feet long, that meet the requirements of a key piece, could be placed across the floodplain within the crossing.

8.2.2 Backwater and Freeboard

The WCDGs recommend the prevention of excessive backwater rise and increased main channel velocities during floods that might lead to scour of the streambed and coarsening of the stream substrate and that allow the free passage of debris expected to be encountered. Washington Administrative Code 220-660-190 requires a minimum 3-foot freeboard over the 100-year water surface elevation for bridge designs. It is practicable to meet the minimum 3 feet of freeboard over the 100-year water surface elevation at this crossing.

The existing Old 99 North roadway elevation is approximately 164 feet (NAVD88). Assuming a conservative structure thickness of 10 feet, this gives a structure low chord of 154 feet. The proposed 100-year water surface elevation 125.9 feet measured at the upstream existing edge of pavement of Old 99 North. This provides approximately 28.1 feet of freeboard. A minimum of 10 feet above the channel thalweg should be provided, if practicable, for constructability, future maintenance, and performing monitoring activity.

The existing SB I-5 roadway elevation is approximately 173 feet (NAVD88). Assuming a conservative structure thickness of 10 feet, this gives a structure low chord of 163 feet. The proposed 100-year water surface elevation is 123.8 feet measured at the upstream existing edge of pavement of SB I-5. This provides approximately 39.2 feet of freeboard. A minimum of 10 feet above the channel thalweg should be provided, if practicable, for constructability, future maintenance, and performing monitoring activity.

8.2.3 Channel Planform and Shape

The WCDGs require that the channel planform and shape mimic conditions within a reference reach, and the reference reaches identified adjacent to and upstream of the SB I-5 crossing and downstream of Dahl Road provides a target for the design of these characteristics. Measurements were made in MicroStation using site survey and LiDAR imagery within the reference reaches to determine a meander radius of curvature range, meander wavelength range, and an average meander belt width. The radius of curvature was measured to range from 20 feet to 60 feet, averaging approximately 35 feet. Average meander wavelength was measured as approximately 165 feet, and meander belt width was relatively consistent with valley bottom width and ranged from 54 feet to 88 feet. Historical Right-of-Way plans were also reviewed and support these planform dimensions.

Additionally, channel geometry design guidance was used to validate the typical channel geometry determined from the reference reach. The U.S. Army Corps of Engineers' Channel Restoration Design for Meandering Rivers (Soar and Thorne 2001) presents expressions based on a composite of relationships between meander wavelength, radius of curvature, and meander amplitude relative to channel BFW from a large sample of meandering channels. Using the results from these expressions for validation purposes, Secret Creek could be represented with an average radius of curvature of approximately 30 feet, a meander amplitude of approximately 60 feet, and meander wavelength of between 135 feet and 150 feet. Based on these stream measurements, design guidance, and the intent to connect to the existing channel alignment as naturally as possible, a design radius of curvature range of 10 feet to 45 feet at main channel centerline, a design meander belt width of 64 feet, and meander wavelengths between 100 and 170 feet were implemented in the proposed design.

8.2.4 Floodplain Continuity and Lateral Migration through Structure

Outside of the crossings, the channel meander belt width has been designed to mimic the meander belt width in the reference reaches, which provides space for the stream to meander within the valley confines similarly to the reference reach. The resulting 100-year peak flow event engages the floodplain and corridor similarly to the reference reach as well. Please see Appendix D for model results depicting the water surfaces through the proposed design, as well as in the reference reaches at the upper and lower extents of the model to compare design to reference reach.

The WCDGs require that the design maintains floodplain continuity. Velocity ratios, presented in the WCDG and HM as the primary metric to determine minimum opening for unconfined systems, indirectly assesses floodplain connectivity by maintaining that any encroachment on the floodplain is limited to the fringes where flows are negligible and not expected to play a significant role in the hydraulic functioning of the channel. The design analysis in Section 8.2.1 above includes minimizing increases in velocity through the crossing in the 100-year and 2080 100-year peak flow events so that the crossings have minimal impact to the hydraulic functioning of the channel within the crossings.

The WCDGs also require that bridges account for lateral channel movement that will occur in their design. The proposed crossing width allows for 28 feet of lateral channel movement. The tops of any structural footings shall be located to a depth such that they will remain below the 500-year total scour. The scour analysis, to be performed during the final design phase, will include calculations that assume the main channel has migrated to the face of the bridge abutment for design purposes to ensure any bridge abutments do not preclude vertical channel adjustment or cause structural stability concerns.

8.2.5 Channel Gradient

The WCDGs recommend, to the extent compatible with safety of the structure, its approach roads, and adjacent private property, allowing natural evolution of the channel planform and longitudinal profile. The proposed channel slope is 1.37 percent. According to the 2017 LiDAR, the stream has an average gradient of 1.11 percent from the SB I-5 culvert inlet to 2,760 feet upstream. Compared to the surveyed upstream profile, the LiDAR average gradient is closer to natural gradients observed downstream and considers a much longer stretch of stream. For these reasons, 1.11 percent is considered the reference reach gradient upstream of SB I-5. The proposed slope ratio is 1.23 (1.37 percent divided by 1.11 percent), less than the maximum of 1.25. The proposed slope connects the upstream profile to the downstream profile, while minimizing the length of channel regrade.

9.0 Streambed Design

The preliminary design presented in this report proposes to remove the existing concrete box culvert at the SB I-5 and Old 99 North crossing, remove the existing steel culvert pipe at the NB I-5 crossing, and to develop a new channel and crossing configuration. The new configuration extends from the upstream of the SB I-5 and Old 99 North culvert downstream to the outlet of the NB I-5 culvert. Changes to the channel and crossings and include a new horizontal main channel and corridor alignment, design profile, proposed channel cross-section, and streambed material. The design includes significant restoration work between the NB I-5 and SB I-5 pavements. Preliminary design sheets are included in Appendix E.

9.1 Alignment

The proposed design includes extensive modification of the existing stream alignment and profile. Under the existing conditions, the stream crosses beneath Old 99 North and SB I-5 via a 366-foot-long, 7-foot-tall by 5-foot-wide concrete box culvert. The stream then enters the approximately 1,200-foot-long reach between NB and SB I-5 culverts. Finally, the stream crosses beneath NB I-5 via an 8-foot-diameter, 240-

foot-long corrugated steel culvert. Under the proposed condition, the stream corridor generally follows the existing stream and culvert alignment to minimize the amount of cut and fill required, but the proposed corridor width has been increased to match the reference reaches and meander bends have been added throughout the entire proposed main channel horizontal alignment. The addition of meander bends through the proposed crossing more closely mimics the natural stream morphology encountered in the reference reach. The proposed channel planform utilizes an irregular pattern of meanders varying in radii of curvature between 10 and 45 feet. Templates for the proposed meander patterns were taken from existing channel meander patterns in the surveyed reference reaches upstream of the SB and downstream of the NB crossings. The inclusion of meanders, in conjunction with LWM and other channel habitat features, including preformed pools and riffles, will be designed to provide improvements for fish habitat.

Grading is proposed to begin 25 feet upstream of the existing SB I-5 culvert inlet at Station 36+17 and ends 17 feet downstream of the existing NB crossing culvert outlet at Station 16+92, giving a total regrade length of 1,925 feet along the proposed horizontal alignment. This regrade length will allow the proposed grade to tie into the existing upstream and downstream grades as naturally as possible, while minimizing the amount of excavation and regrade required. The proposed profile has been designed with a continuous 1.37 percent overall gradient. The upstream end of the profile has been designed to match the existing culvert inlet elevation so that the proposed channel elevation is not reduced in any way in comparison to the existing channel elevation.

Previous iterations of the preliminary design did not propose a regrade of the reach between NB and SB I-5. Based on discussions following the WSDOT internal review process, it was decided that the preferred approach going forward would be to regrade the entire reach between the two crossings. This approach will reduce concerns about long term streambed regrade, is expected to provide aquatic habitat improvement, and generally improves continuity and stream function.

9.2 Proposed Section

The channel cross section has been designed to mimic the reference reach. The channel section was designed with bank slopes like existing Secret Creek cross-sections from the reference reach to maintain consistency in hydraulic performance between the reference reach and proposed channel.

In the proposed cross section through the crossing, a low-flow channel was created with channel bottom slopes of 10(H):1(V) extending 3 feet outward on each side from the channel center. The main channel was then designed with 2(H):1(V) slopes extending 3 feet outwards. This creates a main channel width of 12 feet, a main channel depth of 1.8 feet, and a resultant BFW to a maximum depth ratio of 6.7. The two-year water surface elevation was designed to exceed the breakover point of the floodplain, which is consistent with existing conditions modeling in the reaches upstream and downstream of the I-5 crossings. The low-flow channel will be refined in later stages of the project to connect habitat features together and to ensure that the project is not a low-flow barrier. The low-flow channel will be constructed as directed by the engineer in the field. Floodplain benches were designed with 20(H):1(V) slopes extending outward from the breakover point between the main channel and the floodplain to the edge of the floodplain. Finally, side slopes will extend out from the edge of the floodplain at 2(H):1(V) to tie into the existing surface. Figure 9.1 depicts a proposed cross section near the existing culvert inlet, with an existing cross section from just upstream of the culvert inlet for comparison.

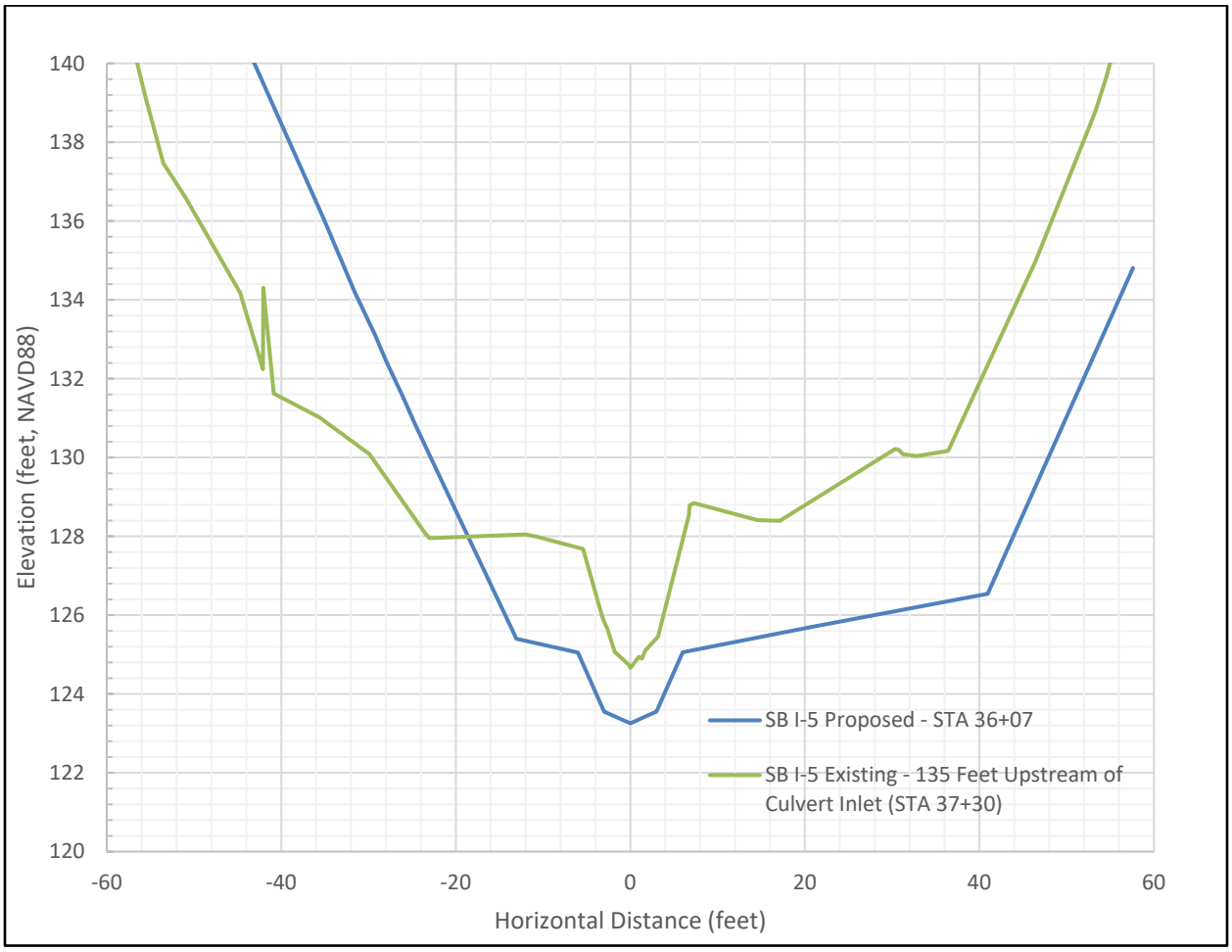


Figure 9.1. Existing and Proposed Channel Cross-Sections Upstream of the SB I-5 Crossing

9.3 Bed Material

The design intent of the proposed streambed gradation is to produce a streambed material gradation that mimics the natural streambed in terms of median particle size. As discussed in Section 5.0, the average pebble count results from the three pebble counts taken in the reference reach downstream of the NB I-5 and Dahl Road crossings will be used as the natural streambed reference material for all crossings. The primary reasons for selecting the downstream reference reach as the natural streambed material reference was due to channel gradient similarities between the downstream reach and the proposed reach where the proposed gradient of 1.37 percent is like the surveyed gradient of 1.30 percent, and the stream corridor confinement is like the proposed corridor design.

The designed streambed gradation was evaluated according to the Modified Shield's methodology as recommended in the WSDOT Hydraulics Manual (WSDOT 2019) for streams under 4 percent gradient. This approach assesses the point of incipient motion for the range of particle sizes in a gradation based on the shear stresses modeled in proposed conditions during the range of design flows. The calculated streambed material gradation is provided in Table 9.1. The average results from the three pebble counts taken in the reference reach downstream of the Dahl Road/log grade controls are also shown for comparison. Gradation results for all three pebble counts and the design gradation are shown in Figure 9.2.

Table 9.1. Proposed Modified Shield's Gradation

Particle Percent Smaller Than	Proposed Streambed Design (mm) (in)	Pebble Count Average (mm) (in)
D_{16}	2.4 (0.1)	9.9 (0.4)
D_{50}	29.1 (1.2)	32.4 (1.3)
D_{84}	87.1 (3.4)	65.0 (2.6)
D_{100}	140.3 (5.5)	106.0 (4.2)

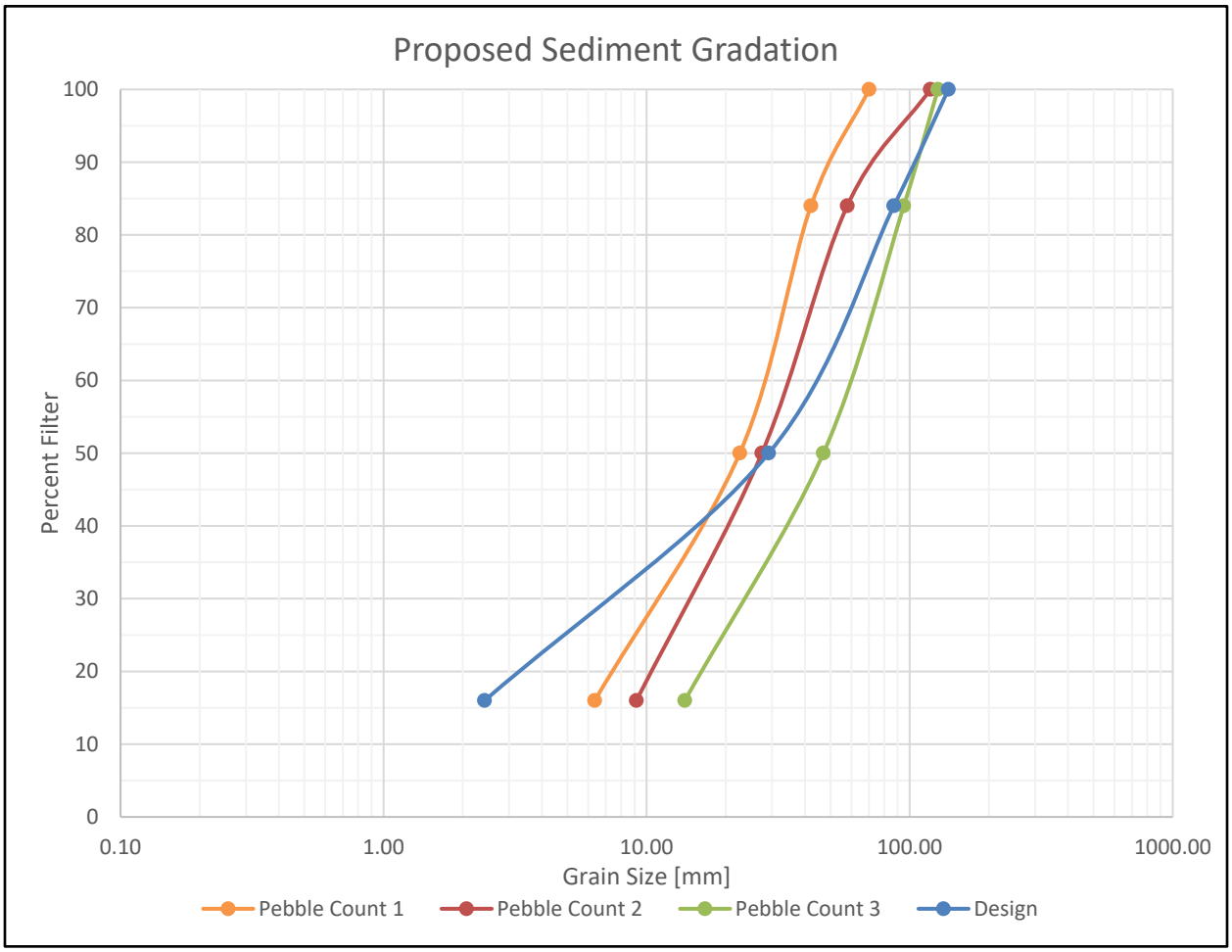


Figure 9.2. Existing and Proposed Streambed Material at the Secret Creek I-5 Crossings

The proposed streambed material should be constructed using WSDOT Standard Specifications for Road, Bridge, and Municipal Construction (WSDOT 2020). The proposed mix consists of 65 percent Streambed Sediment (Section 9-03.11(1)) and 35 percent 6-inch Streambed Cobbles (Section 9-03.11(2)). This gradation results in a D_{50} of 1.2 inch, which is within 20 percent of the average reference reach D_{50} of 1.3 inches. The proposed D_{84} is within 9 percent of the D_{84} of Pebble Count 3 of the design reference reach is therefore within the range of that observed in the reference reach. This streambed sediment composition was chosen because it is the closest gradation possible to satisfy stream simulation criteria while providing the maximum amount of streambed stability. The sizing calculations are available in Appendix F.

9.4 Channel Habitat Features

The installation of LWM is proposed throughout both Secret Creek I-5 crossings. The function of the LWM is to add complexity to the system by imitating natural wood recruitment. Following the WSDOT Hydraulics Manual and WDFW Stream Habitat Restoration Guidelines for guidance, the LWM was calculated using Fox and Bolton's 2007 research for selecting the number and size of key pieces reported in the Stream Habitat Restoration Guidelines (Cramer 2012). Based on the guidance, a BFW of 12.1 feet and a proposed stream length of 1,919 feet result in 64 key pieces using the 75th percentile of observed LWM in unmanaged streams investigated by Fox and Bolton. This meets the recommendation of 0.034 key pieces per foot of stream regrading.

Table 9.2. LWM Metrics

	No. of key pieces	Total No. of LWM pieces	Total LWM volume ($yd^{3)}$
Design	175	415	758.6
Targets	64	222	757.6
	surplus	surplus	surplus

The Stream Habitat Restoration Guidelines also provide guidance on total volume and quantities of all LWM. For streams of this BFW, the 75th percentile of total LWM indicates more than 38 pieces per 100 meters (12 pieces per 100 feet) of channel grading. With a proposed length of grading of 1,925 feet for both NB and SB crossings, this results in the need to place a minimum of 222 total pieces of LWM within the construction limits. The 75th percentile of total LWM volume indicates more than 99 cubic meters per 100 meters (1,066 cubic feet per 100 feet) of channel grading. With a proposed length of grading of 1,925 feet, this results in the need to place a minimum 20,455 cubic feet (757.6 cubic yards) of LWM within the construction limits.

The recommended size of a key piece, based upon BFW, should be a minimum of 1.31 cubic yards. This can be met by a piece approximately 30 feet long by 1.25 feet in diameter. Key pieces should meet the sizing criteria for key pieces reported by Fox and Bolton (2007) and should incorporate root wads for added complexity. The exact configuration and placement will be determined as the design progresses.

The final design must provide stability analyses that reduce the likelihood that adverse impacts to the roadway prism will occur due to the placement of LWM. The final LWM design will follow biomimicry concepts to provide fish habitat similar to that encountered in the reference reach. Preformed scour pools are to be included at stream meanders in the final stream design and may be designed in conjunction with some LWM features. LWM should be included across the floodplain and should include channel spanning wood, since extensive channel spanning wood was observed in the existing condition. The addition of smaller wood will be necessary as well, and slash should be incorporated into the floodplain bed material. Given the large vertical and horizontal clearance provided by the proposed bridge structures relative to the stream size, LWM underneath the bridge is likely feasible and should be included if approved by HQ Hydraulics. Additionally, the design must include bioengineering for bank stability immediately following construction; design coordination with the landscape architect's office is required.

10.0 Floodplain Changes

No net fill will be added within the floodplain, and available floodplain storage will be increased following removal of roadway fill through the crossing. The elimination of the existing culvert and replacement with wider crossings will reduce the backwater effect upstream, reducing upstream water surface elevations. Water surface elevations downstream of the project are expected to remain the same.

11.0 Climate Resilience

WSDOT recognizes climate resilience as a component of the integrity of its built structures. As such, the agency approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. For bridges and buried structures, the greatest 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 to maintain passability for all expected life stages and species in a system.

11.1 Climate Resilience Tools

Climate resilience is evaluated at each crossing using the Climate Impacts Vulnerability Assessment Maps that WSDOT created to assess risk level of infrastructure across the state (WSDOT 2011). The SB I-5 Secret Creek crossing has been evaluated, and it has been determined to be a high-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. For low or medium risk sites, the 2040 percent increase is used; for high-risk sites, the 2080 percent increase is used. Appendix G contains the information received from WDFW for the project site. The 100-year flow event was chosen to be evaluated because, as it is an extreme event, if the channel behaves similarly through the structure during this event as it does in the adjacent reaches, then it is anticipated that this relationship would be true at lower flows as well.

11.2 Hydrology

For each design, WSDOT uses the best available science to assess 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 re-evaluated to determine whether adjustments need be made, including adding standard error to the regression equation, basin changes in size or use, etc.

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 projected 100-year flow event to check for climate resiliency. The design flow for

the crossing is 259 cfs at the 100-year storm event. The projected increase for the 2080 flow rate is 27.6 percent, yielding a projected 2080 flow rate of 330.5 cfs.

11.3 Structure Width

The minimum hydraulic opening for a crossing based on Equation 3.2 from the WCDG is 16.5 feet; however, structure width was increased to 40 feet for reasons discussed in Section 8.0 and Section 9.0. This structure width was evaluated at the 100-year flow event and the projected 2080 100-year-flow event, and it was determined that it would produce similar velocities through the structure and adjacent reaches. The velocity comparisons for these flow rates can be seen in Table 8.1 and Table 8.2.

As the climate resiliency flows produce similar velocities and minimal changes upstream, downstream, and through the structure, it is recommended that the structure width need not be increased. As the velocities did not significantly change, neither did the velocity ratios and all remain within 1.1.

11.4 Freeboard and Countersink

The water surface elevation is projected to increase by up to 0.3 foot for the 2080 projected 100-year flow rate at the upstream face of the Old 99 North crossing to 126.2 feet at the proposed crossing inlet. The water surface elevation is projected to increase by up to 0.3 foot for the 2080 projected 100-year flow rate at the upstream face of the SB I-5 crossing to 124.1 feet. Due to the depth of the channel relative to the crossing roadway surfaces and available freeboard, the minimum required freeboard at this site should be increased to accommodate climate resilience, resulting in a minimum 3.3 feet of freeboard to account for the projected increase in water surface elevation. In addition, 10 feet of clearance should also be provided over the channel thalweg. Achieving minimum freeboard and clearance requirements is not expected to be a problem at this site.

11.5 Summary

A minimum hydraulic opening of 40 feet and a minimum freeboard of 3.3 feet for the current 100-year water surface elevation allow for the channel to behave similarly through the structure as it does in the adjacent reaches under the projected 2080 100-year flow event. A minimum clearance of 10 feet should be provided if practicable for maintenance monitoring. This will help ensure that the structure is resilient to climate change and that the system can function naturally, including the passage of sediment, debris, and water in the future.

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Puget Sound Stocks: North Puget Sound Volume, Olympia, Washington.

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Appendices

Appendix A – WSDOT Field Report

Appendix B – FEMA FIRM Map

Appendix C – SRH-2D Existing Conditions Model Results

Appendix D – SRH-2D Proposed Conditions Model Results

Appendix E – Preliminary Stream Plan, Profile, Details Sheets

Appendix F – Streambed Material Sizing Calculations

Appendix G—WDFW Future Projections for Climate-Adapted Culvert Design Printout

Appendix A

WSDOT Field Report

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WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: XL5949
	Project Name: I-5 Southbound Secret Creek to Pilchuck Creek Fish Barrier Removal PHD	Date: 7/30/2019 – PMX Visit 8/27/2019 – Stakeholder Visit
	Project Office: Mount Vernon Project Engineer's Office	Time of Arrival: 8:05 am / 11:05 am
	Location: I-5 Southbound MP 211.7 Crossing of Secret Creek	Time of Departure: 4:00 pm / ~1:00 pm
Purpose of Visit: Site recon – BFW measurements	Weather: Overcast (PMX visit) Clear, warm (Stakeholder visit)	Prepared By: T. Nabours

Meeting Location:
Intersection of Old 99 North and Lind Road

Attendance List:

Parametrix Field Visit 7/30/2019:

Name	Organization	Role
Sarah Rife	Parametrix	Hydraulics/Hydrology – PHD
Tyler Nabours	Parametrix	Hydraulics/Hydrology – PHD
Steve Krueger	Parametrix	Fisheries Biologist – PHD

Stakeholder Field Visit 8/27/2019:

Name	Organization	Role
Jeff Kamps	WSDOT	Environmental Manager
Joelle Blais	WSDOT	Environmental
Beth Toberer	WSDOT	Env. – Permitting/Biologist
Luke Assink	WSDOT	HQ Hydraulics
Damon Romero	WSDOT	Biologist
Bryan Beemer	WSDOT	PEO
Shane Spahr	WSDOT	PEO
Scott Rockwell	Stillaguamish Tribe	Representative
Derek Marks	Tulalip Tribes	Representative
Stan Walsh	SRSC	Representative
Kevin Lautz	WDFW	Tech Assistance/Permitting
Tyler Nabours	Parametrix	Hydraulics/Hydrology – PHD
Paul Fendt	Parametrix	Hydraulics/Hydrology – PHD

Bankfull Width:

During the 7/30/2019 field visit conducted by Parametrix, bankfull width measurements were as follows. Upstream of the SB I-5 culvert inlet, measurements were taken at 90 feet (BFW 12.3 feet), 244 feet (BFW 11.8 feet), 419 feet (9.3 feet), 469 feet (BFW 9.2 feet), and 514 feet (BFW 16.0 feet). Downstream of the SB I-5 culvert outlet, measurements were taken at 28 feet (BFW 11.2 feet) and 93 feet (BFW 15 feet). Average of all measurements is 12.1 feet.

The 8/27/2019 stakeholder visit focused on visual observation of the channel and a search for locations for bankfull width measurement locations. Participants travelled approximately 550 feet upstream of the crossing to view the extents of the stream documented by Parametrix. BFW measurements were made at some locations identified by Parametrix during the 7/30 field visit for corroboration. A BFW measurement of approximately 16 feet was made by the stakeholder group near the measurement made by Parametrix 515 feet upstream of the culvert inlet and corroborates the two measurements. This location was noted as displaying relatively less characteristic of incision in comparison to the channel nearer to the culvert. Some participants of the field visit travelled beyond 550 feet upstream of the culvert inlet to search for additional opportunities for BFW measurement. The results of their search

were not gathered by Parametrix and are not documented in this Field Report. An additional small tributary input to the stream was noted near the SB I-5 culvert inlet. It is not believed to contribute significantly to the overall hydrology of the stream through the crossing.

A separate Field Report has been produced to document field visits to the NB I-5 crossing (WDFW Site ID 990622). In this report, a reference reach on Secret Creek downstream of the NB I-5 culvert and Dahl Road culvert was identified and the average of six BFW measurements was 12.0 feet.

Reference Reach:

Parametrix identified the reach outside the influence of the culvert in the immediate 500 feet upstream of the culvert inlet as a potential reference reach during the 7/30/2019 field visit (Figure 1).

Discussion during the stakeholder field visit on 8/27/2019 included a recently installed fish-passable 17-foot span culvert upstream at SR 532. It was noted by Derek Marks that no significant tributary occurs between SR 532 and the I-5 crossing, but that significant wetland area drains to roadway ditches that reach the stream. At the end of the stakeholder field visit, there was a discussion on the geomorphology of the stream and preferred location of reference reach. Stakeholders expressed concern over the use of the reach in the immediate 500 feet upstream of the culvert inlet as a reference. This was due in part to their concern over the channel morphology in this reach, which exhibited a low width to depth ratio as a result of possible incision. Discussion among stakeholders included desire to maintain existing culvert inlet elevation to minimize further disconnect of floodplain, and that designing for wildlife connectivity should be considered. During the stakeholder visit, no agreement was made on a reference reach. Parametrix concluded that additional analysis of the watershed, long profile, and surficial geology was needed to help evaluate the characteristics of the potential reference reach.

Date: 5/6/2020 Author: ZieglCor Path: \\parametrix.com\pmx\PSO\Projects\Clients\1631-WSDOT\553-1631-127AE SecretCrk-Pilchuck\99Svcs\GIS\MapDocs\Figures\SecretCreek Figure2.1 ProjectArea Alt.mxd

Source: ESRI, WSDOT, StreamStats, WA DNR, Snohomish County

Figure 2.1 Project Area
Secret Creek

Secret Creek Culverts I-5
Potential Reference Reach Area
Watercourse

0 125 250 500 Feet

Snohomish County, WA

Figure 1. Site Map

Data Collection:

The Parametrix site investigation was conducted on 7/30/2019 by Sarah Rife (hydraulics and hydrology), Steve Krueger (fisheries biologist), and Tyler Nabours (hydraulics and hydrology engineer) from Parametrix. The team recorded site observations and measurements at the crossings, 514 feet upstream of the SB I-5 culvert inlet, and 470 feet downstream of the SB I-5 culvert outlet. The collection of data included site photographs, bankfull width measurements, record of LWM in channel and recruitment potential, pebble counts, fish habitat assessment, record of pool and riffle/step dimensions if applicable, record of rocks and other key features, and records of overbank vegetation and soil types.

Observations:

Distance Upstream of Culvert WDFW ID 990623 (I-5 SB)

meters	feet	Notes
0	0	Culvert (Picture 1)
11	36	LWM (Large Woody Material) 18" ϕ, 20' L (Picture 2)
13	43	MWM (Mobile Woody Material) 4-6" ϕ, 8' L (Picture 3-looking upstream from banks, LWM Picture 4-looking downstream)
		LWM 18" ϕ, 12' L
		LWM 6" ϕ, 15' L
18	59	Clean sand& silty bottom + some small gravel
		High vegetation
		Woody debris in/ spanning the channel (Picture 5)
27.3	90	BFW 12.3'
29	95	High vegetation, overgrown banks, some undercutting (Picture 6)
37.8	124	MWM multiple logs in water, undercut banks >1' (Picture 7)
46.8	154	LWM 40" ϕ, 60' L (cottonwood), channel spanning (Picture 8)
		Channel bottom-very mucky, high clay/ silt content (Picture 9 and 10)
51	167	Pool ~6" depth
51-55	167-180	Riffle
55.5	182	Pool ~1' depth
59	194	LWM 18" ϕ, 25' L, channel spanning
70	230	Fallen tree, lots of LWM
74.3	244	BFW 11.8'
96	315	Lots of little meanders (high sinuosity), some lateral scour/ incised banks
		Dominated by reed canary grass/ stinging nettles
		MWM
		Observed medium gravel sizes ~1" (Picture 11)
		Alternating riffles and pools, residual pools 6-24" depth
		Sediment from the bottom of one of the residual pools (Picture 12)
102	335	LWDx2 12" ϕ
117	384	Large cobbles 4-6" ϕ
127.6	419	BFW 9.3'
142.9	469	BFW 9.2'
156.6	514	Pebble Count 1
		BFW 16.0'

Distance Downstream of Culvert WDFW ID 990623 (I-5 SB)

meters	feet	Notes
0	0	Culvert 5' width by 7' with 3” sediment deposition) (Picture 1)
		Wingwalls 9'7" opening span
		Sediment size in culvert 0.5-5 mm, clean
8.4	28	BFW 11.2'
12.8	42	LWM 1.4' ϕ, 9' L
13.4	44	2' by 4' boulder
14.4	47	LWM 24" ϕ, 29' L + 30" ϕ, 30' L- log in water (alder) (Picture 2)
20	66	LWM (Looking upstream) (Picture 3)
25	82	Pebble Count 1 (Picture 4)
25-29	82-95	Riffle
28.2	93	BFW 15'
29-37	95-121	Pool
37-45	121-148	Riffle with cobbles (Picture 5 and 6)
39-53	128-174	Channel armoring on left bank ~3'ϕ boulders (Picture 7)
45-53	148-174	Pool (Picture 8)
57	187	Woody Material 6"ϕ, 12' L (Picture 9)
60-66	197-217	Channel armoring on right bank ~18" ϕ boulders
72	236	LWM 8-12" ϕ, L unknown (willow)
75.5	248	LWM 6-10" ϕ, 30' L (alder), channel spanning
72.5-76	238-249	Riffle
79	259	LWM 10" ϕ, 15' L, channel spanning (Picture 10)
81.5	267	LWM 6" ϕ, 15' L
82	269	LWM 4" ϕ, 15' L
91.8	301	Pebble Count 2 (Picture 11)
98.5-107.3	323-352	Pool, armoring along both banks (Picture 12)
109-119	358-390	Pool (Picture 13)
105	344	LWM 16" ϕ, 60' L (cottonwood), channel spanning, evidence of beaver
109	358	LWM 16" ϕ, 16' L (alder)
142.9	469	Pebble Count 3 (Picture 14)

Pebble Counts/Sediment Sampling:

Pebble counts were conducted during the 7/30/2019 site visit. One pebble count was conducted upstream of the SB I-5 crossing (Count 1) and two pebble counts were conducted downstream of the SB I-5 crossing (Count 2 and Count 3) the results are presented in Figure 2.

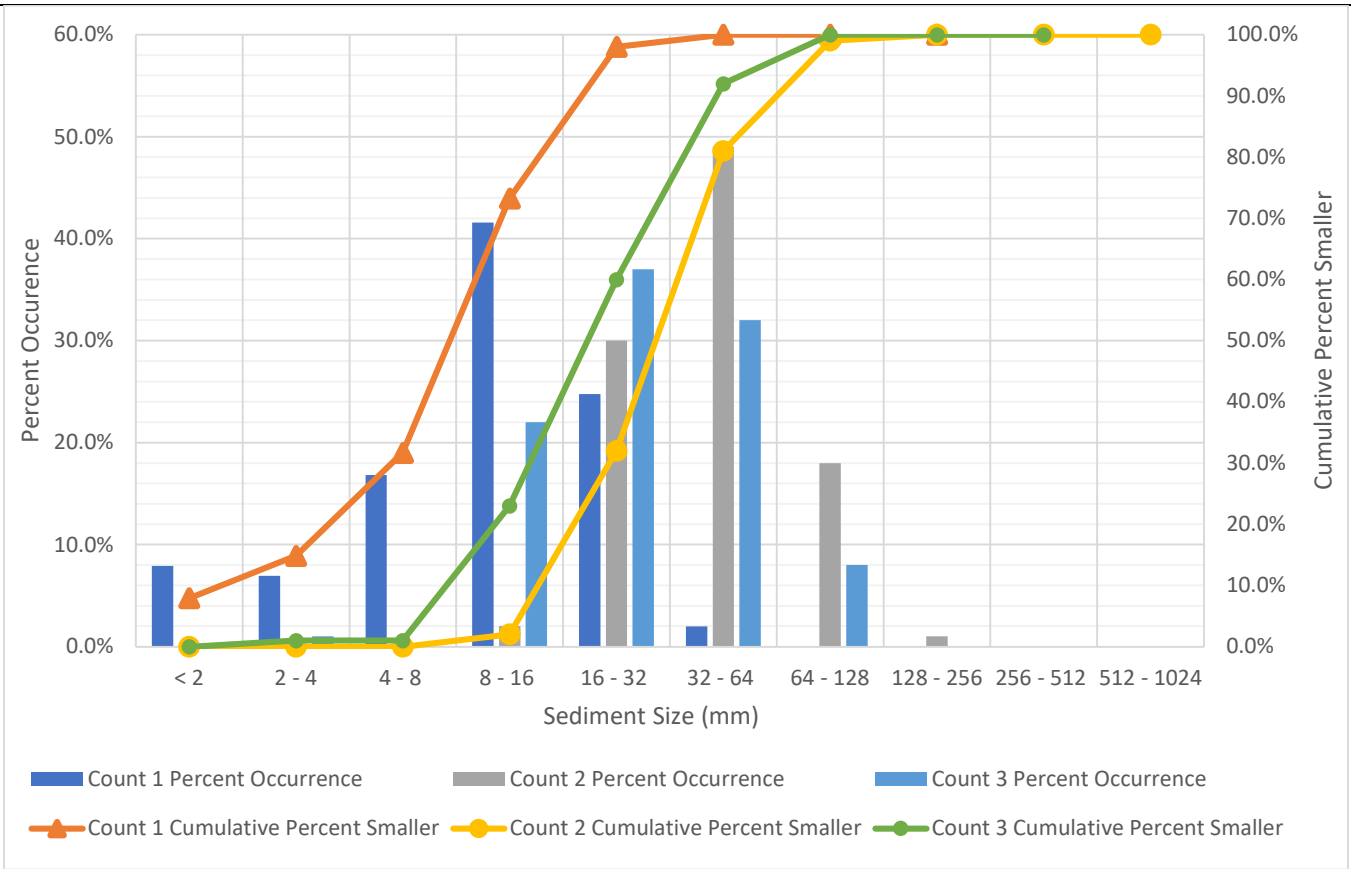

Figure 2. Sediment Properties in Vicinity of SB I-5 Crossing

Photos:

Photographs in Attachment A and Attachment B are referenced in site observations.

Attachment A –

Photographs Upstream of I-5 SB Culvert - WDFW Barrier ID 990623

Photo 1 –

Photo 2 –

Photo 3 –

Photo 4 –

Photo 5 –

Photo 6 –

Photo 7 –

Photo 8 –

Photo 9 –

Photo 10 –

Photo 11 –

Photo 12 –

Attachment B –

Photographs Downstream of I-5 SB Culvert - WDFW Barrier ID 990623

Photo 1 –

Photo 3 –

Photo 2 –

Photo 4 –

Photo 5 –

Photo 6 –

Photo 7 –

Photo 8 –

Photo 9 –

Photo 10 –

Photo 11 –

Photo 12 –

Photo 13 –

Photo 14 –

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Appendix B

FEMA FIRM Map

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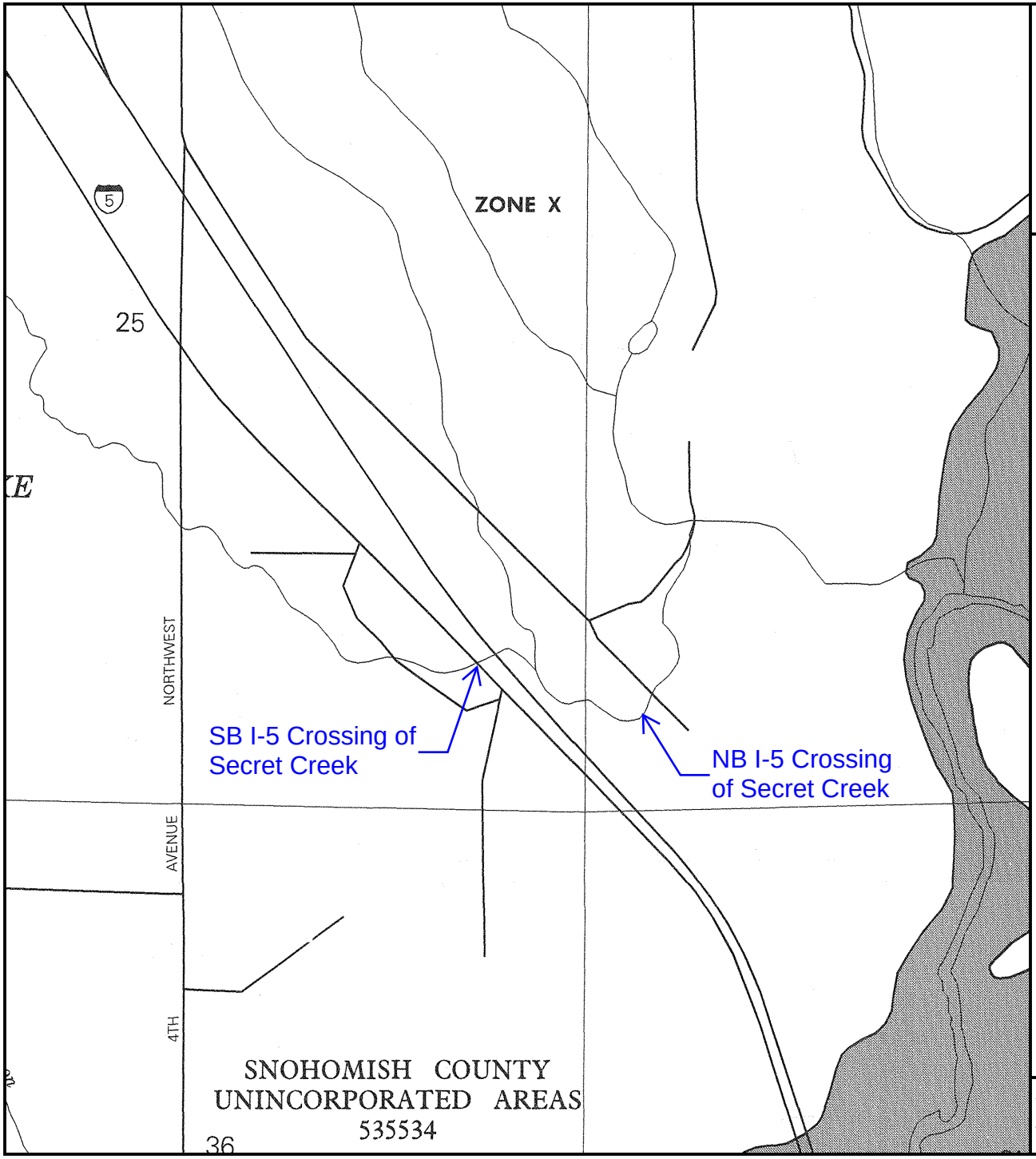

APPROXIMATE SCALE IN FEET

1000 0 1000

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

SNOHOMISH COUNTY, WASHINGTON AND INCORPORATED AREAS

PANEL 380 OF 1575

(SEE MAP INDEX FOR PANELS NOT PRINTED)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
SNOHOMISH COUNTY, UNINCORPORATED AREAS	535534	0380	E

MAP NUMBER
53061C0380 E

EFFECTIVE DATE:
NOVEMBER 8, 1999

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

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Appendix C

SRH-2D Existing Conditions Model Results

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Parametrix

Figure A.1.1
Secret Creek at I-5 Southbound
2-Year Water Surface Elevation

Parametrix

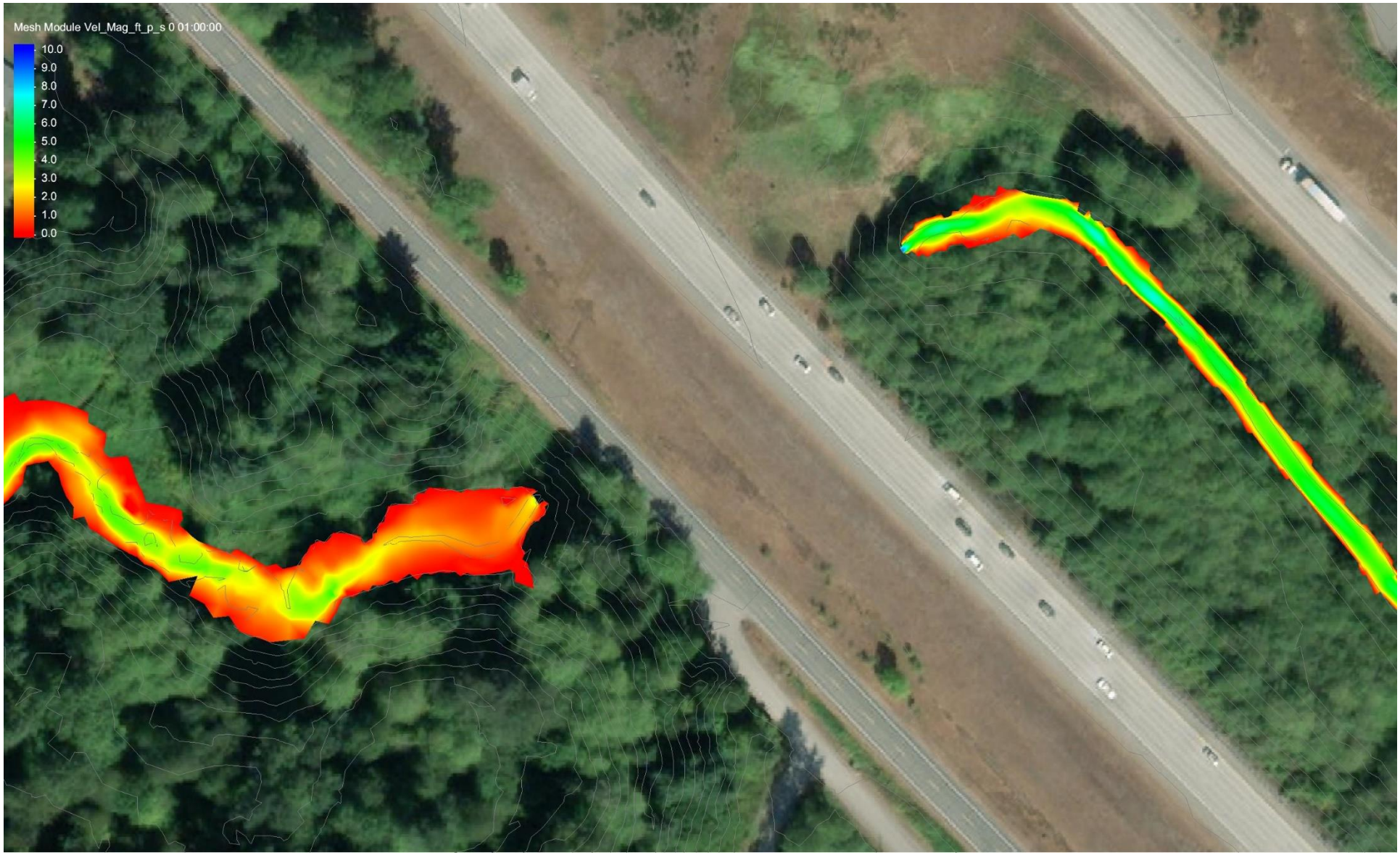
Figure A.1.2
Secret Creek at I-5 Southbound
2-Year Velocity

Parametrix

Figure A.1.3
Secret Creek at I-5 Southbound
2-Year Shear Stress

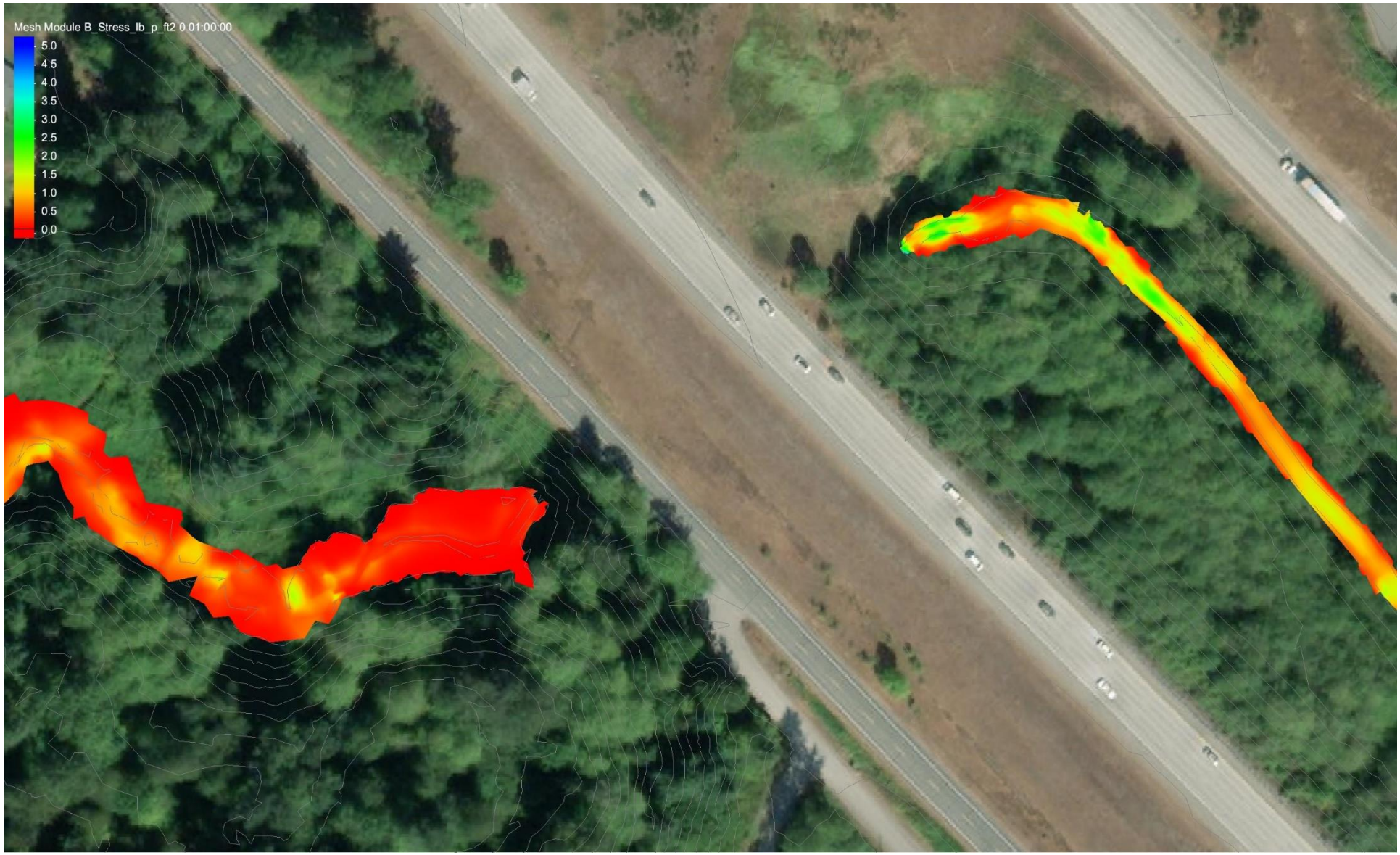
Parametrix

Figure A.1.4
Secret Creek at I-5 Southbound
25-Year Water Surface Elevation



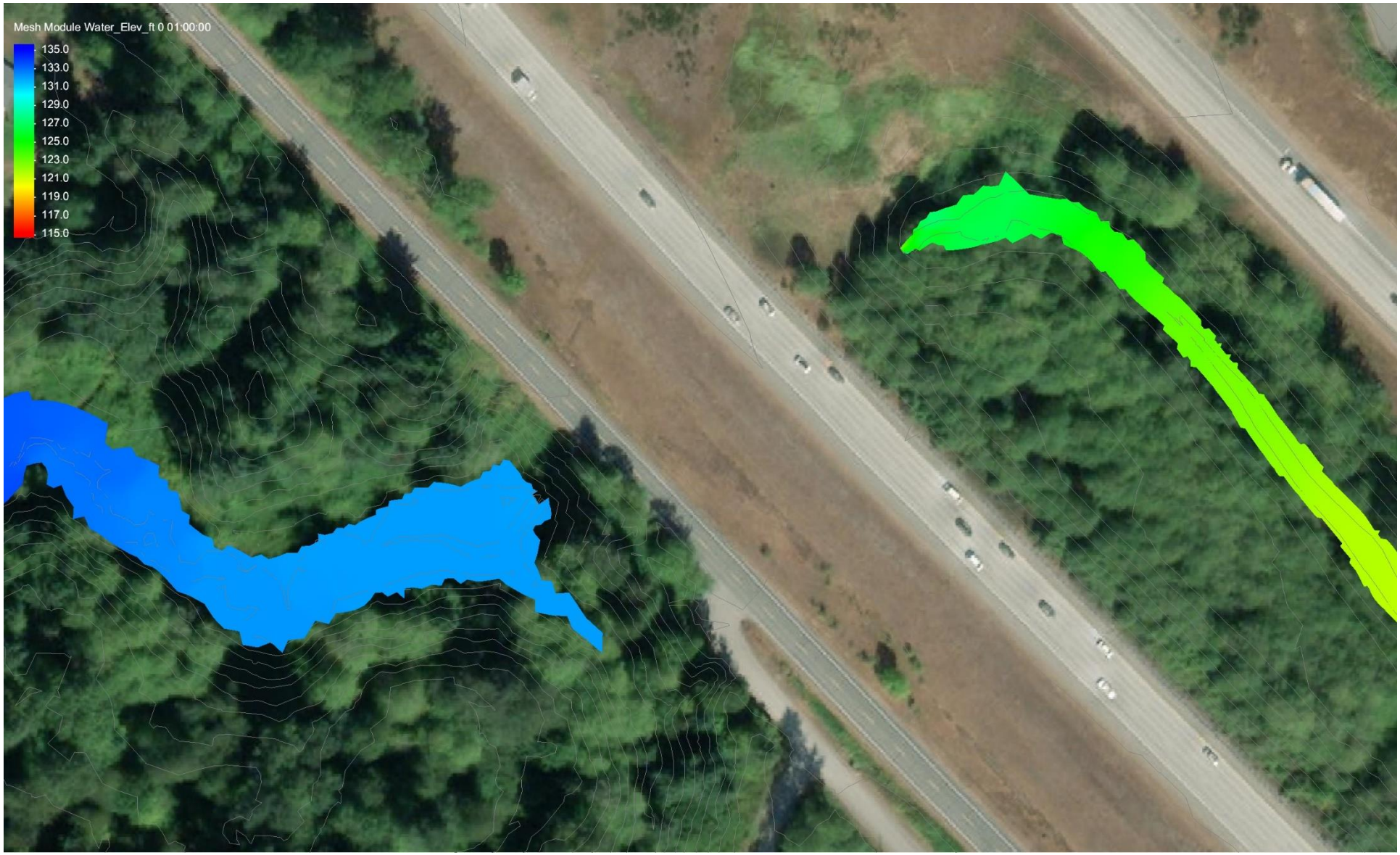
Parametrix

Figure A.1.5
Secret Creek at I-5 Southbound
25-Year Velocity



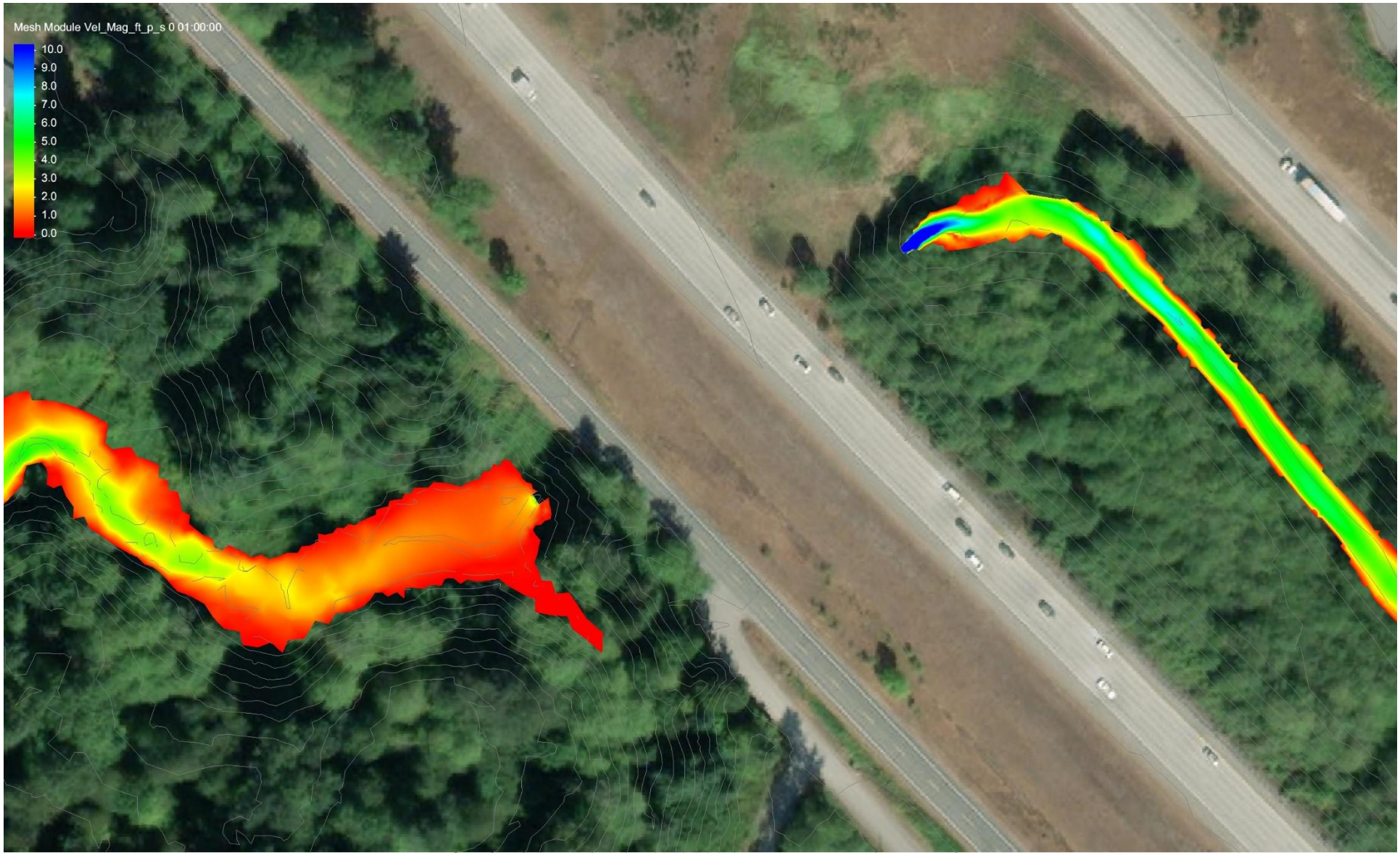
Parametrix

Figure A.1.6
Secret Creek at I-5 Southbound
25-Year Shear Stress



Parametrix

Figure A.1.7
Secret Creek at I-5 Southbound
100-Year Water Surface Elevation



Parametrix

Figure A.1.8
Secret Creek at I-5 Southbound
100-Year Velocity

Parametrix

Figure A.1.9
Secret Creek at I-5 Southbound
100-Year Shear Stress

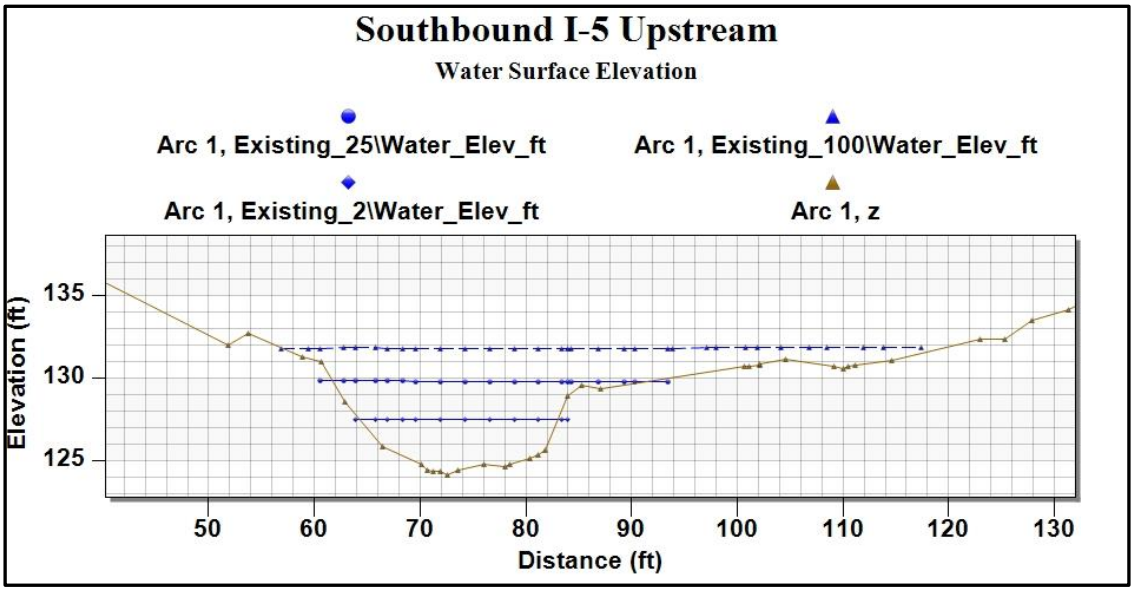


Figure A.2.1
Secret Creek at I-5 Southbound

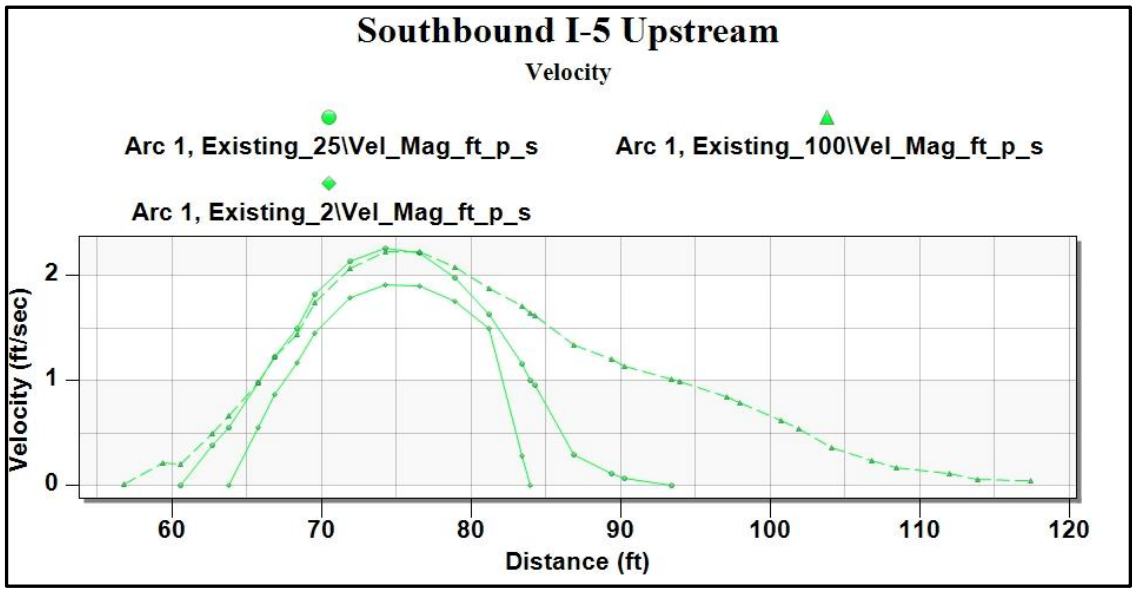


Figure A.2.2
Secret Creek at I-5 Southbound

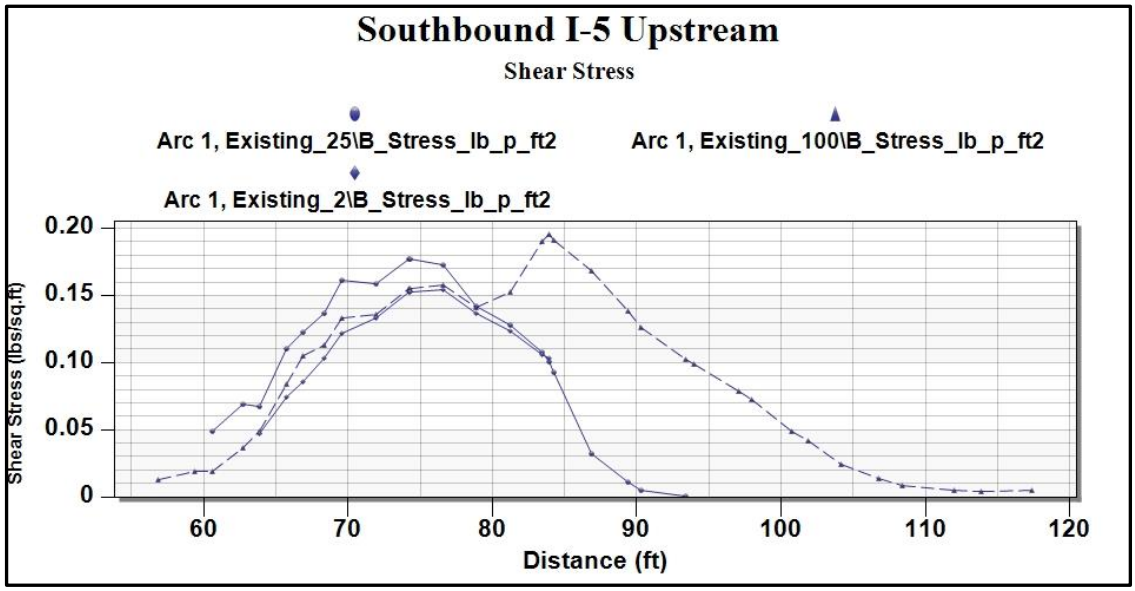


Figure A.2.3
Secret Creek at I-5 Southbound

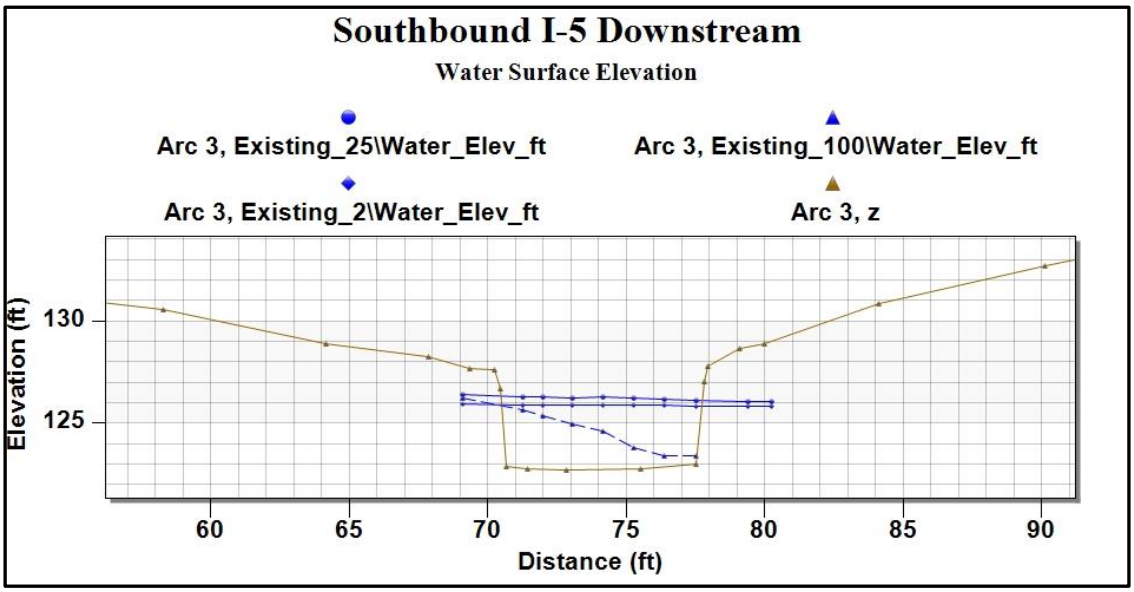


Figure A.2.4
Secret Creek at I-5 Southbound

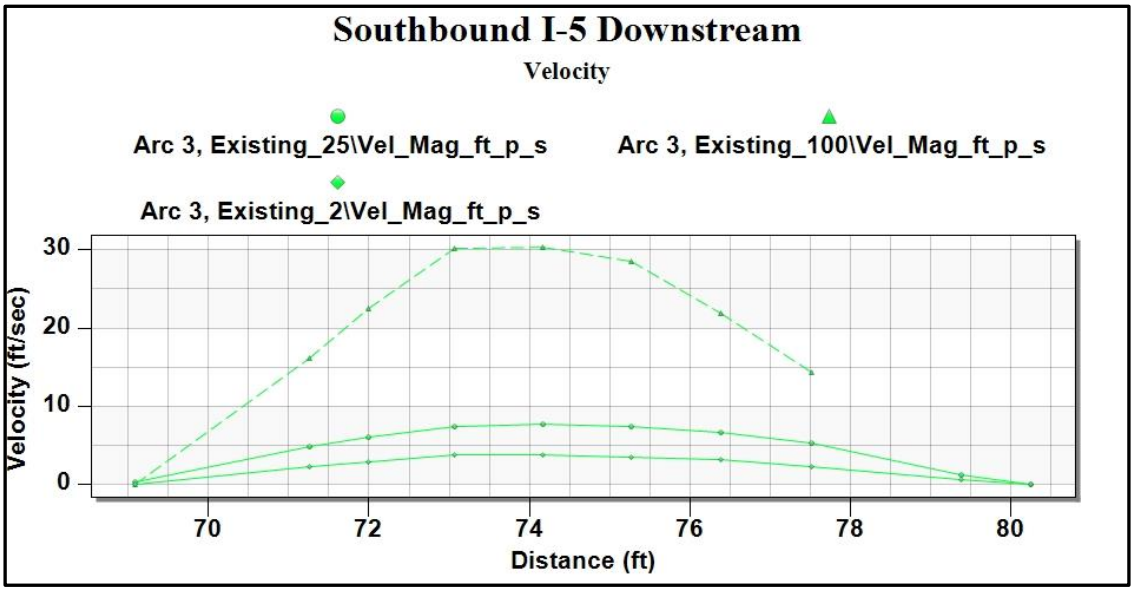


Figure A.2.5
Secret Creek at I-5 Southbound

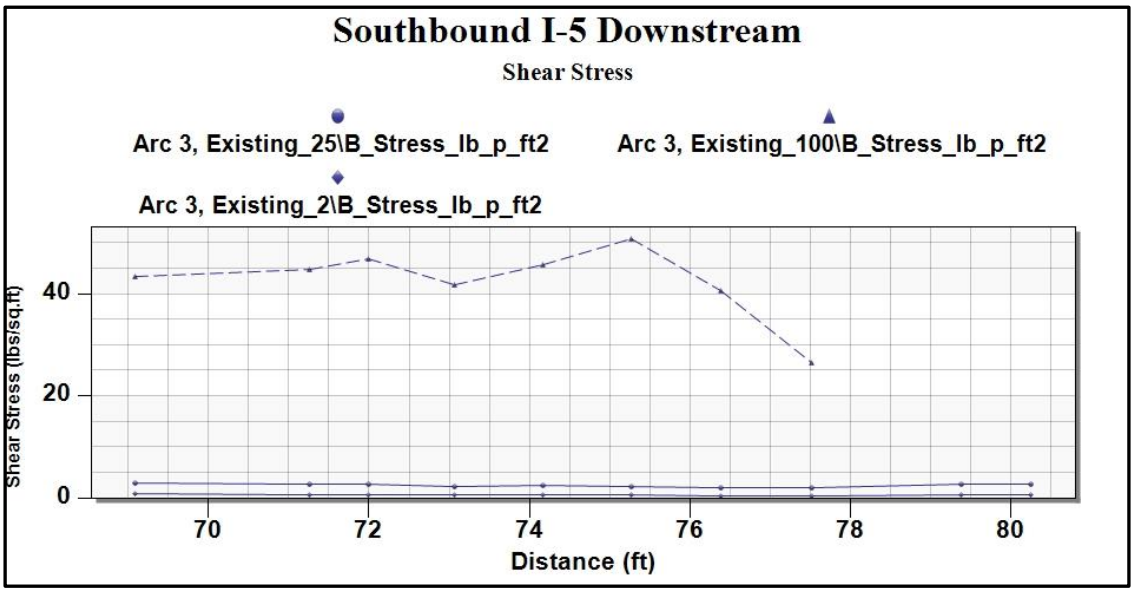


Figure A.2.6
Secret Creek at I-5 Southbound

Appendix D

SRH-2D Proposed Conditions Model Results

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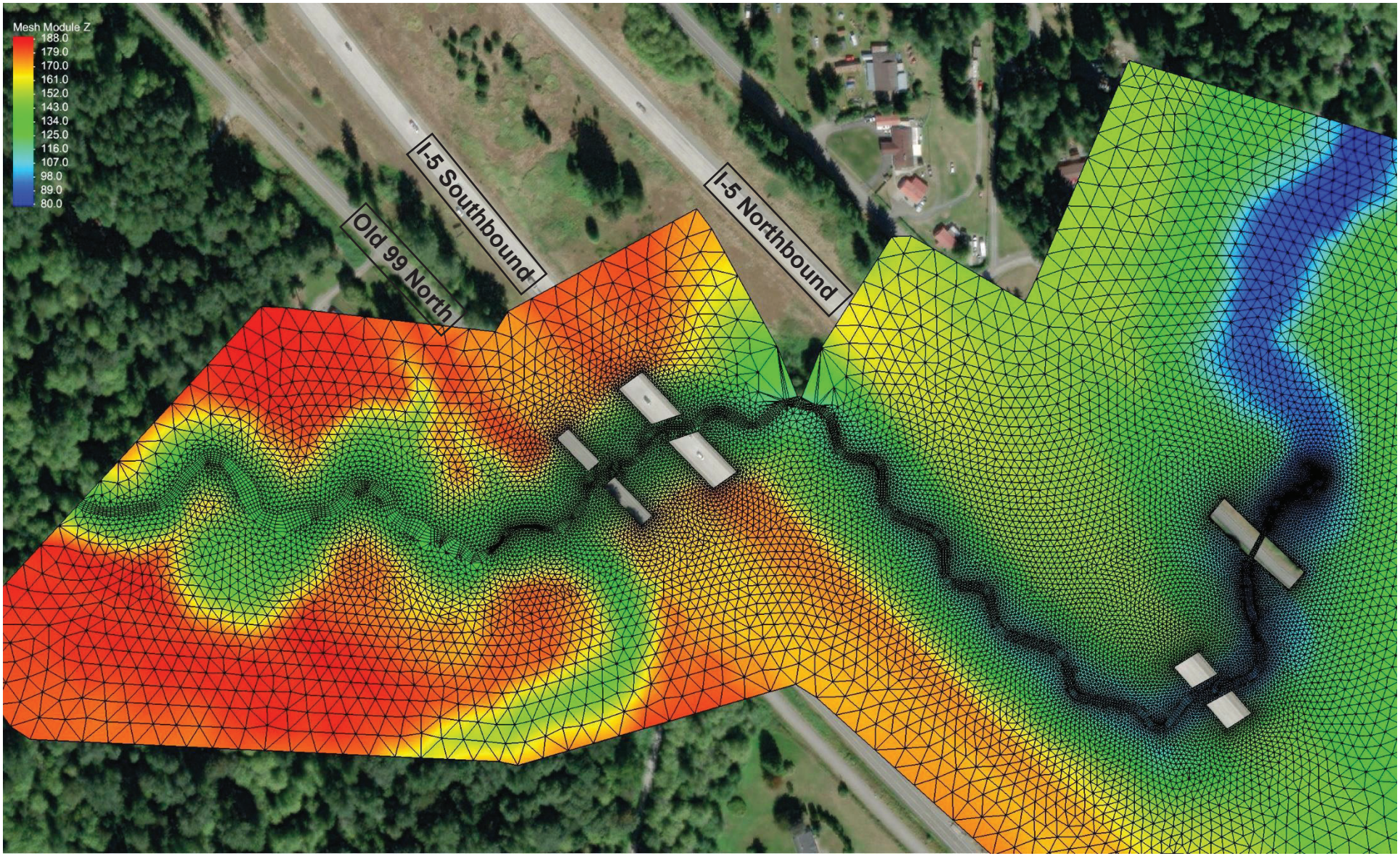
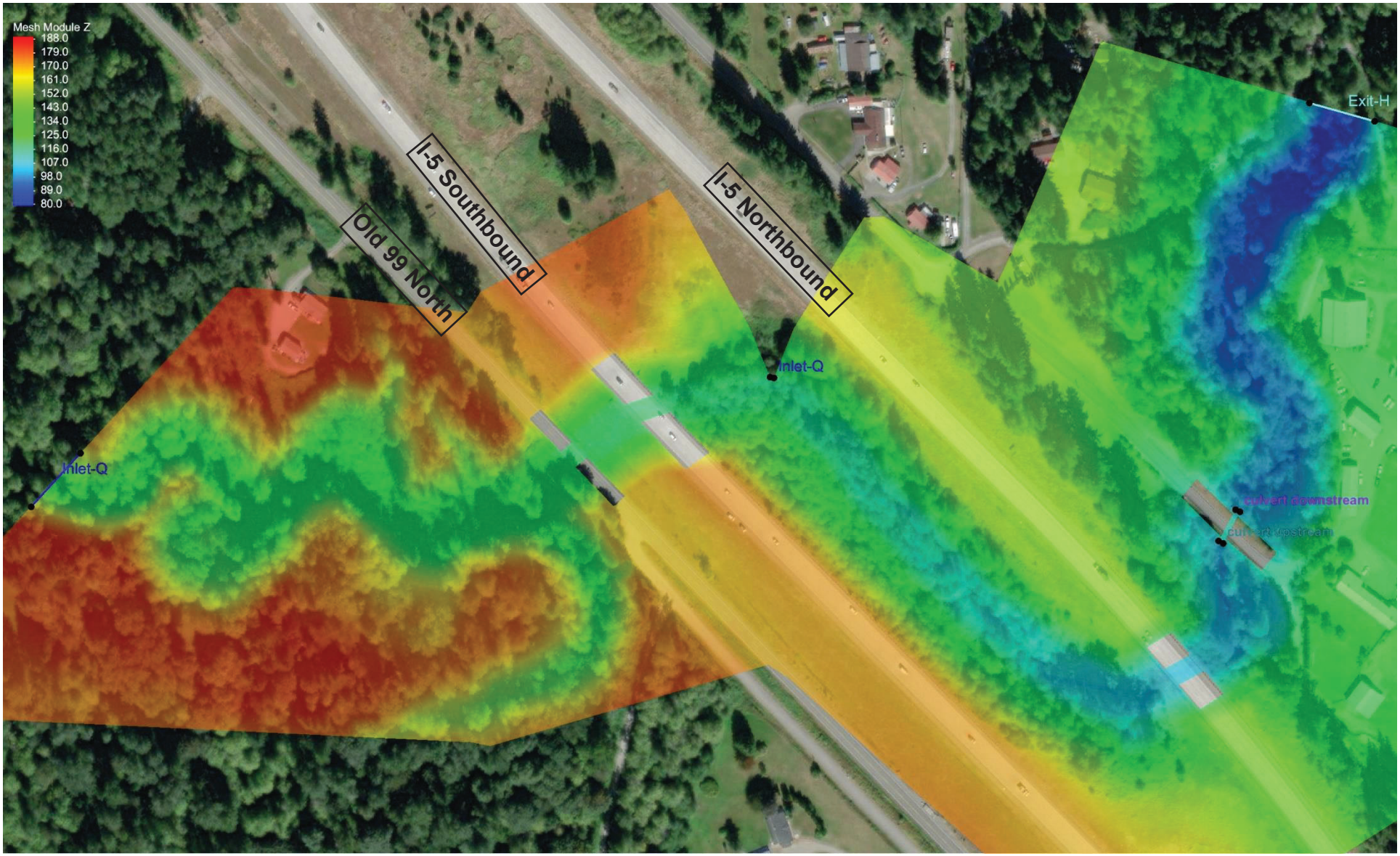


Parametrix

0 250 500 1,000 Feet

Figure B.1.1
Secret Creek at I-5
SRH2D Model Mesh



Parametrix

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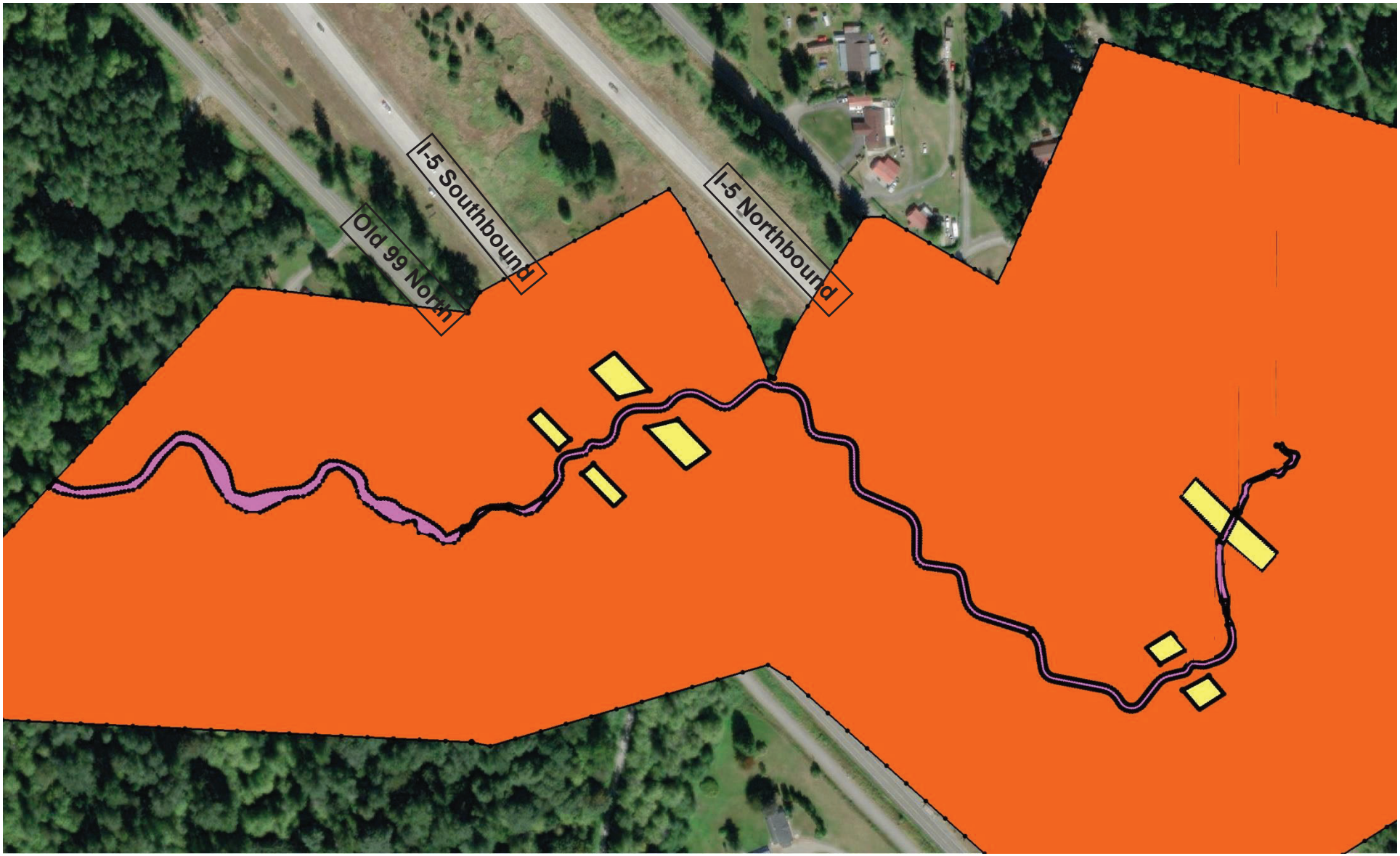
Figure B.1.2
Secret Creek at I-5
Boundary Conditions



Parametrix

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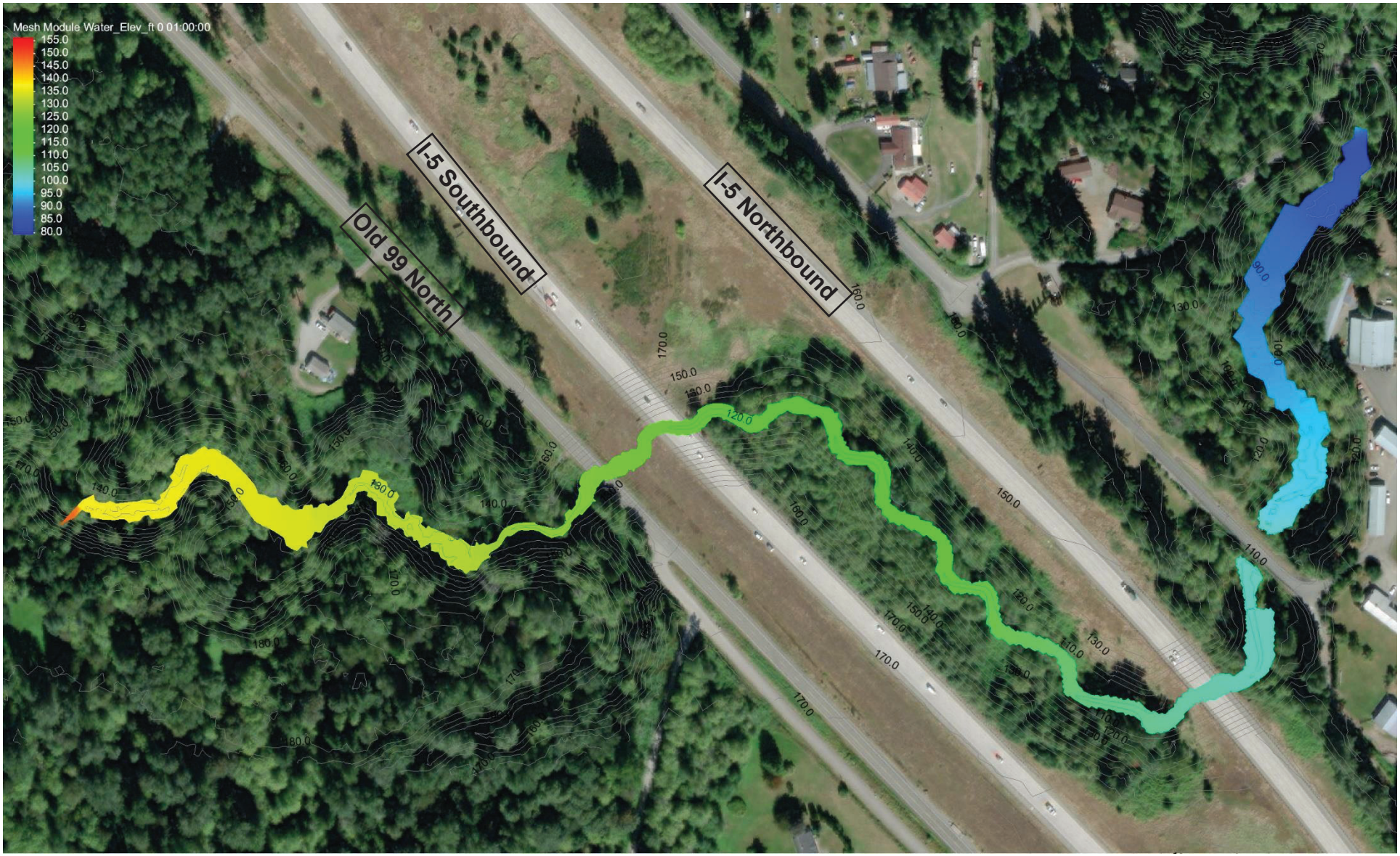
Figure B.1.3
Secret Creek at I-5
Model Roughness



Parametrix

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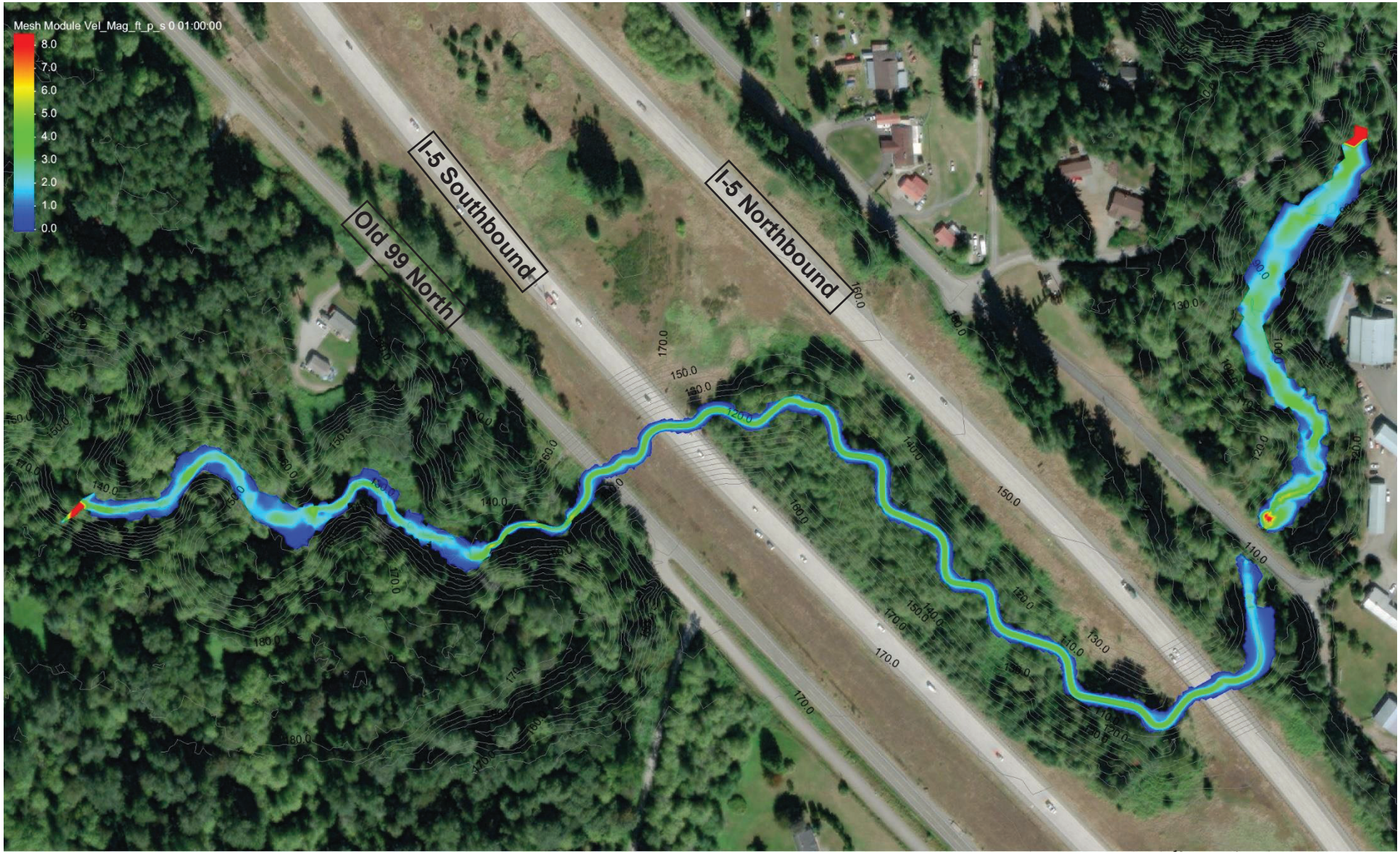
Figure B.1.4
Secret Creek at I-5
2-Year Water Surface Elevation



Parametrix

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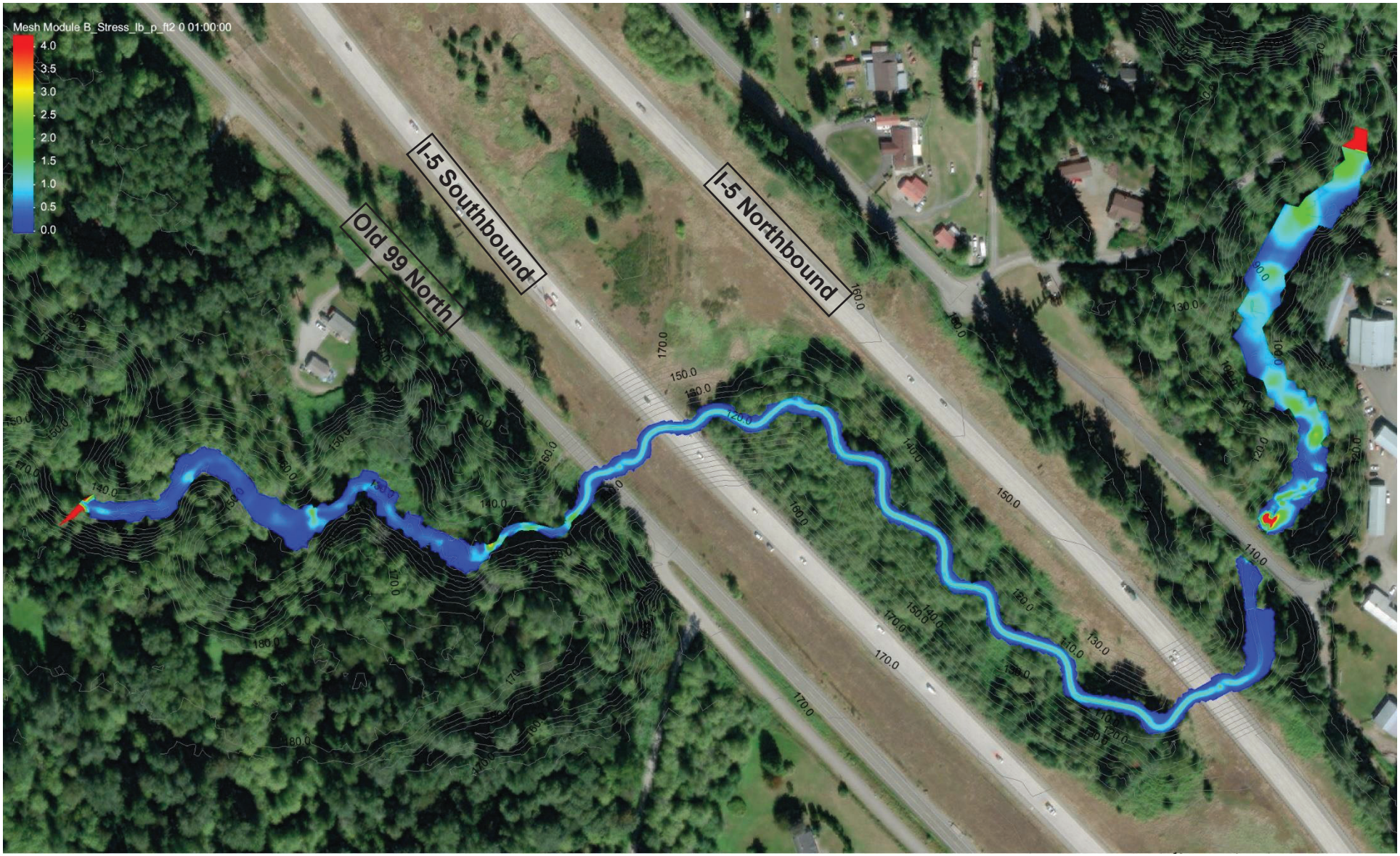
Figure B.1.5
Secret Creek at I-5
2-Year Velocity



Parametrix

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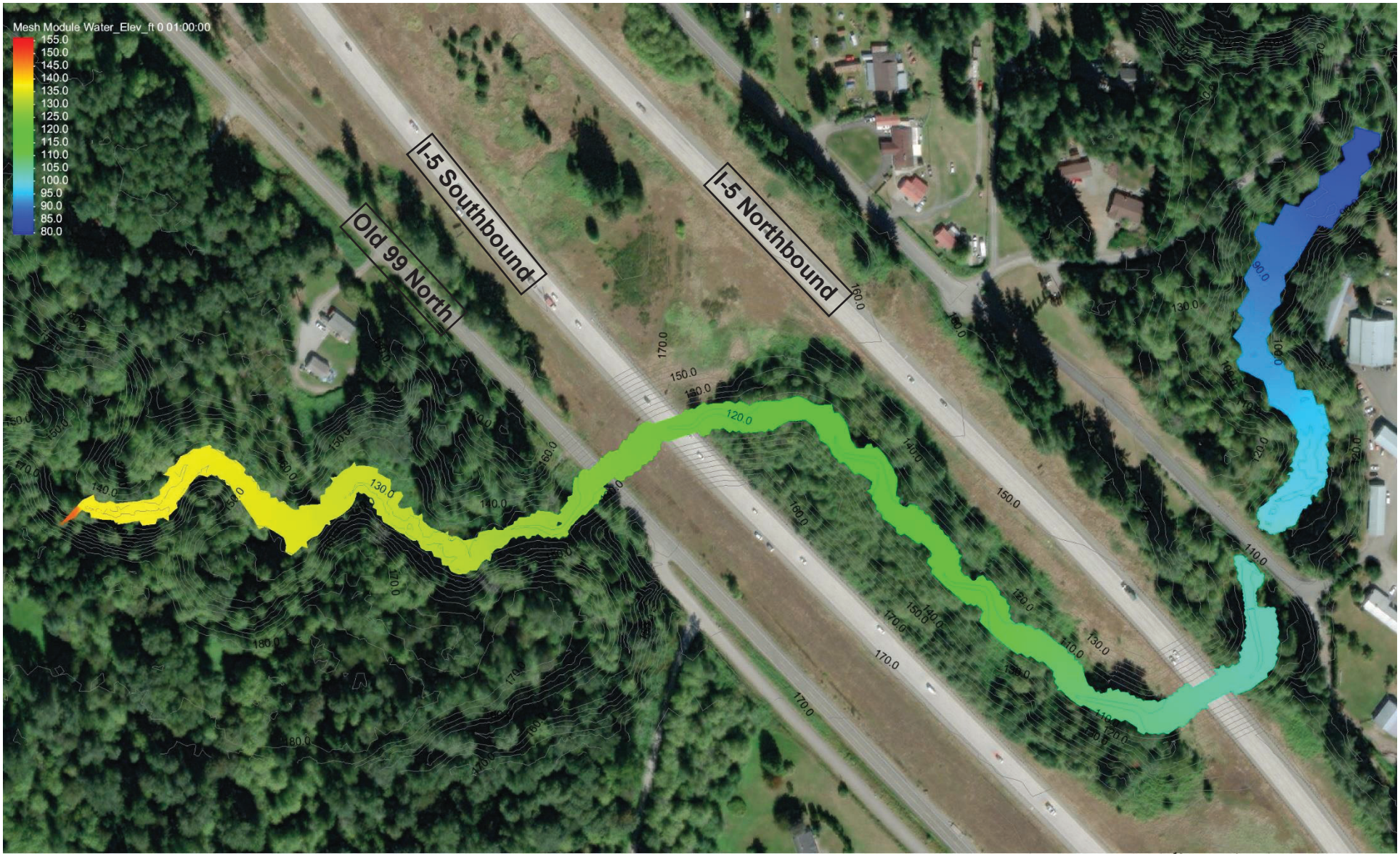
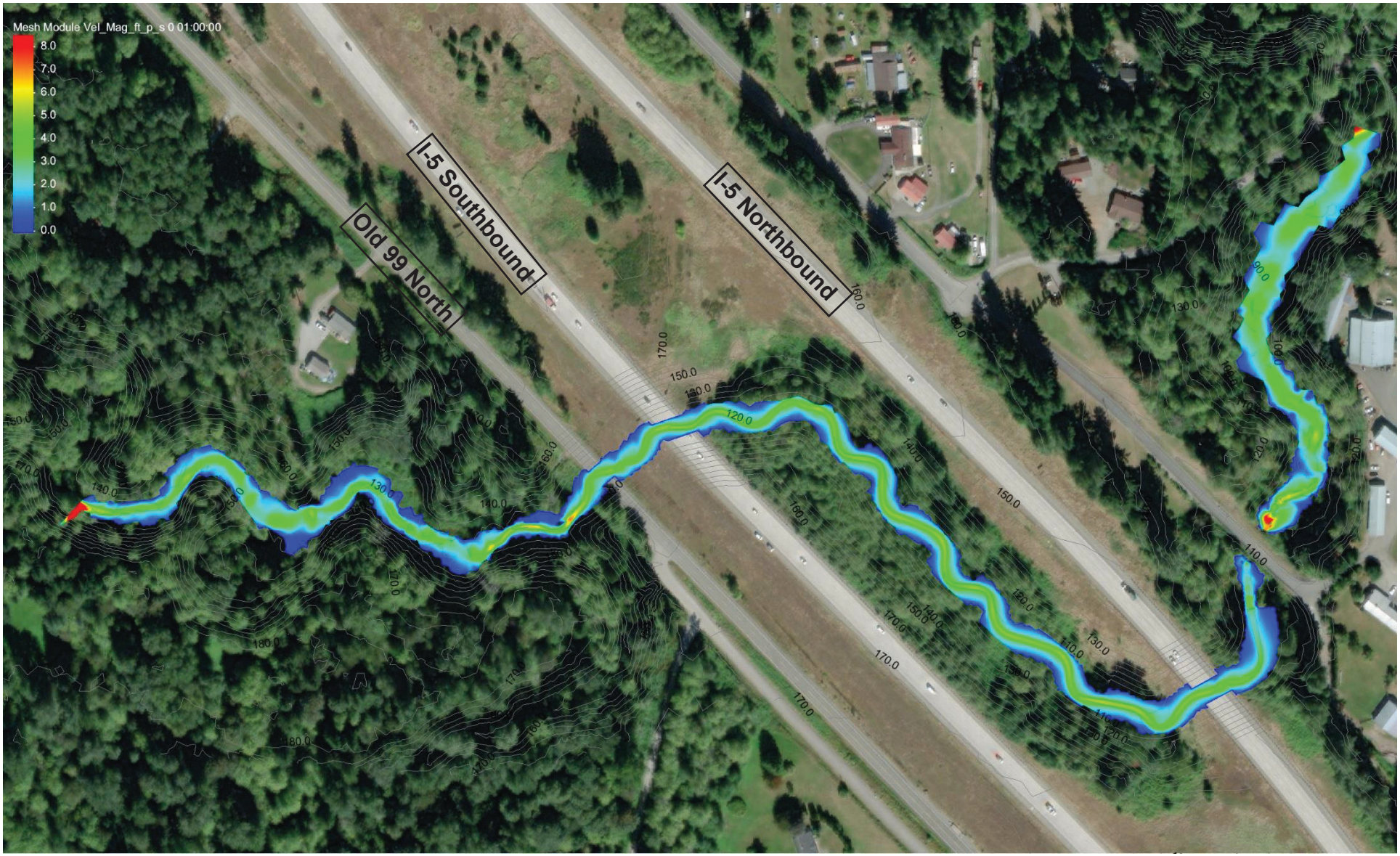
Figure B.1.6
Secret Creek at I-5
2-Year Shear Stress



Parametrix

0 250 500 1,000 Feet

Figure B.1.7
Secret Creek at I-5
25-Year Water Surface Elevation



Parametrix

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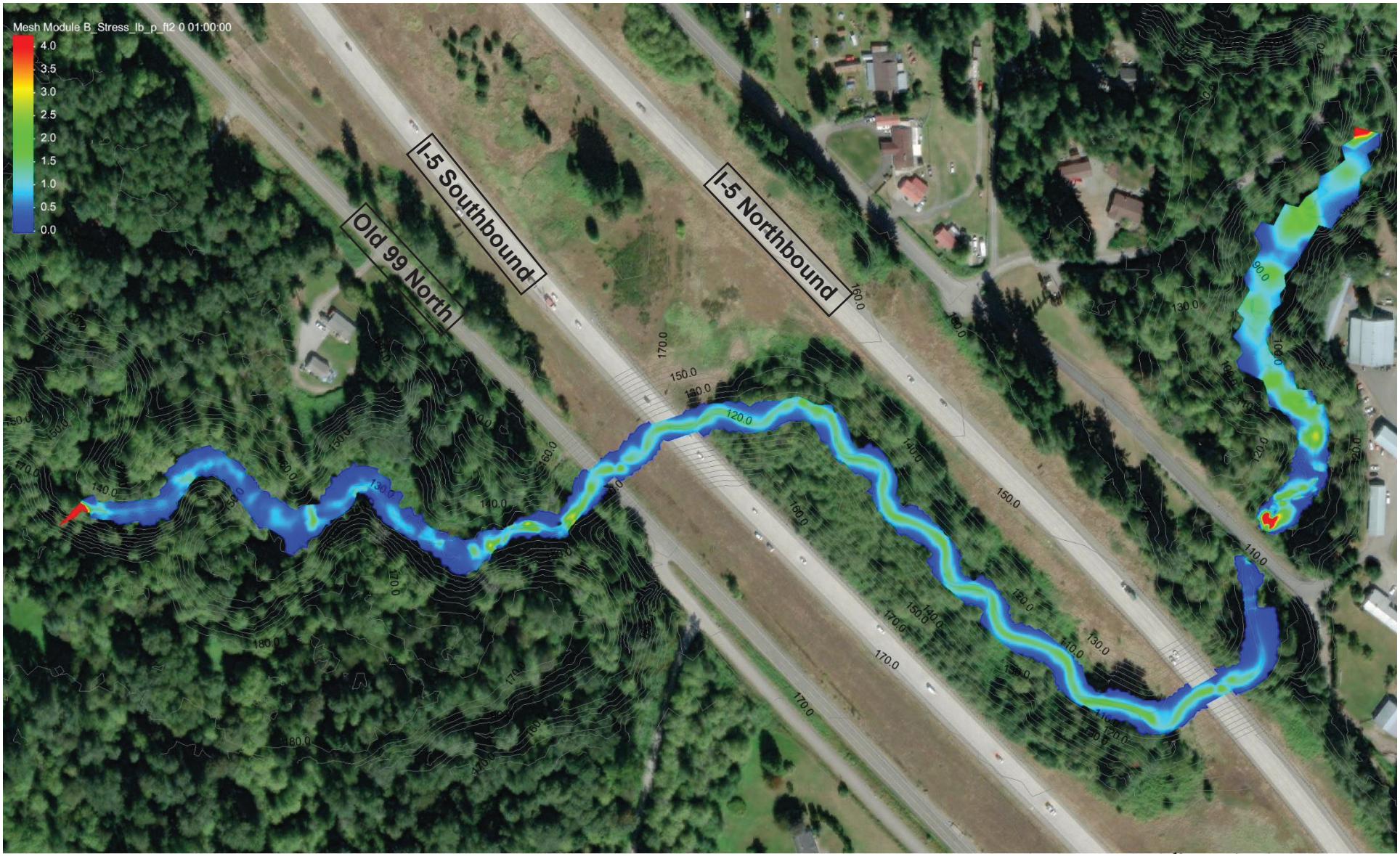
Figure B.1.8
Secret Creek at I-5
25-Year Velocity



Parametrix

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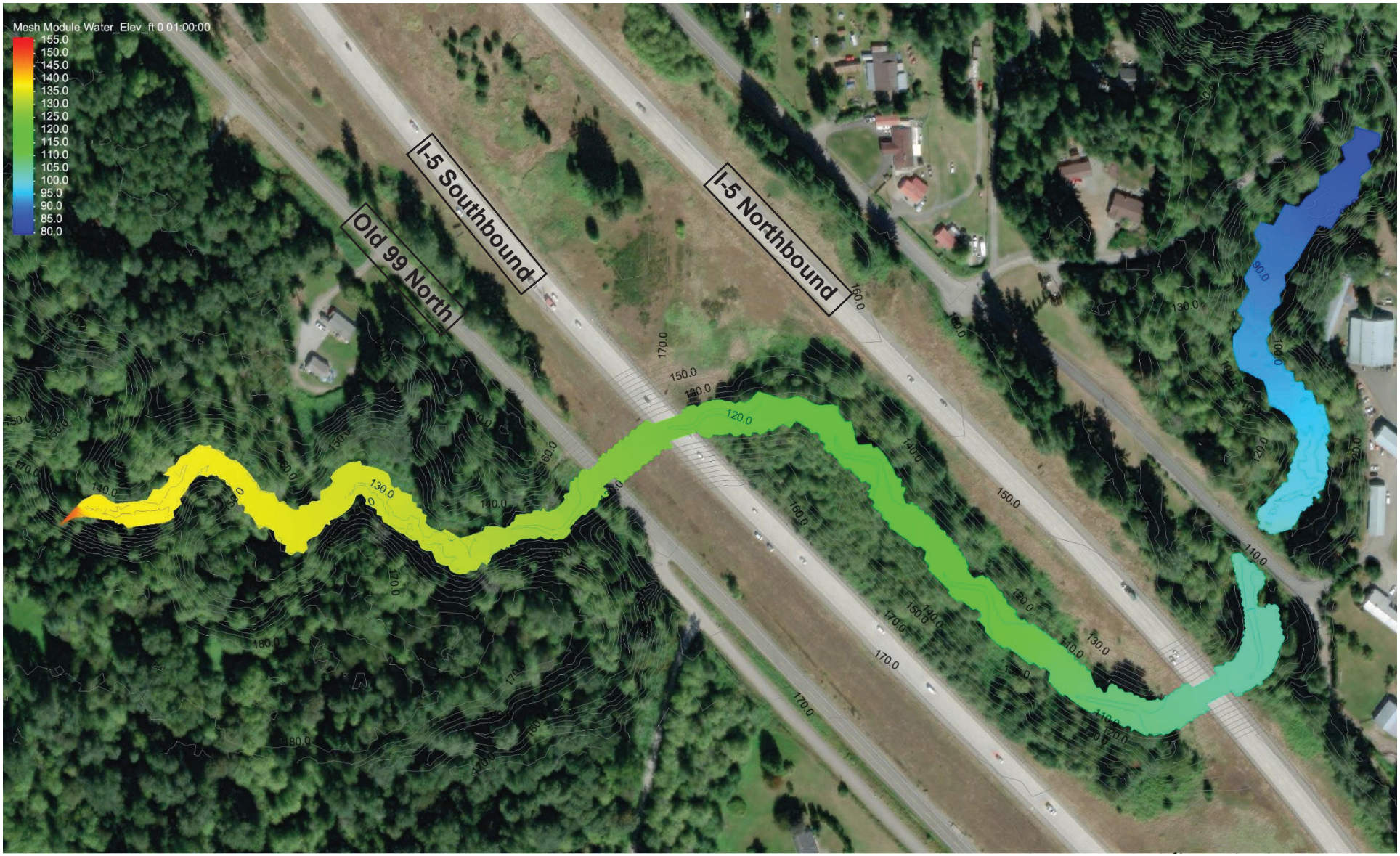
Figure B.1.9
Secret Creek at I-5
25-Year Shear Stress



Parametrix

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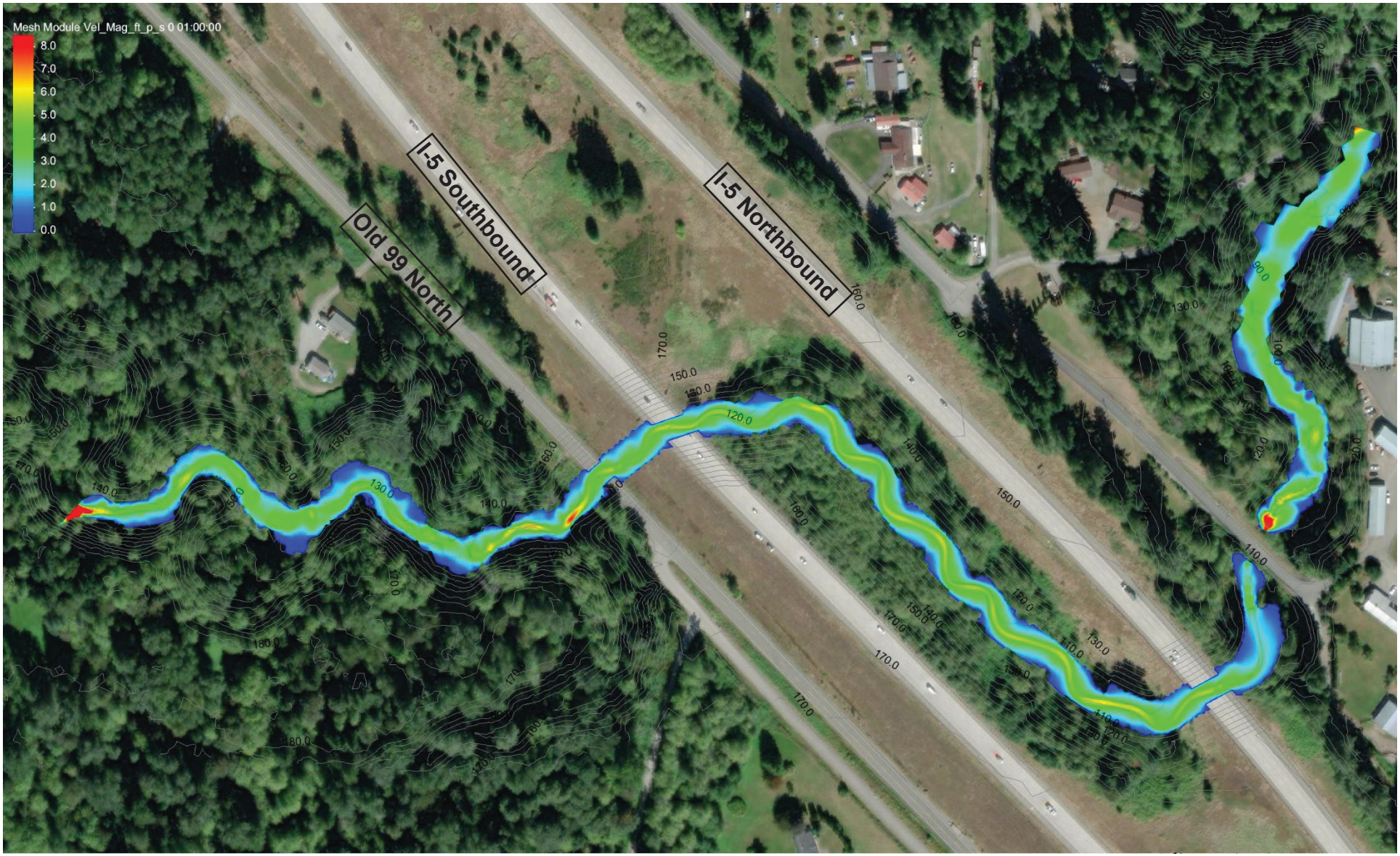
Figure B.1.10
Secret Creek at I-5
100-Year Water Surface Elevation



Parametrix

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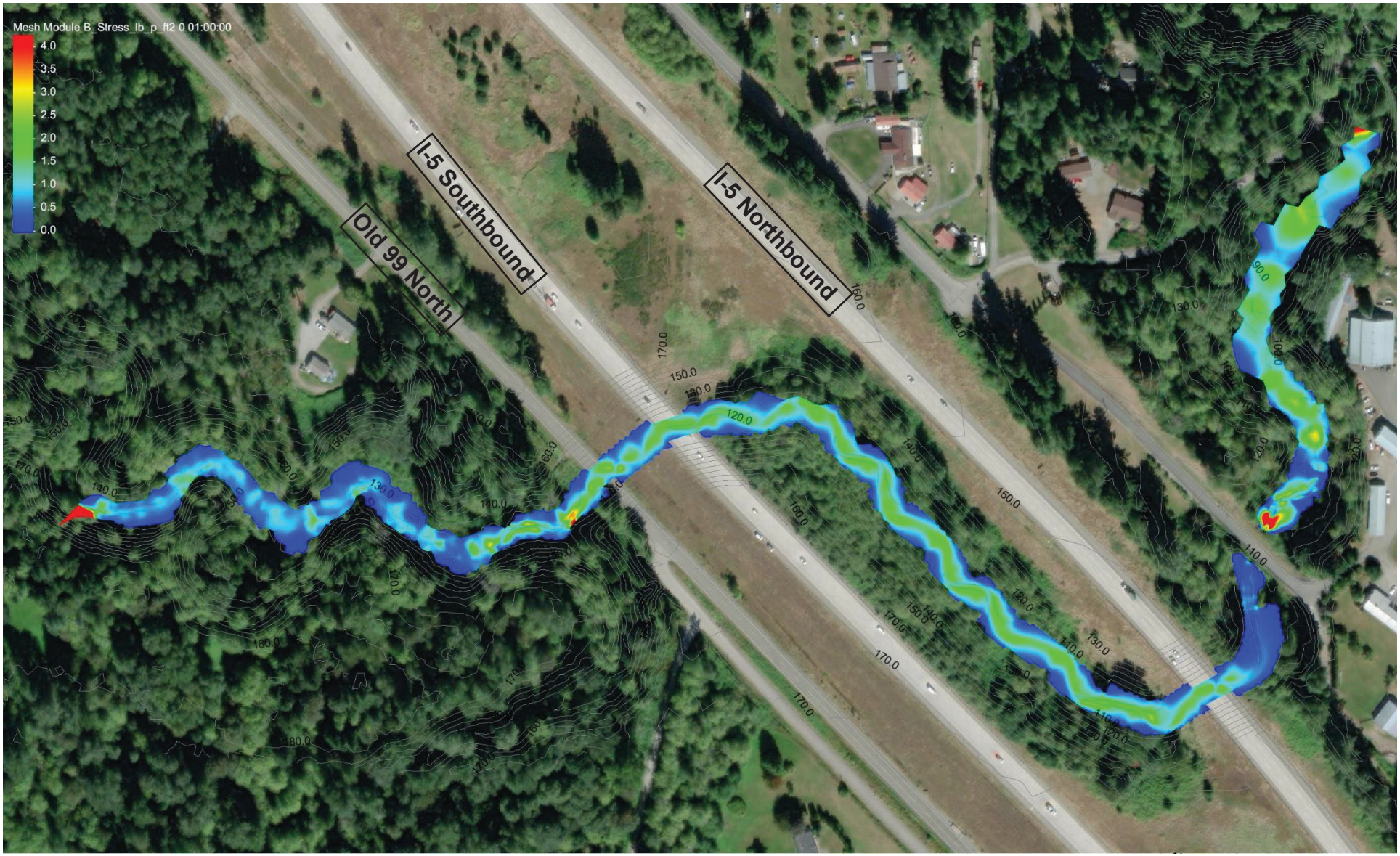
Figure B.1.11
Secret Creek at I-5
100-Year Velocity



Parametrix

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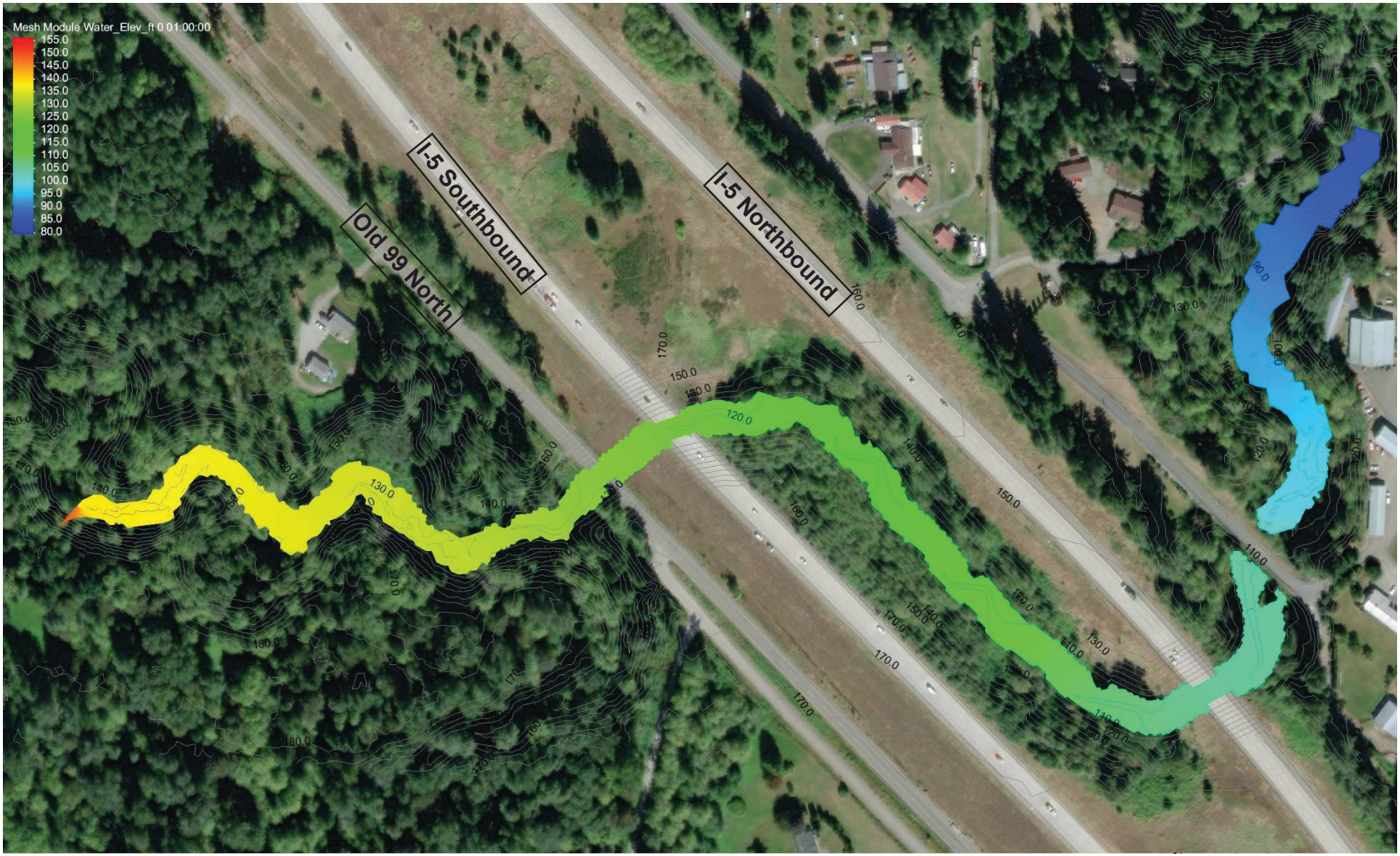
Figure B.1.12
Secret Creek at I-5
100-Year Shear Stress



Parametrix

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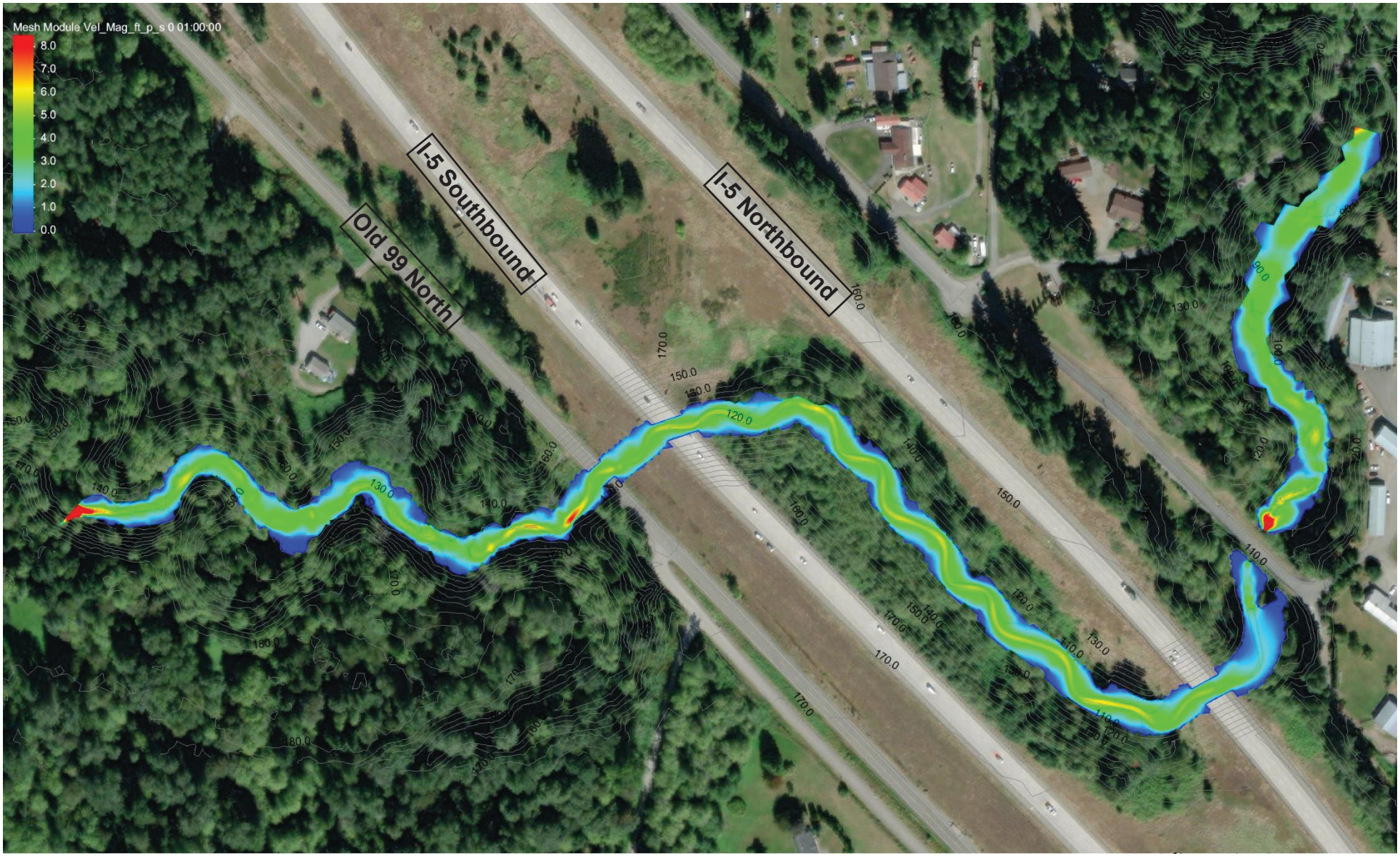
Figure B.1.13
Secret Creek at I-5
500-Year Water Surface Elevation



Parametrix

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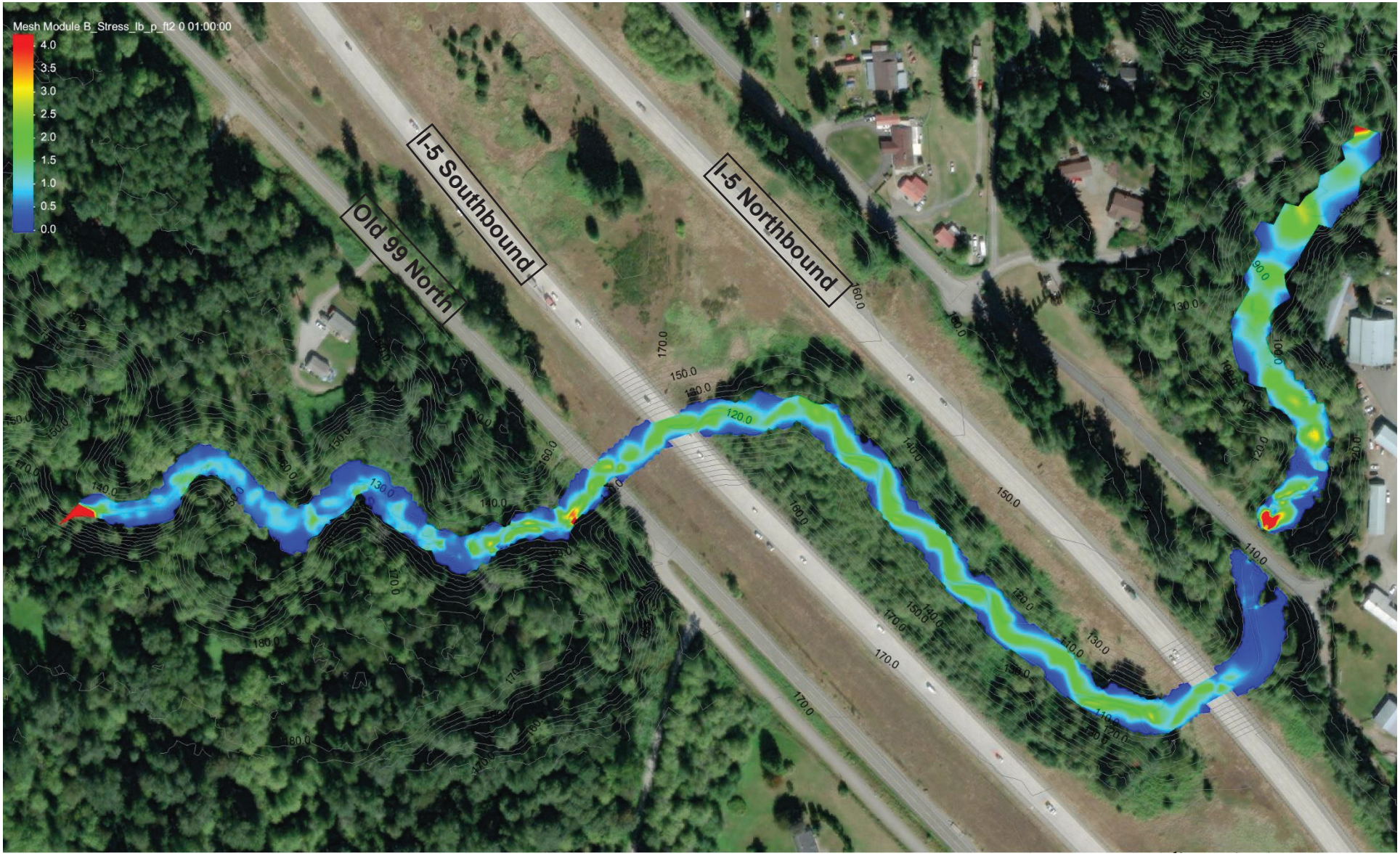
Figure B.1.14
Secret Creek at I-5
500-Year Velocity



Parametrix

0 250 500 1,000 Feet

Figure B.1.15
Secret Creek at I-5
500-Year Shear Stress

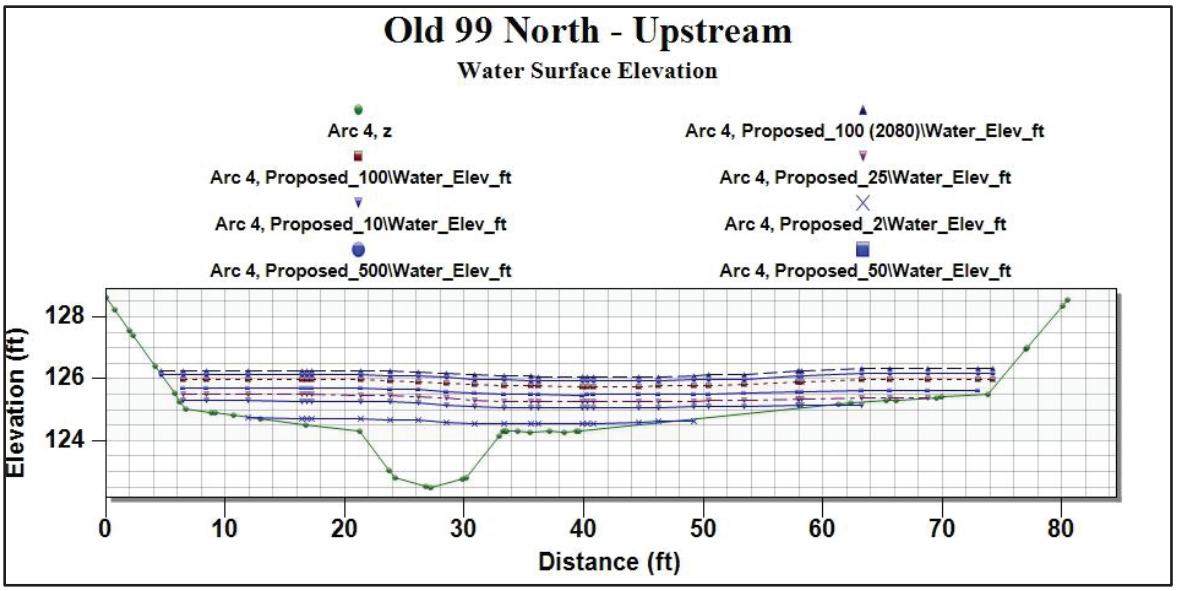


Figure B.2.1
Secret Creek at I-5

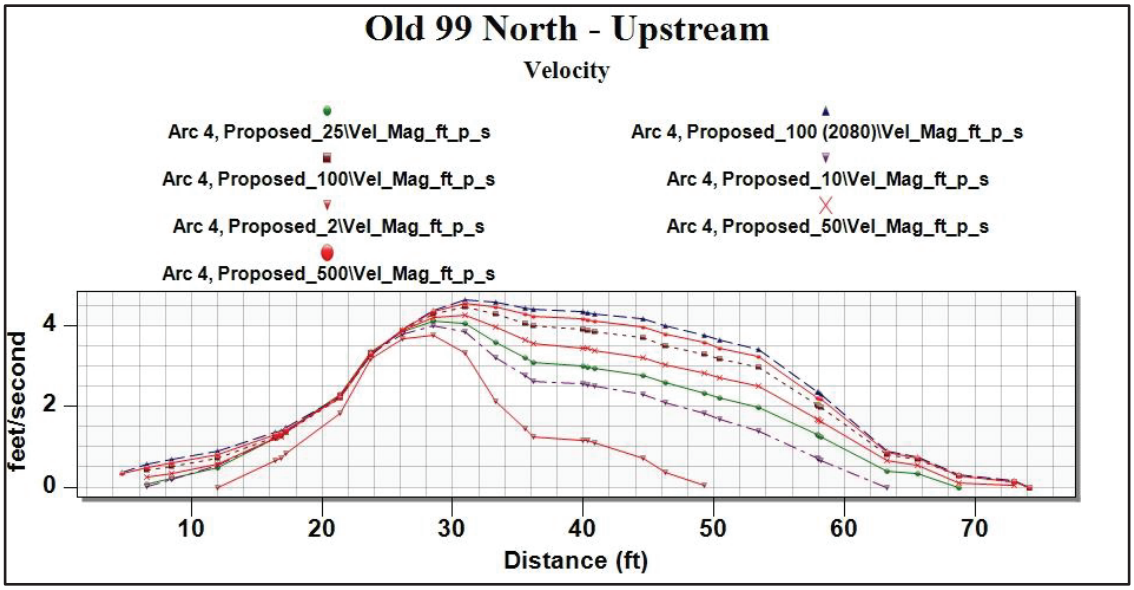


Figure B.2.2
Secret Creek at I-5

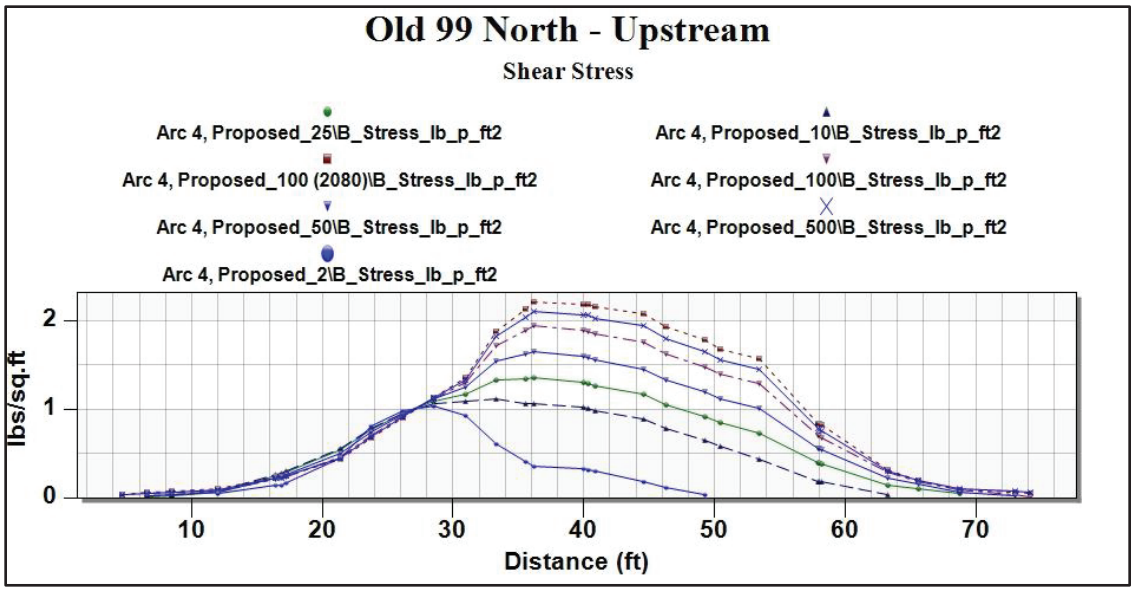


Figure B.2.3
Secret Creek at I-5

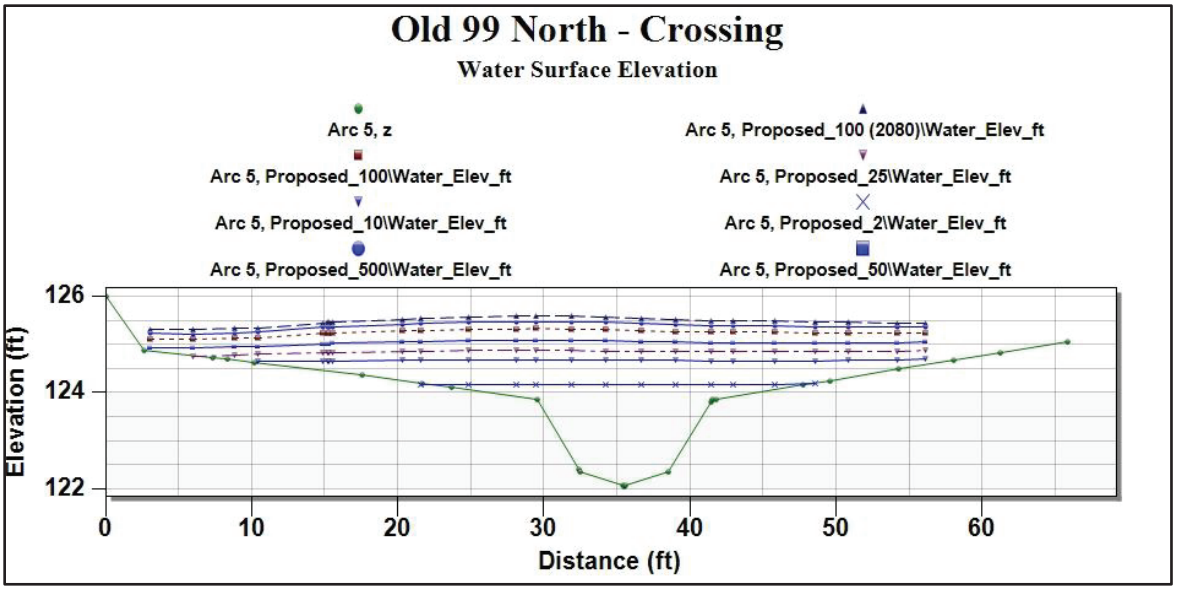


Figure B.2.4
Secret Creek at I-5

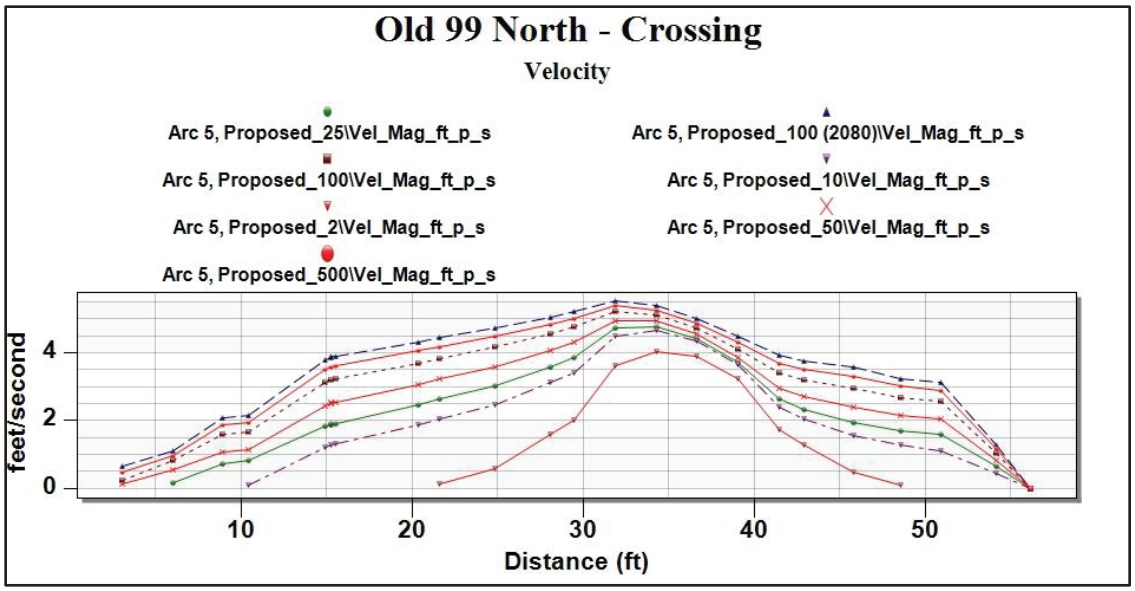
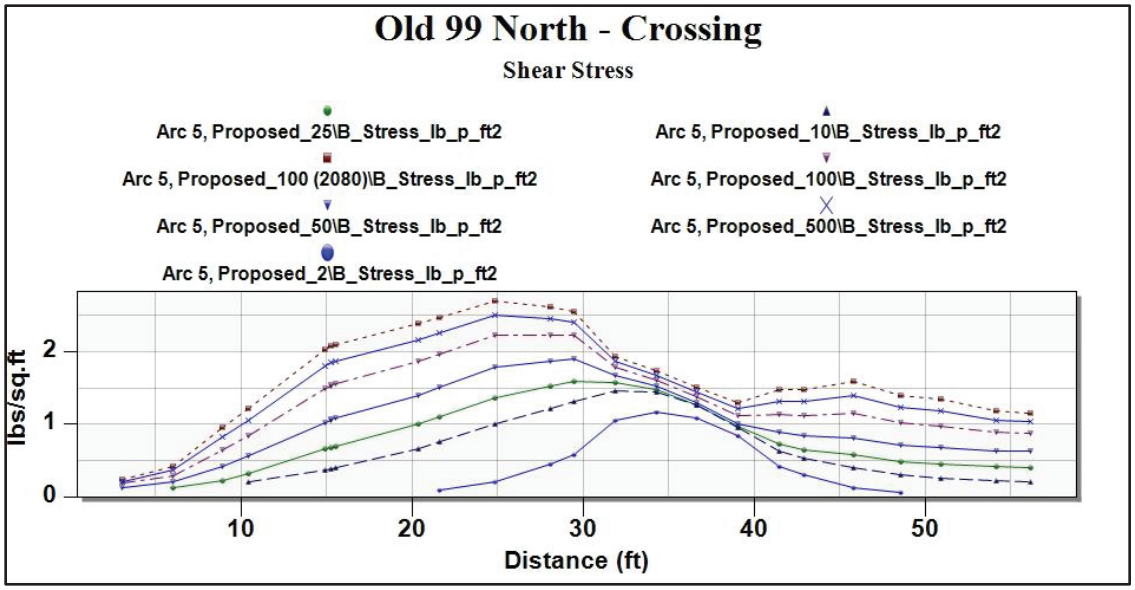


Figure B.2.5
Secret Creek at I-5



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Secret Creek at I-5

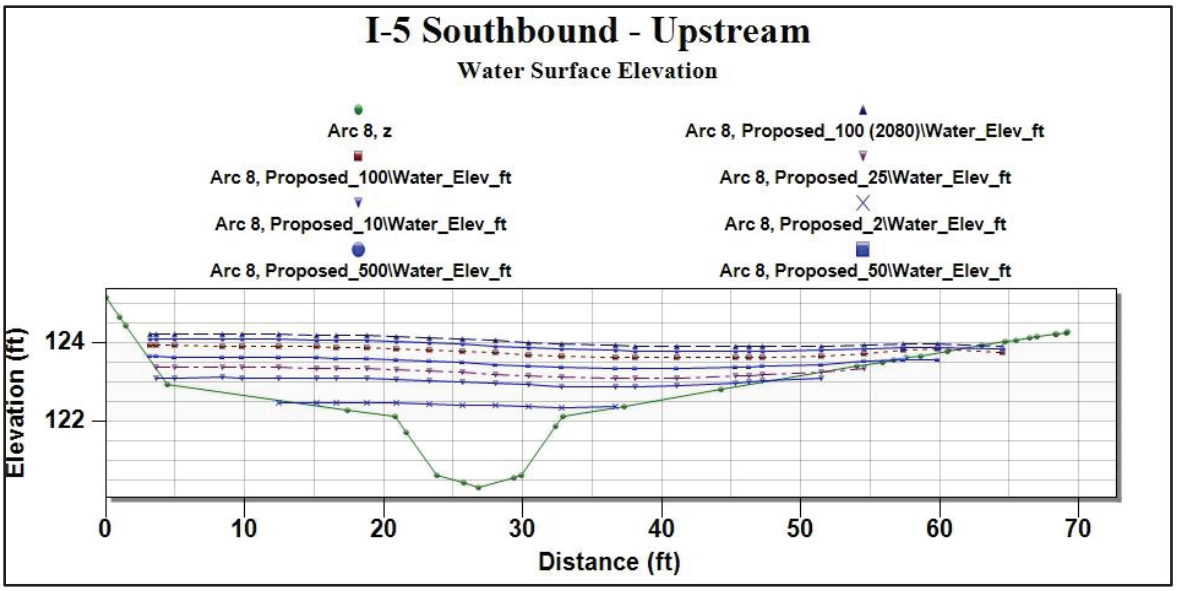

Figure B.2.7
Secret Creek at I-5

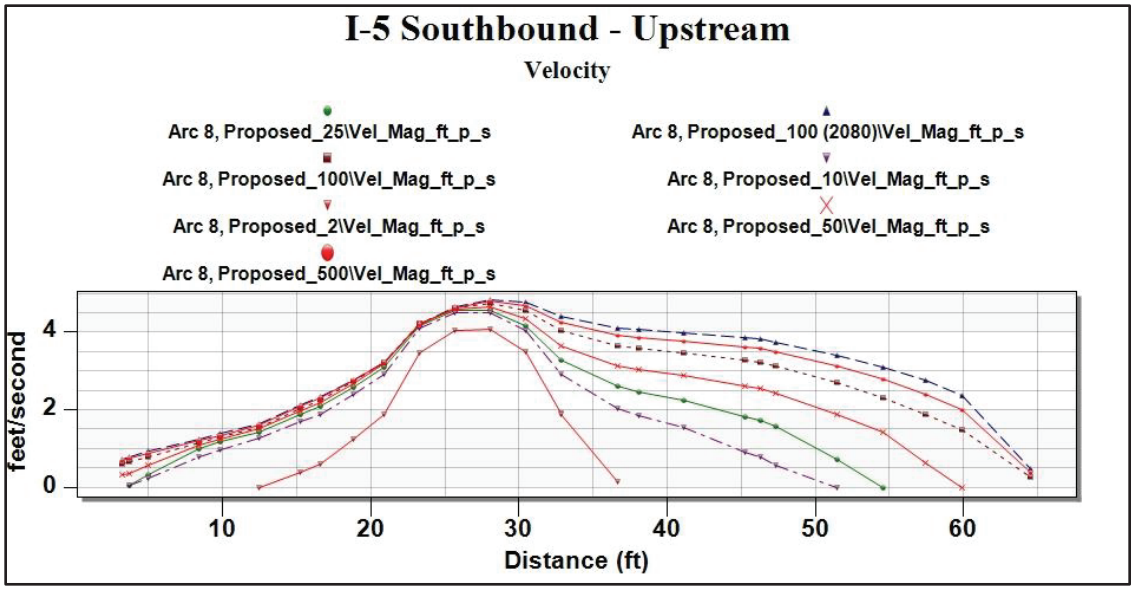

Figure B.2.8
Secret Creek at I-5

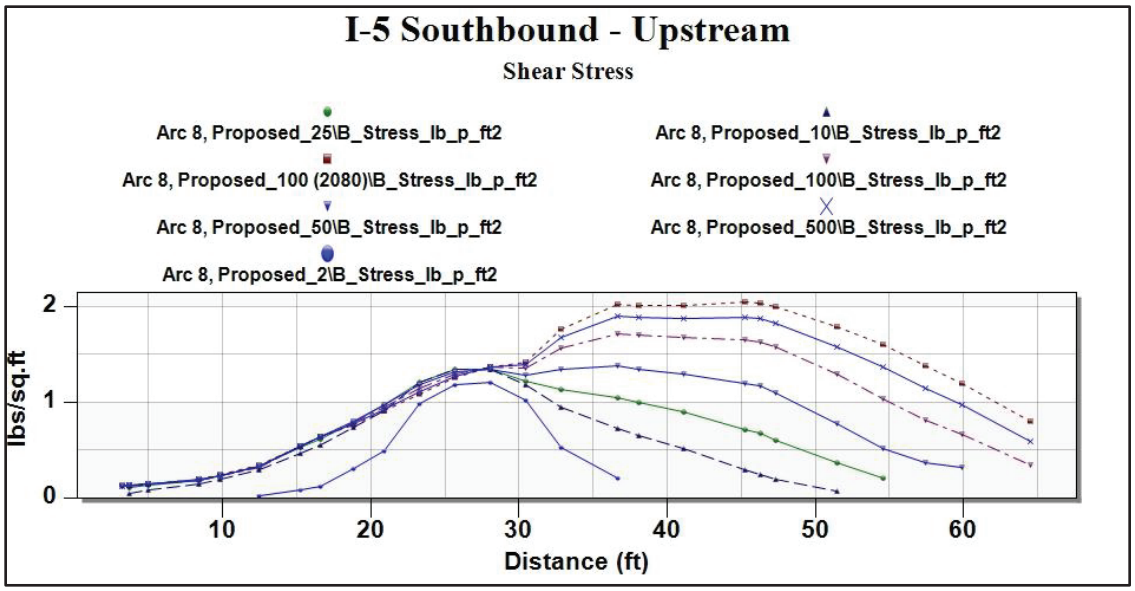

Figure B.2.9
Secret Creek at I-5

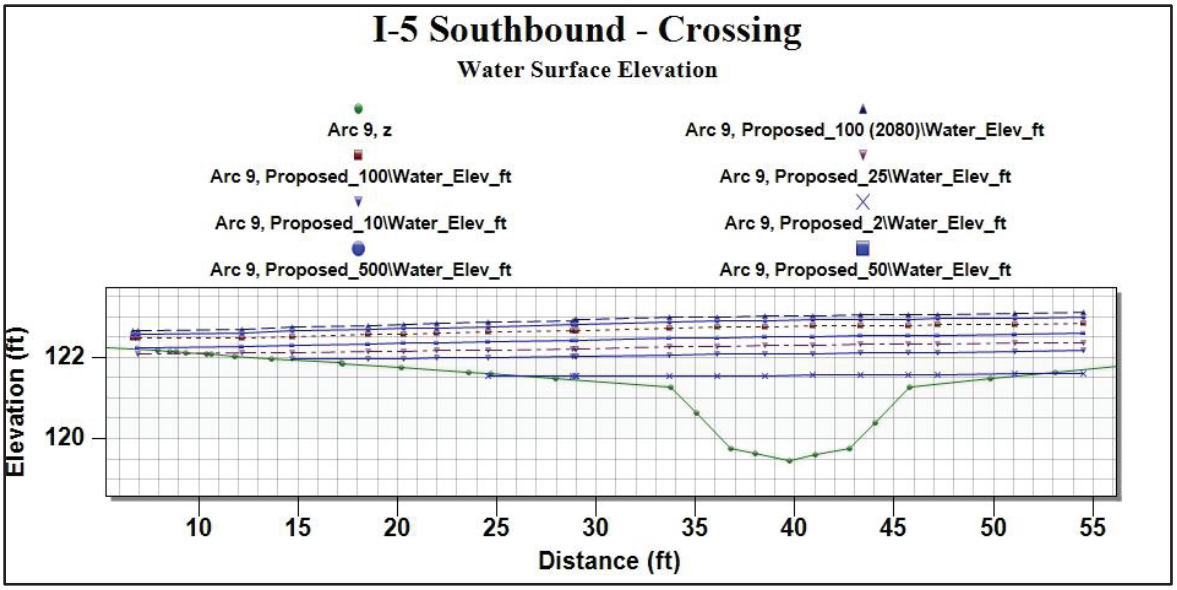

Figure B.2.10
Secret Creek at I-5

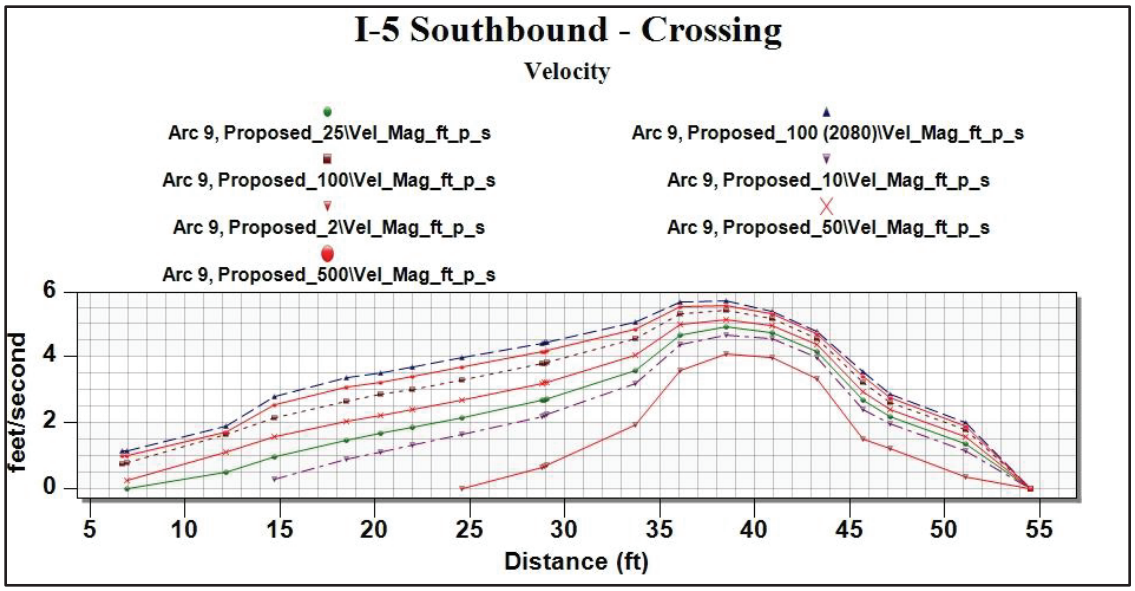

Figure B.2.11
Secret Creek at I-5

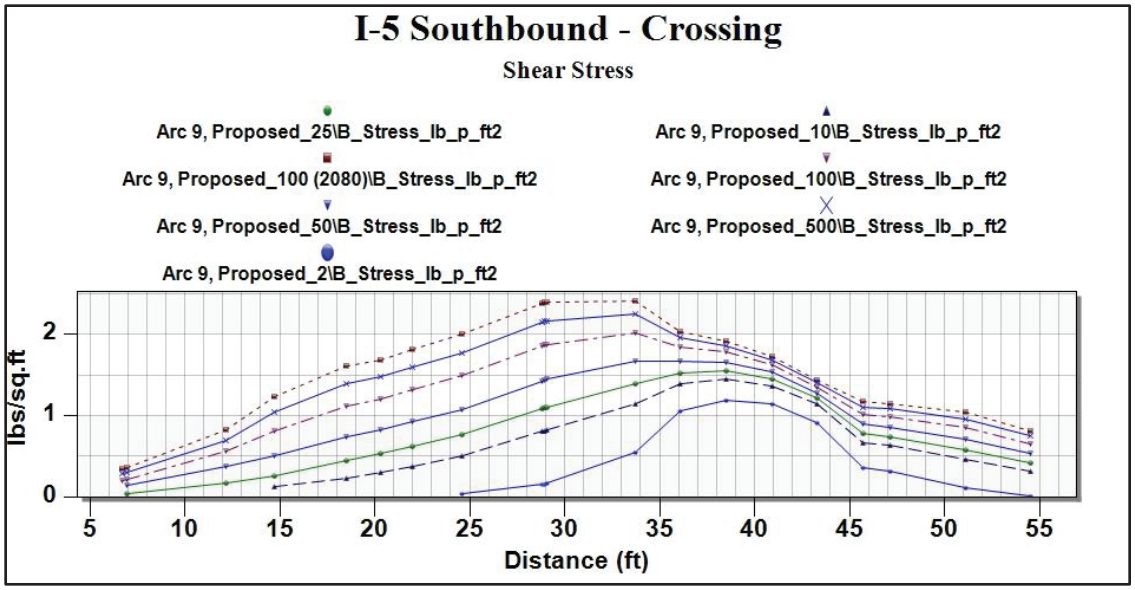

Figure B.2.12
Secret Creek at I-5

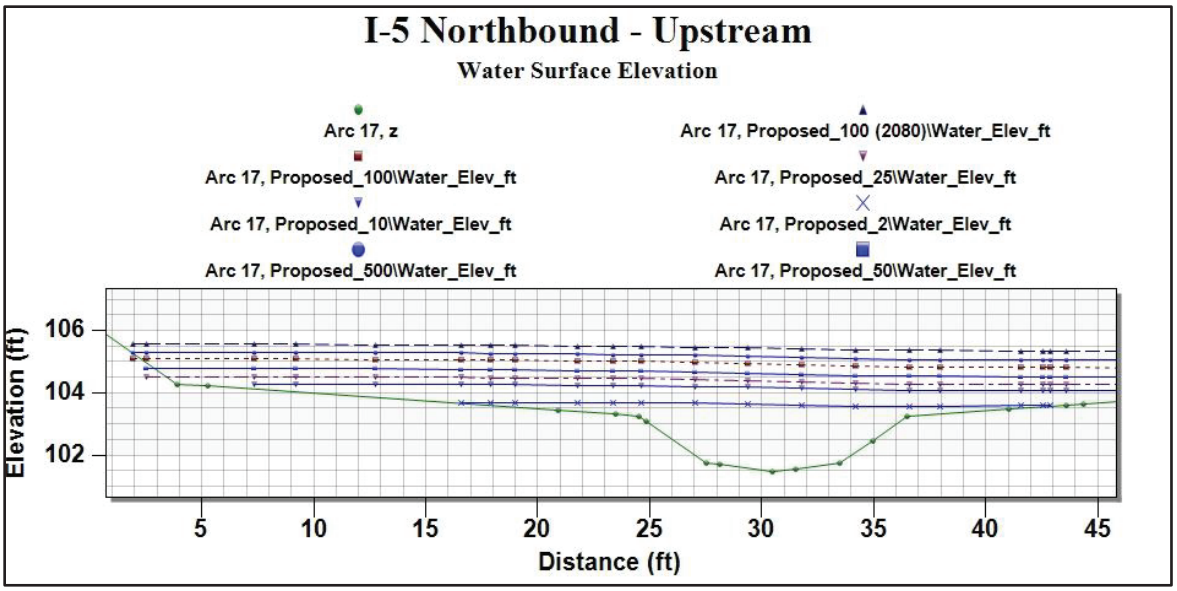

Figure B.2.13
Secret Creek at I-5

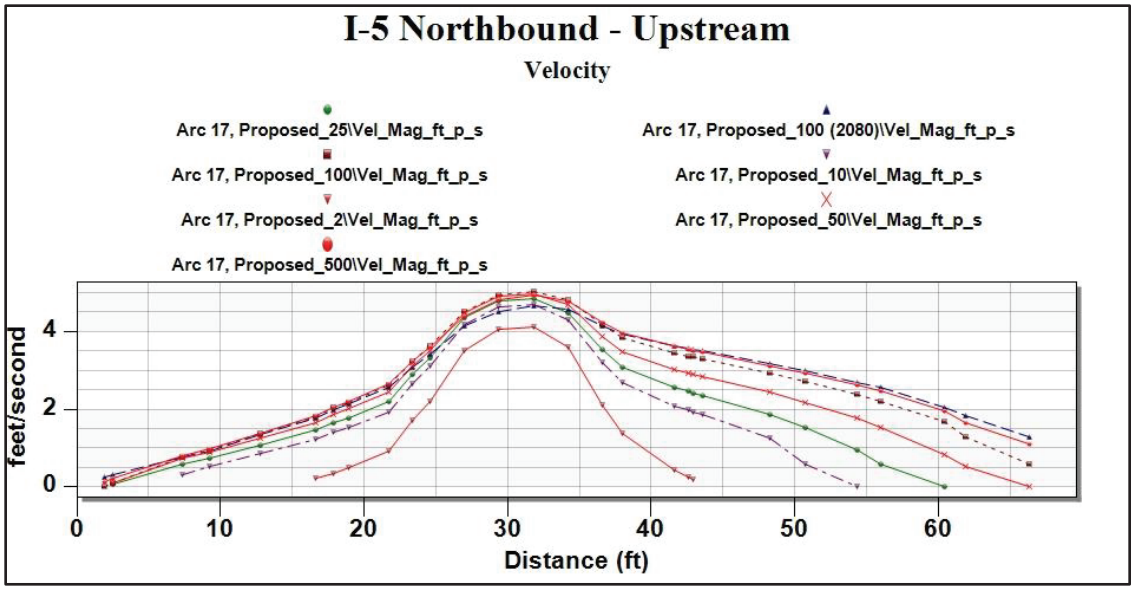

Figure B.2.14
Secret Creek at I-5

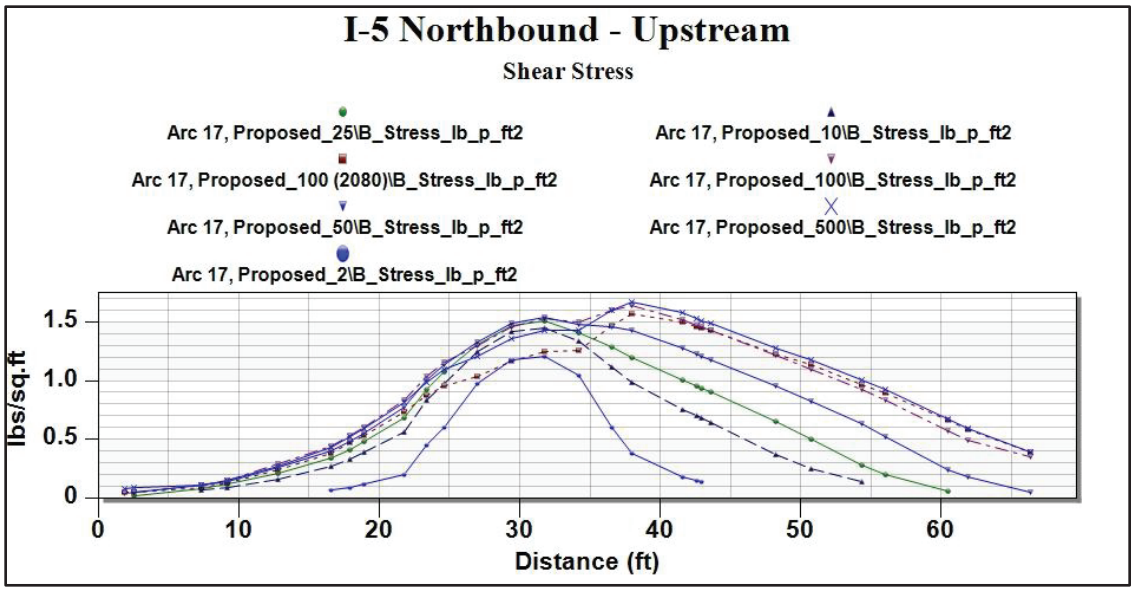

Figure B.2.15
Secret Creek at I-5

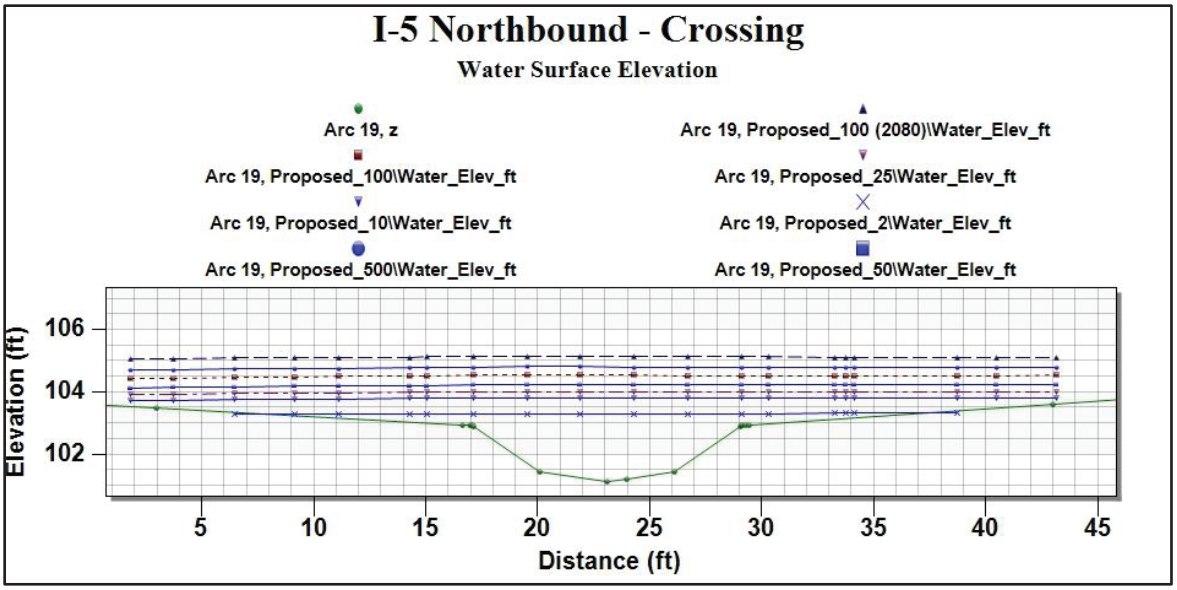

Figure B.2.16
Secret Creek at I-5

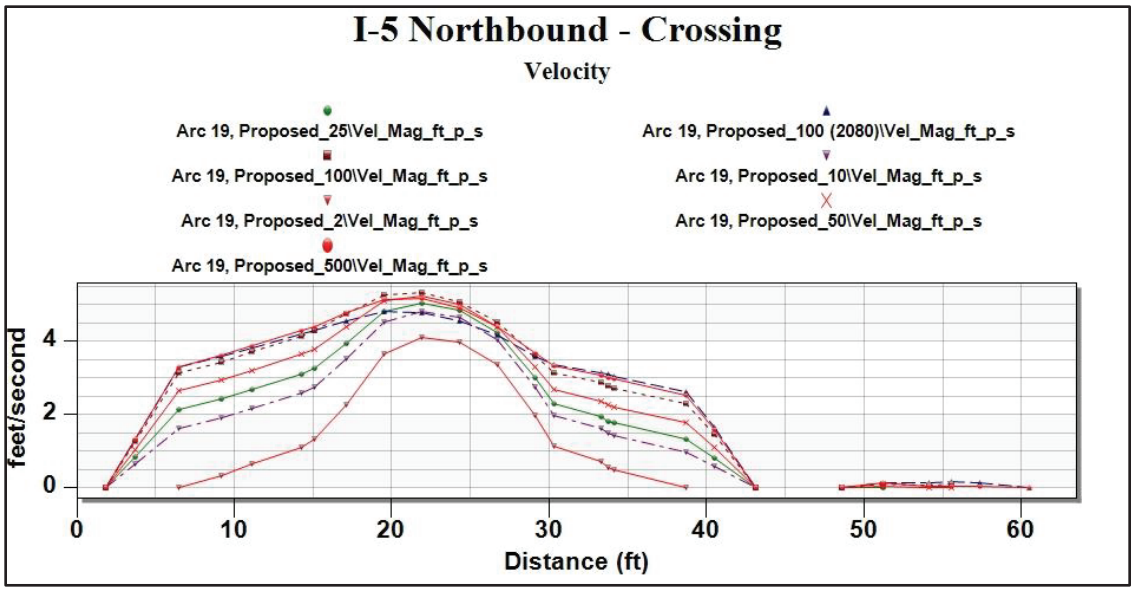

Figure B.2.17
Secret Creek at I-5

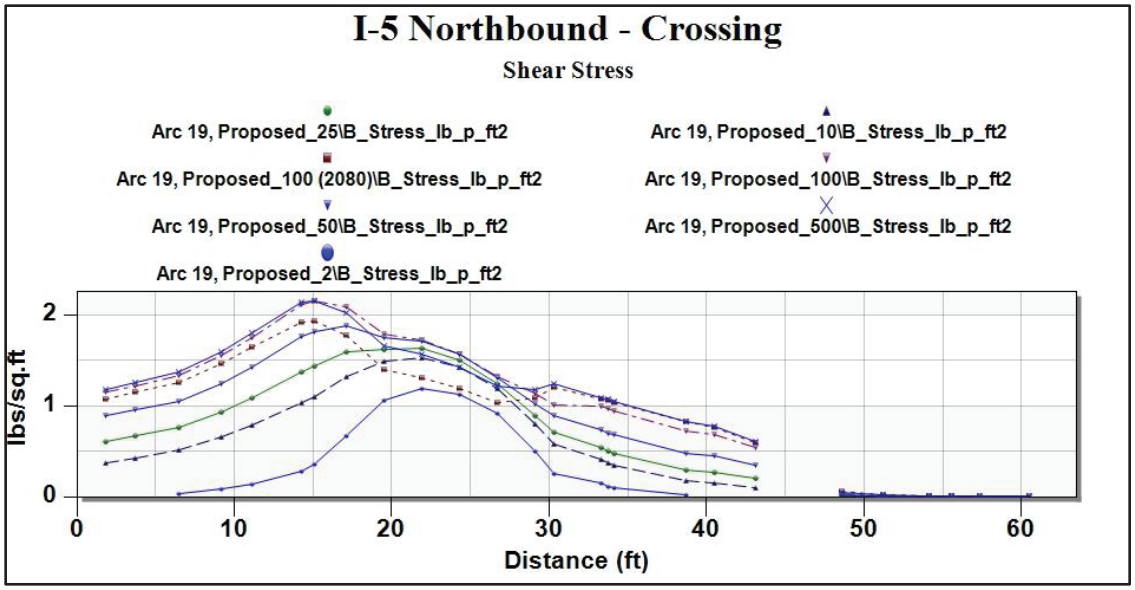

Figure B.2.18
Secret Creek at I-5

Appendix E

Preliminary Stream Plan, Profile, Details Sheets

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DESIGNED BY							
ENTERED BY	S. CROSIER						
CHECKED BY							
PROJ. ENGR.							
REGIONAL ADM.		REVISION	DATE	BY			

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

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

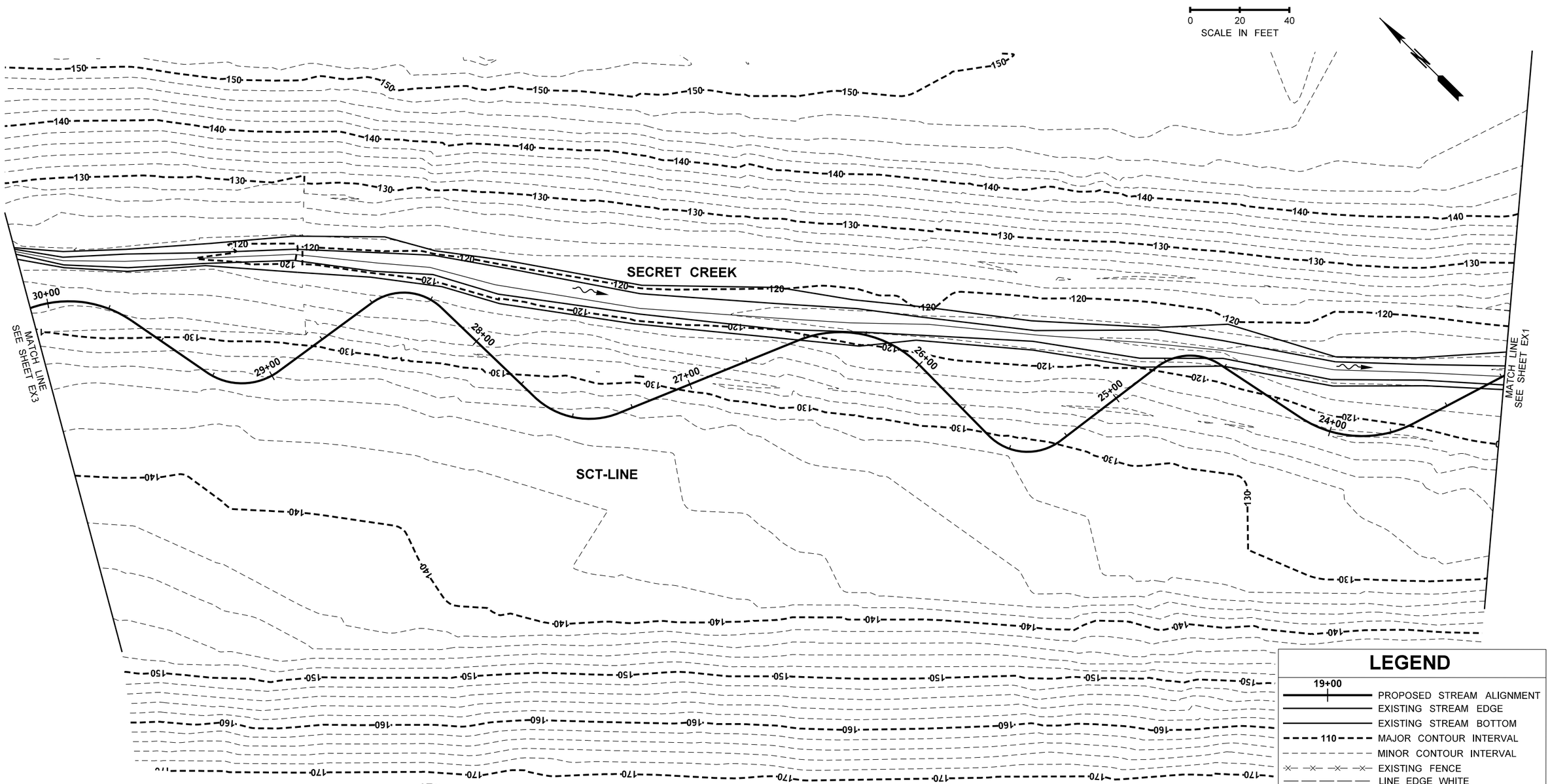
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

EXISTING STREAM

PLAN REF NO
EX1

SHEET XX OF XX SHEETS



LEGEND

19+00	PROPOSED STREAM ALIGNMENT
	EXISTING STREAM EDGE
	EXISTING STREAM BOTTOM
110	MAJOR CONTOUR INTERVAL
	MINOR CONTOUR INTERVAL
	EXISTING FENCE
	LINE EDGE WHITE
	EDGE OF ROADWAY
	CURB
	STREAM THALWEG
	EXISTING DITCH BOTTOM
	FLOW DIRECTION
	EXISTING CULVERT
	EXISTING CATCH BASIN
	EXISTING GUARDRAIL

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

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

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

EXISTING STREAM

PLAN REF NO
EX2

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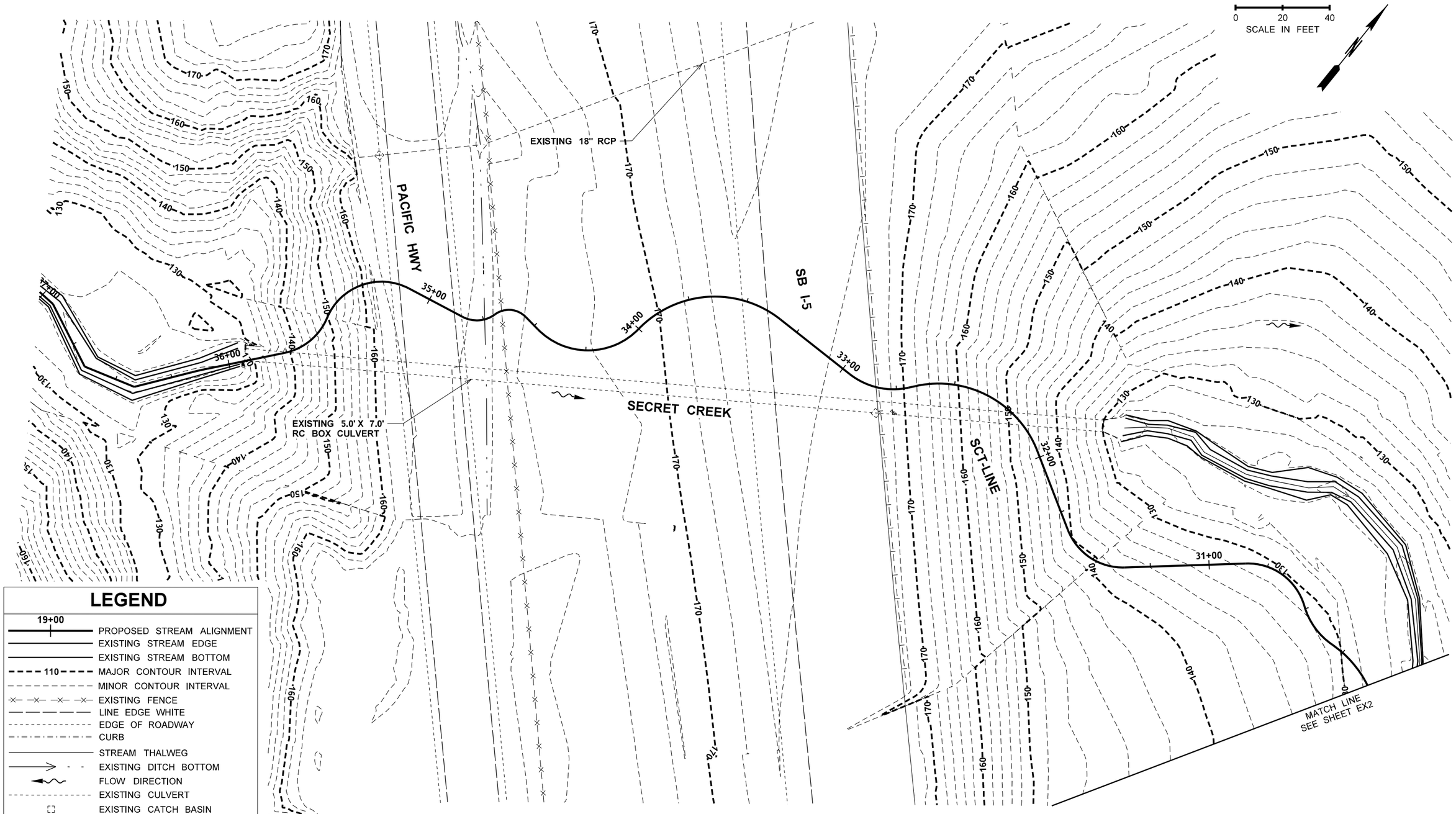

PRELIMINARY - NOT FOR CONSTRUCTION

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ENTERED BY	S. CROSIER				CONTRACT NO.		LOCATION NO.
CHECKED BY							
PROJ. ENGR.							
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

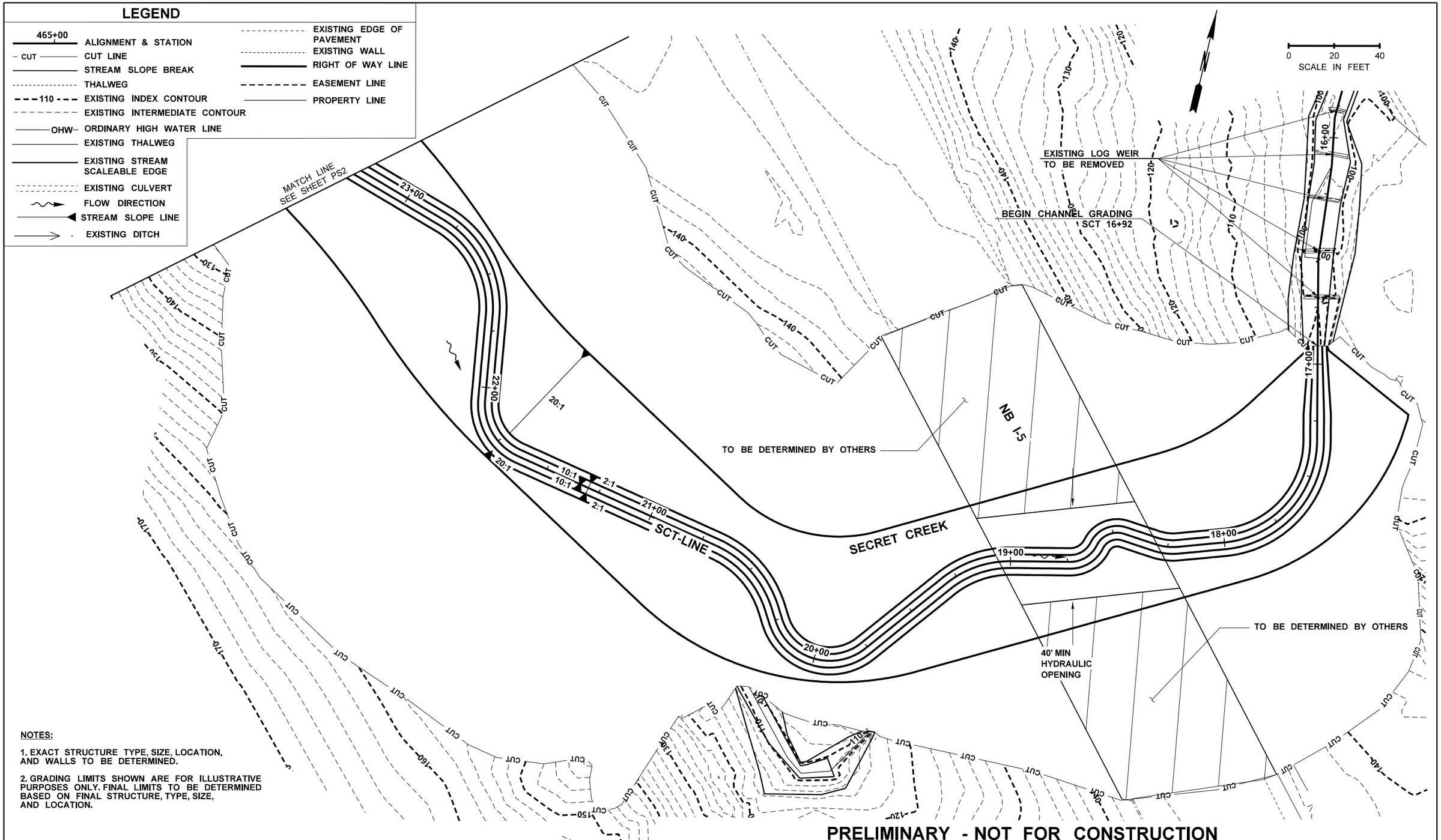
EXISTING STREAM

PLAN REF NO
EX3

SHEET XX OF XX SHEETS

LEGEND

- 465+00 — ALIGNMENT & STATION
- CUT — CUT LINE
- STREAM SLOPE BREAK
- THALWEG
- 110 — EXISTING INDEX CONTOUR
- EXISTING INTERMEDIATE CONTOUR
- OHW — ORDINARY HIGH WATER LINE
- EXISTING THALWEG
- EXISTING STREAM SCALEABLE EDGE
- EXISTING CULVERT
- FLOW DIRECTION
- STREAM SLOPE LINE
- EXISTING DITCH
- EXISTING EDGE OF PAVEMENT
- EXISTING WALL
- RIGHT OF WAY LINE
- EASEMENT LINE
- PROPERTY LINE



NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

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

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	7/30/2021				JOB NUMBER		
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DESIGNED BY							
ENTERED BY	S. CROSIER						
CHECKED BY					CONTRACT NO.		LOCATION NO.
PROJ. ENGR.							
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX — DATE

PRELIMINARY

P.E. STAMP BOX — DATE

Washington State Department of Transportation

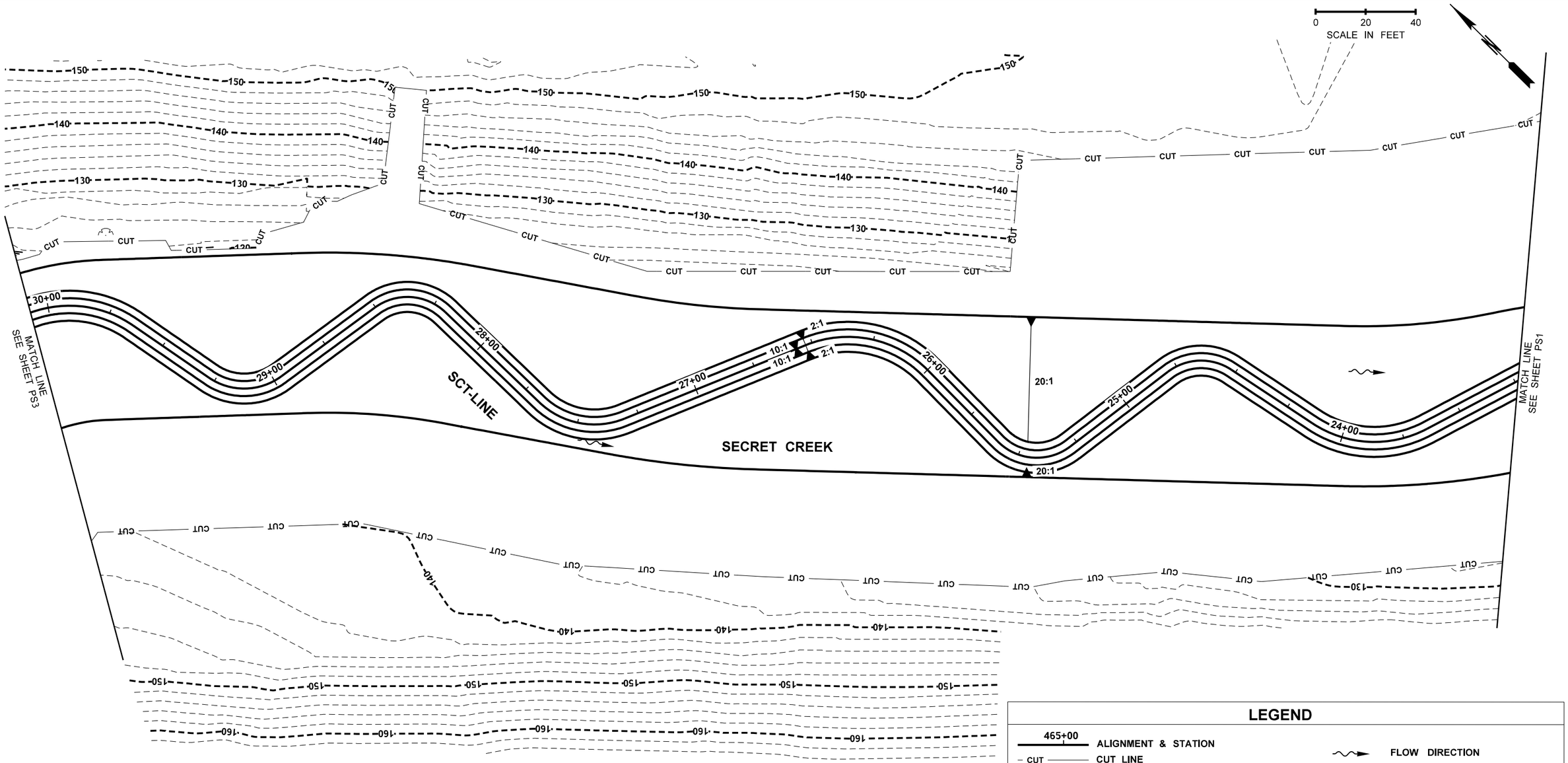
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK FISH PASSAGE

STREAM PLAN

PLAN REF NO PS1

SHEET XX OF XX SHEETS



LEGEND

465+00	ALIGNMENT & STATION
CUT	CUT LINE
	STREAM SLOPE BREAK
	THALWEG
110	EXISTING INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
OHW	ORDINARY HIGH WATER LINE
	EXISTING THALWEG
	EXISTING STREAM SCALEABLE EDGE
	EXISTING CULVERT
	FLOW DIRECTION
	STREAM SLOPE LINE
	EXISTING EDGE OF PAVEMENT
	EXISTING WALL
	EXISTING DITCH
	RIGHT OF WAY LINE
	EASEMENT LINE
	PROPERTY LINE

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

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

PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	
ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION | DATE | BY

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

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

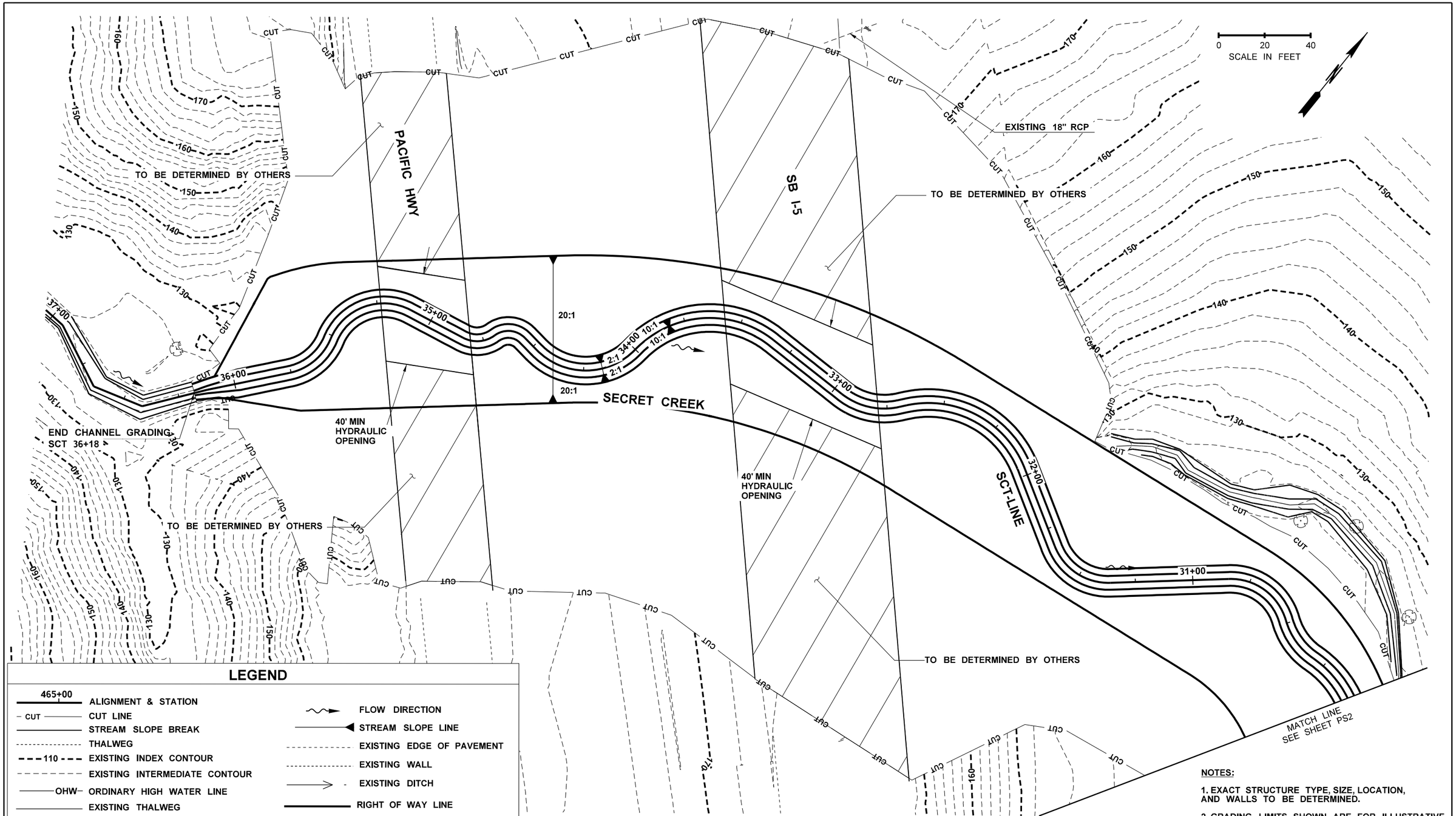
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PLAN

PLAN REF NO PS2

SHEET XX OF XX SHEETS



LEGEND

465+00	ALIGNMENT & STATION
CUT	CUT LINE
	STREAM SLOPE BREAK
	THALWEG
110	EXISTING INDEX CONTOUR
	EXISTING INTERMEDIATE CONTOUR
OHW	ORDINARY HIGH WATER LINE
	EXISTING THALWEG
	EXISTING STREAM SCALEABLE EDGE
	EXISTING CULVERT
	FLOW DIRECTION
	STREAM SLOPE LINE
	EXISTING EDGE OF PAVEMENT
	EXISTING WALL
	EXISTING DITCH
	RIGHT OF WAY LINE
	EASEMENT LINE
	PROPERTY LINE

NOTES:

1. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.

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

PRELIMINARY - NOT FOR CONSTRUCTION

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ENTERED BY	S. CROSIER
CHECKED BY	
PROJ. ENGR.	
REGIONAL ADM.	

REVISION	DATE	BY

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

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PLAN

PLAN REF NO PS3

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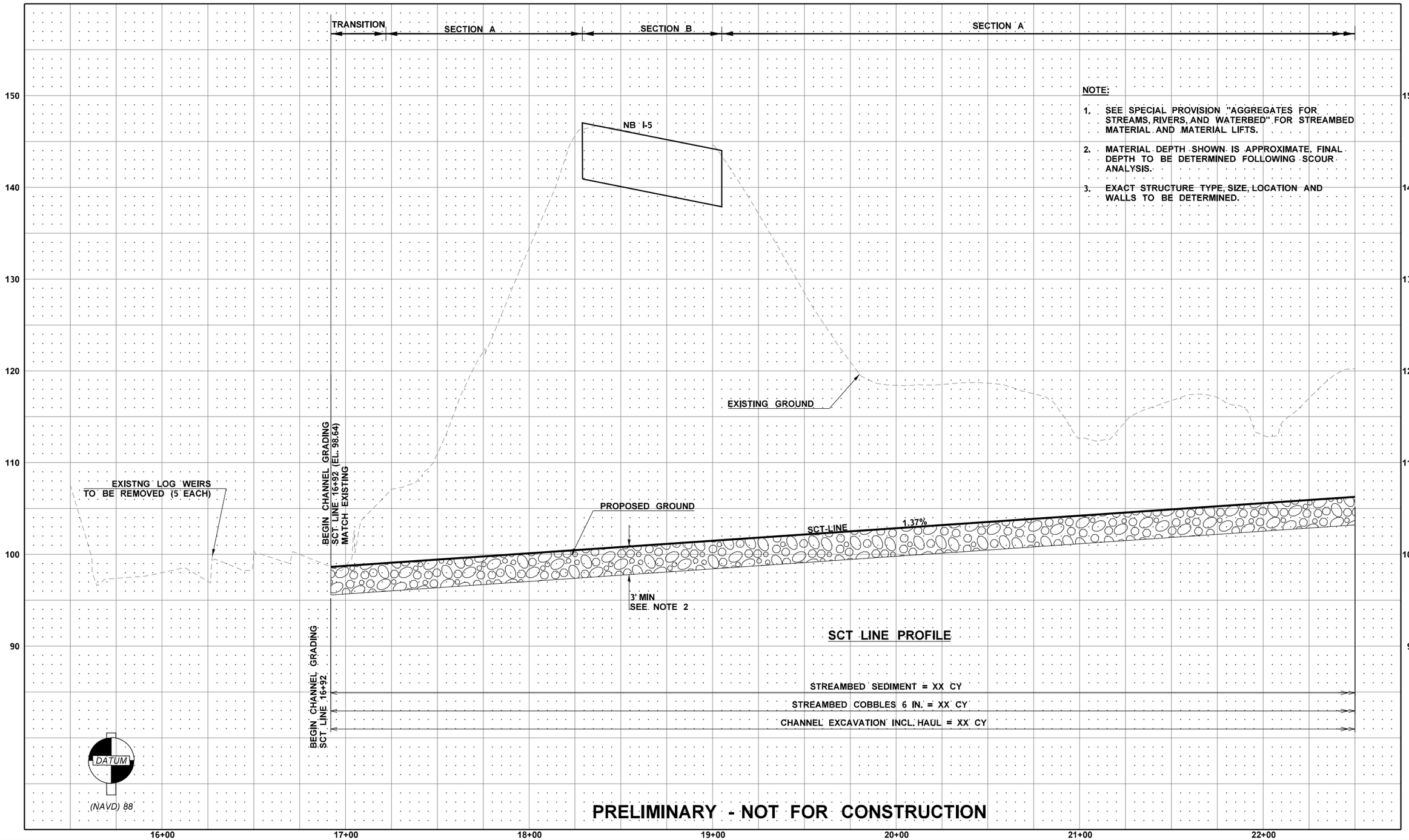

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DESIGNED BY							
ENTERED BY							
CHECKED BY					CONTRACT NO.	LOCATION NO. XL5949	
PROJ. ENGR.							
REGIONAL ADM.		REVISION	DATE	BY			

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

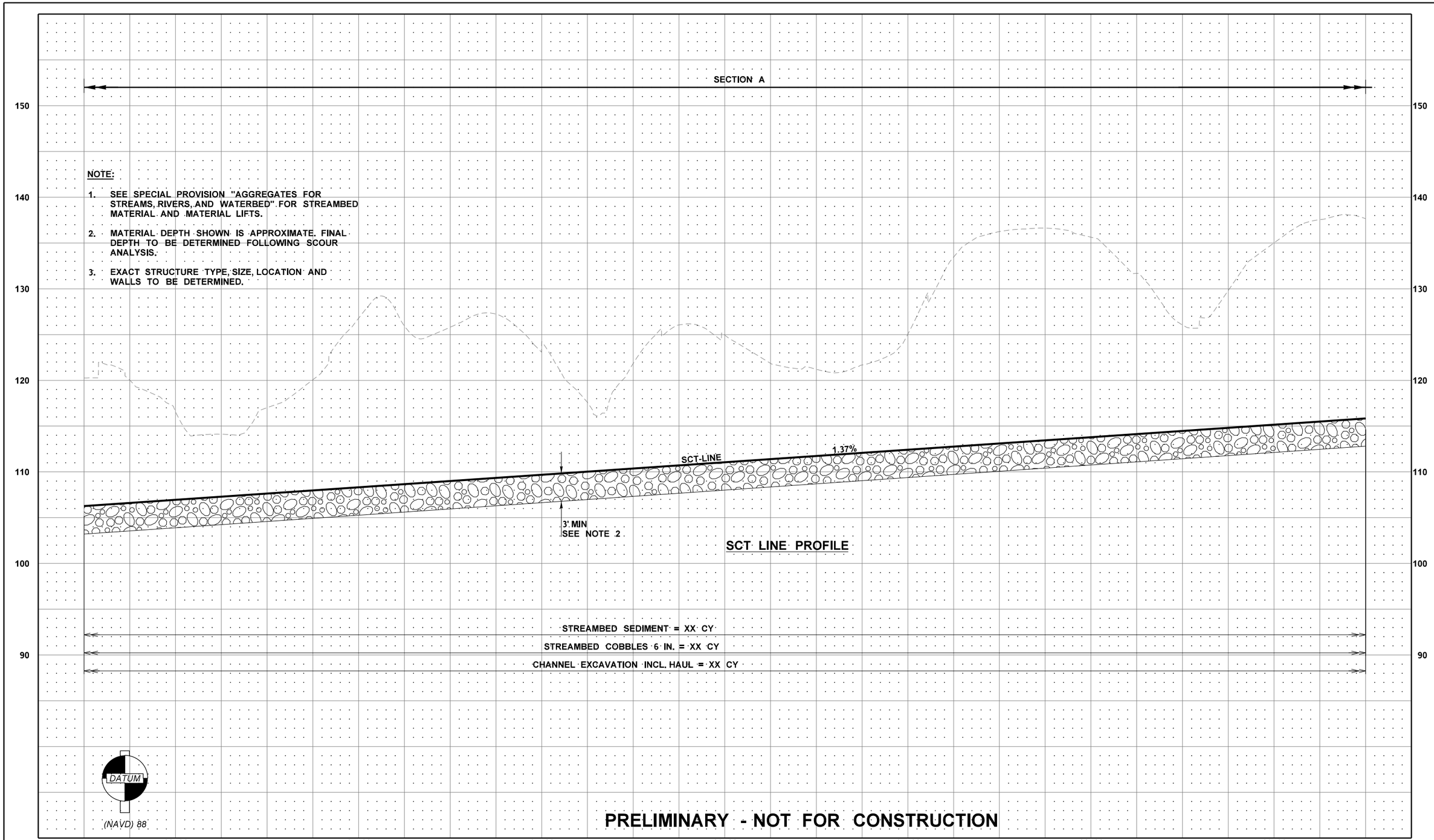
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PROFILE

PLAN REF. NO. STP1

SHEET XX OF XX SHEETS



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PROJ. ENGR.									
REGIONAL ADM.		REVISION	DATE	BY					

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

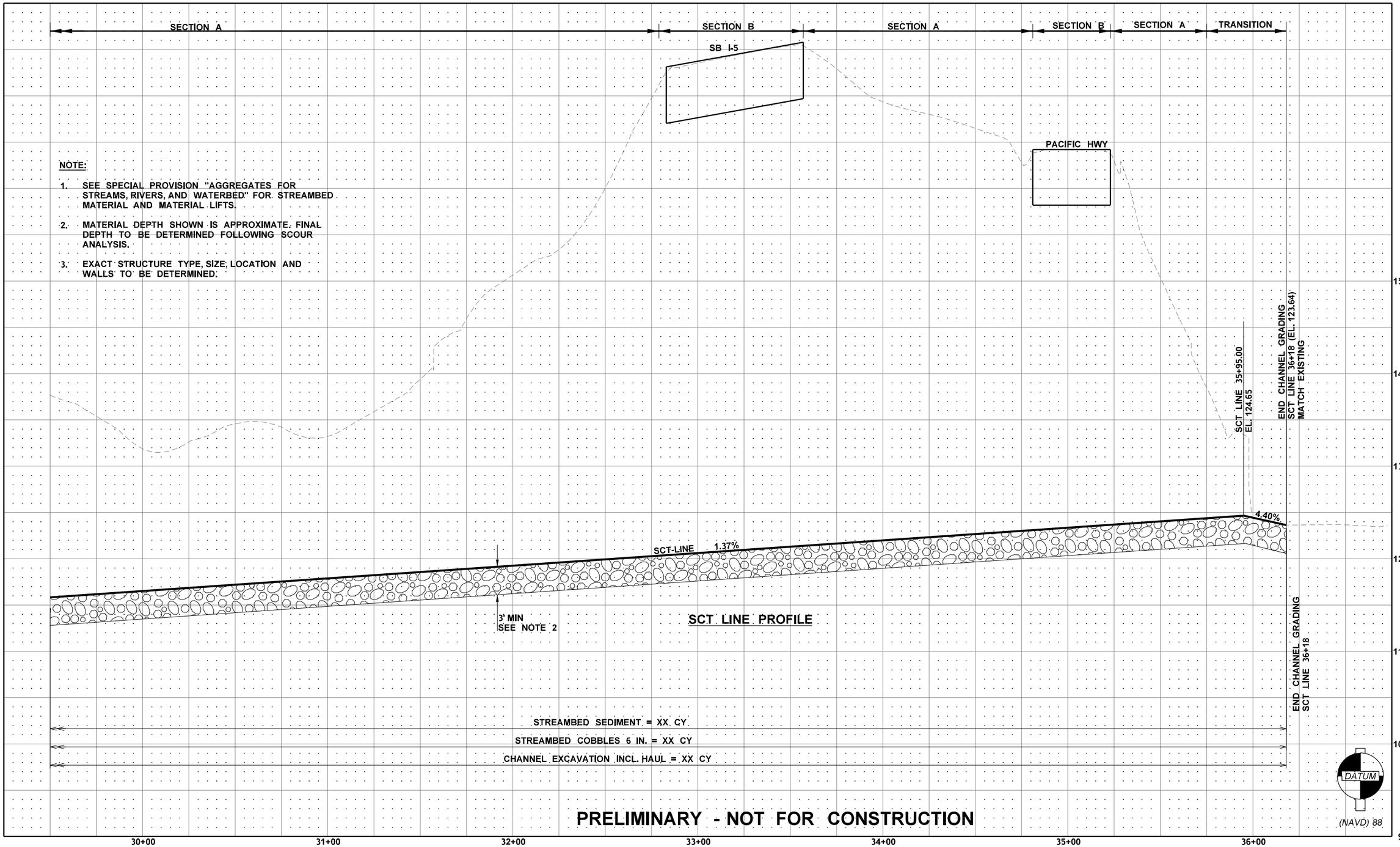
Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PROFILE

PLAN REF. NO. STP2

SHEET XX OF XX SHEETS



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REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		LOCATION NO. XL5949

P.E. STAMP BOX DATE

PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

I-5
SECRET CREEK TO PILCHUCK CREEK
FISH PASSAGE

STREAM PROFILE

PLAN REF. NO. STP3

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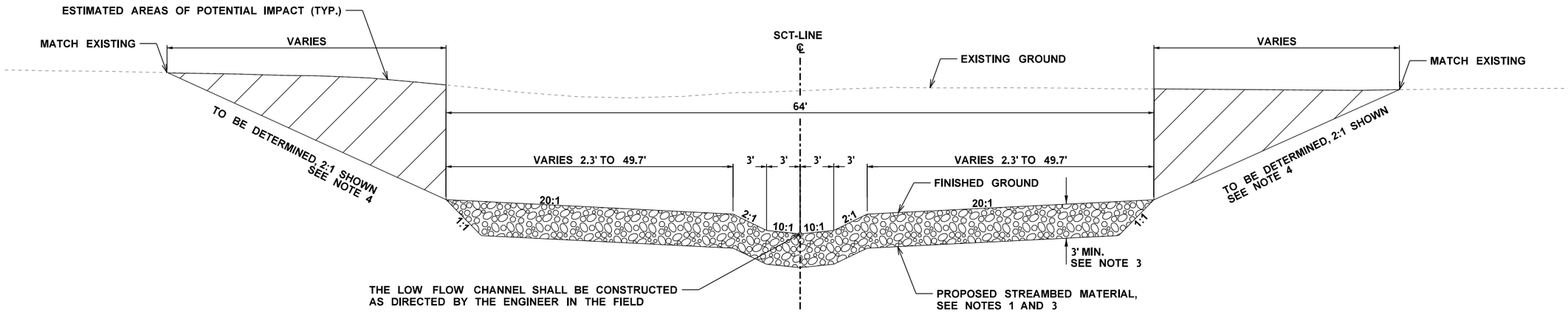
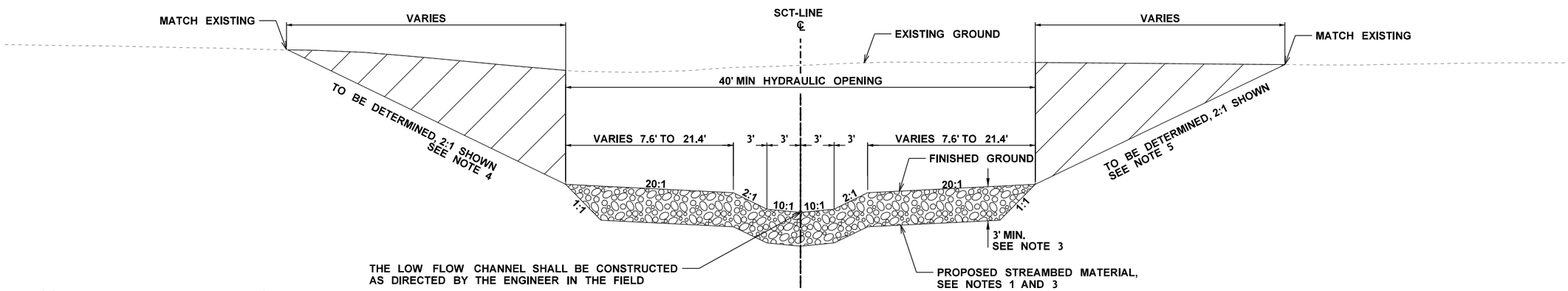


I-5 SECRET CREEK TYPICAL STREAM SECTION A

NOT TO SCALE
STA 17+22 TO STA 18+29
STA 19+05 TO STA 32+79
STA 33+57 TO STA 34+81
STA 35+23 TO STA 35+75



I-5 SECRET CREEK TYPICAL STREAM SECTION B

NOT TO SCALE
STA 18+29 TO STA 19+05
STA 32+79 TO STA 33+57
STA 34+81 TO STA 35+23

NOTE:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS.
2. FROM SCT STA 16+92 TO STA 17+22 AND SCT STA 35+75 TO STA 36+18, TAPER SECTION A TO MATCH EXISTING CHANNEL
3. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
4. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOTECHNICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION

PRELIMINARY - NOT FOR CONSTRUCTION

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PLOTTED BY	crosisus				JOB NUMBER						SHEET XX OF XX SHEETS
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CHECKED BY					CONTRACT NO.		LOCATION NO. XL5949	DATE P.E. STAMP BOX	PRELIMINARY DATE P.E. STAMP BOX	Parametrix	STREAM DETAILS
PROJ. ENGR.											
REGIONAL ADM.		REVISION	DATE	BY							

Appendix F

Streambed Material Sizing Calculations

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Summary - Stream Simulation Streambed Design

Project:	NB I-5 MP 211.5 Secret Creek 990622, SB I-5 MP 211.7 Secret Creek 990623
By:	T. Nabours

Design Gradation:				
Location:	Proposed Grading			
	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.46	0.29	0.10	0.01
in	5.52	3.43	1.15	0.10
mm	140.3	87.1	29.1	2.4

PC Gradation:				
Location:	Pebble Count 1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.23	0.14	0.07	0.02
in	2.76	1.66	0.89	0.25
mm	70.1	42.2	22.6	6.4

PC Gradation:				
Location:	Pebble Count 2			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.39	0.19	0.09	0.03
in	4.72	2.28	1.08	0.36
mm	119.9	57.9	27.4	9.1

PC Gradation:				
Location:	Pebble Count 3			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.42	0.31	0.15	0.05
in	5.04	3.74	1.85	0.55
mm	128.0	95.0	47.0	14.0

Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Fines	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	70	68	57				100.0
5.0	127				70	57	57	45				89.5
4.0	102			100	60	43	45	39				86.0
3.0	76.2			80	50	30	38	34				82.5
2.5	63.5	100		70	40	24	32	28				79.0
2.0	50.8	93		60	30	18	25	22				71.0
1.5	38.1	80		50	20	12	18	16				58.7
1.0	25.4	66		30	10	6	12	11				46.4
0.75	19.1	57		10	0	0	5	5				37.1
0.50	12.7	48										31.2
No. 4 =	4.75	35	100									23.0
No. 10 =	2.00	23	85									14.7
No. 40 =	0.425	10	40									6.5
No. 200 =	0.075	5	20									3.3
% per category		65	0	0	35	0	0	0	0	0	0	--> 100%
% Cobble & Sediment		65.0	0.0	0.0	35.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0%

Streambed Material Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

γ_s	165	specific weight of sediment particle (lb/ft³)
γ	62.4	specific weight of water (1b/ft³)
τ_{D50}	0.047	dimensionless Shields parameter for D50
		uses table E.1 of USFS manual
		or assume 0.045 for poorly sorted channel bed

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

	D_{16}	D_{50}	D_{84}	D_{95}
Size (in)	0.095	1.147	3.429	5.524
Size(ft)	0.01	0.10	0.29	0.46
τ_{ci}	0.22	0.46	0.64	0.74
Mobile at Q100?	Yes	Yes	Yes	Yes

**** Use average channel shear stress throughout proposed channel

Recurrence Interval		2-YR	10-YR	25-YR	50-YR	100-YR	500-YR
Flow (cfs)		73	139	172	218	278	318
Shear Stress (lb/ft²)		0.95	1.25	1.34	1.44	1.54	1.56
τci	1.30	No Motion	No Motion	Motion	Motion	Motion	Motion
	1.25	No Motion	No Motion	Motion	Motion	Motion	Motion
	1.20	No Motion	Motion	Motion	Motion	Motion	Motion
	1.13	No Motion	Motion	Motion	Motion	Motion	Motion
	1.05	No Motion	Motion	Motion	Motion	Motion	Motion
	1.00	No Motion	Motion	Motion	Motion	Motion	Motion
	0.93	Motion	Motion	Motion	Motion	Motion	Motion
	0.88	Motion	Motion	Motion	Motion	Motion	Motion
	0.83	Motion	Motion	Motion	Motion	Motion	Motion
	0.76	Motion	Motion	Motion	Motion	Motion	Motion
	0.72	Motion	Motion	Motion	Motion	Motion	Motion
	0.67	Motion	Motion	Motion	Motion	Motion	Motion
	0.61	Motion	Motion	Motion	Motion	Motion	Motion
	0.58	Motion	Motion	Motion	Motion	Motion	Motion
	0.54	Motion	Motion	Motion	Motion	Motion	Motion
	0.50	Motion	Motion	Motion	Motion	Motion	Motion
	0.44	Motion	Motion	Motion	Motion	Motion	Motion
	0.41	Motion	Motion	Motion	Motion	Motion	Motion
	0.36	Motion	Motion	Motion	Motion	Motion	Motion
	0.27	Motion	Motion	Motion	Motion	Motion	Motion
	0.21	Motion	Motion	Motion	Motion	Motion	Motion
	0.13	Motion	Motion	Motion	Motion	Motion	Motion
	0.08	Motion	Motion	Motion	Motion	Motion	Motion

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

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Appendix G

WDFW Future Projections for Climate-Adapted Culvert Design Printout

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Future Projections for Climate-Adapted Culvert Design

Project Name: 990623

Stream Name:

Drainage Area: 336 ac

Projected mean percent change in bankfull flow:

2040s: 9.2%

2080s: 14.9%

Projected mean percent change in bankfull width:

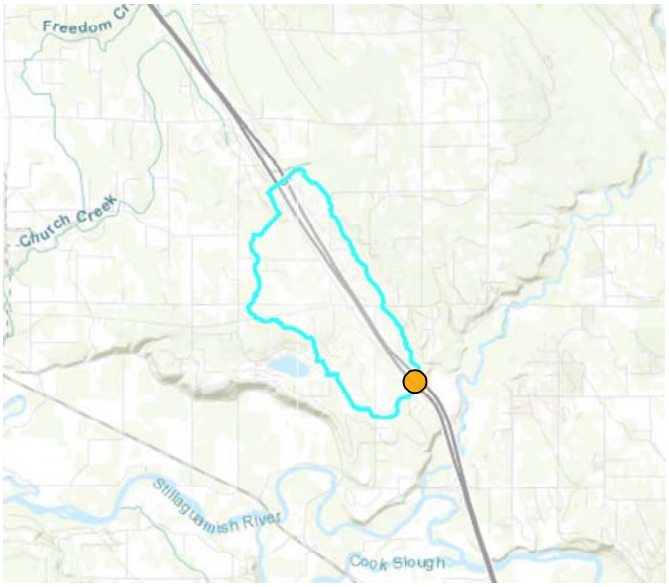
2040s: 4.5%

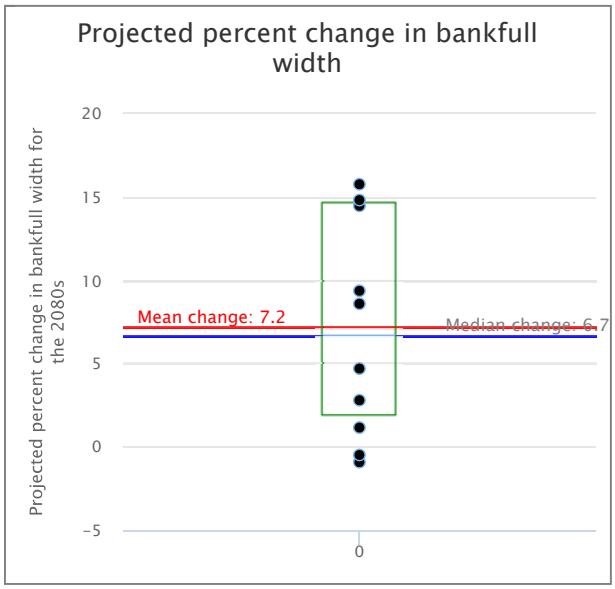
2080s: 7.2%

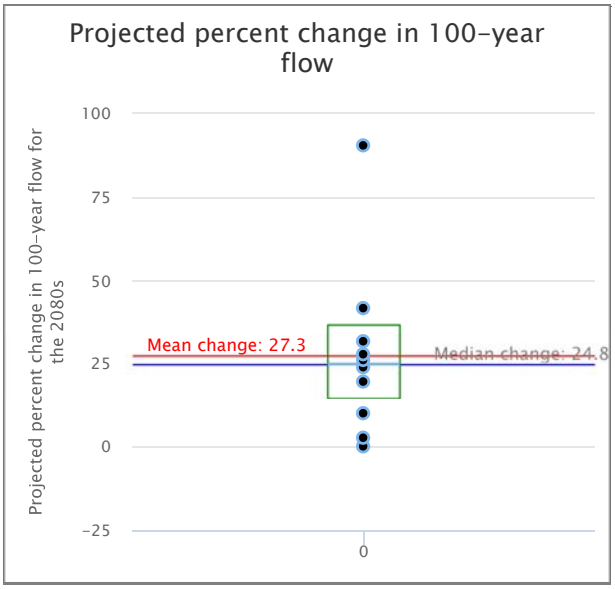
Projected mean percent change in 100-year flood:

2040s: 17.1%

2080s: 27.3%







Black dots are projections from 10 separate models

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