Washington State Department of Transportation

SR 534 MP 0.53 Unnamed Tributary 1 (west) to Carpenter Creek (CR2) / SR 534 ROW MP 0.60 Unnamed Tributary 2 (east) to Carpenter Creek (995265): Final Hydraulic Design Report

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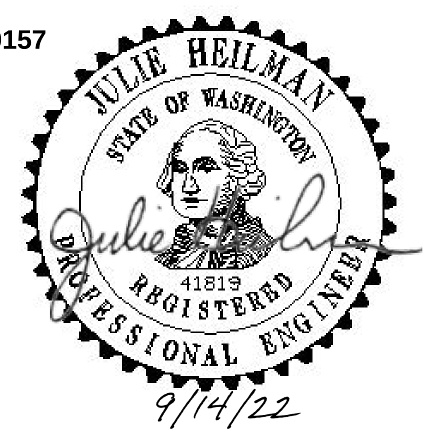

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Acronyms and Abbreviations

ADA — Americans with Disabilities Act

cfs — cubic feet per second

DBH — diameter at breast height

Ecology — Washington State Department of Ecology

ESO — Environmental Services Office

FEMA — Federal Emergency Management Agency

FUR — Floodplain Utilization Ratio

FPW — Flood prone width

GIS — geographic information system

MP — Mile Post

NAVD88 — North American Vertical Datum 1988

NGO — national nonprofit organization

OEO — Office of Equal Opportunity

SR — State Route

SFHA — Special Flood Hazard Area

TMDL — Total Maximum Daily Load

USFS — United States Forest Service

USGS — U.S. Geological Survey

WAC – Washington Administrative Code

WCDG – Water Crossing Design Guidelines

WDFW – Washington Department of Fish and Wildlife

WRIAs – Water Resource Inventory Areas

WSDOT – Washington State Department of Transportation

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1.0 Introduction and Purpose

The Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the following two barriers: (1) the State Route (SR) 534 crossing of an unnamed tributary to Carpenter Creek (Hill Ditch) at Mile Post (MP) 0.60 and (2) at an existing storm sewer pipe that runs within SR 534 ROW at MP 0.53. 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 replacement of the two separate existing barrier structures in WSDOT's Northwest Region is documented in this report. The crossing of SR 534 over the unnamed tributary 1 (west) to Carpenter Creek (Site ID CR2) has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) due to excessive slope, resulting in a fish passability assessment of 33 percent. Upstream of Site ID CR2 and adjacent to SR 534, unnamed tributary 2 (east) (Site ID 995265) consists of a storm sewer pipe that has been identified as a fish barrier due to a water surface elevation drop at the outlet, resulting in a fish passability assessment of zero. Once corrected, the potential fish habitat gain upstream of barrier ID CR2 is 2,508 meters and the potential fish habitat gain upstream of barrier ID 995265 is 2,335 meters. Both barriers are along the same unnamed tributary to Carpenter Creek.

This report documents assessment of the two barriers and a potential reference reach (that was not selected for use in the design), including a geomorphic analysis, hydrologic and hydraulic analyses, fish passage design, streambed material design, and climate change analysis. These were performed by Parametrix, in coordination with WSDOT Headquarters Hydraulics, and the WSDOT Project Office located in Mt. 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) use of a full span bridge, or (c) use of the stream simulation methodology. Avoidance of the stream crossing was determined to not be viable given the location of the highway and the need to maintain this critical transportation corridor. The 2013 WDFW Water Crossing Design Guidelines (WCDG) stipulate that stream simulation design is appropriate for moderately confined channels with bankfull widths of less than 15 feet. Therefore, due to the confined channel and bankfull width of 7.9 feet, WSDOT proposes to replace the existing SR 534 crossing structure (Site ID CR2) with a structure designed using the stream simulation design methodology. Site ID 995265 will be removed and replaced with a daylighted stream reach, and there is no existing or proposed roadway crossing along this segment.

The two project structures (Site ID CR2 and Site ID 995265) are in Skagit County 5.6 miles south of Mt. Vernon, Washington in WRIA 3. SR 534 runs east-west at this location and the existing structure crossing the highway is 175 feet upstream of the confluence with Carpenter Creek. The tributary to Carpenter Creek generally flows south to north, originating about a mile upstream of the SR 534 crossing (Figure 1.1 Vicinity Map.)

The project will replace the existing 35-foot-long, 36-inch diameter concrete pipe barrier culvert beneath SR 534 with a new crossing relocated approximately 45 feet east of the existing culvert. The existing culvert is proposed to be replaced with a 12-foot span structure (measured perpendicular to the structure bearing) to improve fish passage. The proposed structure beneath SR 534 is designed to meet the requirements of the federal injunction utilizing the stream simulation design criteria outlined in the 2013 WCDG (Barnard et al. 2013).

In addition, the barrier created by the 235-foot-long, 24-inch diameter corrugated metal storm sewer pipe running adjacent to SR 534 (Site ID 995265) will be removed and replaced with a proposed open stream channel design.

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Source: WA DNR, ESRI, WSDOT

Figure 1.1 Vicinity Map

Carpenter Creek Tributary SR 534

- SR 534 Carpenter Creek Tributary Project Barriers
- Watercourse
- Waterbody Interior Line

0 750 1,500 3,000 Feet

Skagit County, WA

2.0 Site Assessment

WSDOT performed a site survey of the project area and provided MicroStation and InRoads files to Parametrix in June 2019. The survey extends from the confluence of the tributary with Carpenter Creek 175 feet downstream of the outlet of ID CR2 to 110 feet upstream of the inlet to ID 995265. No as-built drawings were obtained.

Parametrix visited the site with staff from the WSDOT Project Engineer's Office on July 30, 2019 for an introduction to the project and to perform a detailed site assessment of existing conditions (site visit 2). The assessment was conducted by a Parametrix surface water engineer, hydrologist, and fisheries biologist. The team recorded site observations and measurements from the tributary confluence with Carpenter Creek 175 feet downstream of the SR 534 culvert outlet to approximately 500 feet upstream of the inlet to Barrier ID 995265. Information relevant to the preliminary design of the crossing was collected, including site observations, bankfull width measurements, pebble counts, woody debris recruitment potential, fish habitat assessment, record of channel and overbank vegetation, and potential reference reaches were assessed. No maintenance history or flooding history has been obtained by this report's authors. To aid in recording the location of observations, the team extended 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 the location of the potential reference reach upstream and adjacent to ID CR2 that was not ultimately selected for design.

Source: © Mapbox, © OpenStreetMap, WSDOT, Google Aerial Imagery (2020)

0 50 100 200 Feet

- BFW Measurement
- Pebble Count Location
- Carpenter Creek Tributary Thalweg
- Existing Pipe/Culvert Identified As Fish Barrier
- Existing Pipe/Culvert Not Identified As Fish Barrier
- Investigated Potential Reference Reach (Not Selected for Design)

Figure 2.1 Project Area

Carpenter Creek Tributary SR 534

Skagit County, WA

The site assessment began where the unnamed tributary to Carpenter Creek inlets to the SR 534 storm sewer (Site ID 995265) (Figure 2.2). An exposed corrugated metal watermain casing was observed running parallel to the roadway at the stream channel bottom 7 feet upstream of the inlet to barrier ID 995265 (Figure 2.3). Only the top few inches of the casing were exposed within the streambed for a length of approximately 3 feet. The diameter and material of the water main itself was not determined during the site visit. From approximately 50 to 100 feet upstream of the inlet to culvert ID 995265, cobbles and boulders were observed in the stream channel ranging from 6 to 36 inches in diameter (Figure 2.4).

Figure 2.2. Inlet to WDFW ID 995265 (looking downstream)

Figure 2.3. Exposed water main

Figure 2.4. Boulders in upstream reach (looking upstream)

At 57 feet upstream from the ID 995265 storm sewer inlet, the bankfull width was measured to be 6.8 feet; at 75 feet upstream, the bankfull width was measured to be 5.6 feet. The WSDOT site survey ended 87 feet upstream of the storm sewer inlet. At 112 feet upstream the presence of a pool was noted. At 176 feet upstream of the existing inlet, the channel constraint is diminished in relation to the channel upstream and downstream of this location, and the left floodplain extends gradually outward into a forested area west of the channel (Figure 2.5). A bankfull width measurement was taken 251 feet upstream of the storm pipe inlet, measured to be 6.2 feet (Figure 2.6). Pebble counts 1 and 2 of the upstream reach were based on measurements taken at 281 feet and 384 feet upstream, respectively.

Figure 2.5. Shallow section of channel with limited constraint (looking downstream)

Figure 2.6. Location of bankfull width measurement at 251 feet upstream

A 6-foot-long 30-inch diameter corrugated metal pipe forms the inlet to WDFW ID 995265. This pipe segment then connects to a 54-inch diameter WSDOT 54-inch Type 2 catch basin at the edge of SR 534. WDFW ID 995265 then includes, as is indicated from survey, a 219-foot-long, 30-inch diameter corrugated metal pipe that conveys the tributary to Carpenter Creek west where it outfalls to open channel (Figure 2.7). The ID 995265 segment is the most downstream segment of a storm system comprised of 18-inch corrugated metal pipe and catch basins that extends approximately 1,880 feet east to Bulson Road along the south side of SR 534. The storm system serves a drainage area of approximately 30 acres or 10 percent of the total tributary area serving the SR 534 crossing. Downstream of the outlet of ID 995265, approximately 15 feet of open channel conveys the tributary to the Conway Hill Road culvert (WDFW ID CR3), which measures 30 inches in diameter and 76 feet long.

At 10 feet downstream from the Conway Hill Road culvert outlet, the bankfull width was measured to be 9.0 feet (Figure 2.8), and 50 feet downstream the bankfull width was measured to be 7.6 feet. Within this reach adjacent to SR 534, the channel is relatively uniform and shaped like a roadside ditch. Notable features include the presence of angular and rounded boulders around the base of a telephone pole located at 60 feet downstream of the Conway Hill Road culvert outlet.

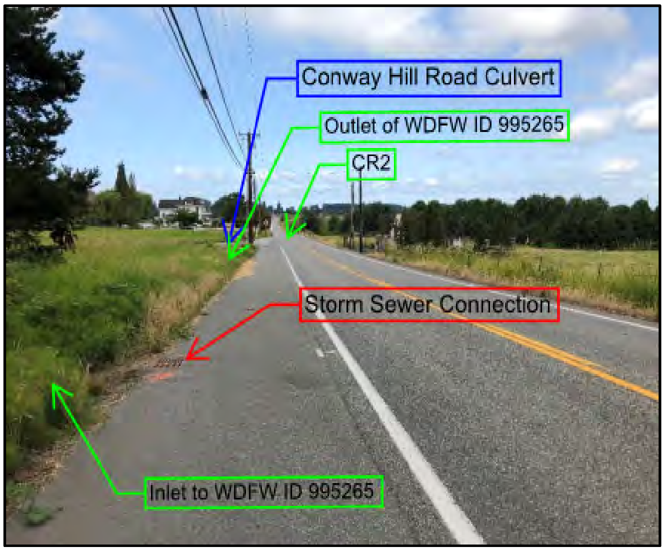


Figure 2.7. Layout of the Barrier WDFW ID 995265 (looking west down SR 534)

Figure 2.8. Channel constructed along SR 534 downstream of Conway Hill Road Culvert

The SR 534 culvert (WDFW ID CR2) inlet is 250 feet downstream of the Conway Hill Road culvert outlet (Figure 2.9). The existing SR 534 culvert is a 35-foot-long, 36-inch concrete pipe placed at a slope of 1.1 percent, as determined from WSDOT site survey. The roadway surface is about 6 feet above the culvert inlet invert elevation. Riprap between 6 and 24 inches in size protects the inlet to this culvert. In the reach between the SR 534 crossing and its confluence with Carpenter Creek, the stream is characterized by a steep-banked channel narrower than the sections observed upstream. The banks are marked by extremely dense reed canarygrass and Himalayan blackberry, which has overgrown into the main channel in most portions of this reach (Figure 2.10). A bankfull width measurement of 5.8 feet was taken at 47 feet downstream of the SR 534 crossing outlet, and a bankfull width measurement of 7.2 feet was taken at 69 feet downstream. The confluence of the tributary with Carpenter Creek occurs 176 feet downstream of the SR 534 culvert outlet (WDFW ID CR2). All bankfull width measurements are recorded in Table 3.1.

Figure 2.9. Inlet of the culvert at the downstream crossing of SR 534

Figure 2.10. Dense reed canarygrass and blackberry on channel overbank areas

A site visit (site visit 3) with the PEO, Environmental Manager, and representatives of WDFW, Upper Skagit Indian Tribe, Skagit River System Cooperative, and Parametrix occurred on August 27, 2019. Due to the lack of BFW indicators in the ditched channel upstream and adjacent of barrier ID CR2, it was agreed upon with stakeholders that field measurements in this reach would be validated with hydraulic modeling to determine an appropriate BFW for the crossing design. This reach was later determined to be lower in gradient than the expected design, and therefore was not selected as a design reference reach. The basis of the design is described in Section 9.

A summary of the site visits can be referenced in Appendix H – Hydraulic Field Report.

3.0 Watershed Assessment

3.1 Watershed and Landcover

The watershed boundary to the SR 534 crossing of the unnamed tributary to Carpenter Creek was first obtained from the National Hydrography Dataset watershed delineations. The delineations were then modified by hand using LiDAR data obtained from LiDAR survey (WSI 2013).

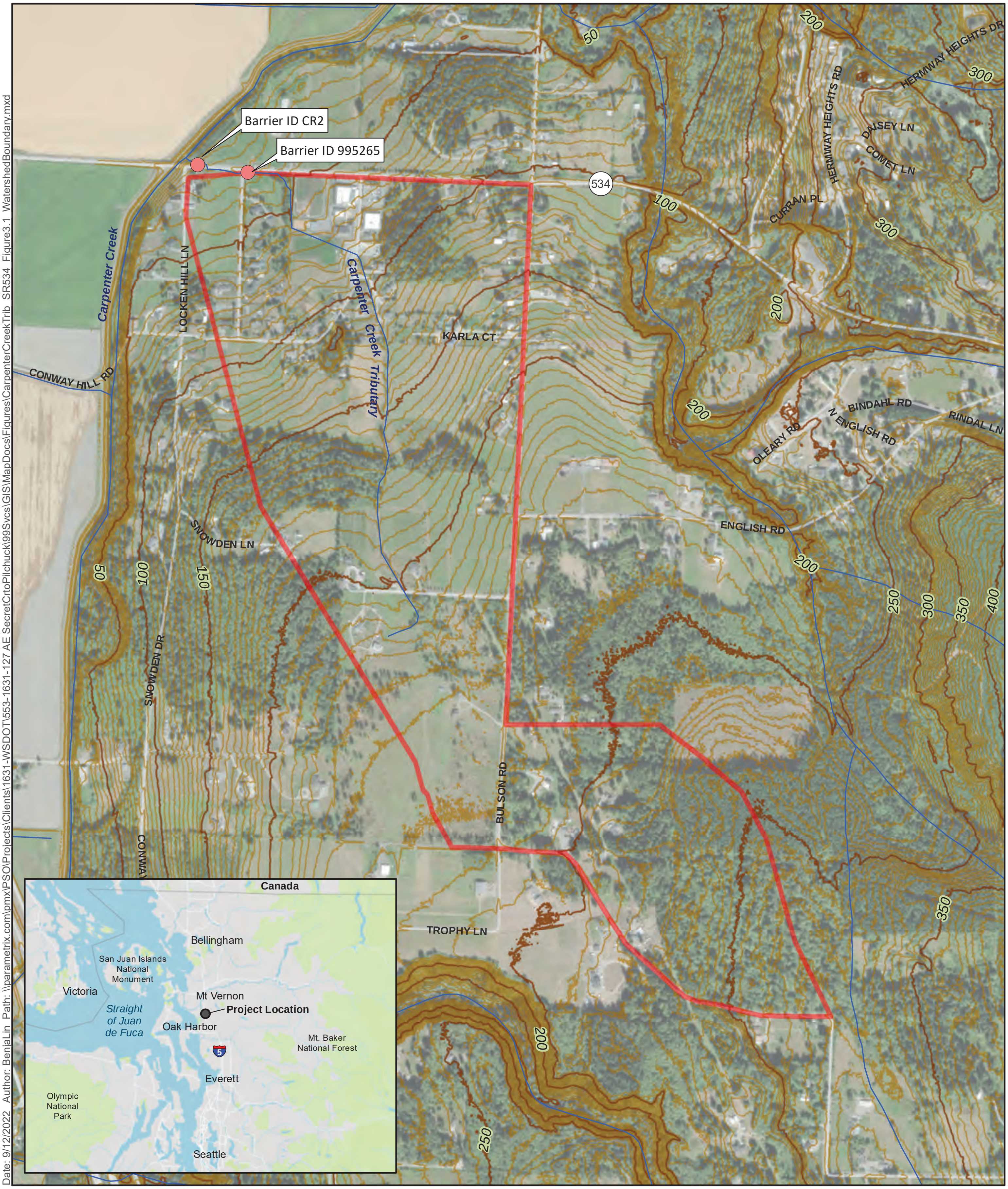
The drainage basin comprises an area of 299 acres. The highest elevation in the watershed reaches approximately 290 feet and the elevation of the channel at the SR 534 culvert inlet is approximately 20 feet (North American Vertical Datum [NAVD] 88). The watershed for the SR 534 crossing contains drainage from the Conway Elementary School at the northeast extent of the basin, as well as agricultural and low-density residential areas that make up most of the basin. The headwaters for the unnamed tributary to Carpenter Creek form east of the intersection of Bulson Road and Trophy Lane. The watershed does not contain any major tributaries.

The land cover in the upper portion of the watershed consists primarily of forested areas, while the land cover in the lower portion of the watershed is a mixture of pasture and low-density residential areas. Based on geographic information system (GIS) delineation of observed land cover in aerial imagery, the watershed land cover comprises forests (34 percent), pastures (55 percent), grasses (4 percent), and impervious surfaces (7 percent). Figure 3.1 depicts the watershed boundary and land cover.

The watershed is designated primarily as Rural Reserve Zoning to allow low-density development and to preserve the open space character of those areas not designated as resource lands or as urban growth areas with minimum lot sizes of 10 acres (Skagit County 2019).

3.2 Mapped Floodplains

The unnamed tributary to Carpenter Creek, including the project site, is not within a mapped floodplain. Downstream however, Carpenter Creek itself is within a floodplain, as reported by the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map Number 53015C0425C (FEMA 1985). The mapped floodplain is in an area designated as a Special Flood Hazard Area, Zone AO, with a noted base flood depth of 3 feet above grade. See Appendix C for the FEMA FIRM map.



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Source: WA DNR, ESRI, WSDOT

SR 534 Carpenter Creek Tributary Project Barriers
Contour (50 ft)
Contour (5 ft)
Watercourse
Carpenter Creek Tributary SR 534 Drainage Basin

0 250 500 1,000 Feet

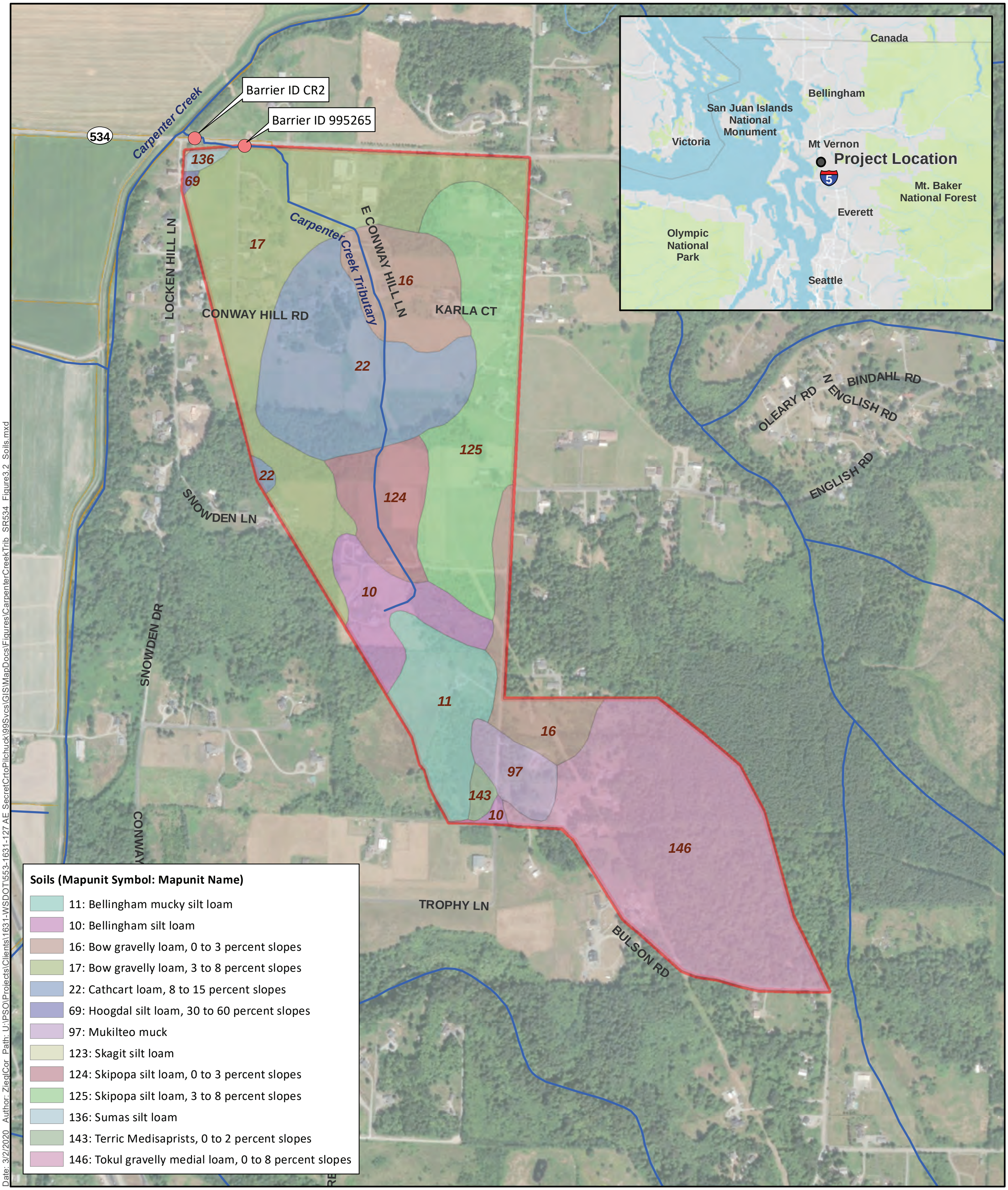
Figure 3.1 Watershed Boundary
Carpenter Creek Tributary SR 534

Skagit County, WA

3.3 Geology and Soils

The surficial geology of the unnamed tributary to the Carpenter Creek watershed is composed mainly of late Pleistocene deposits with some presence of material deposited during the Holocene between 2,000 and 10,00 years before present. The contributing watershed and stream corridor are primarily underlaid by Everson-age fine-grained glaciomarine sediment (geologic unit $Qgdm_{ec}$), deposited between 11,000 and 13,500 years before present (Dragovich et al. 2002). This material is primarily composed of finer grained clays and silts with very little gravel and cobble. During the site visit, some areas of gravel and cobble were observed in the channel which suggests lenses or remnants of this larger material from other deposits is present in some locations along the channel in the proximity of SR 534.

The watershed-specific soils were identified using the National Resource Conservation Service Custom Soil Resource Report for the Skagit County Area of Washington State (USDA NRCS 2019). A graphic representation of the findings is presented in Figure 3.2. The watershed is mainly composed of Bow gravelly loam (38.6 percent), Skipopa silt loam (26.6 percent), and Cathcart loam (19.5 percent). Bow gravelly loam ranges from very gravely ashy loam to clay loam. It has a drainage class of poorly drained and is commonly found on hillslopes and terraces. This soil has a high capacity for water storage and is classified in hydrologic soil group C/D (USDA NRCS 2007). Skipopa silt loam consists of ashy silt loam to silt loam and is commonly present in terraces. The silty loam has a drainage class of poorly drained, low capacity for water storage, and is categorized in hydrologic soil group D. Cathcart loam ranges from medium loam to gravelly medial sandy loam, has a drainage class of well drained, and a moderate water storage capacity. It is categorized in soil group B and is typically found on hillsides. Figure 3.2 depicts the watershed soil types.



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Source: WA DNR, ESRI, WSDOT,
USDA/NRCS (SSURGO Soils Database)

Figure 3.2 Soils.
Carpenter Creek Tributary SR 534

SR 534 Carpenter Creek Tributary Project Barriers

Watercourse

Carpenter Creek Tributary SR 534 Drainage Basin

N

0 250 500 1,000
Feet

Skagit County, WA

3.4 Geomorphology

3.4.1 Channel Geometry

In the upstream vicinity of SR 534, the channel morphology of the tributary to Carpenter Creek is characterized by constraint imposed on the channel due to adjacent land use. The stream has been realigned during transition of adjacent land to agricultural use, as well as the construction of roadway and the Conway School. In general planform, the channel displays no sinuosity in all reaches in the vicinity of SR 534. Channel cross sections display relative consistency within the reaches in the vicinity of SR 534. They are marked by a high level of constraint, either having been modified through ditching efforts upstream of SR 534, or through incision that is evident between the SR 534 and Carpenter Creek.

Bankfull width measurements upstream of barrier WDFW ID 995265 averaged 6.1 feet. Here most measurements were taken upstream of the boulders described in Section 2 and at locations where either a break in grade separating the main channel from overbank area was identifiable, or at the bottom of observed scour marks on channel banks that were observed. The open channel upstream of ID 995265 does not include the hydrology that is provided to the system through the storm sewer that runs along the south side of SR 534.

Bankfull width measurements downstream of the Conway Hill Road culvert (CR3) averaged 7.4 feet. In ditched reaches adjacent to SR 534, BFW measurements were obtained at the base of observed scour marks on the channel banks where possible, and relative to and slightly above vegetative indicators of ordinary high water with input from the Parametrix biologist. Bankfull depths were not measured.

Bankfull width measurements are summarized in Table 3.1 below, and the locations of these measurements are shown in Figure 2.1. Due to concerns about the robustness of the bankfull indicators at the site, a bankfull width for design of the minimum hydraulic opening and for the design channel cross section was selected by other means as described in Section 8.2.3.

Table 3.1 Bankfull Width Measurements

BFW number	Width (ft)	Included in design average?	Location measured
1	7.2	No	69 feet downstream of CR2 outlet
2	5.8	No	47 feet downstream of CR2 outlet
3	7.6	No	50 feet downstream of CR3 outlet
4	9.0	No	10 feet downstream of CR3 outlet
5	6.8	No	57 feet upstream of 995265 inlet
6	5.6	No	75 feet upstream of 995265 inlet
7	5.6	No	202 feet upstream of 995265 inlet
8	6.0	No	210 feet upstream of 995265 inlet
9	4.8	No	233 feet upstream of 995265 inlet
10	6.2	No	251 feet upstream of 995265 inlet
11	7.6	No	384 feet upstream of 995265 inlet
Overall Average	6.6		

A longitudinal profile of the stream from the confluence with Carpenter Creek to 5,400 feet upstream is depicted in Figure 3.3. The gradient over the length of the entire long profile shown is 4.0 percent. Consistent average gradients along the channel profile vary from 4.0 percent to 5.2 percent upstream of the Conway School culvert where the channel is, while still impacted by development, relatively less managed than the channel downstream of the Conway School culvert. The channel is contained within the same glaciomarine drift along the length of profile. Therefore, a conservative equilibrium slope of 4.0 percent was used in the analysis of degradation potential downstream of SR 534 described in Section 3.4.2.

Although planform and channel section geometry display consistency, the gradient of the stream, as determined from WSDOT site survey varies in the vicinity of SR 534. In the approximately 100 feet surveyed upstream of Barrier ID 995265, the gradient averages 5.6 percent. Through the open channel between the Conway Hill Road culvert and the SR 534 crossing culvert (shown as the potential reference reach identified in Figure 2.1), the average gradient is 2.0 percent. For the final reach of stream between the SR 534 crossing and the confluence with Carpenter Creek, the gradient varies between 7.2 percent and 10.5 percent, averaging 7.9 percent. These surveyed gradients are depicted in Figure 3.4.

The floodplain utilization ratio (FUR) for the existing channel upstream and adjacent to the SR 534 crossing was determined from existing conditions modeling of the 100-year event. Backwater effects did not appear to significantly increase the water surface width in the upstream adjacent reach and therefore do not significantly skew the FUR determination. The hydraulics of this reach provides the most representative FUR for the crossing. Here the typical 100-year water surface width was determined to be approximately 9 feet. Refer to Figure A.2.1 in Appendix A for the 100-year water surface width at a representative cross section between CR2 and CR3. The 100-year water surface is consistent in width as depicted in Appendix A Figure A.1.7. The reach where the FUR is being assessed, between CR2 and CR3, has an average BFW measurement of 8.3 feet (BFWs 3 and 4 from Table 3.1). Using the 100-year water surface width of 9 feet and dividing by the BFW average of 8.3 feet results in a FUR value of 1.1. A FUR value of less than 3.0 indicates that the system is confined.

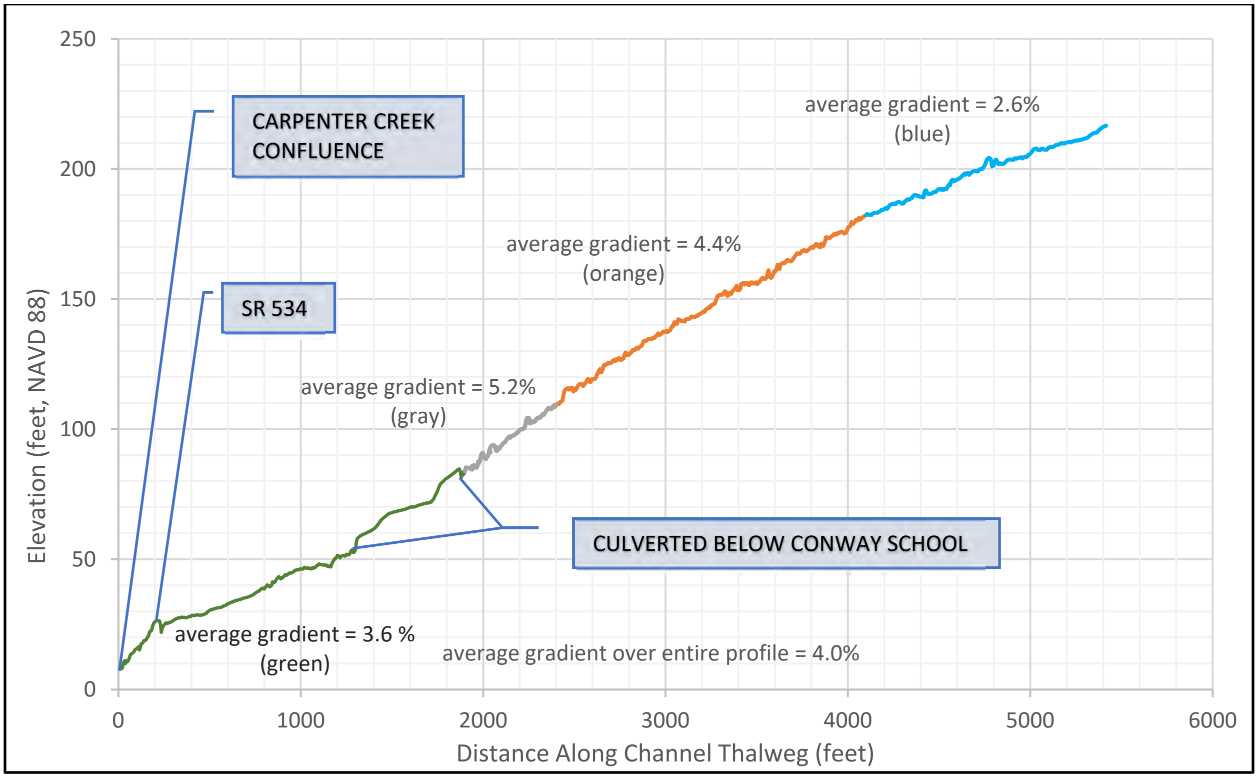


Figure 3.3. Longitudinal Profile of the Unnamed Tributary to Carpenter Creek

3.4.2 Potential for Aggradation, Incision, and Headcutting

The existing channel displays some evidence of degradation. Incision was identified in the reaches upstream of the WDFW ID 995265 site, and minor incision and local scour was observed downstream of the SR 534 crossing. Incision was most pronounced at these locations due to the relative steepness in the gradient of these reaches, the likelihood that the reaches are not in historical locations due to channel realignment, and the predominantly fine material composition of the surficial geology.

In the reach immediately upstream of the WDFW ID 995265 barrier there are large immobile rock boulders in the stream channel. These rocks shown in Figure 2.4 likely act as grade control and limit the potential for propagation of headcutting upstream. The rocks are out of character with the surficial geology of the area. They may be the result of a local lens or remnant of coarse material or have been intentionally placed to resist head cut propagation. In the reach downstream of the SR 534 crossing, the channel section displays a shallow and narrow main channel with steep banks. An armor layer of larger rock material (up to 12 inches in diameter) was observed in the bottom of the main channel. Modeling indicates that the floodplain of the channel is expected to be engaged in flows below the 2-year peak flow event. Though there exists a well-connected floodplain and armored channel bottom, the material was not notably embedded and continued channel incision could pose risk to the crossing. Local scour near the SR 534 culvert outlet was observed, likely caused by increased flow velocities as water exits the culvert.

The existing SR 534 culvert is functioning as grade control to vertical adjustment. Following removal of the existing crossing, long term degradation is possible. An existing slope ratio of 4.0 exists between the downstream gradient (7.9 percent) and the upstream gradient (2.0 percent). Figure 3.4 depicts the longitudinal profile of the channel from approximately 110 feet upstream of the inlet to the storm sewer

(Site ID 995265) downstream to the confluence with Carpenter Creek, along with a vertical adjustment potential (VAP) line. The VAP line represents a potential lower limit regrade of the channel if a head cut in the relatively steeper gradient downstream of SR 534 were to propagate upstream due to the removal of the existing crossing. This VAP line was assumed to be 4.0 percent as described in Section 3.4.1 above. A regrade along this VAP line would result in up to approximately 6.75 feet of degradation at the existing SR 534 crossing. The rate and degree of potential degradation depends on many factors including the stability of the cobble material in the channel downstream of SR 534 and is difficult to predict with certainty. During the final hydraulic design phase, the long-term degradation potential was further assessed and documented in Section 12.2.

Due to the grade controls created by the Conway Hill Road culvert and large immobile material upstream of the project limits, degradation is not expected to be a risk between these two points following the proposed removal of the barrier Site ID 995265. Aggradation may occur in this reach due to the relatively lower gradient in comparison to the upstream gradient, where sediment carried from upstream may be deposited. The risk of aggradation is expected to be low due to the relatively low supply of sediment believed to be available in the system.

Sediment supply in this system is likely dominated by finer materials in the surficial geology and introduced from adjacent farmland, although gravels and cobbles were observed and measured in pebble counts in all reaches in the vicinity of SR 534.

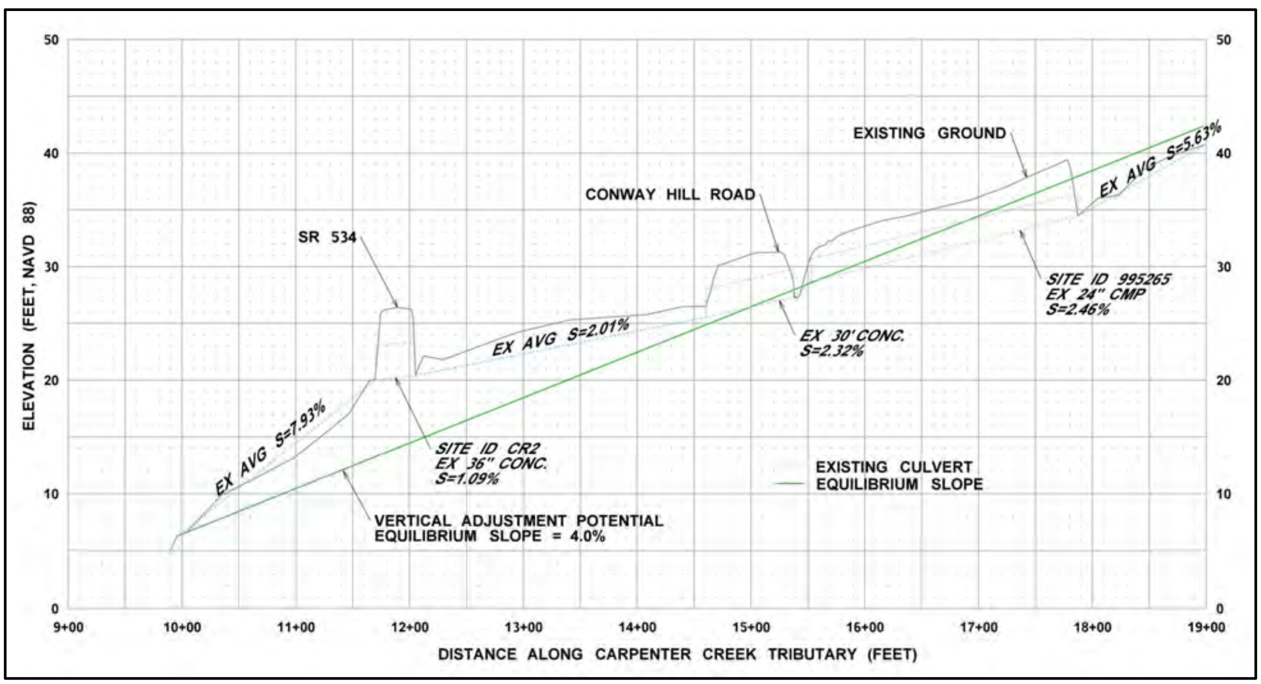


Figure 3.4. Longitudinal Profile of the Unnamed Tributary to Carpenter Creek – Project Vicinity

3.4.3 Floodplain Flow Paths

Due to confinement upstream and downstream of the identified barriers to fish (CR2 and 995265), no defined floodplain exists, except for the reach downstream of the SR 534 crossing. Flows events are contained within the constrained channels, though modeling does indicate the potential for the 100-year flow event to breach the channel in the vicinity of Conway Hill Road. In the future condition, the design reaches will include floodplain benches that will increase the area of overbank flow. The widened SR 534 crossing structure in comparison to the existing culvert will also increase area for floodplain flow between upstream and downstream of SR 534.

3.4.4 Channel Migration

No defined floodplain of the channel exists and sinuosity is near 1. Channel migration is not expected to be an issue due to the heavily modified nature of the stream as result of encroachment. The channel has maintained a mostly straight planform and constrained sections. The existing incision and large boulders in the reach upstream of the WDFW ID 995265 barrier will likely limit the potential for channel migration.

The proposed design will widen the channel corridor. From a geomorphic perspective, the potential for lateral migration is expected to be limited to within the bottom of the proposed channel corridor. Outside of the proposed floodplain corridor, lateral migration risk is low. From a structural perspective, the crossing structure should be designed to accommodate the potential for the main channel to migrate to the inside faces of the structure. Section 12.1 describes the risk of lateral migration in more detail.

3.4.5 Existing Large Woody Material and Potential for Recruitment

The field visit documented no in-channel large woody material in the vicinity of the WDFW ID 995265 or WDFW ID CR2 barriers. The stream courses through very limited woodland areas and the potential for future large woody material recruitment is low.

3.4.6 Sediment Size Distribution

To evaluate the sediment of the tributary to Carpenter Creek in the vicinity of SR 534, two pebble counts were conducted upstream of the WDFW ID 995265 barrier, and one pebble count was conducted downstream of the WDFW ID CR2 barrier. All the pebble counts recorded the exposed surficial streambed material. No pebble counts were conducted in the reach between WDFW Barrier IDs CR2 and CR3 since extremely dense reed canary grass and water depth prohibited the retrieval of pebbles. The Wolman pebble count procedure (USDA 2001) was followed for the two upstream counts, while a modified count was performed at the downstream count by sampling along the length of the channel instead of across the channel due to the narrowness of the channel section there. Figure 3.5 depicts the results of all pebble counts. Photographs of the locations of upstream pebble count 1, upstream pebble count 2, and downstream pebble count 1 are depicted in Figures 3.6, 3.7, and 3.8, respectively. Table 3.2 shows the sediment properties for pebble counts in Carpenter Creek.

During the preliminary design process, it was determined that the hydrology at the locations of the upper pebble counts differ from hydrology at the proposed channel due to the input of flow from the enclosed storm sewer along SR 534. Significant spread in sediment gradations was also observed between pebble counts, related to the local differences in channel gradients at the locations of the pebble counts. The gradients are discussed in the following descriptions of the pebble counts.

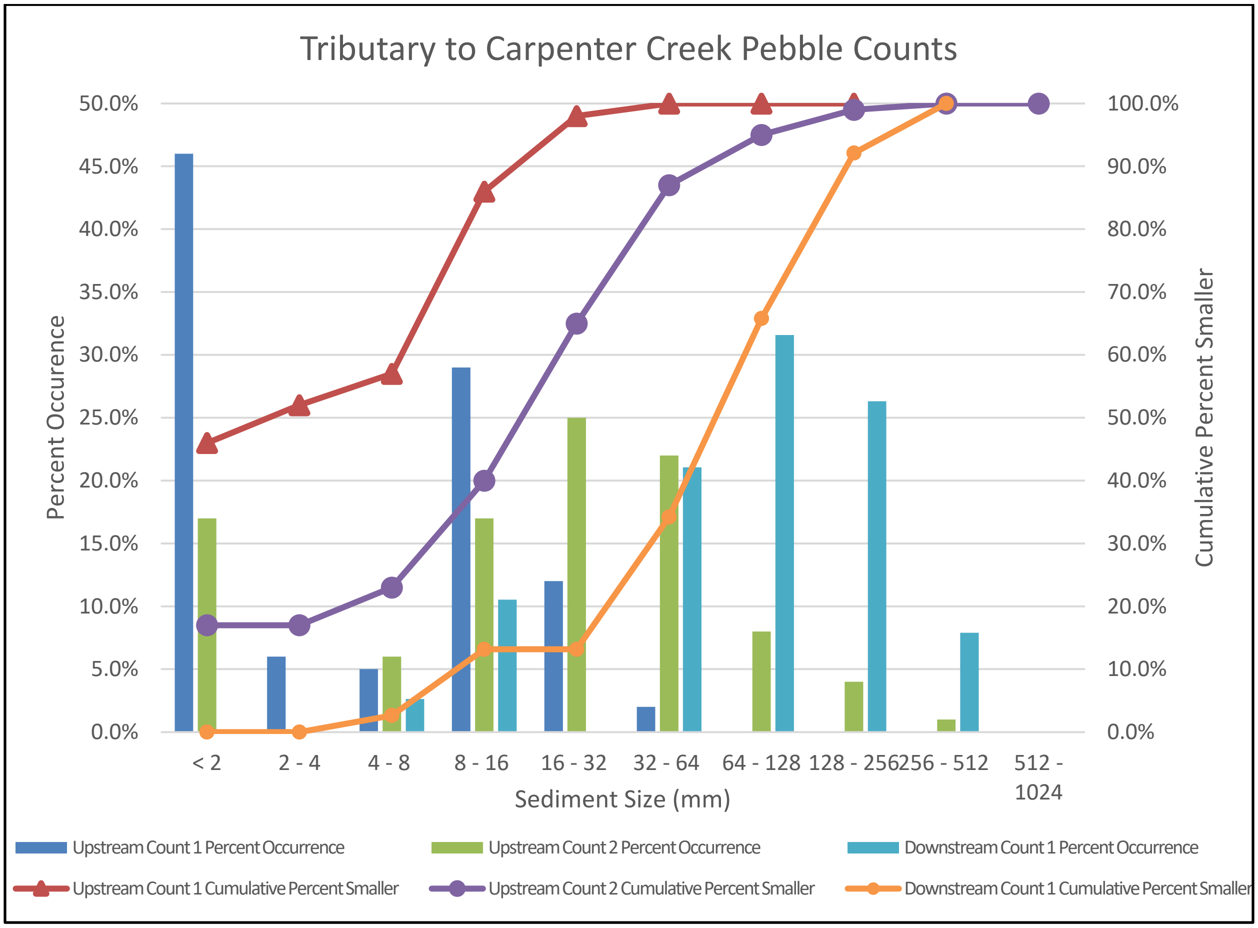


Figure 3.5. Sediment Properties in Vicinity of SR 534 Crossing

Table 3.2 Sediment Properties for all Pebble Counts at Carpenter Creek site

	Upstream Pebble Count 1 Diameter (mm) (in)	Upstream Pebble Count 2 Diameter (mm) (in)	Downstream Pebble Count 1 Diameter (mm) (in)
D_{16}	0.7 (0.03)	1.9 (0.07)	22.5 (0.89)
D_{50}	3.3 (0.13)	22.4 (0.88)	96.0 (3.78)
D_{84}	15.4 (0.61)	59.6 (2.35)	216.6 (8.53)
D_{100}	40.0 (1.57)	300.0 (11.81)	300.0 (11.81)

Upstream Pebble Count 1 was conducted at a section of the channel 281 feet upstream of culvert WDFW ID 995265 in the reach of the tributary to Carpenter Creek that daylights through an area heavily overgrown with Himalayan blackberry. The Wolman analysis results indicate that the streambed of count 1 was composed of 46 percent sand, 11 percent fine gravel, 29 percent medium gravel, and 14 percent coarse gravel. During the site visit, it was noted that the local gradient at this pebble count location was much less than at the other pebble count locations based on observational judgement since survey did not extend to this location and LiDAR is not expected to be detailed enough at this scale to be informative.

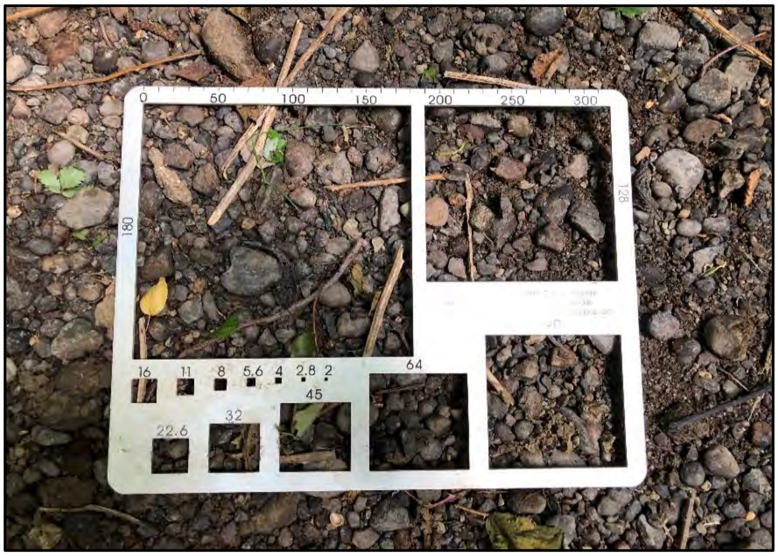


Figure 3.6. Upstream Pebble Count 1

Upstream Pebble Count 2 was conducted at a location 384 feet upstream from culvert WDFW ID 995265 where the channel substrate comprised a mix of gravel, sand, and cobbles. The Wolman analysis results indicated that the streambed of count 2 consisted of 47 percent coarse gravel, 17 percent sand, 17 percent medium gravel, and 12 percent cobble, 6 percent fine gravel, and 1 percent boulders. The local gradient at this location was estimated to be approximately 6 percent.

Figure 3.7. Upstream Pebble Count 2

Downstream Pebble Count 1 was conducted at a location of 47 feet downstream of the outlet of the WDFW ID CR2 barrier. Here, cobbles and large boulders were observed in the stream channel. The pebble count analysis results indicated that the streambed was composed of 57.9 percent cobbles, 21.1 percent coarse gravel, 10.5 percent medium gravel, 7.9 percent boulders, and 2.6 percent fine gravel. The slope in this reach is 6.9 percent as determined by WSDOT site survey.

Figure 3.8. Downstream Pebble Count 1

3.5 Groundwater

No obvious signs of groundwater were observed during the site visits.

4.0 Fish Resources and Site Habitat Assessment

4.1 Fish Use

Native fish potentially found in the project area include cutthroat trout, coho salmon, three-spine stickleback, and steelhead. Of these, steelhead trout are threatened species under the Endangered Species Act of 1973. Coho salmon are federal species of concern. In Washington, steelhead are candidate species for listing; steelhead/rainbow trout, coastal cutthroat trout, and coho salmon are on WDFW's Priority Habitats and Species List. No fish use has been documented by WDFW within the unnamed tributary to Carpenter Creek (WDFW 2019a, 2019b).

4.2 Existing Habitat

Overall, habitat in the Carpenter Creek watershed has been affected by agricultural, forestry, and residential uses with agricultural activities being the current driver for habitat conditions within the lower portion of the watershed. Streams in the lower portion of the watershed, including the subject stream, have been modified into ditches. Wetlands have been drained, and riparian vegetation and large woody debris removed, resulting in simplified habitat and poor water quality conditions. The unnamed tributary to Carpenter Creek is not identified on the 303(d) list of impaired waterbodies for any water quality parameter; however, Carpenter Creek downstream of the confluence with the unnamed tributary is listed on the 303(d) list of impaired waterbodies for dissolved oxygen. Also, a Total Maximum Daily Load (TMDL) is in place on Carpenter Creek for temperature and bacteria (Ecology 2018).

4.2.1 Immediate Crossings

Site ID 995265 is a water surface drop barrier to fish passage (WDFW 2003b), and Site ID CR2 crossing is a slope barrier to fish passage (WDFW 2003a), and. Habitat is limited within both sites.

Site ID 995265

Habitat in the project area downstream of the culvert outlet is limited because the channel is a combination of maintained drainage ditch and piped sections adjacent to SR 534 extending downstream to the Site ID CR2 crossing. The ditch is approximately 6 feet wide between the ordinary high-water line and depths likely range between 1 and 2 feet in depth when wetted. Riparian vegetation within the upstream reach is limited to herbaceous vegetation including bird's-foot trefoil, reed canarygrass, teasel, water parsley, equisetum, bittersweet nightshade, and small patches of common cattail. The dense herbaceous vegetative growth in the channel and lack of cover limit habitat potential within the reach. No woody debris was present within the lower reach. Silts and fines dominate the channel substrate with patchy areas containing quarry spall material. The channel during the summer months is dry. No suitable spawning habitat was observed in the downstream project reach and juvenile rearing habitat is limited by the lack of pools and cover. Beaver activity was not observed.

Upstream of the culvert inlet, the stream is confined within a straight channel at the west edge of the Conway Elementary School parcel. From a perspective looking downstream, most of the channel is incised with a small area along the left bank near the SR 534 crossing that has some limited capacity to allow overbank flow. In comparison to the downstream reach, the upstream reach retains some functioning riparian conditions along the left bank. Riparian vegetation along the right bank is limited to dense Himalayan blackberry and lawn grasses associated with the school property. Riparian vegetation along the left bank includes red alder, Douglas fir, and shore pine with an understory of Indian plum, Himalayan blackberry, bittersweet nightshade, and some reed canarygrass. Sediments are dominated by fine-grained material including sand and silt; however, there were several areas of patchy small- to medium-sized gravels that were heavily embedded with fines. No large woody debris was observed within the reach. Habitat within the upstream reach is primarily low-moderate gradient riffle habitat when the channel is wetted. The upstream reach was dry during the survey.

Overall, there is some limited low-quality spawning habitat upstream of the culvert inlet and potential for some winter rearing/refugia habitat for juvenile salmonids if access were restored. Fine sediment inputs limited riparian habitat, and current hydrology limits use of the system by salmonids.

Site ID CR2

Habitat in the project area upstream of the culvert inlet is limited because the channel is a combination of maintained drainage ditch and piped sections adjacent to SR 534 extending upstream to Site ID 995265. The ditch is approximately 6 feet wide between the ordinary high-water line and depths likely range between 1 and 2 feet in depth when wetted. Riparian vegetation within the upstream reach is limited to herbaceous vegetation including bird's-foot trefoil, reed canarygrass, teasel, water parsley, equisetum, bittersweet nightshade, and small patches of common cattail. The dense herbaceous vegetative growth in the channel and lack of cover limit habitat potential within the reach. Silts and fines dominate the channel substrate with patchy areas containing quarry spall material. The channel during the summer months is dry. No suitable spawning habitat was observed in the upstream project reach and juvenile rearing habitat is limited by the lack of pools and cover. Beaver activity was not observed.

Downstream of the culvert outlet, the stream is confined within a narrow-incised channel along the toe of SR 534 extending to the confluence with Carpenter Creek (Hill Ditch). The channel appears to be armored with large cobble and smaller boulders, which limits the potential for providing suitable spawning habitat. Buffer vegetation is characterized by dense reed canarygrass and bittersweet nightshade growth, which provides some low-quality cover. There is some scattered Nootka rose and immature alder within the buffer. The gradient is significantly steeper than the upstream reach and is dry during the late summer and early fall. The channel likely provides some limited rearing habitat, when wetted, and may also provide some refugia to adult and juvenile salmonids from high-flow events in the mainstem Carpenter Creek.

4.2.2. Quality Within Reach

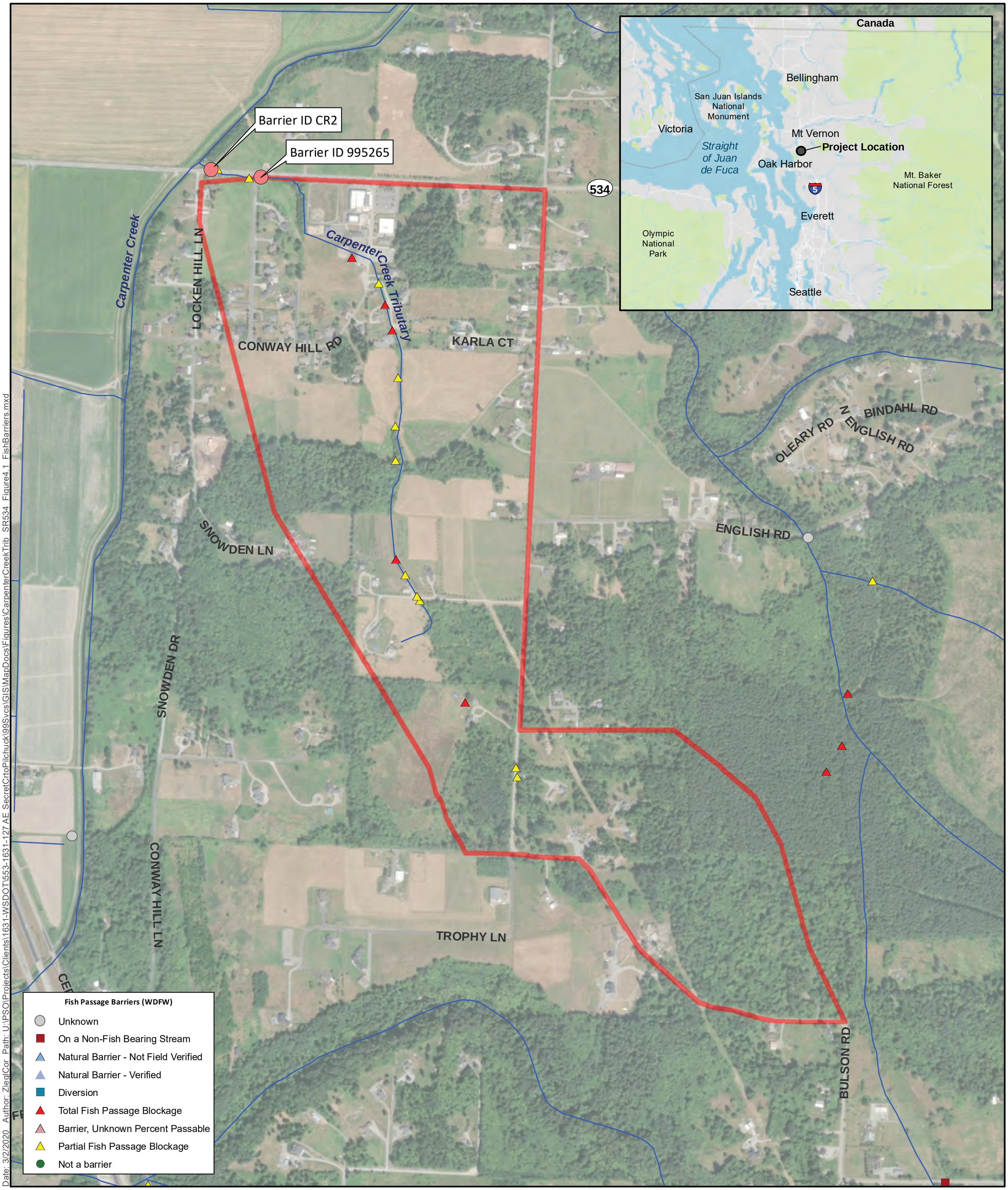
WDFW (2009) conducted a physical habitat survey upstream of the subject culverts to evaluate and characterize the potential habitat. The surveys extended 2.507 meters (1.56 miles) upstream of the lowermost barrier (CR2) to the point where the stream became non-fish habitat. Over the entire reach, the habitat consisted of 77 percent pool habitat and 23 percent riffle habitat. Limiting factors identified for the reach included: lack of instream cover with little to no LWD and some small woody debris in the upper reach; poor riparian cover, lack of channel complexity because of channel straightening and tight lining into a narrow ditch-like feature, and excessive sedimentation of available spawning gravels. Given the seasonal nature of the stream, the upstream reaches likely provide low quality rearing habitat. Potential spawning habitat has been significantly degraded by excessive sedimentation and therefore, the quality of spawning habitat is also low within upstream reaches.

4.2.3 Length of Potential Gain

WDFW (2003a, 2003b) performed a habitat survey upstream from the culvert and reported 1.6 miles of potential fish habitat upstream of the culverts at SR 534. Of that habitat gain, 3,715 square feet/0.09 acre is spawning habitat and 16,501 square feet/0.38 acre is rearing habitat. Habitat gain includes the mainstem.

4.2.4 Other Barriers in System

WDFW (2019) indicates that there are no fish passage barriers downstream of the lowermost culvert (Site ID CR2) extending to Tom Moore Slough, which is within the lower South Fork Skagit River estuary (Figure 4.1). One partial barrier (Site ID CR3) exists between the lowermost culvert (Site ID CR2) and Site ID 995265. Upstream of Site ID 995265, there are nine partial barriers and five complete barriers on the mainstem (Figure 4.1).



Source: Skagit County, ESRI, WSDOT

SR 534 Carpenter Creek Tributary Project Barriers

Watercourse

Carpenter Creek Tributary SR 534 Drainage Basin

0 500 1,000 2,000 Feet

Figure 4.1 Fish Barriers

Carpenter Creek Tributary SR 534

Skagit County, WA

4.2.5 Other Restoration Efforts in System

Carpenter Creek, along with several tributary streams, drain the slopes east of I-5 toward the South Fork Skagit River and the Skagit River delta. The Skagit River supports the largest runs of Pacific salmon and steelhead in the Puget Sound region and is therefore a primary focus for restoration efforts in the region with numerous stakeholders working together to address recovery efforts. The Skagit Watershed Council; Skagit Conservation District; Skagit Delta Tidegates and Fish Initiatives; land trusts, national nonprofit organizations (NGOs); local fisheries enhancement groups including the Skagit Fish Enhancement Group and Skagit River System Cooperative are all currently working with federal, state, local, and tribal entities. They also work with other regional programs including the Puget Sound Nearshore Ecosystem Restoration Program and the Puget Sound Partnership to address many of the issues contributing to salmon population declines in the region.

In addition to the restoring the numerous fish passage issues throughout the overall Skagit basin, including the Carpenter Creek watershed, major efforts are focused on estuarine and floodplain restoration in the lower Skagit River Delta, which includes dike removals, wetland restoration, tide gate removal/repair, among others. The Skagit Fish Enhancement Group is currently involved in the Skagit Watershed Stewardship Project, which focuses on the continued stewardship of native riparian and floodplain forest restoration projects completed throughout the Skagit River watershed, as well as the currently active floodplain wetland restoration project at the Skagit Forks (Britt Slough).

The Skagit River System Cooperative, private landowners, and Skagit County Dike and Drainage District #3 have conducted restoration efforts in the Carpenter Creek watershed, including alluvial fan restoration projects along Johnson Creek and Sandy Creek where they discharge to Carpenter Creek (Hill Ditch). The Skagit County Natural Resource Stewardship Program also implements riparian restoration on private lands in the Skagit River basin, which typically involves invasive species removal and control, livestock exclusion, and native plantings.

5.0 Reference Reach Selection

Because of significant variation in the channel gradient in the vicinity of SR 534, the major input of hydrology to the system through the storm sewer system located along SR 534, and the existing constrained nature of the channel, no appropriate relatively unmanaged reference reach was available. The basis for design of the channel shape and streambed material is described in Section 9.

6.0 Hydrology and Peak Flow Estimates

The watershed for the tributary to Carpenter Creek receives a mean annual precipitation of approximately 34.9 inches and a basin-averaged mean annual precipitation for the years between 1981 and 2010 of 38 inches, as determined from PRISM Climate Group rainfall data (USGS 2014).

The WDFW Water Crossings Design Guidelines (Barnard et al. 2013) present four methods for determining the hydrology for the design of culverts for fish passage. The four methods in preferred order of succession are stream gauging, continuous simulation modeling, local regression models, and regional regression models. There are no existing stream gauges on this tributary to Carpenter Creek. A continuous-simulation hydrologic model using MGSFlood software was used to produce model results (MGS 2019). MGSFlood, a Hydrological Simulation Program-FORTRAN based model, calculates peak flow rates by considering existing land use conditions and underlying soil types. A 15-minute timestep was selected to represent the short time of concentration created by the impervious surface of SR 534 and the Conway School low in the watershed. The model also represents a watershed in a saturated condition, where wetland type soils have runoff characteristics like impervious areas. The MGSFlood model did not provide a peak flow value for the 500-year event. The 500-year peak flow rate was determined by plotting the 2-year through 200-year events by mean recurrence interval and discharge value, then best-fitting a logarithmic curve to extrapolate the 500-year discharge.

In order to help assess the continuous-simulation results, the latest U.S. Geological Survey (USGS) regional regression equation (Mastin et al. 2016), using coefficients designated for Region 3 in western Washington, was applied to the watershed which generated the results reported in Table 6.1.

The continuous-simulation model results are roughly 50 percent greater than the regression equations. Because the regression equations are limited to basins under 5 percent impervious and this basin was determined to have 7 percent impervious coverage, the continuous-simulation model results were selected for hydraulic modeling. It is believed that this model better represents the peaking effects of impervious surface runoff originating along SR 534. It is noted that some portion of runoff from the Conway School property is routed through a detention pond prior to discharge to the stormwater system along SR 534. The pond likely provides flow attenuation, although the performance of the pond was not evaluated in the hydrology model presented in this report. Table 4.1 below reports the results of the methods used to analyze projected peak flow rates at the crossing.

Stream flows are assumed to typically cease during periods of the summer.

Table 6.1. Peak Flows for the Tributary to Carpenter Creek at SR 534

Mean Recurrence Interval (MRI)	USGS Regression Equation (Region 3) (cfs)	MGSFlood (cfs)
2	8.6	**12.5**
10	17.4	**27.6**
25	22.1	**39.8**
50	25.6	**47.0**
100	29.4	**48.3**
200	33.2	**50.5**
500	38.5	**62.7**
2080 100	29.8	**53.5**

7.0 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 534 crossings was performed using the U.S. Department of the Interior, Bureau of Reclamation's (USBR's) SRH-2D computer program—a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). The channel geometry data in the model was obtained from the MicroStation and InRoads files designed by Parametrix, which were developed from topographic surveys performed by WSDOT surveyors from the Northwest Region in June 2019. The hydraulic model was run using a subcritical flow regime. The elevations are in the NAVD 88 vertical datum.

The following two SRH-2D model scenarios were prepared for assessing stream characteristics for the tributary to Carpenter Creek: 1) existing conditions with both the WDFW ID 995265 and CR2 barriers, and 2) future conditions with the proposed crossing structure with a minimum hydraulic opening of 12 feet and daylighting of the WDFW ID 995265 barrier.

7.1 Existing Conditions—235-foot-long, 24-inch diameter corrugated metal pipe, and 36-inch diameter concrete pipe

The existing conditions model represented the tributary to Carpenter Creek from downstream of the WDFW ID 995265 barrier to downstream of the WDFW ID CR2 crossing of SR 534, which also included the Conway Hill Road culvert.

The existing channel geometry data in the model was obtained from the MicroStation and InRoads files supplied by the Project Engineer's Office, which were developed from topographic surveys performed by WSDOT surveyors from the Northwest Region in June 2019. The model extends 30 feet upstream of the Conway Hill Road culvert inlet, and 180 feet downstream of the existing SR 534 culvert outlet.

The SRH-2D model incorporates a channel roughness in the 2-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. Roughness from stream sinuosity is not included in the calculation since that aspect is represented in the hydraulic model surface. A roughness coefficient for the channel and overbanks was then computed based upon the criteria developed by Chow (1959) with applied factors (Arcement and Schneider 1989). Table 7.1 below 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
Manning's 'n' Value	0.044	0.039	0.044

The project channel and surrounding area, including the existing culverts, were imported into SRH-2D. Using the surveyed surface, 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 10,500 elements. The elements along the stream and floodplain have approximately 2- to 5-foot vertex spacing. The existing culverts were represented in the HY-8 culvert analysis software to calculate the hydraulics through the crossing. Appendix A contains the SRH-2D model results of the existing stream and crossing.

The upstream boundary condition was placed approximately 30 feet upstream of the Conway Hill Road crossing, with enough distance from the project site to not influence the hydraulic results at the SR 534 crossing. The upstream boundary condition defines inflow (see Section 6 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.

The downstream boundary condition was placed at the end of the survey at the tributaries confluence with Carpenter Creek, far enough from the project site to not influence the hydraulic results at the crossing. The downstream boundary condition estimates the water surface elevations at the outfall that correspond to the peak flow being modeled. Table 7.2 shows the water surface elevations and velocities for existing conditions. The 2-year flow event was used to compare the modeled water surface widths to the field measured bankfull widths in the channel upstream of the existing SR 534 crossing and downstream of the Hill Road culvert. The modeled 2-year water surface elevation width averaged 6.5 feet through this reach. This is approximately 1 foot less in width than the measured bankfull widths through the same reach reported in Section 3.4.1. Figure 7.1 depicts a cross section 40 feet upstream of the existing private driveway crossing with modeled 2-year peak flow event.

Table 7.2. Water Surface Elevations and Velocities at Existing SR 534 Crossing

	2-Year Flow
Water Surface Elevation at the Existing Inlet (ft)	22.4
Outlet Velocity (ft/s)	13.7
Channel Velocity (ft/s)	2.7

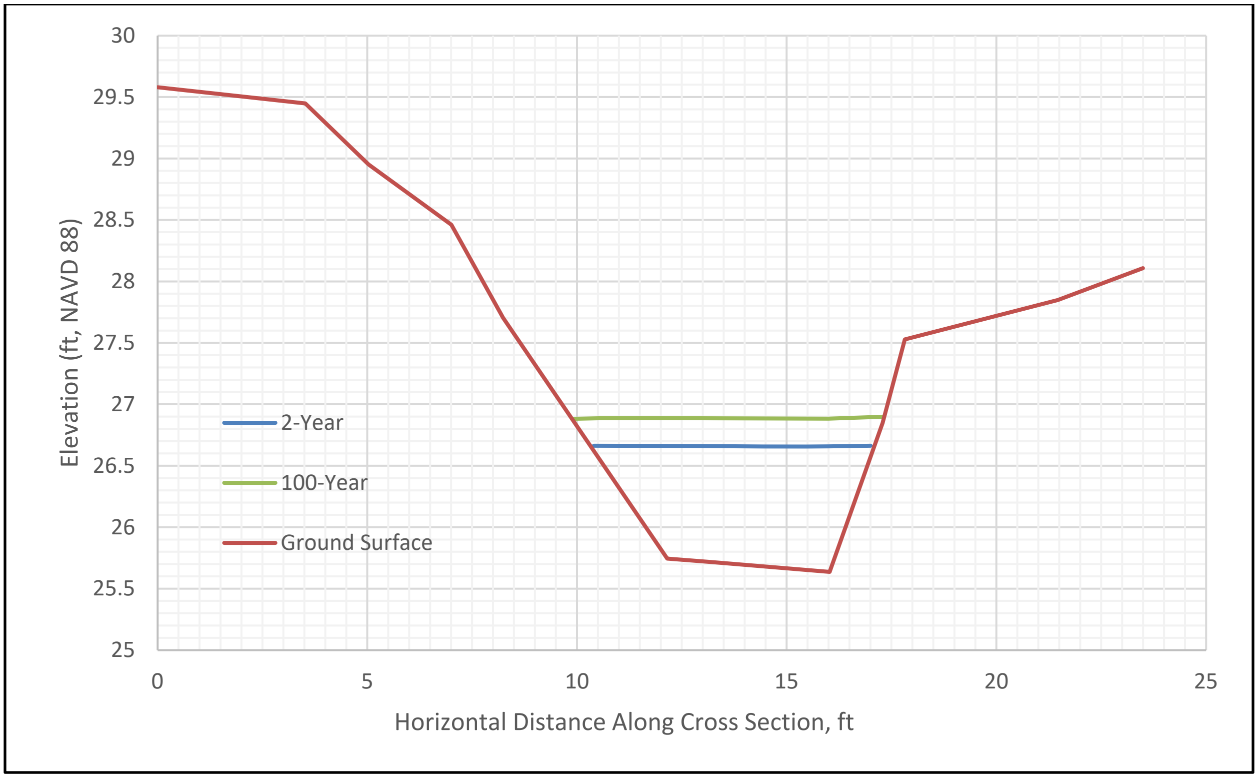


Figure 7.1. Existing tributary to Carpenter Creek section approximately 40 feet upstream of the SR 534 culvert inlet

7.2 Future conditions – Proposed Channel Realignment and 12-foot Span Structure at SR 534 Crossing

The hydraulic analysis of the proposed SR 534 Unnamed Tributary to Carpenter Creek crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2020). Pre- and post-processing for this model was completed using SMS Version 13.1.21 (Aquaveo 2021).

The model begins approximately 610 feet upstream of the existing SR 534 road crossing and extends 200 feet downstream of the crossing. The upstream boundary condition was placed at 55 feet upstream of the WDFW crossing 995265 to exceed the recommended minimum of 3 to 4 times the estimated existing floodplain width of 9 feet. The proposed model conditions of 34,400 mesh elements and covers an area of 2.1 acres (Figure 7.2). The elements along the stream and floodplain have approximately 2 to 5-foot vertex spacing. The proposed culvert was represented in the mesh by removing elements allowing the model to read those empty spaces as the encroachment created by the minimum hydraulic opening.

Figure 7.21. Proposed conditions Computational Mesh with Underlying Terrain

A roughness coefficient for the channel and overbanks was computed based upon the criteria developed by Chow (1959) with applied factors (Arcement and Schneider 1989). The proposed channel roughness is based on a proposed material of coarse gravel, with a moderate degree of surface irregularity, alternating flow that shifts from side to side, and appreciable obstructions upstream and downstream of the proposed structure due to the inclusion of large woody material. Roughness in the existing channels matched those selected for the existing condition model. Roadway was given a roughness typically used for asphalt and areas outside of the floodplains was described as 'Field' and assigned a value of 0.035 to represent tall grasses and other vegetation. Figure 7.3 below shows the roughness coefficients in terms of Manning's n value.

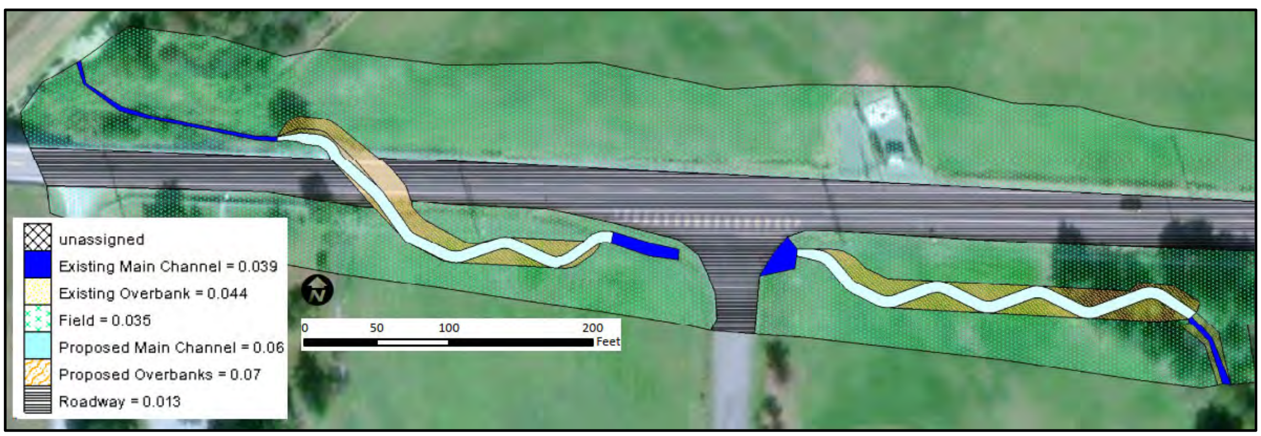


Figure 7.3. Spatial Distribution of Proposed-conditions Roughness Values in SRH-2D Model

The SRH-2D model run controls for the proposed model include a start time of 0.0 hours, a model end time of 3.0 hours and was run using a 0.2 second time step. The initial condition was dry and the model reached stable steady-state results for at least two hours (see Appendix B for SRH-2D model stability and continuity plots).

The future condition model's upstream boundary condition was extended to upstream of the existing inlet to WDFW ID 995265 and upstream of the proposed channel grading limit (Figure 7.4). The inflow for all peak flow simulations was designated subcritical to match the expected flow regimes, matching the existing model scenarios. Discharge values used are reported in Section 6. The downstream boundary condition used a tailwater water elevation of 12.7 feet based on the FEMA 100-year flood elevation of 3 feet above existing general ground level of the SFHA. HY-8 was used to model the Conway Hill Road crossing and its input values are shown as Figure 7.5. Due to the designed location of the outfall for the SR 534 storm system near the inlet of the Conway Hill Road culvert (CR3), flow inputs were split into two Inflow boundaries (one representing the open channel of the tributary downstream of the Conway School culvert, and one from the SR 534 storm system. MGSFlood modeling indicates that approximately 30 percent of the overall peak flow rates reported in Section 6 are conveyed through the SR 534 storm system, with the other 70 percent conveyed through the open channel downstream of the Conway School culvert.

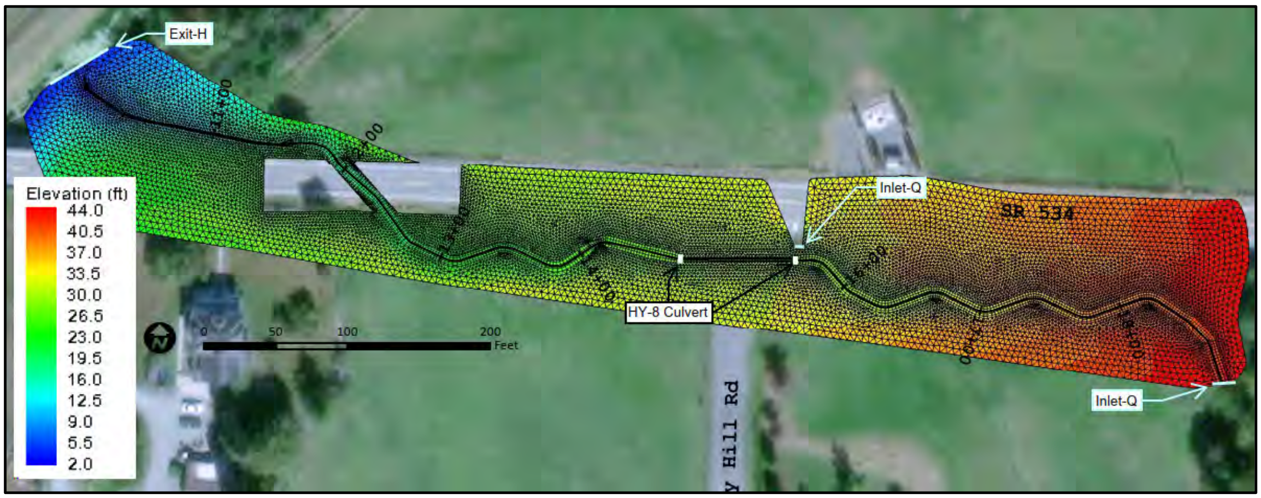
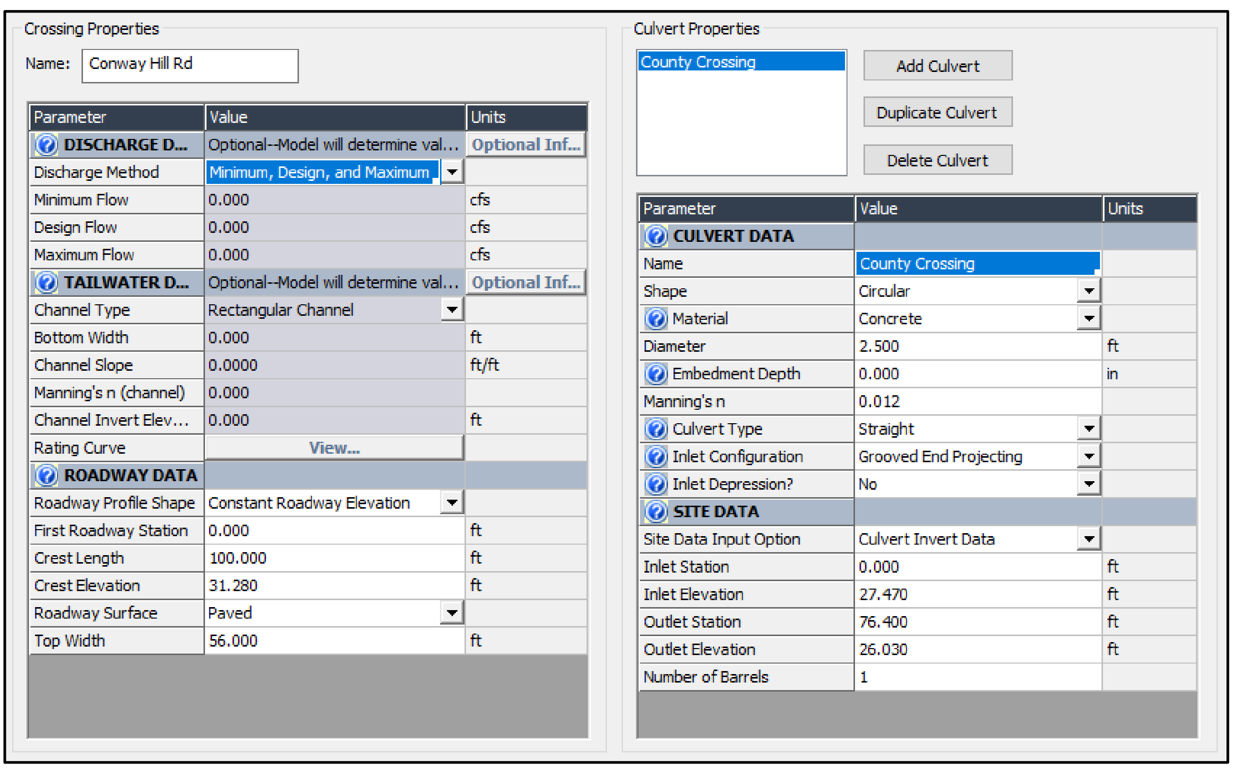


Figure 7.4. Proposed Conditions Boundary Conditions



Crossing Properties

Name: Conway Hill Rd

Parameter	Value	Units
DISCHARGE D...	Optional--Model will determine val...	Optional Inf...
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	0.000	cfs
Design Flow	0.000	cfs
Maximum Flow	0.000	cfs
TAILWATER D...	Optional--Model will determine val...	Optional Inf...
Channel Type	Rectangular Channel	
Bottom Width	0.000	ft
Channel Slope	0.0000	ft/ft
Manning's n (channel)	0.000	
Channel Invert Elev...	0.000	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	100.000	ft
Crest Elevation	31.280	ft
Roadway Surface	Paved	
Top Width	56.000	ft

Culvert Properties

County Crossing

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	County Crossing	
Shape	Circular	
Material	Concrete	
Diameter	2.500	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Grooved End Projecting	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	27.470	ft
Outlet Station	76.400	ft
Outlet Elevation	26.030	ft
Number of Barrels	1	

Figure 7.5. HY-8 Culvert Parameters

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 8.2.1 for a description of how the minimum hydraulic width was determined. Table 7.3 shows the results of water surface elevation, max water depth, velocity, and shear stress for upstream, downstream, and through the structure.

The model was run in steady-state mode for all modeled simulations as well. Appendix B contains the SRH-2D model results of the proposed conditions. Figure 7.6 depicts the locations of cross-sections used to report modeling results in Table 7.4. Figure 7.7 depicts the water surface elevation profile of the proposed crossing; Figure 7.8 depicts the water surface elevations in relation to a section within the proposed SR 534 crossing. Figure 7.9 depicts a plan view map of the 100-year flow velocity.

Modeling results indicate consistent flow depths, velocities, and shear stresses through both the upstream and downstream proposed reaches. In the existing reaches upstream and downstream of the project area, flow velocities and shear stresses are higher than through the project area due to higher gradients. Modeling indicates that the Conway Hill Road culvert will continue to backwater during the higher flow events. A slight backwater occurs where the designed stream corridor transitions to the narrower existing channel at the downstream limit of the channel grading.

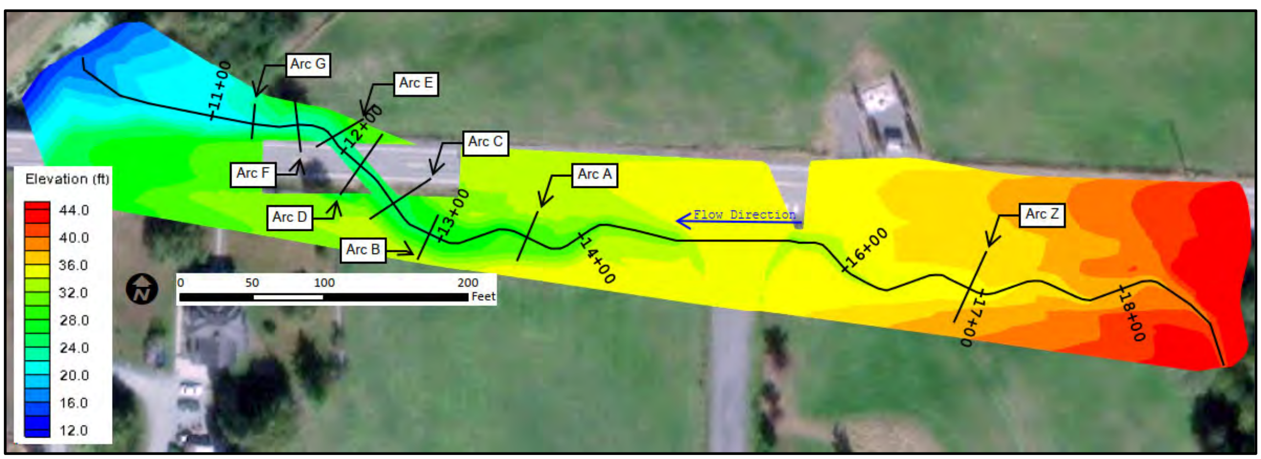


Figure 7.6. Locations of Cross Sections on Proposed Alignment Used for Results Reporting

Table 7.3. Average Main Channel Hydraulic Results for Proposed Conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year	Projected 2080 100-year
Average WSE (ft)	US 16+90 (Z)	33.1	33.7	33.8	33.7
	US 13+61 (A)	24.6	25.2	25.4	25.3
	US 12+89 (B)	22.3	22.9	23.0	23.0
	US 12+55 (C)	21.2	21.8	22.0	21.9
	Structure 12+20 (D)	20.1	20.7	20.9	20.8
	DS 11+92 (E)	19.2	19.9	20.2	20.0
	DS 11+65 (F)	18.7	19.7	20.0	19.8
	DS 11+33 (G)	16.4	16.9	17.0	16.9
Max depth (ft)	US 16+90 (Z)	0.6	1.1	1.2	1.1
	US 13+61 (A)	0.8	1.4	1.5	1.4
	US 12+89 (B)	0.8	1.4	1.5	1.5
	US 12+55 (C)	0.8	1.4	1.6	1.5
	Structure 12+20 (D)	0.8	1.4	1.6	1.5
	DS 11+92 (E)	0.8	1.6	1.8	1.7
	DS 11+65 (F)	1.2	2.2	2.5	2.3
	DS 11+33 (G)	0.8	1.3	1.5	1.4
Average velocity (ft/s)	US 16+90 (Z)	2.0	4.0	4.4	4.0
	US 13+61 (A)	2.1	4.1	4.4	4.2
	US 12+89 (B)	2.3	4.6	5.0	4.8
	US 12+55 (C)	2.2	4.3	4.6	4.4
	Structure 12+20 (D)	2.1	4.3	4.8	4.5
	DS 11+92 (E)	2.2	4.0	4.3	4.1
	DS 11+65 (F)	1.8	2.8	3.1	2.9
	DS 11+33 (G)	6.8	10.0	10.6	10.3
Average shear (lb/SF)	US 16+90 (Z)	0.8	1.8	2.1	1.8
	US 13+61 (A)	0.9	1.8	1.9	1.9
	US 12+89 (B)	1.0	2.0	2.3	2.2
	US 12+55 (C)	1.0	1.9	2.2	2.0
	Structure 12+20 (D)	0.9	2.0	2.3	2.1
	DS 11+92 (E)	0.9	1.5	1.6	1.5
	DS 11+65 (F)	0.3	0.6	0.7	0.6
	DS 11+33 (G)	2.4	4.1	4.5	4.2

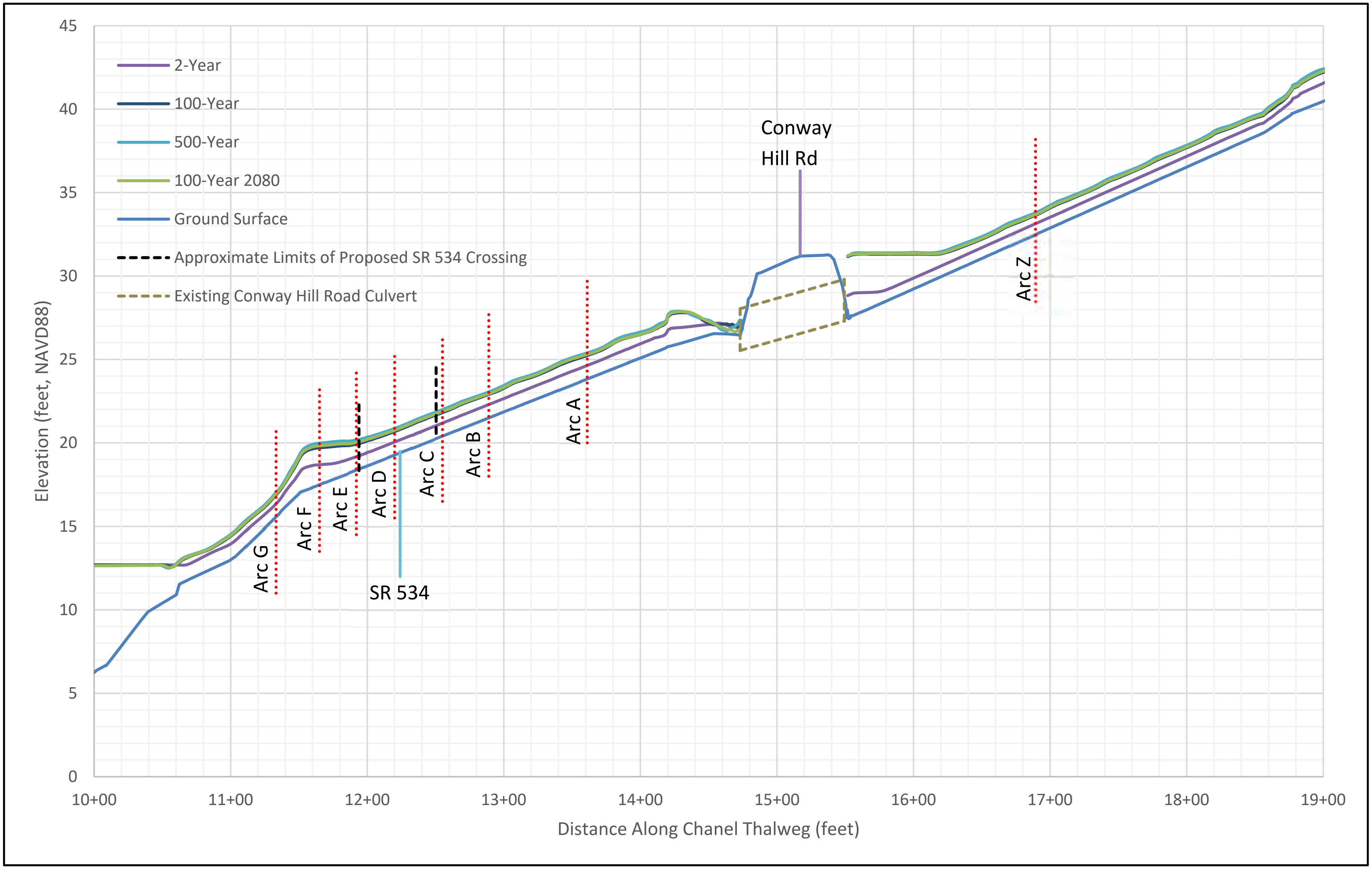


Figure 7.7. Water Surface Elevations at Proposed SR 534 Crossing and Constructed Channel

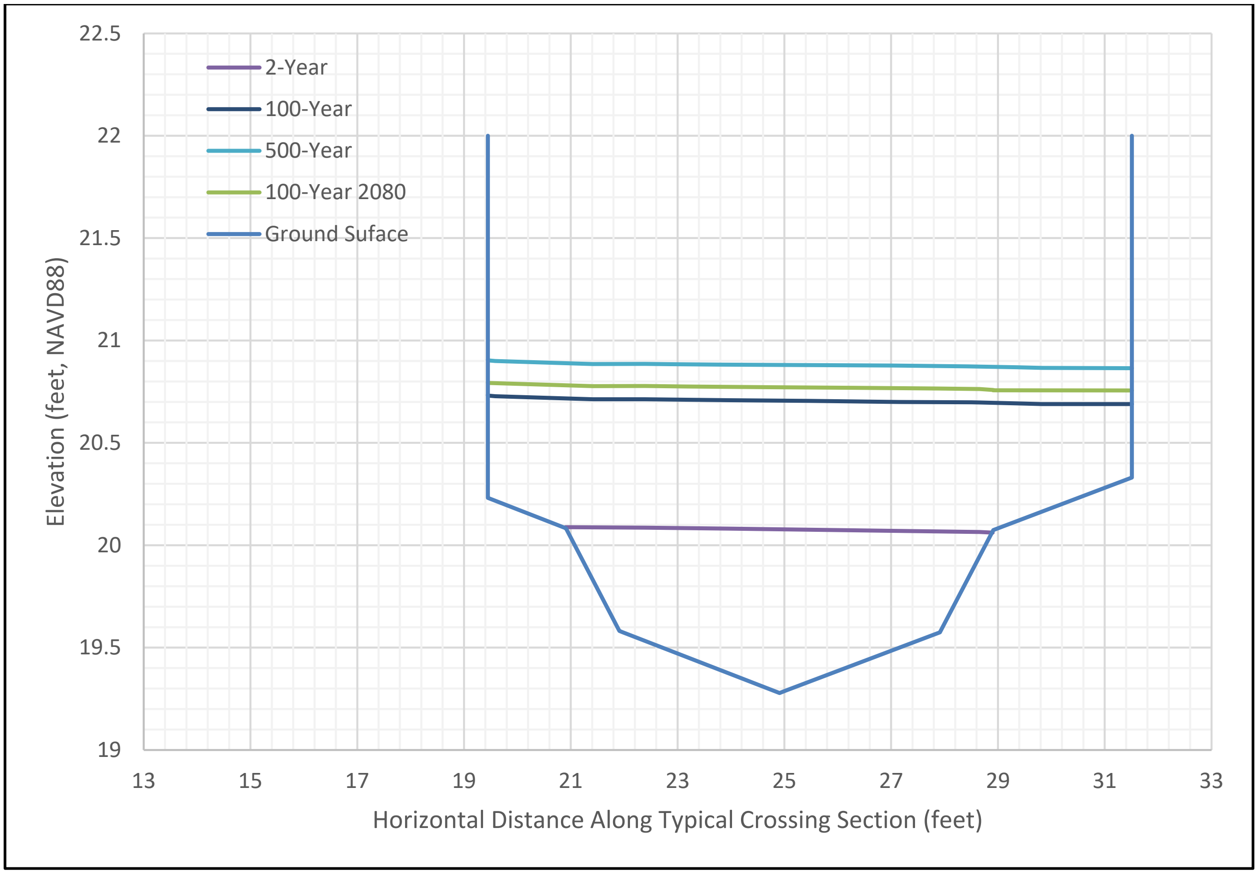


Figure 7.8. Proposed Tributary to Carpenter Creek Typical Section with 12-foot Opening at SR 534 Crossing

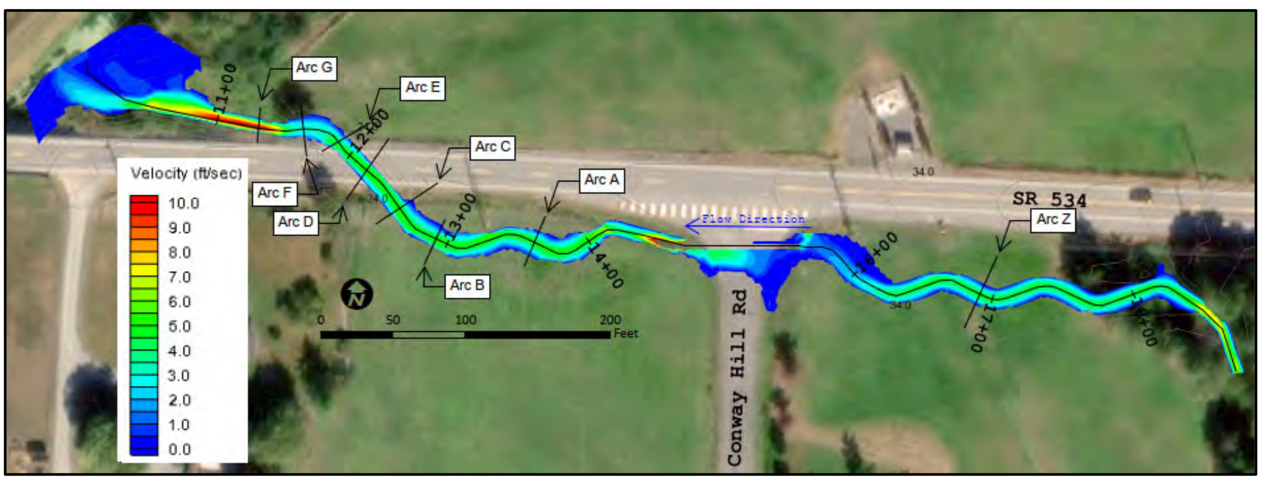


Figure 7.9. Proposed-conditions 100-year velocity map

Table 7.4. Proposed conditions Average Channel and Floodplains Velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
US 16+90 (Z)	1.8	4.0	1.2	1.8	4.0	1.2
US 13+61 (A)	1.9	4.1	1.6	2.0	4.2	1.8
US 12+89 (B)	3.0	4.6	1.4	3.5	4.8	1.5
US 12+55 (C)	2.0	4.3	1.3	2.4	4.4	1.3
Structure 12+20 (D)	1.0	4.3	2.3	1.1	4.5	2.4
DS 11+92 (E)	2.3	4.0	1.8	2.4	4.1	2.0
DS 11+65 (F)	1.6	2.8	1.3	1.8	2.9	1.3
DS 11+33 (G)	1.3	10.0	5.4	1.4	10.3	5.8

Right overbank (ROB)/left overbank (LOB) locations were approximated inspection of the topographic grade breaks

8.0 Fish Passage Design Methods Selection

8.1 Design Methodology Selection

The 2013 WCDG 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 site. According to the WCDG, a bridge should be considered for a site if the following factors apply: the Floodplain Utilization Ratio (FUR) is greater than 3; the stream has a bankfull width greater than 15 feet; the channel is believed to be unstable; the slope ratio exceeds 1.25 between the new channel and the existing channel; or the culvert length to width ratio exceeds 10.

Stream simulation was deemed the most appropriate method for this crossing because of the following: the bankfull width was determined to be 7.9 feet and well below 15 feet; the FUR of 1.1 is less than 3 in the upstream adjacent reach; the FUR calculated for the proposed channel is 1.9 which is less than 3; and the length to width ratio of the proposed structure is 4.2 which is less than 10. That stated, the proposed slope ratio is 1.6 (3.2 percent for the design slope through the crossing compared to 2.0 percent in the existing reach between SR 534 and Conway Hill Road). The design of countersink of the crossing structure should consider the potential for long term degradation as described in Section 3.4.2 and Section 9.3, and Section 12.2. The proposed structure crossing SR 534 is designed to meet the requirements of the federal injunction and Washington Administrative Code (WAC) 220-660-190, utilizing the stream simulation design criteria specified in the injunction and developed by WDFW.

8.2 Stream Simulation Criteria

The 2013 WCDG present the methodology for designing a stream simulation crossing. The method is defined primarily by the channel bankfull width. The width of the bed inside the culvert is equal to 1.2 times the bankfull width plus an additional 2 feet. Under the stream simulation guidelines there are two scenarios, which are dependent upon channel slopes above or below 4 percent. In this case, the proposed channel slopes are 3.2 percent for the west segment and 3.7 percent for the east segment, so Scenario 1 will be applied for both segments. Scenario 1 stipulates that the culvert shall be countersunk 30 to 50 percent of its rise, shall have a pool-riffle morphology, and that the bed may deform, scour, and reform with natural channel processes. Scenario 1 also includes the use of coarse bands to control channel shape and initiate stream structure.

8.2.1 Culvert Span and Length

The 2013 WCDG recommend sizing the span of the proposed structure based on the agreed upon bankfull width, with the bed width being 1.2 x bankfull width + 2 feet (WCDG Equation 3.2). Using this equation, along with the calculated bankfull width of 7.9 feet discussed in Section 9.2, results in a bed width of 11.5 feet. For additional safety, the bed width was then rounded up to the next whole number, resulting in a minimum bed width of 12 feet.

The length of the proposed crossing is approximately 50 feet, which results in a length to width ratio of 4.2.

8.2.2 Backwater and Freeboard

The 2013 WCDG 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, thereby allowing the free passage of debris. The WCDG suggests a minimum of 2 feet above the 100-year water surface elevation be provided. It is practicable to meet the minimum 2 feet of freeboard at this crossing.

In addition to freeboard, a minimum of 6 feet above the highest bed elevation in the channel cross section should be provided, if practicable, for constructability, future maintenance, and monitoring.

Table 8.1. Vertical Clearance Summary

Parameter	Downstream face of structure	Upstream face of structure
Station	11+94	12+47
Thalweg elevation (ft)	18.4	20.1
Highest streambed ground elevation within hydraulic width (ft)	19.6	21.3
100-year WSE (ft)	19.9	21.8
2080 100-year WSE (ft)	20.0	21.9
Required freeboard (ft)	2	2
Recommended maintenance clearance (ft)	6	6
Required minimum low chord, 100-year WSE + freeboard (ft)	21.9	23.8
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	22.0	23.9
Recommended minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	25.6	27.3
Required minimum low chord (ft)	**22.0**	**23.9**
Recommended minimum low chord (ft)	**25.6**	**27.3**

8.2.3 Channel Planform and Shape

In ideal circumstances, the proposed channel planform and shape mimic conditions within a relatively unmanaged reference reach. An unmanaged reference reach could not be located for this project due to differences in the existing and proposed channel gradients, and due to the significant modifications made to the channel over time. The proposed channel geometry was determined through guidance from several sources. The basis for channel bankfull width and depth were provided by empirical relationships and then refined using an analytical approach. Regional regression equations (Castro and Jackson 2001; Bieger et al. 2015) provide guidance on channel bankfull width with respect to tributary basin size. Using the formula presented in their research results in a bankfull width of between 7.9 and 8.9 feet. A bankfull width of 7.9 feet was selected since it was nearest to the measurements made in the field, and typical cross-section slopes were designed for consistency with other recent western Washington lowland fish barrier removal and replacement projects. A proposed section was then evaluated and modified through analytical modeling of stream flows to seek a 2-year water surface that aligned with bankfull. Proposed floodplain benches create a modeled FUR value (flood prone width to bankfull width) of approximately 1.9 upstream of the proposed crossing. The cross-section dimensions are described in Section 9.2.

The proposed gradient of the stream, with the inclusion of LWM, is intended to be characterized as a wood forced pool-riffle type morphology. The channel planform was designed to provide a meandering main channel within a straight floodplain corridor. WDFW Stream Habitat Restoration Guidelines (Cramer et al. 2012) provide that riffle and pool spacing should be every 5 to 7 channel widths. Applying this to the channel width of 7.9 feet results in a target pool (or riffle) spacing of 39 to 55 feet. Those values can be doubled to provide a target for meander wavelength, resulting in a range of 78 to 110 feet. The lower end of this range was then selected to accommodate a LWM layout, and the wavelength was adjusted down to approximately 70 feet to fit the platform to the desired channel alignment, tie-ins, and crossing location.

Channels of similar slope to the design reaches typically exhibit low sinuosity, and constraint on meander amplitude caused by the proposed conversion of private property to stream channel resulted in a limited meander amplitude. A channel corridor belt width of 20 feet was selected to coincide with a target sinuosity near 1.1 and provide space for meander.

8.2.4 Channel Gradient

The WCDG recommend that the proposed culvert bed gradient not be more than 25 percent steeper than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed stream gradient is 3.2 percent through the SR 534 crossing and the existing upstream gradient is 2.0 percent. This existing gradient was measured in the reach between SR 534 and Conway Hill Road. This gives the proposed design a slope ratio of 1.6. The difference in gradient is due to the alignment of the channel that runs along SR 534 and likely not in the historical alignment. Due to the relatively steeper average gradient downstream of the proposed west segment of channel grading, there is a potential for long term degradation, as described in Section 3.4.2 and Section 12.2. The design of the countersink is such that it will accommodate the expected long-term degradation potential.

The design gradient of 3.7 percent for the eastern segment of proposed channel grading, when compared to the 5.6 percent average gradient of the existing channel upstream, yields a slope ratio of 0.7.

9.0 Streambed Design

Originally it was anticipated that designing the upper segment of daylighted stream channel to follow the existing alignment would conflict with a high-pressure gas main that runs north-south across the barrier ID 995265 addressed in this report. Therefore, Parametrix was instructed to pursue a proposed design for a new SR 534 crossing east of the gas line and to continue the stream alignment in an entirely new constructed reach north to its confluence with Carpenter Creek. The alignment was proposed to be located parallel to, and east of the existing gas line. On January 15, 2020, Parametrix was then instructed to pursue a new preliminary alignment (presented by WSDOT as Option 4), which generally aligns the stream to follow the existing stream and storm system alignment. This section documents the hydraulic analysis of the proposed channel crossing and stream realignment following Option 4, with some modification made to the SR 534 crossing skew and grading limits.

The preliminary design presented in this report proposes modifications to the existing stream alignment and profile in two distinct locations. The design in the upper (east) segment will remove a 24-inch corrugated metal pipe that conveys the tributary to Carpenter Creek parallel to SR 534 over two gas pipelines and replace it with a reach of daylighted channel. The top of gas pipe elevation was surveyed to be 26.7 feet (west pipe) and 27.6 feet (east pipe) at the crossing location of the proposed channel. At the lower (west) segment of proposed channel, the design includes removal of a 36-inch concrete pipe that conveys the tributary to Carpenter Creek beneath SR 534 and replaces it with a crossing structure with a minimum hydraulic opening of 12 feet. Figure 9.1 depicts the existing and proposed stream alignment presented in this report.

9.1 Alignment

At the upper segment in existing conditions, the stream is conveyed west in a 24-inch corrugated metal pipe storm sewer beneath the SR 534 shoulder to outfall in a ditch-like channel. The stream continues west in an open channel for 15 feet before crossing beneath Conway Hill Road in a 30-inch concrete pipe, maintained by Skagit County.

In proposed conditions, the stream alignment shifts from beneath the SR 534 shoulder to an easement located south of the roadway to daylight the channel. In this segment, grading is proposed to begin 60 feet upstream of the existing inlet to the 24-inch corrugated metal pipe storm sewer and continues downstream to tie-in to the existing channel 5 feet upstream of the inlet of the Conway Hill Road culvert. During draft phases of the preliminary hydraulic design, regrading all the way to the confluence with Carpenter Creek was discussed and WSDOT preferred to limit grading impacts in the existing reach downstream of SR 534. The alignment was placed to be as close to the road as possible, while maintaining sinuosity when crossing the gas pipelines as directed by the PEO. Under review by the owners of the Olympic pipeline, the stream corridor was shifted further to the south to satisfy a requirement that the cut line for construction of the corridor was located a minimum of 10 feet away from two existing pipeline vents located adjacent to SR 539. The Conway Hill Road culvert will remain in place. The proposed profile in the upper segment of grading was designed to connect the upstream limits of grading to the downstream limits near the inlet to the Conway Hill Road culvert. The total length of grading for the east segment is 301 feet. The proposed gradient is 3.7 percent.

Downstream of the Conway Hill Road culvert, the existing tributary to Carpenter Creek is characterized as a ditch-like channel conveying flow west to the inlet of the 36-inch concrete pipe located beneath SR 534. Downstream of the SR 534 crossing, flow is conveyed northwest to Carpenter Creek.

The upstream grading limit for the west segment of proposed channel grading occurs 56 feet downstream of the Conway Hill Road culvert outlet to preserve existing channel and 172 feet upstream of the proposed SR 534 crossing inlet. The downstream grading limit for the proposed west segment occurs 43 feet downstream of the proposed SR 534 crossing outlet to preserve the existing channel reach that extends to the confluence with Carpenter Creek. The total length of grading for the west segment is 268 feet. The proposed gradient is 3.2 percent.

Proposed grading of both segments totals approximately 569 feet, including the proposed crossing structure. The main channel was designed to meander within a floodplain corridor with a sinuosity of 1.07. There are no known future corridor plans for SR 534 near the crossing.

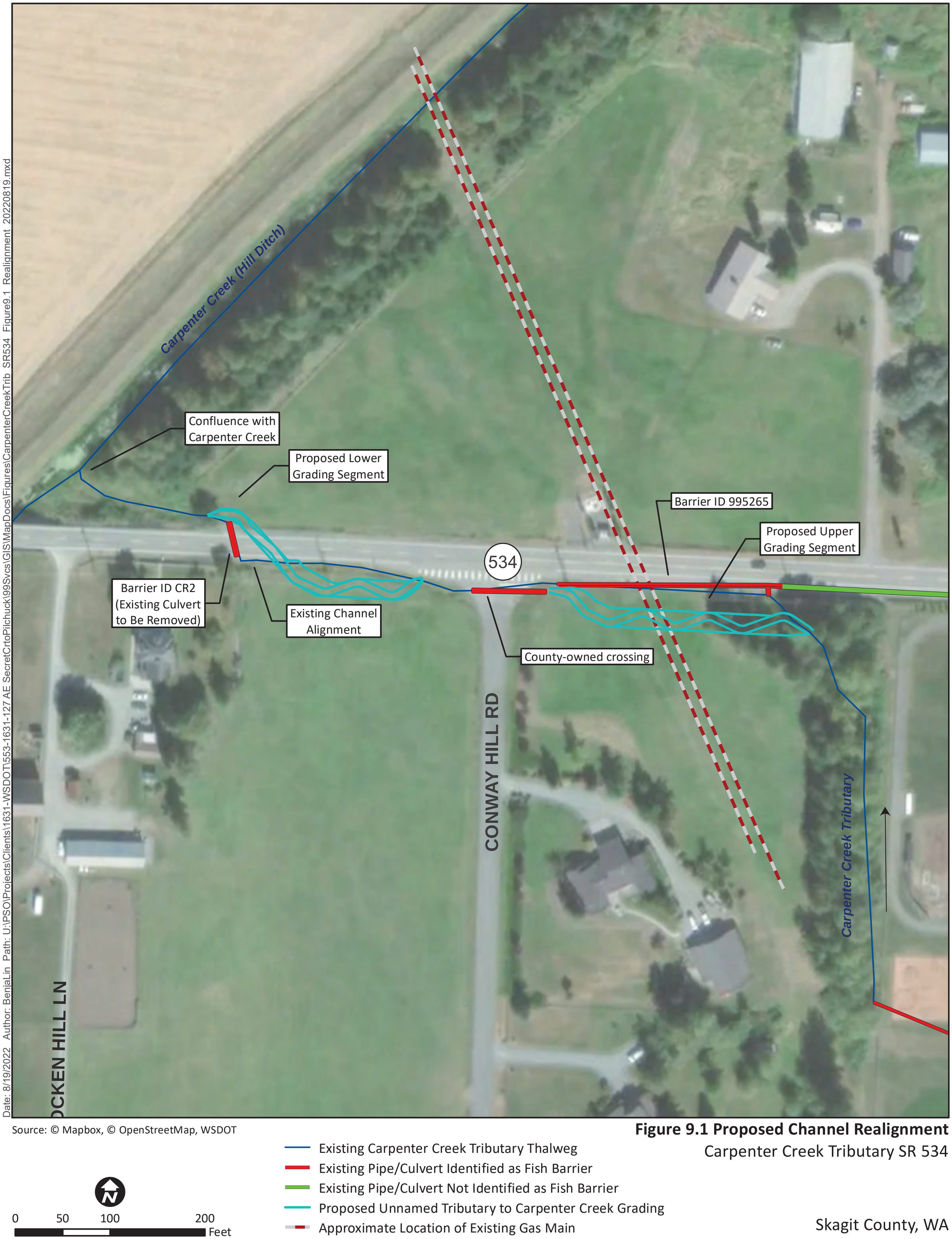


Figure 9.1 Proposed Channel Realignment
Carpenter Creek Tributary SR 534

Skagit County, WA

9.2 Proposed Section

The existing channel sections are highly constrained due to development as described in Section 3.4.1; therefore, these sections were not selected for use as a reference to design the proposed section. The basis for the channel cross-section design is described in Section 8.2.3.

A low-flow channel was created with channel bottom slopes of 10 (H) to 1 (V) extending 3 feet outward from the channel center. The main channel was then designed with 2 (H) to 1 (V) slopes extending 1 foot outward. This creates a main channel width of 8 feet, a main channel depth of 0.8 foot, with a resultant bankfull width to maximum depth ratio of 10. Typically, the 2-year peak flow event will occur with the water surface elevation reaching the bankfull breakover point. A low-flow channel will be constructed to connect habitat features and ensure the project is not a low-flow barrier. The low-flow channel will be as directed by the Engineer in the field.

In the proposed channel outside of the crossing, floodplain benches were designed with 10 (H) to 1 (V) slopes extending outward between 0 feet and 12 feet on left and right banks, with variability created by main channel sinuosity.

At the outside edges of the corridor the proposed grading slopes upward to match existing grade. The upper design segment and the lower design segments along SR 534 have been designed with 2 (H) to 1 (V) slopes to minimize easement area and impacts to the SR 534 roadway prism.

Through the SR 534 crossing, the minimum hydraulic opening was modeled to be 12 feet wide, which allows for a total of 4 feet of floodplain benching to exist within the crossing at any given cross-section. Meander of the main channel is proposed within the crossing which results in floodplain bench width variability ranging from 0 feet to 4 feet for left and right benches. Downstream of the crossing, daylighting slopes typically are 2 (H) to 1 (V), though the left bank slope will steepen to 1.5 (H) to 1 (V) in the transition area the downstream tie-in to existing grade.

Figure 9.2 depicts a comparison of the design channel section with the existing cross-section near the same location in the channel. The water surfaces shown are those of the existing condition. Figure 7.8 above depicts the proposed water surfaces in relation to the design section. Figure 9.3 depicts the design cross section with an existing cross section from upstream of the crossing and downstream of the crossing shown for comparison. Appendix D contains the final design drawings.

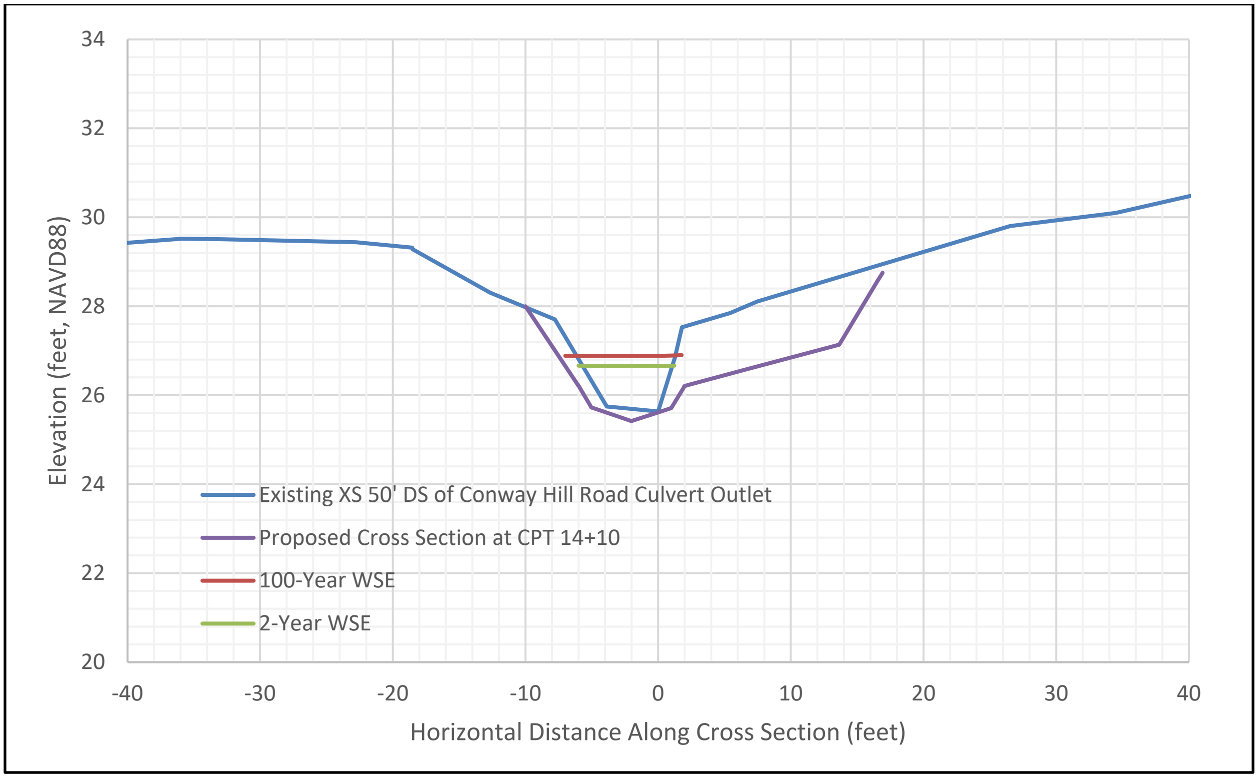


Figure 9.2. Existing (with Water Surfaces) and Proposed Channel Cross Sections in Vicinity of SR 534 Crossing

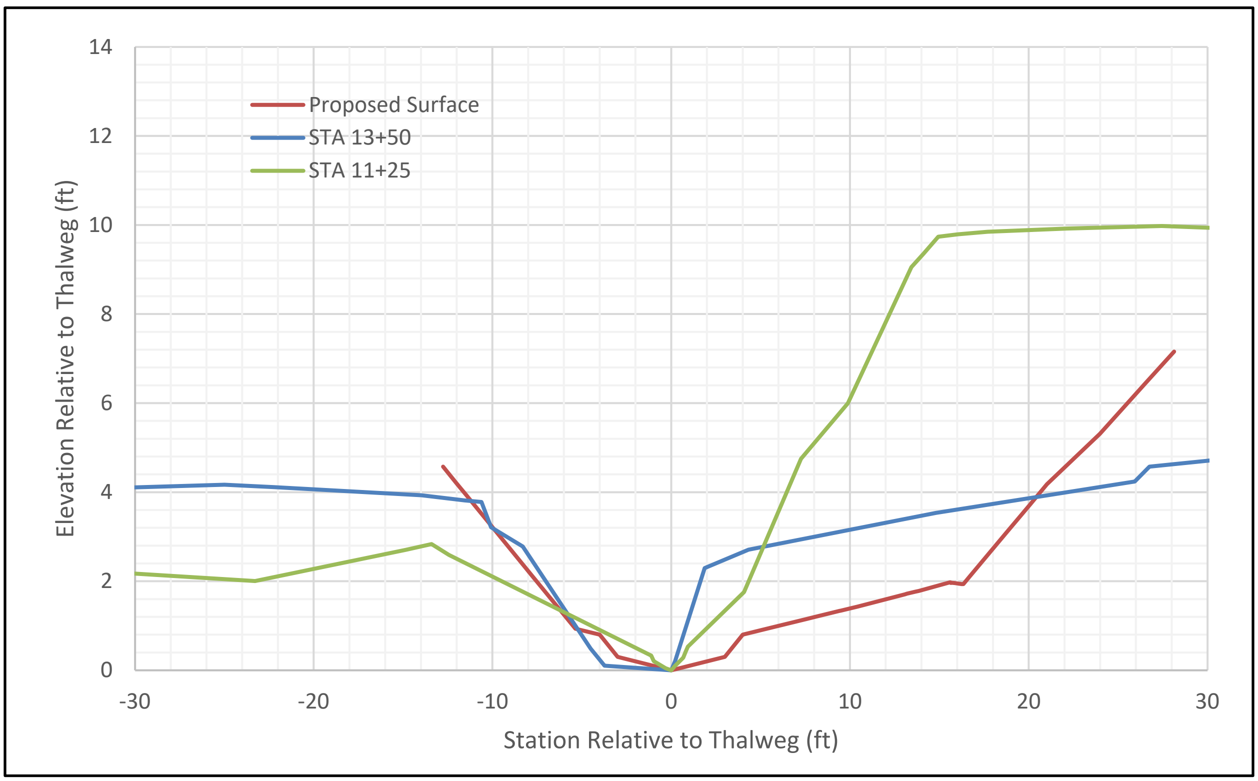


Figure 9.3. Proposed Cross Section Superimposed with Existing Survey Cross Sections

9.3 Bed Material

This section documents a streambed material designed to function in both the east and west design segments described in Section 9.1 and depicted in Figure 9.1. The gradients and main channel shear stresses are similar between the two reaches; therefore, the material is expected to behave similarly in the two segments. The proposed channel geometry has been designed based upon an empirical and analytical approach and not through mimicry of a reference reach. Therefore the pebble counts obtained upstream and downstream of the crossing do not provide an appropriate target for designing the proposed streambed sediment.

Based upon the design slopes of 3.2 percent and 3.7 percent in the proposed east and west segments respectively, WSDOT recommends using the Modified Critical Shear Stress design approach described in Appendix E of the Stream Simulation manual (USFS 2008). This approach assesses the point of incipient motion for the range of particle sizes in a gradation based upon the shear stresses modeled in proposed conditions during the range of design flows. The basis of the design selected here is to produce a streambed material gradation that mimics a channel in regime; therefore, for a normally functioning stream system the D_{84} particle is sized for incipient motion at channel forming flow (Cramer et al. 2012). Specifically, the streambed mix was designed such that the D_{84} particle was mobilized at the 2-year event. The calculated streambed material gradations are provided in Table 9.1.

Table 9.1. Summary of Proposed Streambed Material for the Tributary to Carpenter Creek

Particle Percent Smaller Than	Modified Critical Shear Stress Approach to Proposed Particle Size Diameter (inches) (millimeters)
D_{16}	0.11 (2.9)
D_{50}	1.49 (38.0)
D_{84}	6.57 (166.9)
D_{100}	12.00 (304.8)

The proposed streambed material should be constructed utilizing WSDOT Standard Specifications and Aggregates for Streams, Rivers, and Waterbodies special provision (WSDOT 2022a). Specifically, 60 percent of Streambed Sediment (Section 9-03.11(1)) mixed with 40 percent 12-inch Streambed Cobble grading (Section 9-03.11(2)) should be utilized, overall producing a well-graded mixture.

With this gradation, particles approximately smaller than the D_{84} are mobilized during the 2-year flow event, and all particle sizes are mobilized in the 100-year flow event. The proposed streambed material gradation in relation to the observations of the existing streambed material made at pebble count locations is depicted in Figure 9.3. The streambed material sizing calculations are provided in Appendix E.

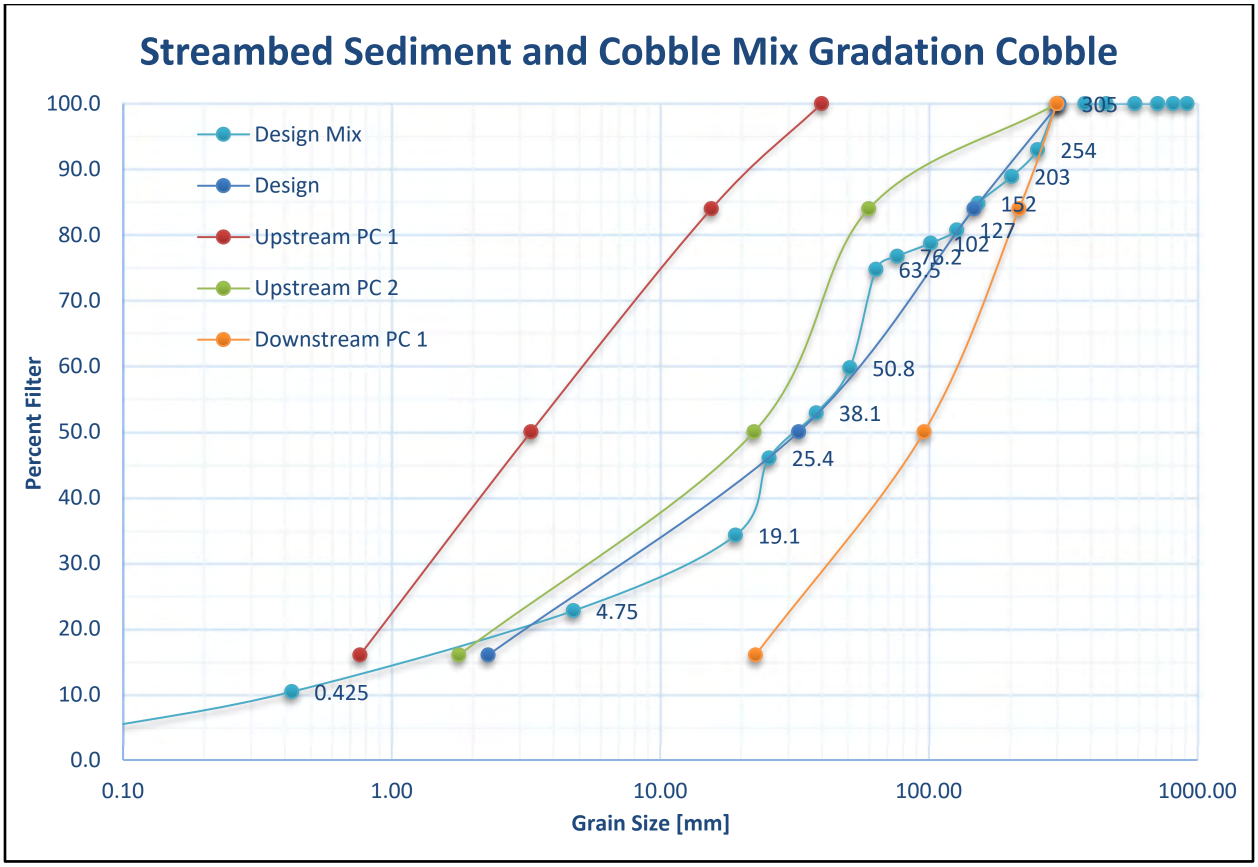


Figure 9.4. Existing and Proposed Streambed Material Gradation at Upper Design Segment

Coarse bands with upstream adjacent spawning bands have been incorporated into the design to increase channel complexity, increase the availability of material suitable for salmonid spawning, and encourage global stability of the streambed. Each coarse and spawning band consists of 6 feet (measured longitudinally along channel centerline at surface) of coarse material followed immediately upstream by 6 feet (measured longitudinally along channel centerline at surface) of material for spawning. The bands were spaced to occur such the spawning material would be located downstream of each stream bend apex where a pool tail out will be constructed, and the coarse band would follow immediately downstream to mimic a riffle section. The middle of the bands are located downstream of each bend apex approximately one-third of the distance between successive stream bends.

The coarse band material should consist of 30 percent of Streambed Sediment (Section 9-03.11(1)) mixed with 55 percent 12-inch Streambed Cobbles (Section 9-03.11(2)) and 15 percent 12 to 18-inch Streambed Boulders (Section 9-03.11(3)), overall producing a well-graded mixture. For the coarse band gradation, the D_{84} particle was designed for increased stability over the general streambed mix described above. Though it is still deformable, as it is sized for incipient motion at the 100-year event. Particles approximately smaller than the D_{74} are mobilized during the 100-year flow event. The upstream spawning band material consists of 100 percent Streambed Sediment (Section 9-03.11(1)). This gradation is fully mobile during the 2-year though 500-year flow events. The calculated coarse and spawning band material gradations are provided in Table 9.2. The streambed material sizing calculations are provided in Appendix E.

Table 9.2. Summary of Proposed Coarse and Spawning Band Material for Tributary to Carpenter Creek

Particle Percent Smaller Than	Coarse Band Material Diameter (inches) (millimeters)	Spawning Band Material Diameter (inches) (millimeters)
D_{16}	0.61 (16.0)	0.02 (0.43)
D_{50}	3.49 (88.6)	0.75 (19.1)
D_{84}	11.82 (300.2)	2.10 (53.3)
D_{100}	18.00 (457.2)	2.50 (63.5)

9.4 Channel Habitat Features

This section describes the channel complexity of the streambed design developed for the Unnamed Tributary to Carpenter Creek at SR 534 MP 0.60 and MP 0.53.

9.4.1 Design Concept

Boulders are included in the design within the culvert to provide habitat, flow and streambed complexity, and to mitigate flow entrainment along the culvert walls. Two clusters of Streambed Boulders One-man (12- to 18-inch) are proposed to be added to the floodplain benches within the crossing. Each cluster should include 4 to 5 Streambed Boulders. The boulders should be placed on the floodplain benches at the point of the two alternating meanders that are designed within the culvert. The final of the boulders will be as directed by the Engineer in the field.

LWM is proposed to be incorporated into the design. The function of the LWM is to add complexity to the system by imitating a natural reach which encourages pool formation, the maintenance of fish habitat and is meant to encourage global stability of the streambed. Using the WSDOT LWM Metric Calculator tool, the proposed LWM sizes and quantities were calculated based on Fox and Bolton's 2007 research for selecting the number and size of key pieces, the number of total LWM pieces, and the total wood volume. This tool calculates target values using the 75th percentile of observed LWM in unmanaged streams investigated by Fox and Bolton. Based on a bankfull width of 7.9 feet and a proposed stream regrade length of 569 feet, the target number of key pieces is 19, the target number of total LWM pieces is 66, and the target LWM volume is 224.6 cubic yards. The proposed design includes 19 key pieces, 63 total LWM pieces, and a total LWM volume of 86.5 cubic yards. See Appendix G for the full WSDOT LWM Metric Calculator results.

The recommended size of a key piece, based upon BFW, should be a minimum of 1.3 cubic yards. This is met by a piece approximately 20 feet long by 1.6 feet in diameter at breast height (DBH). Key pieces should incorporate root wads for added complexity. Table 9.3 shows the proposed wood dimensions, quantities, and volumes. See the final stream design plans in Appendix D for the proposed LWM layout. The diameter at midpoint values shown in Table 9.3 were chosen such that the DBH of the log was to the nearest half foot.

Table 9.3. Design Wood Dimensions and Quantities

Log type	Diameter at midpoint (ft)	Length(ft)^d	Volume (yd^3/log)^d	Rootwad?	Qualifies as key piece?	No. LWM pieces	Total wood volume (yd^3)
A	2.0	20	2.23	yes	yes	19	42.46
B	1.5	20	1.22	yes	no	19	23.24
C	1.4	15	0.83	no	no	25	20.77

LWM has been placed within 50 feet of the culvert in the proposed design. WSDOT typically does not allow LWM to be placed within 50 feet upstream of downstream of a crossing structure, but the proposed LWM are all designed to be stable up to the 100-year flow, limiting the potential for transport and racking of LWM debris at the culvert. No mechanical anchoring is included in the design, though some pieces require other pieces to be placed above for stability, as indicated in Table 9.4 below. No mobile LWM wood is proposed.

LWM structures were placed to create localized pool habitat and cover, provide flow direction, and reduce flow velocities at the channel fringe. Pool habitat and reduced flow velocities will provide refuge for fish species during high flow events. Preformed pools should be constructed downstream of the apex of stream bends and at select LWM as shown on the plans and as directed by the Engineer to jump-start the channel forming process. It is possible that unplanned bank scour will occur at various locations along the channel banks as the channel approaches a natural equilibrium, especially where LWM placement redirects water towards the bank. It should be noted that this type of bank scour is expected and does not pose a significant structural risk. Adequate corridor and main channel width has been provided to allow for some amount of bank erosion and low-flow channel migration. LWM orientations and log angles were placed to mimic the natural LWM recruitment process. LWM is primarily oriented with the root wads engaged with the main channel flow to provide fish habitat, but some pieces were placed with stem tips engaged in the flow.

9.4.2 Stability Analysis

The Hydraulics Manual describes the USFS Computational Design Tool for Evaluating the Stability of Large Wood Structures as the accepted method for performing LWM stability analysis and recommends a factor of safety of 1.5 (WSDOT 2022b) (Rafferty 2016). The stability analysis for Carpenter Creek used this tool and incorporated the recommended factor of safety of 1.5. Table 9.4 provides an inventory of the LWM pieces with minimum DBH and minimum length measured from root wad collar to end of bole, along with the buoyancy factor of safety. The stability calculations are provided in Appendix G.

Hydraulic output for use in the analysis was collected from a series of cross-sections taken from the SMS model developed for the tributary to Carpenter Creek. The channel design includes bends and tangents curves, leading to varying hydraulic results. For this reason, a total of 19 cross-sections were taken from the SMS model to coincide with the placement of LWM. Meander radii of curvature were measured at the upstream and downstream ends of the proposed grading, which affects velocity calculations for logs located on the outside of meander bends.

Table 9.4. Wood Stability Summary

Log ID Number	Min. Diameter (in)	Min. Length (ft)	Buoyancy Factor of Safety	Net Vertical Force Downward (lb)	Logs Placed Above
1	18	20	10.44	1,351	-
2	18	20	10.44	1,351	-
3	18	20	10.44	1,351	-
4	18	20	10.44	1,351	-
5	18	20	10.44	1,351	-
6	24	20	2.28	2,049	-
7	18	20	2.86	1,751	-
8	24	20	2.28	2,049	-
9	24	20	2.28	2,049	-
10	18	15	2.18	1,012	-
11	18	20	2.07	774	-
12	18	20	2.07	774	-
13	24	20	1.74	1,947	11, 12
14	18	20	2.07	822	-
15	18	20	2.84	1,035	-
16	24	20	3.43	2,221	-
17	24	20	3.43	2,221	-
18	18	15	1.67	1,390	19
19	24	20	2.22	1,563	-
20	18	20	2.73	1,275	-
21	24	20	2.67	1,777	-
22	18	15	1.98	884	-
23	18	15	1.74	1,568	21
24	18	20	4.07	1,771	-
25	24	20	2.22	1,563	-
26	18	15	3.19	1,798	-
27	18	15	1.67	1,390	25
28	18	20	3.21	1,032	-
29	18	15	4.05	904	-
30	24	20	10.37	2,568	-
31	18	15	8.53	1,058	-
32	24	20	10.37	2,568	-
33	18	15	8.53	1,058	-
34	24	20	10.37	2,568	-
35	18	15	8.53	1,058	-
36	24	20	10.37	2,568	-

Table 9.4 (Continued) – Wood Stability Summary

Log ID Number	Min. Diameter (in)	Min. Length (ft)	Buoyancy Factor of Safety	Net Vertical Force Downward (lb)	Logs Placed Above
37	18	15	8.53	1,058	-
38	18	20	4.07	1,771	-
39	24	20	2.22	1,563	-
40	18	15	3.19	1,798	-
41	18	15	1.67	1,390	39
42	18	20	3.21	1,032	-
43	18	15	4.05	904	-
44	24	20	2.20	1,732	-
45	18	20	4.07	1,771	-
46	24	20	2.22	1,563	-
47	18	15	3.19	1,798	-
48	18	15	1.67	1,390	46
49	18	20	3.21	1,032	-
50	18	15	4.05	904	-
51	24	20	2.20	1,732	-
52	18	20	4.07	1,771	-
53	24	20	2.22	1,563	-
54	18	15	3.19	1,798	-
55	18	15	1.67	1,390	53
56	18	20	3.21	1,032	-
57	18	15	4.05	904	-
58	24	20	2.67	1,777	-
59	18	15	1.74	1,568	58
60	18	15	2.38	516	-
61	18	15	2.38	516	-
62	18	15	3.53	638	-
63	18	15	3.53	638	-

The proposed streambed substrate discussed in Section 9.3 was used in the stability analysis. A dense gravel mixture was chosen for the bank soils, determined based on review of photos collected during field reconnaissance and pebble count results.

Coastal Douglas-fir was selected as the tree species used in the stability analysis. Douglas-fir is the preferred species for LWM structures in the pacific northwest, as it has high density, excellent durability, and is the most commercially available (WSDOT 2022b). Douglas-fir was observed upstream of the crossing, indicating that it could be recruited to the stream through natural channel processes. Any large wood recruited would not be expected to be transported to the crossing. Factors provided in the USFS tool were used to calculate root wad diameter (3 times bole diameter) and length (1 times bole diameter) based on the diameter of the LWM piece.

10.0 Floodplain Changes

This project is within a FEMA special flood hazard area (SFHA) Zone AO, see Appendix C for FIRM. The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk. See Appendix J for the Flood Risk Assessment Memorandum.

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 largest risk to the structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and maintain passability for all expected life stages and species in a system.

11.1 Climate Resilience Tools

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

WSDOT also evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. For low or medium risk sites, the 2040 percent increase is used; for high-risk sites, the 2080 percent increase is used. Appendix F contains the information received from WDFW for the project site. The 100-year flow event was chosen to be evaluated because, being an extreme event, if the channel behaves similarly through the structure during this event as it does the adjacent reaches, then it is anticipated this relationship would also be true at lower flows as well.

11.2 Hydrology

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

In addition to using the best available science for current site hydrology, WSDOT is evaluating the structure at the 2080 projected 100-year flow event to check for climate resiliency. The design flow for the crossing is 48.3 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 flow rate is 10.7 percent, yielding a projected 2080 flow rate of 53.5 cfs.

11.3 Structure Width

The minimum width for a crossing given by Equation 3.2 was 11.5 feet. The horizontal opening of the culvert structure is rounded up to 12-feet for conventional fabrication purposes. This structure width was evaluated at the 100-year flow event and projected 2080 100-year flow event and determined to produce similar velocities through the structure and adjacent reaches. The velocity comparisons for these flow rates are shown in Table 7.5 in Section 7.2.

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

11.4 Freeboard and Countersink

Freeboard considerations with respect to climate resiliency are reported in Table 8.1 in Section 8.2.2. Water surface elevations are expected to increase by 0.1 feet with the projected 2080 100-year peak flow.

11.5 Summary

A minimum hydraulic opening of 12 feet and a minimum freeboard of 2.1 feet over the current 100-year water surface elevations 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. This will help ensure that the structure is resilient to climate change and the system can function naturally, including the passage of sediment, debris, and water in the future. Due to the relatively low impact of the projected climate impacts to 100-year flow velocities and water surface elevations, no additional modifications to the design were made.

12.0 Final Scour Analysis

For this FHD, the risk for lateral migration, potential for long-term degradation, and evaluation of total scour are based on information provided the WSDOT Geotechnical office, including the Geotechnical Report, SR 534/Unnamed Tributary to Carpenter Creek – Fish Passage dated August 2022.

Using the results of the hydraulic analysis (Section 7.2) of the final four-sided buried structure with a 12-foot opening, and considering the potential for lateral channel migration, final scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges, HEC No. 18* (Arneson et al. 2012). Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

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

12.1 Lateral Migration

Lateral migration risk was assessed in the immediate vicinity of the proposed crossing and within the proposed crossing itself.

In the immediate vicinity of the proposed crossing, the main channel meanders within a 20-foot-wide floodplain corridor defined by 10 (H) to 1 (V) grading outside of the main channel. Lateral migration is expected to be possible within the limits of this proposed floodplain corridor. Potential causes of lateral migration include scour and sediment rearrangement during flood events, flow interaction with LWM during flood events, and due to debris accumulation leading to avulsions through floodplain area. The proposed condition hydraulic modeling indicates shear stresses from the 2-year through the 500-year peak flow events are expected to be capable of mobilizing the general streambed mix. Lateral migration could occur within the proposed 3-foot depth of the design streambed following construction. The potential for long-term degradation, described in Section 7.2, could lead the channel to down cut through the designed streambed material and into the underlying elastic silt and fat clay over time. Both materials are expected to be erodible.

The corridor embankments, defined by 2 (H) to 1 (V) graded slopes outside of the floodplain corridor, are cut into the in-situ material. The in-situ materials defining the corridor embankments in the proposed condition are composed of silts with gravel, elastic silt, and fat clay. Potential for long-term degradation could expose in-situ corridor embankment material composed of fat clay. These materials are expected to be erodible and are described in more detail in Section 7.2. Despite erodibility, the embankments defining the floodplain corridor are expected to provide general limits to lateral migration potential because stream flow energy will primarily be directed down the corridor instead of into corridor embankments.

At the upstream and downstream faces of the proposed crossing, headwalls retaining the roadway embankment encroach within the proposed floodplain corridor. The portions of headwalls that encroach within the floodplain corridor could be affected by lateral migration. These portions of the headwalls were designed with foundation depth 2-feet below the total scour at the design flood event, described in more detail below.

Within the crossing itself, there is potential for lateral migration to the inside faces of the crossing structure. The total scour depth calculation reflects the possibility that the stream migrates to the inside face of the structure.

Since headwall foundation elevations within the typical 20-foot-wide floodplain corridor (and potential lateral migration extents) and the structure bottom elevation has been designed to a depth below total scour, no lateral migration countermeasures are proposed.

12.2 Long-term Degradation of the Channel Bed

Long-term degradation potential was evaluated for the lower unnamed tributary to Carpenter Creek reach between the confluence with Carpenter Creek (Hill Ditch) and the Conway Hill Road culvert which includes the SR 534 crossing as required during the PHD and FHD process. The analysis documented below indicates that there is potential for long-term degradation of this reach including at the associated crossing.

During the PHD process, a potential vertical adjustment slope of 4 percent, as described in Section 3.4.2, was determined, and projected upstream from a base level control point selected at the tributary's confluence with Carpenter Creek. Figure 3.4 depicts this vertical adjustment potential.

During the FHD process, Geotechnical information was made available that indicated that the material underlying the relatively steeper reach downstream of the project grading limits (where degradation is assumed would originate) is cohesive. No explicit guidance for estimating long-term degradation potential of a channel in cohesive materials was obtained. Instead, to provide an estimate for design guidance, the long-term degradation potential was assessed with the following two approaches: an equilibrium slope calculation using formula for non-cohesive material (Section 12.2.1) and an assessment of stability of the cohesive materials based on critical shear stress (Section 12.2.2). The following subsections document the inputs and assumptions of each of these approaches used to establish a final assumed degradation potential of up to 3.9 feet at the proposed crossing outlet and up to 3.4 feet at the proposed crossing inlet. Those values do not include contraction or local scour depths. Total scour is documented in Section 12.5.

12.2.1 Equilibrium Slope Calculation

Initially during the FHD process, an equilibrium slope calculation was performed using the HEC-20 (Lagasse et al. 2012) equilibrium slope equation 6.17. This equation applies to non-cohesive materials with grain sizes greater than 0.2 millimeters, assumes no upstream sediment supply, and relies on main channel stream unit discharge determined from hydraulic modeling, a Manning roughness coefficient selected to match the proposed main channel value reported in Section 7.2, and a critical bed material size, D_c.

The D_c size was selected to match the D_{84} of the general proposed streambed mix since it was assumed that the design material proposed upstream could mobilize into and become present as the surface layer of material in the relatively steeper reach from which the long-term degradation is assumed to originate. The HEC guidance states that the D_{90} should be selected, but the D_{84} of the general design mix was used since it is a readily reported value in the design reports and is a typical value used by WSDOT to assess stream stability. The D_{84} and D_{90} values of the general proposed streambed mix vary (6.6 inches and 9.1 inches, respectively). This difference has an impact on the equilibrium slope calculation results. For example, the equilibrium slope calculation for the check flood event results in an equilibrium slope of 4.2 percent using the D_{84} size and 6.7 percent using the D_{90} size. The calculation using the D_{90} predicts nearly no long-term degradation and was not used. The calculation using the D_{84} provided a resulting equilibrium slope that supported the vertical adjustment potential grade of 4 percent documented in Section 3.4.2, and therefore was used for design purposes.

The 4.2 percent equilibrium slope determined from the check flood event and using the D_{84} of the proposed general streambed mix for the D_c value was then projected upstream from a base level control point. This point was selected to be located at the thalweg elevation of the unnamed tributary where it joins Carpenter Creek. It is assumed that this elevation is a relatively consistent elevation in that it is likely partially maintained by the hydraulics of Carpenter Creek. This base level control point is below the surveyed ordinary high-water elevation of Carpenter Creek. No appropriate base level control points exist upstream of this point and any base level control points selected further downstream (the thalweg elevation of Carpenter Creek is 1.5 feet lower in elevation) is assumed to not be warranted due to the hydraulics of Carpenter Creek. A projection of the 4.2 percent equilibrium slope upstream indicates that there is potential for degradation up to 3.9 feet at the proposed crossing outlet and up to 3.4 feet at the proposed crossing inlet for the check flood event. An equilibrium slope was calculated to be 5.1 percent for the 100-year design flood, which resulted in a potential degradation depth of 1.2 feet at the inlet and 2.2 feet at the outlet. These calculations do not consider the properties of the cohesive materials underlying this reach from which the degrading channel is assumed to cut into, though there were ultimately selected for the design.

12.2.2 Assessment of Underlying Cohesive Material Erodibility

The WSDOT Geotechnical Office provided a Draft Boring Log and Draft Laboratory Test Results memorandum dated March 4, 2021 and a follow-up memorandum on June 22, 2022 that provides additional soil parameters for the cohesive material to help with scour evaluation. The memos indicate that, based on boring H-1vwp-20, the stream substrate in the reach downstream of the channel grading limit (from between 5 feet and 17 feet in elevation, NAVD88) is expected to be cohesive material comprised of fat clay, lean clay, and silt (labeled ESU 2). Since this reach is relatively steeper than the upstream adjacent reaches, as described in Section 3.4, it is assumed that long-term degradation would originate in this reach.

To predict the stability of this reach, erodibility and potential erosion rates of the cohesive material were assessed to understand how the cohesive material may impact the long-term degradation potential reported in Section 12.2.1. The following describes the process used to determine the erodibility and potential rate of erosion of the cohesive material. It was ultimately determined that the long-term degradation potential is best represented by the analysis documented in Section 12.2.1

Section 2.5 of HEC-20 provides some detail on stability of cohesive boundary channels. Here it is stated that “the responses and types of channel instability at a bridge are dependent on the cohesion of the local bed and bank materials and the duration and magnitude of erosive flows over time” with little additional guidance provided on methods of determining these elements.

HEC-18 provides guidance on evaluating scour at bridges. This guidance provides some additional detail on estimating scour in cohesive soils, though it focuses primarily on contraction and pier scour in cohesive soils, and not on overall channel stability. Section 3.1 of the manual states that cohesive soils can be more scour-resistant but that “ultimate scour in cohesive or cemented soils can be as deep as scour in sand-bed streams”. With that in mind, we can first confirm the erodibility of a cohesive soil by determining the critical shear stress, τc, of that material and then compare that with expected flow shear stresses obtained from the hydraulic model.

Two sources for guidance on estimating the critical shear stress of a cohesive material were reviewed. The first source came from HEC-18. Equations, known as Briaud bounds, used to estimate upper and lower bounds of critical shear stress for material with a particle size less than 0.2 millimeters (0.008 inches) are provided in HEC-18 Figure 6.9. Applying the D_{50} of 0.006 millimeters of the ESU 2 material from boring H-1vwp-20 due its proximity to the reach in question results in lower and upper critical shear stress boundaries of 0 pounds per square foot and 3.5 pounds per square foot respectively. The lower bound suggests the material could be erodible at virtually all flows. The upper bound suggests that the material may not be erodible at flows less than the 25-year but may be erodible at flows from the 25-year through the 500-year peak flow events. The shear stresses used in the comparison are average main channel shear stresses obtained from cross section G in the downstream reach (Table 7.4). Due to the significant range, Section 6.7 states that "the only reliable way of determining critical shear for silt and clay particles is to perform materials testing." The HEC guidance does not provide a method for determining critical shear stress from testing.

The second source of guidance on estimating critical shear stress of a cohesive material comes from FHWA Publication Number FHWA-HRT-15-033 Scour in Cohesive Soil (Haoyin et al. 2015). This guidance analyzed data collected on cohesive soils from various sources to produce design equations for determining critical shear stress based on typical Geotech tested parameters. Figure 63 from this document presents a design equation for determining critical shear stress (Figure 12.1).

$$\tau_c = \alpha_d \left(\frac{w}{F} \right)^{-2.0} PI^{1.3} q_u^{0.4}$$

Figure 63. Equation. Design equation for critical shear stress.

Where:
α_d = Unit conversion constant for design, 0.007 in U.S. customary units and 0.07 in S.I.

Figure 12.1. Formula for Calculating Critical Shear Stress of Cohesive Material

The following characteristics of the ESU 2 material provided by Geotech for use in the calculation:

- Water content, w = 41 percent
- Fines content as a fraction, F = 95 percent
- Plasticity Index, PI = 27 percent
- Undrained shear strength, S_u = 1,000 pounds per square foot
- Unconfined compressive strength, q_u ($q_u = 2 * S_u$) = 2,000 pounds per square foot

A critical shear stress for the ESU 2 material was calculated to be 0.14 pounds per square foot. This value is well below the 2.4 to 4.5 pounds per square foot average main channel flow shear stress of the 2-year through 500-year modeled flow events for the downstream reach at cross section G, and therefore this material could be expected to erode during flow events that include the 2-year through 500-year peak events. Flow events less than the 2-year event may also erode this material, though flows lower than the 2-year event have not been determined or modeled.

The FHWA publication also provides a formula for calculating a predicted erosion rate based on the critical shear stress of the cohesive material and initial applied shear stress from the flow. This formula (Figure 60 of the FHWA publication) is only applicable for applied shear stress less than 2.1 pounds per square foot according to the guidance based on the limited set of empirical data used in its development. This maximum applicable shear stress value is less than all modeled flows from the 2-year through 500-year events in the downstream cross section G. If we assume a maximum initial applied shear stress of 2.1 pounds per square foot, the result is an erosion rate of 6.8 inches per hour.

Calculating an estimate of total erosion over the course of the life of the crossing structure would require estimating the amount of time in which flow occur with shear stress that exceeds the critical shear stress of the material, and then multiplying by respective erosion rate of that flow. This could be simplified by extracting flow rates in 15-minute time series from MGSFlood for a period matching the expected design life of the structure, around 75 years. Intervals of peak flows could be created and the number of instances and estimated time with which those peak flows occur in each interval could be determined. An average main channel shear stress concurrent with each flow interval could then be determined from hydraulic modeling and a median erosion rate could be calculated for each interval.

Given that all flows from the 2-year through 500-year flow, and likely flows less than the 2-year could be expected to erode this cohesive material at a rate of at least 6.8 inches per hour given the process described above, it is estimated that erosion would exceed the maximum 3.9 feet of long-term degradation predicted in Section 12.2.1 with no more than 6.9 hours of erosive flow. It is expected that erosive flows will exceed 6.9 hours over the life of the structure, and therefore using engineering judgement we propose to use the results of the preliminary equilibrium slope calculation in Section 12.2.1, backed up with analysis of the longitudinal profile documented in Section 3.4.2, for the long-term degradation portion of total scour depth.

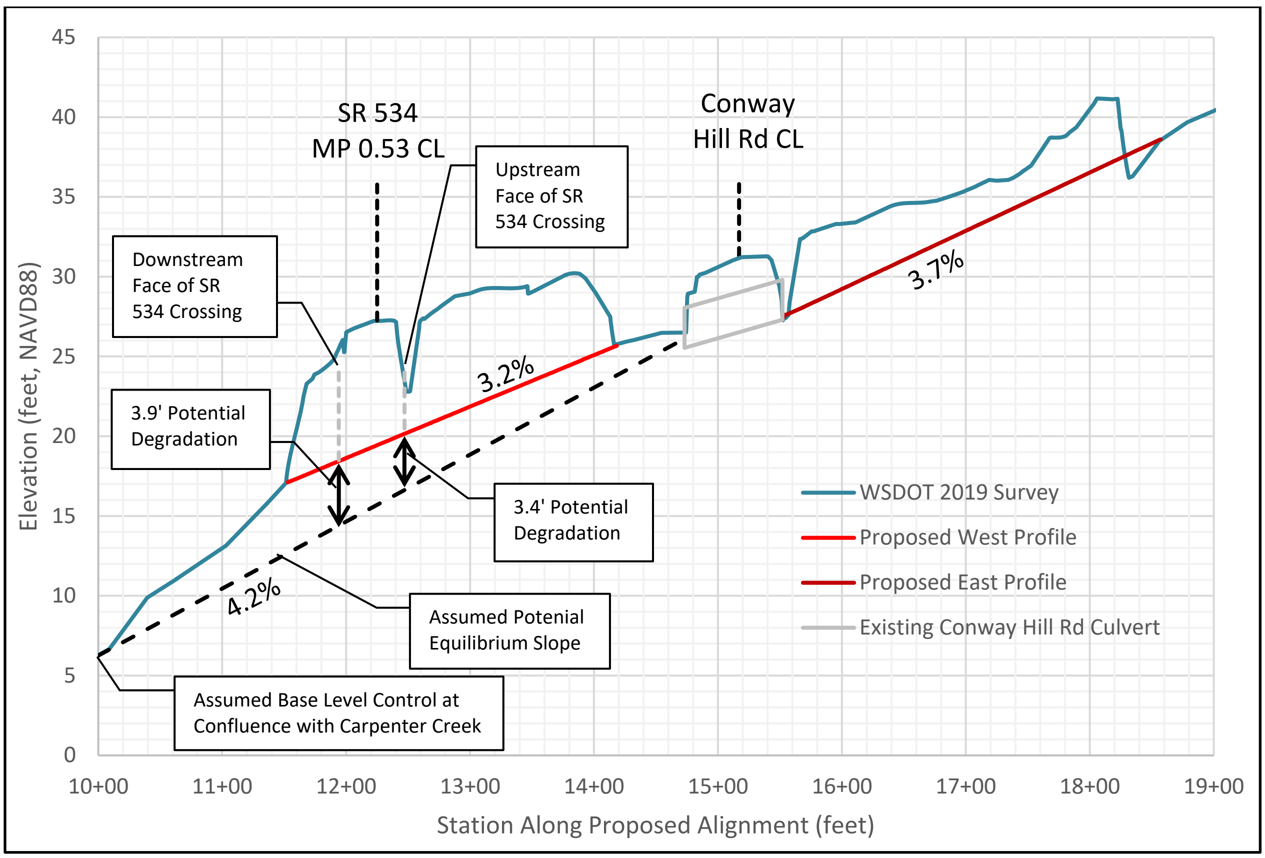


Figure 12.2. Potential Long-term Degradation at the Proposed SR 534 Crossing

12.3 Contraction Scour

Contraction scour analysis was performed following guidance from Hydraulics Engineering Circular (HEC) No. 18. The selected design flow for scour calculations was the 100-year event (both current and projected 2080-year), and the 500-year event was analyzed as the check flood.

Contraction scour was determined to be clear water based on the critical velocity calculated. The results of the calculations for main channel and left and right bank indicate no scour is expected for the 100- or 500-year event.

12.4 Local Scour

Types of local scour analysis for this crossing are abutment and bend scour. The 100-year flow event was analyzed as the scour design flood and the 500-year as the scour check flood.

12.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

12.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach for the scour design flood and scour check flood. The abutment scour calculated using the NCHRP methodology includes contraction scour, therefore contraction scour should not be added to total scour since it is part of abutment scour. Like contraction scour, abutment scour has live-bed and clear-water conditions depending on the amount of bed material transported from the upstream reach. For abutment scour, clear-water analysis was used for the left and right abutments. These calculations predict zero scour for each.

An abutment scour analysis based on a scenario in which the main channel has migrated to the abutment face. This assumed a live-bed scour condition with a vertical-wall abutment. The results estimated a scour depth of 0.2 feet for the scour design flood (100-year) and 0.2 feet for the scour check flood (500-year). This depth should be applied below the channel thalweg elevation to both the left and right abutment faces, as well as the portions of the headwalls both upstream and downstream that occur within the bottom of the 20-foot-wide floodplain corridor.

12.4.3 Bend Scour

Bend scour was calculated following the methodology outlined in HEC-20 (Lagasse et al. 2012). Depth of bend scour was estimated using Maynord’s method. The analysis indicates that the depth of bend scour is 1.0 feet for the 100-year and 1.2 feet for the 500-year event. This depth should be applied below the channel thalweg elevation to both the left and right abutment faces, as well as the portions of the headwalls both upstream and downstream that occur within the bottom of the 20-foot-wide floodplain corridor.

12.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood at the proposed unnamed tributary to Carpenter Creek crossing structure components shown in the plans dated August 2022 are provided in Table 12.1. Scour depths are provided for both the upstream and downstream faces of the crossing structure. The scour depths reported for upstream and downstream also apply to the associated structure headwalls for all portions of the walls located within the proposed floodplain corridor, due to the potential for lateral migration. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 12.1.

Table 12.1. Scour Analysis Summary

Calculated Scour Components and Total Scour for SR 534 Unnamed Tributary to Carpenter Creek				
	Upstream Face of Structure[1]		**Downstream Face of Structure[1]**	
Scour Type	**100-year (Design Flood)**	**500-year (Check Flood)**	**100-year (Design Flood)**	**500-year (Check Flood)**
Long-Term Degradation (ft)	1.2	3.4	2.2	3.9
Contraction/ Abutment Scour (Live Bed) (ft)	0.2	0.2	0.2	0.2
Bend Scour (ft)	1.0	1.2	1.0	1.2
Total Depth of Scour (ft)[2]	2.4	4.8	3.4	5.3
Channel Thalweg Elevation (ft)	20.1		18.4	
Scour Elevation (NAVD 88)[2]	17.7	15.3	15.0	13.1

[1] Includes portion adjacent head(wing) walls located within proposed floodplain corridor due to potential for lateral migration
[2] Depths do not include geotechnical requirements for any additional depth below the calculated scour

13.0 Scour Countermeasures

No scour countermeasures are proposed for the SR 534 crossing of the unnamed tributary to Carpenter Creek.

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Appendices

Appendix A – SRH-2D Existing Conditions Model Results

Appendix B – SRH-2D Proposed Conditions Model Results

Appendix C – FEMA FIRM Map

Appendix D – Final Stream Plan, Profile, Details Sheets

Appendix E – Streambed Material Sizing Calculations

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

Appendix G—Large Woody Material Calculations

Appendix H—Hydraulic Field Report Form

Appendix I—Scour Calculations

Appendix J—Flood Risk Assessment Memorandum

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Appendix A

SRH-2D Existing Conditions Model Results

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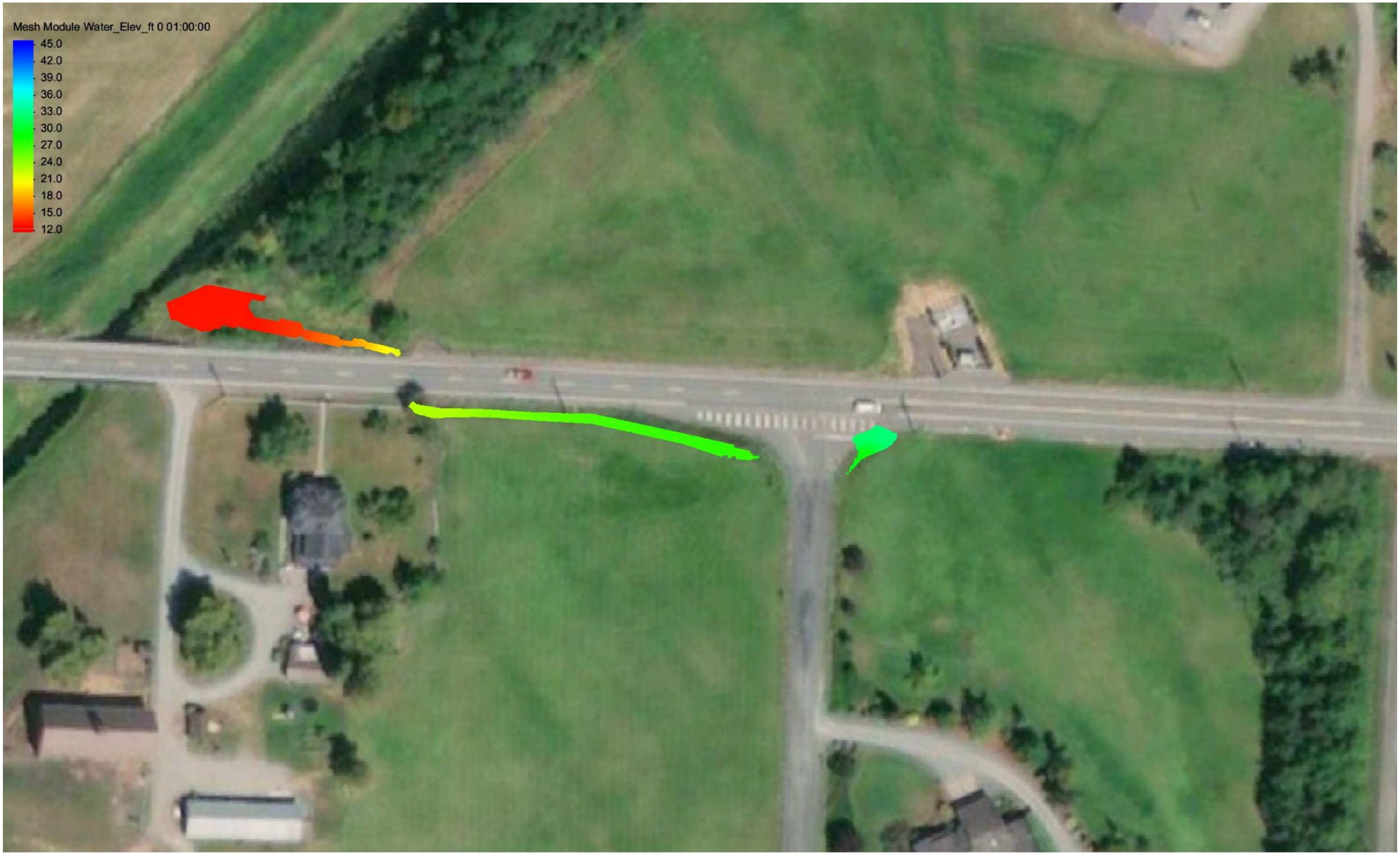
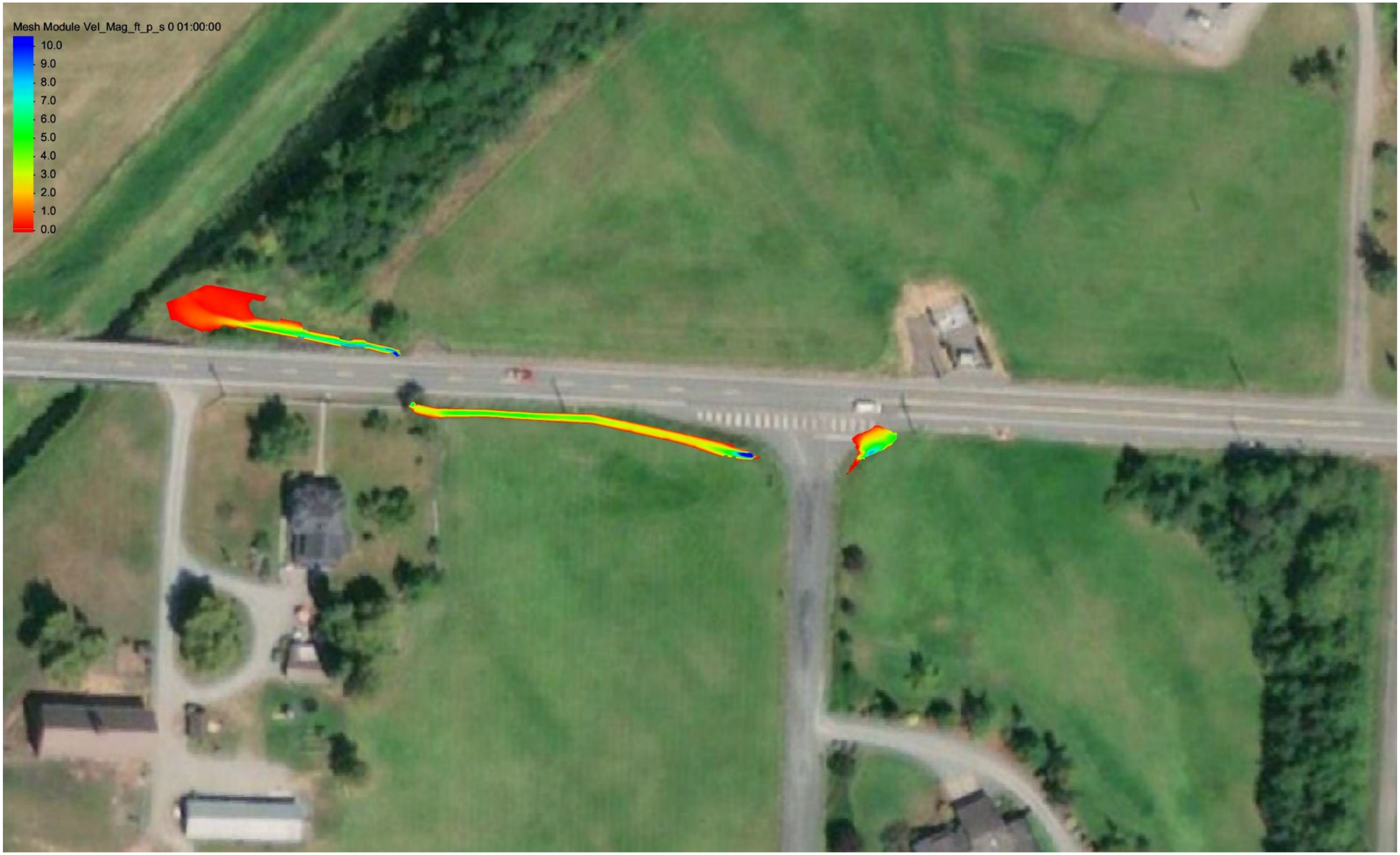


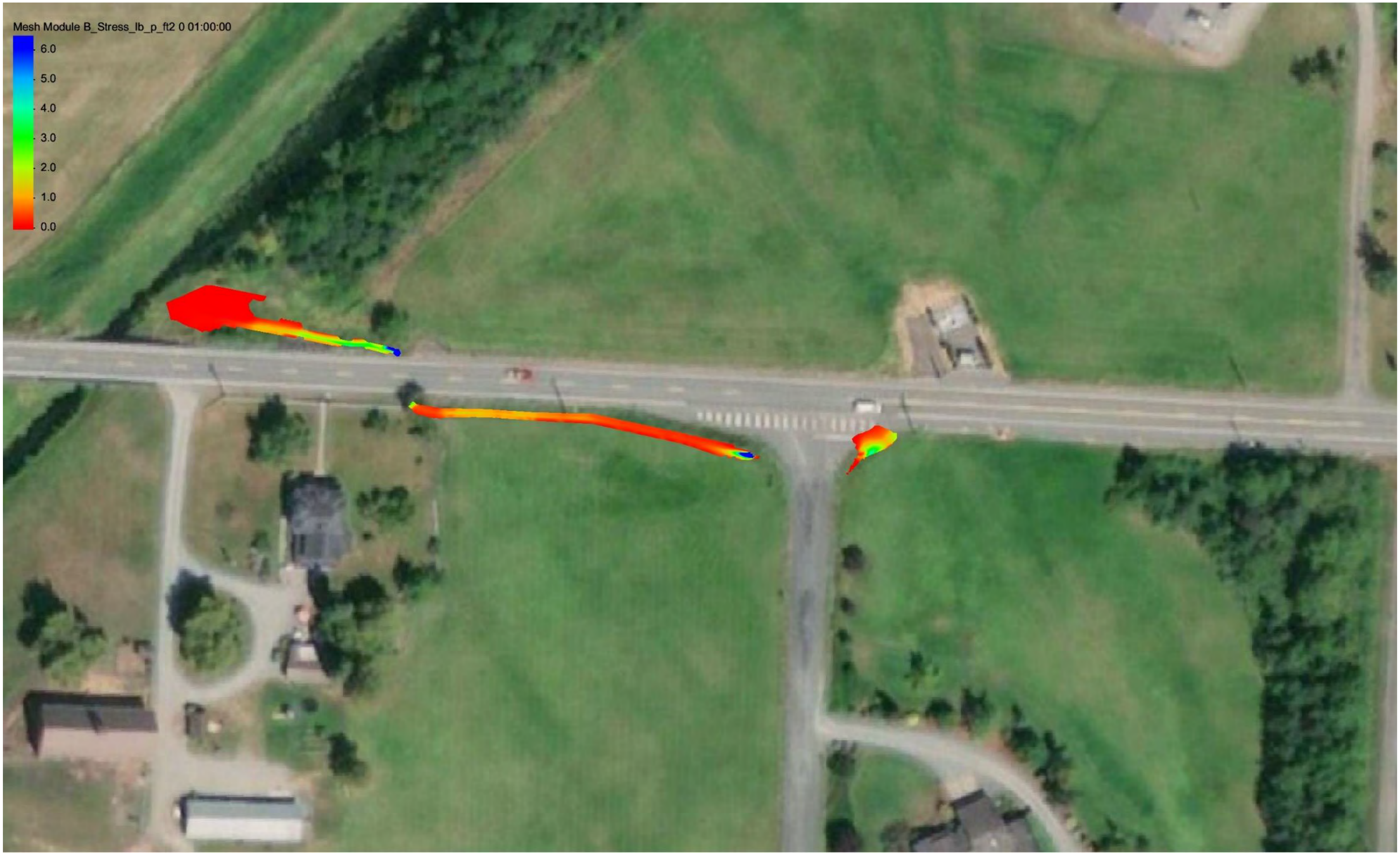
Parametrix

Figure A.1.1
2-Year Flow Event
Water Surface Elevation



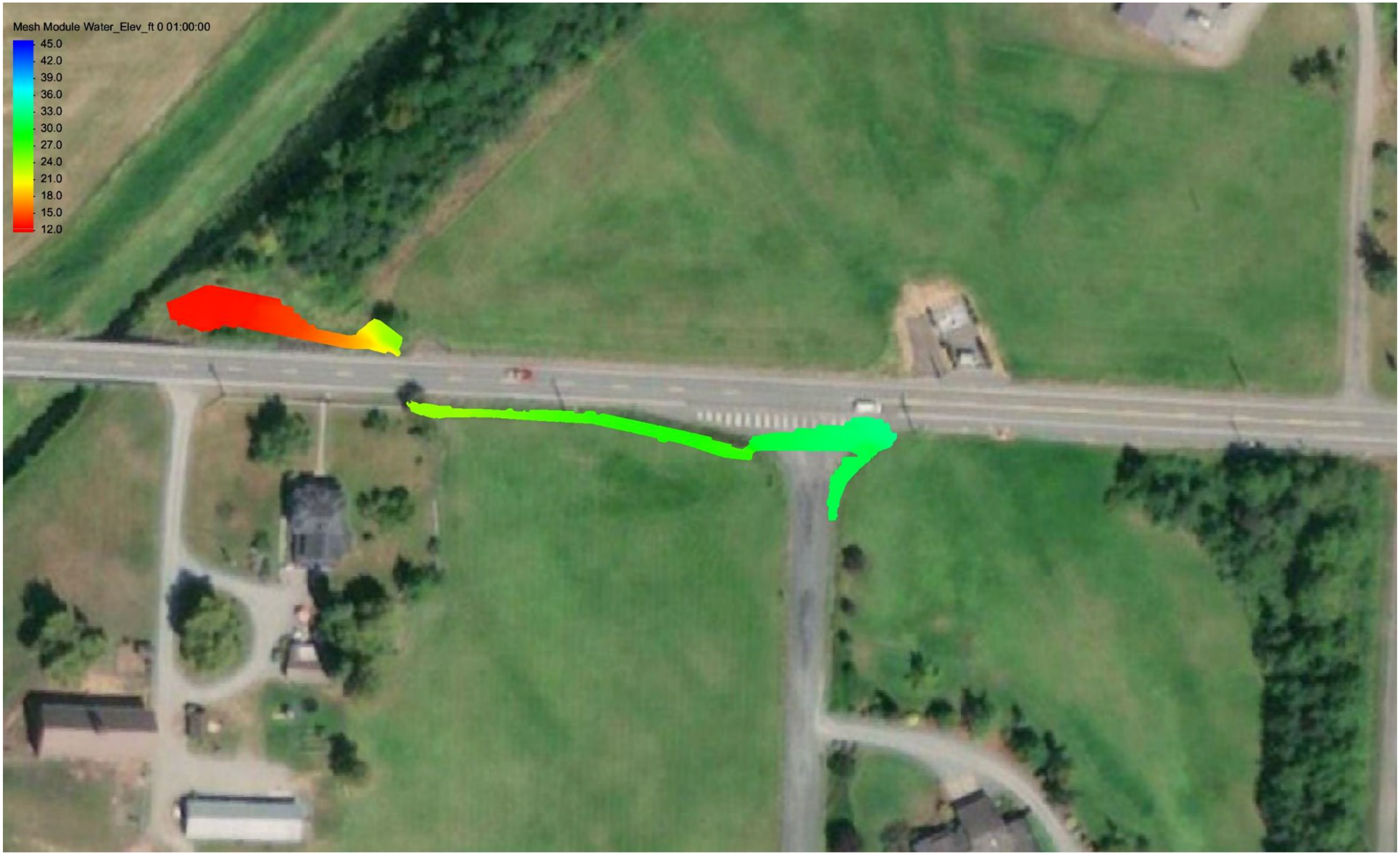
Parametrix

Figure A.1.2
2-Year Flow Event
Velocity



Parametrix

Figure A.1.3
2-Year Flow Event
Shear Stress

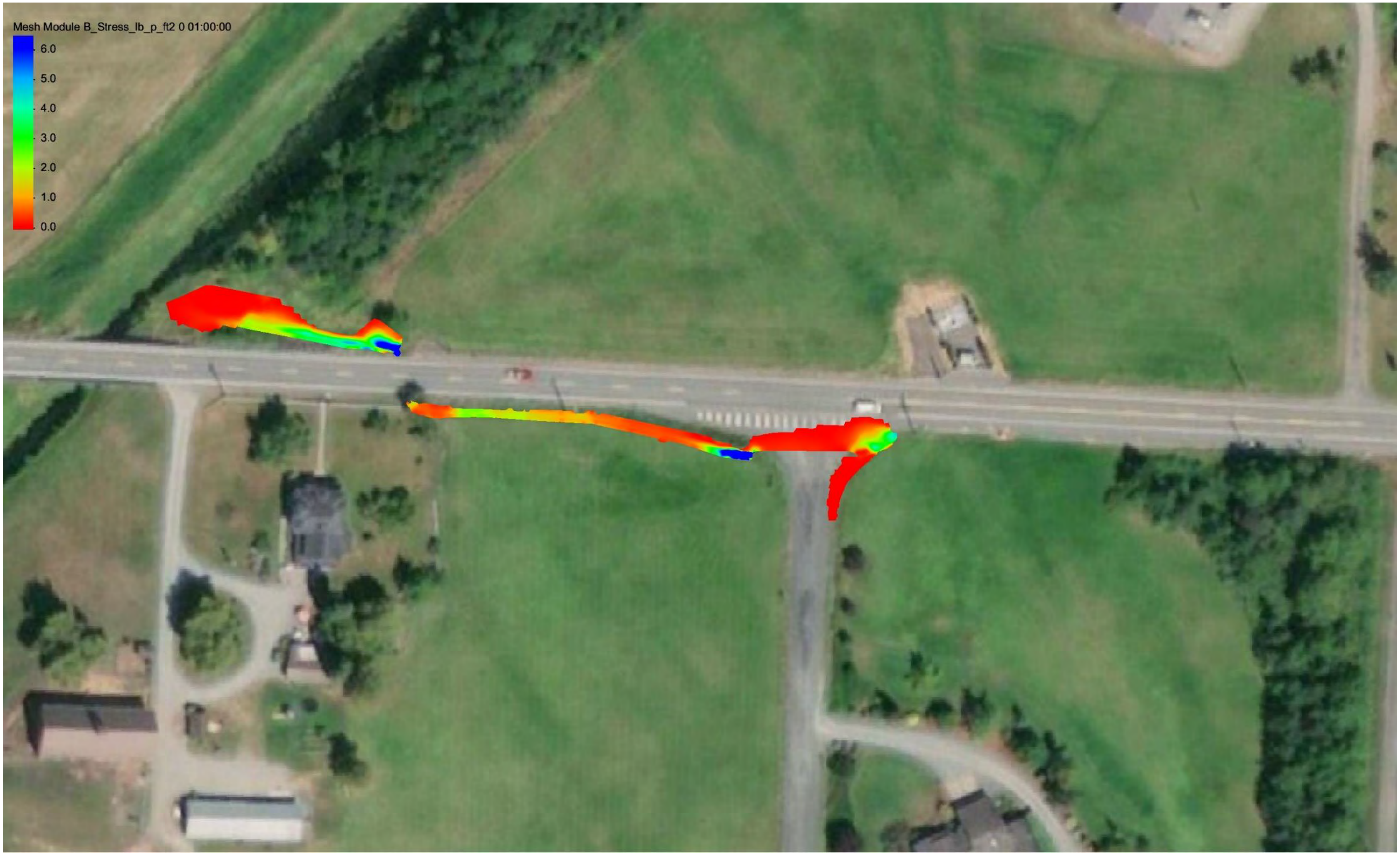


Parametrix

Figure A.1.4
25-Year Flow Event
Water Surface Elevation

Parametrix

Figure A.1.5
25-Year Flow Event
Velocity



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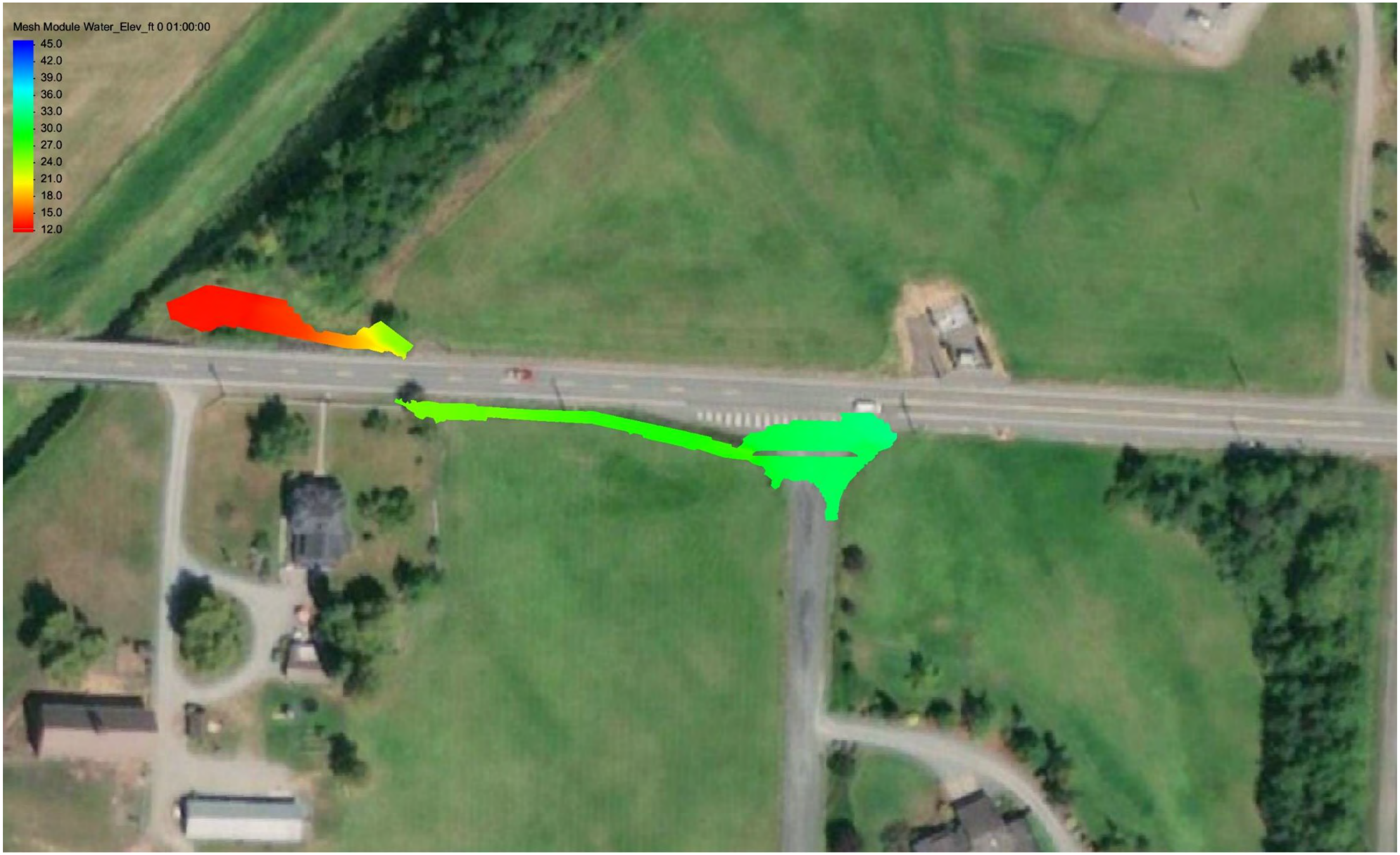
25-Year Flow Event
Shear Stress



Parametrix

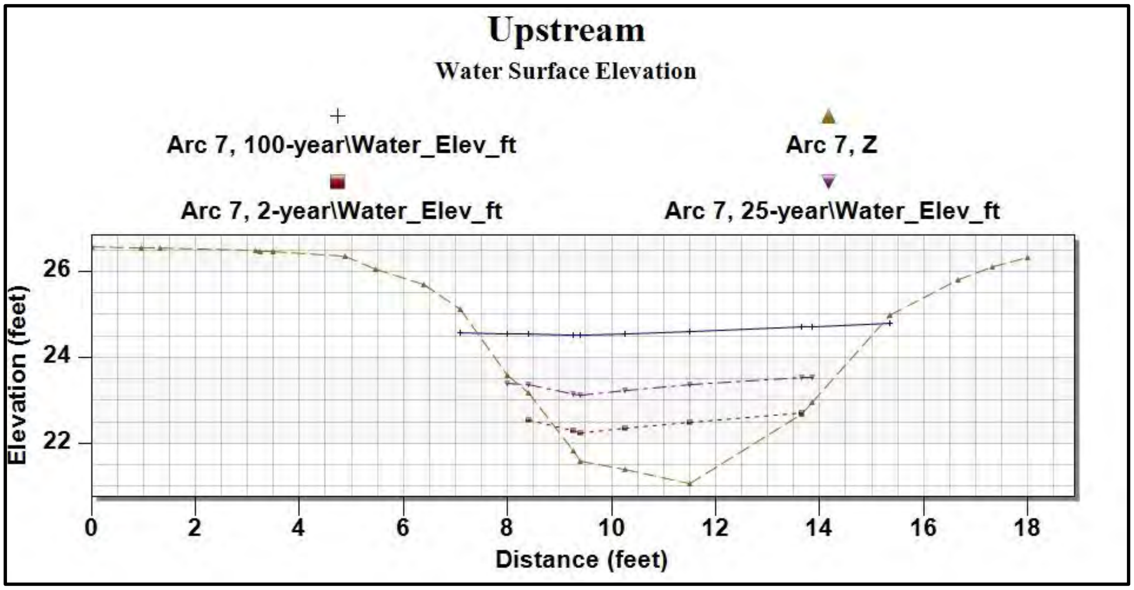
Figure A.1.7
100-Year Flow Event
Water Surface Elevation

Parametrix

Figure A.1.8
100-Year Flow Event
Velocity

Parametrix

Figure A.1.9
100-Year Flow Event
Shear Stress



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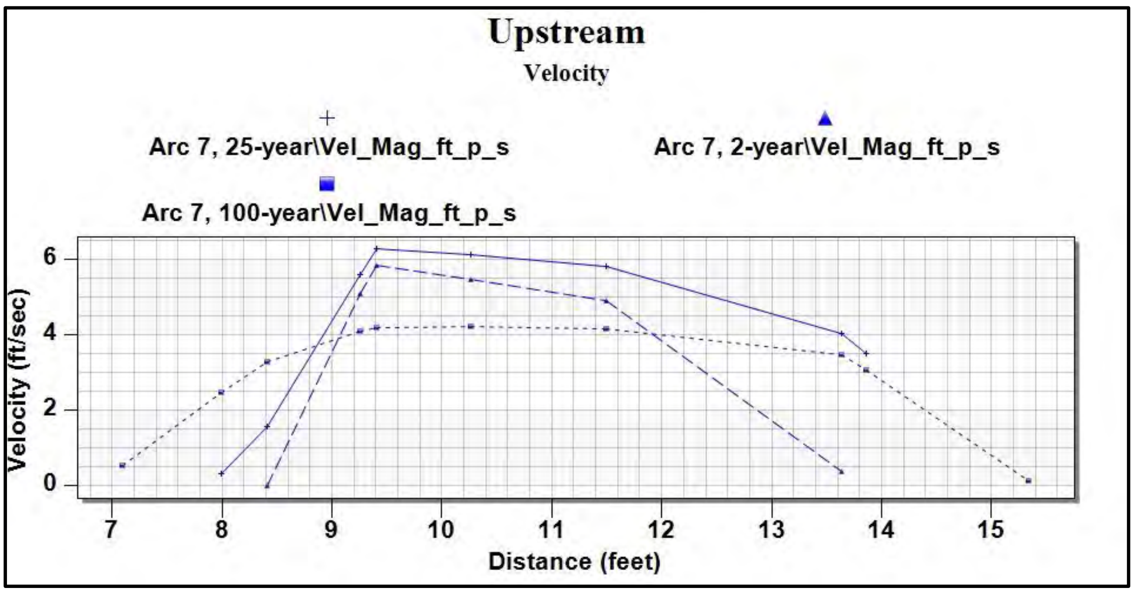
Unnamed Tributary to Carpenter Creek SR 534



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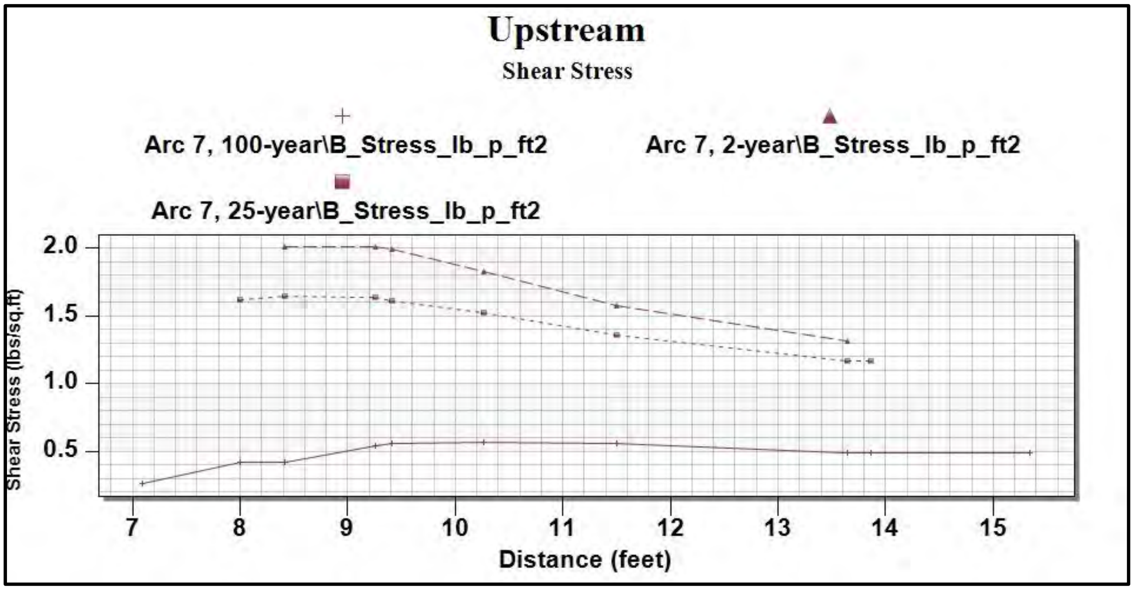

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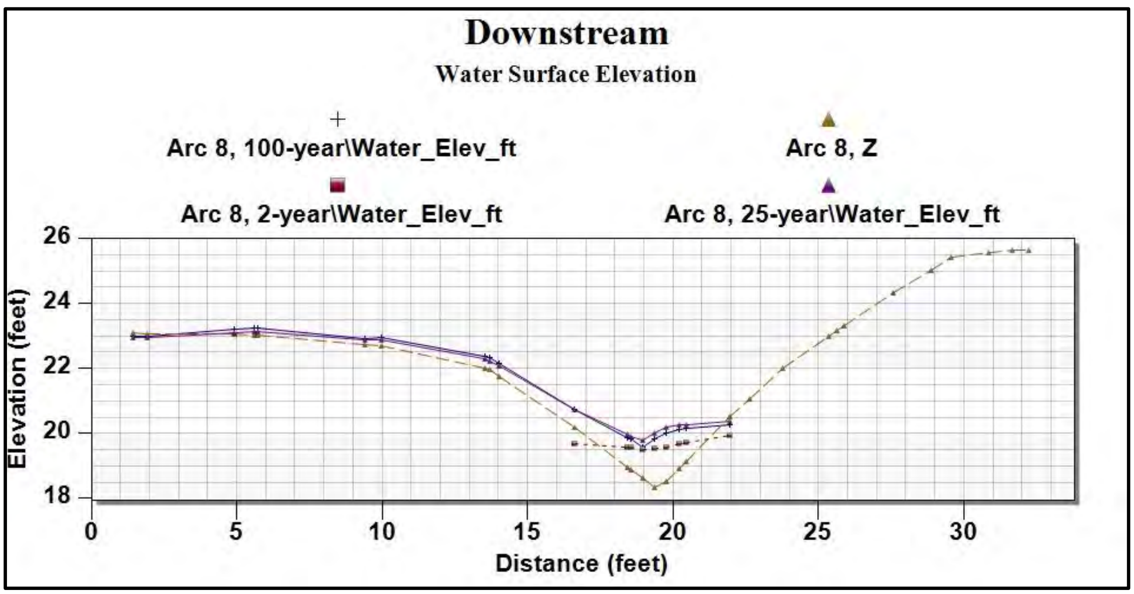

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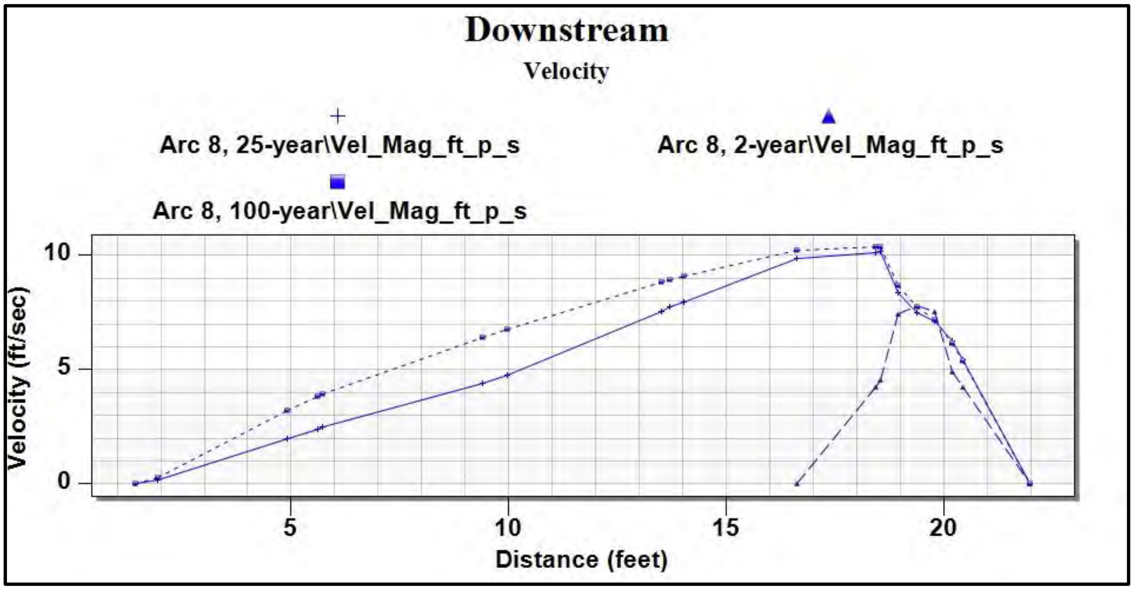

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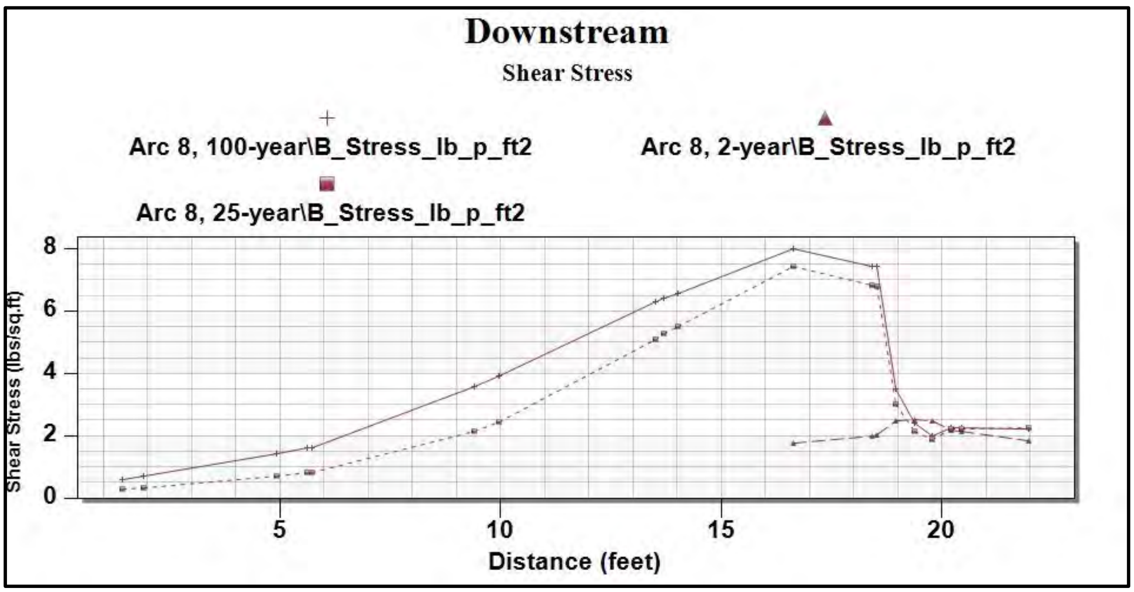

Figure A.2.6
Unnamed Tributary to Carpenter Creek SR 534

Appendix B

SRH-2D Proposed Conditions Model Results

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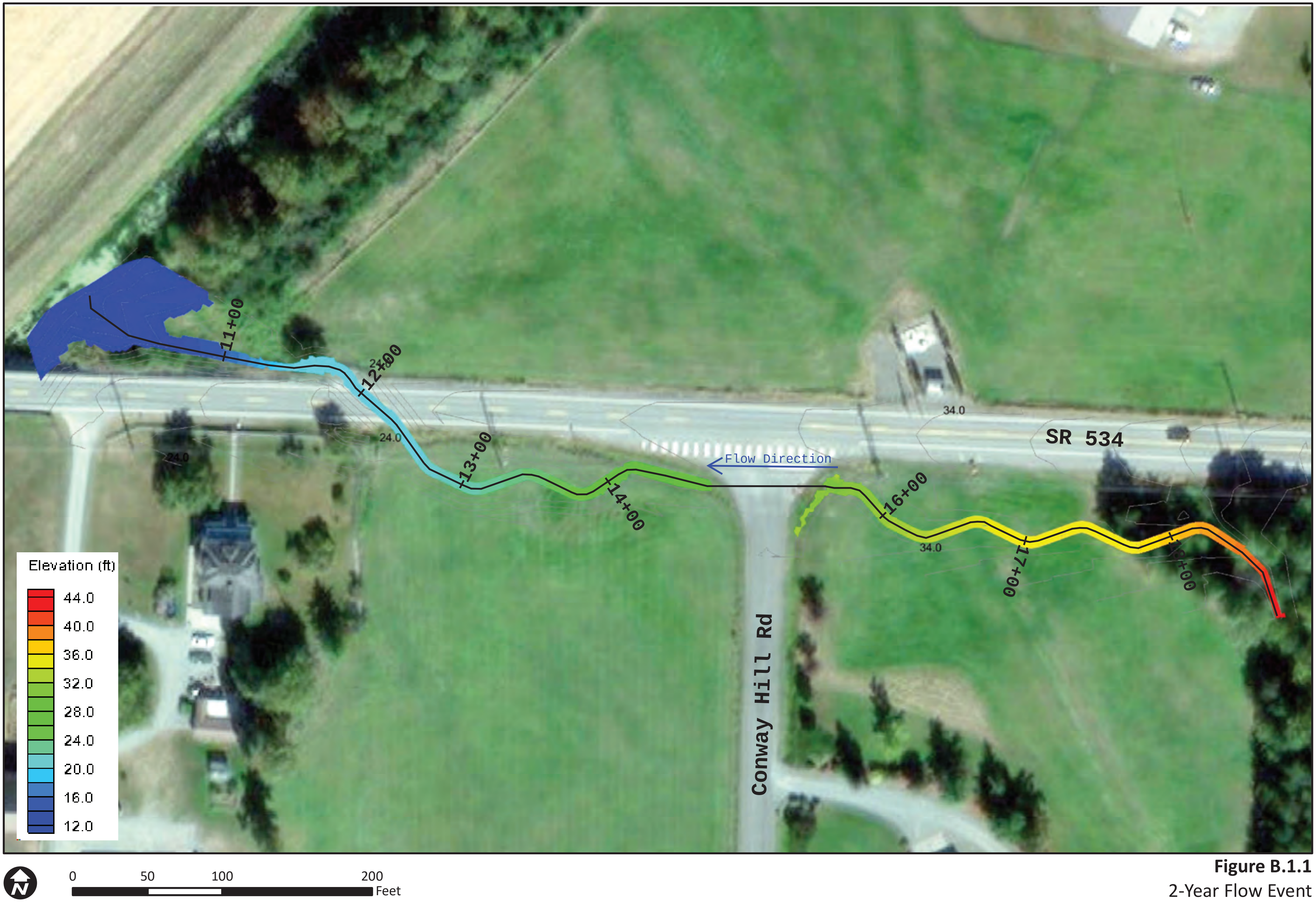

Figure B.1.1
2-Year Flow Event
Proposed Water Surface Elevation

Unnamed Tributary to Carpenter Creek SR 534

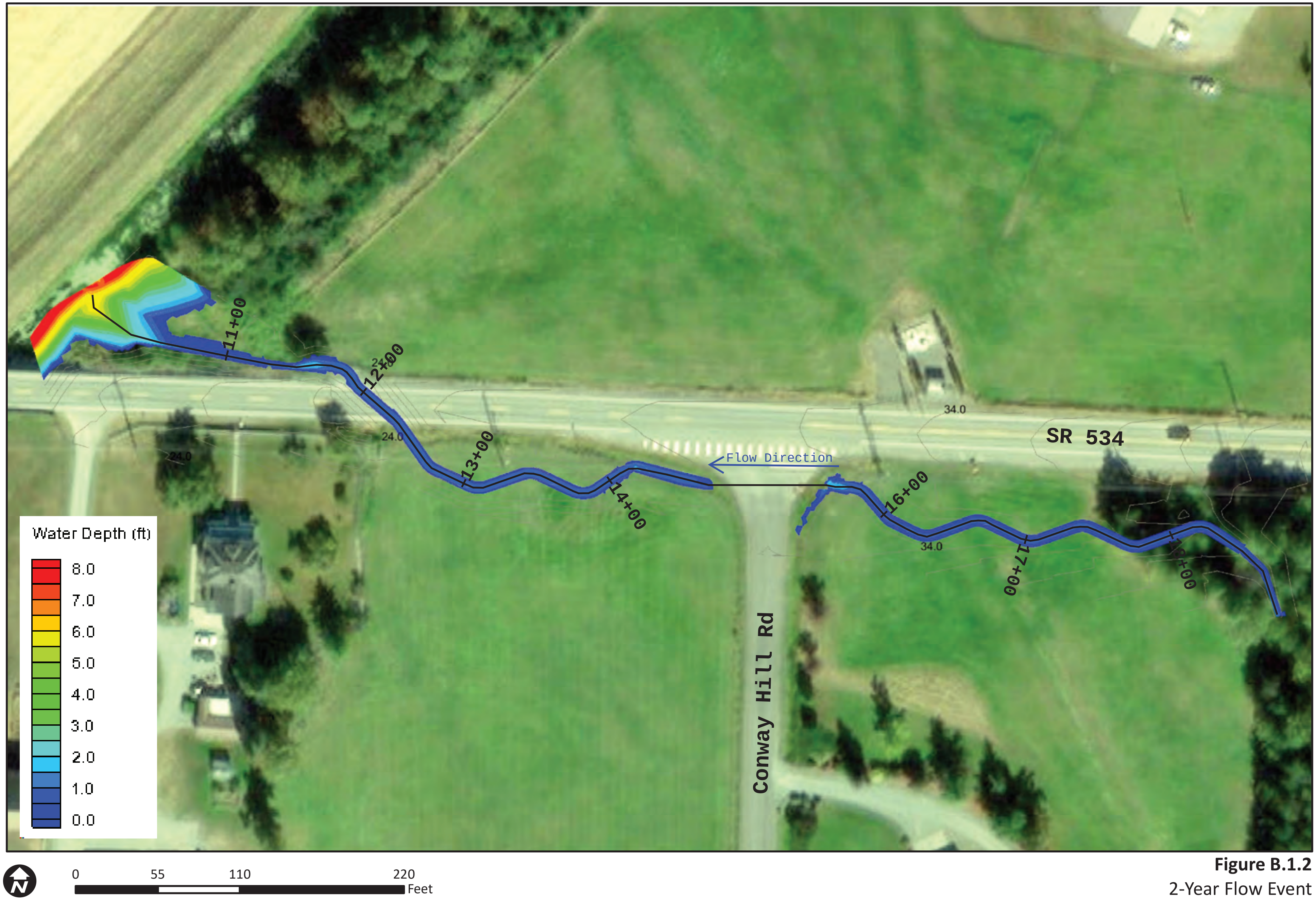

Figure B.1.2
2-Year Flow Event
Proposed Water Depth

Unnamed Tributary to Carpenter Creek SR 534

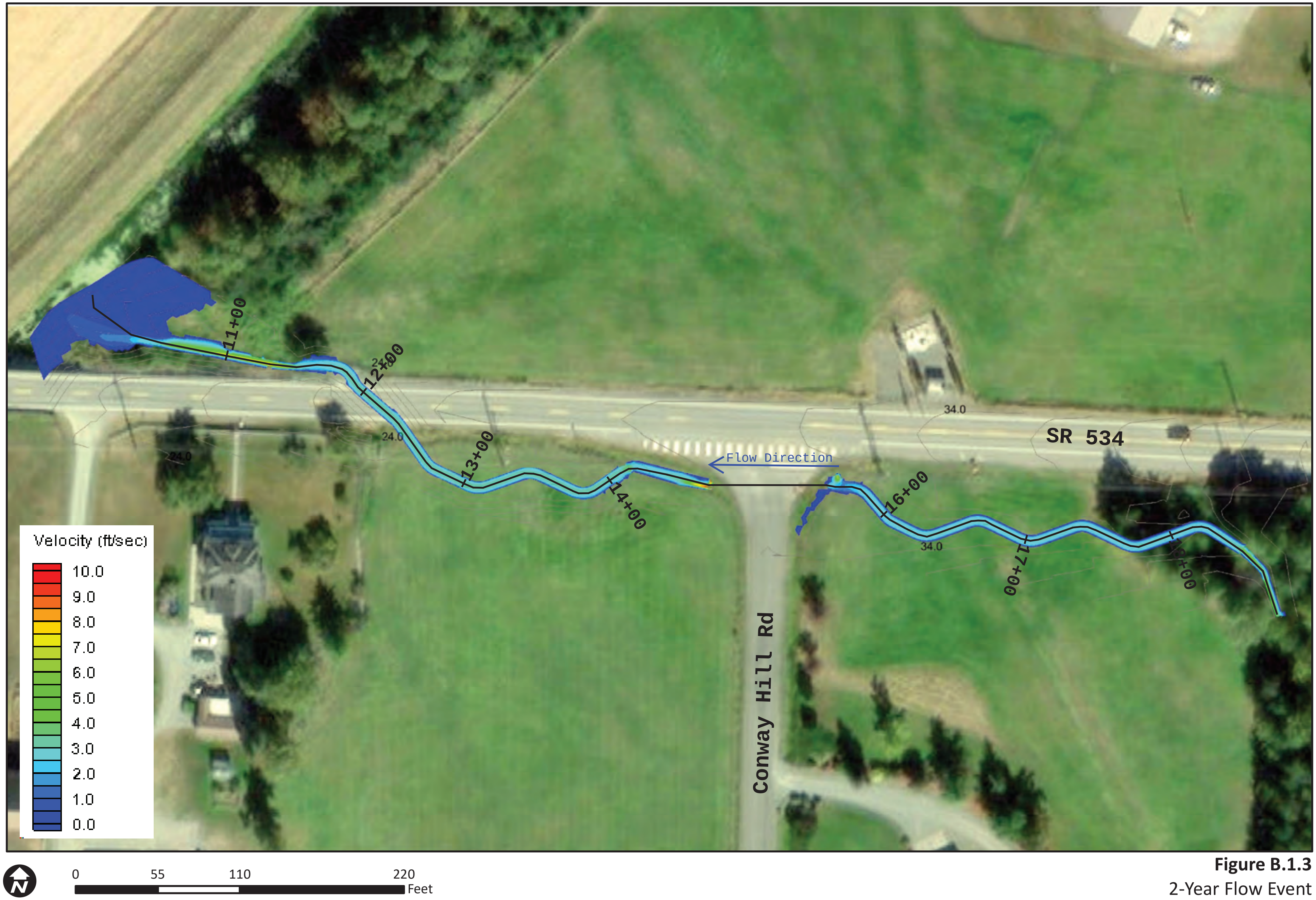

Figure B.1.3
2-Year Flow Event
Proposed Velocity

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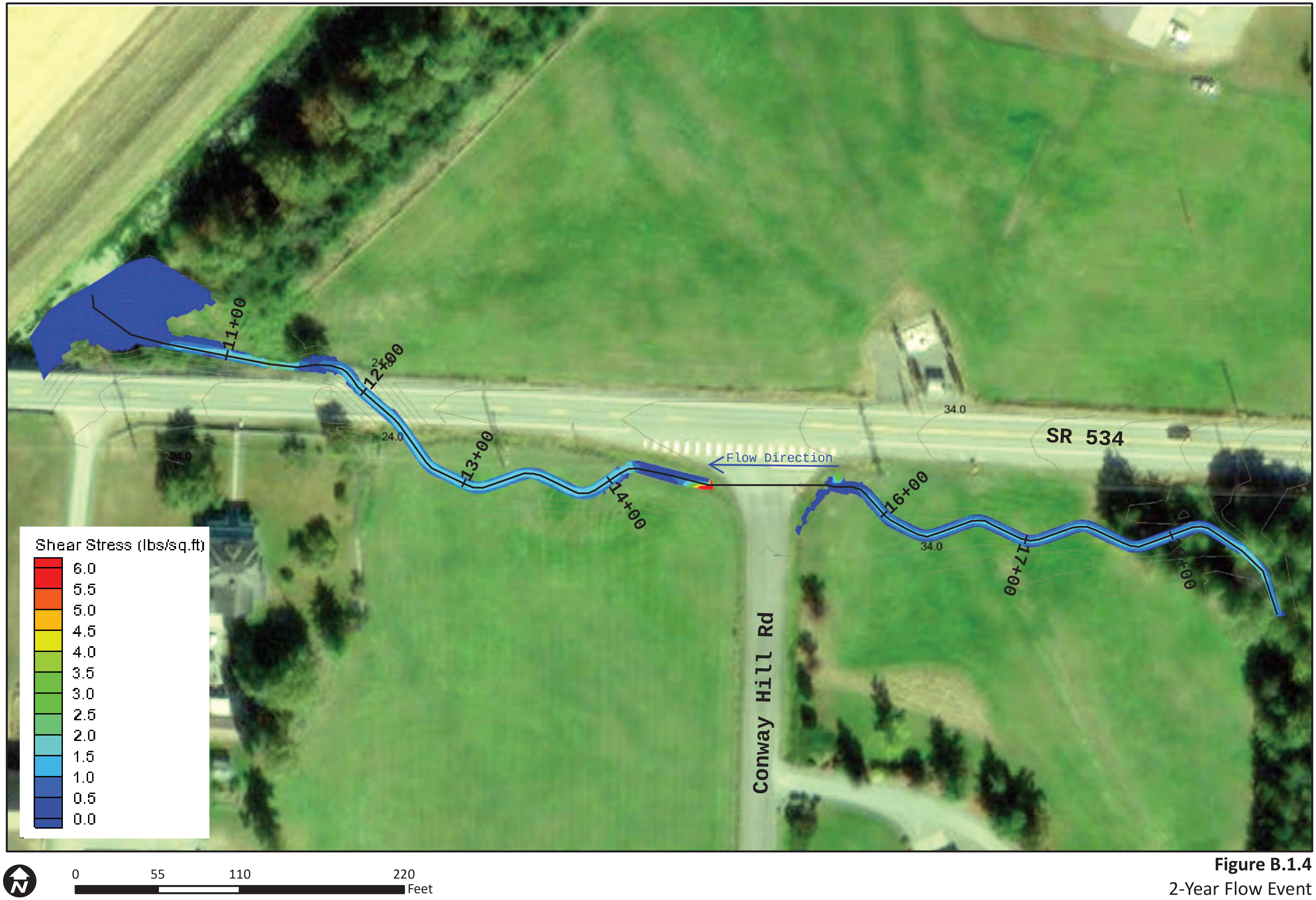

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2-Year Flow Event
Proposed Shear Stress

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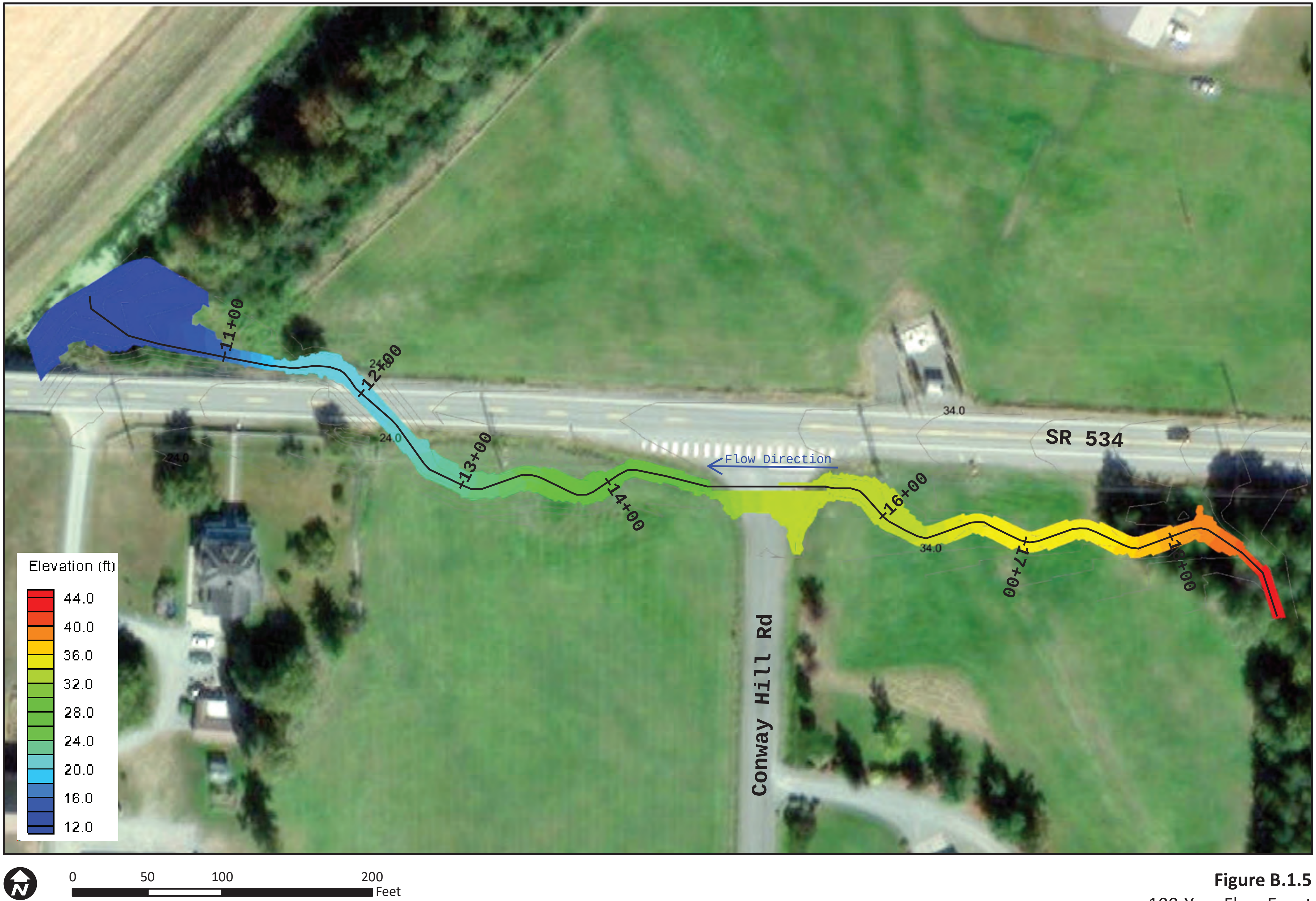

Figure B.1.5
100-Year Flow Event
Proposed Water Surface Elevation

Unnamed Tributary to Carpenter Creek SR 534

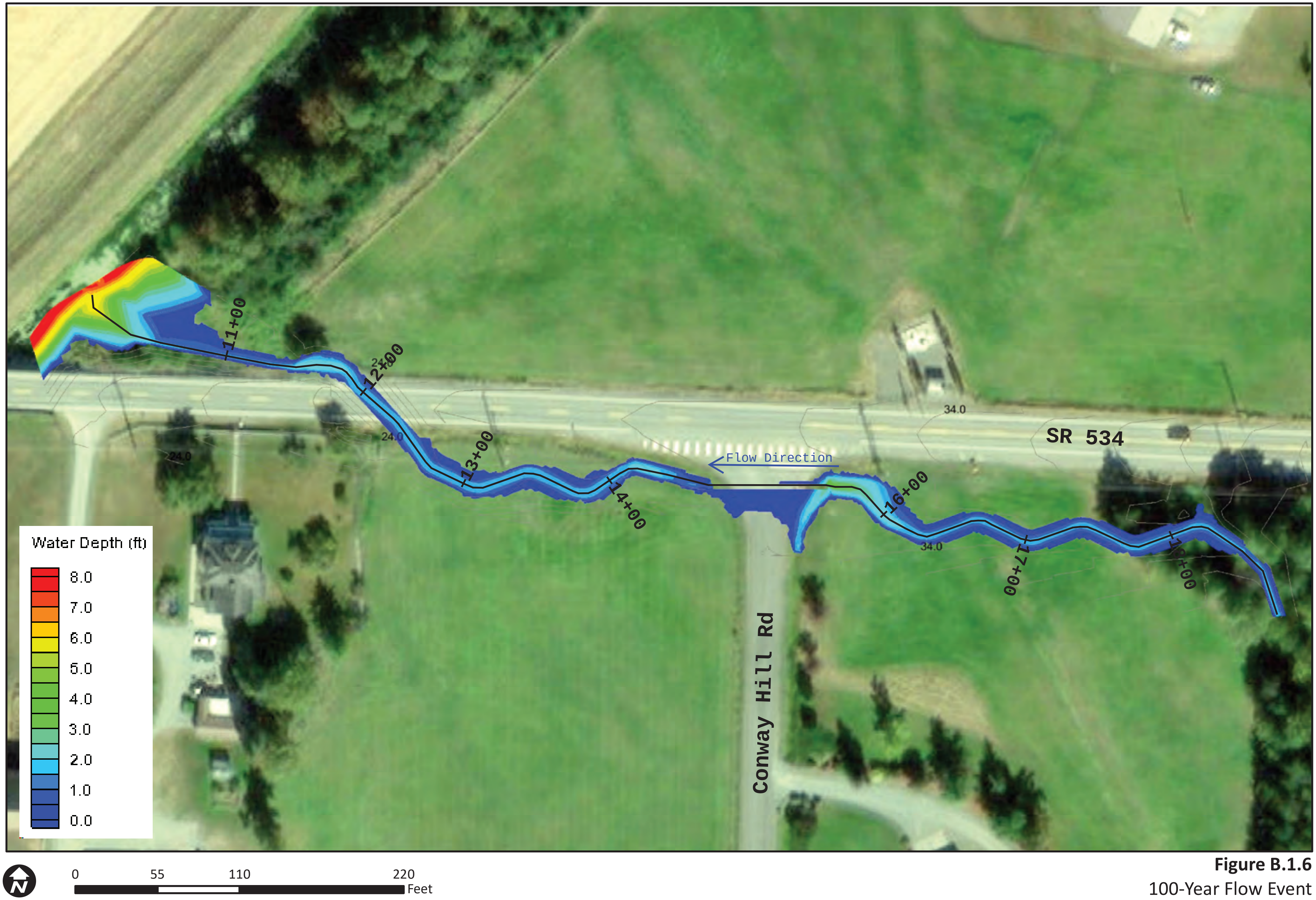

Figure B.1.6
100-Year Flow Event
Proposed Water Depth

Unnamed Tributary to Carpenter Creek SR 534

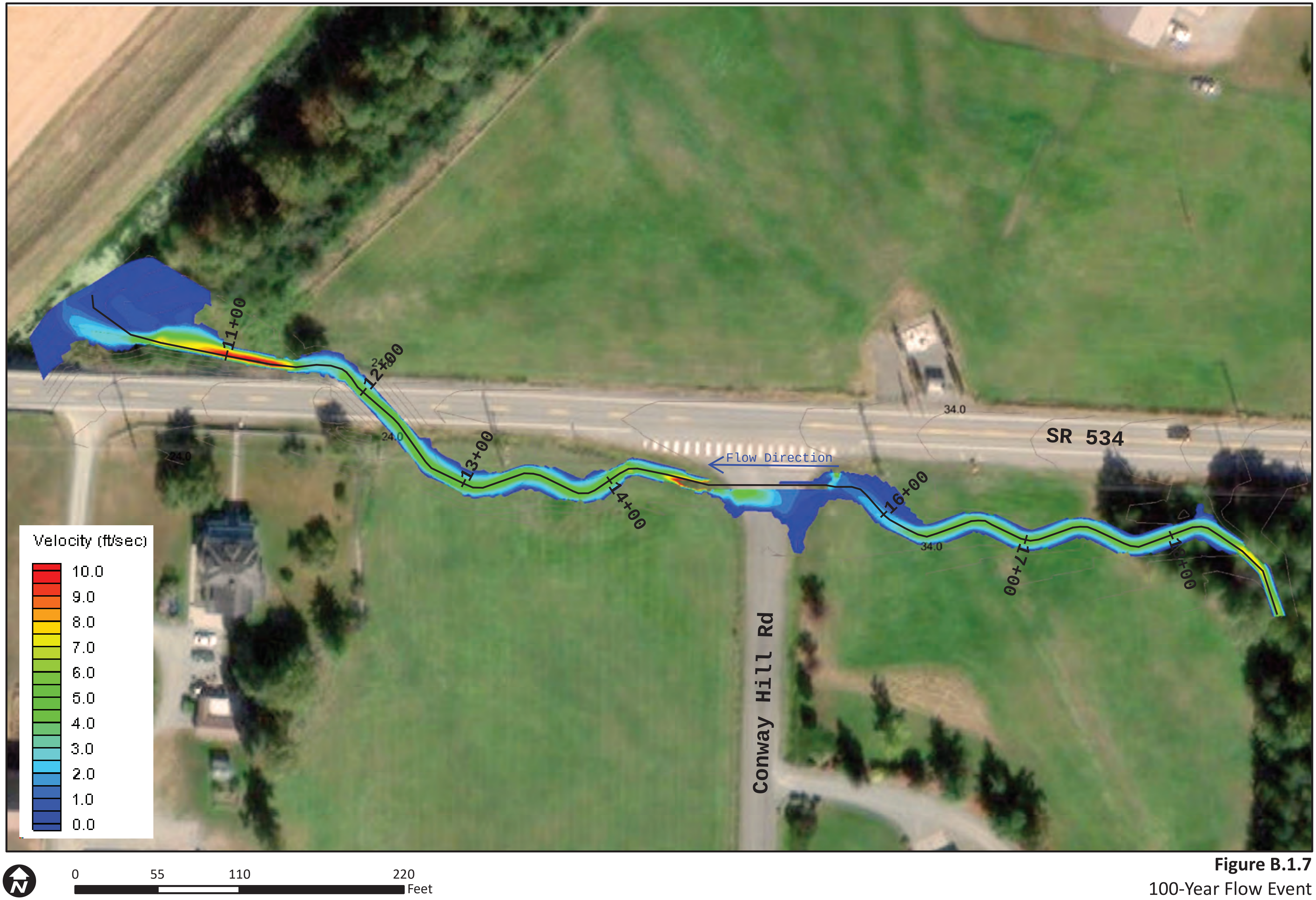

Figure B.1.7
100-Year Flow Event
Proposed Velocity

Unnamed Tributary to Carpenter Creek SR 534

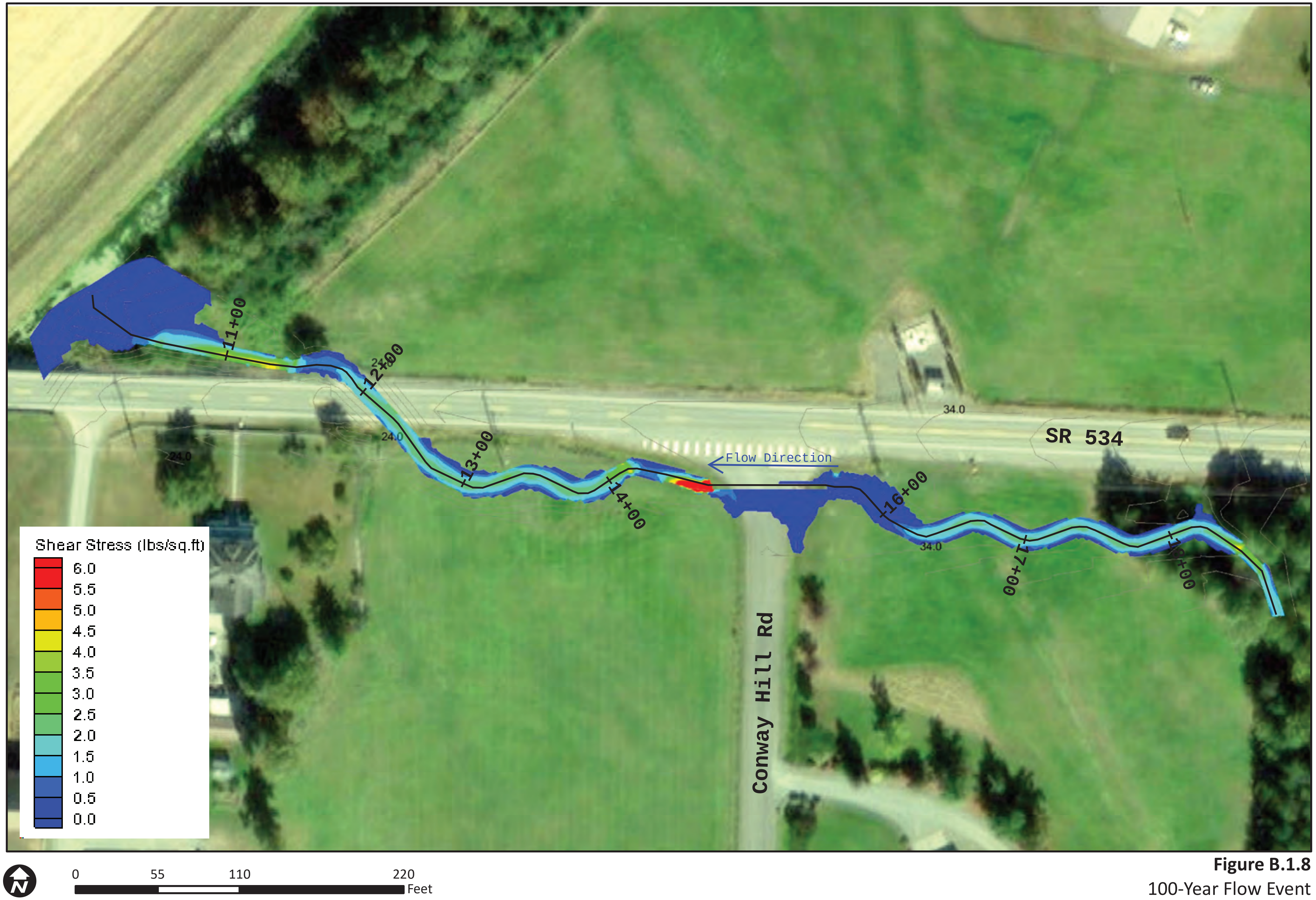

Figure B.1.8
100-Year Flow Event
Proposed Shear Stress

Unnamed Tributary to Carpenter Creek SR 534

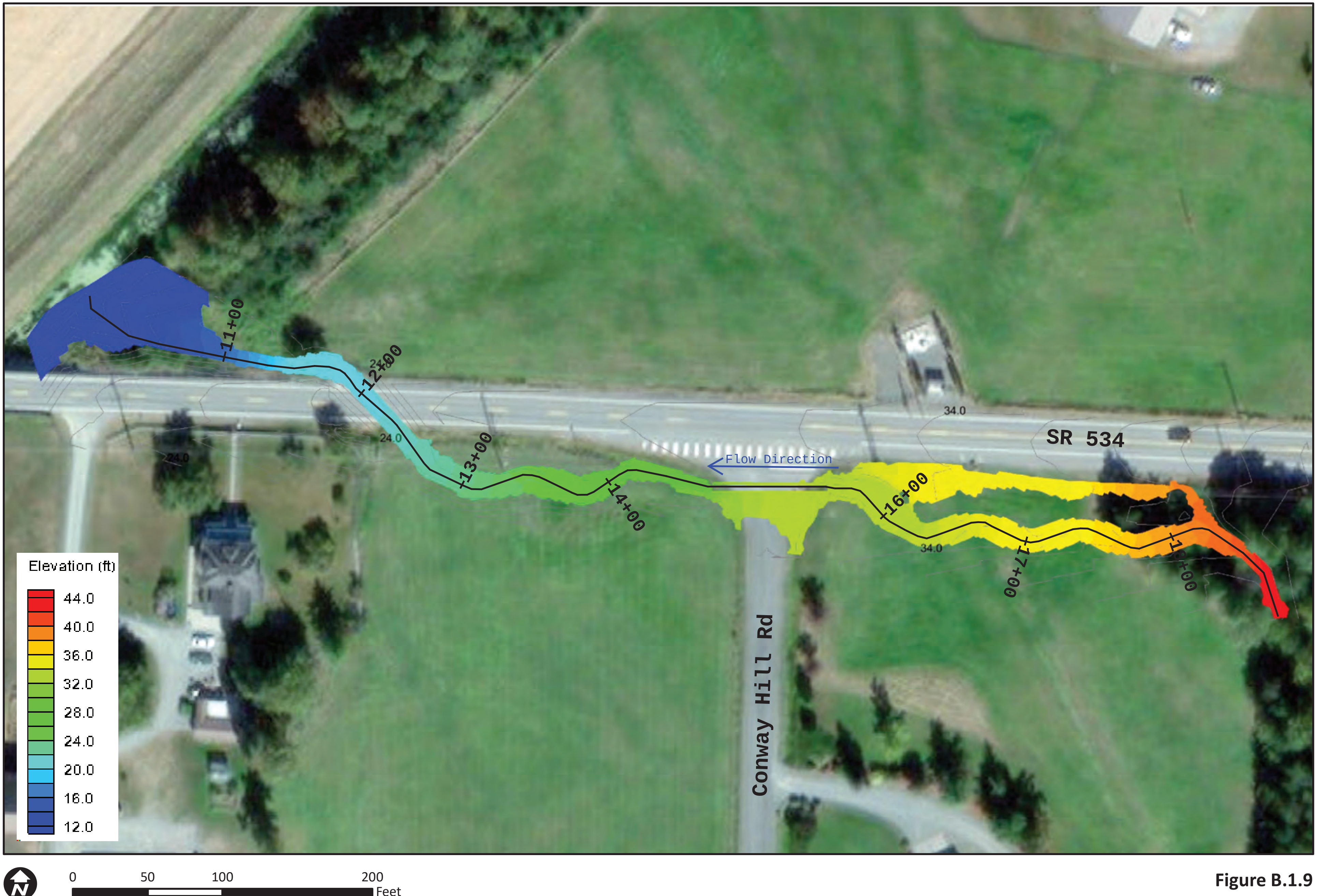

Figure B.1.9
500-Year Flow Event
Proposed Water Surface Elevation

Unnamed Tributary to Carpenter Creek SR 534

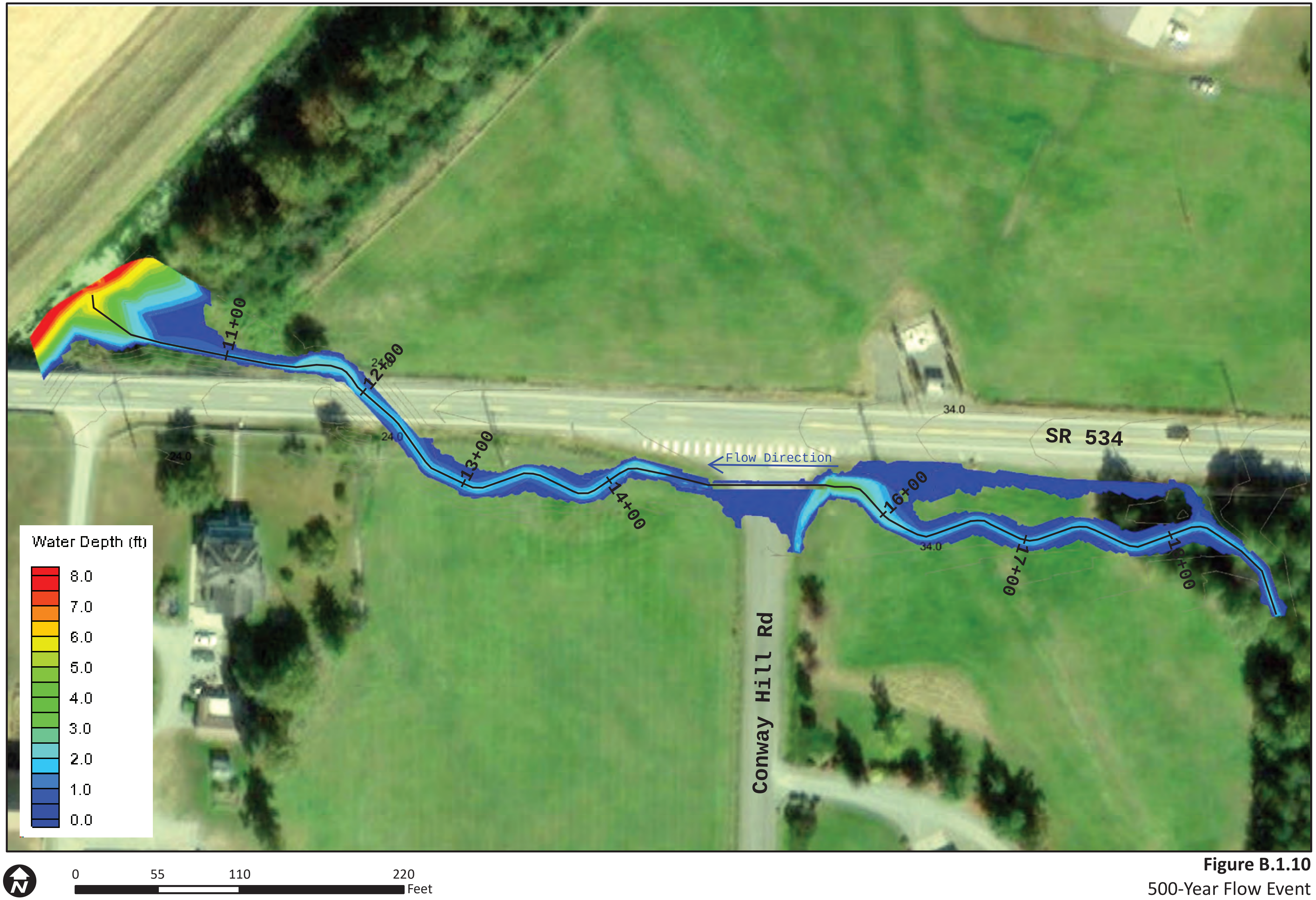

Figure B.1.10
500-Year Flow Event
Proposed Water Depth

Unnamed Tributary to Carpenter Creek SR 534

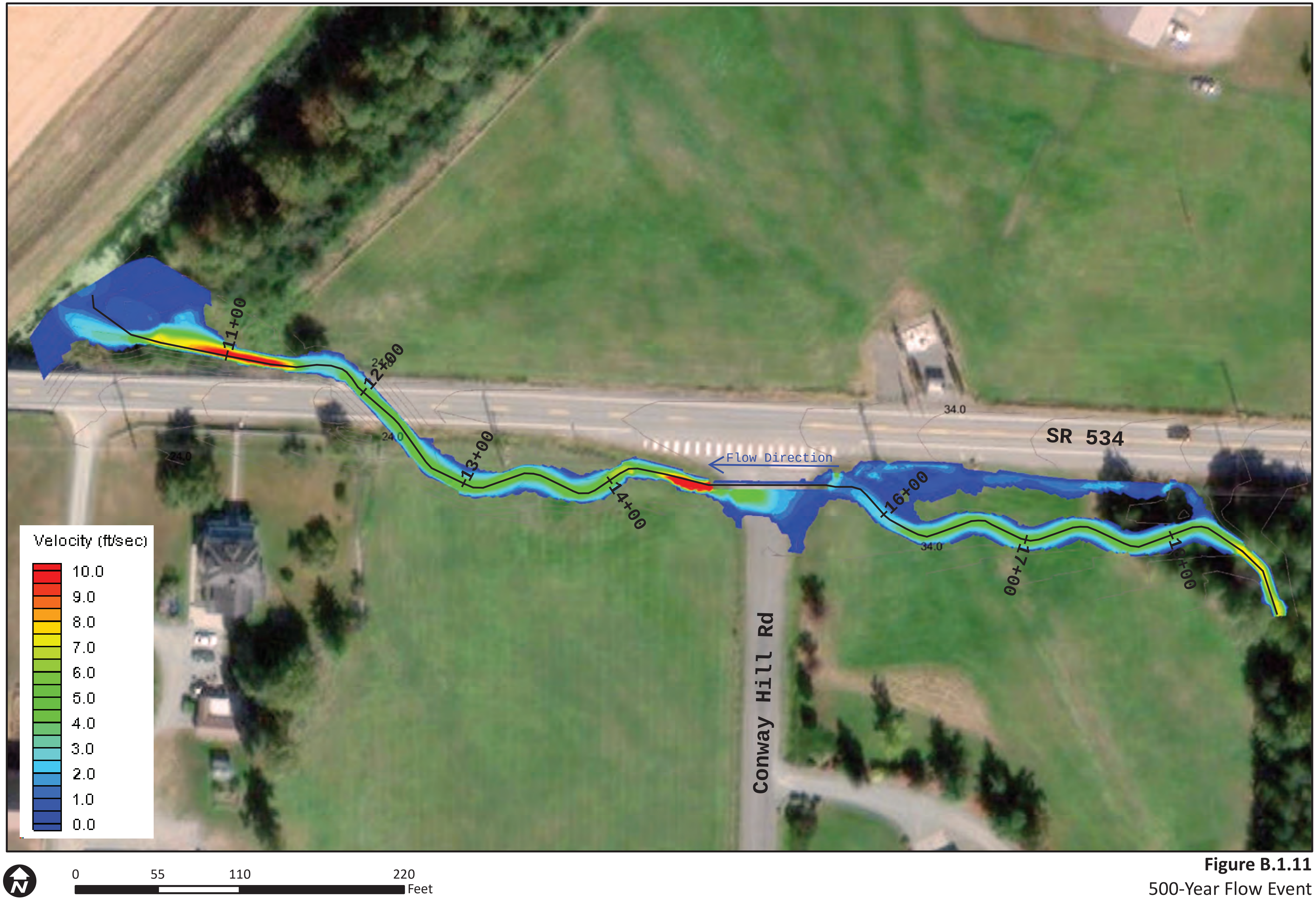

Figure B.1.11
500-Year Flow Event
Proposed Velocity

Unnamed Tributary to Carpenter Creek SR 534

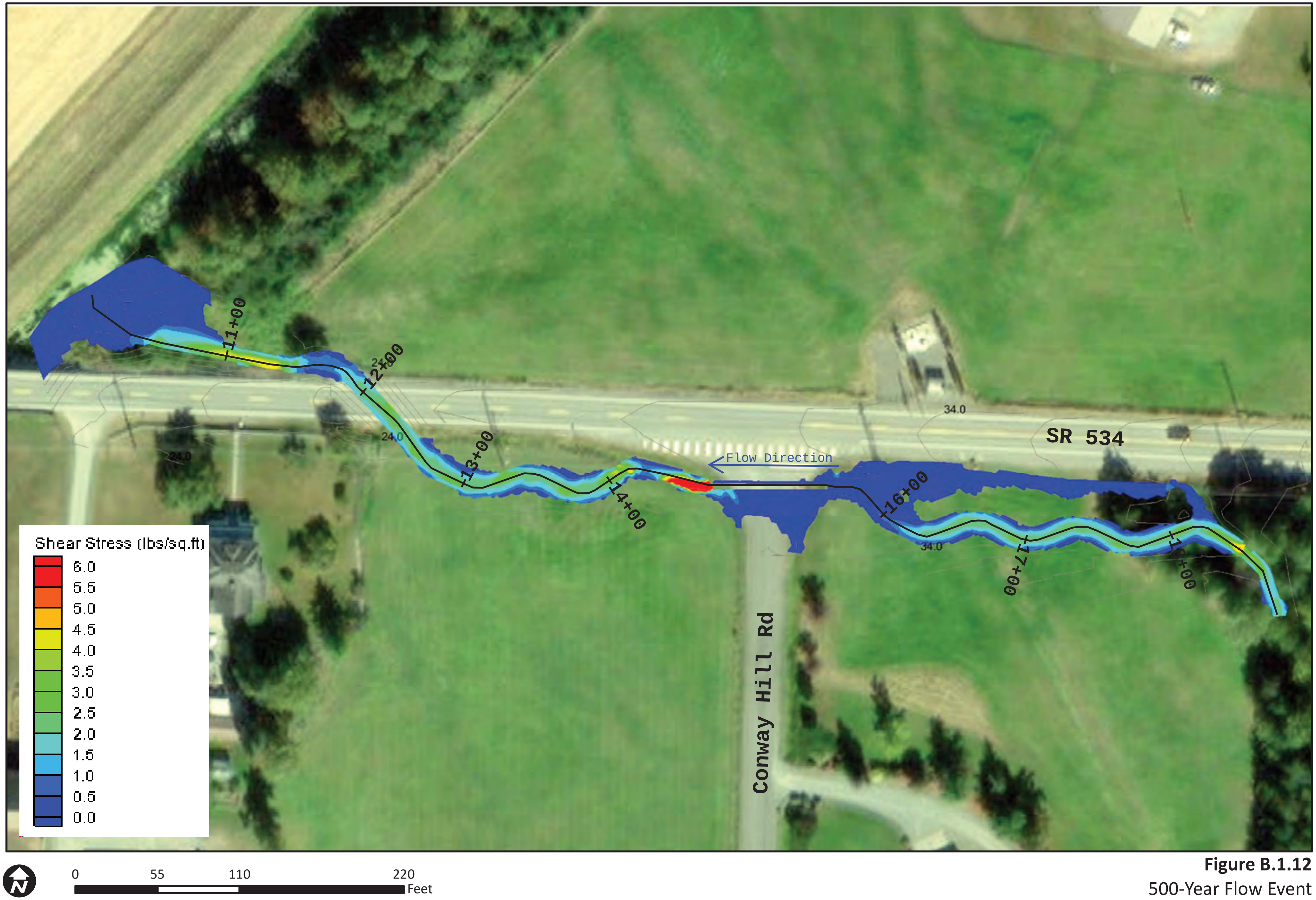

Figure B.1.12
500-Year Flow Event
Proposed Shear Stress

Unnamed Tributary to Carpenter Creek SR 534

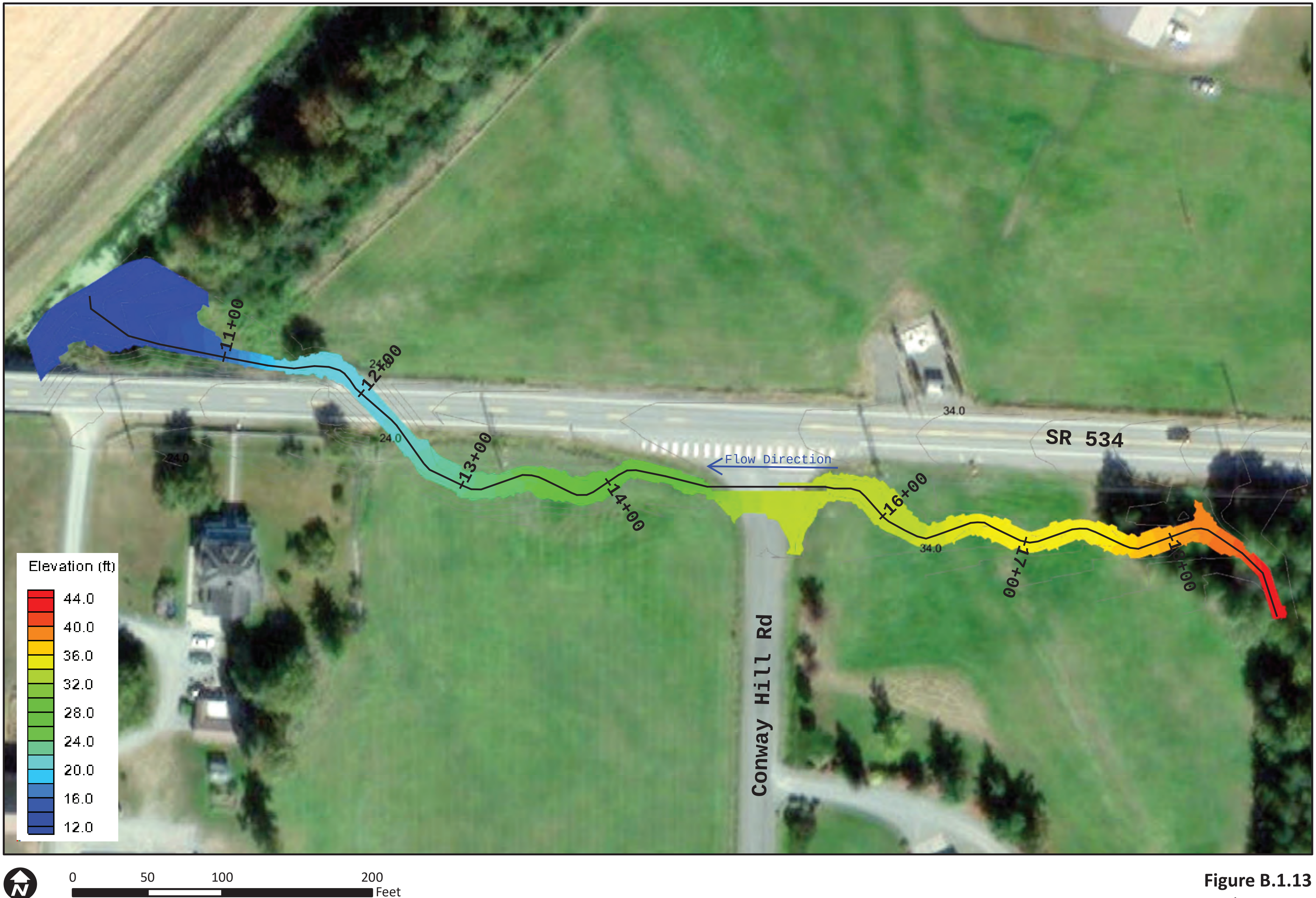

Figure B.1.13
100-Year 2080 Flow Event
Proposed Water Surface Elevation

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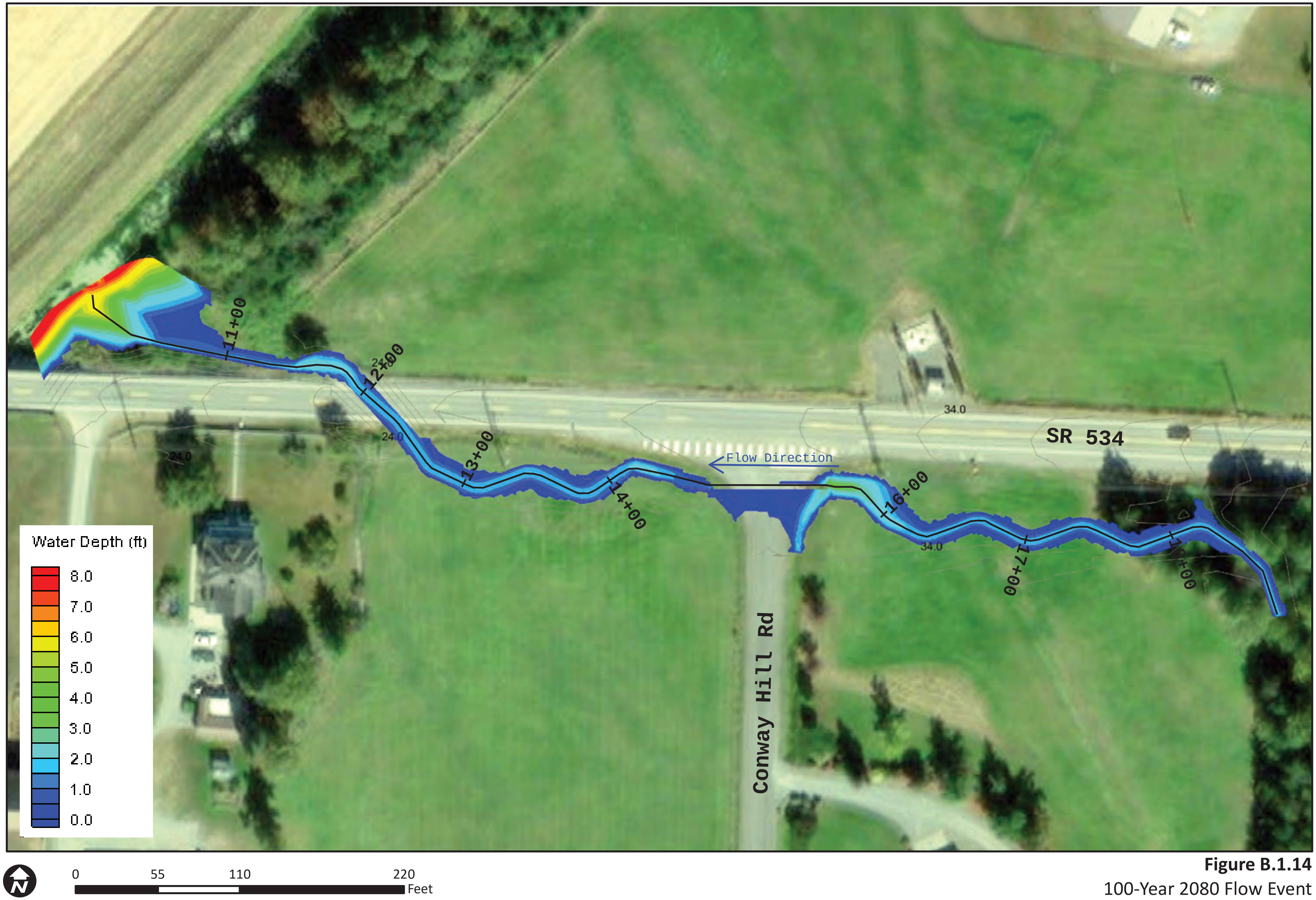

Figure B.1.14
100-Year 2080 Flow Event
Proposed Water Depth

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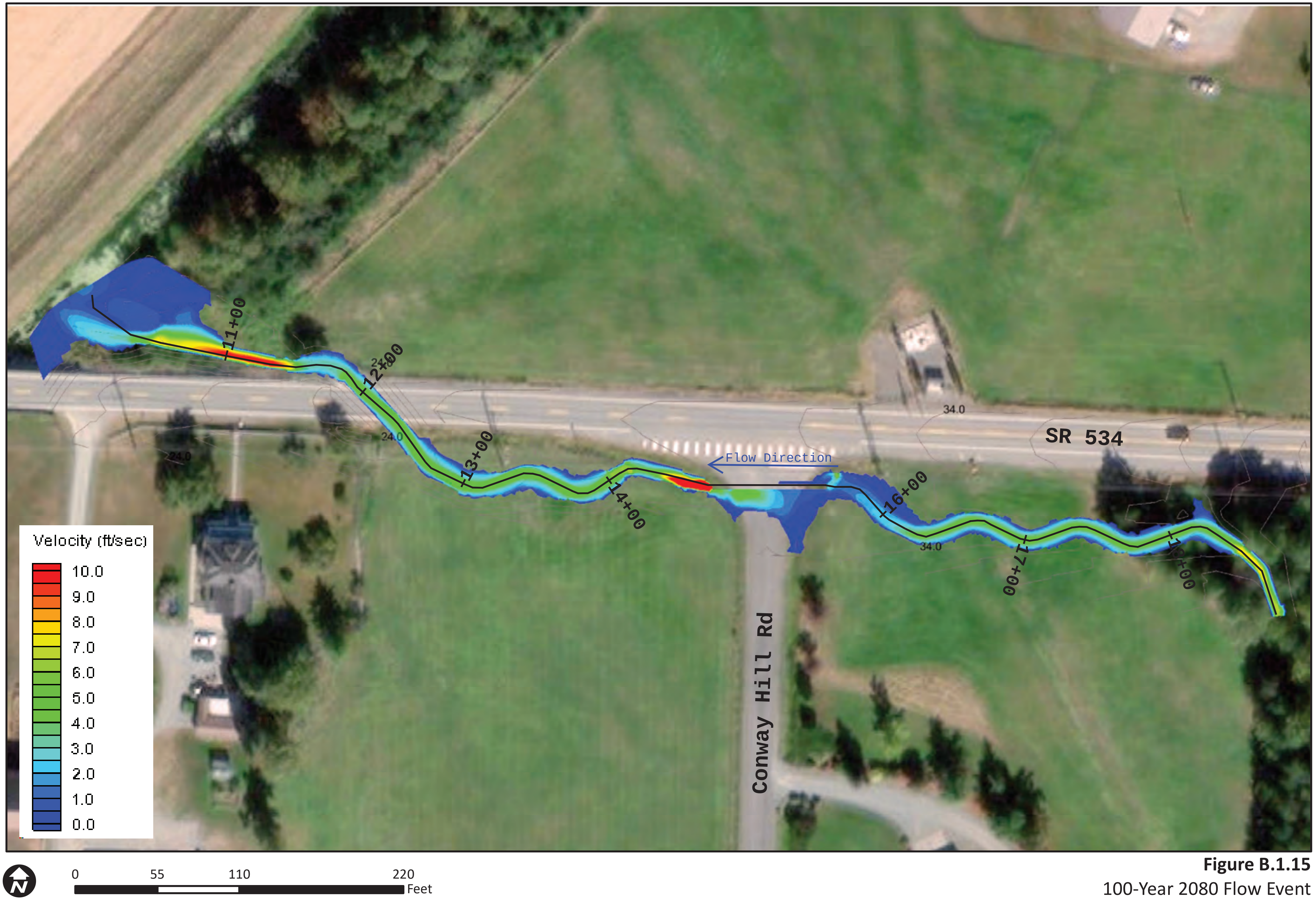

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100-Year 2080 Flow Event
Proposed Velocity

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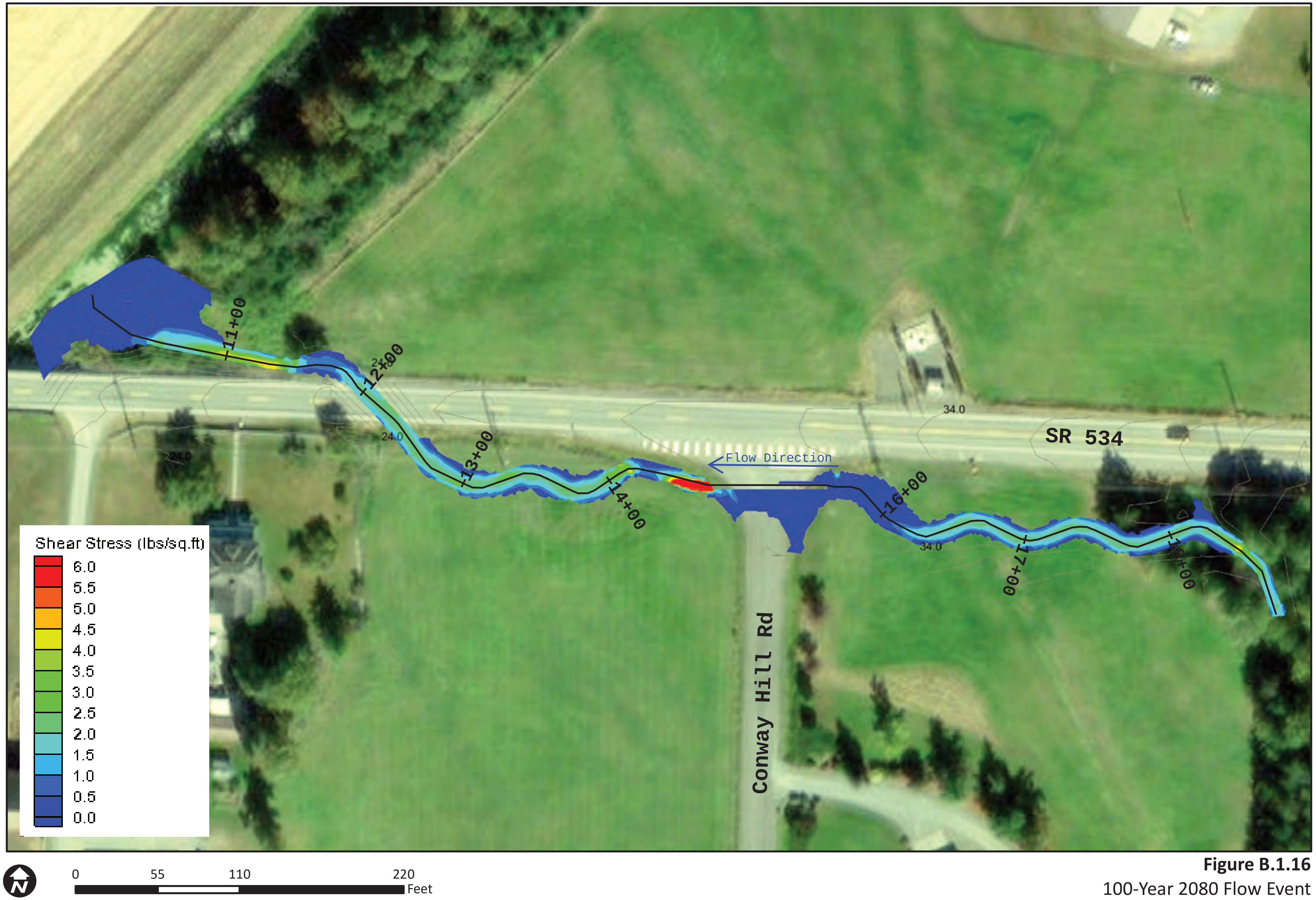

Figure B.1.16

100-Year 2080 Flow Event

Proposed Shear Stress

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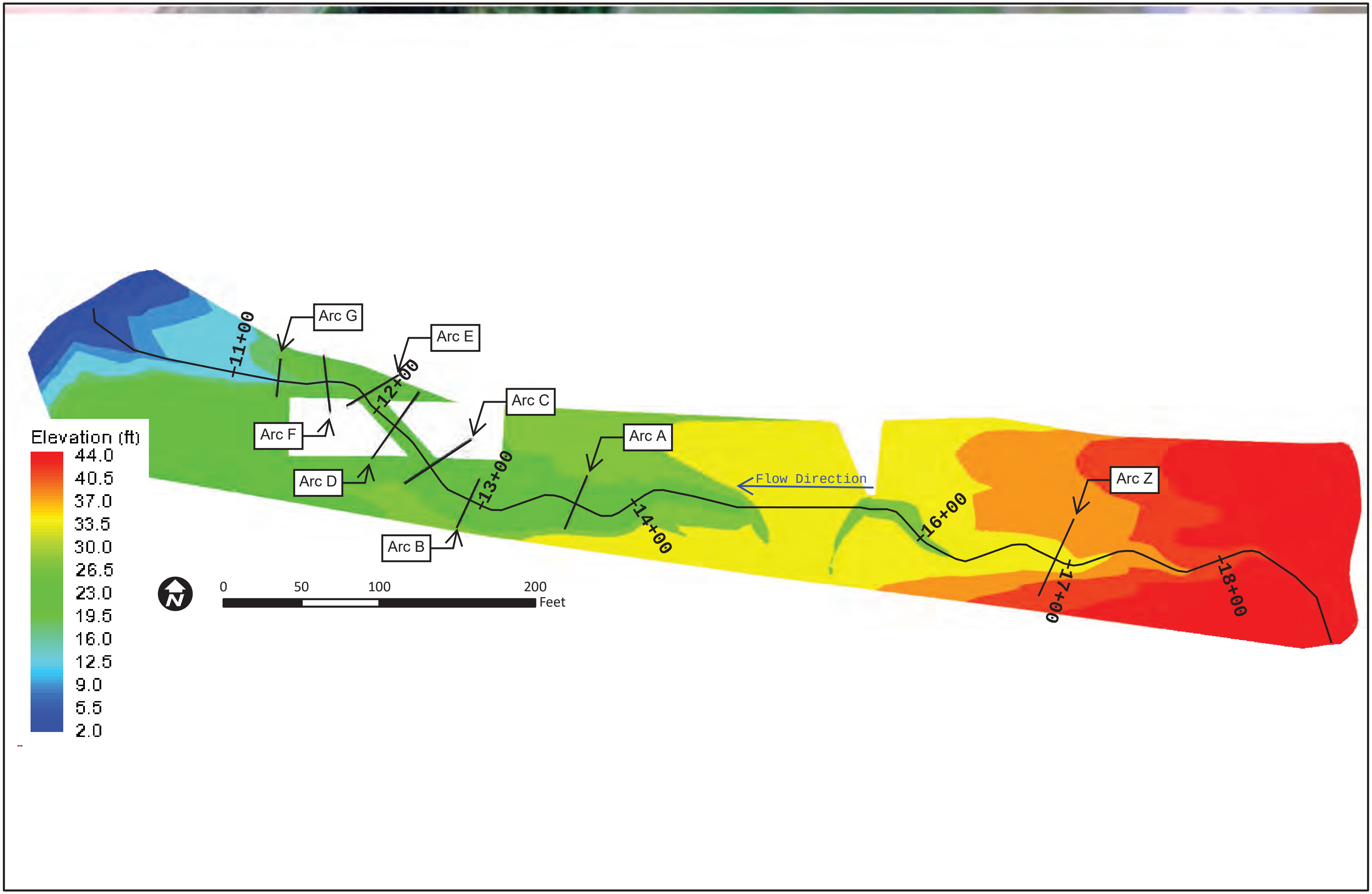


Figure B.2.1

Proposed Condition Monitor Points

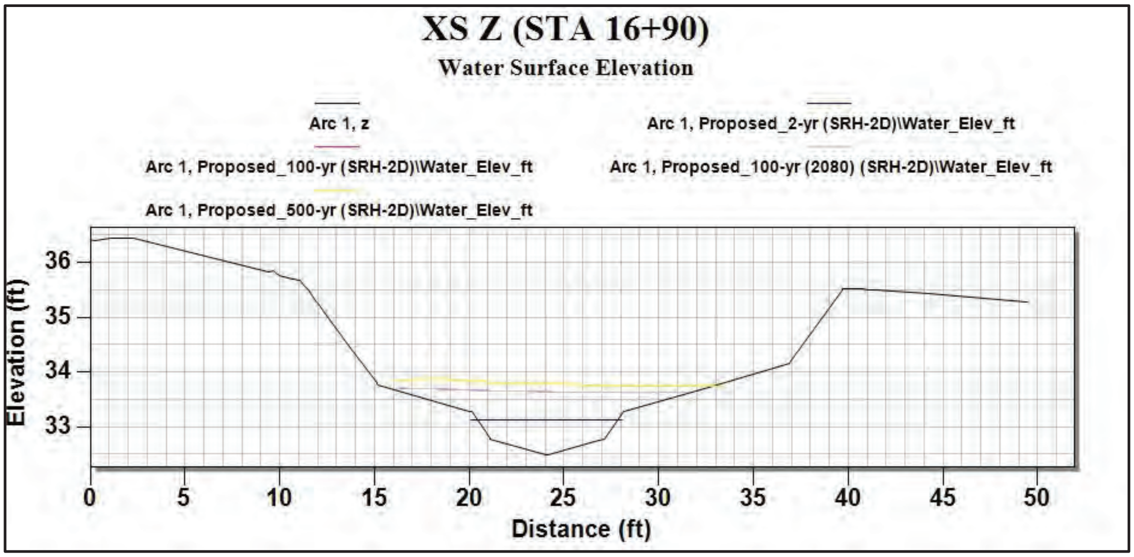


Figure B.2.2

Arc Z – Water Surface Elevation

Unnamed Tributary to Carpenter Creek SR 534

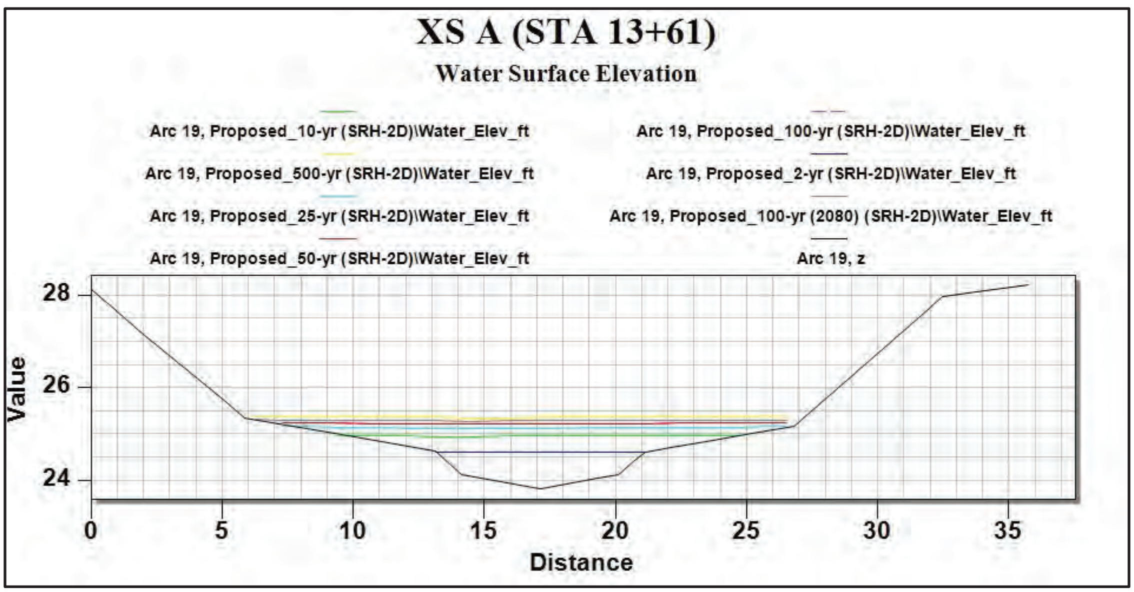


Figure B.2.3

Arc A – Water Surface Elevation

Unnamed Tributary to Carpenter Creek SR 534

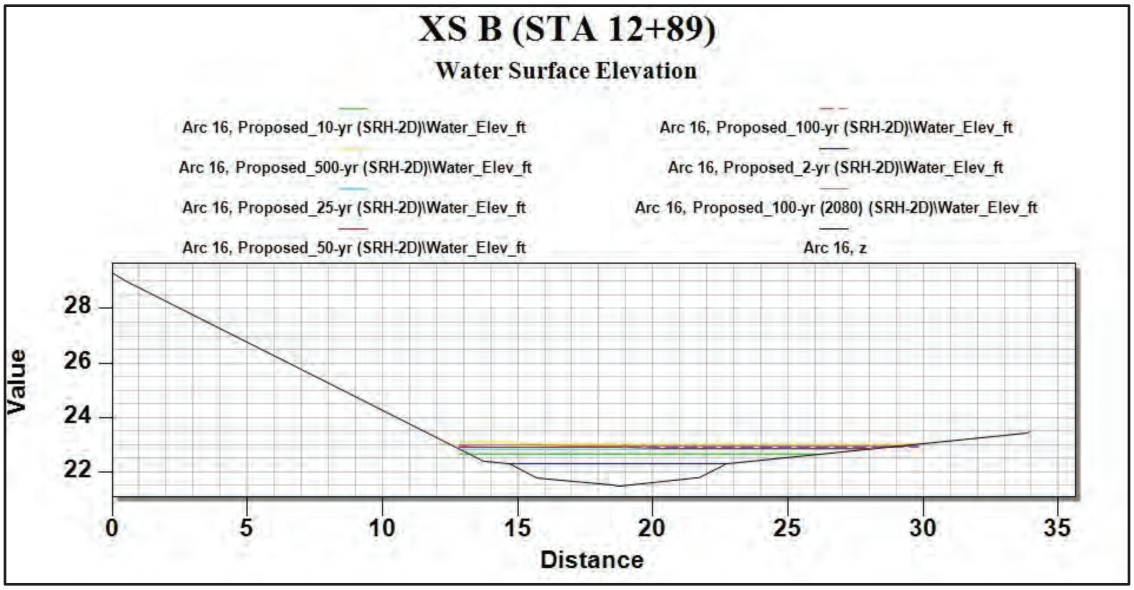


Figure B.2.4
Arc B – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

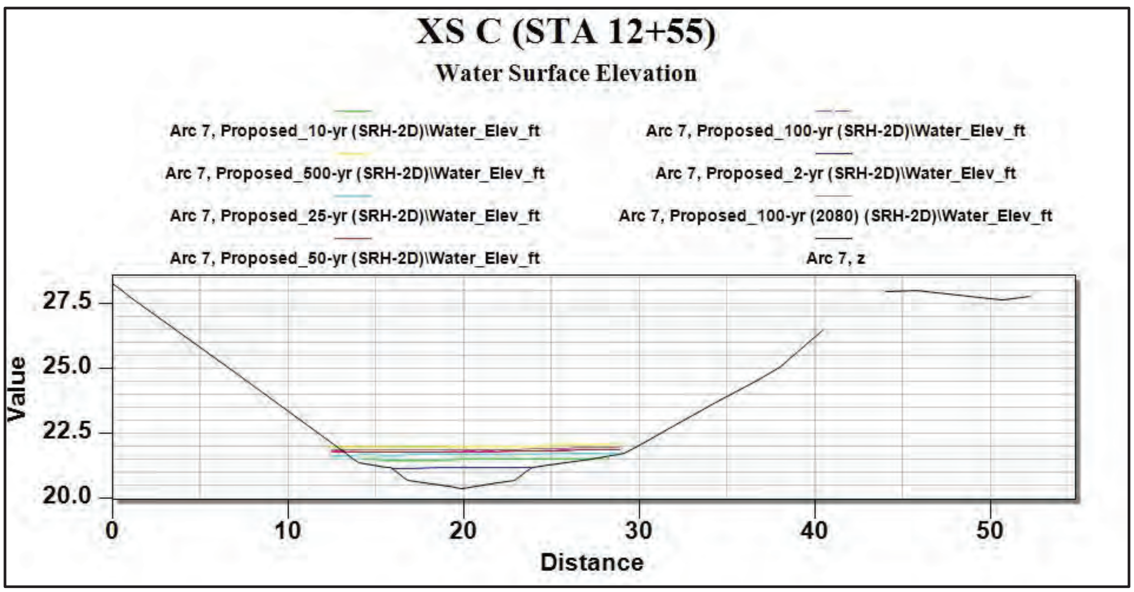


Figure B.2.5
Arc C – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

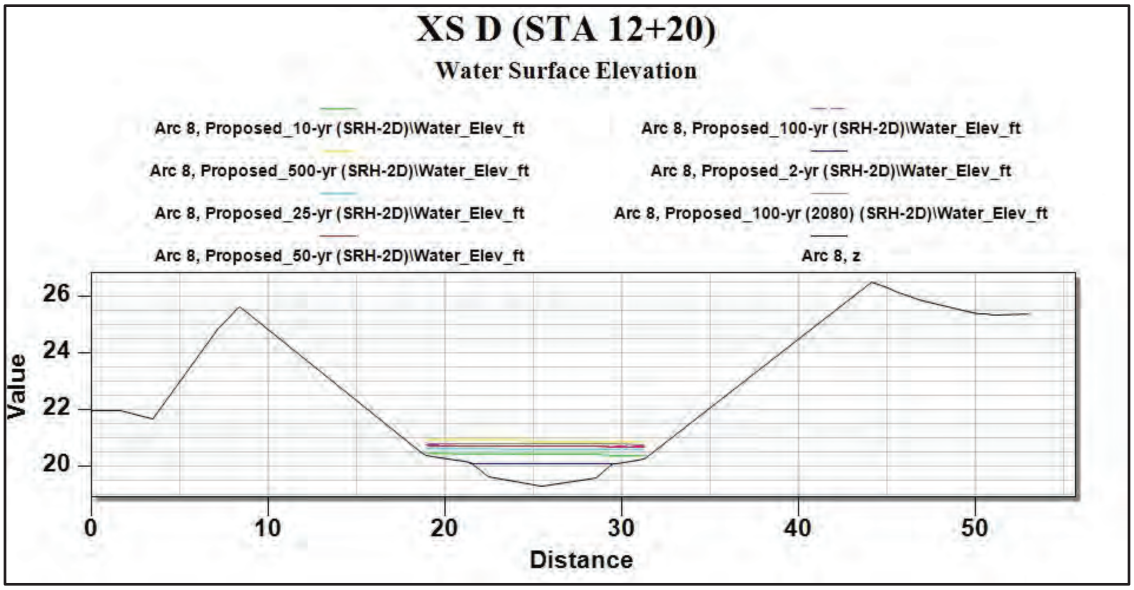


Figure B.2.6
Arc D – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

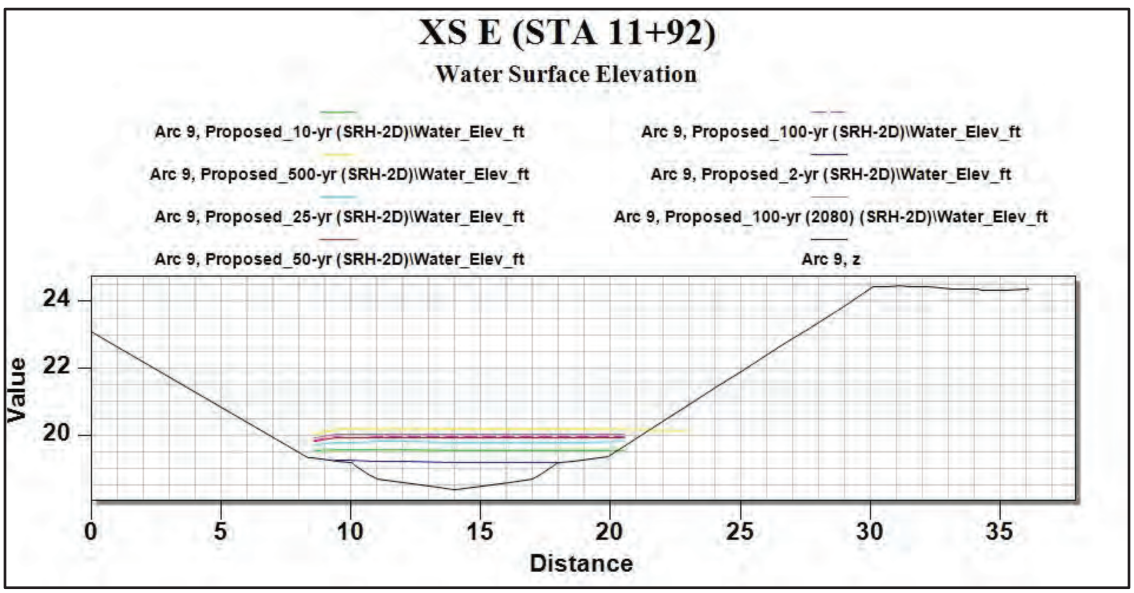


Figure B.2.7
Arc E – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

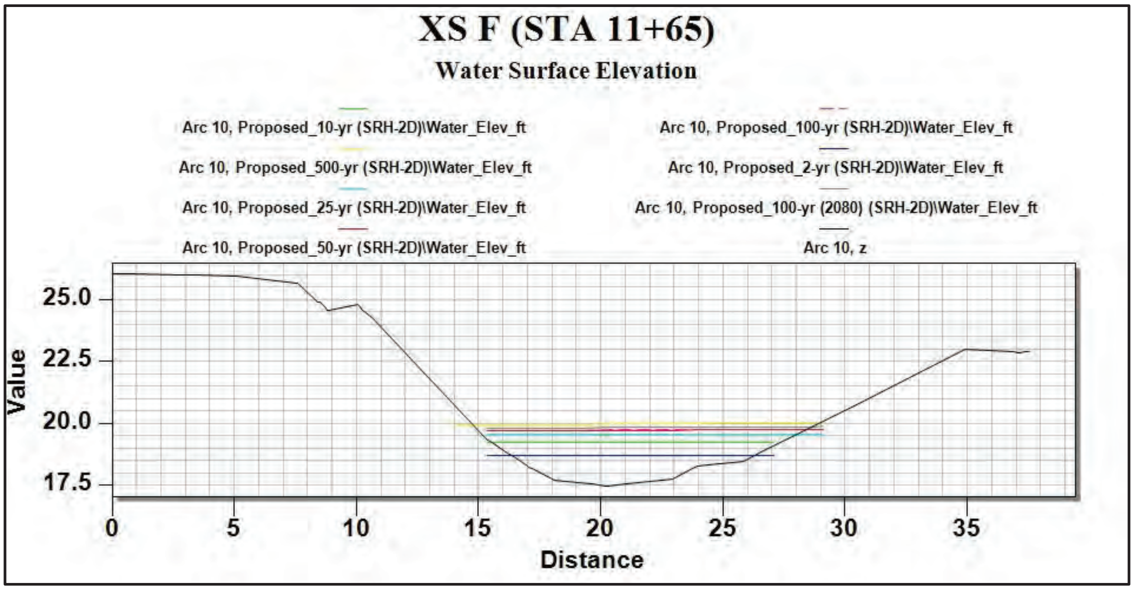


Figure B.2.8
Arc F – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

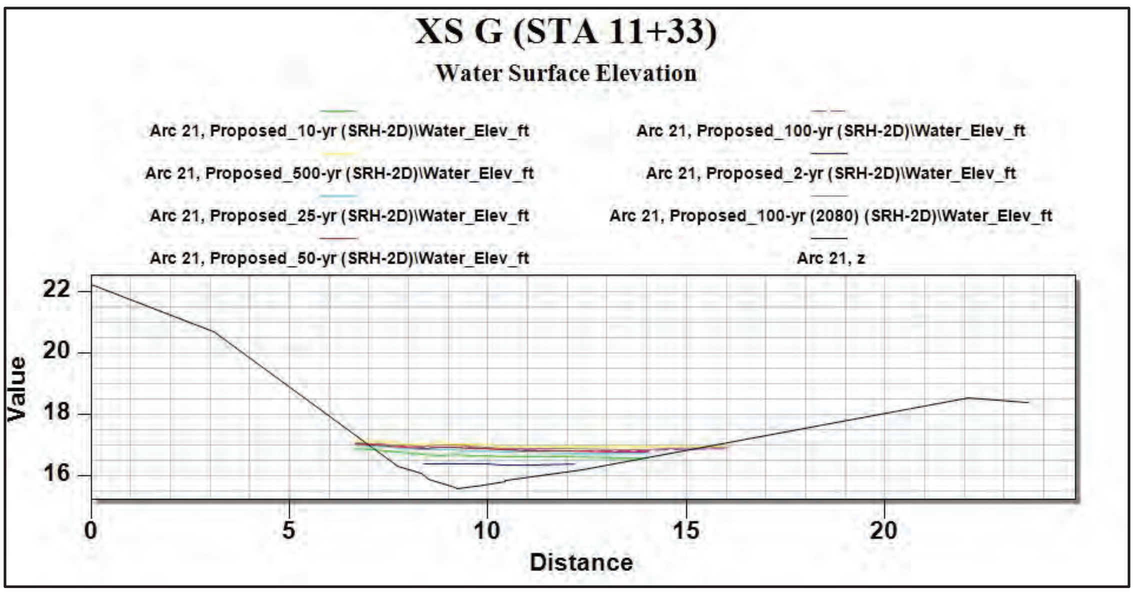


Figure B.2.9
Arc G – Water Surface Elevation
Unnamed Tributary to Carpenter Creek SR 534

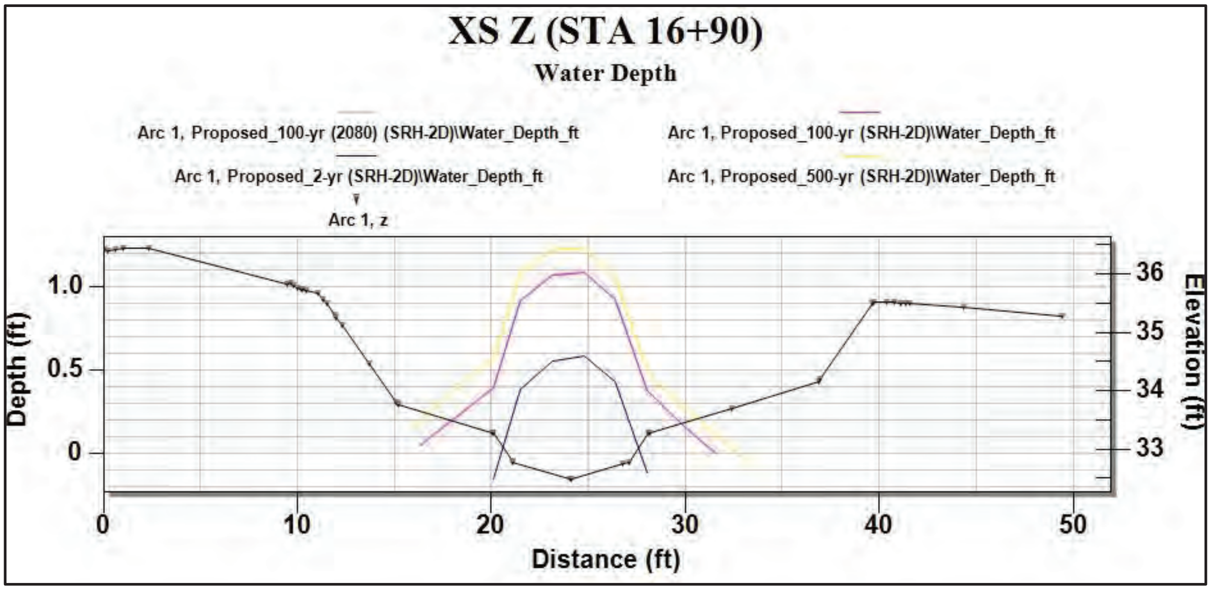


Figure B.2.10
Arc Z – Water Depth
Unnamed Tributary to Carpenter Creek SR 534

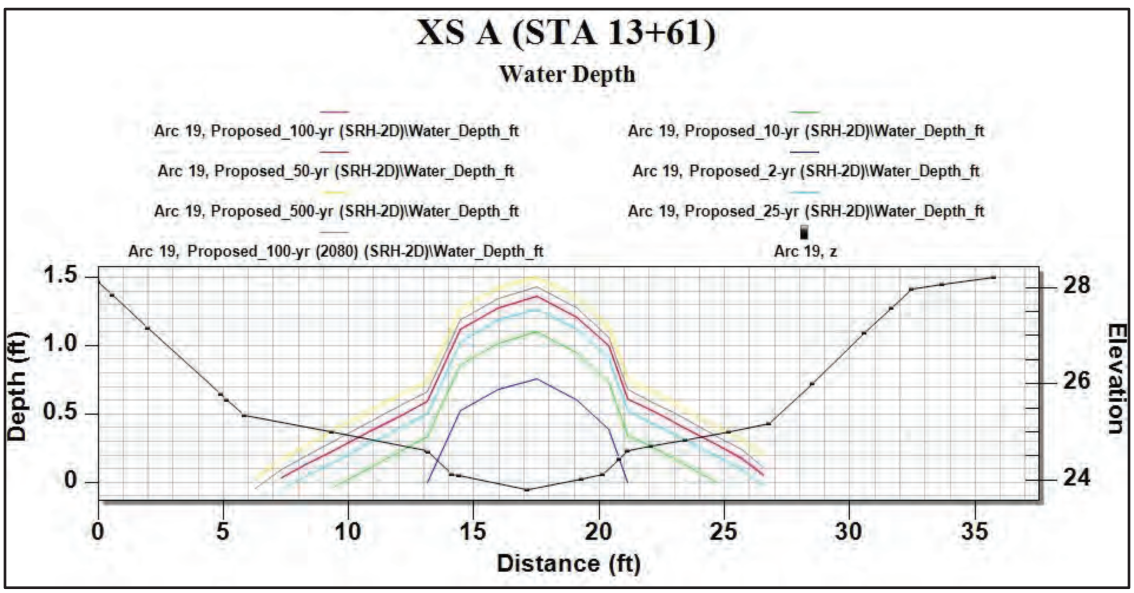
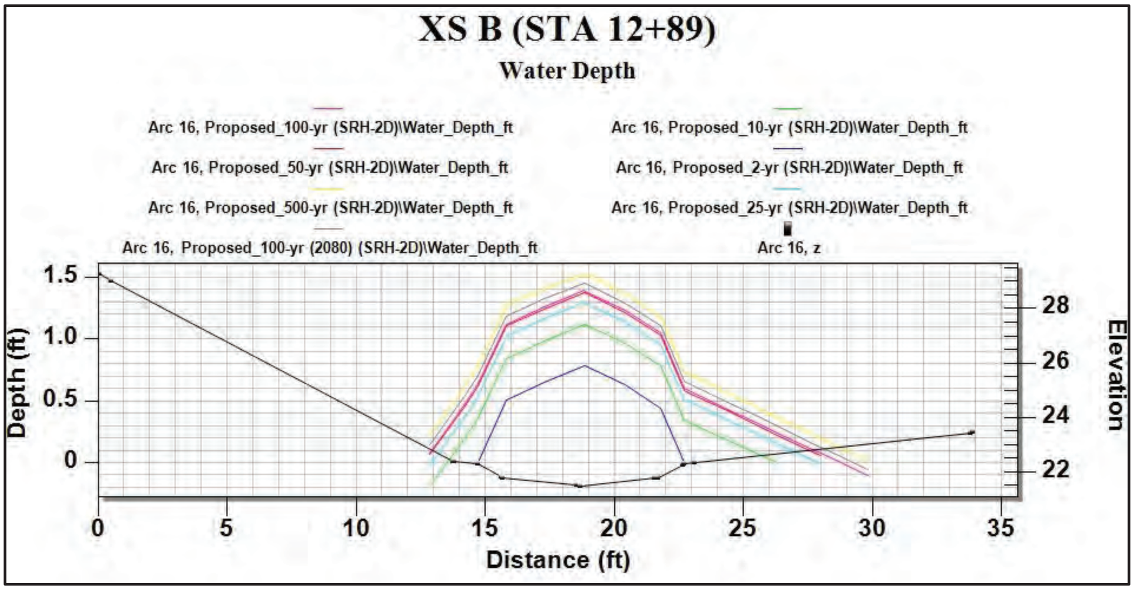


Figure B.11
Arc A – Water Depth
Unnamed Tributary to Carpenter Creek SR 534



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Arc B – Water Depth
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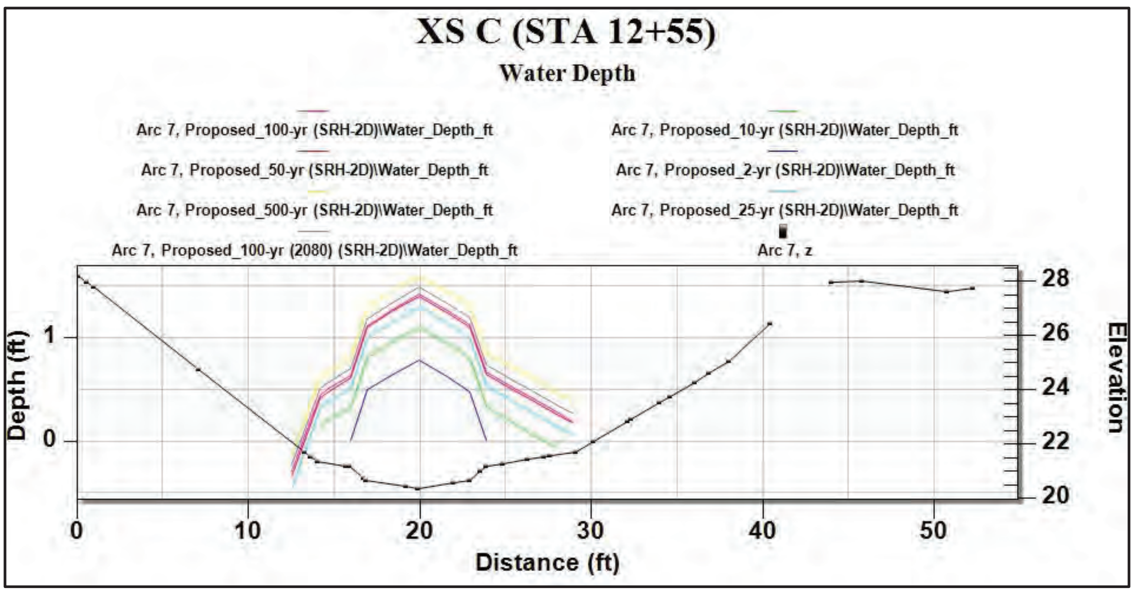

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Arc C – Water Depth
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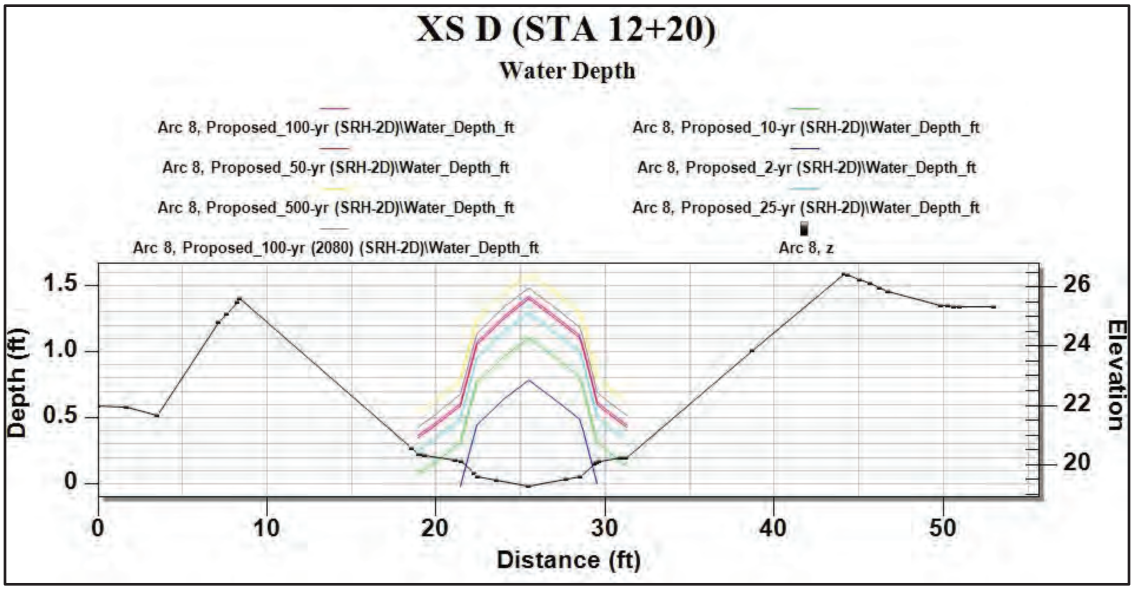

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Arc D – Water Depth
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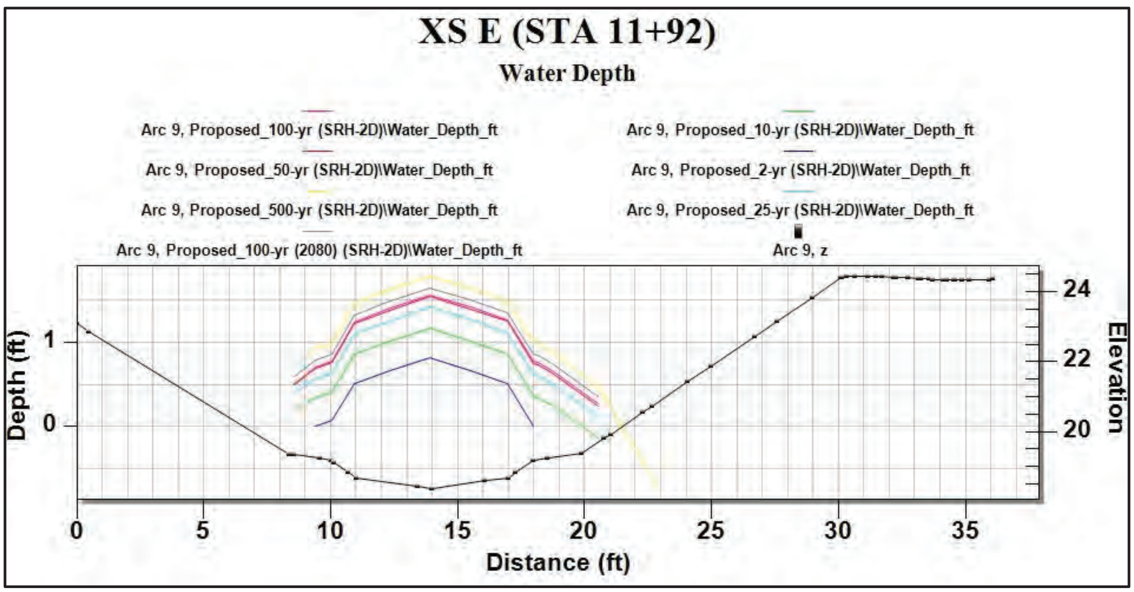

Figure B.2.15
Arc E – Water Depth
Unnamed Tributary to Carpenter Creek SR 534

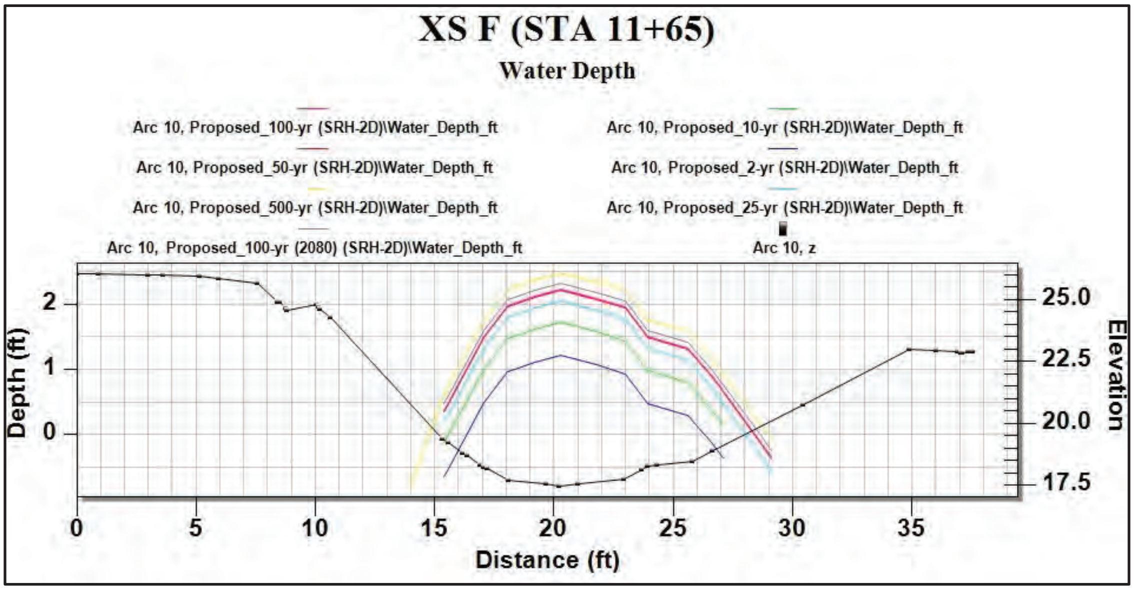

Figure B.2.16
Arc F – Water Depth
Unnamed Tributary to Carpenter Creek SR 534

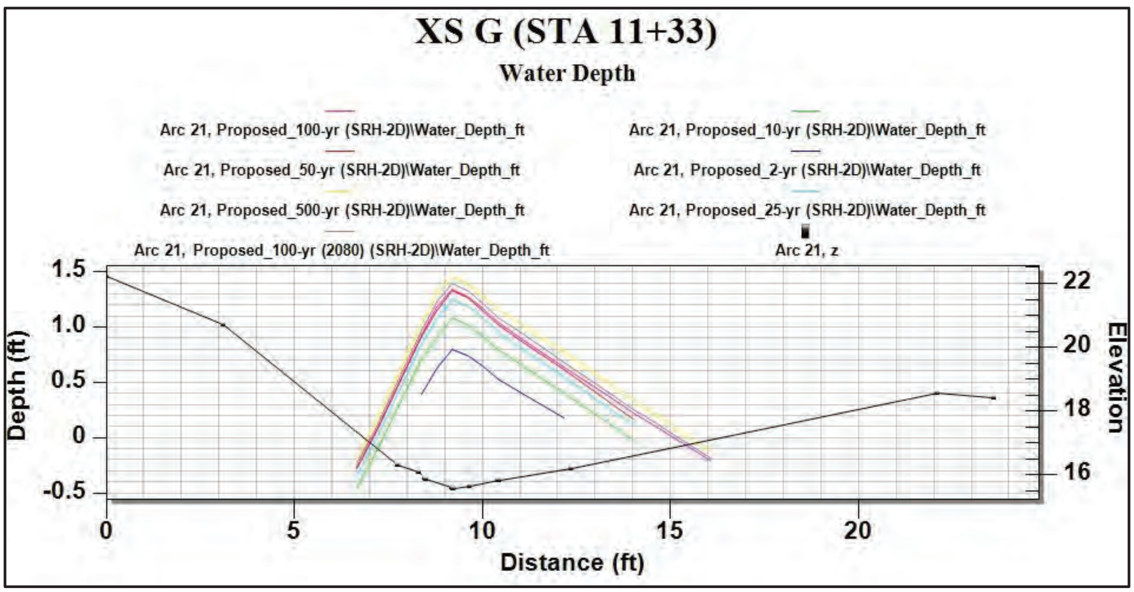

Figure B.2.17
Arc G – Water Depth
Unnamed Tributary to Carpenter Creek SR 534

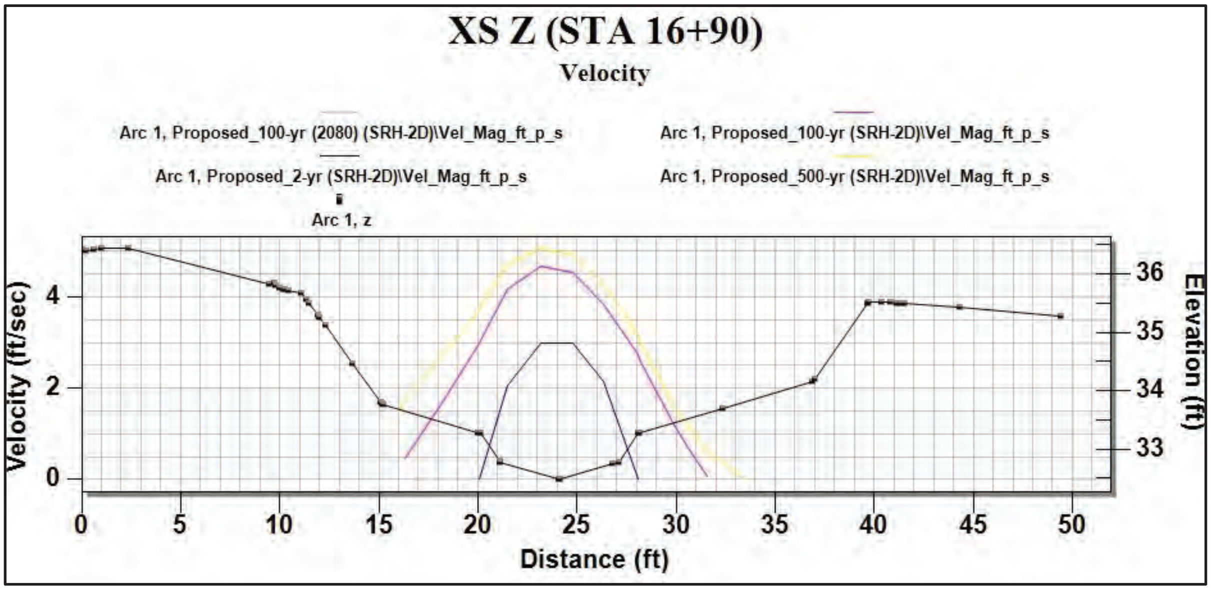

Figure B.2.18
Arc Z – Velocity
Unnamed Tributary to Carpenter Creek SR 534

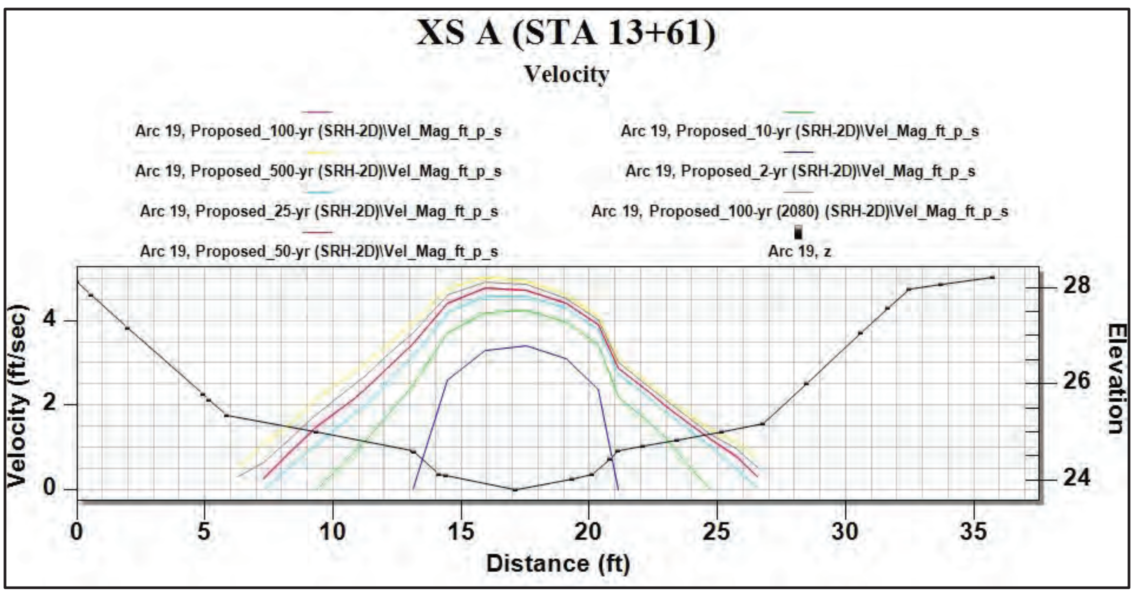

Figure B.2.19
Arc A – Velocity
Unnamed Tributary to Carpenter Creek SR 534

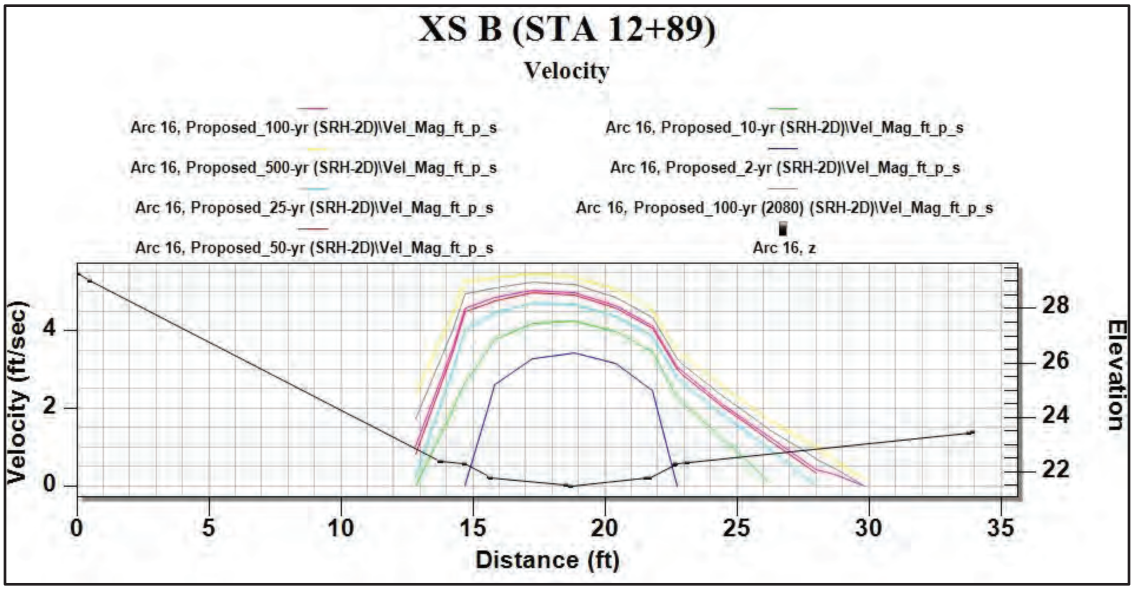

Figure B.2.20
Arc B – Velocity
Unnamed Tributary to Carpenter Creek SR 534

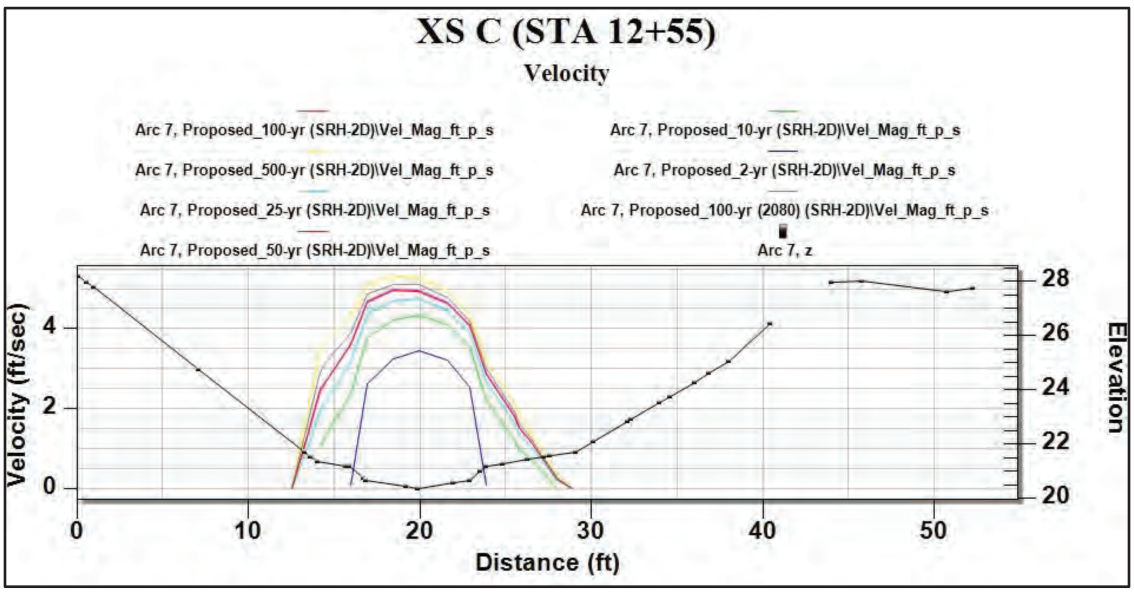

Figure B.2.21
Arc C – Velocity
Unnamed Tributary to Carpenter Creek SR 534

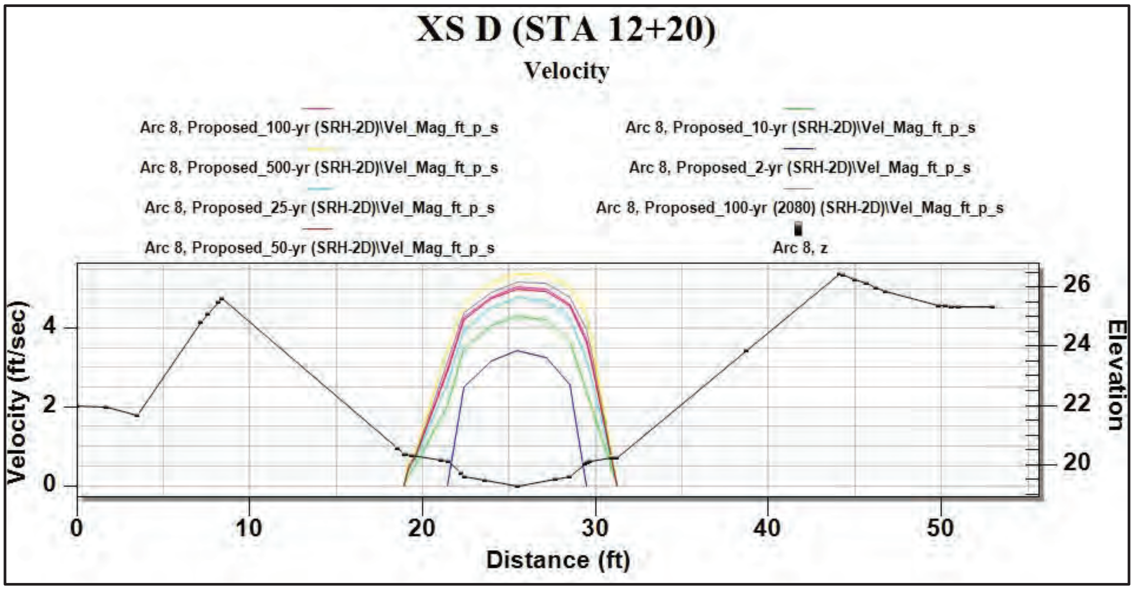

Figure B.2.22

Arc D – Velocity

Unnamed Tributary to Carpenter Creek SR 534

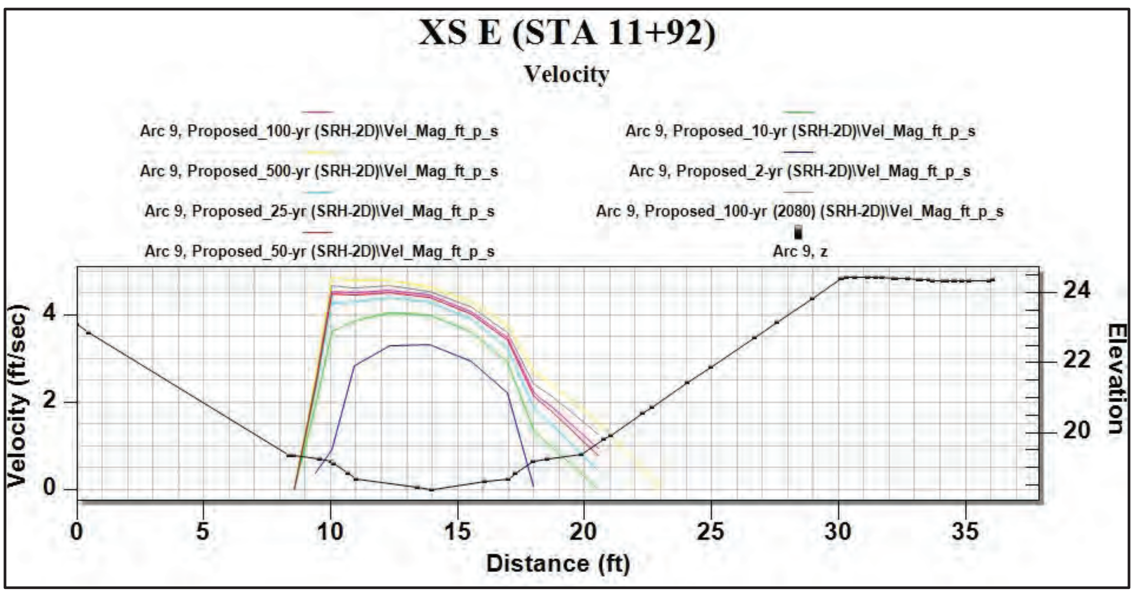

Figure B.2.23

Arc E – Velocity

Unnamed Tributary to Carpenter Creek SR 534

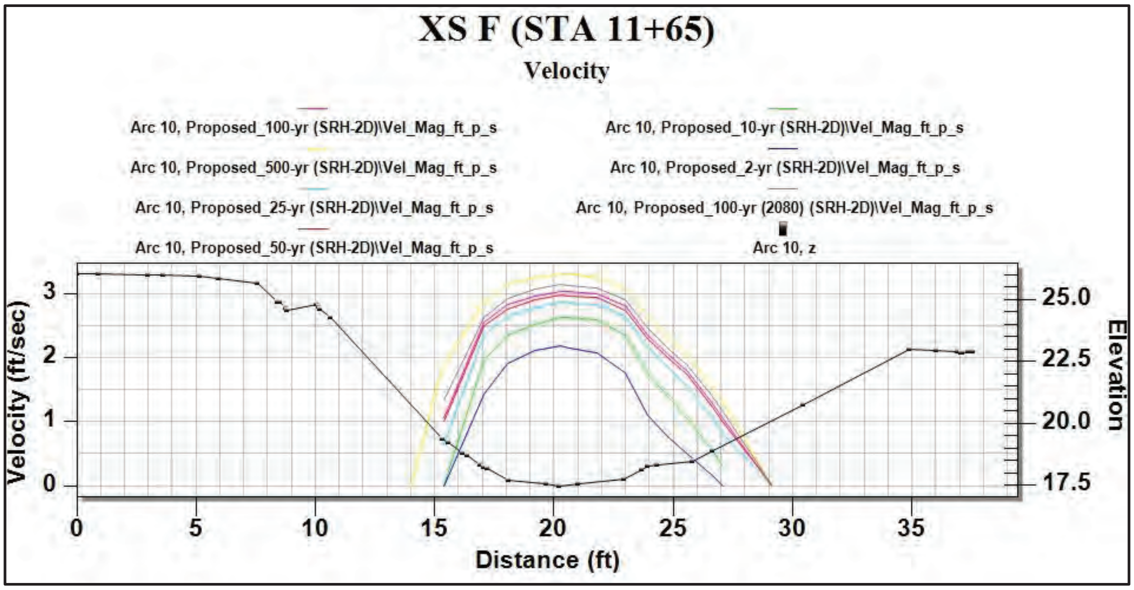

Figure B.2.24
Arc F – Velocity
Unnamed Tributary to Carpenter Creek SR 534

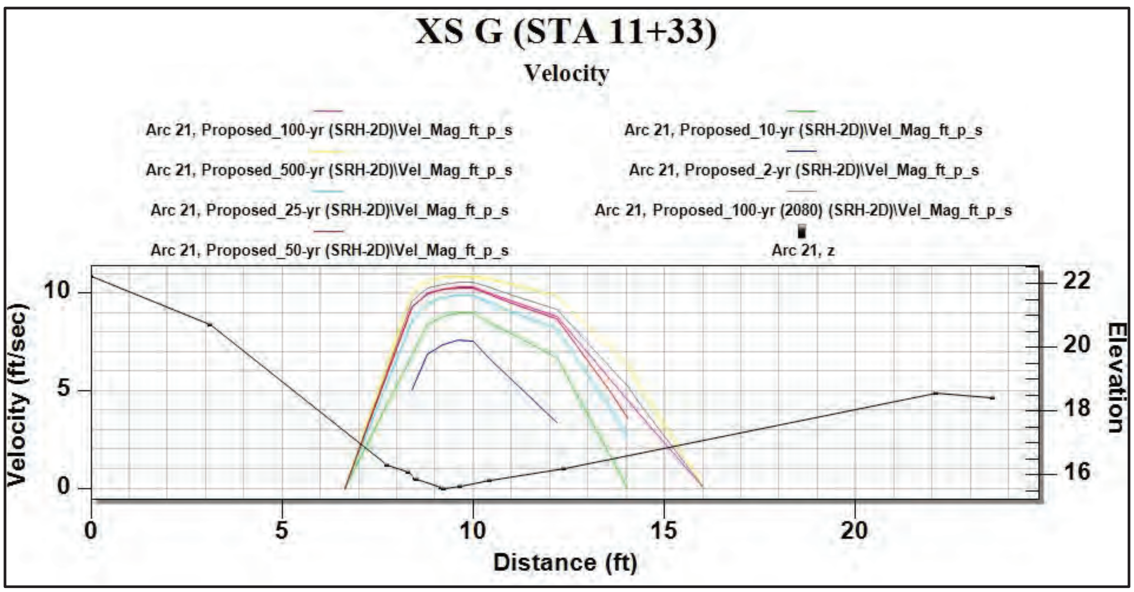

Figure B.2.25
Arc G – Velocity
Unnamed Tributary to Carpenter Creek SR 534

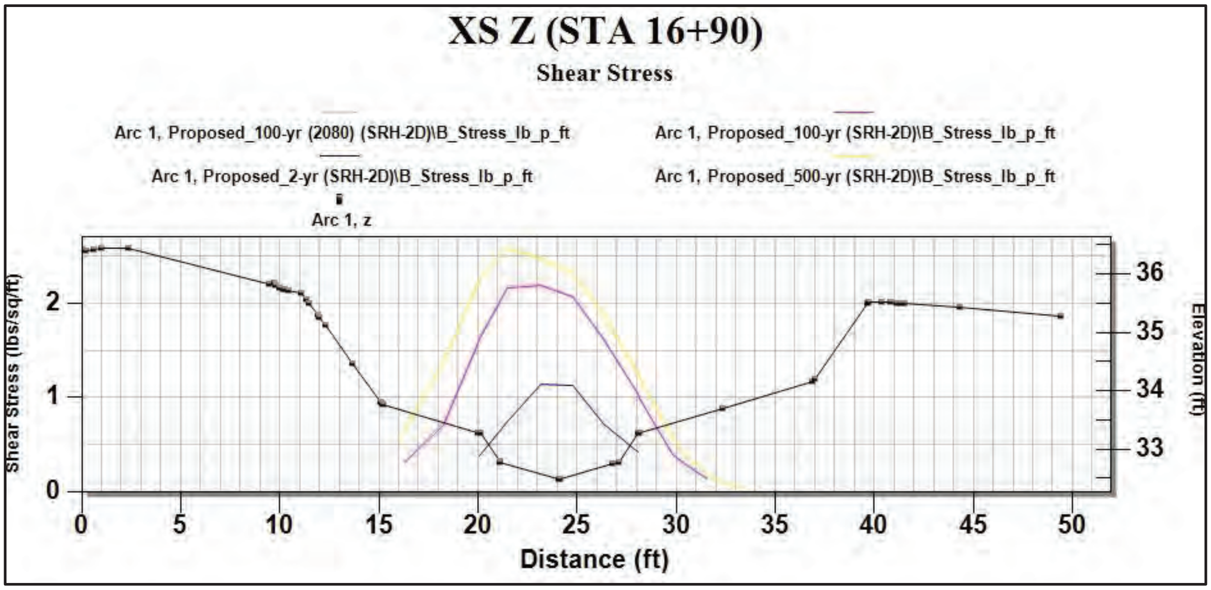

Figure B.2.26
Arc Z – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

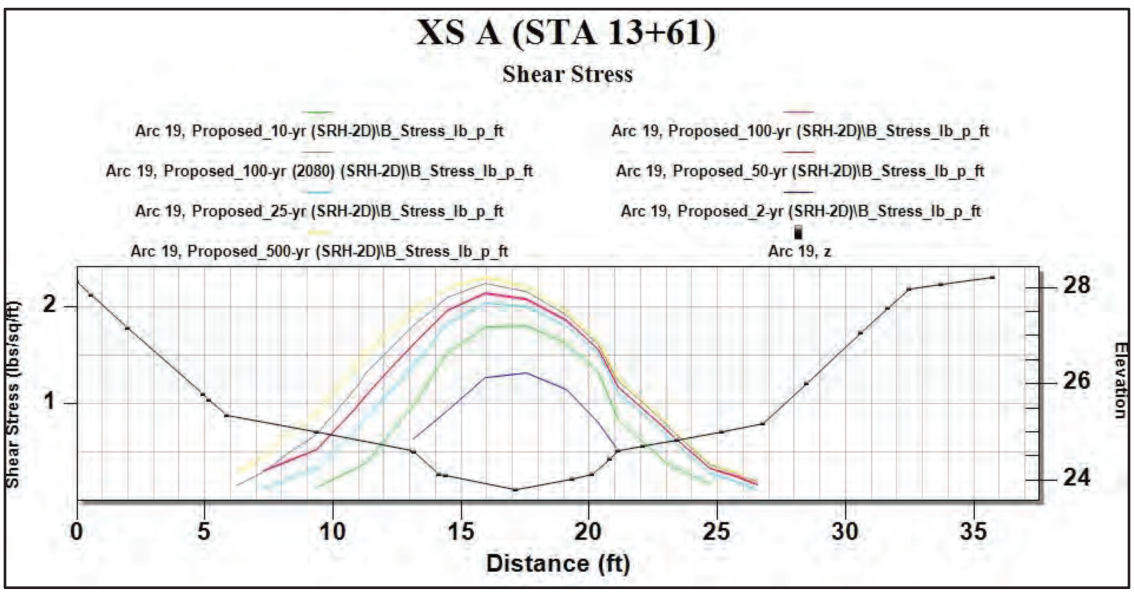

Figure B.2.27
Arc A – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

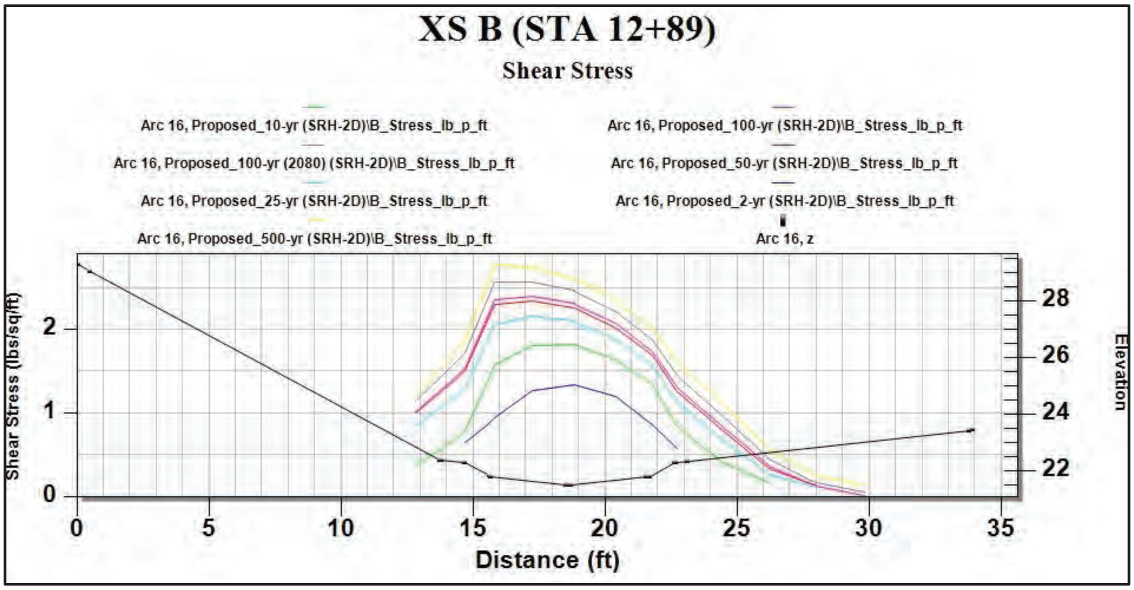

Figure B.2.28
Arc B – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

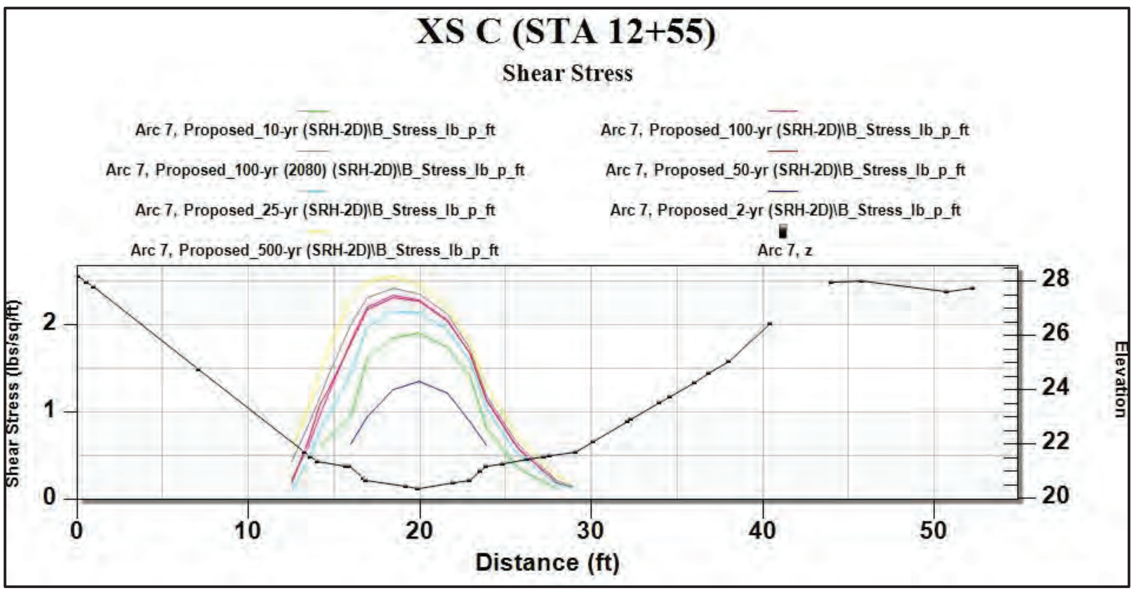

Figure B.2.29
Arc C – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

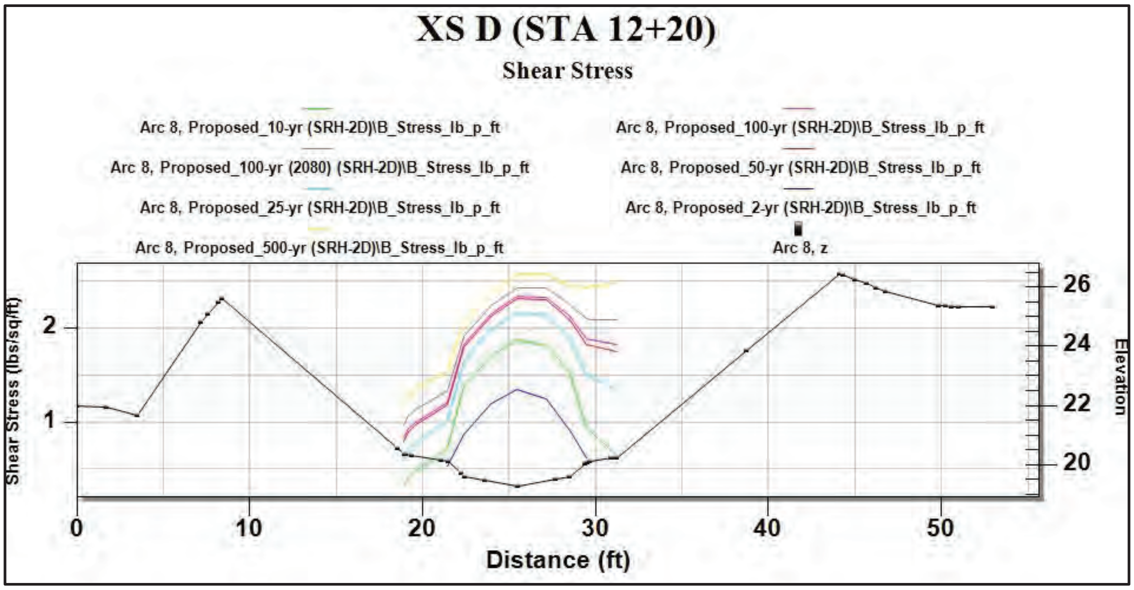

Figure B.2.30

Arc D – Shear Stress

Unnamed Tributary to Carpenter Creek SR 534

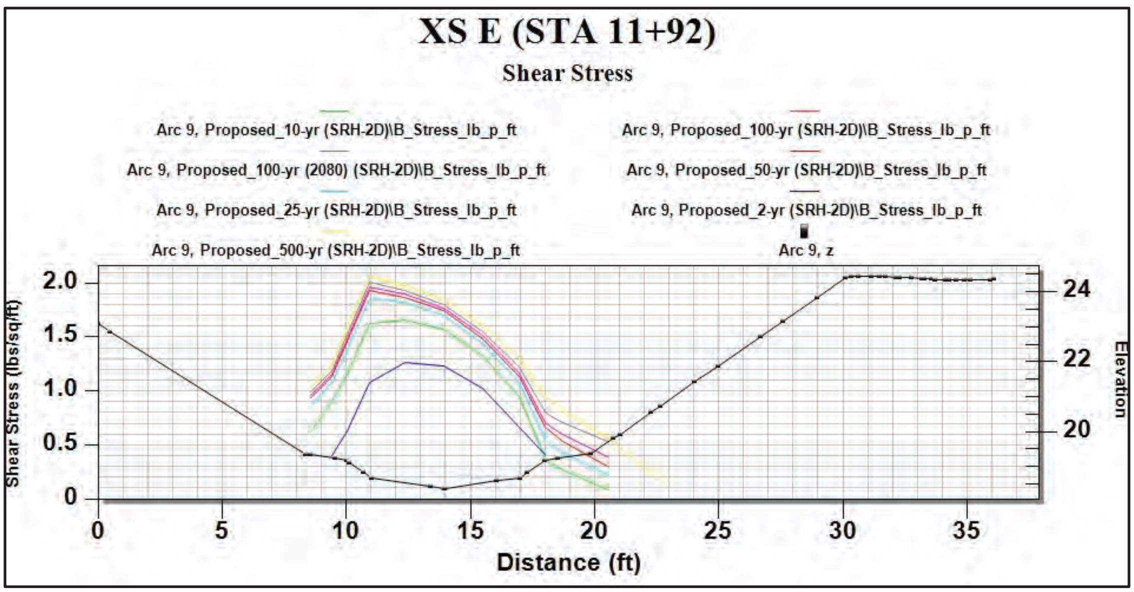

Figure B.2.31

Arc E – Shear Stress

Unnamed Tributary to Carpenter Creek SR 534

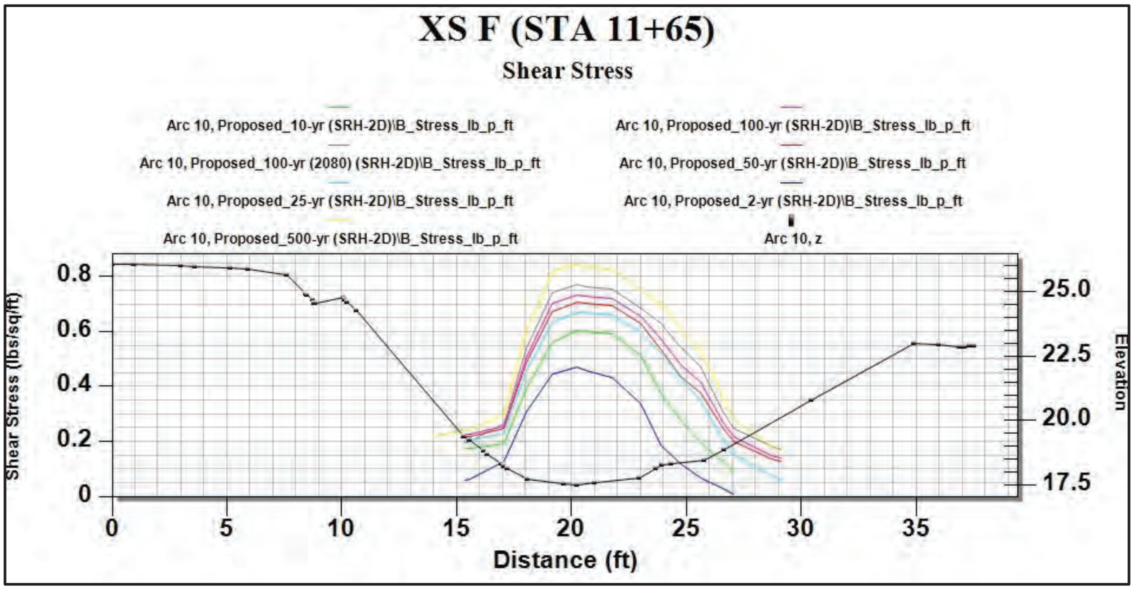

Figure B.2.32
Arc F – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

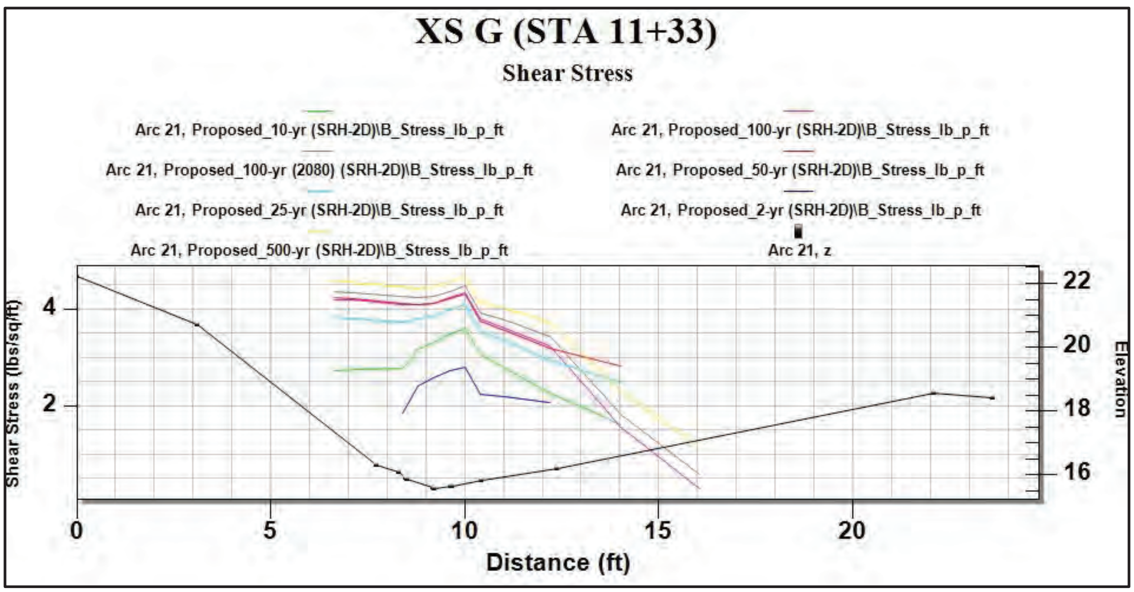

Figure B.2.33
Arc G – Shear Stress
Unnamed Tributary to Carpenter Creek SR 534

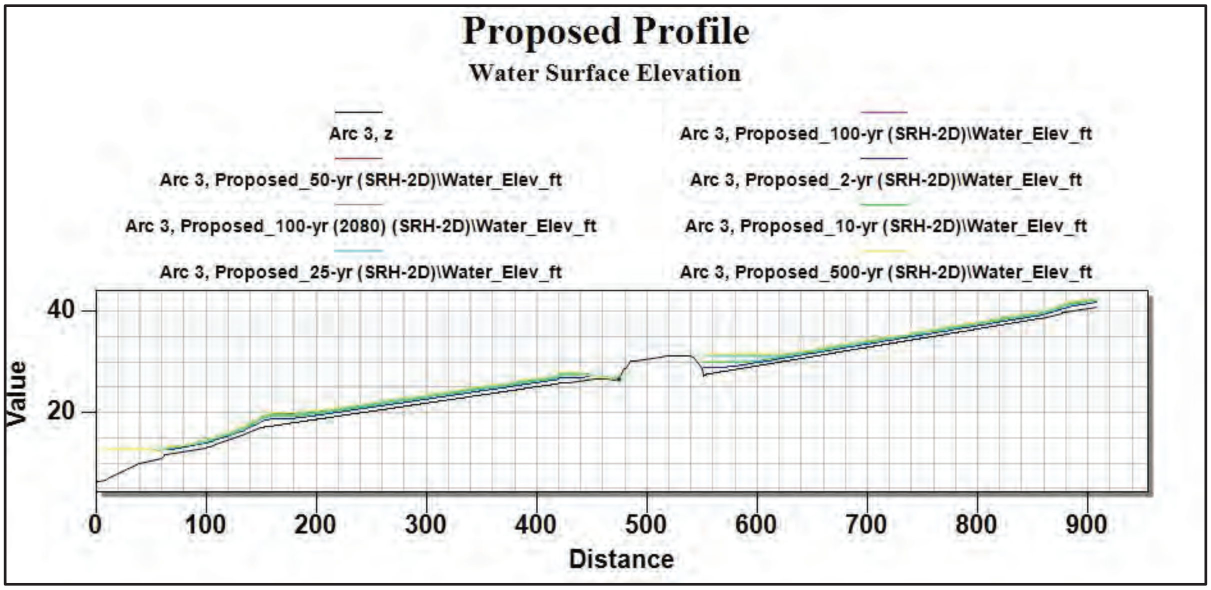

Figure B.2.34
Proposed Conditions Profile
Unnamed Tributary to Carpenter Creek SR 534

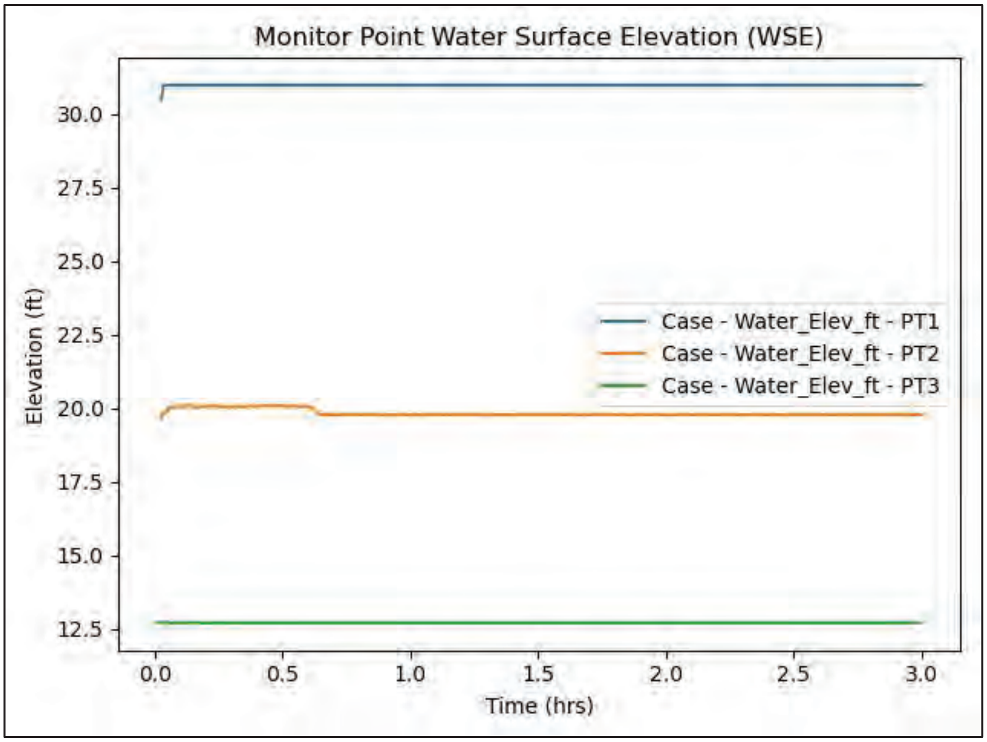

Figure C.3.1
2-Year Flow Event
Proposed Condition Simulation Plot
Unnamed Tributary to Carpenter Creek SR 534

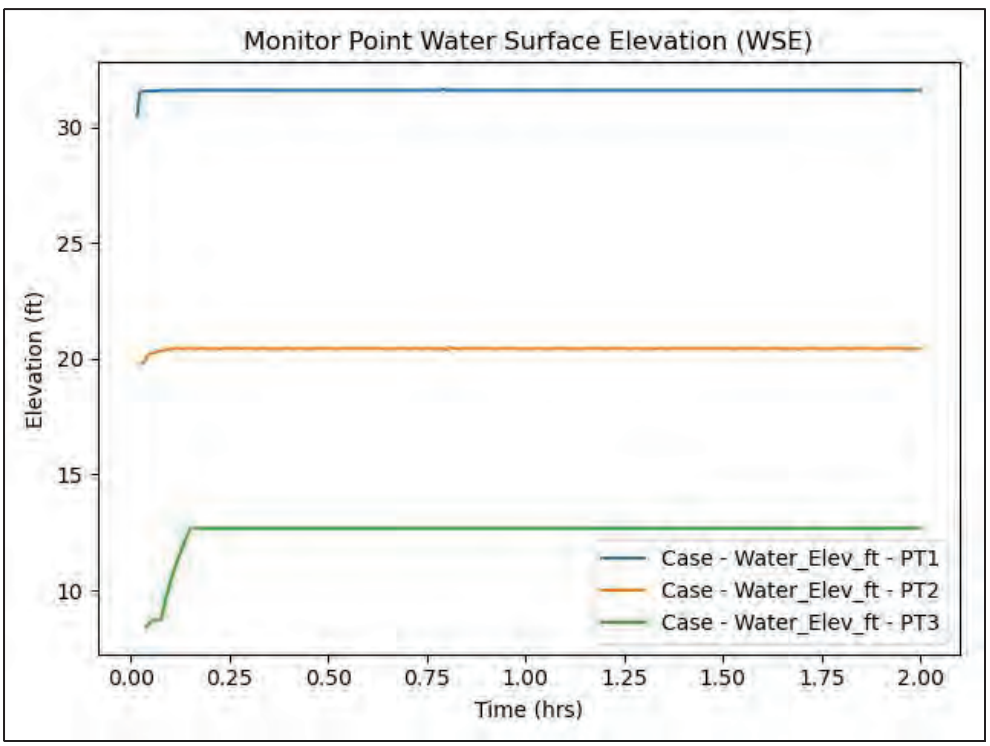

Figure C.3.2
100-Year Flow Event
Proposed Condition Simulation Plot
Unnamed Tributary to Carpenter Creek SR 534

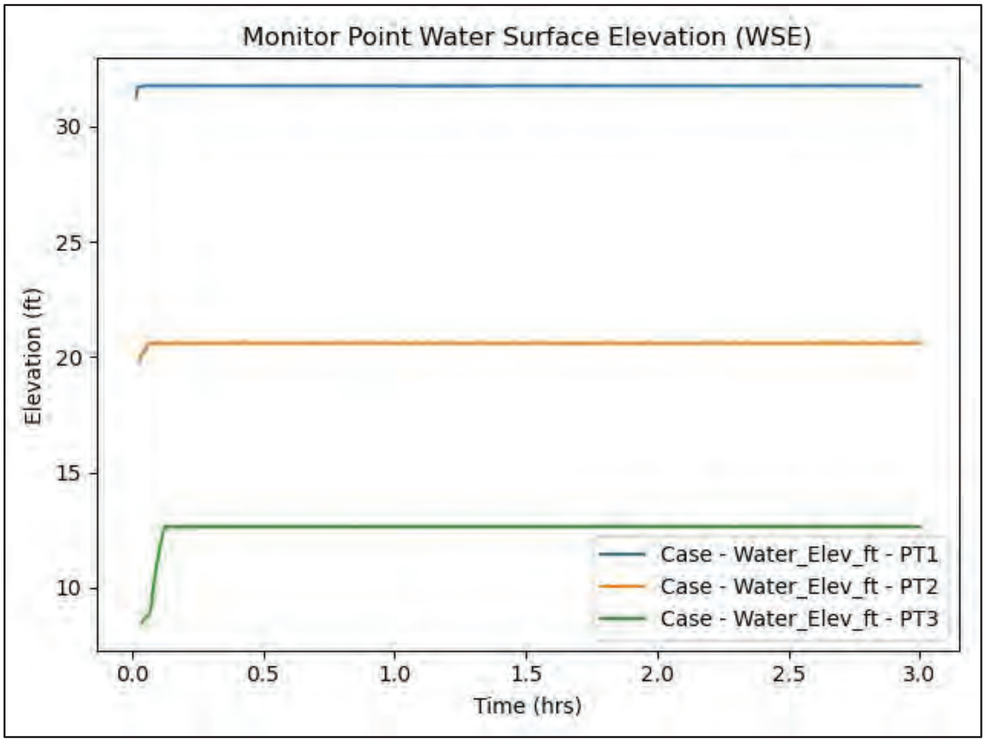

Figure C.3.3
500-Year Flow Event
Proposed Condition Simulation Plot
Unnamed Tributary to Carpenter Creek SR 534

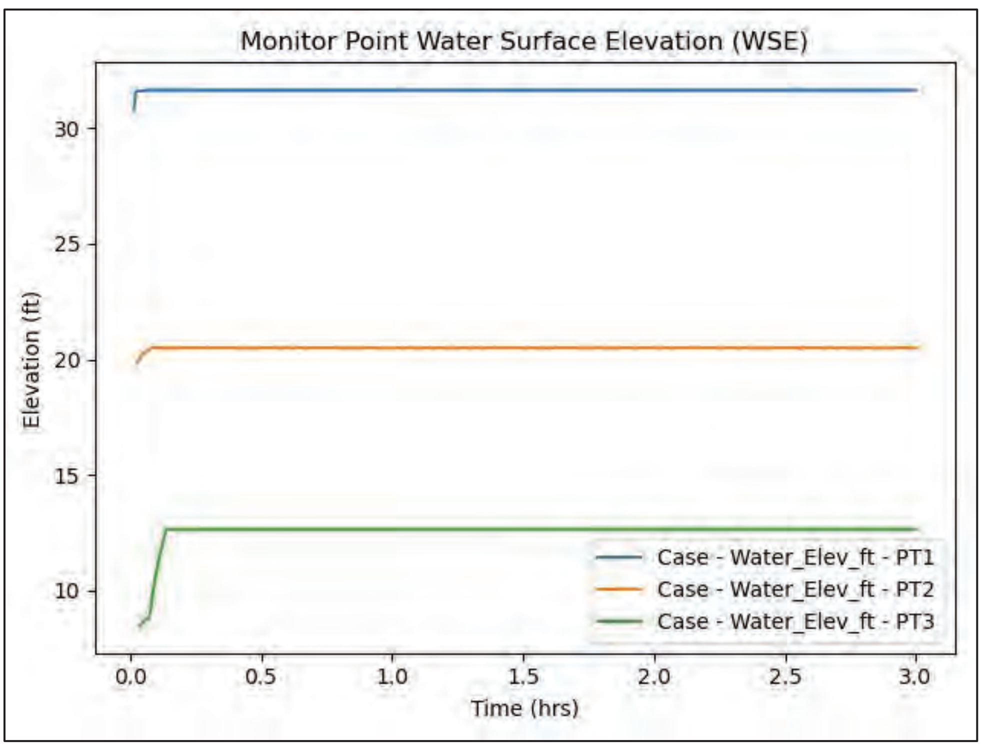

Figure C.3.4
100-Year 2080 Flow Event
Proposed Condition Simulation Plot
Unnamed Tributary to Carpenter Creek SR 534

Appendix C

FEMA FIRM Map

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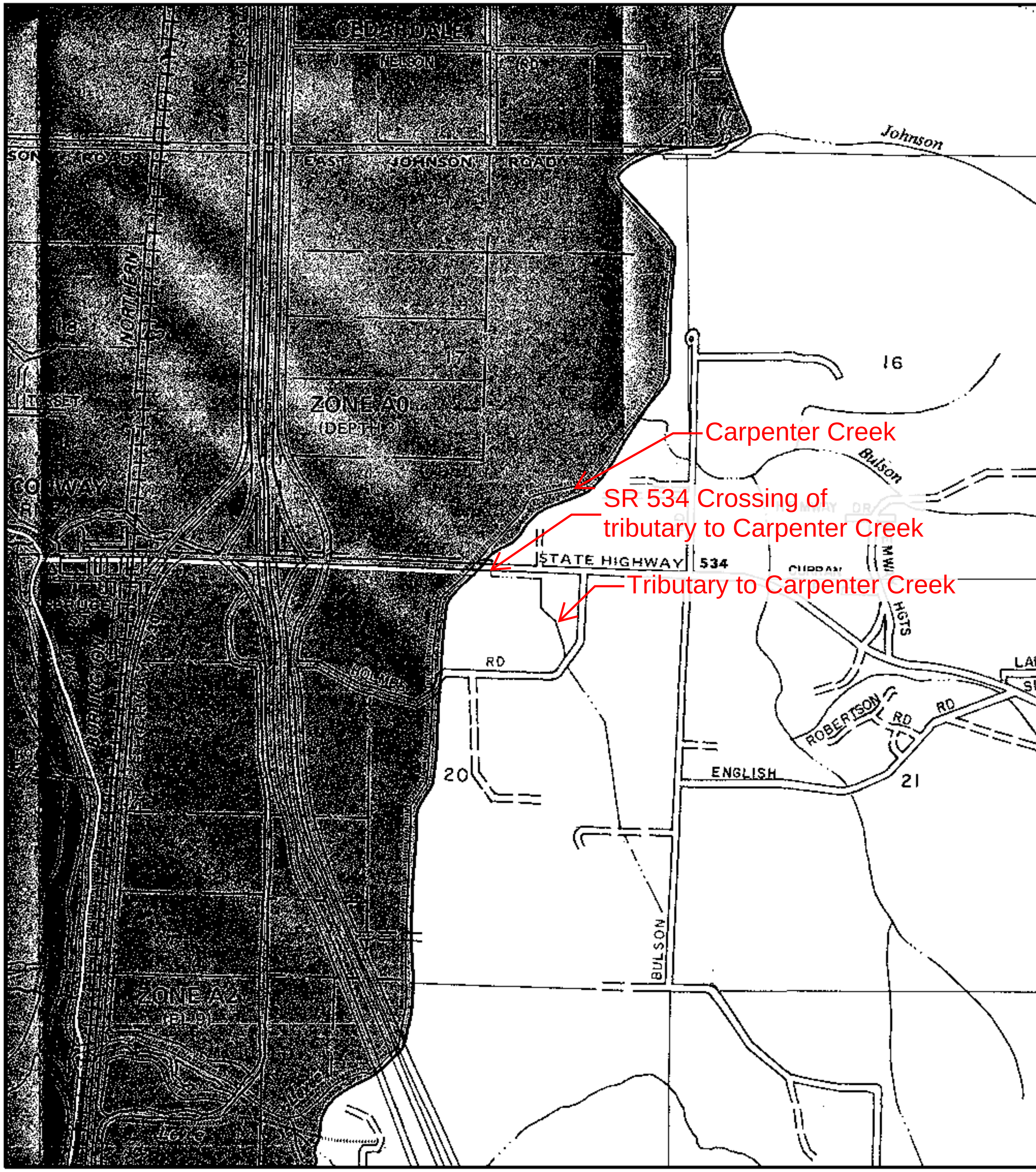

N

APPROXIMATE SCALE

2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

SKAGIT COUNTY, WASHINGTON (UNINCORPORATED AREAS)

PANEL 425 OF 550

(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
530151 0425 C

EFFECTIVE DATE:
JANUARY 3, 1985

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 D

Final Stream Plan, Profile, Details Sheets

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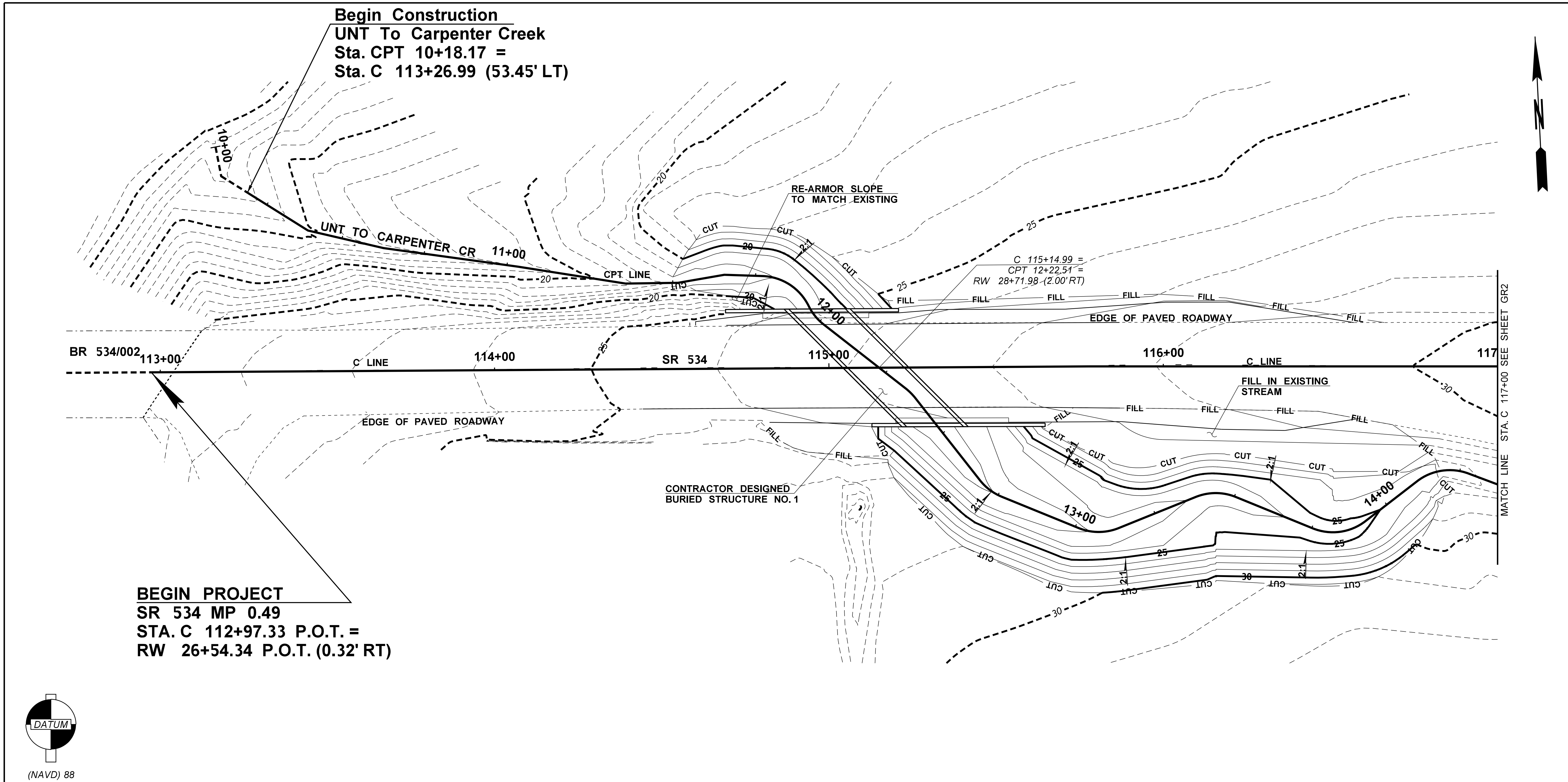

LEGEND	
13+00 (solid)	NEW STREAM / ROADWAY CENTERLINE
13+00 (dashed)	EXISTING STREAM CENTERLINE
- - - 53 - - -	EXISTING GRADE CONTOUR
——53——	NEW GRADE CONTOUR
	EXISTING CULVERT
	CONTRACTOR DESIGNED BURIED STRUCTURE NO. 1

NOTES:

1. SEE ALIGNMENT / RIGHT-OF-WAY PLAN, SHEET AL1 FOR STREAM ALIGNMENT DATA AND CONTROL POINT LOCATIONS.

0 15 30
SCALE IN FEET

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DATE	9/6/2022
PLOTTED BY	HarDoug
DESIGNED BY	D. HARRIS
ENTERED BY	J. MOE
CHECKED BY	A. WILLIAMS
PROJ. ENGR.	S. BEIER
REGIONAL ADM.	B. NIELSEN

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER 22A021
CONTRACT NO. | LOCATION NO.

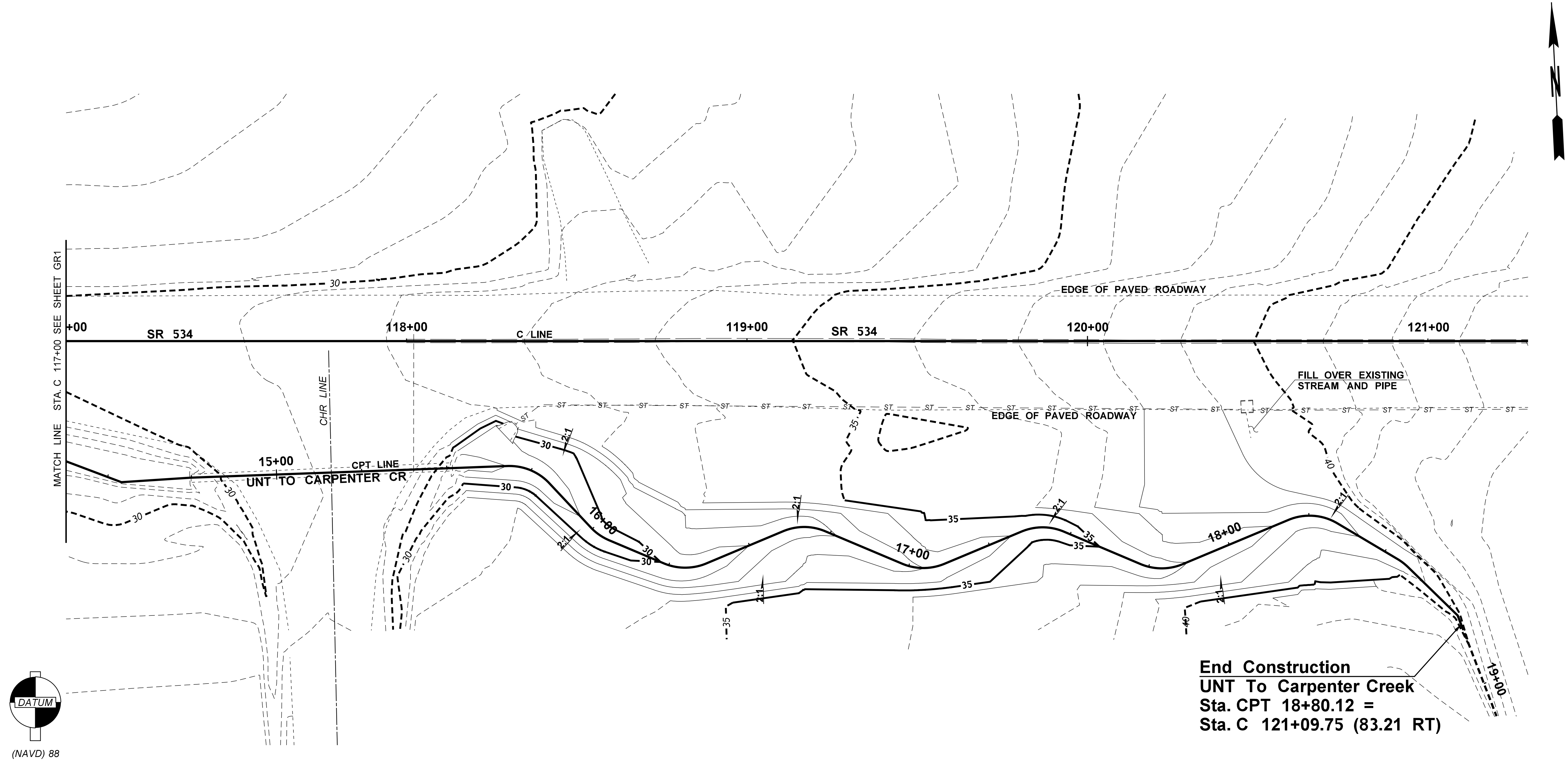
SPENCER T. BEIER — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER
PRELIMINARY
SEE CT1
DATE
P.E. STAMP BOX
DATE
P.E. STAMP BOX

Washington State
Department of Transportation

SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

GRADING PLAN

Plot 1
PLAN REF NO
GR1
SHEET 9 OF 52 SHEETS



LEGEND

13+00	NEW STREAM / ROADWAY CENTERLINE
13+00	EXISTING STREAM CENTERLINE
---53---	EXISTING GRADE CONTOUR
—53—	NEW GRADE CONTOUR
	EXISTING CULVERT
	CONTRACTOR DESIGNED BURIED STRUCTURE NO. 1

NOTES:

1. SEE ALIGNMENT / RIGHT-OF-WAY PLAN, SHEET AL1 FOR STREAM ALIGNMENT DATA AND CONTROL POINT LOCATIONS.

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PLOTTED BY	HarDoug
DESIGNED BY	D. HARRIS
ENTERED BY	J. MOE
CHECKED BY	A. WILLIAMS
PROJ. ENGR.	S. BEIER
REGIONAL ADM.	B. NIELSEN

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER 22A021		
CONTRACT NO.		LOCATION NO.

SPENCER T. BEIER, STATE OF WASHINGTON, REGISTERED PROFESSIONAL ENGINEER — PRELIMINARY

SEE CT1 — DATE — P.E. STAMP BOX

DATE — P.E. STAMP BOX

Washington State Department of Transportation

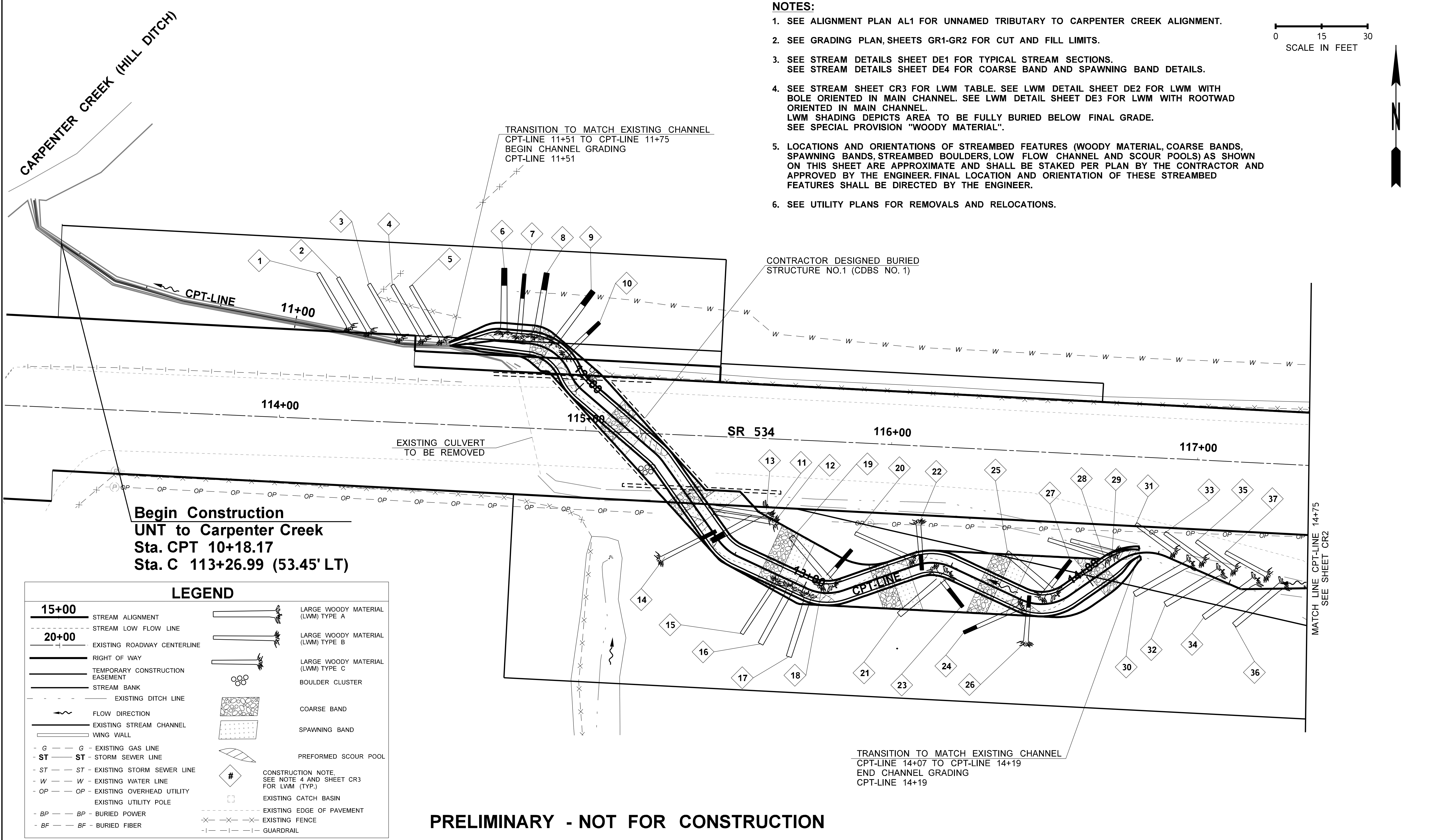
SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

GRADING PLAN

Plot 2
PLAN REF NO GR2
SHEET 10 OF 52 SHEETS

NOTES:

1. SEE ALIGNMENT PLAN AL1 FOR UNNAMED TRIBUTARY TO CARPENTER CREEK ALIGNMENT.
2. SEE GRADING PLAN, SHEETS GR1-GR2 FOR CUT AND FILL LIMITS.
3. SEE STREAM DETAILS SHEET DE1 FOR TYPICAL STREAM SECTIONS.
   SEE STREAM DETAILS SHEET DE4 FOR COARSE BAND AND SPAWNING BAND DETAILS.
4. SEE STREAM SHEET CR3 FOR LWM TABLE. SEE LWM DETAIL SHEET DE2 FOR LWM WITH BOLE ORIENTED IN MAIN CHANNEL. SEE LWM DETAIL SHEET DE3 FOR LWM WITH ROOTWAD ORIENTED IN MAIN CHANNEL.
   LWM SHADING DEPICTS AREA TO BE FULLY BURIED BELOW FINAL GRADE.
   SEE SPECIAL PROVISION "WOODY MATERIAL".
5. LOCATIONS AND ORIENTATIONS OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, STREAMBED BOULDERS, LOW FLOW CHANNEL AND SCOUR POOLS) AS SHOWN ON THIS SHEET ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.
6. SEE UTILITY PLANS FOR REMOVALS AND RELOCATIONS.



PRELIMINARY - NOT FOR CONSTRUCTION

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DATE	9/7/2022				JOB NUMBER 22A021	FED.AID PROJ.NO.
PLOTTED BY	crosisus				CONTRACT NO.	LOCATION NO.
DESIGNED BY	A. MILLER					
ENTERED BY	S. CROSIER					
CHECKED BY	T. NABOURS					
PROJ. ENGR.	S. BEIER					
REGIONAL ADM.	B. NIELSEN	REVISION	DATE	BY		

P.E. STAMP BOX DATE

PRELIMINARY — JULIE HEILMAN — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM PLAN

PLAN REF NO CR1

SHEET 19 OF 52 SHEETS

NOTES:

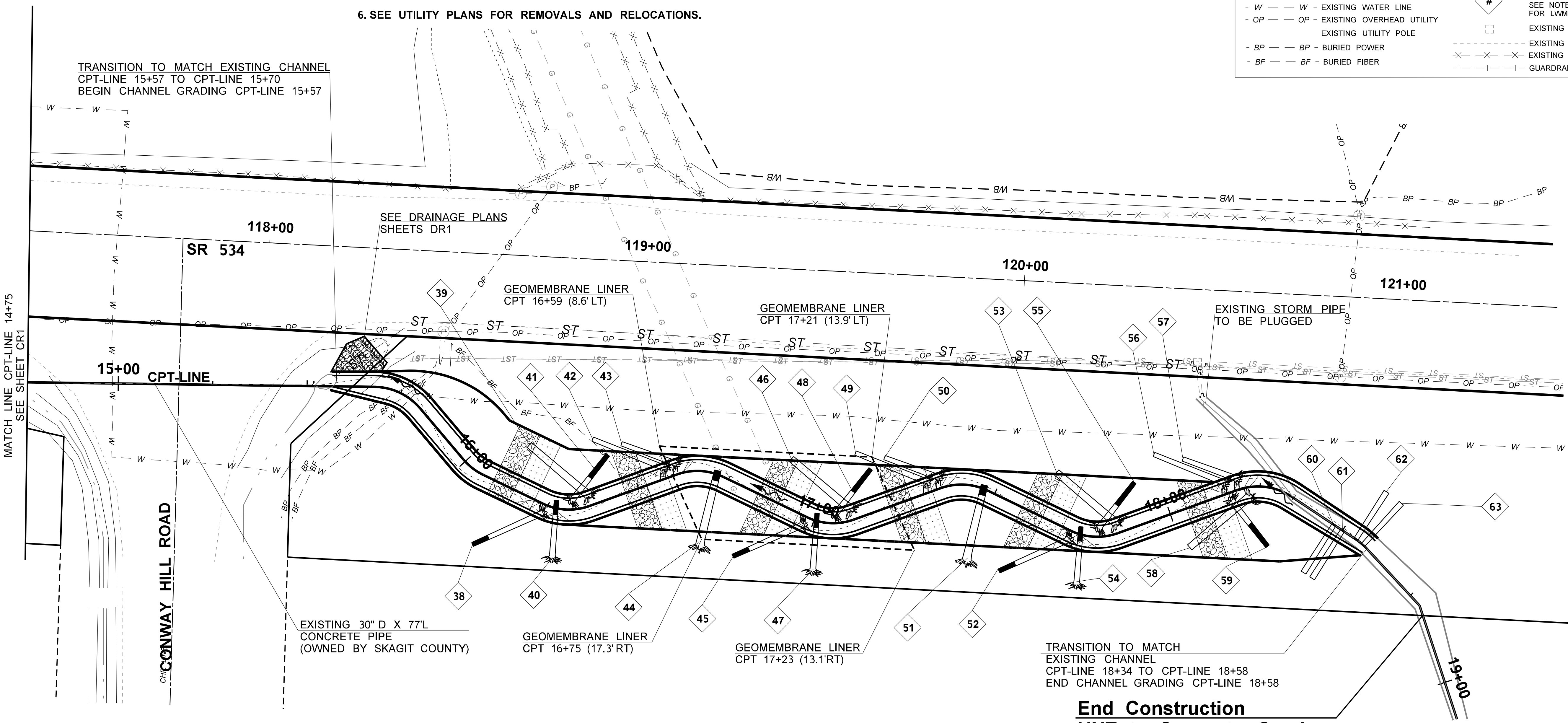
1. SEE ALIGNMENT PLAN AL1 FOR UNNAMED TRIBUTARY TO CARPENTER CREEK ALIGNMENT.
2. SEE GRADING PLAN, SHEETS GR1-GR2 FOR CUT AND FILL LIMITS.
3. SEE STREAM DETAILS SHEET DE1 FOR TYPICAL STREAM SECTIONS. SEE STREAM DETAILS SHEET DE4 FOR COARSE BAND AND SPAWNING BAND DETAILS.
4. SEE STREAM SHEET CR3 FOR LWM TABLE. SEE LWM DETAIL SHEET DE2 FOR LWM WITH BOLE ORIENTED IN MAIN CHANNEL. SEE LWM DETAIL SHEET DE3 FOR LWM WITH ROOTWAD ORIENTED IN MAIN CHANNEL. LWM SHADING DEPICTS AREA TO BE FULLY BURIED BELOW FINAL GRADE. SEE SPECIAL PROVISION "WOODY MATERIAL".
5. LOCATIONS AND ORIENTATIONS OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL AND SCOUR POOLS) AS SHOWN ON THIS SHEET ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.
6. SEE UTILITY PLANS FOR REMOVALS AND RELOCATIONS.

0 15 30
SCALE IN FEET

N

LEGEND

15+00	STREAM ALIGNMENT		LARGE WOODY MATERIAL (LWM) TYPE A
	STREAM LOW FLOW LINE		LARGE WOODY MATERIAL (LWM) TYPE B
20+00	EXISTING ROADWAY CENTERLINE		LARGE WOODY MATERIAL (LWM) TYPE C
	RIGHT OF WAY		BOULDER CLUSTER
	TEMPORARY CONSTRUCTION EASEMENT		COARSE BAND
	STREAM BANK		SPAWNING BAND
	EXISTING DITCH LINE		PREFORMED SCOUR POOL
	FLOW DIRECTION	#	CONSTRUCTION NOTE, SEE NOTE 4 AND SHEET CR3 FOR LWM (TYP.)
	EXISTING STREAM CHANNEL		EXISTING CATCH BASIN
	WING WALL		EXISTING EDGE OF PAVEMENT
G — G	EXISTING GAS LINE		EXISTING FENCE
ST — ST	STORM SEWER LINE		GUARDRAIL
ST — ST	EXISTING STORM SEWER LINE		
W — W	EXISTING WATER LINE		
OP — OP	EXISTING OVERHEAD UTILITY		
	EXISTING UTILITY POLE		
BP — BP	BURIED POWER		
BF — BF	BURIED FIBER		



End Construction
UNT to Carpenter Creek
Sta. CPT 18+80.12
Sta. C 121+09.75 (83.21' RT)

PRELIMINARY - NOT FOR CONSTRUCTION

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ENTERED BY	S. CROSIER			
CHECKED BY	T. NABOURS			
PROJ. ENGR.	S. BEIER			
REGIONAL ADM.	B. NIELSEN	REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER 22A021		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

JULIE HEILMAN — STATE OF WASHINGTON — REGISTERED PROFESSIONAL ENGINEER — PRELIMINARY

P.E. STAMP BOX DATE

Washington State Department of Transportation

Parametrix

SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM PLAN

PLAN REF NO CR2

SHEET 20 OF 52 SHEETS

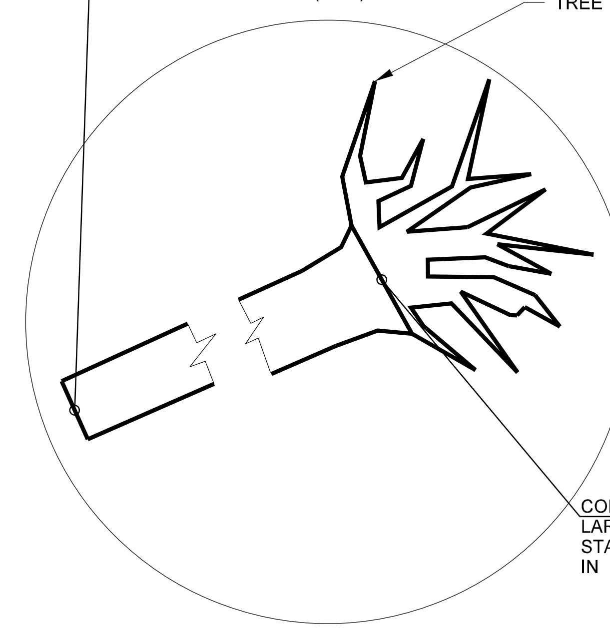
LARGE WOODY MATERIAL (LWM) LOCATION TABLE

SHEET NO.	LWM NO.	TYPE	IN STREAM FEATURE (SEE NOTE 2)	ROOTWAD (Y/N)	STATION / OFFSET (SEE NOTE 2)	ANGLE A (DEG.)	ANGLE B (DEG.)	DISTANCE C (FT) (SEE NOTE 1)	LOGS TO BE PLACED ABOVE LWM NO.
CR1	1	B	RW	Y	CPT 11+17 (2' LT)	315	6	1.3	-
CR1	2	B	RW	Y	CPT 11+24 (2' LT)	315	6	1.3	-
CR1	3	B	RW	Y	CPT 11+34 (2' LT)	315	6	1.3	-
CR1	4	B	RW	Y	CPT 11+42 (2' LT)	315	6	1.3	-
CR1	5	B	RW	Y	CPT 11+48 (2' LT)	315	6	1.3	-
CR1	6	A	RW	Y	CPT 11+68 (3.5' LT)	270	15	0.3	-
CR1	7	B	RW	Y	CPT 11+74 (2.5' LT)	270	15	0.3	-
CR1	8	A	RW	Y	CPT 11+79 (3.5' LT)	270	15	0.3	-
CR1	9	A	RW	Y	CPT 11+84 (3.5' LT)	270	15	0.3	-
CR1	10	C	RW	Y	CPT 11+89 (2.5' LT)	270	15	0.3	-
CR1	11	B	STEM	Y	CPT 12+57 (4' LT)	45	10	0.8	-
CR1	12	B	STEM	Y	CPT 12+60 (4' LT)	45	10	0.8	-
CR1	13	A	STEM	Y	CPT 12+67 (2' RT)	80	15	-2.9	11, 12
CR1	14	B	STEM	Y	CPT 12+65 (1' LT)	260	23	-2.0	-
CR1	15	B	RW	Y	CPT 12+91 (2.5' RT)	90	21	0.4	-
CR1	16	A	RW	Y	CPT 12+96 (2.5' RT)	90	19	0.6	-
CR1	17	A	RW	Y	CPT 13+02 (2.5' RT)	90	19	0.6	-
CR1	18	C	RW	Y	CPT 13+06 (2.5' LT)	235	-5	-0.3	19
CR1	19	A	RW	Y	CPT 13+10 (3' LT)	315	0	1.0	-
CR1	20	B	RW	Y	CPT 13+38 (2.5' LT)	315	10	0.3	-
CR1	21	A	RW	Y	CPT 13+50 (3.0' RT)	20	0	1.1	-
CR1	22	C	STEM	Y	CPT 13+40 (2' RT)	90	30	-3.2	-
CR1	23	C	RW	Y	CPT 13+45 (2.5' RT)	110	-5	-0.4	21
CR1	24	B	RW	Y	CPT 13+76 (2.5' RT)	50	6	0.3	-
CR1	25	A	RW	Y	CPT 13+87 (3' LT)	315	0	1.0	-
CR1	26	C	STEM	Y	CPT 13+78 (2' LT)	270	30	-3.2	-
CR1	27	C	RW	Y	CPT 13+83 (2.5' LT)	235	-5	-0.3	25
CR1	28	B	RW	Y	CPT 14+09 (3' LT)	320	4	0.4	-
CR1	29	C	RW	Y	CPT 14+12 (3' LT)	320	4	0.7	-
CR1	30	A	RW	Y	CPT 14+35 (1' LT)	45	6	1.2	-
CR1	31	C	RW	Y	CPT 14+29 (2.5' LT)	340	7	1.0	-
CR1	32	A	RW	Y	CPT 14+45 (2.2' LT)	45	6	1.2	-
CR1	33	C	RW	Y	CPT 14+39 (3.6' LT)	340	7	1.0	-
CR1	34	A	RW	Y	CPT 14+59 (2.6' LT)	45	6	1.2	-
CR1	35	C	RW	Y	CPT 14+49 (5.2' LT)	340	7	1.0	-
CR1	36	A	RW	Y	CPT 14+68 (1.1' LT)	45	6	1.2	-
CR1	37	C	RW	Y	CPT 14+62 (4.6' LT)	340	7	1.0	-
CR2	38	B	RW	Y	CPT 16+24 (2.5' RT)	50	6	0.3	-
CR2	39	A	RW	Y	CPT 16+37 (3' RT)	315	0	1.0	-
CR2	40	C	STEM	Y	CPT 16+27 (2' LT)	270	30	-3.2	-
CR2	41	C	RW	Y	CPT 16+32 (2.5' LT)	235	-5	-0.3	39
CR2	42	B	RW	Y	CPT 16+58 (3' LT)	320	4	0.4	-
CR2	43	C	RW	Y	CPT 16+61 (3' LT)	320	4	0.7	-
CR2	44	A	STEM	Y	CPT 16+71 (1' LT)	290	25	-2.9	-
CR2	45	B	RW	Y	CPT 16+98 (2.5' RT)	50	6	0.3	-
CR2	46	A	RW	Y	CPT 17+11 (3' LT)	315	0	1.0	-
CR2	47	C	STEM	Y	CPT 17+00 (2' LT)	270	30	-3.2	-
CR2	48	C	RW	Y	CPT 17+06 (2.5' LT)	235	-5	-0.3	46
CR2	49	B	RW	Y	CPT 17+32 (3' LT)	320	4	0.4	-
CR2	50	C	RW	Y	CPT 17+35 (3' LT)	320	4	0.7	-
CR2	51	A	STEM	Y	CPT 17+47 (1' LT)	290	25	-2.9	-
CR2	52	B	RW	Y	CPT 17+73 (2.5' RT)	50	6	0.3	-
CR2	53	A	RW	Y	CPT 17+86 (3' LT)	315	0	1.0	-
CR2	54	C	STEM	Y	CPT 17+75 (2' LT)	270	30	-3.2	-
CR2	55	C	RW	Y	CPT 17+80 (2.5' LT)	235	-5	-0.3	53
CR2	56	B	RW	Y	CPT 18+16 (3' LT)	320	4	0.4	-
CR2	57	C	RW	Y	CPT 18+20 (3' LT)	320	4	0.7	-
CR2	58	A	RW	Y	CPT 18+21 (3' RT)	20	0	1.1	-
CR2	59	C	RW	Y	CPT 18+17 (2.5' RT)	110	-5	-0.4	58
CR2	60	C	RW	N	CPT 18+47 (0' RT)	90	12	-0.4	-
CR2	61	C	RW	N	CPT 18+50 (0' RT)	90	12	-0.4	-
CR2	62	C	RW	N	CPT 18+54 (0' LT)	270	20	-0.4	-
CR2	63	C	RW	N	CPT 18+57 (0' LT)	270	20	-0.4	-

NOTES:

1. SEE DE SHEETS FOR LWM DETAILS.
2. SEE STATION/OFFSET LOCATION DETAIL BELOW FOR STATION/OFFSET LOCATION BASED ON IN STREAM FEATURE REFERRED TO IN LWN LOCATION TABLE.
3. MINIMUM LENGTH IS MEASURED FROM COLLAR OF ROOT WAD TO END OF BOLE (STEM TIP).
4. ANGLE "A" IS MEASURED COUNTER CLOCKWISE FROM THE STREAM CENTERLINE TO THE LOG CENTERLINE AT THE STEM TIP AS DEPICTED ON DETAIL SHEET DE2 AND DE3.
5. ANGLE "B" IS MEASURED FROM HORIZONTAL AS SHOWN ON SHEETS DE2 AND DE3. A POSITIVE ANGLE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM MAIN CHANNEL IS HIGHER THAN THE LOG END NEAREST TO THE MAIN CHANNEL. A NEGATIVE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM THE MAIN CHANNEL IS LOWER THAN THE LOG END NEAREST TO THE MAIN CHANNEL.
6. A NEGATIVE "C" VALUE INDICATES DEPTH BENEATH THALWEG. A POSITIVE "C" VALUE INDICATES DEPTH ABOVE THALWEG.
7. LOCATIONS AND ORIENTATION OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL, AND SCOUR POOLS) ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.

LARGE WOODY MATERIAL (LWM)			
LWM TYPE	LENGTH	DIAM.	TOTAL
TYPE A	20 FT	2.0 FT	19
TYPE B	20 FT	1.5 FT	19
TYPE C	15 FT	1.5 FT	25



STATION / OFFSET LOCATION DETAIL
PLAN VIEW

PRELIMINARY - NOT FOR CONSTRUCTION

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DATE 9/7/2022
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DESIGNED BY A. MILLER
ENTERED BY S. CROSIER
CHECKED BY T. NABOURS
PROJ. ENGR. S. BEIER
REGIONAL ADM. B. NIELSEN

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.
JOB NUMBER 22A021
CONTRACT NO. | LOCATION NO.

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

JULIE HEILMAN STATE OF WASHINGTON PROFESSIONAL ENGINEER REGISTERED PRELIMINARY

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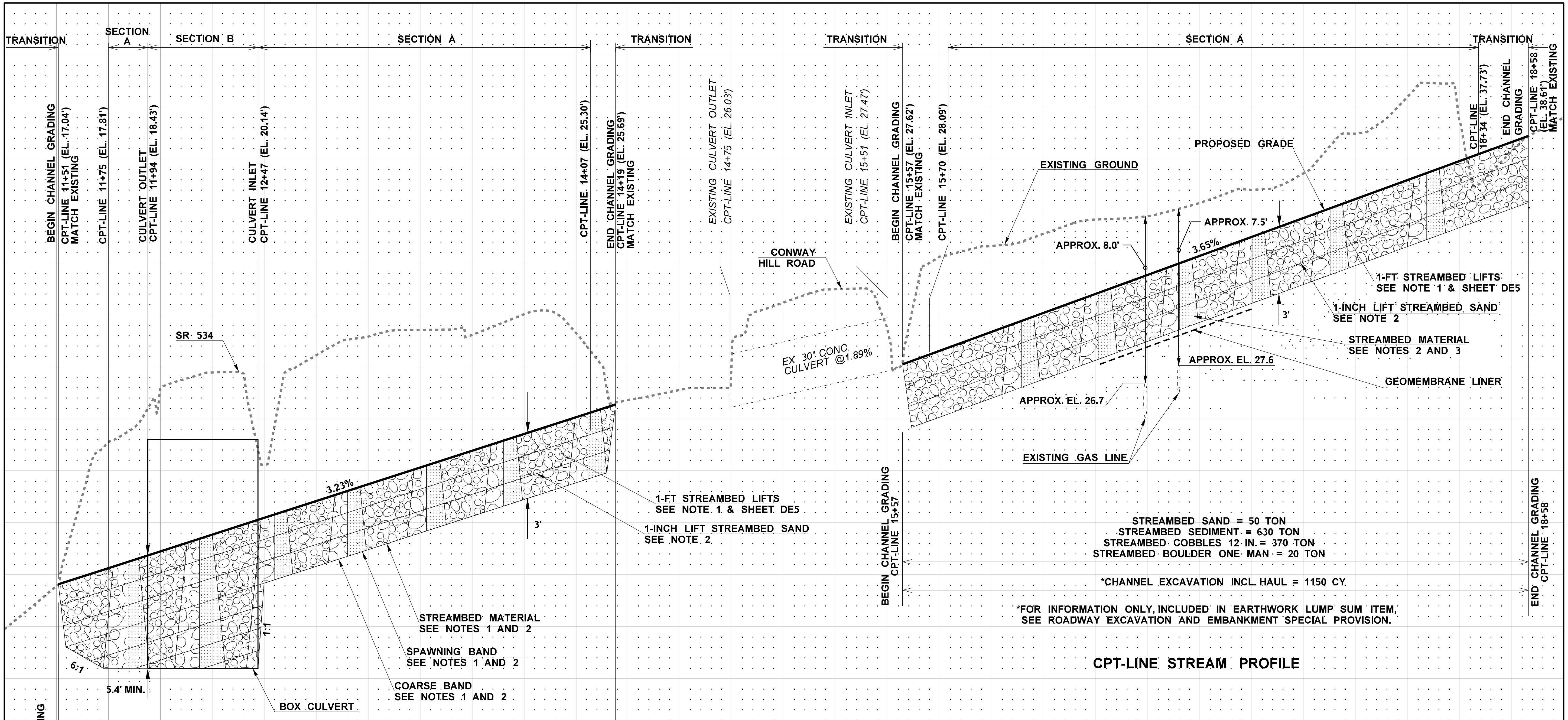
SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE
STREAM PLAN

PLAN REF NO CR3
SHEET 21 OF 52 SHEETS



BEGIN CHANNEL GRADING CPT-LINE 11+51

END CHANNEL GRADING CPT-LINE 14+19

STREAMBED SAND = 50 TON
STREAMBED SEDIMENT = 710 TON
STREAMBED COBBLES 12 IN. = 400 TON
STREAMBED BOULDER ONE MAN = 30 TON

*CHANNEL EXCAVATION INCL. HAUL = 200 CY

*STRUCTURAL EXCAVATION CLASS A INCL. HAUL 650 CY

*CHANNEL EXCAVATION INCL. HAUL = 1180 CY

*FOR INFORMATION ONLY, INCLUDED IN EARTHWORK LUMP SUM ITEM, SEE ROADWAY EXCAVATION AND EMBANKMENT SPECIAL PROVISION.

CPT-LINE STREAM PROFILE

NOTES:

1. SEE DE SHEETS FOR TYPICAL STREAM SECTION, COARSE BAND, SPAWNING BAND DETAILS, AND STREAMBED MATERIAL PLACEMENT SEQUENCE OF WORK.

2. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES."

3. MATERIAL DEPTH SHOWN IS FINAL DEPTH AT CPT LINE.

4. LOCATIONS AND ORIENTATIONS OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL AND SCOUR POOLS) ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.

DATUM (NAVD) 88

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12+00 13+00 14+00 15+00 16+00 17+00 18+00

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PROJ. ENGR.	S. BEIER
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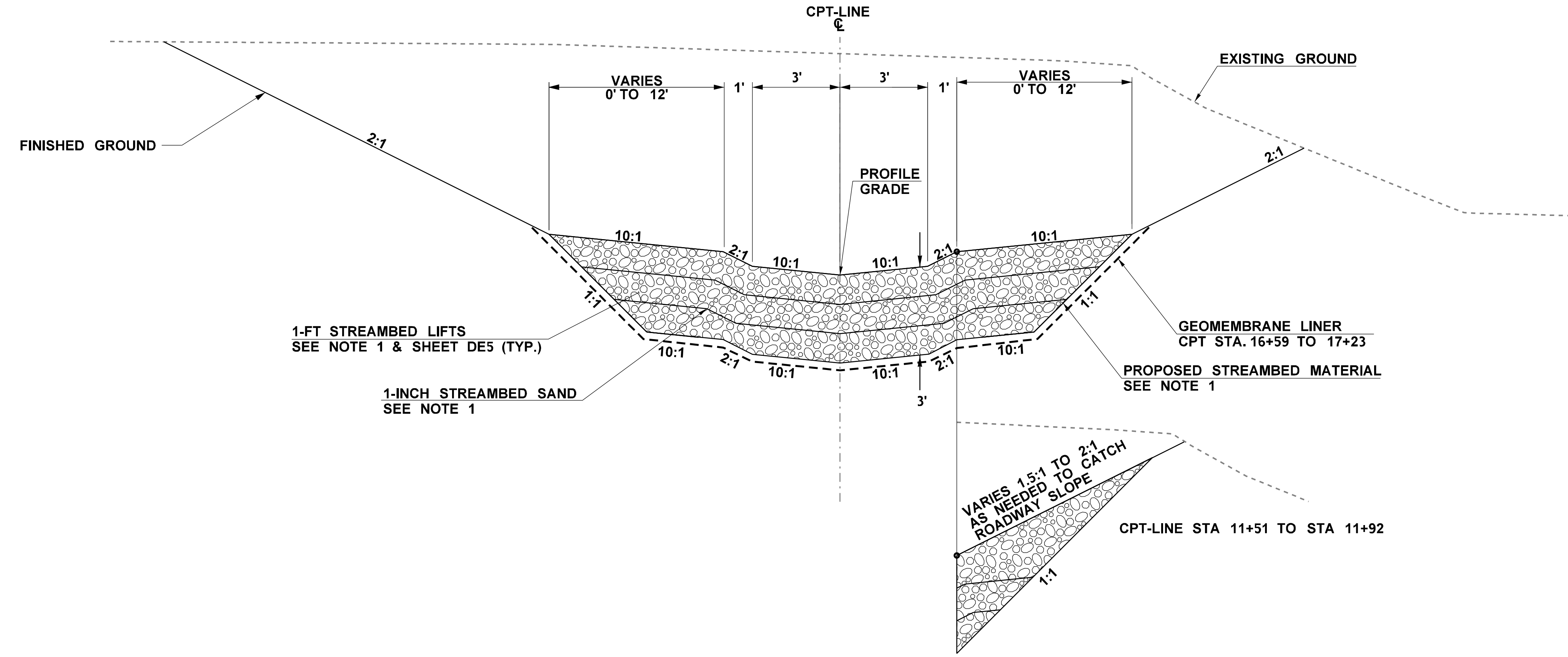
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM PROFILE

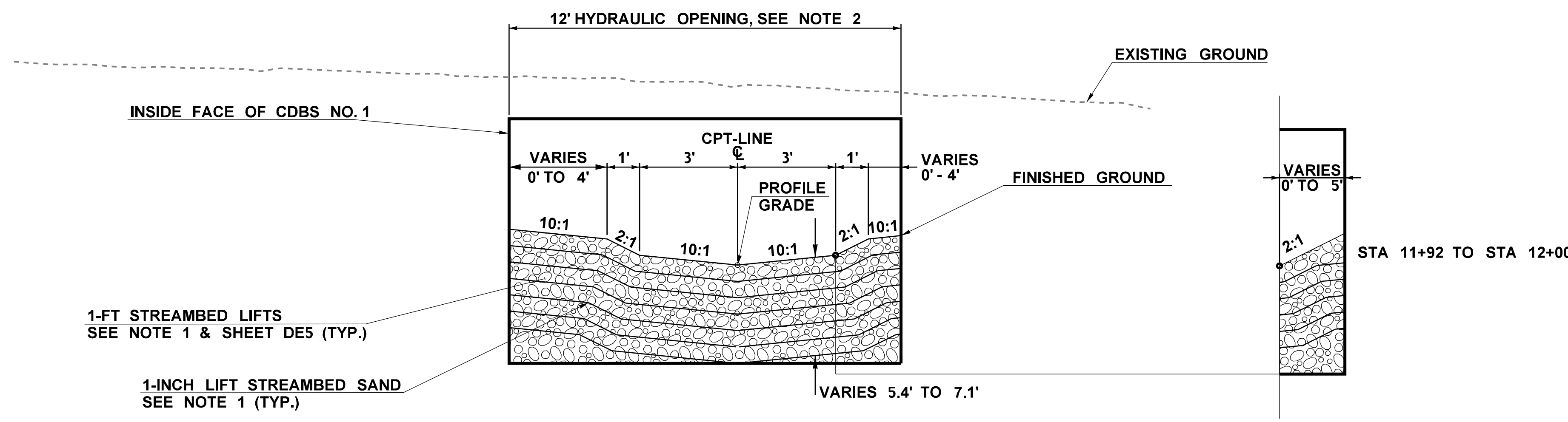
Plot 1
PLAN REF. NO. STP1
SHEET 22 OF 52 SHEETS



UNNAMED TRIBUTARY TO CARPENTER CREEK TYPICAL STREAM SECTION A

NOT TO SCALE
CPT STA 11+51 TO STA 11+92 RT / STA 12+04 LT AND STA 12+52 LT / STA 12+42 RT TO STA 14+19
TRANSITION TO EXISTING CPT STA 11+51 TO STA 11+75
TRANSITION TO EXISTING CPT STA 14+07 TO STA 14+19

CPT STA 15+57 TO STA 18+58
TRANSITION TO EXISTING CPT STA 15+57 TO STA 15+70
TRANSITION TO EXISTING CPT STA 18+34 TO STA 18+58



NOTE:

1. SEE SPECIAL PROVISION "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES".
2. HYDRAULIC OPENING AS MEASURED PERPENDICULAR TO BEARING OF CULVERT.

UNNAMED TRIBUTARY TO CARPENTER CREEK TYPICAL STREAM SECTION B

NOT TO SCALE
CPT STA 11+92 RT / STA 12+04 LT TO
CPT STA 12+52 LT / STA 12+42 RT

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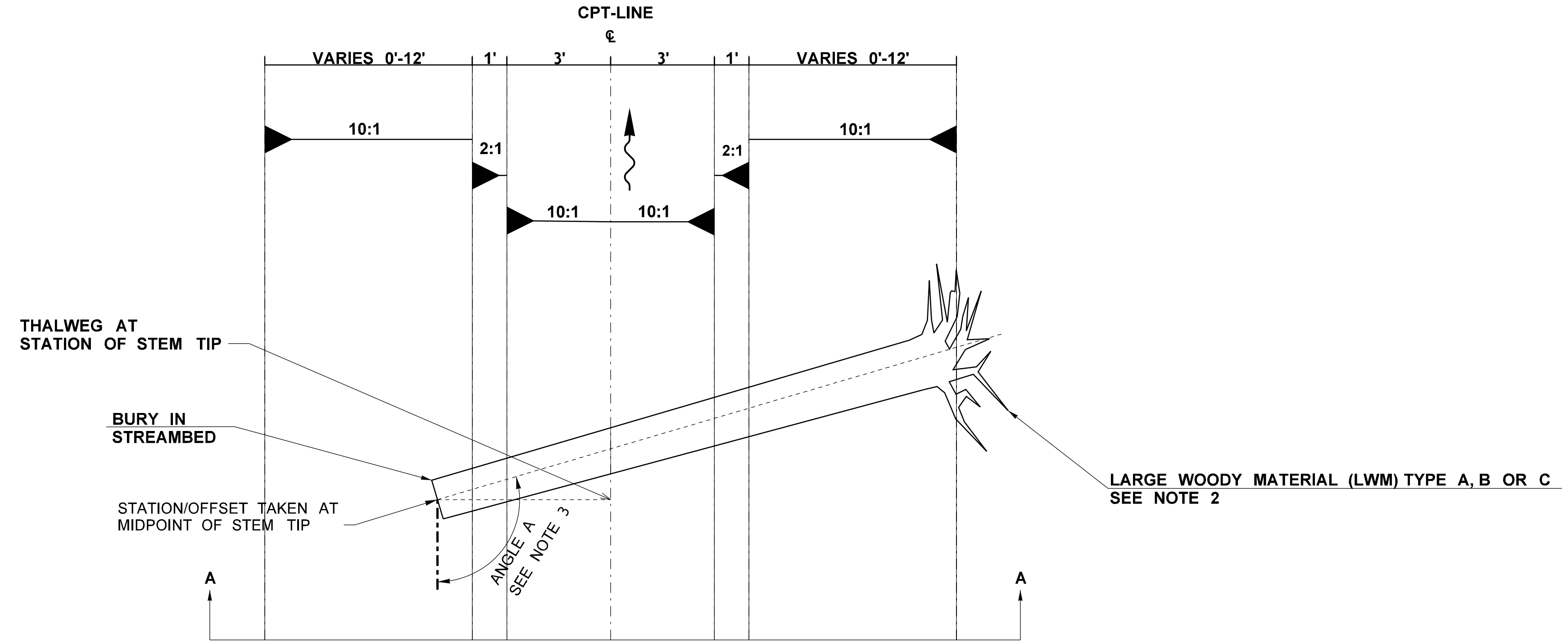
SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

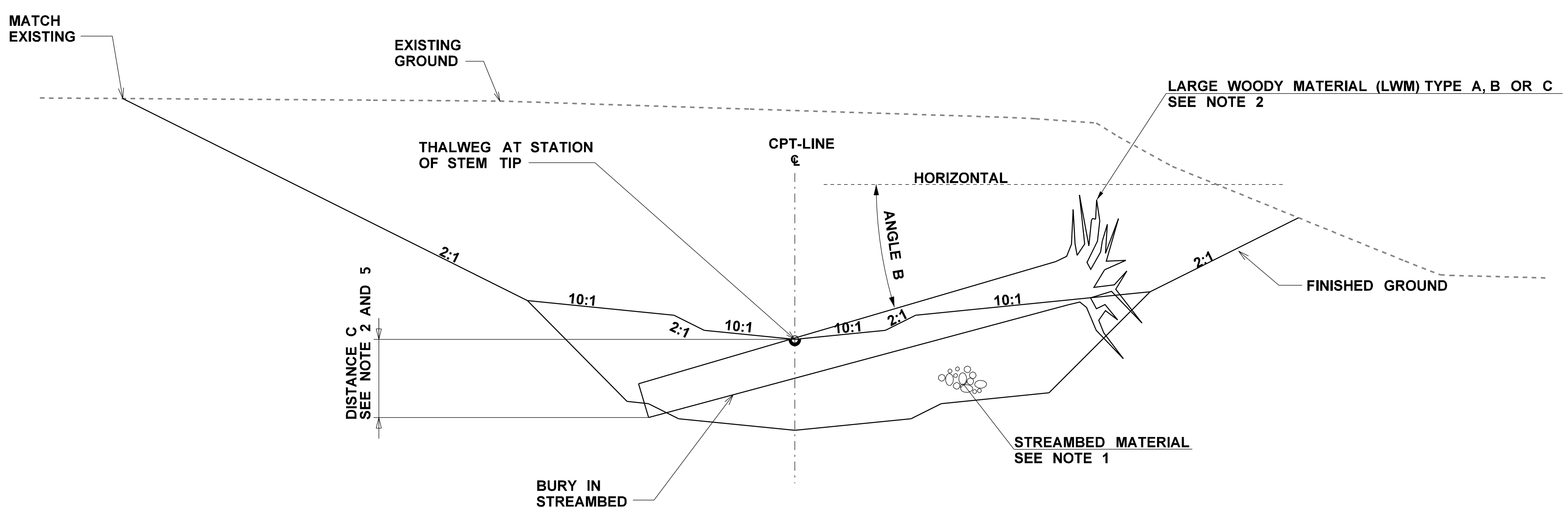
STREAM DETAILS

Plot 2
PLAN REF NO DE1
SHEET 23 OF 52 SHEETS



LARGE WOODY MATERIAL (LWM) TYPE A, B OR C - STEM TIP IN CHANNEL

(NOT TO SCALE)



SECTION A-A

(NOT TO SCALE)

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES."
2. SEE LARGE WOODY MATERIAL (LWM) TABLE ON SHEET CR3 FOR LOG TYPE, ANGLE A, ANGLE B, AND DISTANCE C.
3. ANGLE "A" IS MEASURED COUNTER CLOCKWISE FROM THE STREAM CENTERLINE TO THE LOG CENTERLINE AT THE STEM TIP.
4. ANGLE "B" IS MEASURED FROM HORIZONTAL AS SHOWN ON SHEETS DE2 AND DE3. A POSITIVE ANGLE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM MAIN CHANNEL IS HIGHER THAN THE LOG END NEAREST TO THE MAIN CHANNEL. A NEGATIVE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM THE MAIN CHANNEL IS LOWER THAN THE LOG END NEAREST TO THE MAIN CHANNEL.
5. A NEGATIVE "C" VALUE INDICATES DEPTH BENEATH THALWEG. A POSITIVE "C" VALUE INDICATES DEPTH ABOVE THALWEG.
6. LOCATIONS AND ORIENTATION OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL, AND SCOUR POOLS) ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.

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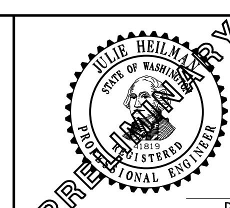
DESIGNED BY	A. MILLER
ENTERED BY	S. CROSIER
CHECKED BY	T. NABOURS
PROJ. ENGR.	S. BEIER
REGIONAL ADM.	B. NIELSEN

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER 22A021		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE



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SR 534

UNNAMED TRIBUTARY TO CARPENTER CR

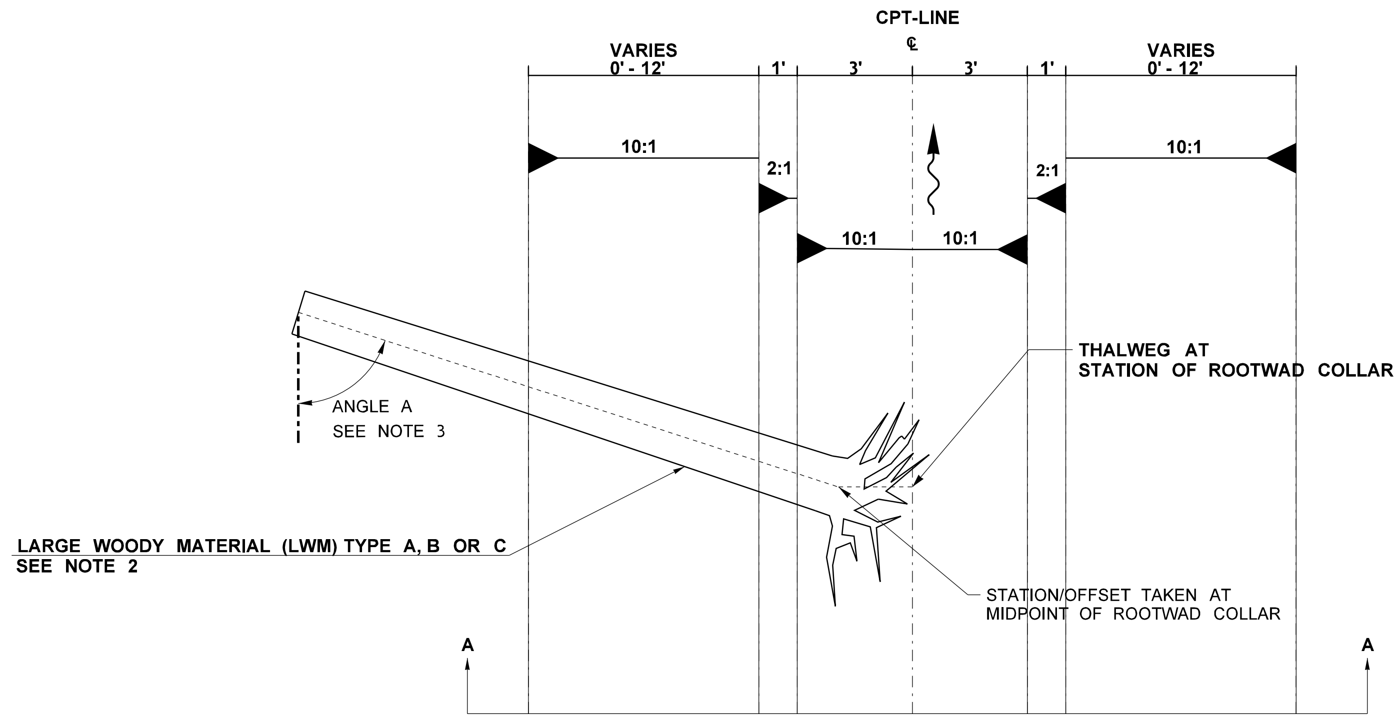
FISH PASSAGE

STREAM DETAILS

Plot 3

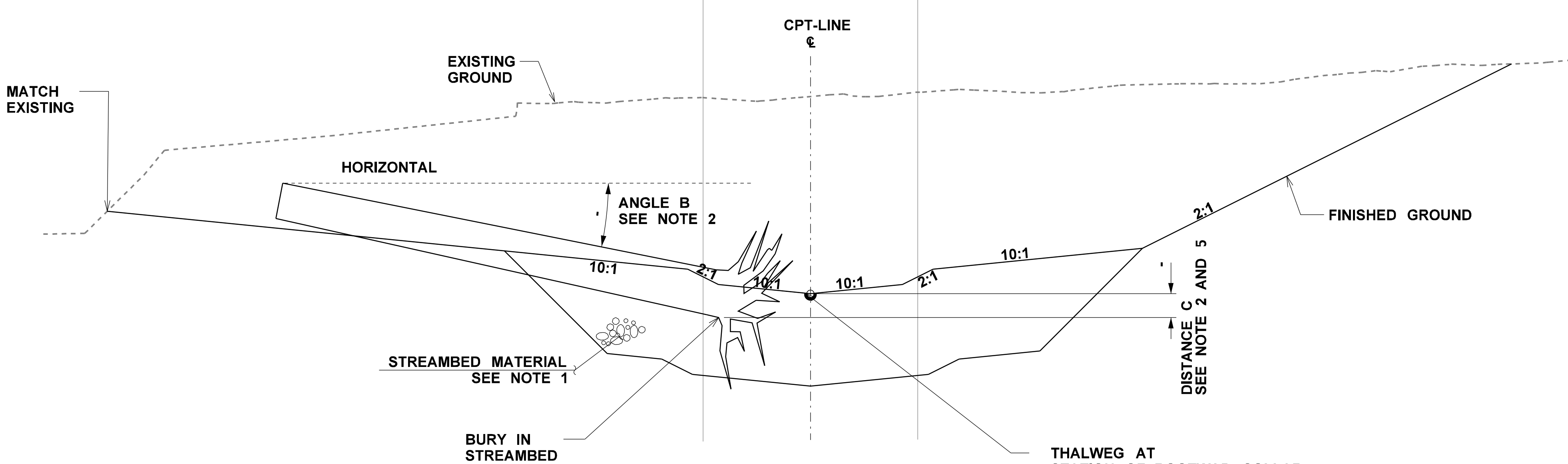
PLAN REF NO DE2

SHEET 24 OF 52 SHEETS



LARGE WOODY MATERIAL (LWM) TYPE A, B OR C - ROOTWAD IN CHANNEL

(NOT TO SCALE)



SECTION A-A
(NOT TO SCALE)

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES."
2. SEE LARGE WOODY MATERIAL (LWM) TABLE ON SHEET CR3 FOR LOG TYPE, ANGLE A, ANGLE B, AND DISTANCE C.
3. ANGLE "A" IS MEASURED COUNTER CLOCKWISE FROM THE STREAM CENTERLINE TO THE LOG CENTERLINE AT THE STEM TIP.
4. ANGLE "B" IS MEASURED FROM HORIZONTAL AS SHOWN ON SHEETS DE2 AND DE3. A POSITIVE ANGLE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM MAIN CHANNEL IS HIGHER THAN THE LOG END NEAREST TO THE MAIN CHANNEL. A NEGATIVE "B" VALUE INDICATES THAT THE ELEVATION OF THE LOG END FURTHEST FROM THE MAIN CHANNEL IS LOWER THAN THE LOG END NEAREST TO THE MAIN CHANNEL.
5. A NEGATIVE "C" VALUE INDICATES DEPTH BENEATH THALWEG. A POSITIVE "C" VALUE INDICATES DEPTH ABOVE THALWEG.
6. LOCATIONS AND ORIENTATION OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL, AND SCOUR POOLS) ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.

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DESIGNED BY	A. MILLER
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CHECKED BY	T. NABOURS
PROJ. ENGR.	S. BEIER
REGIONAL ADM.	B. NIELSEN

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

JOB NUMBER: 22A021

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UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM DETAILS

Plot 4

PLAN REF NO: DE3

SHEET 25 OF 52 SHEETS

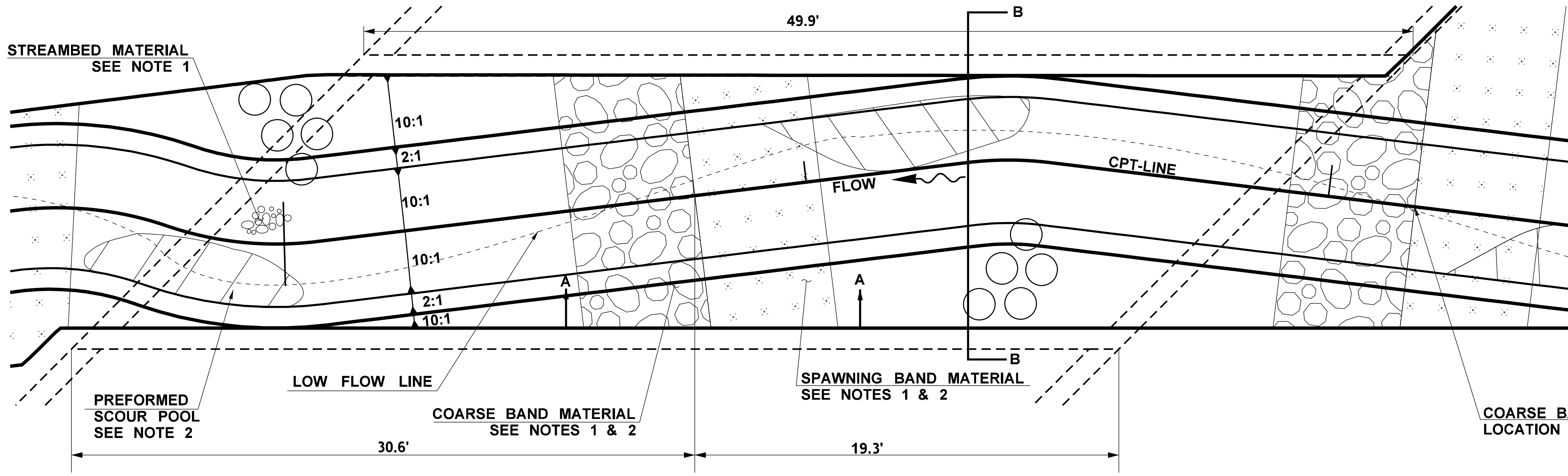
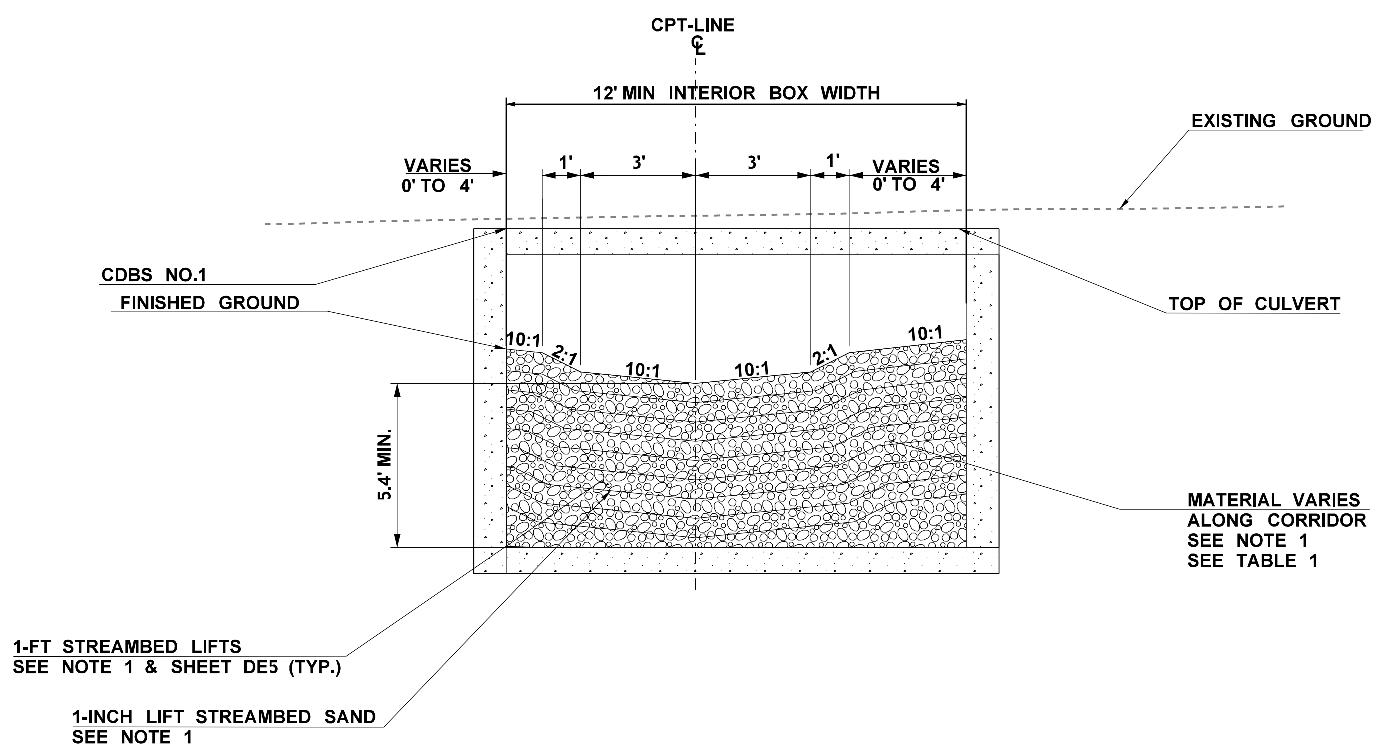
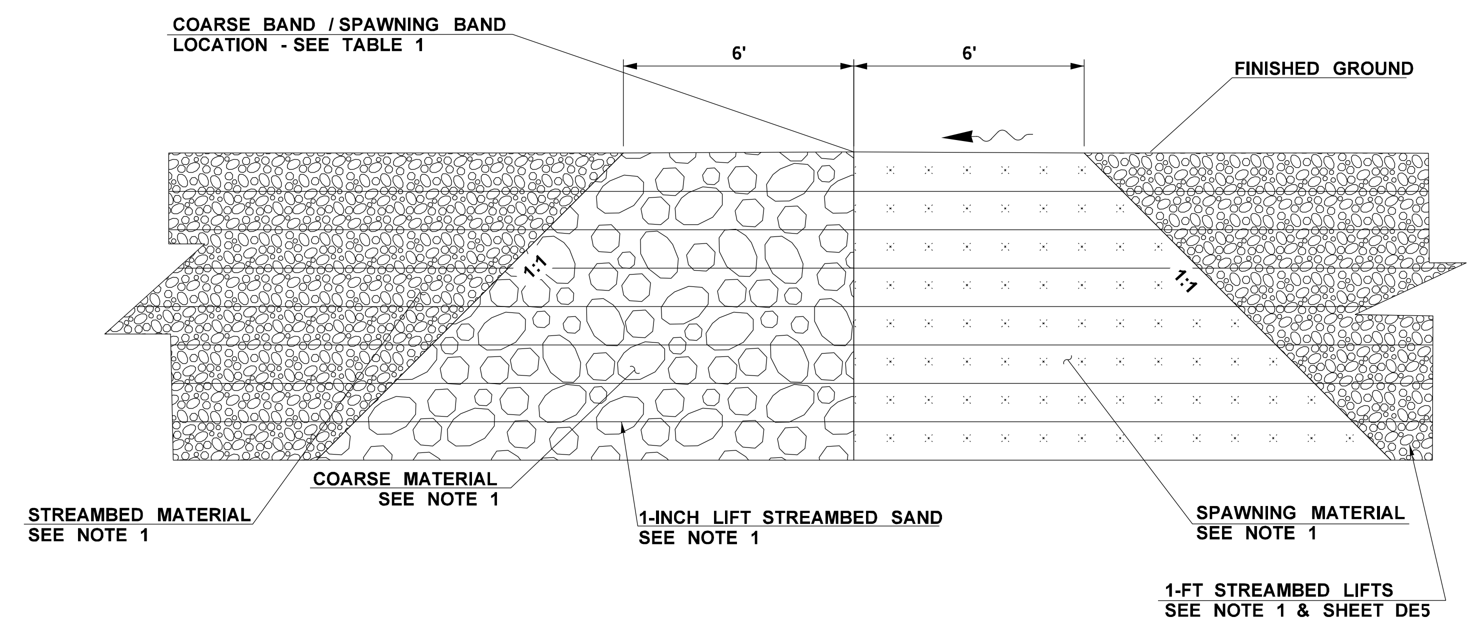


TABLE 1:
COARSE BAND / SPAWNING BAND LOCATION
CPT-LINE 11+83.66
CPT-LINE 12+19.66
CPT-LINE 12+54.13
CPT-LINE 12+91.10
CPT-LINE 13+29.76
CPT-LINE 13+66.88
CPT-LINE 14+06.91
CPT-LINE 16+15.10
CPT-LINE 16+52.35
CPT-LINE 16+89.60
CPT-LINE 17+26.84
CPT-LINE 17+64.09
CPT-LINE 18+10.47



UNNAMED TRIBUTARY TO CARPENTER CREEK TYPICAL CULVERT SECTION

NOT TO SCALE
SECTION B-B



COARSE BAND AND SPAWNING BAND DETAIL

SECTION A-A
NOT TO SCALE

NOTE:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES". SEE SHEET DE5 FOR STREAMBED MATERIAL PLACEMENT DETAIL
2. LOCATIONS AND ORIENTATIONS OF STREAMBED FEATURES (WOODY MATERIAL, COARSE BANDS, SPAWNING BANDS, LOW FLOW CHANNEL AND SCOUR POOLS) ARE APPROXIMATE AND SHALL BE STAKED PER PLAN BY THE CONTRACTOR AND APPROVED BY THE ENGINEER. FINAL LOCATION AND ORIENTATION OF THESE STREAMBED FEATURES SHALL BE DIRECTED BY THE ENGINEER.

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PROJ. ENGR.	S. BEIER
REGIONAL ADM.	B. NIELSEN

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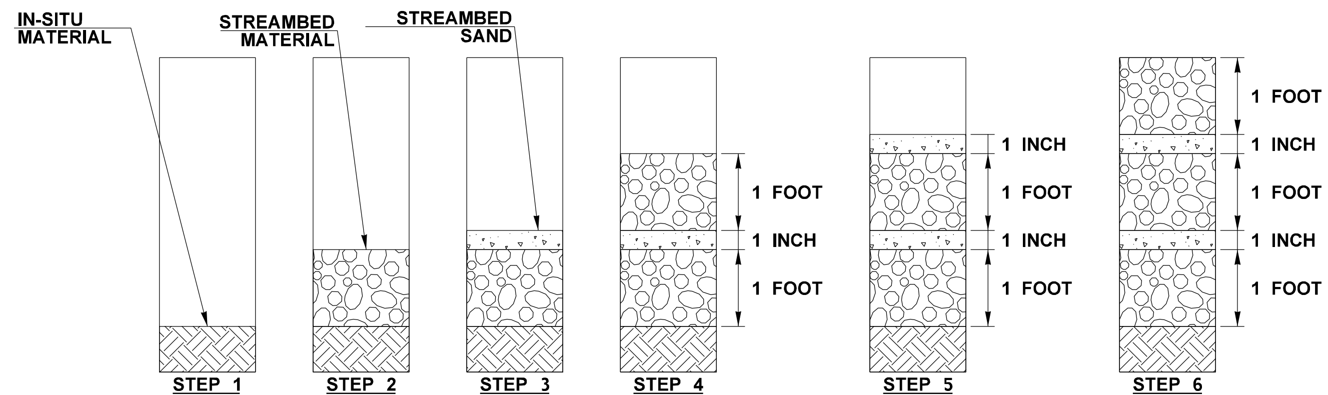
SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM DETAILS

Plot 5
PLAN REF NO DE4
SHEET 26 OF 52 SHEETS



STREAMBED CHANNEL PREPARATION

STEP 1

EXCAVATE CHANNEL TO ACCOMODATE STREAMBED MATERIAL.

STEP 2

PLACE 1 FOOT LIFT OF STREAMBED MATERIAL.

STEP 3

PLACE 1 INCH OF STREAMBED SAND UNIFORMLY OVER STREAMBED MATERIAL. APPLY WATER TO STREAMBED SAND. SEE DETAIL NOTE 2.

STEP 4

(REPEAT STEP 2), SEE NOTE 3

STEP 5

(REPEAT STEP 3), SEE NOTE 3

STEP 6

PLACE REMAINING 1 FOOT LIFT OF STREAMBED MATERIAL GRADE AS NOTED BELOW.

STREAMBED MATERIAL PLACEMENT - SEQUENCE OF WORK

NOT TO SCALE

DETAIL NOTES:

1. SLASH FROM THE TREES SHALL BE INCORPORATED INTO STREAMBED MIX AS DIRECTED BY ENGINEER.
2. APPLY WATER TO STREAMBED SAND LAYERS TO FACILITATE FILLING INTERSTITIAL VOIDS. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR MORE DETAILS.
3. STEPS 2 AND 3 SHALL BE REPEATED AS NECESSARY FOR PLACEMENT OF STREAMBED MATERIAL, COARSE BANDS, AND SPAWNING BANDS TO FULL DEPTH AS DEPICTED ON SHEET STP1.

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SR 534
UNNAMED TRIBUTARY TO CARPENTER CR
FISH PASSAGE

STREAM DETAILS

Plot 6
PLAN REF NO DE5
SHEET 27 OF 52 SHEETS

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Appendix E

Streambed Material Sizing Calculations

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Streambed Material Design

Project:	**SR 534 at Tributary to Carpenter Creek: East/West Design Segment**
By:	**Tyler Nabours**

Design Gradation:

Location: General Streambed Material Design

	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.00	0.55	0.12	0.01
in	12.00	6.57	1.49	0.11
mm	304.8	166.9	38.0	2.9

Design Gradation:

Location: Upstream PC 1

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.13	0.05	0.01	0.00
in	1.57	0.61	0.13	0.03
mm	40	15	3.3	0.8

Design Gradation:

Location: Upstream PC 2

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in	11.8	2.4	0.9	0.1
mm	300	60	22.4	1.8

Design Gradation:

Location: Downstream PC 1

	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.98	0.71	0.32	0.07
in	11.80	8.53	3.78	0.89
mm	300	217	96.0	22.6

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	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				92.0
8.0	203				100	80	68				87.3
6.0	152			100	80	68	57				82.7
5.0	127			80	68	57	45				78.0
4.0	102		100	71	57	45	39				75.7
3.0	76.2		80	63	45	38	34				73.4
2.5	63.5	100	65	54	37	32	28				71.1
2.0	50.8	80	50	45	29	25	22				56.9
1.5	38.1	73	35	32	21	18	16				50.1
1.0	25.4	65	20	18	13	12	11				43.3
0.75	19.1	50	5	5	5	5	5				32.0
No. 4 =	4.75	35									21.0
No. 40 =	0.425	16									9.6
No. 200 =	0.0750	7									4.2
% per category		60	0	0	0	0	40	0	0	0	*--> 100%*
% Cobble & Sediment		60.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

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

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.05	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Flow	2-YR (12.5 cfs)	10-YR (27.6 cfs)	25-YR (39.8 cfs)	50-YR (47.0 cfs)	100-YR (48.3 cfs)	500-YR (50.5 cfs)	100-YR (2080) (53.5 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.0	1.5	1.9	2.1	2.1	2.4	2.2
τ_{ci}		Structure					
1.66	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.60	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.54	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.45	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.35	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.28	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.19	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.13	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.06	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.97	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.92	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.86	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.79	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.75	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.70	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.64	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.57	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.52	Motion	Motion	Motion	Motion	Motion	Motion	Motion

D16	2.853	mm	0.11	in
D50	1.49	inches	38.0	mm
	0.12	ft		
D84	6.57	inches	166.9	mm
D90	9.14	inches		
D100	12	inches	304.8	mm

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

Coarse Band Material Design

Project:	**SR 534 at Tributary to Carpenter Creek: East/West Design Segment**
By:	**Tyler Nabours**

Design Gradation:

Location:	Coarse Band Material Design			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	1.50	0.98	0.29	0.05
in	18.00	11.82	3.49	0.61
mm	457.2	300.2	88.6	15.6

Design Gradation:

Location:	Upstream PC 1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.13	0.05	0.01	0.00
in	1.57	0.61	0.13	0.03
mm	40	15	3.3	0.8

Design Gradation:

Location:	Upstream PC 2			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.98	0.20	0.07	0.01
in	11.8	2.4	0.9	0.1
mm	300	60	22.4	1.8

Design Gradation:

Location:	Downstream PC 1			
	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.98	0.71	0.32	0.07
in	11.80	8.53	3.78	0.89
mm	300	217	96.0	22.6

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size		Streambed Sediment	Streambed Cobbles					Streambed Boulders			D_{size}
[in]	[mm]		4"	6"	8"	10"	12"	12"-18"	18"-28"	28"-36"	
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			92.5
12.0	305						100				85.0
10.0	254					100	80				74.0
8.0	203				100	80	68				67.6
6.0	152			100	80	68	57				61.2
5.0	127			80	68	57	45				54.8
4.0	102		100	71	57	45	39				51.6
3.0	76.2		80	63	45	38	34				48.5
2.5	63.5	100	65	54	37	32	28				45.3
2.0	50.8	80	50	45	29	25	22				36.2
1.5	38.1	73	35	32	21	18	16				30.8
1.0	25.4	65	20	18	13	12	11				25.4
0.75	19.1	50	5	5	5	5	5				17.8
No. 4 =	4.75	35									10.5
No. 40 =	0.425	16									4.8
No. 200 =	0.0750	7									2.1
% per category		30	0	0	0	0	55	15	0	0	--> 100%
% Cobble & Sediment		35.3	0.0	0.0	0.0	0.0	64.7	17.6	0.0	0.0	85.0%

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

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

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.052	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Flow	2-YR (12.5 cfs)	10-YR (27.6 cfs)	25-YR (39.8 cfs)	50-YR (47.0 cfs)	100-YR (48.3 cfs)	500-YR (50.5 cfs)	100-YR (2080) (53.5 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.0	1.5	1.9	2.0	2.1	2.4	2.2
τ_{ci}		Structure					
3.12	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
3.02	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.90	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.73	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.54	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.40	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion	No Motion
2.25	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	No Motion
2.13	No Motion	No Motion	No Motion	No Motion	No Motion	Motion	Motion
1.99	No Motion	No Motion	No Motion	Motion	Motion	Motion	Motion
1.83	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.73	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.62	No Motion	No Motion	Motion	Motion	Motion	Motion	Motion
1.48	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.40	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.31	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.20	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
1.07	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.98	Motion	Motion	Motion	Motion	Motion	Motion	Motion

D16	16	mm	0.61	in
D50	3.49	inches	88.6	mm
	0.3	ft		
D84	11.82	inches	300.2	mm
D100	18	inches	457.2	mm

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

Fine Band Material Design

Project:	**SR 534 at Tributary to Carpenter Creek: East/West Design Segment**
By:	**Tyler Nabours**

Design Gradation:

Location: Spawning Band Material Design	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.21	0.18	0.06	0.00
in	2.50	2.10	0.75	0.02
mm	63.5	53.3	19.1	0.4

Design Gradation:

Location: Upstream PC 1	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.13	0.05	0.01	0.00
in	1.57	0.61	0.13	0.03
mm	40	15	3.3	0.8

Design Gradation:

Location: Upstream PC 2	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.00	0.00	0.00	0.00
in	11.8	2.4	0.9	0.1
mm	300	60	22.4	1.8

Design Gradation:

Location: Downstream PC 1	D_{100}	D_{84}	D_{50}	D_{16}
ft	0.98	0.71	0.32	0.07
in	11.80	8.53	3.78	0.89
mm	300	217	96.0	22.6

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	[mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				100.0
5.0	127			80	68	57	45				100.0
4.0	102		100	71	57	45	39				100.0
3.0	76.2		80	63	45	38	34				100.0
2.5	63.5	100	65	54	37	32	28				100.0
2.0	50.8	80	50	45	29	25	22				80.0
1.5	38.1	73	35	32	21	18	16				72.5
1.0	25.4	65	20	18	13	12	11				65.0
0.75	19.1	50	5	5	5	5	5				50.0
No. 4 =	4.75	35									35.0
No. 40 =	0.425	16									16.0
No. 200 =	0.0750	7									7.0
% per category		100	0	0	0	0	0	0	0	0	*--> 100%*
% Cobble & Sediment		100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*100.0%*

Streambed Mobility/Stability Analysis

Modified Shields Approach

References:

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

Appendix E--Methods for Streambed Mobility/Stability Analysis

Limitations:

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

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

Slopes less than 5%

Sand/gravel streams with high relative submergence

γ_s	165	specific weight of sediment particle (lb/ft^3)
γ	62.4	specific weight of water (1b/ft^3)
τ_{D50}	0.049	dimensionless Shields parameter for D50, use table E.1 of USFS manual or assume 0.045 for poorly sorted channel bed

Flow	2-YR (12.5 cfs)	10-YR (27.6 cfs)	25-YR (39.8 cfs)	50-YR (47.0 cfs)	100-YR (48.3 cfs)	500-YR (50.5 cfs)	100-YR (2080) (53.5 cfs)
Average Modeled Shear Stress (lb/ft^2)	1.0	1.5	1.9	2.0	2.1	2.4	2.2
τ_{ci}		Structure					
1.00	No Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.97	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.93	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.88	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.82	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.77	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.72	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.68	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.64	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.59	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.56	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.52	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.48	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.45	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.42	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.39	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.34	Motion	Motion	Motion	Motion	Motion	Motion	Motion
0.31	Motion	Motion	Motion	Motion	Motion	Motion	Motion

D16	0.425	mm	0.02	in	
D50	0.75	inches	19.1	mm	
	0.1	ft			
D84	2.10	inches	53.3	mm	
D100	2.5	inches	63.5	mm	

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

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Appendix F

WDFW Future Projections for Climate-Adapted Culvert Design Printout

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Future Projections for Climate-Adapted Culvert Design

Project Name: CR2

Stream Name:

Drainage Area: 64 ac

Projected mean percent change in bankfull flow:

2040s: 12%

2080s: 16.7%

Projected mean percent change in bankfull width:

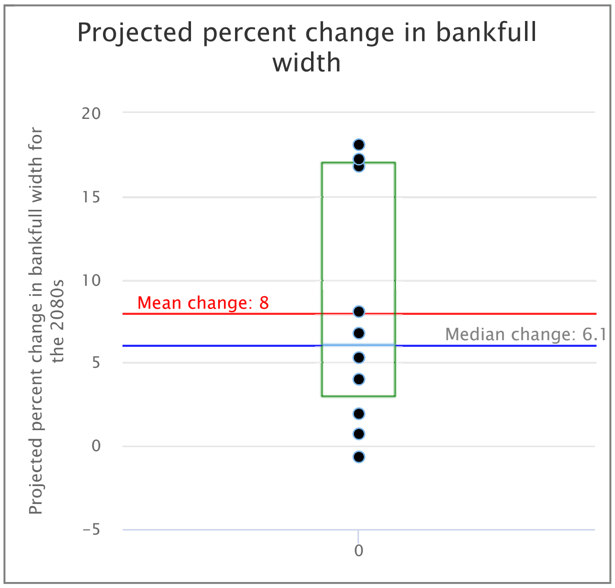
2040s: 5.8%

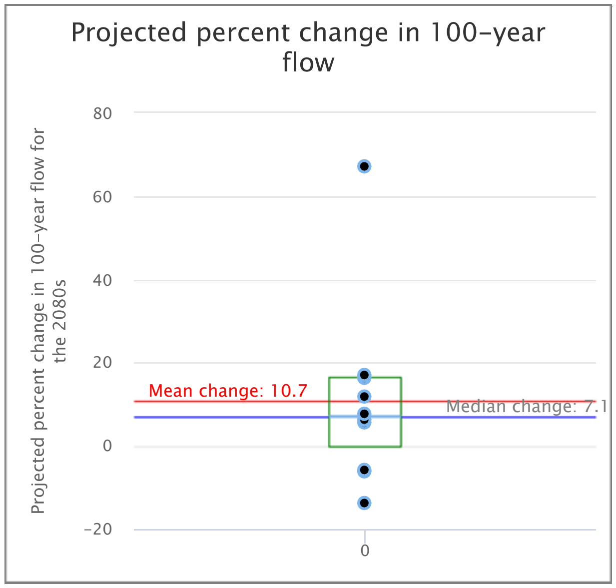
2080s: 8%

Projected mean percent change in 100-year flood:

2040s: 1.3%

2080s: 10.7%





Black dots are projections from 10 separate models

The Washington Department of Fish and Wildlife makes no guarantee concerning the data's content, accuracy, precision, or completeness. WDFW makes no warranty of fitness for a particular purpose and assumes no liability for the data represented here.

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Appendix G

Large Woody Material Calculations

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WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	***SR 534 MP 0.60***		**Key piece volume**	***1.310***	*yd3*	
Stream name	*UNT to Carpenter Creek*		**Key piece/ft**	***0.0335***	*per ft stream*	
length of regrade[a]	*569*	*ft*	**Total wood vol./ft**	***0.3948***	*yd3/ft stream*	
Bankfull width	*7.9*	*ft*	**Total LWM[c] pieces/ft stream**	***0.1159***	*per ft stream*	
Habitat zone[b]	*Western WA*					

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd^3/log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter (ft)	$D_{root\ collar}$ (ft)	L/2-Lrw (ft)
A	2.0	*20*	2.23	**yes**	yes	19	42.46	2.00	2.07	7.06
B	1.5	*20*	1.22	**yes**	no	19	23.24	1.50	1.57	7.825
C	1.4	*15*	0.83	**no**	no	25	20.77	1.50	1.46	5.43
D			0.00				0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	19	63	86.5
Targets	**19**	**66**	**224.6**
	on target	deficit	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington lowla	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa pine	(mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d]includes rootwad if present

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SR 534 Tributary to Carpenter Creek

Large Wood Structure Stability Analysis

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Factors of Safety and Design Constants	2
Hydrologic and Hydraulic Inputs	3
Stream Bed Substrate Properties	4
Bank Soil Properties	5
Wood Properties	6
Single Log Stability Analysis	7 - 8
Notation and List of Symbols	9 - 10

Date of Last Revision: January 7, 2016

Designer:
Aaron Miller

Reviewed by:
Tyler Nabours, 1/21/2021

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

Reference for Companion Paper:
Rafferty, M. 2016. *Computational Design Tool for Evaluating the Stability of Large Wood Structures.* Technical Note TN-103.1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, National Stream & Aquatic Ecology Center. 27 p.

SR 534 Tributary to Carpenter Creek
Factors of Safety and Design Constants

Spreadsheet developed by
Michael Rafferty, P.E.

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

Symbol	Description	Units	Value
C_{Lrock}	Coefficient of lift for submerged boulder (D'Aoust, 2000)	-	0.17
C_{Drock}	Coefficient of drag for submerged boulder (Schultz, 1954)	-	0.85
g	Gravitational acceleration constant	ft/s^2	32.174
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-	3.00
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-	1.00
SG_{rock}	Specific gravity of quartz particles	-	2.65
γ_{rock}	Dry unit weight of boulders	lb/ft^3	165.0
γ_w	Specific weight of water at 50ºF	lb/ft^3	62.40
η	Rootwad porosity from NRCS Tech Note 15 (2001)	-	0.20
ν	Kinematic viscosity of water at 50ºF	ft/s^2	1.41E-05

SR 534 Tributary to Carpenter Creek
Hydrologic and Hydraulic Inputs

Spreadsheet developed by
Michael Rafferty, P.E.

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

Site ID	Proposed Station	Design Discharge, Q_{des} (cfs)	Maximum Depth, d_w (ft)	Average Velocity, u_{avg} (ft/s)	Bankfull Width, W_{BF} (ft)	Wetted Area, A_W (ft^2)	Radius of Curvature, R_c (ft)
Arc 1	11+29	48	1.30	7.04	8.0	6	16
Arc 2	11+49	48	2.02	6.72	8.0	8	
Arc 3	11+80	48	1.85	3.52	8.0	16	16
Arc 4	12+74	48	1.44	4.28	8.0	13	
Arc 5	13+00	48	1.40	4.27	8.0	12	16
Arc 6	13+42	48	1.51	4.30	8.0	12	16
Arc 7	13+80	48	1.52	4.41	8.0	12	16
Arc 8	14+15	48	1.48	5.68	8.0	9	16
Arc 9	18+51	48	1.05	5.39	8.0	7	
Arc 10	18+23	48	1.20	3.98	8.0	10	16
Arc 11	18+03	48	1.08	4.03	8.0	8	16
Arc 12	17+78	48	1.16	3.94	8.0	9	16
Arc 13	17+40	48	1.15	4.16	8.0	8	
Arc 14	14+42	48	0.94	3.28	8.0	10	
Arc 15	14+60	48	0.89	8.00	8.0	5	16
Arc 16	17+26	48	1.08	3.99	8.0	8	16
Arc 17	16+99	48	1.14	3.97	8.0	8	16
Arc 18	15+99	48	2.06	1.79	8.0	27	
Arc 19	15+76	48	2.88	1.11	8.0	37	16

SR 534 Tributary to Carpenter Creek
Stream Bed Substrate Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Site ID	Proposed Station	Stream bed D_{50} (mm)	Stream Bed Substrate Grain Size Class	Bed Soil Class	Dry Unit Weight[1], γ_{bed} (lb/ft^3)	Buoyant Unit Weight, γ'_{bed} (lb/ft^3)	Friction Angle, ϕ_{bed} (deg)
Arc 1	11+29	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 2	11+49	32.80	Very coarse gravel	5		#DIV/0!	40
Arc 3	11+80	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 4	12+74	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 5	13+00	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 6	13+42	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 7	13+80	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 8	14+15	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 9	18+51	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 10	18+23	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 11	18+03	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 12	17+78	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 13	17+40	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 14	14+42	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 15	14+60	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 16	17+26	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 17	16+99	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 18	15+99	32.80	Very coarse gravel	5	128.3	79.9	40
Arc 19	15+76	32.80	Very coarse gravel	5	128.3	79.9	40

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

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

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

SR 534 Tributary to Carpenter Cree
Bank Soil Properties

Spreadsheet developed by Michael Rafferty, P.E.

Site ID	Proposed Station	Bank Soils (from field observations)	Bank Soil Class	Dry Unit Weight, γ_{bank} (lb/ft^3)	Buoyant Unit Weight, γ'_{bank} (lb/ft^3)	Friction Angle, ϕ_{bank} (deg)
Arc 1	11+29	**Gravel, loose**	5	125.7	78.3	36
Arc 2	11+49	**Gravel, loose**	5	125.7	78.3	36
Arc 3	11+80	**Gravel, loose**	5	125.7	78.3	36
Arc 4	12+74	**Gravel, loose**	5	125.7	78.3	36
Arc 5	13+00	**Gravel, loose**	5	125.7	78.3	36
Arc 6	13+42	**Gravel, loose**	5	125.7	78.3	36
Arc 7	13+80	**Gravel, loose**	5	125.7	78.3	36
Arc 8	14+15	**Gravel, loose**	5	125.7	78.3	36
Arc 9	18+51	**Gravel, loose**	5	125.7	78.3	36
Arc 10	18+23	**Gravel, loose**	5	125.7	78.3	36
Arc 11	18+03	**Gravel, loose**	5	125.7	78.3	36
Arc 12	17+78	**Gravel, loose**	5	125.7	78.3	36
Arc 13	17+40	**Gravel, loose**	5	125.7	78.3	36
Arc 14	14+42	**Gravel, loose**	5	125.7	78.3	36
Arc 15	14+60	**Gravel, loose**	5	125.7	78.3	36
Arc 16	17+26	**Gravel, loose**	5	125.7	78.3	36
Arc 17	16+99	**Gravel, loose**	5	125.7	78.3	36
Arc 18	15+99	**Gravel, loose**	5	125.7	78.3	36
Arc 19	15+76	**Gravel, loose**	5	125.7	78.3	36

SR 534 Tributary to Carpenter Creek
Large Wood Properties

Spreadsheet developed by
Michael Rafferty, P.E.

Project Location: West Coast

Timber Unit Weights			Air-dried[1] γ_{Td} (lb/ft^3)	Green[2] γ_{Tgr} (lb/ft^3)
Selected Species	**Common Name**	**Scientific Name**		
Tree Type #1:	**Alder, Red**	Alnus rubra	28.7	46.0
Tree Type #2:	**Cedar, Western redcedar**	Thuja plicata	22.4	27.0
Tree Type #3:	**Maple, Bigleaf**	Acer macrophyllum	33.5	47.0
Tree Type #4:	**Douglas-fir, Coast**	Pseudotsuga menziesii var. menzi.	33.5	38.0
Tree Type #5:	**Hemlock, Western**	Tsuga heterophylla	31.4	41.0
Tree Type #6:				
Tree Type #7:				
Tree Type #8:				
Tree Type #9:				
Tree Type #10:				

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

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

Source for timber unit weights:

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

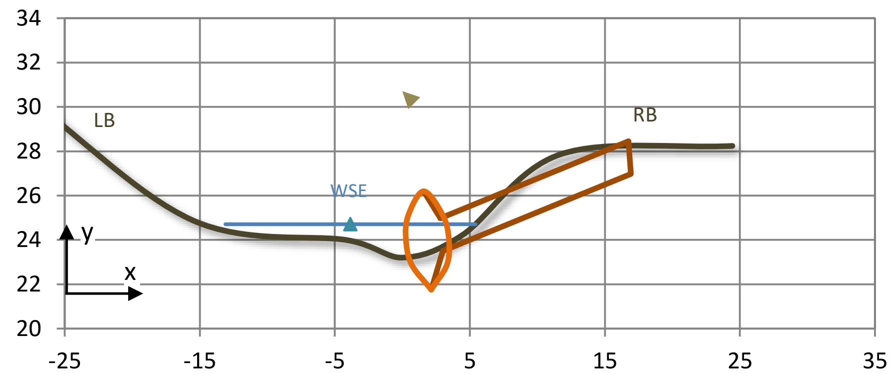
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 6	Flow Deflection	Left bank	Outside	13+42	1.51	2.00	6.81

Multi-Log Structures	Layer	Log ID
	N/A	20

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-28.29	30.71
Top LB	-15.60	24.91
Toe LB	-4.03	23.98
Thalweg	0.00	23.20
Toe RB	4.45	24.22
Top RB	11.73	27.86
Fldpln RB	24.44	28.24

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



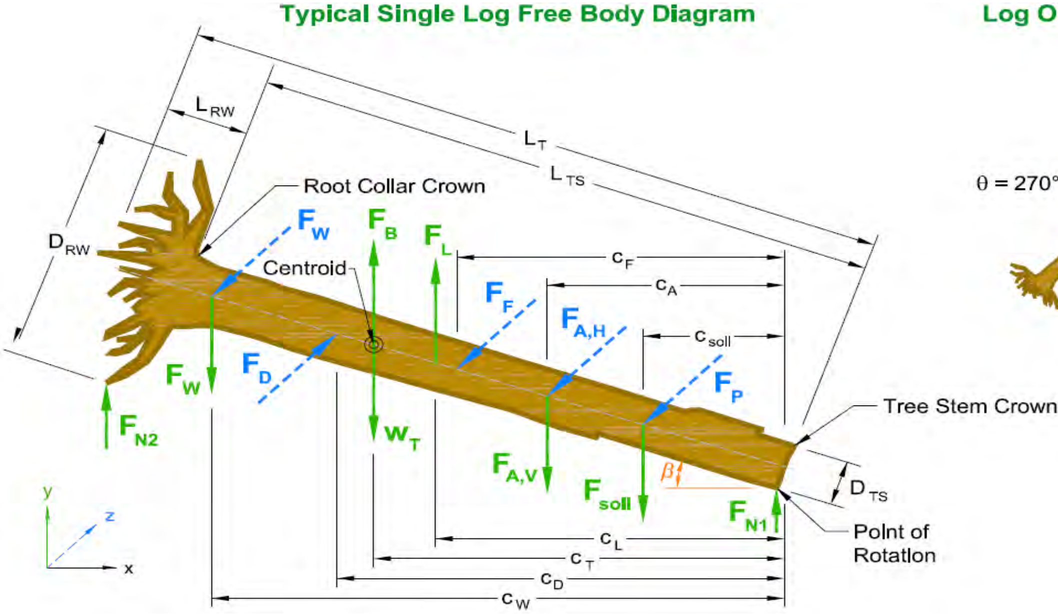
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	10.0	Root collar: Bottom	3.00	23.50	21.76	28.45	4.00

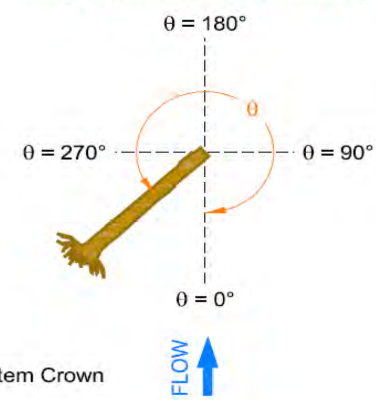
Tip Bury Depth 0.30 Crown Embedded Length 8.14

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	8.14	0.66	0.33

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	30.4	2.3	32.7	1,098	0
↓WS↑Thw	4.9	5.3	10.2	343	637
↓Thalweg	0.0	1.6	1.6	61	99
Total	35.3	9.2	44.5	1,501	737

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	737	↑
F_L (lbf)	0	
W_T (lbf)	1,501	↓
F_{soil} (lbf)	510	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,275	↓
FS_V	2.73	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	4.1	0.0	4.1	510
Total	4.1	0.0	4.1	510

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.32	0.98	1.10	0.00	2.44	440

Horizontal Force Balance

F_D (lbf)	440	→
F_P (lbf)	983	←
F_F (lbf)	962	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,505	←
FS_H	4.42	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	5.82	0.84	265
Bank	3.85	983	17.68	0.73	697
Total	-	983	23.50	-	962

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	0.0	17.3	12.3	6.9	10.8	6.9

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	8,485	↷
M_r (lbf)	58,681	↶
FS_M	6.92	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

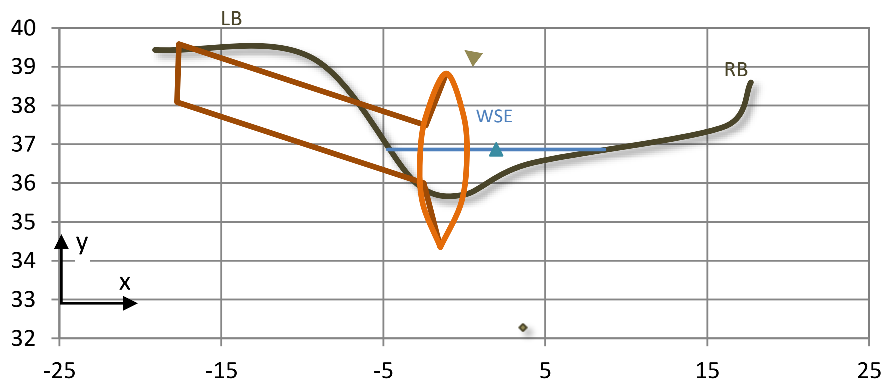
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 12	Flow Deflection	Left bank	Outside	17+78	1.16	2.00	6.25

Multi-Log Structures	Layer	Log ID
	N/A	24, 38, 45, 52,

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.10	39.43
Top LB	-9.48	39.25
Toe LB	-3.00	36.01
Thalweg	0.00	35.71
Toe RB	4.00	36.50
Top RB	16.03	37.45
Fldpln RB	17.70	38.60

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



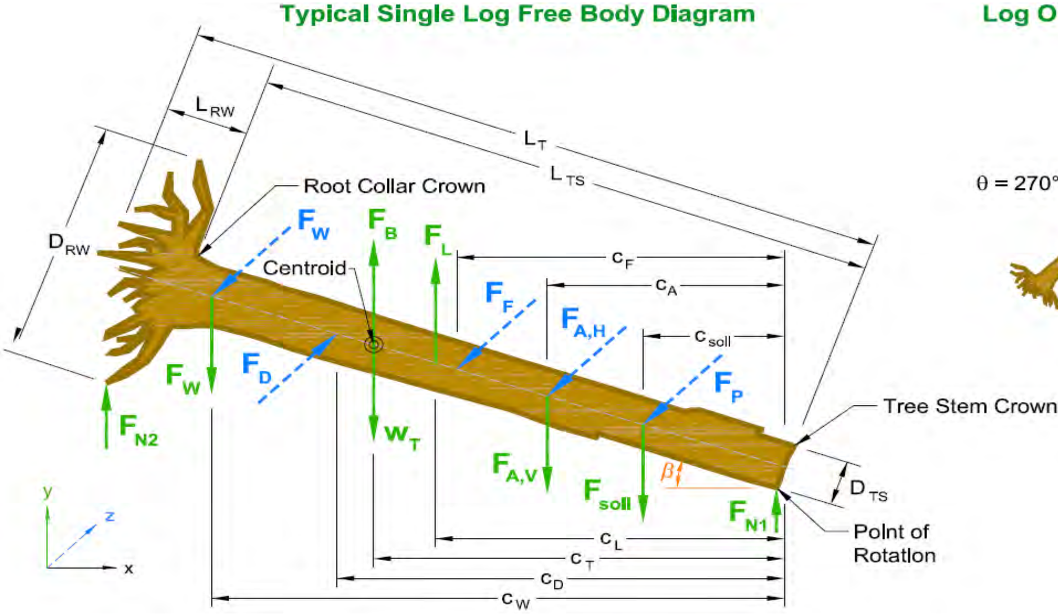
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	50.0	6.0	Root collar: Bottom	-2.50	36.00	34.35	39.58	4.00

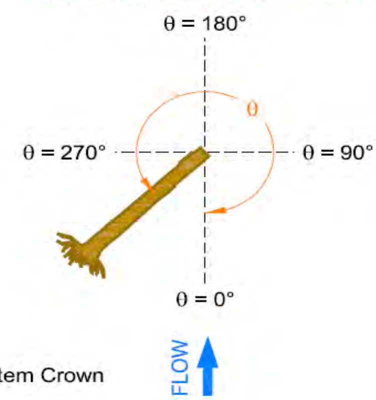
Tip Bury Depth 0.30   Crown Embedded Length 11.52

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	11.52	0.78	0.39

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	31.5	3.8	35.3	1,184	0
↓WS↑Thw	3.8	4.0	7.8	261	485
↓Thalweg	0.0	1.5	1.5	56	92
Total	35.3	9.2	44.5	1,500	576

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	576	↑
F_L (lbf)	0	
W_T (lbf)	1,500	↓
F_{soil} (lbf)	847	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,771	↓
FS_V	4.07	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	6.7	0.0	6.7	847
Total	6.7	0.0	6.7	847

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.46	0.90	1.14	0.00	4.12	623

Horizontal Force Balance

F_D (lbf)	623	→
F_P (lbf)	1,631	←
F_F (lbf)	1,306	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,314	←
FS_H	4.71	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	142
Bank	3.85	1,631	18.87	0.73	1,163
Total	-	1,631	20.87	-	1,306

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	0.0	17.5	12.3	7.7	9.4	7.7

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	7,735
M_r (lbf)	84,632
FS_M	10.94

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by Michael Rafferty, P.E.

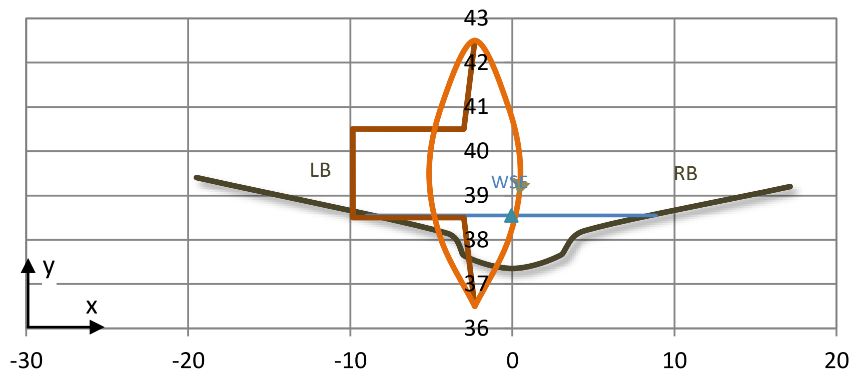
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 10	Rootwad	Right bank	Inside	18+23	1.20	2.00	3.98

Multi-Log Structures	Layer	Log ID
	Key Log	21, 58

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.50	39.41
Top LB	-4.01	38.15
Toe LB	-3.00	37.65
Thalweg	0.00	37.35
Toe RB	3.00	37.66
Top RB	4.41	38.20
Fldpln RB	17.14	39.20

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



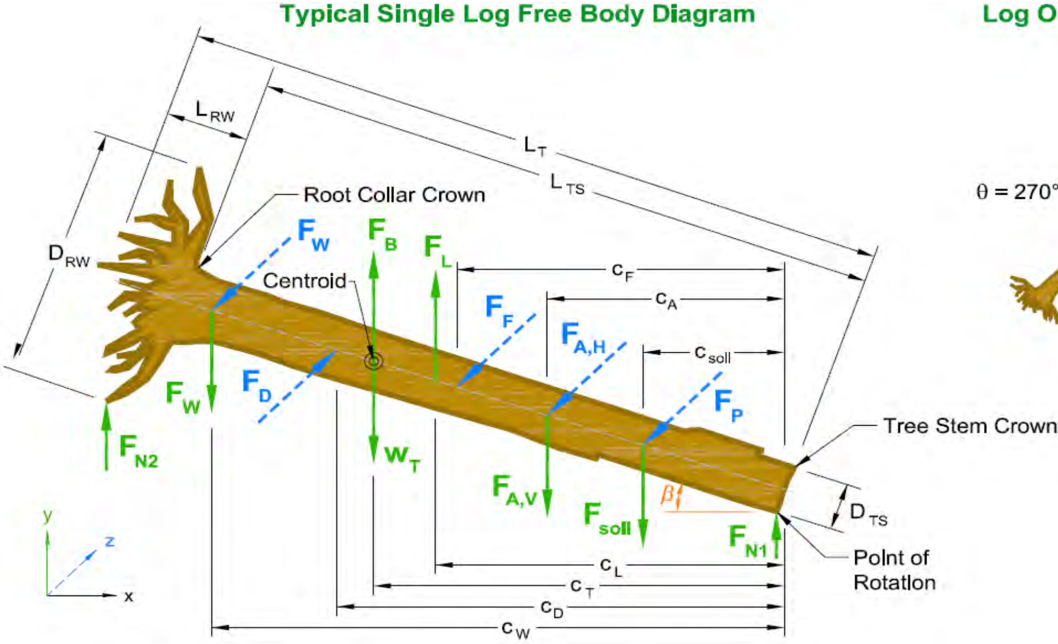
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	20.0	0.0	Root collar: Bottom	-3.00	38.50	36.50	42.50	5.00

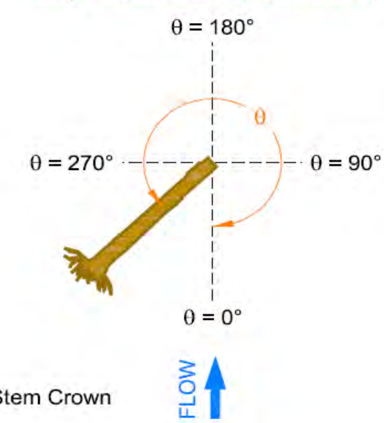
Tip Bury Depth 1.15 Crown Embedded Length 0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	62.4	16.7	79.1	2,655	0
↓WS↑Thw	0.4	4.4	4.8	162	301
↓Thalweg	0.0	0.7	0.7	25	41
Total	62.8	21.8	84.6	2,841	342

Lift Force

C_{LT}	0.24
F_L (lbf)	19

Vertical Force Balance

F_B (lbf)	342	↑
F_L (lbf)	19	↑
W_T (lbf)	2,841	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	704	↑
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,777	↓
FS_V	2.67	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.48	0.50	1.24	0.00	4.81	369

Horizontal Force Balance

F_D (lbf)	369	→
F_P (lbf)	0	
F_F (lbf)	1,355	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	986	←
FS_H	3.67	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	478
Bank	3.85	0	4.24	0.73	877
Total	-	0	6.24	-	1,355

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.9	13.1	11.0	12.9	0.0	2.1	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	10,850
M_r (lbf)	88,159
FS_M	8.13 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

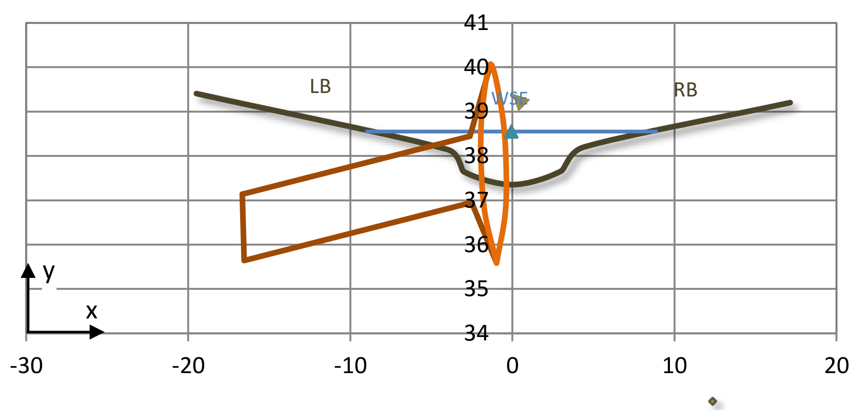
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 10	Log Vane	Right bank	Inside	18+23	1.20	2.00	3.98

Multi-Log Structures	Layer	Log ID
	Footer	23,59

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.50	39.41
Top LB	-4.01	38.15
Toe LB	-3.00	37.65
Thalweg	0.00	37.35
Toe RB	3.00	37.66
Top RB	4.41	38.20
Fldpln RB	17.14	39.20

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



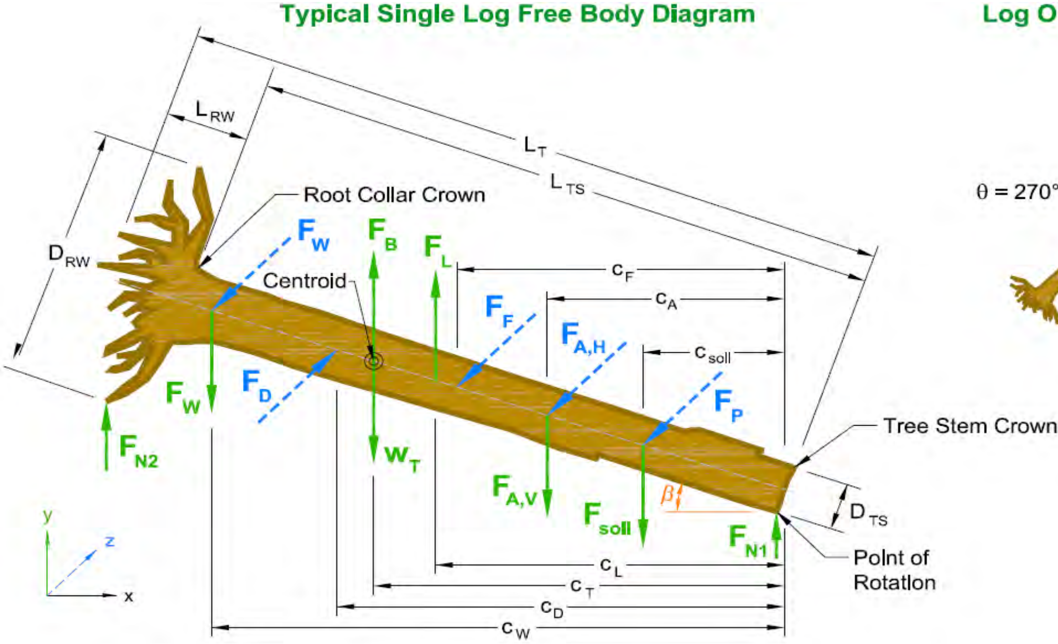
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	110.0	-5.0	Root collar: Bottom	-2.50	36.95	35.59	40.07	4.08

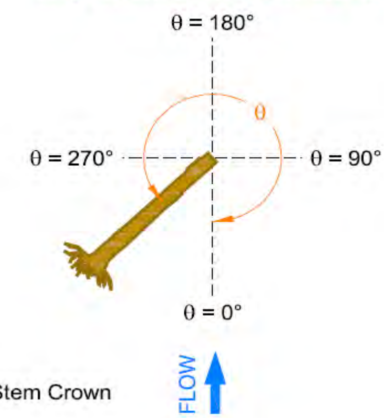
Tip Bury Depth -0.40 Crown Embedded Length 12.5

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	12.48	2.04	1.02

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	1.9	1.9	65	0
↓WS↑Thw	7.8	4.2	11.9	401	745
↓Thalweg	18.7	3.1	21.8	829	1,361
Total	26.5	9.2	35.7	1,295	2,106

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,106
F_L (lbf)	0
W_T (lbf)	1,295
F_{soil} (lbf)	1,676
$F_{W,V}$ (lbf)	704
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,568
FS_V	1.74

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	3.9	15.2	19.1	1,676
Total	3.9	15.2	19.1	1,676

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.39	0.57	1.00	0.43	3.98	249

Horizontal Force Balance

F_D (lbf)	249
F_P (lbf)	3,228
F_F (lbf)	1,177
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	4,156
FS_H	17.68

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.94	0.84	280
Bank	3.85	3,228	14.56	0.73	897
Total	-	3,228	18.50	-	1,177

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.6	0.0	14.5	9.6	6.2	8.3	8.3

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	23,767
M_r (lbf)	83,979
FS_M	3.53

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

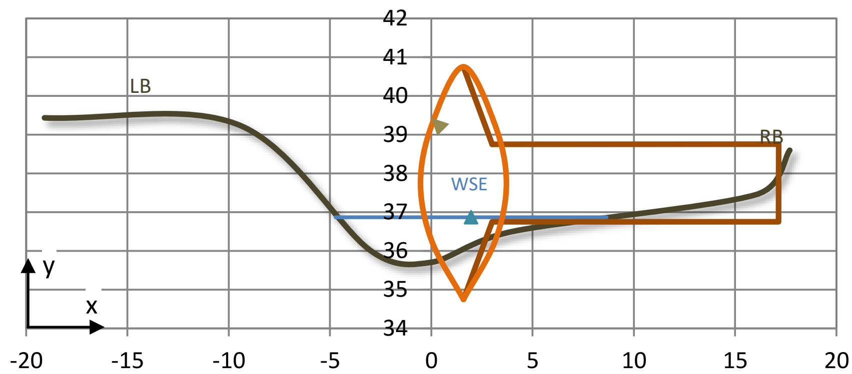
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 12	Rootwad	Right bank	Inside	17+78	1.16	2.00	3.94

Multi-Log Structures	Layer	Log ID
	Key Log	19, 25, 39, 46, 53

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.10	39.43
Top LB	-9.48	39.25
Toe LB	-3.00	36.01
Thalweg	0.00	35.71
Toe RB	4.00	36.50
Top RB	16.03	37.45
Fldpln RB	17.70	38.60

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



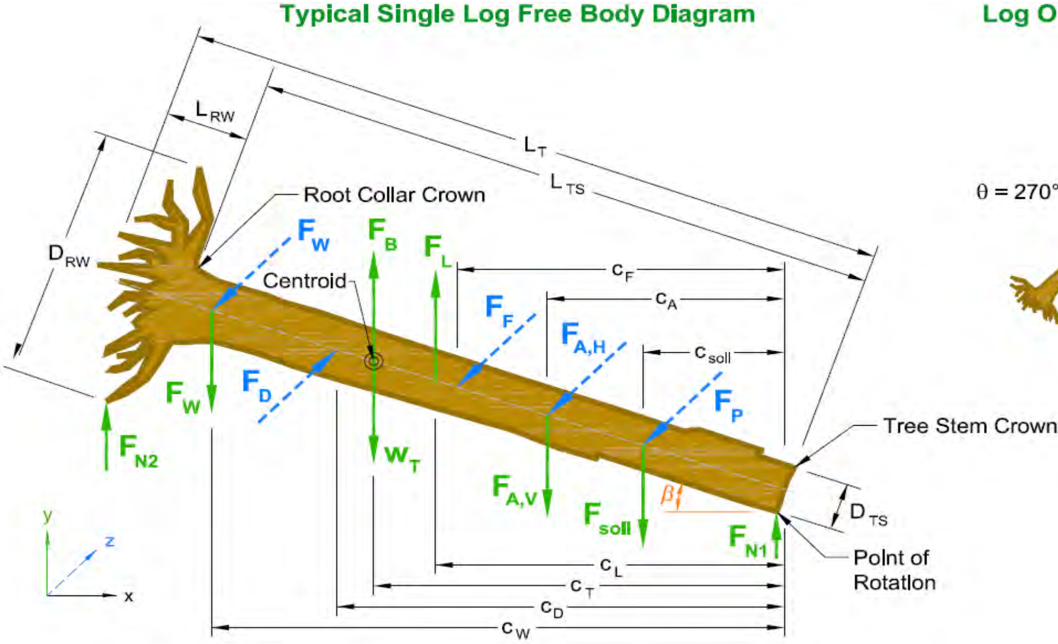
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	0.0	Root collar: Bottom	3.00	36.75	34.75	40.75	4.50

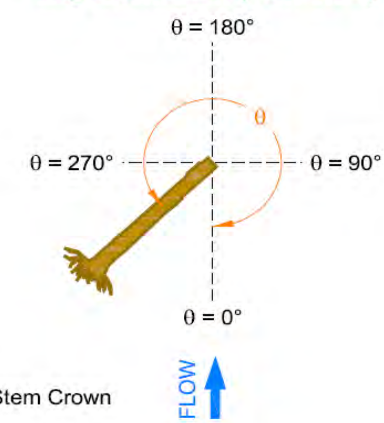
Tip Bury Depth 1.05 Crown Embedded Length 0.00

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	61.4	16.3	77.7	2,606	0
↓WS↑Thw	1.5	4.6	6.1	204	379
↓Thalweg	0.0	0.9	0.9	32	53
Total	62.8	21.8	84.6	2,842	432

Lift Force

C_{LT}	0.11
F_L (lbf)	8

Vertical Force Balance

F_B (lbf)	432	↑
F_L (lbf)	8	↑
W_T (lbf)	2,842	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	839	↑
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,563	↓
FS_V	2.22	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.52	0.49	1.10	0.00	5.02	341

Horizontal Force Balance

F_D (lbf)	341	→
F_P (lbf)	0	
F_F (lbf)	1,157	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	817	←
FS_H	3.40	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	163
Bank	3.85	0	14.14	0.73	995
Total	-	0	16.14	-	1,157

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.9	18.1	11.0	12.9	0.0	7.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	11,900
M_r (lbf)	66,501
FS_M	5.59 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

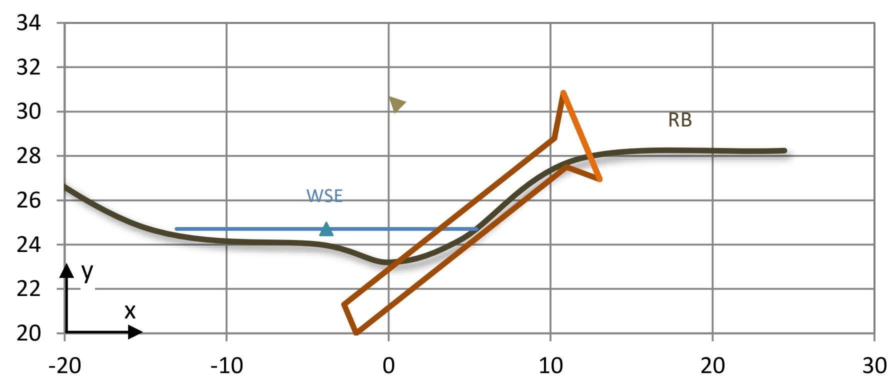
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 6	Flow Deflection	Left bank	Outside	13+42	1.51	2.00	6.81

Multi-Log Structures	Layer	Log ID
	N/A	22

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-28.29	30.71
Top LB	-15.60	24.91
Toe LB	-4.03	23.98
Thalweg	0.00	23.20
Toe RB	4.45	24.22
Top RB	11.73	27.86
Fldpln RB	24.44	28.24

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



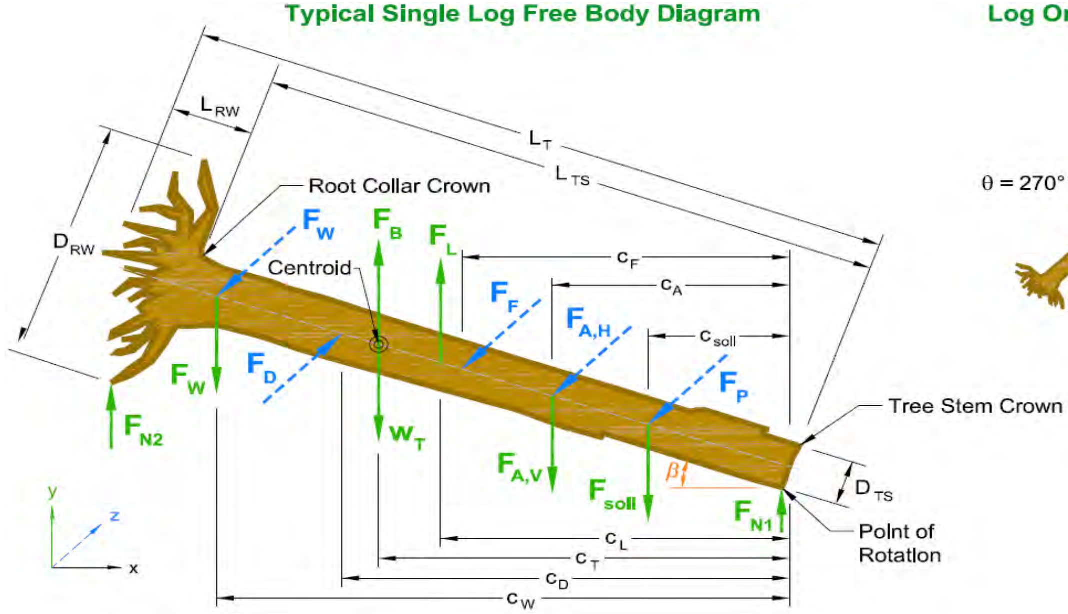
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.0	-30.0	Stem tip: Bottom	-2.00	20.00	20.00	30.85	3.82

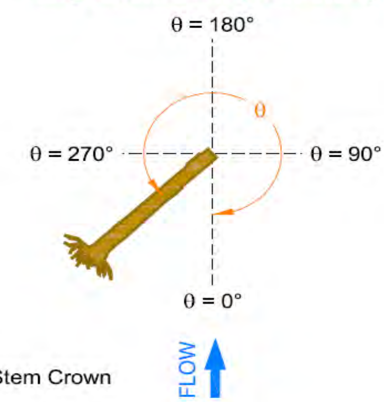
Tip Bury Depth -3.20 Crown Embedded Length 4.2

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	4.22	2.44	1.08
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft³)	V_{RW} (ft³)	V_T (ft³)	W_T (lbf)	F_B (lbf)
↑WSE	12.2	9.2	21.4	716	0
↓WS↑Thw	5.3	0.0	5.3	178	332
↓Thalweg	9.0	0.0	9.0	343	563
Total	26.5	9.2	35.7	1,238	895

Lift Force

C_{LT}	0.01
F_L (lbf)	2

Vertical Force Balance

F_B (lbf)	895	↑
F_L (lbf)	2	↑
W_T (lbf)	1,238	↓
F_{soil} (lbf)	543	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	884	↓
FS_V	1.98	

Soil Ballast Force

Soil	V_{dry} (ft³)	V_{sat} (ft³)	V_{soil} (ft³)	F_{soil} (lbf)
Bed	0.0	6.8	6.8	543
Bank	0.0	0.0	0.0	0
Total	0.0	6.8	6.8	543

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.31	0.98	0.90	0.21	2.35	403

Horizontal Force Balance

F_D (lbf)	403	→
F_P (lbf)	1,249	←
F_F (lbf)	733	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	1,579	←
FS_H	4.92	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	1,249	10.29	0.84	676
Bank	3.85	0	0.99	0.73	56
Total	-	1,249	11.28	-	733

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.6	9.4	6.8	9.6	2.1	4.6	2.8

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	9,859
M_r (lbf)	20,794
FS_M	2.11

Anchor Forces

Additional Soil Ballast

V_{Adry} (ft³)	V_{Awet} (ft³)	c_{Asoil} (ft)	$F_{A,Vsoil}$ (lbf)	$F_{A,HP}$ (lbf)

Mechanical Anchors

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

Boulder Ballast

Position	D_r (ft)	c_{Ar} (ft)	$V_{r,dry}$ (ft³)	$V_{r,wet}$ (ft³)	W_r (lbf)	$F_{L,r}$ (lbf)	$F_{D,r}$ (lbf)	$F_{A,Vr}$ (lbf)	$F_{A,Hr}$ (lbf)
								0	0
								0	0
								0	0

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

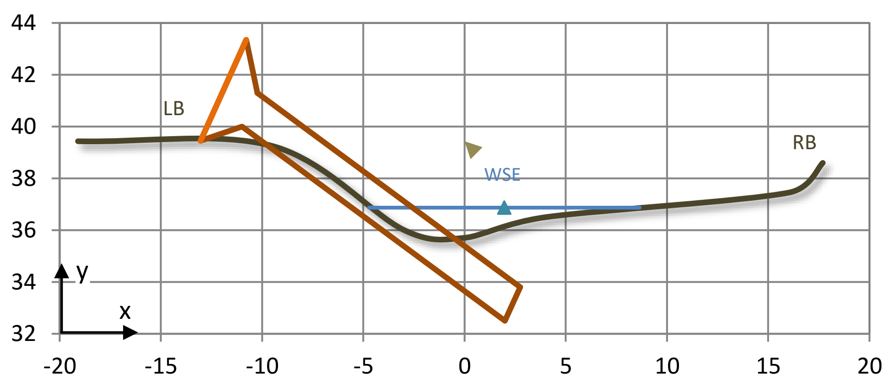
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 12	Flow Deflection	Left bank	Outside	17+78	1.16	2.00	6.25

Multi-Log Structures	Layer	Log ID
	N/A	26, 40, 47, 54

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.10	39.43
Top LB	-9.48	39.25
Toe LB	-3.00	36.01
Thalweg	0.00	35.71
Toe RB	4.00	36.50
Top RB	16.03	37.45
Fldpln RB	17.70	38.60

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



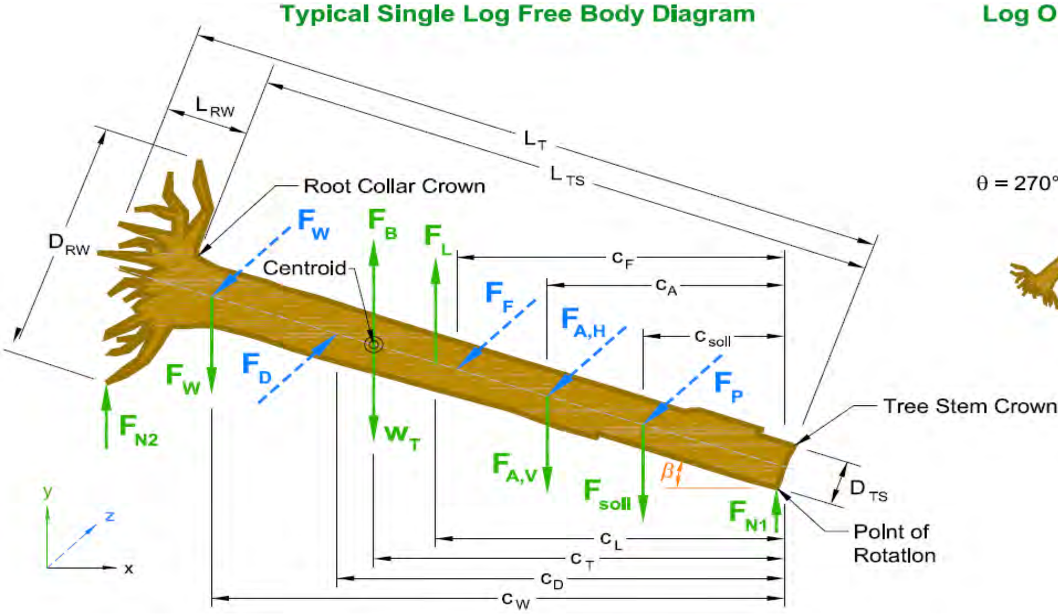
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	270.0	-30.0	Stem tip: Bottom	2.00	32.50	32.50	43.35	3.73

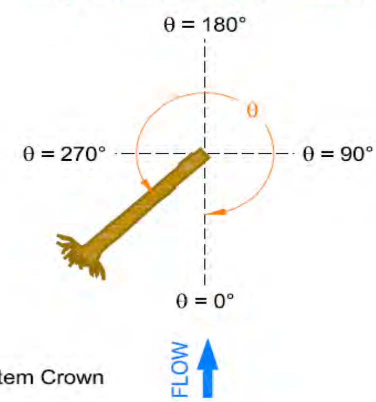
Tip Bury Depth -3.21 Crown Embedded Length 3.9

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	3.95	2.45	1.17
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	13.4	9.2	22.6	757	0
↓WS↑Thw	4.1	0.0	4.1	138	257
↓Thalweg	9.0	0.0	9.0	343	564
Total	26.5	9.2	35.7	1,238	820

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	820	↑
F_L (lbf)	0	
W_T (lbf)	1,238	↓
F_{soil} (lbf)	542	↓
$F_{W,V}$ (lbf)	839	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,798	↓
FS_V	3.19	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	6.8	6.8	542
Bank	0.0	0.0	0.0	0
Total	0.0	6.8	6.8	542

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.43	0.90	0.90	0.33	3.93	555

Horizontal Force Balance

F_D (lbf)	555	→
F_P (lbf)	1,246	←
F_F (lbf)	1,459	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,151	←
FS_H	4.88	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	1,246	8.64	0.84	1,139
Bank	3.85	0	2.81	0.73	320
Total	-	1,246	11.45	-	1,459

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.6	0.0	6.3	9.6	1.9	4.7	2.6

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	9,858
M_r (lbf)	35,989
FS_M	3.65 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by Michael Rafferty, P.E.

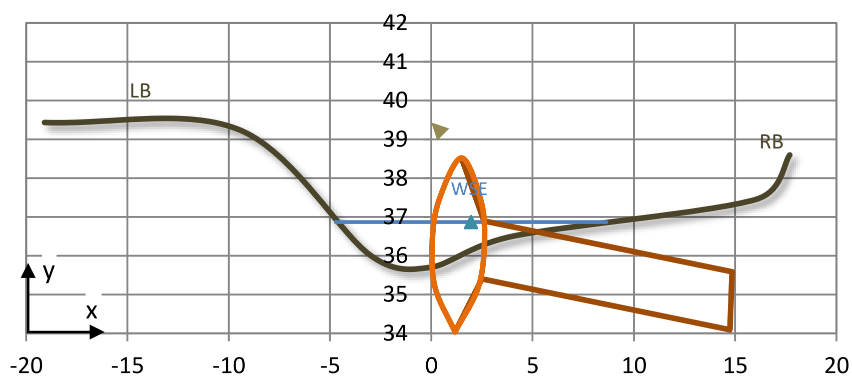
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 12	Log Vane	Right bank	Inside	17+78	1.16	2.00	3.94

Multi-Log Structures	Layer	Log ID
	Footer	18, 27, 41, 48, 55

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-19.10	39.43
Top LB	-9.48	39.25
Toe LB	-3.00	36.01
Thalweg	0.00	35.71
Toe RB	4.00	36.50
Top RB	16.03	37.45
Fldpln RB	17.70	38.60

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



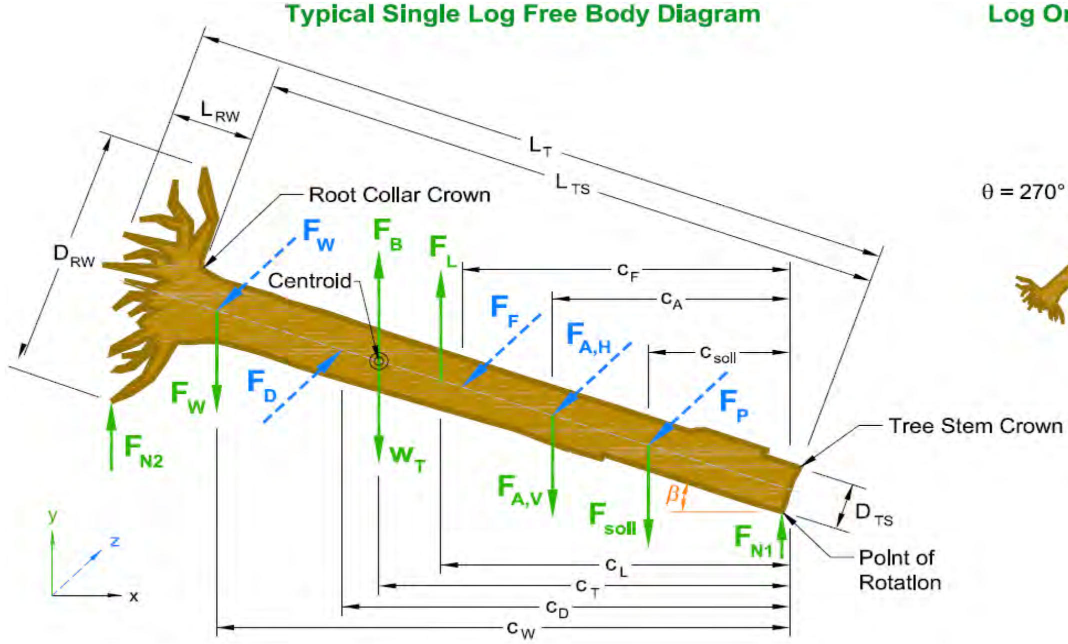
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	235.0	-5.0	Root collar: Bottom	2.50	35.40	34.04	38.52	4.76

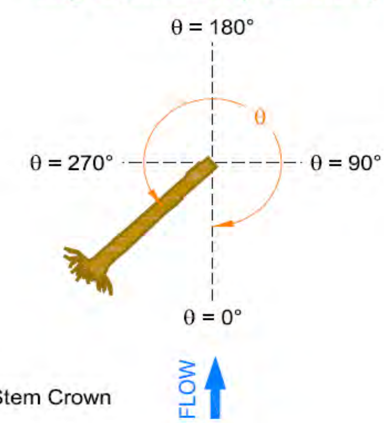
Tip Bury Depth -0.31 Crown Embedded Length 11.7

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	11.68	1.77	0.89

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	0.0	2.3	2.3	78	0
↓WS↑Thw	9.4	4.1	13.5	453	843
↓Thalweg	17.1	2.7	19.8	754	1,239
Total	26.5	9.2	35.7	1,286	2,082

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,082	↑
F_L (lbf)	0	
W_T (lbf)	1,286	↓
F_{soil} (lbf)	1,347	↓
$F_{W,V}$ (lbf)	839	↓
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,390	↓
FS_V	1.67	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	2.8	12.7	15.5	1,347
Total	2.8	12.7	15.5	1,347

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.55	0.57	1.10	0.43	8.01	575

Horizontal Force Balance

F_D (lbf)	575	→
F_P (lbf)	2,593	←
F_F (lbf)	1,053	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	3,071	←
FS_H	6.34	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	5.18	0.84	326
Bank	3.85	2,593	13.32	0.73	727
Total	-	2,593	18.50	-	1,053

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.6	0.0	14.1	9.6	5.8	8.3	7.8

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	28,020	↷
M_r (lbf)	70,261	↶
FS_M	2.51	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

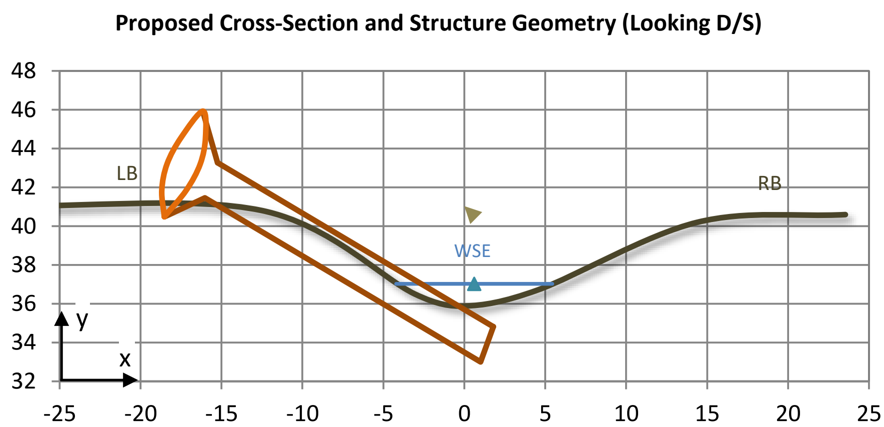
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 13	Rootwad	Left bank	Inside	16+43	1.15		4.16

Multi-Log Structures	Layer	Log ID
	Key Log	44, 51

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-28.96	41.03
Top LB	-12.51	40.80
Toe LB	-3.05	36.50
Thalweg	0.00	35.88
Toe RB	4.56	36.72
Top RB	14.37	40.19
Fldpln RB	23.54	40.59



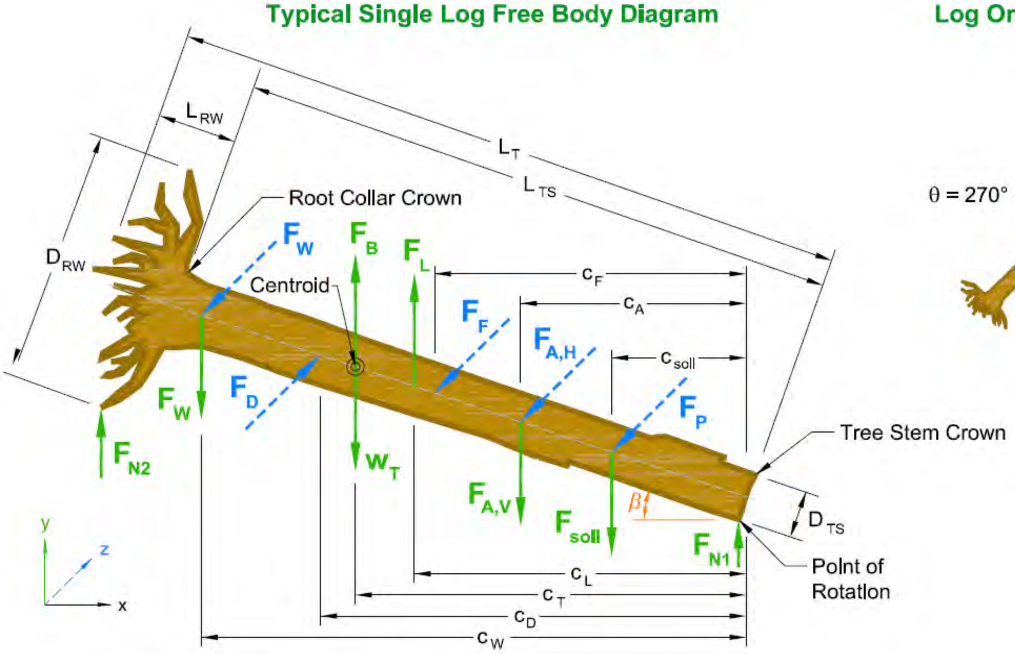
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	290.0	-25.0	Stem tip: Bottom	1.00	33.00	33.00	45.92	2.47

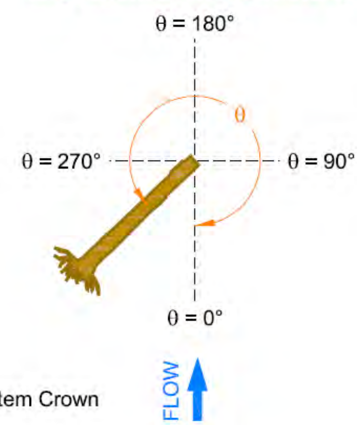
Tip Bury Depth -2.88 Crown Embedded Length 2.8

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	2.81	1.40	0.63
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	39.6	21.8	61.4	2,061	0
↓WS↑Thw	8.5	0.0	8.5	286	531
↓Thalweg	14.7	0.0	14.7	558	916
Total	62.8	21.8	84.6	2,904	1,447

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	1,447	↑
F_L (lbf)	0	
W_T (lbf)	2,904	↓
F_{soil} (lbf)	275	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,732	↓
FS_V	2.20	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	3.4	3.4	275
Bank	0.0	0.0	0.0	0
Total	0.0	3.4	3.4	275

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.31	0.52	1.12	0.43	3.30	137

Horizontal Force Balance

F_D (lbf)	137	→
F_P (lbf)	632	←
F_F (lbf)	1,331	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,826	←
FS_H	14.33	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	632	7.67	0.84	542
Bank	3.85	0	12.87	0.73	789
Total	-	632	20.54	-	1,331

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.8	0.0	6.2	12.8	1.4	9.2	1.8

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	17,608
M_r (lbf)	60,847
FS_M	3.46 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

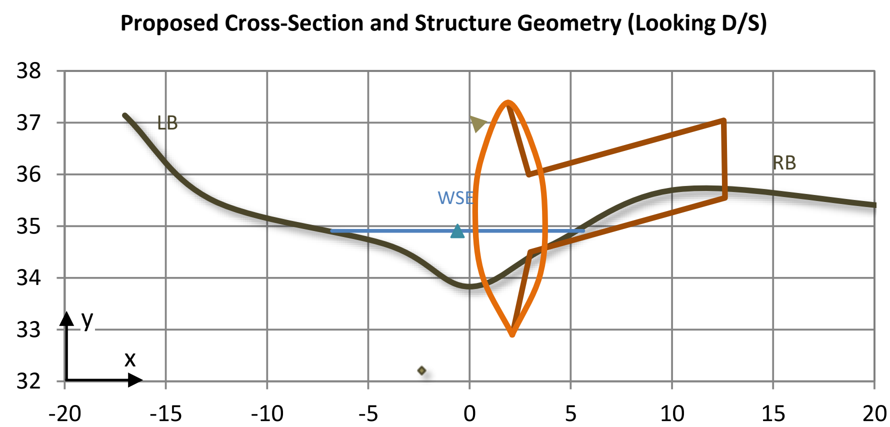
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 16	Flow Deflection	Right bank	Straight	16+12	1.08	2.00	3.99

Multi-Log Structures	Layer	Log ID
	N/A	9, 43, 50, 5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-17.03	37.14
Top LB	-12.67	35.49
Toe LB	-4.00	34.63
Thalweg	0.00	33.83
Toe RB	4.00	34.63
Top RB	10.26	35.71
Fldpln RB	20.97	35.37



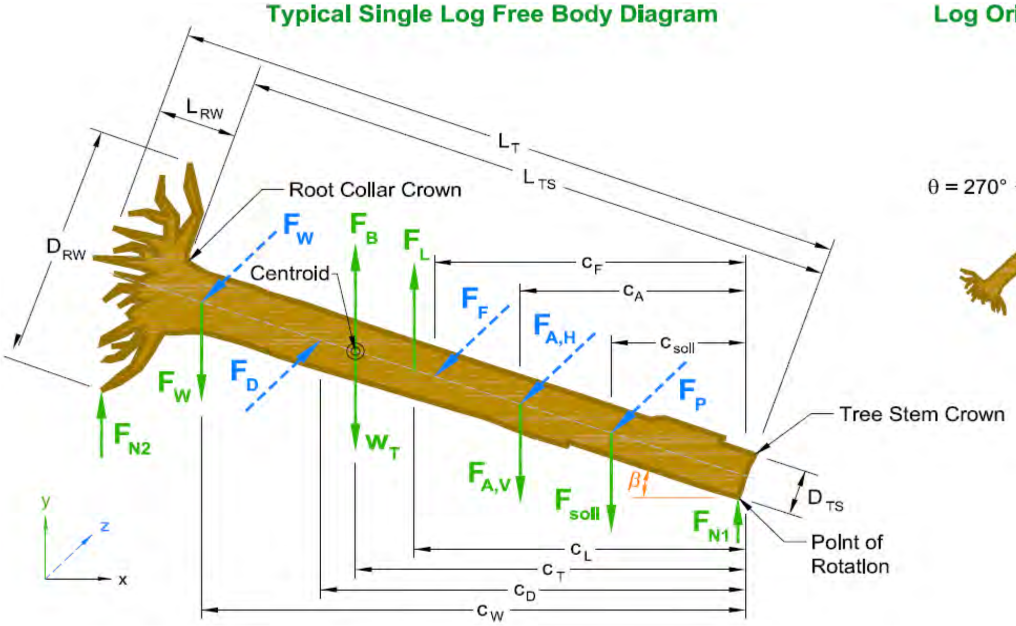
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	320.0	4.0	Root collar: Bottom	3.00	34.50	32.90	37.39	4.56

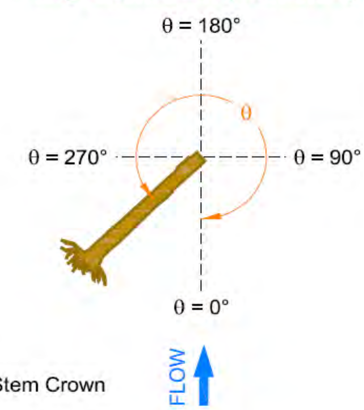
Tip Bury Depth 0.67 Crown Embedded Length 0.0

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	25.6	5.6	31.1	1,044	0
↓WS↑Thw	0.9	3.0	3.9	132	246
↓Thalweg	0.0	0.6	0.6	24	39
Total	26.5	9.2	35.7	1,200	285

Lift Force

C_{LT}	0.16
F_L (lbf)	11

Vertical Force Balance

F_B (lbf)	285	↑
F_L (lbf)	11	↑
W_T (lbf)	1,200	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	904	↓
FS_V	4.05	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.54	0.57	1.10	0.00	5.48	386

Horizontal Force Balance

F_D (lbf)	386	→
F_P (lbf)	0	
F_F (lbf)	672	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	285	←
FS_H	1.74	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.25	0.84	109
Bank	3.85	0	13.32	0.73	562
Total	-	0	15.57	-	672

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.7	15.1	12.8	9.7	0.0	6.8	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	3,364
M_r (lbf)	23,446
FS_M	6.97 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

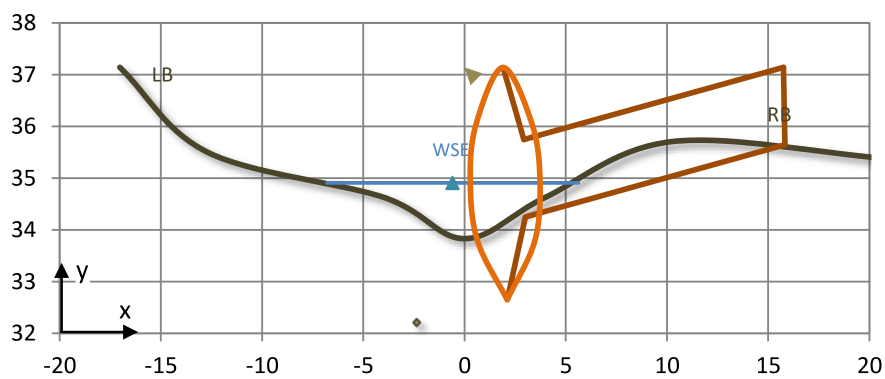
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 16	Flow Deflection	Left bank	Straight	16+12	1.08	2.00	3.99

Multi-Log Structures	Layer	Log ID
	N/A	8, 42, 49, 5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-17.03	37.14
Top LB	-12.67	35.49
Toe LB	-4.00	34.63
Thalweg	0.00	33.83
Toe RB	4.00	34.63
Top RB	10.26	35.71
Fldpln RB	20.97	35.37

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



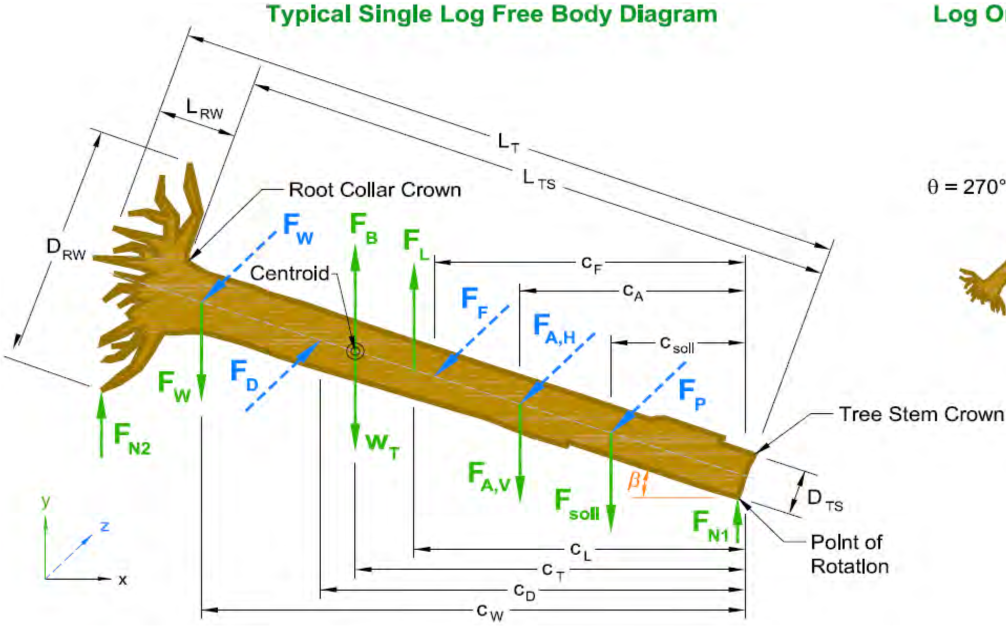
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	320.0	4.0	Root collar: Bottom	3.00	34.25	32.65	37.14	4.86

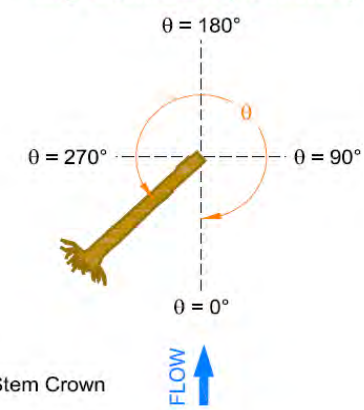
Tip Bury Depth 0.42 Crown Embedded Length 0.0

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	32.4	4.7	37.0	1,243	0
↓WS↑Thw	3.0	3.4	6.4	214	398
↓Thalweg	0.0	1.1	1.1	42	69
Total	35.3	9.2	44.5	1,499	467

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	467	↑
F_L (lbf)	0	
W_T (lbf)	1,499	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,032	↓
FS_V	3.21	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.58	0.57	1.10	0.00	6.49	488

Horizontal Force Balance

F_D (lbf)	488	→
F_P (lbf)	0	
F_F (lbf)	777	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	289	←
FS_H	1.59	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	5.17	0.84	201
Bank	3.85	0	17.09	0.73	575
Total	-	0	22.26	-	777

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	0.0	16.1	12.3	0.0	11.4	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	6,930
M_r (lbf)	31,991
FS_M	4.62 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

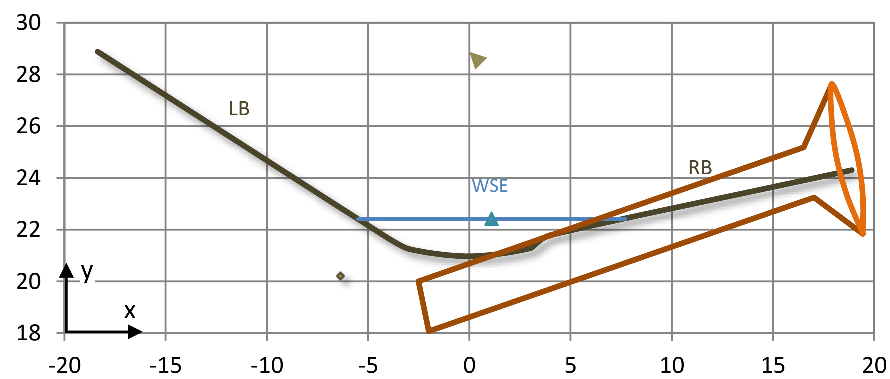
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 4	Flow Deflection	Right bank	Straight	12+75	1.44		4.28

Multi-Log Structures	Layer	Log ID
	N/A	13

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-18.36	28.88
Top LB	-4.23	21.77
Toe LB	-3.02	21.26
Thalweg	0.00	20.97
Toe RB	3.04	21.29
Top RB	4.05	21.80
Fldpln RB	18.89	24.30

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



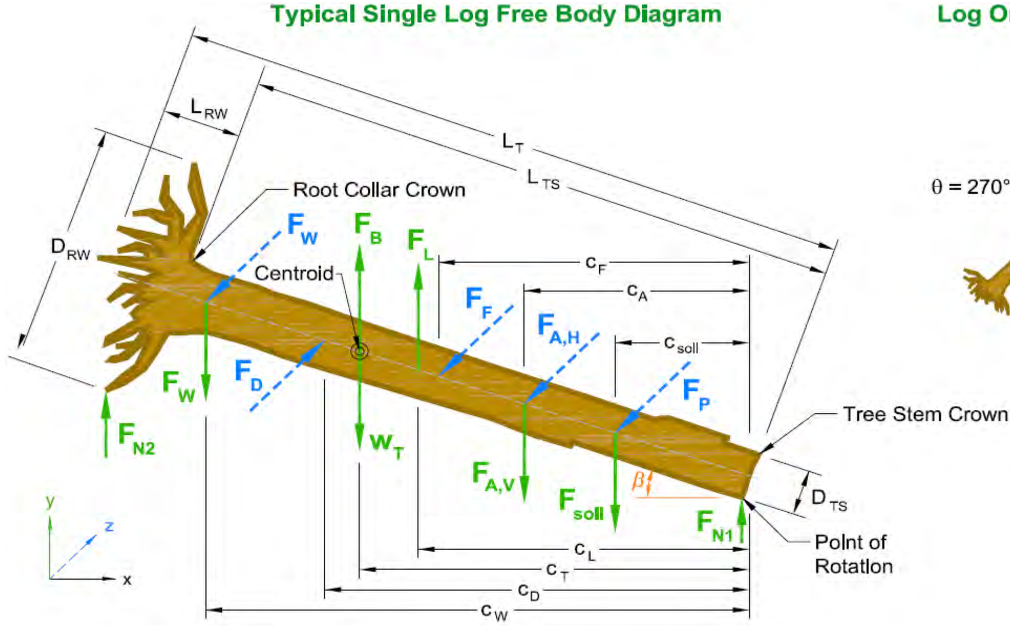
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	80.0	-15.0	Stem tip: Bottom	-2.00	18.07	18.07	27.63	1.82

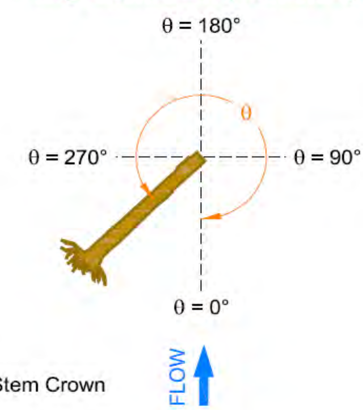
Tip Bury Depth -2.90 Crown Embedded Length 4.5

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	4.43	1.21	0.51
Bank	Gravel, loose	125.7	78.3	36.0	5	0.11	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	21.9	20.7	42.6	1,429	0
↓WS↑Thw	17.5	1.1	18.6	622	1,158
↓Thalweg	23.5	0.0	23.5	892	1,465
Total	62.8	21.8	84.6	2,943	2,623

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,623	↑
F_L (lbf)	0	
W_T (lbf)	2,943	↓
F_{soil} (lbf)	356	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	676	↓
FS_V	1.26	✗

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	4.5	4.5	355
Bank	0.0	0.0	0.0	0
Total	0.0	4.5	4.5	356

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.14	0.53	1.10	0.43	2.10	68

Horizontal Force Balance

F_D (lbf)	68	→
F_P (lbf)	817	←
F_F (lbf)	516	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	1,266	←
FS_H	19.64	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	817	7.89	0.84	186
Bank	3.85	0	16.12	0.73	330
Total	-	817	24.00	-	516

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.8	0.0	10.6	12.8	2.3	11.0	4.6

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	33,144	↷
M_r (lbf)	53,514	↶
FS_M	1.61	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

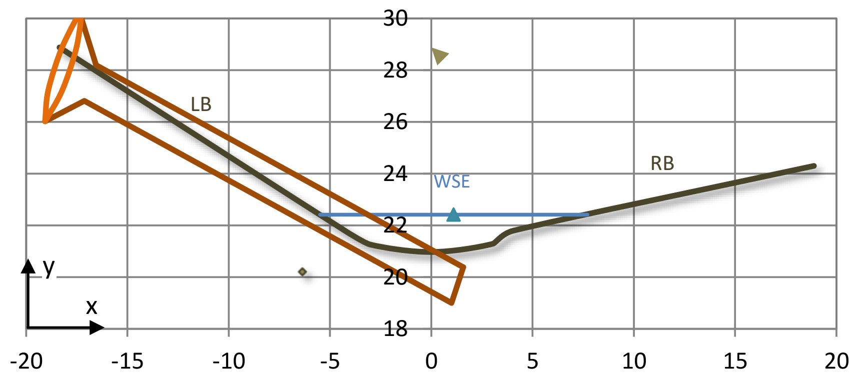
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 4	Log Weir	Left bank	Straight	12+75	1.44		4.28

Multi-Log Structures	Layer	Log ID
	Key Log	14

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-18.36	28.88
Top LB	-4.23	21.77
Toe LB	-3.02	21.26
Thalweg	0.00	20.97
Toe RB	3.04	21.29
Top RB	4.05	21.80
Fldpln RB	18.89	24.30

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



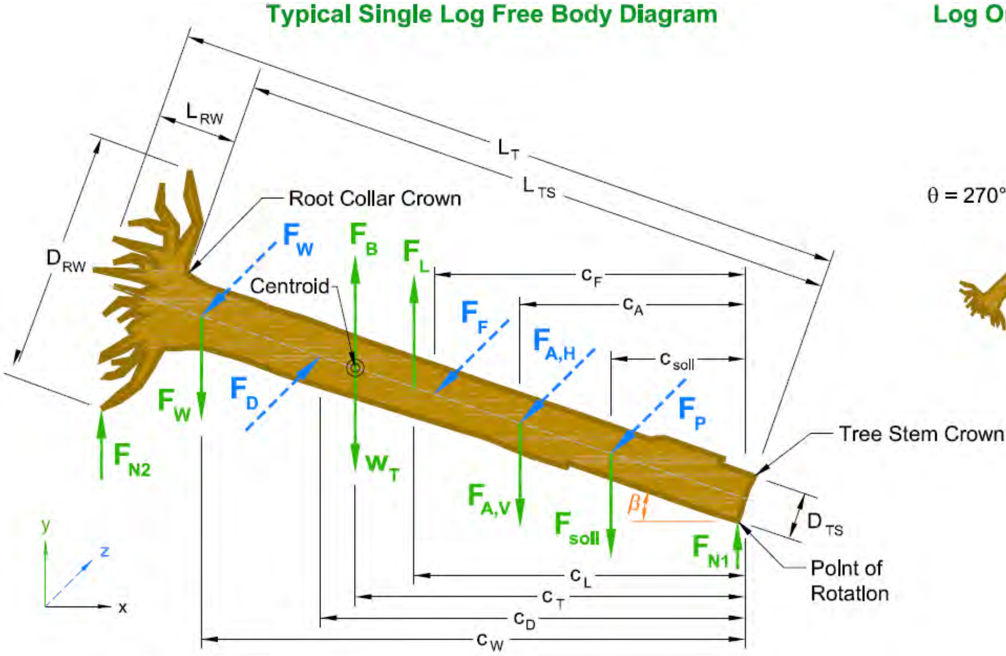
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	260.0	-23.0	Stem tip: Bottom	1.00	19.00	19.00	30.16	4.26

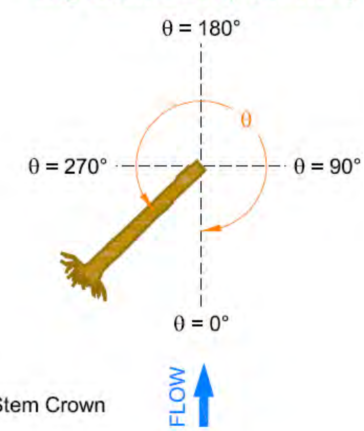
Tip Bury Depth -1.97 Crown Embedded Length 1.6

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	1.55	0.75	0.39
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	23.0	9.2	32.2	1,081	0
↓WS↑Thw	6.5	0.0	6.5	219	407
↓Thalweg	5.8	0.0	5.8	220	361
Total	35.3	9.2	44.5	1,520	768

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	768	↑
F_L (lbf)	0	
W_T (lbf)	1,520	↓
F_{soil} (lbf)	70	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	822	↓
FS_V	2.07	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.9	0.9	70
Bank	0.0	0.0	0.0	0
Total	0.0	0.9	0.9	70

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.34	0.62	1.10	0.43	3.55	268

Horizontal Force Balance

F_D (lbf)	268	→
F_P (lbf)	161	←
F_F (lbf)	625	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	518	←
FS_H	2.93	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	161	7.11	0.84	209
Bank	3.85	0	16.39	0.73	416
Total	-	161	23.50	-	625

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.2	0.0	5.2	12.2	0.8	10.8	1.0

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	9,921	↷
M_r (lbf)	31,619	↶
FS_M	3.19	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

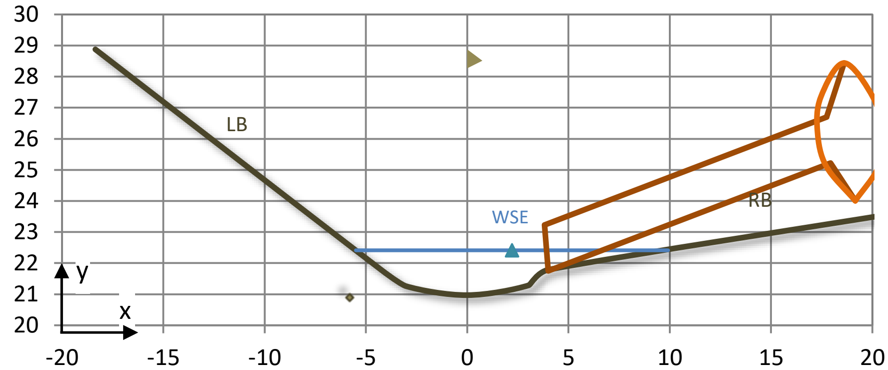
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 4	Floodplain	Right bank	Straight	12+75	1.44		4.28

Multi-Log Structures	Layer	Log ID
	N/A	11

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-18.36	28.88
Top LB	-4.23	21.77
Toe LB	-3.02	21.26
Thalweg	0.00	20.97
Toe RB	3.04	21.29
Top RB	4.05	21.80
Fldpln RB	25.00	24.00

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



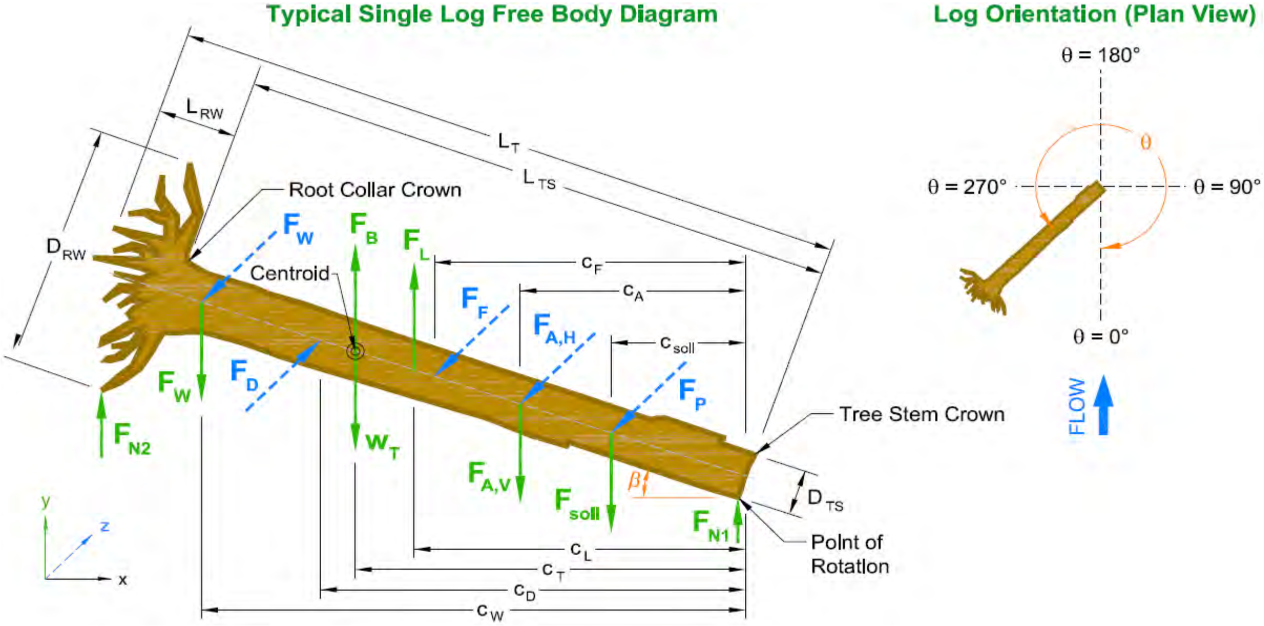
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	-10.0	Stem tip: Bottom	4.00	21.75	21.75	28.44	1.24

Tip Bury Depth 0.78 Crown Embedded Length 0.0

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram **Log Orientation (Plan View)**



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	34.1	9.2	43.3	1,453	0
↓WS↑Thw	1.2	0.0	1.2	41	77
↓Thalweg	0.0	0.0	0.0	0	0
Total	35.3	9.2	44.5	1,494	77

Lift Force

C_{LT}	0.35
F_L (lbf)	8

Vertical Force Balance

F_B (lbf)	77	↑
F_L (lbf)	8	↑
W_T (lbf)	1,494	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	636	↑
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	774	↓
FS_V	2.07	

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.10	0.62	0.76	0.00	0.94	21

Horizontal Force Balance

F_D (lbf)	21	→
F_P (lbf)	0	
F_F (lbf)	649	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	629	←
FS_H	31.32	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	649
Bank	3.85	0	0.00	0.73	0
Total	-	0	2.00	-	649

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	1.9	1.9	12.3	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	6,253
M_r (lbf)	43,721
FS_M	6.99

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

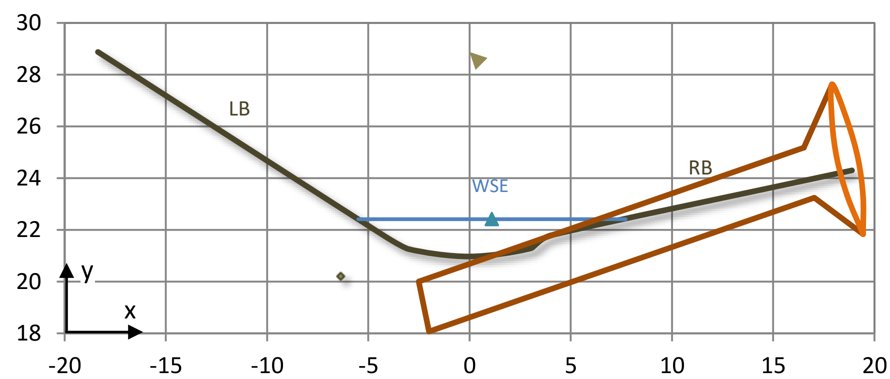
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 4	Flow Deflection	Right bank	Straight	12+75	1.44		4.28

Multi-Log Structures	Layer	Log ID
	N/A	13

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-18.36	28.88
Top LB	-4.23	21.77
Toe LB	-3.02	21.26
Thalweg	0.00	20.97
Toe RB	3.04	21.29
Top RB	4.05	21.80
Fldpln RB	18.89	24.30

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



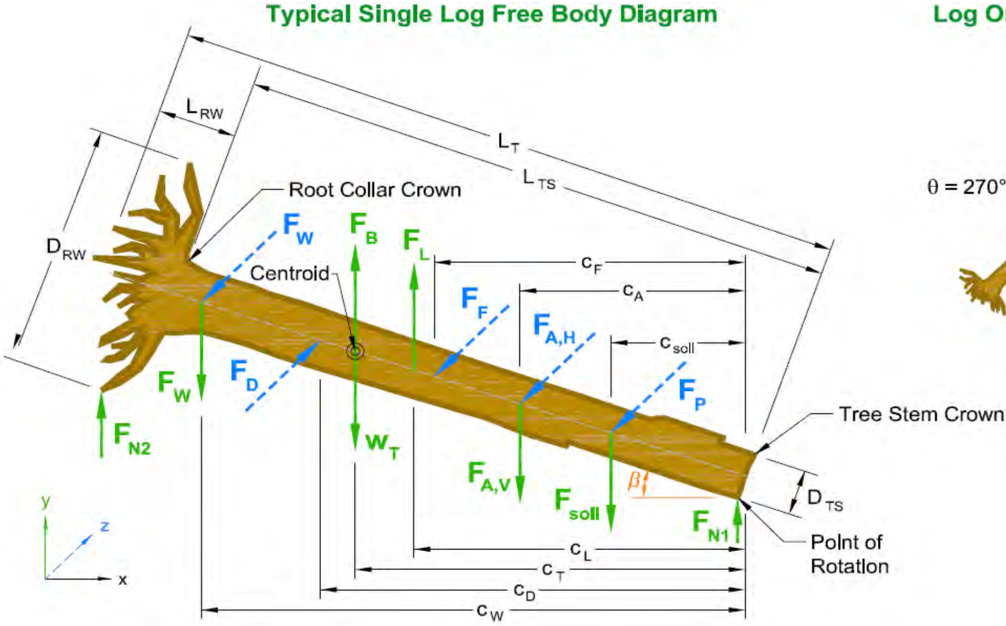
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	80.0	-15.0	Stem tip: Bottom	-2.00	18.07	18.07	27.63	1.82

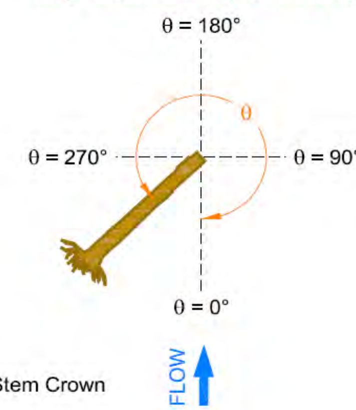
Tip Bury Depth -2.90 Crown Embedded Length 4.5

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	4.43	1.21	0.51
Bank	Gravel, loose	125.7	78.3	36.0	5	0.11	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	21.9	20.7	42.6	1,429	0
↓WS↑Thw	17.5	1.1	18.6	622	1,158
↓Thalweg	23.5	0.0	23.5	892	1,465
Total	62.8	21.8	84.6	2,943	2,623

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	2,623	↑
F_L (lbf)	0	
W_T (lbf)	2,943	↓
F_{soil} (lbf)	356	↓
$F_{W,V}$ (lbf)	1,271	↓
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,947	↓
FS_V	1.74	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	4.5	4.5	355
Bank	0.0	0.0	0.0	0
Total	0.0	4.5	4.5	356

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.14	0.53	1.10	0.43	2.10	68

Horizontal Force Balance

F_D (lbf)	68	→
F_P (lbf)	817	←
F_F (lbf)	1,486	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,236	←
FS_H	33.93	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	817	7.89	0.84	537
Bank	3.85	0	16.12	0.73	950
Total	-	817	24.00	-	1,486

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.8	0.0	10.6	12.8	2.3	11.0	4.6

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	33,144
M_r (lbf)	96,360
FS_M	2.91 ✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

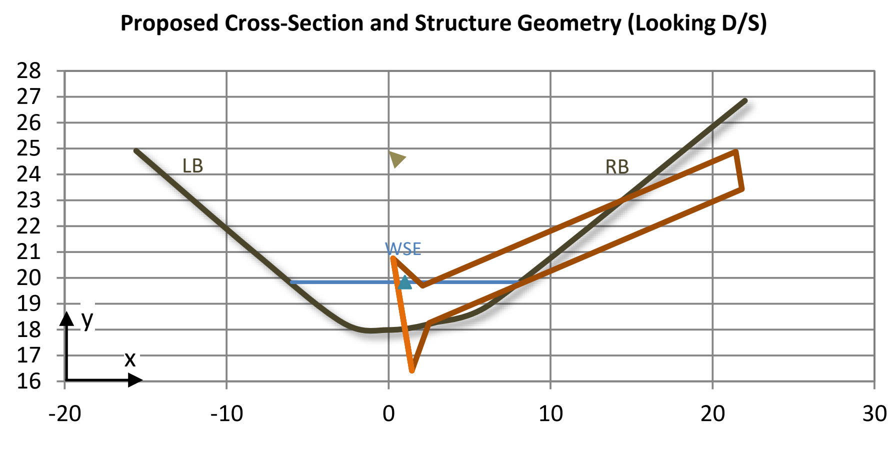
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 3	Rootwad	Right bank	Outside	11+80	1.85	2.00	5.58

Multi-Log Structures	Layer	Log ID
	N/A	7

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-15.59	24.91
Top LB	-8.40	21.04
Toe LB	-2.83	18.27
Thalweg	0.00	17.99
Toe RB	2.93	18.28
Top RB	6.39	19.03
Fldpln RB	22.01	26.85



Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

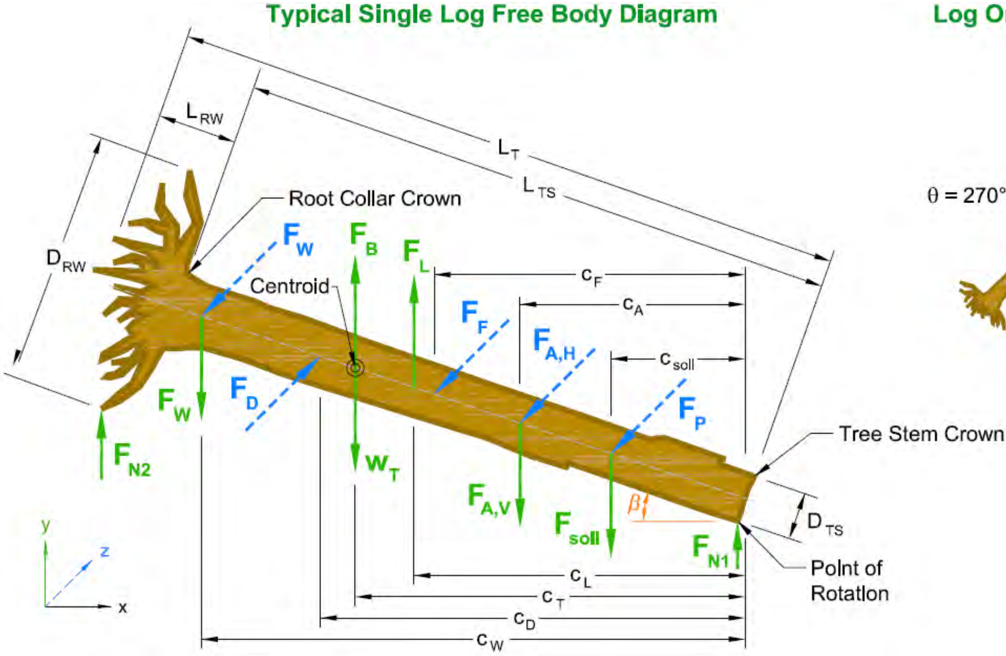
3

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	270.0	15.0	Root collar: Bottom	2.50	18.25	16.41	24.88	7.03

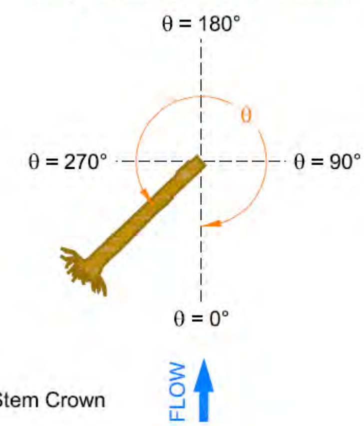
Tip Bury Depth 0.27 Crown Embedded Length 7.5

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	7.49	1.69	0.85

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	29.5	0.9	30.3	1,018	0
↓WS↑Thw	5.9	6.5	12.4	416	773
↓Thalweg	0.0	1.8	1.8	69	113
Total	35.3	9.2	44.5	1,502	886

Lift Force

C_{LT}	0.27
F_L (lbf)	57

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	9.5	0.0	9.5	1,192
Total	9.5	0.0	9.5	1,192

Vertical Force Balance

F_B (lbf)	886	↑
F_L (lbf)	57	↑
W_T (lbf)	1,502	↓
F_{soil} (lbf)	1,192	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,751	↓
FS_V	2.86	

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.44	0.80	1.10	0.43	5.11	1,086

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.13	0.84	270
Bank	3.85	2,295	13.92	0.73	1,039
Total	-	2,295	17.05	-	1,308

Horizontal Force Balance

F_D (lbf)	1,086	→
F_P (lbf)	2,295	←
F_F (lbf)	1,308	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	2,518	←
FS_H	3.32	

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	17.1	17.7	12.3	3.7	8.0	4.9

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	30,080
M_r (lbf)	56,818
FS_M	1.89

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

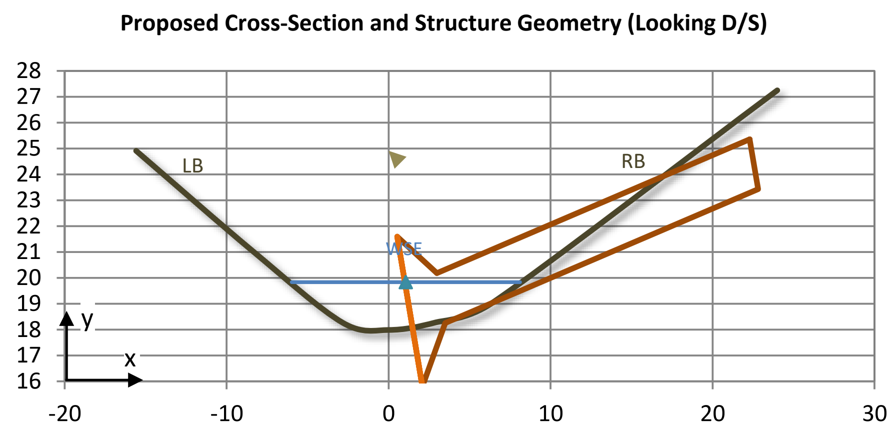
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 3	Rootwad	Right bank	Outside	11+80	1.85	2.00	5.58

Multi-Log Structures	Layer	Log ID
	N/A	6, 8, 9

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-15.59	24.91
Top LB	-8.40	21.04
Toe LB	-2.83	18.27
Thalweg	0.00	17.99
Toe RB	2.93	18.28
Top RB	6.39	19.03
Fldpln RB	24.00	27.25



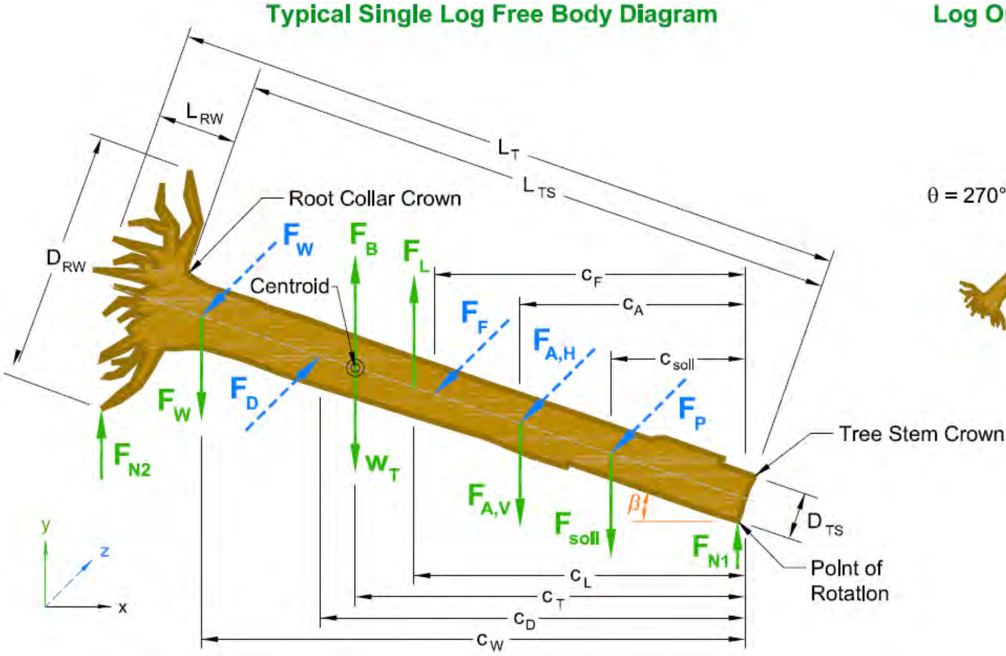
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	270.0	15.0	Root collar: Bottom	3.50	18.25	15.80	25.36	8.04

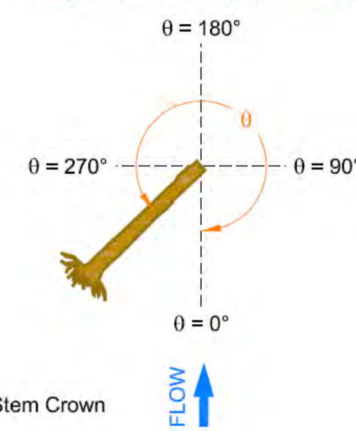
Tip Bury Depth 0.27 Crown Embedded Length 5.7

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	5.72	1.10	0.56

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	55.1	4.5	59.7	2,001	0
↓WS↑Thw	7.7	12.5	20.3	680	1,264
↓Thalweg	0.0	4.7	4.7	178	293
Total	62.8	21.8	84.6	2,859	1,557

Lift Force

C_{LT}	0.18
F_L (lbf)	43

Vertical Force Balance

F_B (lbf)	1,557	↑
F_L (lbf)	43	↑
W_T (lbf)	2,859	↓
F_{soil} (lbf)	789	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	2,049	↓
FS_V	2.28	

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	6.3	0.0	6.3	789
Total	6.3	0.0	6.3	789

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.51	0.70	1.10	0.43	6.57	1,596

Horizontal Force Balance

F_D (lbf)	1,596	→
F_P (lbf)	1,520	←
F_F (lbf)	1,533	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,457	←
FS_H	1.91	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.93	0.84	328
Bank	3.85	1,520	16.67	0.73	1,205
Total	-	1,520	20.59	-	1,533

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
13.0	17.5	18.0	13.0	2.8	9.8	3.7

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	47,950
M_r (lbf)	77,416
FS_M	1.61

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

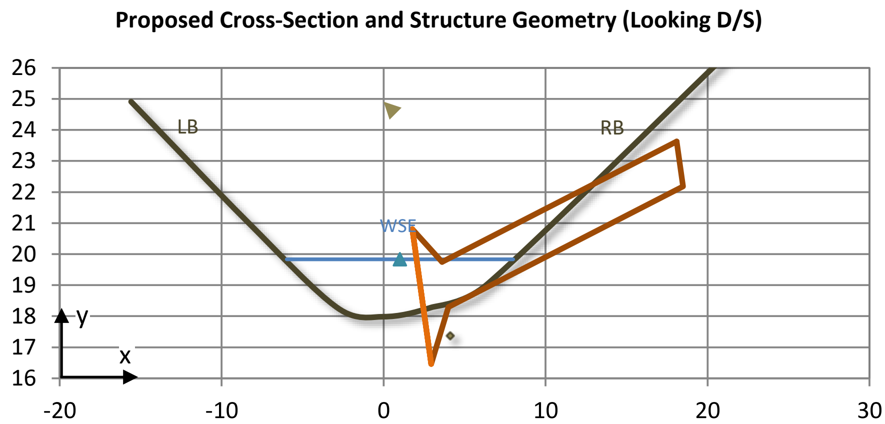
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 3	Rootwad	Right bank	Outside	11+80	1.85	2.00	5.58

Multi-Log Structures	Layer	Log ID
	N/A	10

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-15.59	24.91
Top LB	-8.40	21.04
Toe LB	-2.83	18.27
Thalweg	0.00	17.99
Toe RB	2.93	18.28
Top RB	6.39	19.03
Fldpln RB	22.01	26.85



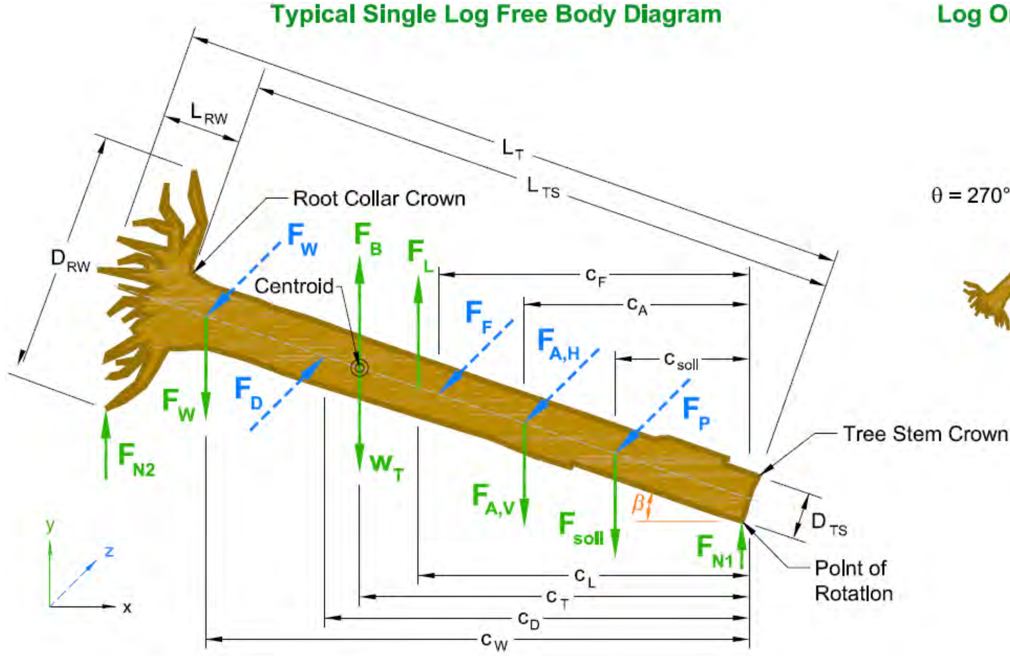
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	270.0	15.0	Root collar: Bottom	4.00	18.30	16.46	23.63	5.89

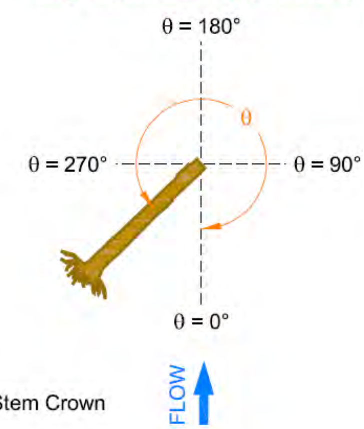
Tip Bury Depth 0.32 Crown Embedded Length 5.6

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	5.61	1.26	0.63

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	21.0	1.0	22.0	737	0
↓WS↑Thw	5.5	6.5	12.1	405	753
↓Thalweg	0.0	1.7	1.7	64	105
Total	26.5	9.2	35.7	1,205	857

Lift Force

C_{LT}	0.02
F_L (lbf)	3

Vertical Force Balance

F_B (lbf)	857	↑
F_L (lbf)	3	↑
W_T (lbf)	1,205	↓
F_{soil} (lbf)	668	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
ΣF_V (lbf)	1,012	↓
FS_V	2.18	

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	5.3	0.0	5.3	668
Total	5.3	0.0	5.3	668

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.37	0.80	1.10	0.43	3.98	707

Horizontal Force Balance

F_D (lbf)	707	→
F_P (lbf)	1,287	←
F_F (lbf)	753	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
ΣF_H (lbf)	1,332	←
FS_H	2.88	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.78	0.84	130
Bank	3.85	1,287	15.39	0.73	623
Total	-	1,287	18.17	-	753

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.7	12.3	12.8	9.7	2.8	8.2	3.7

*Distances are from the stem tip

Point of Rotation:	Stem Tip

Moment Force Balance

M_d (lbf)	16,831
M_r (lbf)	31,700
FS_M	1.88

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

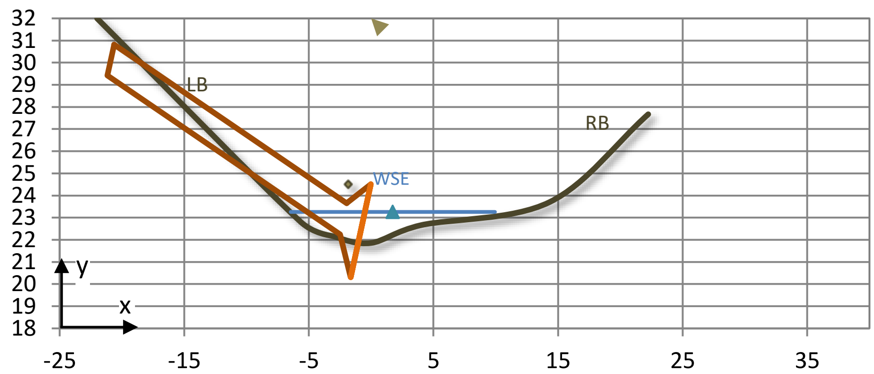
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 5	Flow Deflection	Left bank	Outside	12+75	1.40	2.00	6.76

Multi-Log Structures	Layer	Log ID
	Stacked	15

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-22.00	32.00
Top LB	-5.68	22.82
Toe LB	-3.00	22.16
Thalweg	0.00	21.86
Toe RB	4.00	22.66
Top RB	14.31	23.70
Fldpln RB	22.24	27.67

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



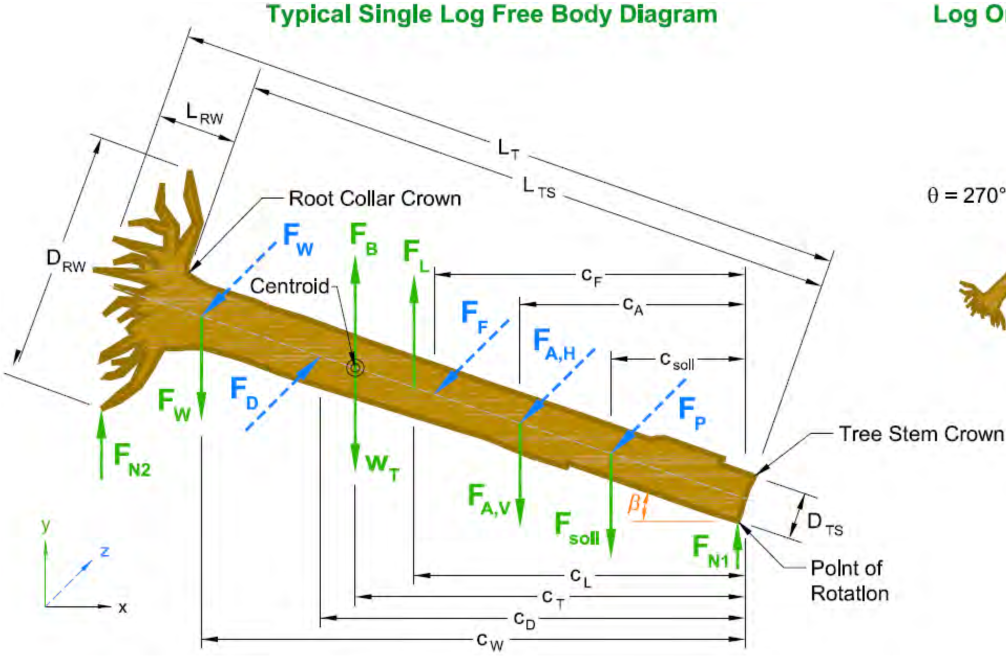
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	21.0	Root collar: Bottom	-2.50	22.25	20.31	30.82	4.00

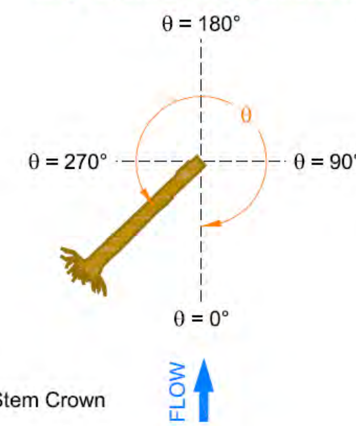
Tip Bury Depth 0.39 Crown Embedded Length 2.5

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	2.48	0.41	0.21

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	33.6	1.9	35.5	1,191	0
↓WS↑Thw	1.7	5.7	7.4	250	465
↓Thalweg	0.0	1.6	1.6	60	98
Total	35.3	9.2	44.5	1,501	563

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	563	↑
F_L (lbf)	0	
W_T (lbf)	1,501	↓
F_{soil} (lbf)	97	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,035	↓
FS_V	2.84	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	0.8	0.0	0.8	97
Total	0.8	0.0	0.8	97

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.33	0.97	0.97	0.27	2.82	500

Horizontal Force Balance

F_D (lbf)	500	→
F_P (lbf)	187	←
F_F (lbf)	776	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	463	←
FS_H	1.93	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.81	0.84	178
Bank	3.85	187	10.91	0.73	598
Total	-	187	13.72	-	776

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	0.0	19.4	12.3	1.2	6.6	1.6

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	15,497	↻
M_r (lbf)	28,748	↺
FS_M	1.86	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

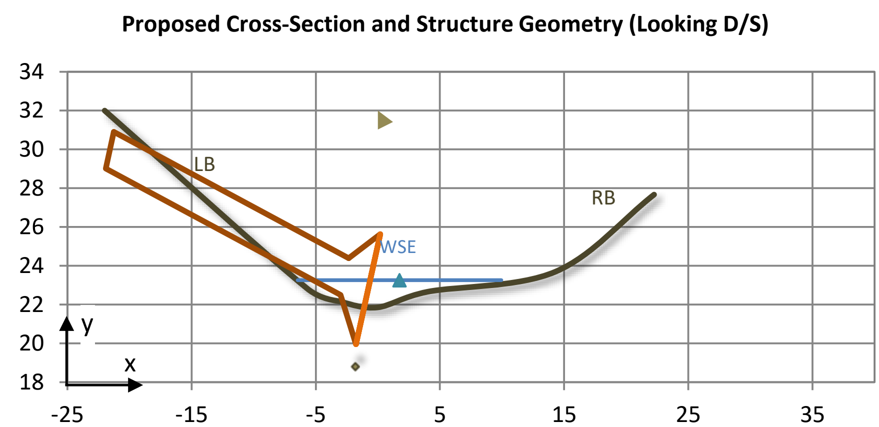
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 5	Flow Deflection	Left bank	Outside	12+75	1.40	2.00	6.76

Multi-Log Structures	Layer	Log ID
	Footer	16

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-22.00	32.00
Top LB	-5.68	22.82
Toe LB	-3.00	22.16
Thalweg	0.00	21.86
Toe RB	4.00	22.66
Top RB	14.31	23.70
Fldpln RB	22.24	27.67



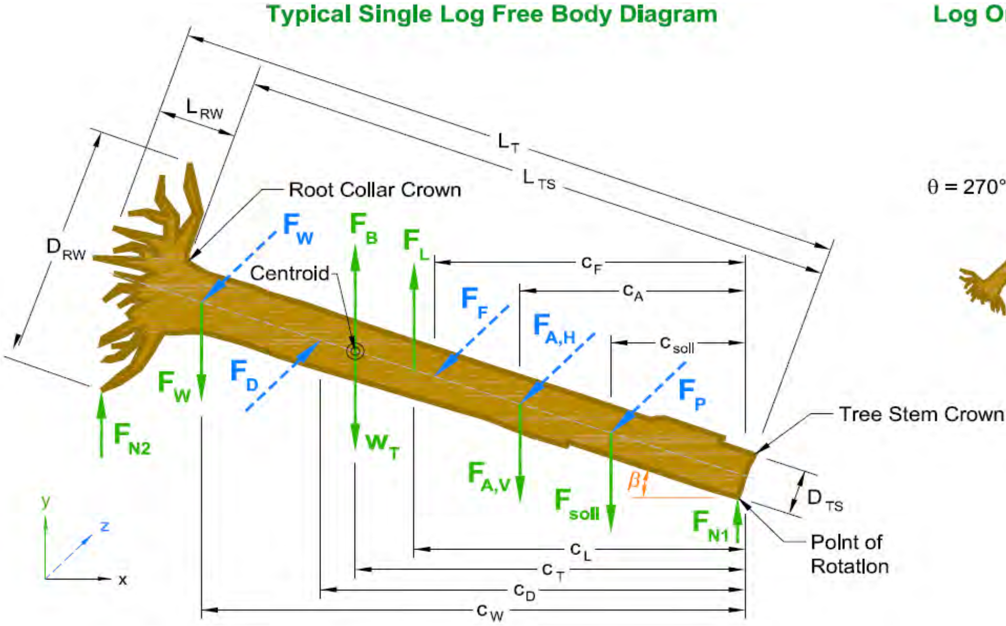
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	19.0	Root collar: Bottom	-3.00	22.50	19.96	30.90	6.00

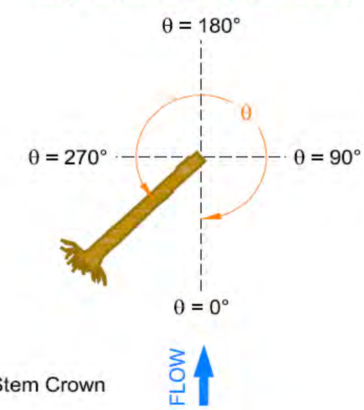
Tip Bury Depth 0.64 Crown Embedded Length 3.3

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	3.30	0.68	0.34

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	61.7	8.3	70.0	2,347	0
↓WS↑Thw	1.1	10.3	11.5	384	715
↓Thalweg	0.0	3.2	3.2	122	200
Total	62.8	21.8	84.6	2,853	915

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	915	↑
F_L (lbf)	0	
W_T (lbf)	2,853	↓
F_{soil} (lbf)	283	↓
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	2,221	↓
FS_V	3.43	✓

Soil Ballast Force

Soil	V_{dry} (ft^3)	V_{sat} (ft^3)	V_{soil} (ft^3)	F_{soil} (lbf)
Bed	0.0	0.0	0.0	0
Bank	2.2	0.0	2.2	283
Total	2.2	0.0	2.2	283

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.50	0.84	0.97	0.00	3.97	1,057

Horizontal Force Balance

F_D (lbf)	1,057	→
F_P (lbf)	545	←
F_F (lbf)	1,652	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	1,140	←
FS_H	2.08	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.28	0.84	287
Bank	3.85	545	12.49	0.73	1,365
Total	-	545	14.76	-	1,652

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
13.0	0.0	19.9	13.0	1.7	6.6	2.2

*Distances are from the stem tip

Point of Rotation: Stem Tip

Moment Force Balance

M_d (lbf)	31,038
M_r (lbf)	60,742
FS_M	1.96

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

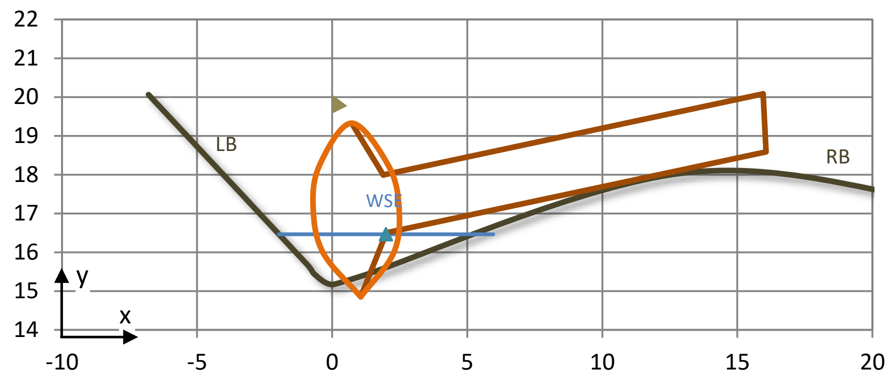
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 1	Rootwad	Left bank	Straight	11+25	1.30	2.00	7.04

Multi-Log Structures	Layer	Log ID
	N/A	1, 2, 3, 4, 5

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-6.80	20.06
Top LB	-0.92	15.68
Toe LB	-0.69	15.45
Thalweg	0.00	15.17
Toe RB	1.07	15.38
Top RB	13.18	18.06
Fldpln RB	24.38	17.06

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



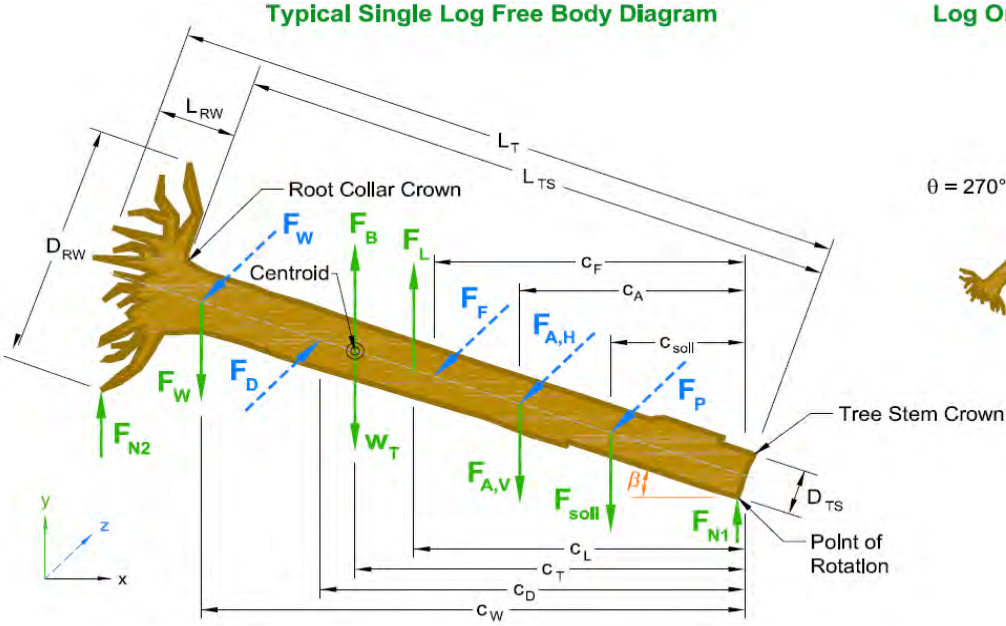
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	21.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	315.0	6.0	Root collar: Bottom	2.00	16.50	14.85	20.08	3.52

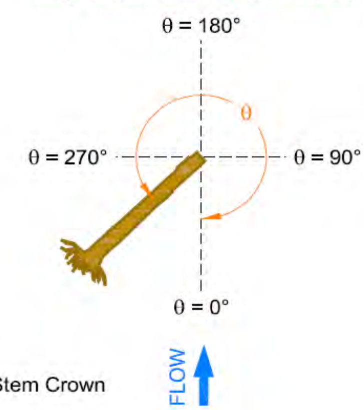
Tip Bury Depth 1.33 c1

Soils	Material	γ_S (lb/ft^3)	γ'_S (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	35.3	6.9	42.2	1,417	0
↓WS↑Thw	0.0	2.3	2.3	76	140
↓Thalweg	0.0	0.0	0.0	2	3
Total	35.3	9.2	44.5	1,494	143

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	143
F_L (lbf)	0
W_T (lbf)	1,494
F_{soil} (lbf)	0
$F_{W,V}$ (lbf)	0
$F_{A,V}$ (lbf)	0
ΣF_V (lbf)	1,351
FS_V	10.44

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.64	1.01	1.10	0.00	8.95	1,515

Horizontal Force Balance

F_D (lbf)	1,515
F_P (lbf)	0
F_F (lbf)	1,134
$F_{W,H}$ (lbf)	0
$F_{A,H}$ (lbf)	0
ΣF_H (lbf)	381
FS_H	0.75

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	1,134
Bank	3.85	0	0.00	0.73	0
Total	-	0	2.00	-	1,134

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.3	0.0	21.0	12.3	0.0	21.5	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	2,124
M_r (lbf)	13,719
FS_M	6.46

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

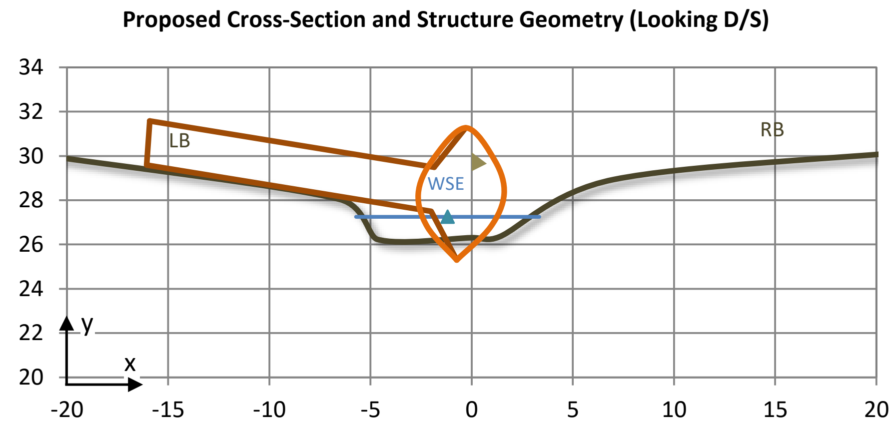
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 14	Rootwad	Left bank	Straight	14+40	0.94		3.28

Multi-Log Structures	Layer	Log ID
	N/A	30, 32, 34, 36

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-22.19	30.16
Top LB	-6.53	28.04
Toe LB	-4.66	26.23
Thalweg	0.00	26.31
Toe RB	1.38	26.35
Top RB	7.03	28.94
Fldpln RB	22.82	30.28



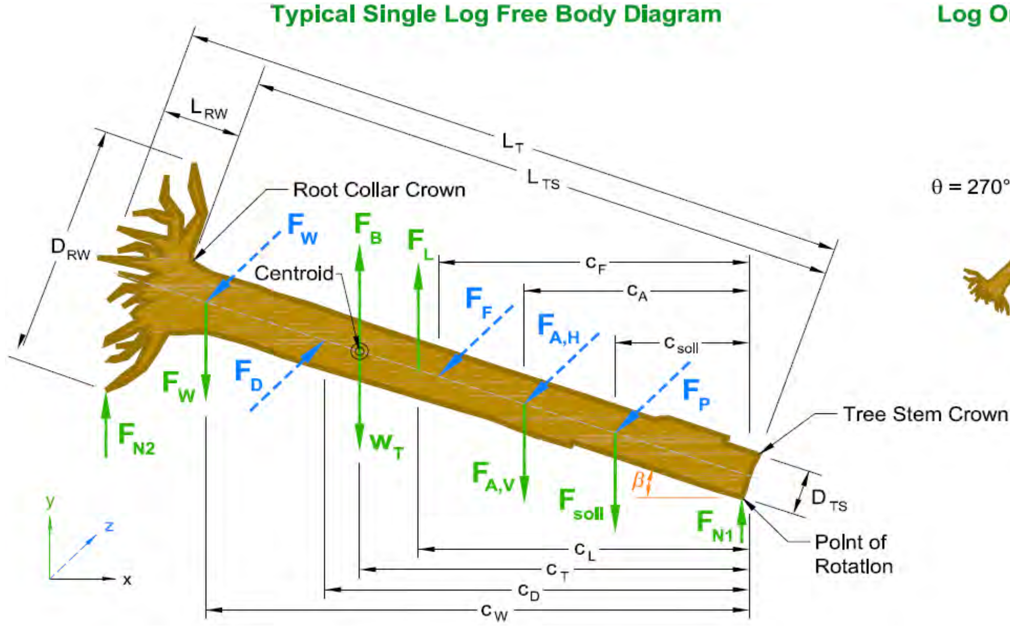
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	22.0	2.00	2.00	6.00	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	45.0	6.0	Root collar: Bottom	-2.00	27.50	25.30	31.58	3.55

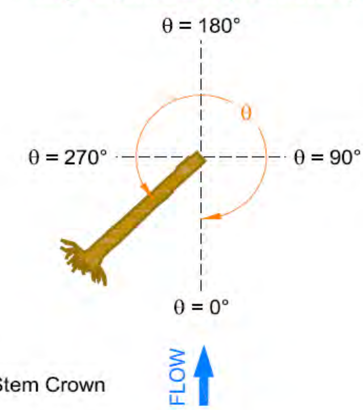
Tip Bury Depth 1.19 c1

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	φ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	62.8	17.4	80.2	2,691	0
↓WS↑Thw	0.0	3.5	3.5	118	220
↓Thalweg	0.0	0.9	0.9	33	55
Total	62.8	21.8	84.6	2,842	274

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	274	↑
F_L (lbf)	0	
W_T (lbf)	2,842	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	2,568	↓
FS_V	10.37	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.34	0.41	1.12	0.00	2.63	97

Horizontal Force Balance

F_D (lbf)	97	→
F_P (lbf)	0	
F_F (lbf)	2,155	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	2,058	←
FS_H	22.14	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	2,155
Bank	3.85	0	0.00	0.73	0
Total	-	0	2.00	-	2,155

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
12.9	0.0	0.0	12.9	0.0	0.0	0.0

*Distances are from the stem tip

Point of Rotation:	Rootwad

Moment Force Balance

M_d (lbf)	4,605	↷
M_r (lbf)	129,002	↶
FS_M	28.02	✓

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

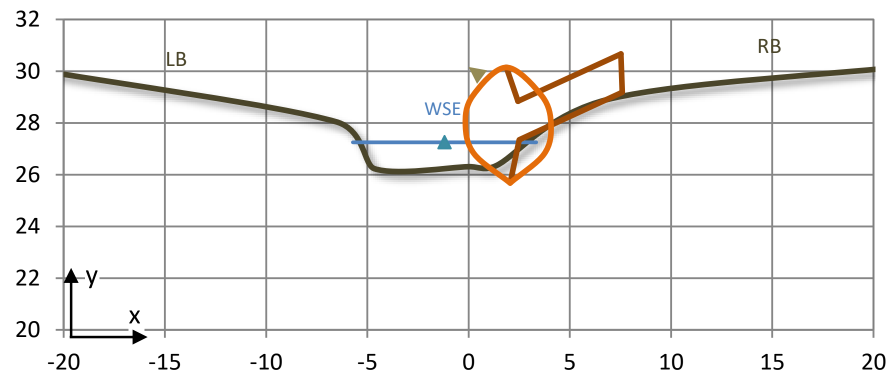
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 14	Rootwad	Left bank	Straight	14+40	0.94		3.28

Multi-Log Structures	Layer	Log ID
	N/A	1, 33, 35, 3

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-22.19	30.16
Top LB	-6.53	28.04
Toe LB	-4.66	26.23
Thalweg	0.00	26.31
Toe RB	1.38	26.35
Top RB	7.03	28.94
Fldpln RB	22.82	30.28

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



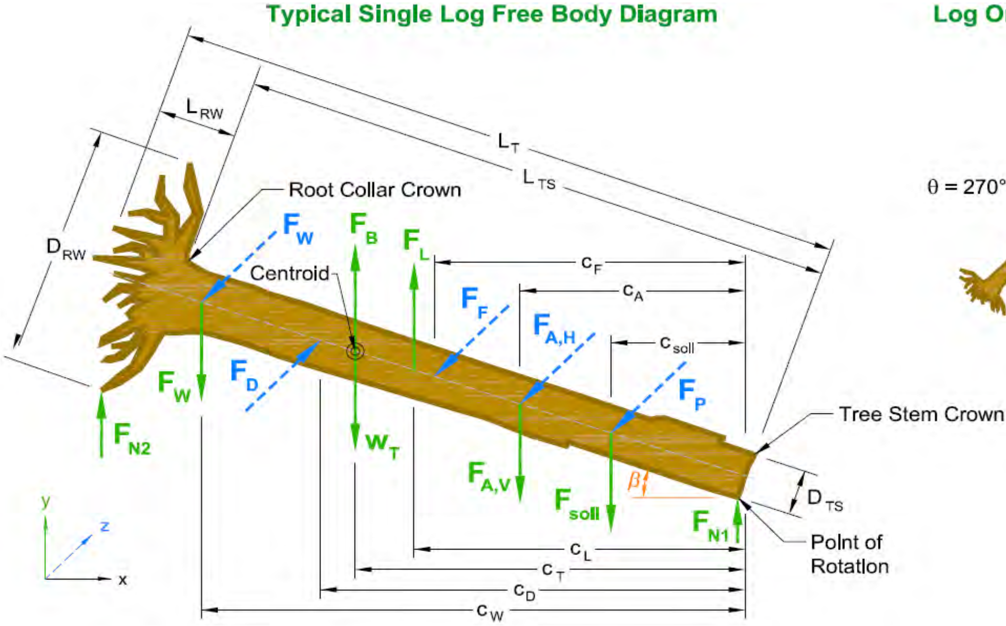
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	Yes	16.5	1.50	1.50	4.50	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	340.0	7.0	Root collar: Bottom	2.50	27.35	25.68	30.67	3.59

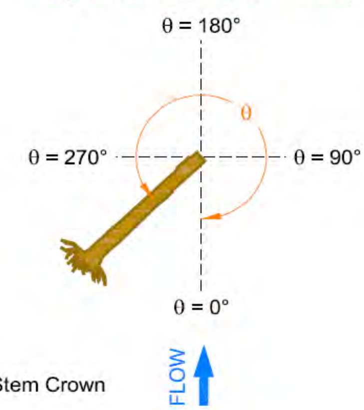
Tip Bury Depth 1.04 c1

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	26.5	7.0	33.5	1,124	0
↓WS↑Thw	0.0	1.9	1.9	65	121
↓Thalweg	0.0	0.2	0.2	9	15
Total	26.5	9.2	35.7	1,199	136

Lift Force

C_{LT}	0.12
F_L (lbf)	4

Vertical Force Balance

F_B (lbf)	136	↑
F_L (lbf)	4	↑
W_T (lbf)	1,199	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	1,058	↓
FS_V	8.53	✓

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.34	0.47	1.10	0.00	2.61	98

Horizontal Force Balance

F_D (lbf)	98	→
F_P (lbf)	0	
F_F (lbf)	888	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	790	←
FS_H	9.09	✓

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	2.00	0.84	888
Bank	3.85	0	0.00	0.73	0
Total	-	0	2.00	-	888

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
9.7	16.2	16.2	9.7	0.0	16.5	0.0

*Distances are from the stem tip

Point of Rotation: Rootwad

Moment Force Balance

M_d (lbf)	954
M_r (lbf)	8,103
FS_M	8.50

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

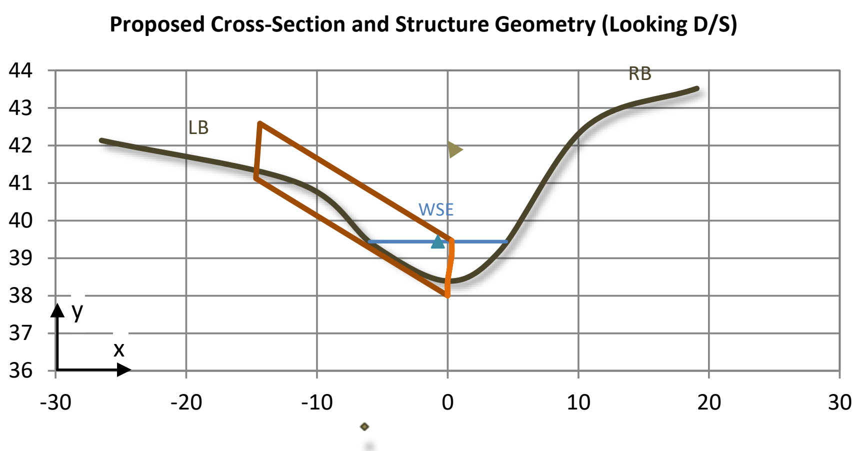
Spreadsheet developed by
Michael Rafferty, P.E.

Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 9	Log Vane	Right bank	Inside	18+51	1.05		5.39

Multi-Log Structures	Layer	Log ID
	Footer	60,61

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-26.48	42.13
Top LB	-11.41	41.00
Toe LB	-5.56	39.32
Thalweg	0.00	38.39
Toe RB	4.02	39.20
Top RB	10.58	42.50
Fldpln RB	19.07	43.52



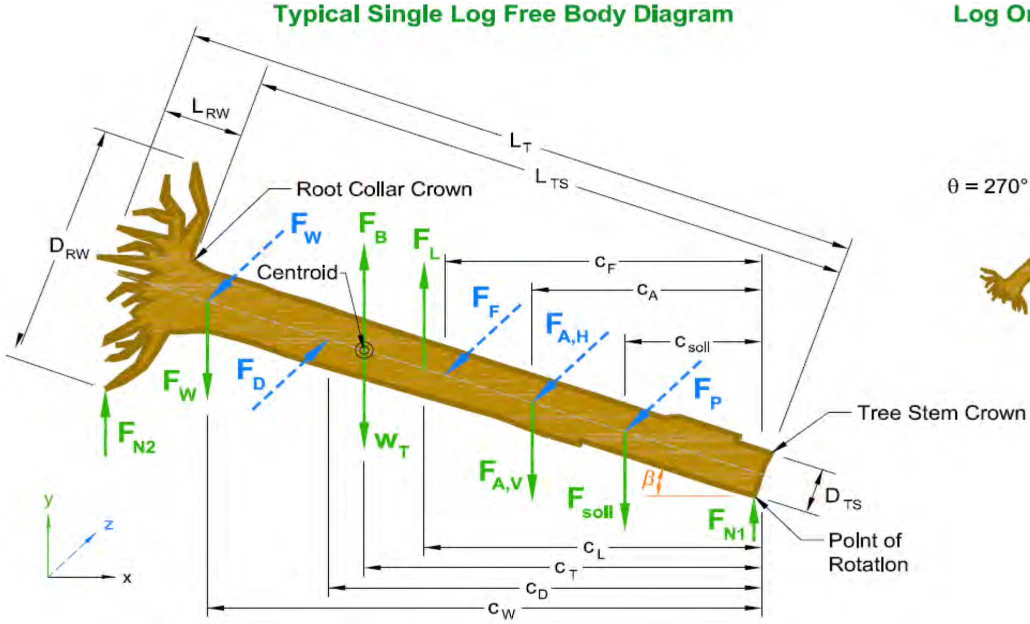
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	15.0	1.50	-	-	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	90.1	12.0	Root collar: Bottom	0.00	38.00	38.00	42.59	3.00

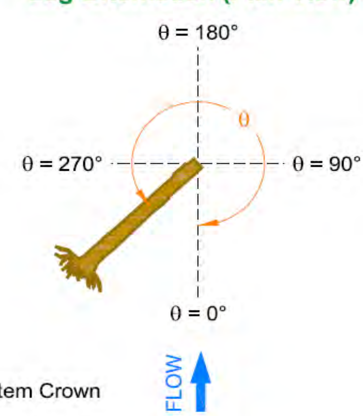
Tip Bury Depth -0.39 Crown Embedded Length 0.0

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	20.5	0.0	20.5	688	0
↓WS↑Thw	5.7	0.0	5.7	191	356
↓Thalweg	0.3	0.0	0.3	11	18
Total	26.5	0.0	26.5	891	374

Lift Force

C_{LT}	0.00
F_L (lbf)	0

Vertical Force Balance

F_B (lbf)	374	↑
F_L (lbf)	0	
W_T (lbf)	891	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	516	↓
FS_V	2.38	

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.43	0.78	0.90	0.00	2.85	241

Horizontal Force Balance

F_D (lbf)	241	→
F_P (lbf)	0	
F_F (lbf)	403	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	161	←
FS_H	1.67	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	8.04	0.84	205
Bank	3.85	0	8.96	0.73	198
Total	-	0	17.00	-	403

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
7.5	0.0	11.6	7.5	0.0	7.5	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	3,559
M_r (lbf)	13,275
FS_M	3.73

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek

Spreadsheet developed by
Michael Rafferty, P.E.

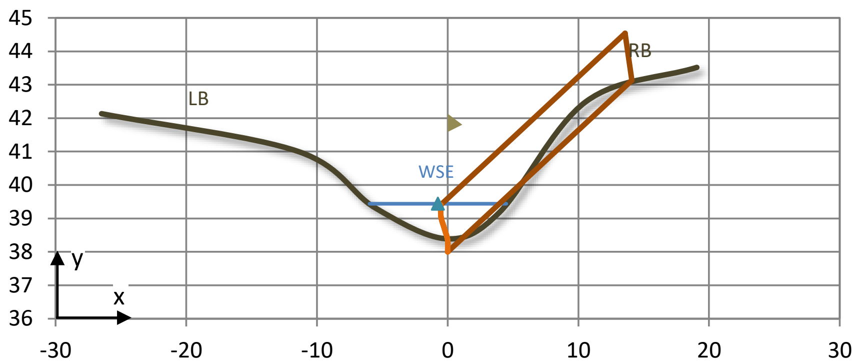
Single Log Stability Analysis Model Inputs

Site ID	Structure Type	Structure Position	Meander	Station	d_w (ft)	R_c/W_{BF}	u_{des} (ft/s)
Arc 9	Log Vane	Right bank	Inside	18+51	1.05		5.39

Multi-Log Structures	Layer	Log ID
	Footer	60, 61, 65, 66

Channel Geometry Coordinates		
Proposed	x (ft)	y (ft)
Fldpln LB	-26.48	42.13
Top LB	-11.41	41.00
Toe LB	-5.56	39.32
Thalweg	0.00	38.39
Toe RB	4.02	39.20
Top RB	10.58	42.50
Fldpln RB	19.07	43.52

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



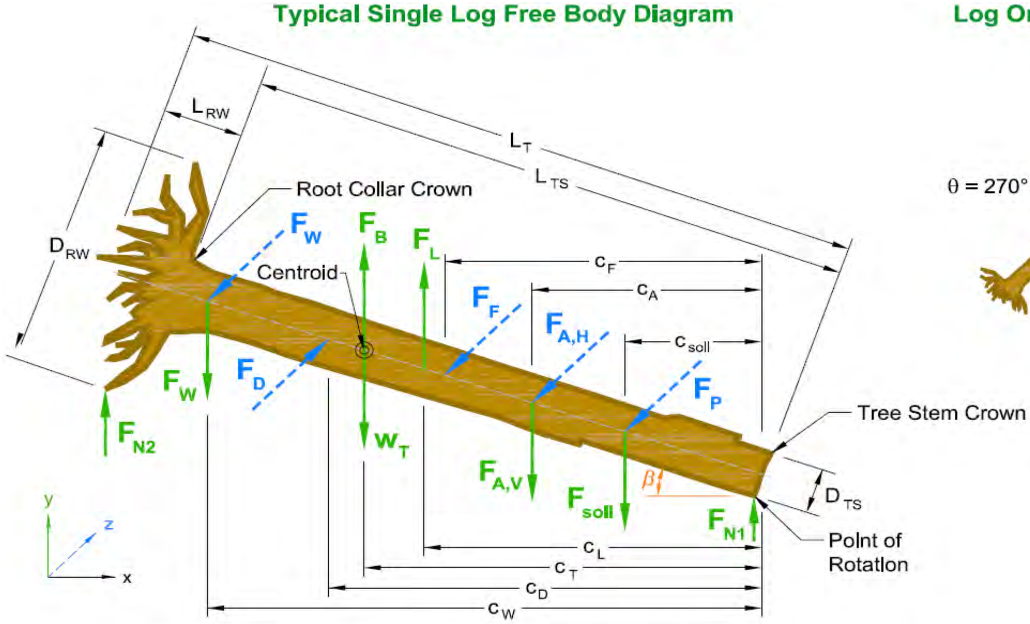
Wood Species	Rootwad	L_T (ft)	D_{TS} (ft)	L_{RW} (ft)	D_{RW} (ft)	γ_{Td} (lb/ft^3)	γ_{Tgr} (lb/ft^3)
Douglas-fir, Coast	No	15.0	1.50	-	-	33.5	38.0

Structure Geometry	θ (deg)	β (deg)	Define Fixed Point	x_T (ft)	y_T (ft)	$y_{T,min}$ (ft)	$y_{T,max}$ (ft)	A_{Tp} (ft^2)
	270.1	20.0	Root collar: Bottom	0.00	38.00	38.00	44.54	2.88

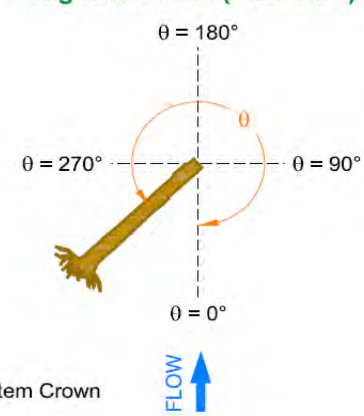
Tip Bury Depth -0.39 Crown Embedded Length 0.0

Soils	Material	γ_s (lb/ft^3)	γ'_s (lb/ft^3)	ϕ (deg)	Soil Class	$L_{T,em}$ (ft)	$d_{b,max}$ (ft)	$d_{b,avg}$ (ft)
Stream Bed	Very coarse gravel	128.3	79.9	40.0	5	0.00	0.00	0.00
Bank	Gravel, loose	125.7	78.3	36.0	5	0.00	0.00	0.00

Typical Single Log Free Body Diagram



Log Orientation (Plan View)



Vertical Force Analysis

Net Buoyancy Force

Wood	V_{TS} (ft^3)	V_{RW} (ft^3)	V_T (ft^3)	W_T (lbf)	F_B (lbf)
↑WSE	22.7	0.0	22.7	762	0
↓WS↑Thw	3.6	0.0	3.6	121	225
↓Thalweg	0.2	0.0	0.2	7	12
Total	26.5	0.0	26.5	890	237

Lift Force

C_{LT}	0.19
F_L (lbf)	15

Vertical Force Balance

F_B (lbf)	237	↑
F_L (lbf)	15	↑
W_T (lbf)	890	↓
F_{soil} (lbf)	0	
$F_{W,V}$ (lbf)	0	
$F_{A,V}$ (lbf)	0	
Σ F_V (lbf)	638	↓
FS_V	3.53	

Soil Ballast Force

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

Horizontal Force Analysis

Drag Force

A_{Tp} / A_W	Fr_L	C_{Di}	C_w	C_D*	F_D (lbf)
0.41	0.78	0.90	0.43	3.97	323

Horizontal Force Balance

F_D (lbf)	323	→
F_P (lbf)	0	
F_F (lbf)	493	←
$F_{W,H}$ (lbf)	0	
$F_{A,H}$ (lbf)	0	
Σ F_H (lbf)	171	←
FS_H	1.53	

Passive Soil Pressure / Friction Force

Soil	K_P	F_P (lbf)	L_{Tf} (ft)	μ	F_F (lbf)
Bed	4.60	0	3.91	0.84	221
Bank	3.85	0	5.55	0.73	272
Total	-	0	9.46	-	493

Moment Force Balance

Driving Moment Centroids / Resisting Moment Centroids

$c_{T,B}$ (ft)	c_L (ft)	c_D (ft)	$c_{T,W}$ (ft)	c_{soil} (ft)	$c_{F\&N}$ (ft)	c_P (ft)
7.5	11.9	12.9	7.5	0.0	6.6	0.0

*Distances are from the stem tip

Point of Rotation: Root Collar

Moment Force Balance

M_d (lbf)	2,349
M_r (lbf)	15,237
FS_M	6.49

Anchor Forces

Additional Soil Ballast

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

Mechanical Anchors

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

Boulder Ballast

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

SR 534 Tributary to Carpenter Creek
Notation, Units, and List of Symbols

Notation

Symbol	Description	Unit
A_W	Wetted area of channel at design discharge	ft^2
A_{Tp}	Projected area of wood in plane perpendicular to flow	ft^2
c_D	Centroid of the drag force along log axis	ft
c_{Am}	Centroid of a mechanical anchor along log axis	ft
c_{Ar}	Centroid of a ballast boulder along log axis	ft
c_{Asoil}	Centroid of the added ballast soil along log axis	ft
$c_{F\&N}$	Centroid of friction and normal forces along log axis	ft
c_L	Centroid of the lift force along log axis	ft
c_P	Centroid of the passive soil force along log axis	ft
c_{soil}	Centroid of the vertical soil forces along log axis	ft
$c_{T,B}$	Centroid of the buoyancy force along log axis	ft
$c_{T,W}$	Centroid of the log volume along log axis	ft
c_{WI}	Centroid of a wood interaction force along log axis	ft
C_{Lrock}	Coefficient of lift for submerged boulder	-
C_{LT}	Effective coefficient of lift for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_D*	Effective coefficient of drag for submerged tree	-
C_{Di}	Base coefficient of drag for tree, before adjustments	-
C_W	Wave drag coefficient of submerged tree	-
$d_{b,avg}$	Average buried depth of log	ft
$d_{b,max}$	Maximum buried depth of log	ft
d_w	Maximum flow depth at design discharge in reach	ft
D_{50}	Median grain size in millimeters (SI units)	mm
D_r	Equivalent diameter of boulder	ft
D_{RW}	Assumed diameter of rootwad	ft
D_{TS}	Nominal diameter of tree stem (DBH)	ft
DF_{RW}	Diameter factor for rootwad ($DF_{RW} = D_{RW}/D_{TS}$)	-
e	Void ratio of soils	-
$F_{A,H}$	Total horizontal load capacity of anchor techniques	lbf
$F_{A,HP}$	Passive soil pressure applied to log from soil ballast	lbf
$F_{A,Hr}$	Horizontal resisting force on log from boulder	lbf
F_{Am}	Load capacity of mechanical anchor	lbf
$F_{A,V}$	Total vertical load capacity of anchor techniques	lbf
$F_{A,Vr}$	Vertical resisting force on log from boulder	lbf
$F_{A,Vsoil}$	Vertical soil loading on log from added ballast soil	lbf
F_B	Buoyant force applied to log	lbf
F_D	Drag forces applied to log	lbf
$F_{D,r}$	Drag forces applied to boulder	lbf
F_F	Friction force applied to log	lbf
F_H	Resultant horizontal force applied to log	lbf
F_L	Lift force applied to log	lbf
$F_{L,r}$	Lift force applied to boulder	lbf
F_P	Passive soil pressure force applied to log	lbf
F_{soil}	Vertical soil loading on log	lbf
$F_{W,H}$	Horizontal forces from interactions with other logs	lbf
$F_{W,V}$	Vertical forces from interactions with other logs	lbf

Notation (continued)

Symbol	Description	Unit
F_V	Resultant vertical force applied to log	lbf
Fr_L	Log Froude number	-
FS_V	Factor of Safety for Vertical Force Balance	-
FS_H	Factor of Safety for Horizontal Force Balance	-
FS_M	Factor of Safety for Moment Force Balance	-
g	Gravitational acceleration constant	ft/s^2
K_P	Coefficient of Passive Earth Pressure	-
$L_{T,em}$	Total embedded length of log	ft
L_{RW}	Assumed length of rootwad	ft
L_T	Total length of tree (including rootwad)	ft
L_{Tf}	Length of log in contact with bed or banks	ft
L_{TS}	Length of tree stem (not including rootwad)	ft
$L_{TS,ex}$	Exposed length of tree stem	ft
LF_{RW}	Length factor for rootwad ($LF_{RW} = L_{RW}/D_{TS}$)	-
M_d	Driving moment about embedded tip	lbf
M_r	Driving moment about embedded tip	lbf
N	Blow count of standard penetration test	-
p_o	Porosity of soil volume	-
Q_{des}	Design discharge	cfs
R	Radius	ft
R_c	Radius of curvature at channel centerline	ft
SG_r	Specific gravity of quartz particles	-
SG_T	Specific gravity of tree	-
u_{avg}	Average velocity of cross section in reach	ft/s
u_{des}	Design velocity	ft/s
u_m	Adjusted velocity at outer meander bend	ft/s
V_{dry}	Volume of soils above stage level of design flow	ft^3
V_{sat}	Volume of soils below stage level of design flow	ft^3
V_{soil}	Total volume of soils over log	ft^3
V_{RW}	Volume of rootwad	ft^3
V_S	Volume of solids in soil (void ratio calculation)	ft^3
V_T	Total volume of log	ft^3
V_{TS}	Total volume of tree	ft^3
V_V	Volume of voids in soil	ft^3
V_{Adry}	Volume of ballast above stage of design flow	ft^3
V_{Awet}	Volume of ballast below stage of design flow	ft^3
$V_{r,dry}$	Volume of boulder above stage of design flow	ft^3
$V_{r,wet}$	Volume of boulder below stage of design flow	ft^3
W_{BF}	Bankfull width at structure site	ft
W_r	Effective weight of boulder	lbf
W_T	Total log weight	lbf
x	Horizontal coordinate (distance)	ft
y	Vertical coordinate (elevation)	ft
$y_{T,max}$	Minimum elevation of log	ft
$y_{T,min}$	Maximum elevation of log	ft

Greek Symbols

Symbol	Description	Unit
β	Tilt angle from stem tip to vertical	deg
γ_{bank}	Dry specific weight of bank soils	lb/ft^3
$\gamma_{bank,sat}$	Saturated unit weight of bank soils	lb/ft^3
γ'_{bank}	Effective buoyant unit weight of bank soils	lb/ft^3
γ_{bed}	Dry specific weight of stream bed substrate	lb/ft^3
γ'_{bed}	Effective buoyant unit weight of stream bed substrate	lb/ft^3
γ_{rock}	Dry unit weight of boulders	lb/ft^3
γ_s	Dry specific weight of soil	lb/ft^3
γ'_s	Effective buoyant unit weight of soil	lb/ft^3
γ_{Td}	Air-dried unit weight of tree (12% MC basis)	lb/ft^3
γ_{Tgr}	Green unit weight of tree	lb/ft^3
γ_w	Specific weight of water at 50ºF	lb/ft^3
η	Rootwad porosity	-
θ	Rootwad (or large end of log) orientation to flow	deg
μ	Coefficient of friction	-
ν	Kinematic viscosity of water at 50ºF	ft/s^2
Σ	Sum of forces	-
ϕ_{bank}	Internal friction angle of bank soils	deg
ϕ_{bed}	Internal friction angle of stream bed substrate	deg

Units

Notation	Description
cfs	Cubic feet per second
ft	Feet
lb	Pound
lbf	Pounds force
kg	Kilograms
m	Meters
mm	Millimeters
s	Seconds
yr	Year

Abbreviations

Notation	Description
ARI	Average return interval
Avg	Average
DBH	Diameter at breast height
deg	Degrees
Dia	Diameter
Dist	Distance
D/S	Downstream
ELJ	Engineered log jam
Ex	Example
Fldpln	Floodplain
H&H	Hydrologic and hydraulic
ID	Identification
i.e.	That is
LB	Left bank
LW	Large wood
Max	Maximum
MC	Moisture content
Min	Minimum
ML	Multi-log
SL	Single log
N/A	Not applicable
no	Number
Pt	Point
rad	Radians
RB	Right bank
RW	Rootwad
SL	Single log
Thw	Thalweg (lowest elevation in channel bed)
Typ	Typical
U.S.	United States
WS	Water surface
WSE	Water surface elevation
↑	Above
↓	Below

Appendix H

Hydraulic Field Report Form

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WSDOT Hydraulics Section	Hydraulics Field Report	Project Number: XL5949
	Project Name: SR 534 Unnamed Tributary to Carpenter Creek Remove Fish Barrier PHD	Date: 8/27/2019
	Project Office: Mount Vernon Project Engineer's Office	Time of Arrival: 9:30 am
	Location: SR 534 crossing of Unnamed Tributary to Carpenter Creek WDFW ID CR2 and 995265	Time of Departure: 11:00 am
Purpose of Visit: Site recon – BFW measurements	Weather: Clear, warm	Prepared By: T. Nabours

Meeting Location:
SR 534 and Conway Hill Road

Attendance List:

Name	Organization	Role
Jeffrey 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	Designer
Jon-Paul Shannahan	Upper Skagit IT	Representative
Stan Walsh	SRSC	Representative
Rick Hartson	Upper Skagit IT	Representative
Kevin Lautz	WDFW	Tech Assistance/Permitting
Tyler Nabours	Parametrix	Hydraulics/Hydrology – PHD
Paul Fendt	Parametrix	Hydraulics/Hydrology – PHD

Bankfull Width:

During a 7/30/2019 field visit conducted by Parametrix, bankfull width measurements were obtained. Upstream of structure WFDW ID 995265, measurements were taken between 57 feet and 384 feet from the inlet of the culvert, and average 6.2 feet in width. The stream has been highly modified by human encroachment over time, evident by its straight-line planform and constrained section.

Between structure WFDW ID 995265 and CR2, the unnamed tributary is conveyed through a reach of ditched stream that parallels adjacent to SR 534 with a crossing in culvert beneath Conway Hill Road. Bankfull widths were measured downstream of the Conway Hill Road crossing as well, and average 7.4 feet in width.

Downstream of crossing of SR 534 (WDFW ID CR2), the stream runs through a steep incised channel before outfall to Carpenter Creek (Hill Ditch). Here bankfull width measurements result in an average of 6.5 feet in width.

During the 8/27/2019 field visit with stakeholder, it was decided that this location would be reviewed to see if this was a situation where the culverts could be removed from the injunction list. No determination on bank full width was made.

Reference Reach:

The WDFW Fish Passage Level A Culvert Assessment Report states that the stream runs in ditches near and through agricultural areas upstream of barrier WDFW ID 995265.

Summary of the 8/27/2019 site visit below provided by Joelle Blais, WSDOT:

"Team met at the upstream fish passage culvert. Bryan Beemer described the current layout. He noted the depth of the petroleum lines that the culvert crosses are approximately 4' deep that the minimum coverage for the pipes is 2'. Since this made it impossible to cross the pipelines with an open stream. The design team proposes to have the stream cross the road at this location with a new channel running next to the pipelines across the farm field to Carpenter Creek. It was noted that the PUD water main was exposed in the channel approximately 5' from the existing pipe inlet.

The team explored the channel leading to the pipe. The channel bottom was covered in litter and did not look like it had much water flow. The channel ended at the gas pipelines. The stream channel was located on the southeast side of Conway Elementary school. It looks like the creek is then piped under the school grounds. It is not known where the drainage goes. It was noted that there is water flowing in the storm drain system and the channel is dry."

Supplemental information provided by Bryan Beemer, WSDOT identifies the location of the outfall of the culvert beneath Conway School. A storm sewer that collects runoff from the school and SR 534 provides additional hydrological input, as depicted in Figure 1 below.

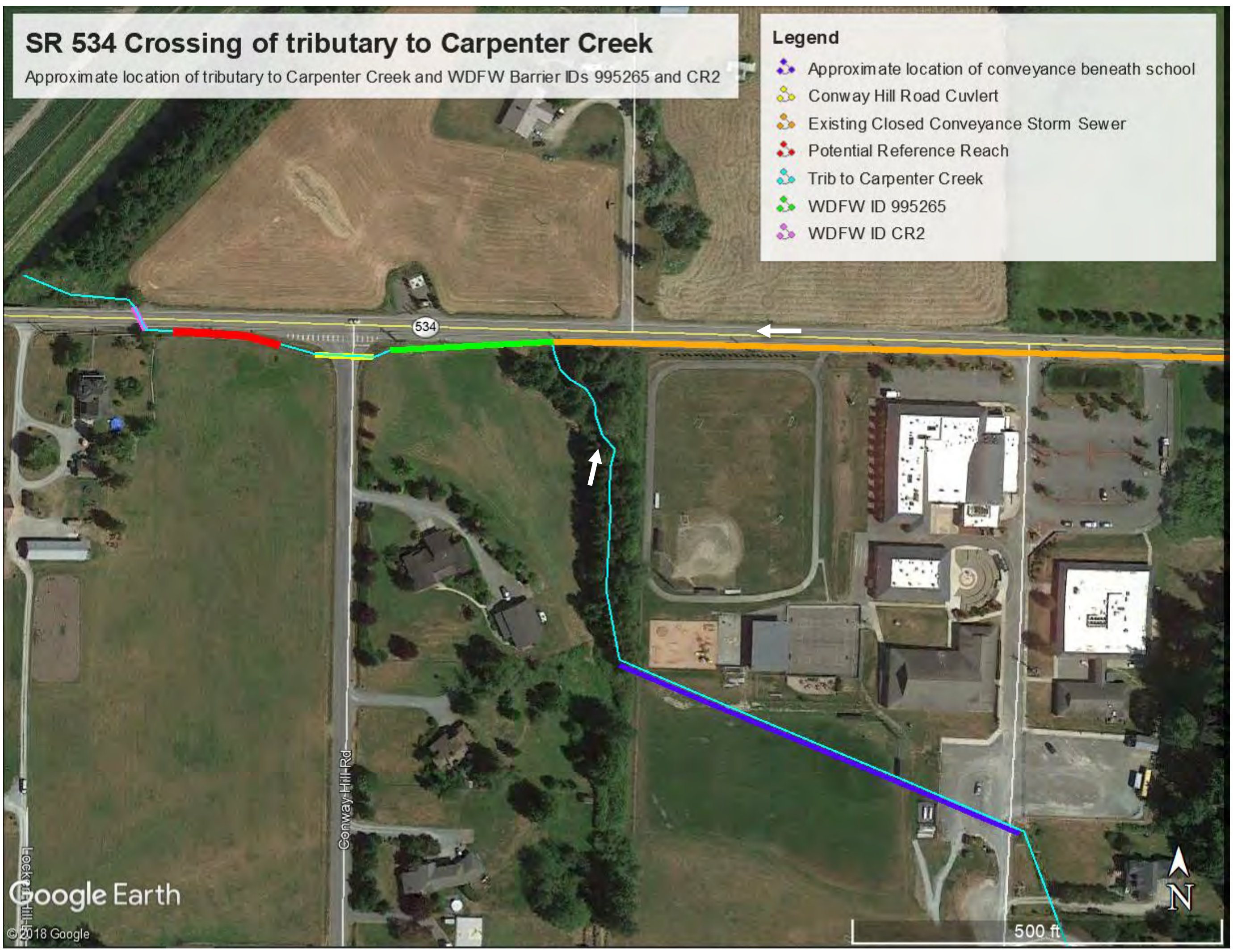

Figure 1. Site Map

A potential reference reach was identified adjacent to and upstream of the culvert WDFW ID CR2. The creek is marked by manmade encroachment due to roadway construction and clearing for agriculture. Due to the manmade nature and likely repeated dredging over time, no clear appropriate geomorphic or vegetative indicator of bankfull width exists. Due to this, it was agreed upon during the site visit with stakeholders on 8/27 that field measurements will be validated with hydraulic modeling of channel forming flows to determine an appropriate agreed upon bankfull width. It was later determined that the proposed channel gradients were dissimilar from the gradients at this reach and therefore this reach was not used as a reference for bankfull width or for streambed material sizing.

Data Collection:

The primary site investigation was conducted on 7/30/2019 by Sarah Rife (hydraulics and hydrology engineer), Steven Krueger (fish biologist), and Tyler Nabours (hydraulics and hydrology engineer) from Parametrix. The team recorded site observations and measurements at the crossings, downstream to the confluence with Carpenter Creek, and approximately 500 feet upstream of the barriers. 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 from Culvert WDFW ID 995265

meters	feet	Notes
0	0	Culvert Inlet - 2.5' ϕ (Photo 1)
2	7	Exposed pipe (water main) running parallel to roadway through stream channel (Photo 2)
7	23	Channel looking downstream (Photo 3)
16	52	Large boulders 6" to 30"-plus (Photo 4)
17.5	57	BFW 6.8' (Photo 5)
22.9	75	BFW 5.6'
26.5	87	End of cross section land survey conducted by WSDOT
34.1	112	Pool
42.5	139	Stream has dense blackberry presence on overbanks areas
53.5	176	Decrease in channel constraint, shallower section (Photo 6)
58.5	192	Substrate consists of sandy silt with some boulders
61.5	202	BFW 5.6' (Photo 7)
64	210	BFW 6.0'
70.9	233	BFW 4.8'
76.5	251	BFW 6.2' (Photo 8)
		Downstream Observation
85.5	281	Pebble Count 1 (Photo 9 and 10)
117.0	384	Access to stream through thick Himalayan blackberry
		Pebble Count 2 (Photo 11)
		BFW 7.6'
		Channel substrate comprised of mix of Gravel, sand, cobbles - 50/50 angular/ round rock
		Estimated channel gradient over 20 linear foot local drop 1.2'/20' = 0.06

Distance Downstream of Conway Hill Road Crossing

meters	feet	Notes
0	0	30" ϕ culvert (Photo 1- Roadway looking downstream)
3	10	BFW 9.0'
		Constructed channel along road (Photo 2)
15.2	50	BFW 7.6'
18.3	60	Angular/ Rounded boulders (at telephone poles) (Photo 3)
76.2	250	Inlet of culvert crossing SR 534 (WDFW ID CR2) - 3.0' ϕ (Photo 4)

		Evidence of scour, large riprap (Photo 5)

Distance Downstream from Culvert WDFW ID CR2		
meters	feet	Notes
0	0	Outlet of culvert crossing SR 534 (WDFW ID CR2)
		Steep channel gradient below culvert outlet
14.3	47	BFW 5.8' (main channel width)
		Cobbles/ boulders in stream channel (Photo 6)
21	69	BFW 7.2'
53.5	176	End of stream, confluence with Carpenter Creek (Photo 7)
		High vegetation mat of canary grass and blackberries over stream from end of culvert to start of levee (Photo 8)

Pebble Counts/Sediment Sampling:

Pebble counts were conducted during the 7/30 site visit. Two pebble counts were conducted upstream of the 995265 crossing and the results are presented below.

An abbreviated pebble count was conducted on the reach between the CR2 crossing and the confluence with Carpenter Creek from approximately 100 feet downstream of the CR2 crossing outlet to approximately 150 feet downstream of the CR2 crossing outlet. Due to the narrow, incised channel bottom (approximately 2 to 3 feet in width), the pebble count was conducted longitudinal to the stream alignment in order to provide some information on the size of material present through this reach. The results are presented in Figure 2 below.

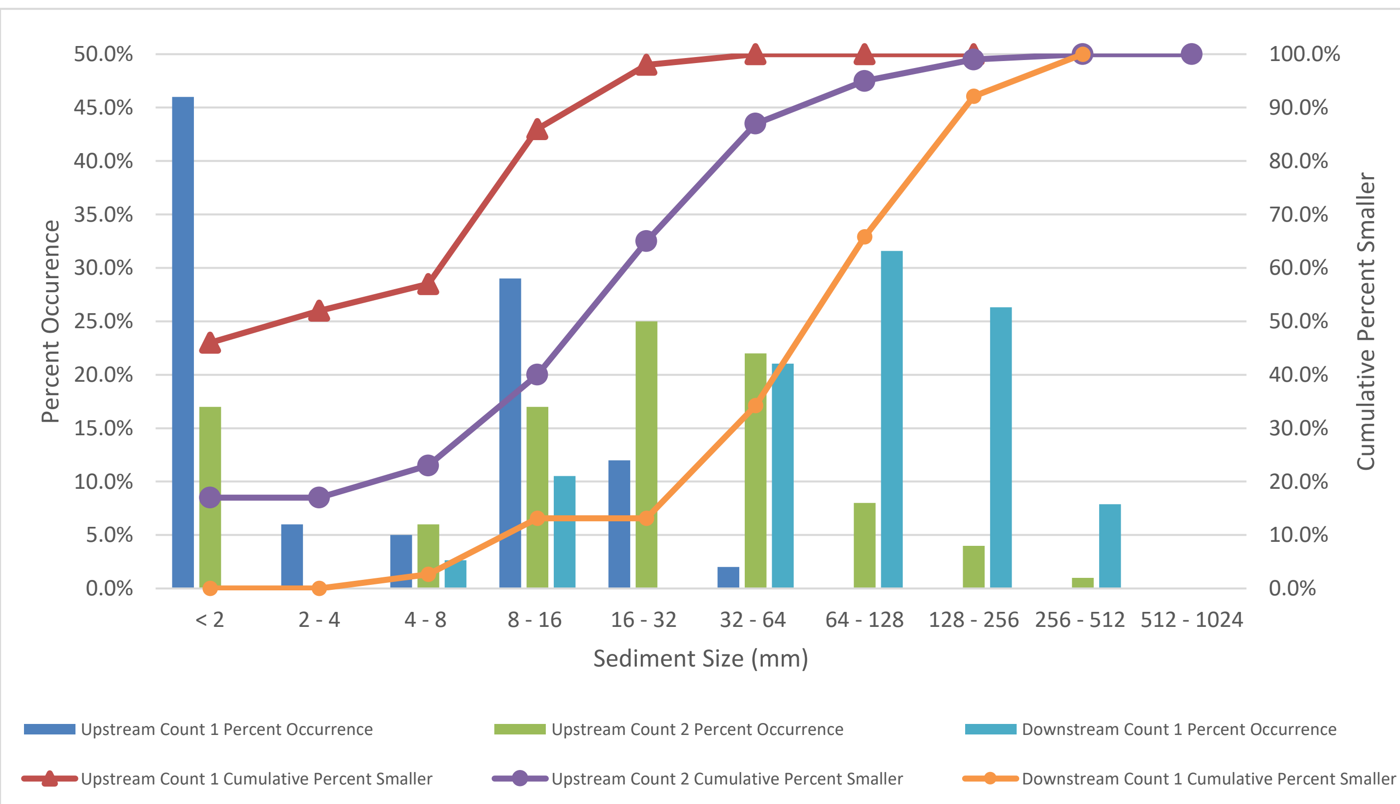

Figure 2. Sediment Properties in Vicinity of SR 534 Crossing

Photos:

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

Attachment A –

Photographs Upstream of Barrier WDFW ID 995265

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Photo 1 – Upstream of Culvert WDFW ID 995265

Photo 2 – Upstream of Culvert WDFW ID 995265

Photo 3 – Upstream of Culvert WDFW ID 995265

Photo 4 – Upstream of Culvert WDFW ID 995265

Photo 5 – Upstream of Culvert WDFW ID 995265

Photo 6 – Upstream of Culvert WDFW ID 995265

Photo 7 – Upstream of Culvert WDFW ID 995265

Photo 8 – Upstream of Culvert WDFW ID 995265

Photo 9 – Upstream of Crossing WDFW ID 995265

Photo 10 – Upstream of Culvert WDFW ID 995265

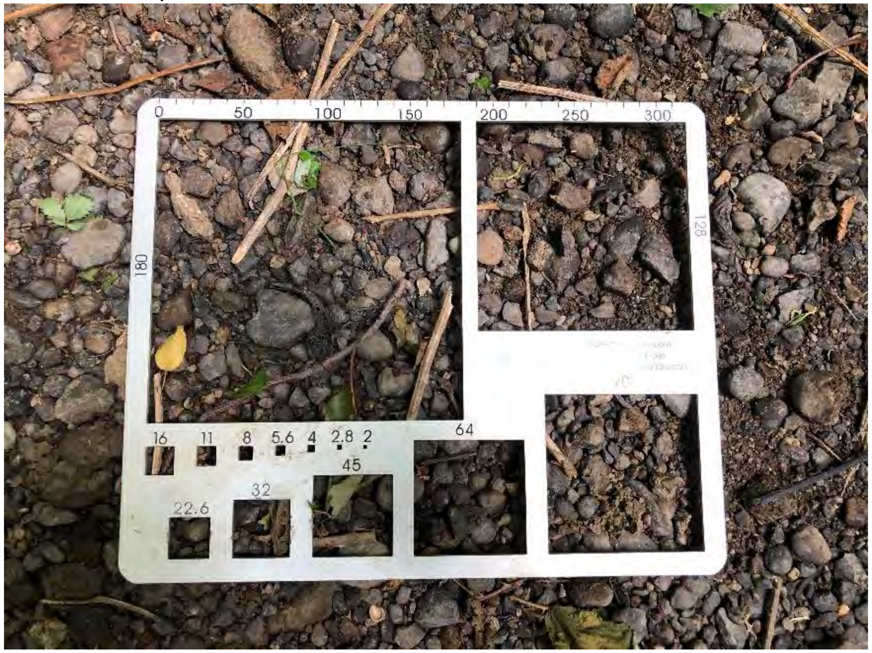

Photo 11 – Upstream of Culvert WDFW ID 995265

Attachment B –

Photographs Downstream of Barrier WDFW ID 995265

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Photo 1 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 2 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 3 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 4 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 5 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 6 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 7 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Photo 8 – Downstream of Culvert WDFW ID 995265/Upstream of Crossing WDFW ID CR2

Appendix I

Scour Calculations

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Hydraulic Analysis Report

Project Data

Project Title: Unnamed Tributary to Carpenter Creek SR 534

Designer: Sarah Rife, PE

Project Date: Monday, August 22, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis: Bridge Scour Analysis

Notes:

Scenario: Proposed_100-yr (SRH-2D)

Local Scour Due to Main Channel Migration to Face of Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth ~~0.34 ft~~ = 0.22 ft

Abutment scour was adjusted based on change to amplification factor. See more details below.

Main Channel Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.15 ft

D50: 38.100000 mm

Average Velocity Upstream: 4.71 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.72 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 43.82 cfs

Bottom Width in Contracted Section: 7.94 ft

Depth Prior to Scour in Contracted Section: 1.17 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 0.91 ft

Scour Depth: -0.26 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.36 ft

D50: 38.100000 mm

Average Velocity Upstream: 3.92 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.70 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 2.96 cfs

Bottom Width in Contracted Section: 2.71 ft

Depth Prior to Scour in Contracted Section: 0.48 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 0.23 ft

Scour Depth: -0.26 ft

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.36 ft

D50: 38.100000 mm

Average Velocity Upstream: 2.10 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.71 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 0.82 cfs

Bottom Width in Contracted Section: 1.50 ft

Depth Prior to Scour in Contracted Section: 0.55 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 0.13 ft

Scour Depth: -0.42 ft

Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment with wing wall

Angle of Embankment to Flow: 89.44 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 5.42 cfs

Unit Discharge in the Constricted Area (q2): 5.52 cfs/ft

D50: 38.100000 mm

Upstream Flow Depth: 1.15 ft

Flow Depth Prior to Scour: 1.17 ft

Result Parameters

q2/q1: 1.02

Average Velocity Upstream: 4.71 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 5.72 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.30

Flow Depth including Contraction Scour: 1.17 ft

Maximum Flow Depth including Abutment Scour: 1.51 ft

Scour Hole Depth from NCHRP Method: 0.34 ft

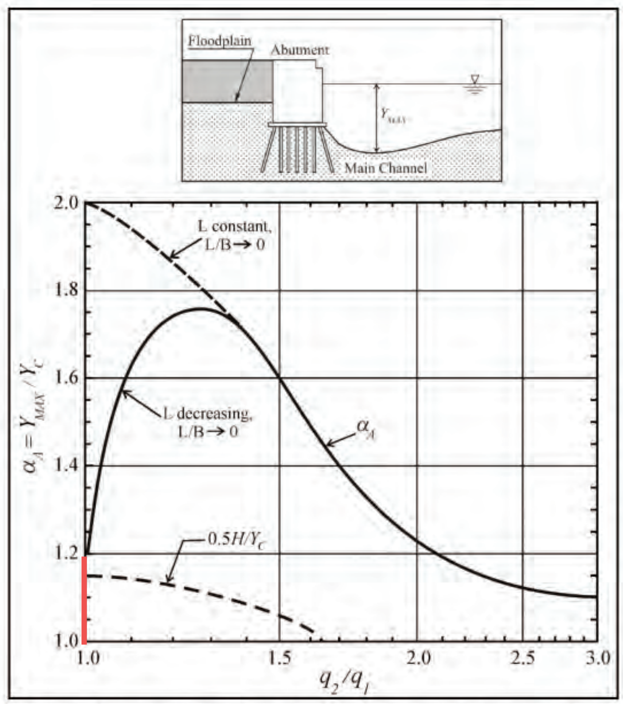

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

Based on the q2/q1 ratio of 1.02, the amplification factor was estimated to be 1.2 from Figure 8.10 (HEC-18 Manual).
This adjusts the abutment scour from main channel migration to 0.22 ft. See manual calculations attached below.

Hydraulic Analysis Report

Project Data

Project Title: Unnamed Tributary to Carpenter Creek SR 534

Designer: Sarah Rife, PE

Project Date: Monday, August 22, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis: Bridge Scour Analysis

Notes:

Scenario: Proposed_500-yr (SRH-2D)

Local Scour Due to Main Channel Migration to Face of Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth ~~0.36 ft~~ = 0.23 ft

Abutment scour was adjusted based on change to amplification factor. See more details below.

Main Channel Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 1.29 ft

D50: 38.100000 mm

Average Velocity Upstream: 5.15 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 5.83 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 54.38 cfs

Bottom Width in Contracted Section: 7.94 ft

Depth Prior to Scour in Contracted Section: 1.34 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 1.10 ft

Scour Depth: -0.25 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.50 ft

D50: 38.100000 mm

Average Velocity Upstream: 4.66 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.97 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 4.74 cfs

Bottom Width in Contracted Section: 2.71 ft

Depth Prior to Scour in Contracted Section: 0.66 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 0.34 ft

Scour Depth: -0.32 ft

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.49 ft

D50: 38.100000 mm

Average Velocity Upstream: 2.36 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 4.97 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 1.24 cfs

Bottom Width in Contracted Section: 1.50 ft

Depth Prior to Scour in Contracted Section: 0.73 ft

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 47.625000 mm

Average Depth in Contracted Section after Scour: 0.18 ft

Scour Depth: -0.55 ft

Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Vertical-wall abutment

Angle of Embankment to Flow: 88.60 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 6.64 cfs

Unit Discharge in the Constricted Area (q2): 6.76 cfs/ft

D50: 38.100000 mm

Upstream Flow Depth: 1.29 ft

Flow Depth Prior to Scour: 1.34 ft

Result Parameters

q2/q1: 1.02

Average Velocity Upstream: 5.14 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 5.83 ft/s

Scour Condition: Clear Water

Embankment Length/Floodplain Width Ratio: 0.00

Scour Condition: a (Main Channel)

Amplification Factor: 1.30

Flow Depth including Contraction Scour: 1.31 ft

Maximum Flow Depth including Abutment Scour: 1.70 ft

Scour Hole Depth from NCHRP Method: 0.36 ft

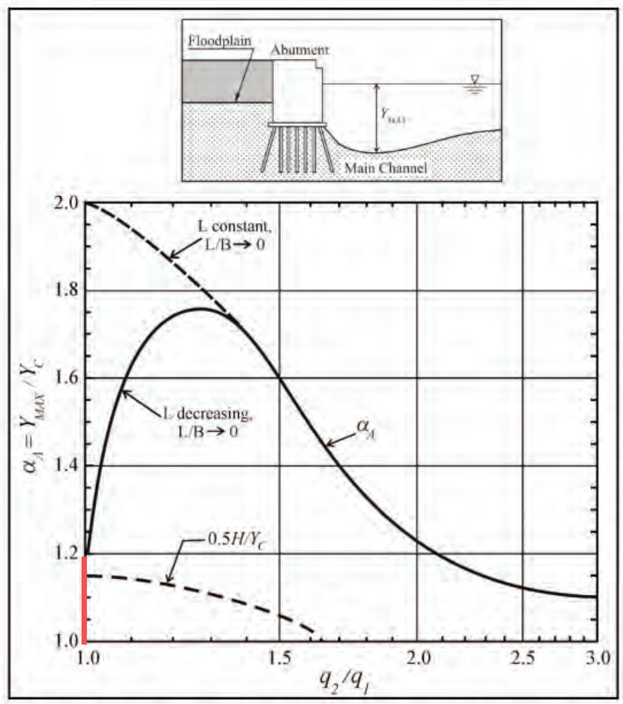

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

Based on the q2/q1 ratio of 1.02, the amplification factor was estimated to be 1.2 from Figure 8.10 (HEC-18 Manual). This adjusts the abutment scour from main channel migration to 0.22 ft. See manual calculations attached below.

SR 534 Unnamed Tributary to Carpenter Creek Scour Analysis Summary (Natural Conditions Material) - 7/13/2022	Peak Flow Event	
	100-Year (feet)	500-Year (feet)
Abutment Scour Assuming Channel Migration (Includes contraction scour)	0.2	0.2
Long-term Degradation (at proposed SR 534 crossing structure outlet)	2.2	3.9
Bend Scour	1.0	1.2
Total Scour Below Proposed Streambed (at proposed SR 534 crossing structure outlet)[1]	3.4	5.3
Minimum Additional Countersink Below Total Scour at Design Flood[2]	2.0	
Total Minimum Countersink Depth[1] (at proposed SR 534 crossing structure outlet)	5.4	5.3

[1]Sum of 'Abutment Scour Assuming Channel Migration' and any applicable 'Long-term Degradation' and 'Bend Scour'

[2]See Note 1

Notes:

1) Per WSDOT Hydraulics Manual: "All four-sided buried structures shall be countersunk a minimum of 2 feet below the total scour depth at the design flood <100-year> and shall be countersunk deep enough for the bottom to not become exposed during the check flood <500-year>."

2)Long-term degradation was calculated using the equilibrium slope equation 6.17 from 2004 HEC 20 Stream Stability at Crossings. Downstream control point used is Carpenter Creek (Hill Ditch) channel bottom adjacent to the tributary confluence (at elevation 4.75 feet, NAVD88). The calculations assume no upstream sediment supply, and results from Equation 6.17 were selected over the results from alternative method (Equation 6.18) due to consistency between equilibrium slope calculation from Equation 6.17 and gradient observed through the extents of the tributary and described in Section 3.4.2 of the PHD. For critical material size, D_C , the guidance recommends using $D_{90.}$ Based on the assumption of no upstream sediment supply, long-term degradation would occur as sediment is mobilized from upstream to downstream. WSDOT Hydraulics Manual Section 7-4.7 describes system stability based on the D_{84} particle size, therefore the D_{84} particle size of the proposed streambed mix was used in these calculations.

3) Bend scour based on Maynord (1996) provides conservative estimate for gravel-bed systems. Significant scour associated with bends was not observed in existing conditions and proposed conditions will result in lessened bend angles and reduced flow velocities in comparison to existing conditions.

4) Contraction analysis performed following guidance from 2012 HEC 18 Evaluating Scour at Bridges (5th Ed.). Abutment scour analysis performed following NCHRP 24-20 Abutment Scour Approach as documented in 2012 HEC 18 Evaluating Scour at Bridges (5th Ed.).

100-Year Scour Analysis

Approach Cross Section

	Left Bank	Main Channel	Right Bank
Flow (cfs)	2.28	43.26	3.72
Top Width (ft)	1.85	8.00	6.08
Avg. Vel. (ft/s)	3.50	4.71	2.05
Hydr. Depth (ft)	0.35	1.15	0.30
E.G. Slope (ft/ft)	0.032		

Color Key

Color Key
Designer Comment
Data Used from SMS Observation Lines
Data Entry Required from Table/ Figure/ Geotech Report/ etc.

Bridge Cross Section

	Left Bank	Main Channel	Right Bank
Flow (cfs)	2.16	43.79	1.96
Top Width (ft)	2.55	8.03	1.75
Avg. Vel. (ft/s)	1.72	4.67	2.08
Hydr. Depth (ft)	0.49	1.17	0.54
E.G. Slope (ft/ft)	0.032		

Contraction Scour

Contraction Scour - Calculation to determine Clear-Water or Live Bed Analysis

Critical Velocity

Vc	5.70	critical velocity (ft/sec)	Flow velocity in main channel of approach section (ft/s): 4.71
Ku	11.17	constants, 11.17 English units, 6.19 SI units	**Use:**
y1	1.15	average flow depth of flow upstream of the bridge (ft)	**Clear-Water**
D_{50}	0.124	median particle size (ft)	

Clear-Water Main Channel Contraction Scour

ys	**-0.26**	**average scour depth (ft)**
y2	0.91	average equilibrium depth in contracted section after contraction scour (ft)
y0	1.17	existing depth at contracted section before scour (ft)
Ku	0.01	English (0.025 SI)
Q	43.79	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s
D_{50}	0.12	particle size (ft)
Dm	0.16	1.25*D50
W	8.03	top width main channel in contracted section less pier width(s) (ft)

A negative scour is when the calculated scour is less than the measured water depth at the section.

100-Year Scour Analysis

Left Bank Contraction Scour

ys	**-0.31**	**average scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.
y2	0.18	average equilibrium depth in contracted section after contraction scour (ft)	
y0	0.49	existing depth at contracted section before scour (ft)	
Ku	0.01	English (0.025 SI)	
Q	2.16	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s	
D_{50}	0.12	median particle size (ft)	
Dm	0.16	1.25*D50	
W	2.55	left bank width l in contracted section less pier width(s) (ft)	
W(pier)	0.00	width of piers (ft)	

Right Bank Contraction Scour

ys	**-0.31**	**average scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.
y2	0.23	average equilibrium depth in contracted section after contraction scour (ft)	
y0	0.54	existing depth at contracted section before scour (ft)	
Ku	0.01	English (0.025 SI)	
Q	1.96	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s	
D_{50}	0.12	median particle size (ft)	
Dm	0.16	1.25*D50	
W	1.75	right bank width in contracted section less pier width(s) (ft)	
W(pier)	0.00	width of piers (ft)	

Abutment Scour

These left & right abutment scour calcs assume no channel migration and clear-water scour at abutment.
These calculations show would the abutment scour would be if abutments were in the floodplain area.

Left Abutment Scour (for noncohesive soils)

yc	0.20	flow depth including clear-water contraction scour (ft)	
Q1	2.28	flow in the upstream channel transporting sediment (cfs)	
Q2	2.16	flow in the contracted channel (cfs)	
W1	1.85	width of left overbank area upstream of bridge (ft)	
W2	2.55	width of left overbank area in contracted section less pier width(s) (ft)	
D_{50}	0.12	median particle size (ft)	
αB	2.10	Amplification factor, HEC-18 Figure 8.11 or 8.12	
q2/q1	0.69	Apply ratio to Figure 8.11 (Sheet Tables & Info)	
q1	1.23	unit discharge in the upstream channel accounting for non-uniform flow distribution (ft2/s)	
q2	0.85	unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)	
ymax	0.42	maximum flow depth resulting from abutment scour (ft)	
y0	0.49	flow depth prior to scour (ft)	
ys	**-0.07**	**abutment scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.

Right Abutment Scour (for noncohesive soils)

yc	0.25	flow depth including clear-water contraction scour (ft)	
Q1	3.72	flow in the upstream channel transporting sediment (cfs)	
Q2	1.96	flow in the contracted channel (cfs)	
W1	6.08	width of right overbank area upstream of bridge (ft)	
W2	1.75	width of right overbank area in contracted section less pier width(s) (ft)	
D_{50}	0.12	median particle size (ft)	
αB	1.80	Amplification factor, HEC-18 Figure 8.11 or 8.12	
q2/q1	1.83	Apply ratio to Figure 8.11 (Sheet Tables & Info)	
q1	0.61	unit discharge in the upstream channel accounting for non-uniform flow distribution (ft2/s)	
q2	1.12	unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)	
ymax	0.45	maximum flow depth resulting from abutment scour (ft)	
y0	0.54	flow depth prior to scour (ft)	
ys	**-0.09**	**abutment scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.

100-Year Scour Analysis

These calculations show what the abutment scour would be if the main channel migrated to face of abutment.

Abutment Scour Assuming Main Channel Migration (for noncohesive soils and live-bed analysis)

yc	1.16	flow depth including clear-water contraction scour (ft)
Q1	43.26	flow in the upstream channel transporting sediment (cfs)
Q2	43.79	flow in the contracted channel (cfs)
W1	8.00	top width of upstream main channel (ft)
W2	8.03	top width main channel in contracted section less pier width(s) (ft)
D_{50}	0.12	median particle size (ft)
αB	1.20	Amplification factor, HEC-18 Figure 8.9 or 8.10
q2/q1	1.01	Apply ratio to Figure 8.11 (Sheet 2)
q1	5.41	Upstream unit discharge (ft2/s)
q2	5.45	Unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)
ymax	1.39	maximum flow depth resulting from abutment scour (ft)
y0	1.17	flow depth prior to scour (ft)
y1	1.15	average depth at approach cross section main channel (ft)
ys	**0.22**	**abutment scour depth (ft)**

Bend Scour-- Maynord Method

Approach Cross Section

Max Chl Dpth (ft)	1.2	Max Channel Depth

R_c	16.0	Centerline radius of the bend, ft
W	8.0	Width of bend, ft
A	9.2	Cross Sectional Area (ft^2)
D_{mnc}	1.2	Average water depth in the crossing upstream of the bend, ft

Limitations Checks:

		Check	Ratio Used:
R_C/W	2.0	TRUE	2.0
W/D_{mnc}	7.0	FALSE	20.0

If R_c/W is less than 1.5 or W/D_{mnc} is less than 20
R_c/W=1.5 and W/D_{mnc}=20 should be used.

D_{mxb}	2.1	
d	**1.0**	Bend Scour Depth (ft)

Location of Maximum Depth

Lp	**1.1**
R	1.12
n	0.06

100-Year Scour Analysis

Long-term Degradation

These calculations show what the long-term degradation could be if the slope adjusted until the critical streambed material no longer mobilized. These caclulations assume no supply of sediment from upstream.

Alternative 1:

HEC 20 Equation 6.17

S_{eq}	0.0513	Channel slope at which particles D_c will no longer move (ft/ft)
q	5.453	Channel discharge per unit width (ft^2/s)
K_s	0.050	Shields parameter
K_u	1.486	(1.0 SI)
n	0.050	Manning roughness coefficient
D_c	0.550	Critical bed material size (ft) (D_84 used)
γ	62.400	specific weight of water (lb/ft^3)
γ_s	165.000	specific weight of sediment (lb/ft^3)

Ultimate Degradation Amount at Crossing Outlet

Ys	**2.2**	**Ultimate degradation amount measured in CADD (ft)**

OR:

$Ys = L(S_x - S_{eq})$

Ys	**2.2**	**Ultimate degradation amount (ft)**
L	196.9	Distance to downstream culvert
S_x	0.062	Existing slope *average slope from culvert outlet to downstream control at tributary confluence with Carpenter Creek.
S_{eq}	0.0513	(from above)

Ultimate Degradation Amount at Crossing Inlet

Ys	**1.2**	**Ultimate degradation amount measured in CADD(ft)**

OR:

$Ys = L(S_x - S_{eq})$

Ys	**1.23**	**Ultimate degradation amount (ft)**
L	246	Distance to downstream culvert
S_x	0.056	Existing slope *average slope from culvert inlet to downstream control at tributary confluence with Carpenter Creek.
S_{eq}	0.0513	(from above)

500-Year Scour Analysis

Approach Cross Section

	Left Bank	Main Channel	Right Bank
Flow (cfs)	3.84	53.14	6.14
Top Width (ft)	1.85	8.00	7.12
Avg. Vel. (ft/s)	4.20	5.15	2.30
Hydr. Depth (ft)	0.50	1.29	0.37
E.G. Slope (ft/ft)	0.032		

Color Key

Color Key
Designer Comment
Data Used from SMS Observation Lines
Data Entry Required from Table/ Figure/ Geotech Report/ etc.

Bridge Cross Section

	Left Bank	Main Channel	Right Bank
Flow (cfs)	3.28	54.32	2.97
Top Width (ft)	2.55	8.03	1.75
Avg. Vel. (ft/s)	1.94	5.04	2.37
Hydr. Depth (ft)	0.66	1.34	0.71
E.G. Slope (ft/ft)	0.032		

Contraction Scour

Contraction Scour - Calculation to determine Clear-Water or Live Bed Analysis

Critical Velocity

Vc	5.81	critical velocity (ft/sec)	Flow velocity in main channel of approach section (ft/s): 5.15
Ku	11.17	constants, 11.17 English units, 6.19 SI units	**Use:**
y1	1.29	average flow depth of flow upstream of the bridge (ft)	**Clear-Water**
D_{50}	0.124	median particle size (ft)	

Clear-Water Main Channel Contraction Scour

ys	**-0.25**	**average scour depth (ft)**
y2	1.09	average equilibrium depth in contracted section after contraction scour (ft)
y0	1.34	existing depth at contracted section before scour (ft)
Ku	0.01	English (0.025 SI)
Q	54.32	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s
D_{50}	0.12	median particle size (ft)
Dm	0.16	1.25*D50
W	8.03	top width main channel in contracted section less pier width(s) (ft)

A negative scour is when the calculated scour is less than the measured water depth at the section.

500-Year Scour Analysis

Left Bank Contraction Scour

ys	**-0.40**	**average scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.
y2	0.26	average equilibrium depth in contracted section after contraction scour (ft)	
y0	0.66	existing depth at contracted section before scour (ft)	
Ku	0.01	English (0.025 SI)	
Q	3.28	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s	
D_{50}	0.12	particle size (ft)	
Dm	0.16	1.25*D50	
W	2.55	left bank width l in contracted section less pier width(s) (ft)	
W(pier)	0.00	width of piers (ft)	

Right Bank Contraction Scour

ys	**-0.38**	**average scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.
y2	0.33	average equilibrium depth in contracted section after contraction scour (ft)	
y0	0.71	existing depth at contracted section before scour (ft)	
Ku	0.01	English (0.025 SI)	
Q	2.97	discharge through bridge or on set back overbank area at bridge associated with width W, ft^3/s	
D_{50}	0.12	median particle size (ft)	
Dm	0.16	1.25*D50	
W	1.75	right bank width in contracted section less pier width(s) (ft)	
W(pier)	0.00	width of piers (ft)	

Abutment Scour

These left & right abutment scour calcs assume no channel migration and clear-water scour at abutment.
These calculations show would the abutment scour would be if abutments were in the floodplain area.

Left Abutment Scour (for noncohesive soils)

yc	0.28	flow depth including clear-water contraction scour (ft)	
Q1	3.84	flow in the upstream channel transporting sediment (cfs)	
Q2	3.28	flow in the contracted channel (cfs)	
W1	1.85	width of left overbank area upstream of bridge (ft)	
W2	2.55	width of left overbank area in contracted section less pier width(s) (ft)	
D_{50}	0.12	median particle size (ft)	
αB	2.20	Amplification factor, HEC-18 Figure 8.11 or 8.12	
q2/q1	0.6	Apply ratio to Figure 8.11 (Sheet Tables & Info)	
q1	2.08	unit discharge in the upstream channel accounting for non-uniform flow distribution (ft2/s)	
q2	1.29	unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)	
ymax	0.63	maximum flow depth resulting from abutment scour (ft)	
y0	0.66	flow depth prior to scour (ft)	
ys	**0.0**	**abutment scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.

Right Abutment Scour (for noncohesive soils)

yc	0.36	flow depth including clear-water contraction scour (ft)	
Q1	6.14	flow in the upstream channel transporting sediment (cfs)	
Q2	2.97	flow in the contracted channel (cfs)	
W1	7.12	width of right overbank area upstream of bridge (ft)	
W2	1.75	width of right overbank area in contracted section less pier width(s) (ft)	
D_{50}	0.12	median particle size (ft)	
αB	1.60	Amplification factor, HEC-18 Figure 8.11 or 8.12	
q2/q1	2.0	Apply ratio to Figure 8.11 (Sheet Tables & Info)	
q1	0.86	unit discharge in the upstream channel accounting for non-uniform flow distribution (ft2/s)	
q2	1.70	unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)	
ymax	0.58	maximum flow depth resulting from abutment scour (ft)	
y0	0.71	flow depth prior to scour (ft)	
ys	**-0.1**	**abutment scour depth (ft)**	A negative scour is when the calculated scour is less than the measured water depth at the section.

500-Year Scour Analysis

These calculations show what the abutment scour would be if the main channel migrated to face of abutment.

Abutment Scour Assuming Main Channel Migration (for noncohesive soils and live-bed analysis)

yc	1.31	flow depth including clear-water contraction scour (ft)
Q1	53.14	flow in the upstream channel transporting sediment (cfs)
Q2	54.32	flow in the contracted channel (cfs)
W1	8.00	top width of upstream main channel (ft)
W2	8.03	top width main channel in contracted section less pier width(s) (ft)
D_{50}	0.12	median particle size (ft)
αB	1.20	Amplification factor, HEC-18 Figure 8.9 or 8.10
q2/q1	1.02	Apply ratio to Figure 8.11 (Sheet 2)
q1	6.64	Upstream unit discharge (ft2/s)
q2	6.76	Unit discharge in the constricted opening accounting for non-uniform flow distribution (ft2/s)
ymax	1.57	maximum flow depth resulting from abutment scour (ft)
y0	1.34	flow depth prior to scour (ft)
y1	1.29	average depth at approach cross section main channel (ft)
ys	**0.23**	**abutment scour depth (ft)**

Bend Scour-- Maynord Method

Approach Cross Section

Max Chl Dpth (ft)	1.29	Max Channel Depth
R_c	16.0	Centerline radius of the bend, ft
W	17.0	Width of bend, ft
A	10.8	Cross Sectional Area (ft^2)
D_{mnc}	1.3	Average water depth in the crossing upstream of the bend, ft

Limitations Checks:

		Check	Ratio Used:
R_C/W	0.9	FALSE	1.5
W/D_{mnc}	13.2	FALSE	20.0

If R_c/W is less than 1.5 or W/D_{mnc} is less than 20

R_c/W=1.5 and W/D_{mnc}=20 should be used.

D_{mxb}	2.4	
d	**1.2**	Bend Scour Depth (ft)

Location of Maximum Depth

Lp	**1.3**
R	1.25
n	0.06

500-Year Scour Analysis

Long-term Degradation

These calculations show what the long-term degradation could be if the slope adjusted until the critical streambed material no longer mobilized. These caclulations assume no supply of sediment from upstream.

Alternative 1:

HEC 20 Equation 6.17

S_{eq}	0.0427	Channel slope at which particles D_c will no longer move (ft/ft)
q	6.765	Channel discharge per unit width (ft^2/s)
K_s	0.050	Shields parameter
K_u	1.486	(1.0 SI)
n	0.050	Manning roughness coefficient
D_c	0.550	Critical bed material size (ft) (D_84 used)
ϒ	62.400	specific weight of water (lb/ft^3)
$ϒ_s$	165.000	specific weight of sediment (lb/ft^3)

Ultimate Degradation Amount at Crossing Outlet

Ys	**3.9**	**Ultimate degradation amount measured in CADD (ft)**

OR:

$Ys = L(S_x-S_{eq})$

Ys	**3.9**	**Ultimate degradation amount (ft)**
L	196.9	Distance to downstream culvert
S_x	0.062	Existing slope *average slope from culvert inlet to downstream control at Carpenter Creek bottom of bank
S_{eq}	0.043	(from above)

Ultimate Degradation Amount at Crossing Inlet

Ys	**3.4**	**Ultimate degradation amount measured in CADD (ft)**

OR:

$Ys = L(S_x-S_{eq})$

Ys	**3.4**	**Ultimate degradation amount (ft)**
L	246	Distance to downstream culvert
S_x	0.056	Existing slope *average slope from culvert inlet to downstream control at Carpenter Creek bottom of bank.
S_{eq}	0.043	(from above)

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Appendix J

Flood Risk Assessment Memorandum

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TECHNICAL MEMORANDUM

DATE:	August 9, 2021
TO:	Julie Heilman, P.E., State Hydraulics Engineer; Aaron Williams, P.E., WSDOT Hydraulics
FROM:	Paul Fendt, P.E., Parametrix; Tyler Nabours, P.E., Parametrix
PROJECT NUMBER:	553-1631-156
PROJECT NAME:	Flood Risk Assessment for the SR 534 MP 0.53 Unnamed Tributary 1 (west) and SR 534 ROW MP 0.60 Unnamed Tributary 2 (east) to Carpenter Creek Fish Barrier Removal Project

INTRODUCTION

The Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 534 crossing of Carpenter Creek at mile post (MP) 0.60 and at an existing storm sewer pipe that runs adjacent to SR 534 reported at MP 0.53. The project includes elements that could affect the stream floodplains, hydraulics, and stream channel properties. Specifically, the project includes two existing structures, both of which create barriers along the same unnamed tributary to Carpenter Creek. The existing crossing of SR 534 over Unnamed Tributary #1 (west) (Site ID CR2) to Carpenter Creek has been identified as a fish barrier by Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office due to an excessive slope that results in a fish passibility assessment of 33 percent. Upstream and adjacent to SR 534, Unnamed Tributary #2 (east) (Site ID 995265) includes a storm sewer pipe that has been identified as a fish barrier due to a water surface elevation drop at the outlet, resulting in a fish passibility assessment of 0 percent.

Figure 1 displays the project vicinity, and Figure 2 depicts the project stream crossing locations. The proposed project area for the unnamed tributary to Carpenter Creek, including the project site, is not within a mapped floodplain. However, Carpenter Creek itself is within a floodplain, as reported by the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map Number 53015C0425C (FEMA 1985). The mapped floodplain is in an area designated as a Special Flood Hazard Area (SFHA) Zone AO, with a base food depth of 3 feet above grade noted. See Attachment A for the FEMA FIRM. SFHA Zone AO and the floodplain management codes of the local jurisdictions require the development of a model of the existing condition for the SR 534 crossing project and a no-rise analysis based on a requirement for floodplain impacts not greater than 1 foot from the existing condition.

The evaluation for the Flood Risk Assessment demonstrates that the base flood elevation would not increase by 1 foot or more. This memorandum describes the methodology used to perform the analysis and the water surface elevation that is expected to result from the proposed project activities, as projected by the model.

Date: 7/27/2021 Author: ZieglCor Path: U:\PSO\Projects\Clients\1631-WSDOT\553-1631-127 AE SecretCrtoPilchuck\99Svcs\GIS\MapDocs\Figures\CarpenterCreekTrib SR534 Figure1 VicinityMap.mxd

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Source: WA DNR, ESRI, WSDOT

SR 534 Carpenter Creek Tributary Project Barriers

Watercourse

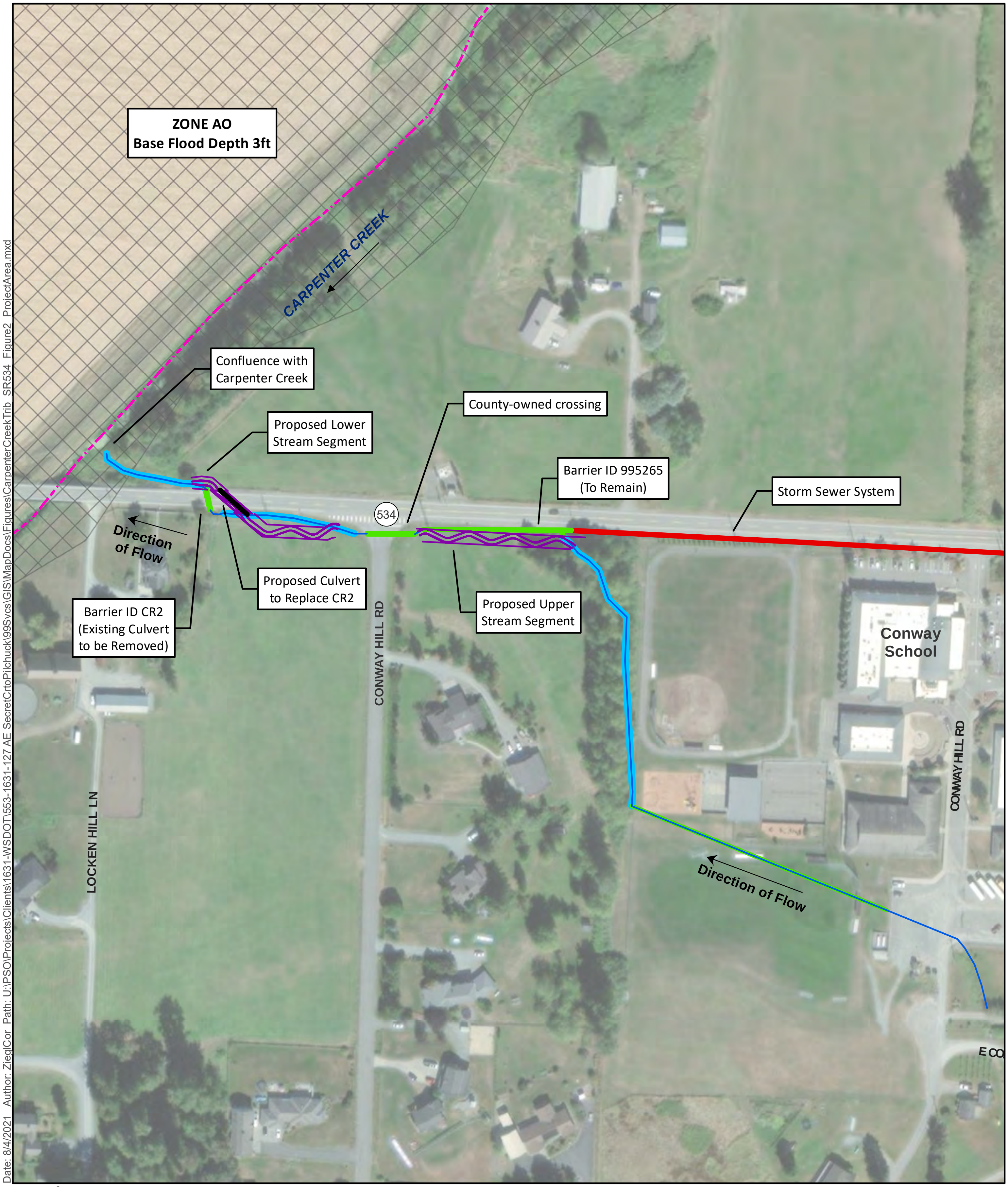
Waterbody Interior Line

0 750 1,500 3,000 Feet

Figure 1. Vicinity Map

Carpenter Creek Tributary SR 534

Skagit County, WA



Source: © Mapbox, © OpenStreetMap, WSDOT

- Carpenter Creek Tributary Thalweg
- Existing Storm Sewer Not Identified as Fish Barrier
- Existing Pipe/Culvert Identified as Fish Barrier
- Proposed Unnamed Tributary to Carpenter Creek Grading
- Proposed Culvert to Replace CR2
- Watercourse
- Open Channel
- Levees
- Floodplain Extent

0 50 100 200 Feet

Figure 2. Project Area
Carpenter Creek Tributary SR 534

Skagit County, WA

HYDRAULIC MODELING

Overview

The modeling includes an analysis of the anticipated changes to the base flood (100-year peak flow) using the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) one-dimensional hydraulic modeling software. The model was constructed using survey data provided by WSDOT and supplemented with lidar data to analyze the project reach.

The unnamed tributary to Carpenter Creek in the pre-project condition receives flow inputs from an upstream storm pipe that joins the tributary flows entering Culvert 995265, which can not be readily modeled in HEC-RAS. Therefore, the two reach geometries were modeled independently, and a separate hydraulic calculator software, HY-8, was used to determine tailwater conditions for the east-reach HEC-RAS Model created by Culvert 995265. In order to determine if the proposed channel design and replacement of Culvert CR2 would impact the base flood elevations, 11 cross sections were placed throughout the reach where the existing and proposed alignments would overlap in order to create coincident cross sections for comparison. The post-project condition was modeled as one continuous reach, and the base flood elevations of the coincident cross sections were compared manually.

Hydrology

The flow data used in the HEC-RAS model was sourced from the approved Preliminary Hydraulic Design Report for SR 534 MP 0.53 Unnamed Tributary 1 (west) and SR 534 ROW MP 0.60 Unnamed Tributary 2 (east) to Carpenter Creek. A storm sewer pipe conveys some runoff from the Conway along SR 534, which joins the flows from the Unnamed Tributary to Carpenter Creek at different points along the alignment in the pre- and post-project models. The flow input locations used for both the pre- and post-project models are identified in Table 1 as well as on the respective hydraulic modeling schematics of the existing and proposed conditions. Detailed results from the MGSFlood continuous-simulation hydrologic modeling results can be found in Attachment B.

Table 1. 100-Year Mean Recurrence Interval (MRI) Peak Flows for the Conveyance of the Unnamed Tributary (UNT) to Carpenter Creek and Stormwater System Flows along the SR 534 Project

Flows	Milepost (MP) and Tributary Association for UNT to Carpenter Creek	Station Flow Is Introduced in Existing Condition Model	Station Flow Is Introduced in Proposed Condition Model	100-Year MRI Peak Flows (cubic feet per second)
UNT to Carpenter Creek	MP 0.60 Tributary 2 (east)	1895.80	1904.46	32.5
Storm Sewer System Along SR 534	MP 0.53 Tributary 1 (west)	1552.55	1562.80	15.8
Total Peak Flows (UNT to Carpenter Creek +ST System)	MP 0.53 Tributary 1 (west)	1552.55	1562.80	48.3

Pre-Project Conditions

A pre-project conditions model surface was created to represent the current configuration of the channel geometry and existing culvert. The channel alignment and surveyed land surface was supplied to Parametrix by the WSDOT Project Engineer's Office in Bentley System's InRoads Program files, which were developed from the topographic surveys performed by WSDOT surveyors from the Northwest Region. Channel cross sections used in the HEC-RAS model were selected in InRoads along the existing stream alignment, perpendicular to the flow, and the channel banks and overbanks were identified as continuous features within each reach. The placement of cross sections followed the guidance in the HEC-RAS User's Manual, placing cross sections in locations that would provide representative channel reaches and capture energy losses. The surface data was then exported to two separate georeferenced GIS files using the “generate water surface data” output function, a hydrologic and hydraulic evaluation tool in MicroStation. The “.geo” files were then imported to HEC-RAS to display georeferenced channel cross sections and the existing west- and east-reach alignments. Figure 3 depicts the existing condition stream plan geometries from HEC-RAS, detailing how the reaches were analyzed separately.

The west reach extends from the outlet of Culvert 995265 through a channelized ditch, then flows across a private driveway through the Conway Hill Road culvert, continuing approximately 250 feet along an open channel and through the SR 534 culvert crossing (Culvert CR2) before the final 180-foot reach of the stream through a shallow and narrow channel, where it joins in confluence with Carpenter Creek. Due to the presence of steep slopes in portions of the existing conditions reaches, the flow regime would pass from subcritical to supercritical, requiring the model to be run in a mixed-flow regime mode. When using a mixed flow regime throughout this stream system, it is necessary to enter both upstream and downstream boundary conditions. The upstream boundary condition was set to the critical water surface elevation, and the downstream boundary conditions were set to a known water surface elevation (WSE) relevant to each respective reach. The known WSE used for the boundary condition of the west-reach flow was sourced from the FEMA Firm Panel number 530151 0425C, using the mapped base flood elevation of Zone A2 (9 feet in National Geodetic Vertical Datum of 1929 [NGVD 29]) downstream of where the Unnamed Tributary to Carpenter Creek joins Carpenter Creek in confluence (FEMA 1985). The base flood elevation was converted from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the North American Vertical Datum of 1988 (NAVD 88) using a conversion factor of +3.701 feet, resulting in a base flood elevation of 12.701 feet NAVD 88.

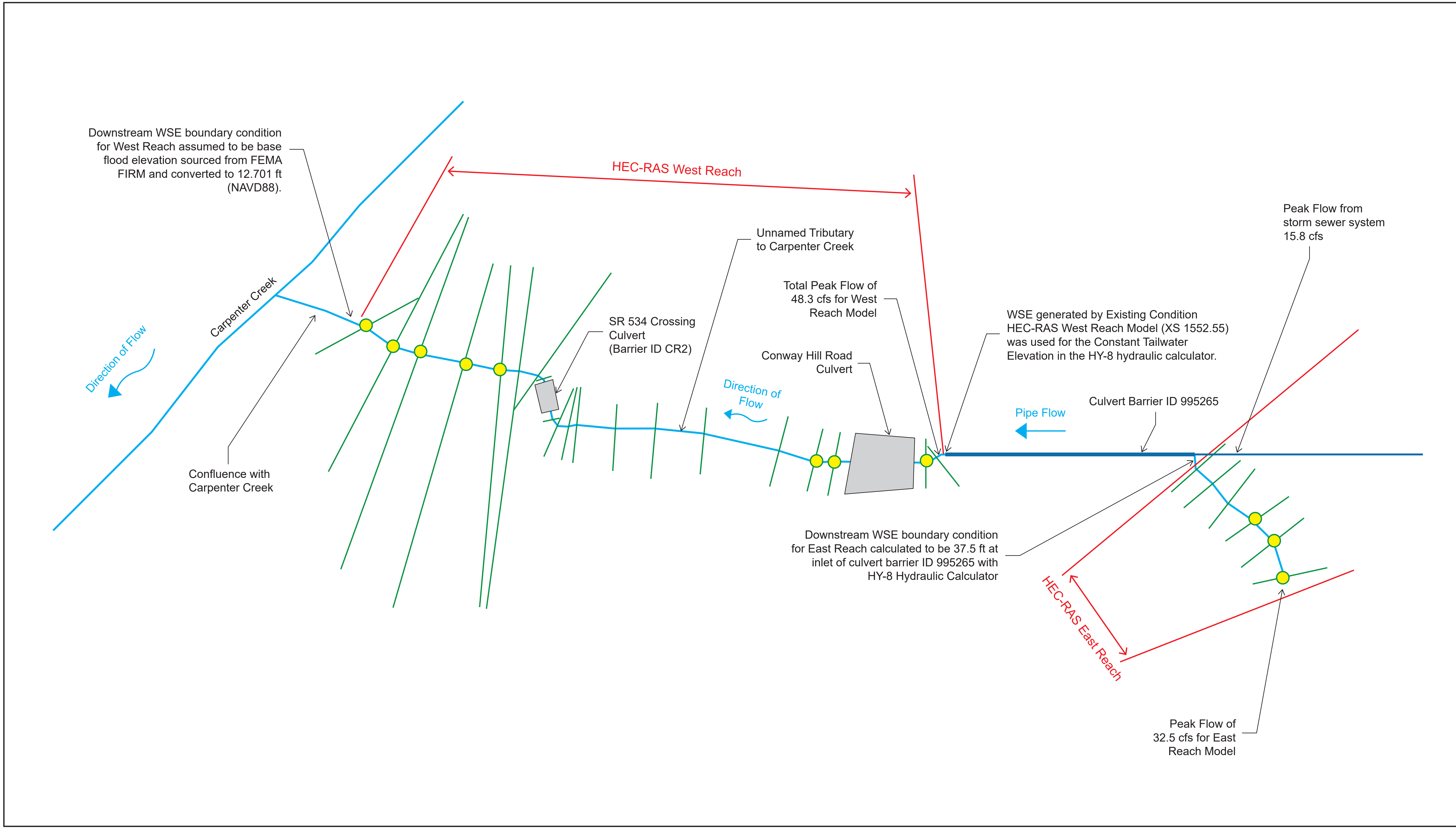
The east reach extends from approximately 110 feet upstream of Culvert 995265 to the outlet of the approximately 239-foot-long culvert. An analysis was performed using the HY-8 Hydraulic Calculator in order to estimate the known WSE at the inlet of Culvert 995265, which creates the downstream boundary condition for the peak flow for the east reach. The HY-8 model results confirmed that the system is in surcharge condition during the base flood event and likely experiences flooding at the culvert inlet. Therefore, a tailwater elevation of 37.5 feet was calculated for the east reach at the crown of Culvert 995265. The headwater surface elevation computed by the HY-8 model at the entrance of culvert 995265 rises to an elevation that overtops a low saddle point (at elevation 37.35 feet NAVD 88) in the surrounding topography and is located approximately 35 feet to the west of the existing inlet. It is assumed that overtopping of the saddle would prevent any additional increase in headwater at the culvert inlet. Details of the HY-8 Hydraulic Calculations and approach can be found in Attachment C.

The existing culvert geometry was then built into HEC-RAS using information contained within the InRoads survey base map, which includes culvert dimensions, invert elevations, and lengths. The geometry data was supplemented with roughness values (Manning’s *n* coefficients) determined using field observations of the channel and overbank surface material, surface irregularity, variation in channel size and shape, physical obstruction, live vegetation, and stream sinuosity. A roughness coefficient for the channel and overbanks was then computed based upon the criteria developed by Chow (Chow 1959), documented below in Table 2. See Attachment D for supporting calculations of Manning’s roughness coefficients for the existing condition.

Table 2. Manning’s Roughness Coefficients Used in the Existing Conditions Model

HEC-RAS Cross Section	Left Overbank Area Manning’s “n” Value	Main Channel Manning’s “n” Value	Right Overbank Area Manning’s “n” Value
All Cross Sections in East and West Reaches	0.044	0.039	0.044

The results of the existing conditions HEC-RAS model are included in Attachment E. Figures 4 and 5 depict the modeled existing condition, 100-year water surface profiles for the east and west reaches, respectively.



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Storm Sewer Pipes
Open Channel
HEC-RAS Cross Section (typical)
Coincident Cross Sections
Culverts

Figure 3. Hydraulic Modeling Schematic - Existing Conditions

Carpenter Creek Tributary SR 534

Skagit County, WA

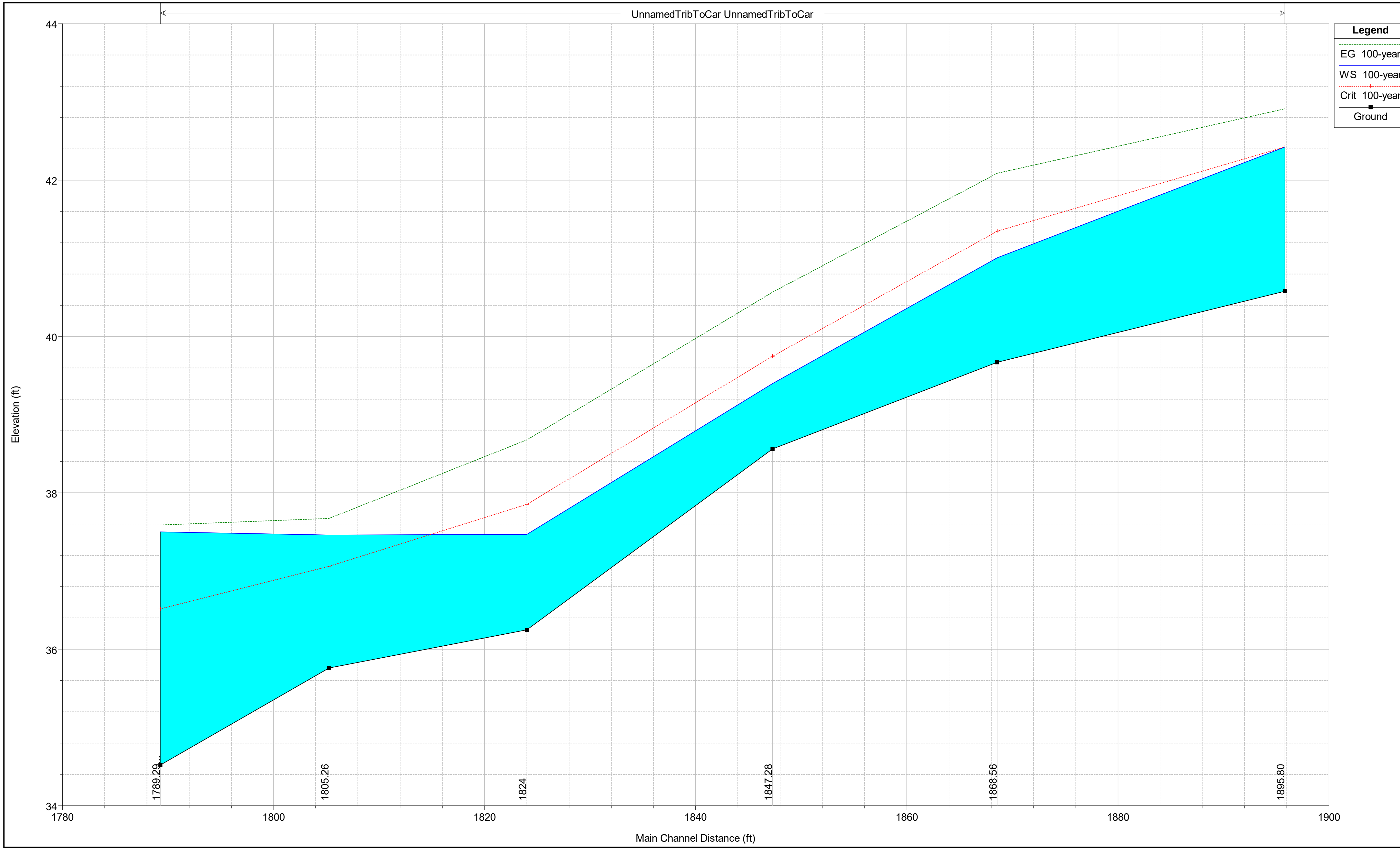

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Figure 4. Existing Conditions East Reach Water Surface Profile
Carpenter Creek Tributary SR 534

Skagit County, WA

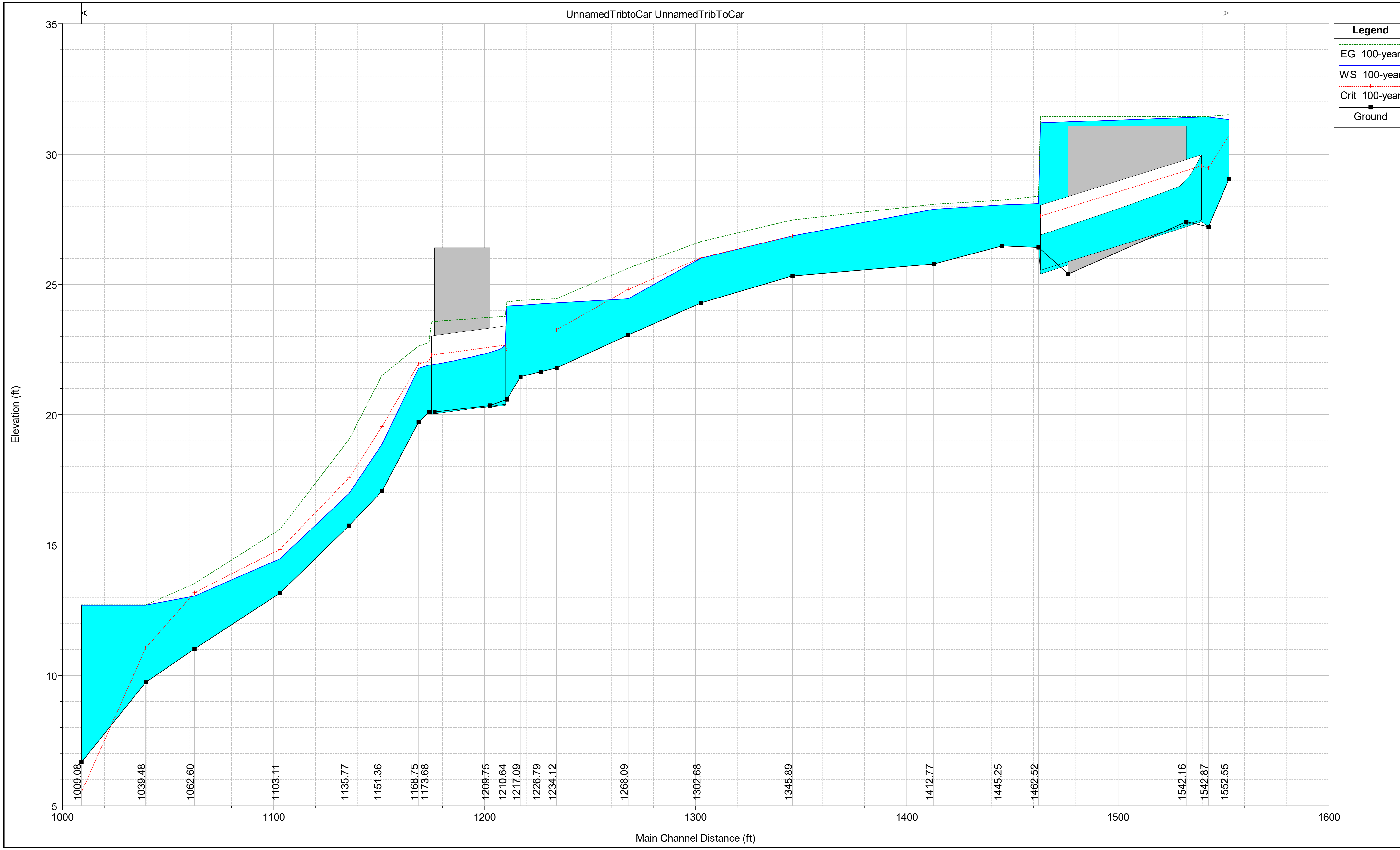

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Figure 5. Existing Conditions West Reach Water Surface Profile

Carpenter Creek Tributary SR 534

Skagit County, WA

Post-Project Conditions

The post-project conditions include a new channel alignment, profile, and cross section, as well as daylighting of barrier ID 995265 and replacement of barrier ID CR2 with a new fish passable design. WSDOT provided a survey base map in Bentley System's InRoads to Parametrix to aid in the analysis. WSDOT selected the general channel corridor alignment documented here and provided the design for the proposed crossing structure, while Parametrix provided the new channel cross section geometry, main channel meander, and profile for the alignment; as well as the minimum span, recommended freeboard, and minimum streambed depth of the proposed SR 534 crossing.

In the proposed conditions, the stream alignment shifts from beneath the SR 534 shoulder to a field located south of the roadway in order to daylight the channel. In the east segment of the reach, channel grading is proposed to begin 60 feet upstream of the existing inlet to Culvert 995265 and would continue downstream to tie into the existing channel 5 feet upstream of the inlet of the Conway Hill Road culvert. In order to fill the to-be-abandoned segment of existing channel and floodplain, finished grade will be constructed to a minimum elevation of 37.35 feet (NAVD 88) at approximately 35 feet west of the existing culvert inlet to a finished grade of 40.4 feet (NAVD 88) near the proposed Sta 18+23 cross section. Finished grade of this floodplain fill will vary between these points, but the slope will be graded to provide drainage within the area of constructed fill from the low saddle point that exists approximately 35 feet to the west of the existing inlet to Culvert 995265. The Conway Hill Road culvert will remain in place, and the project does not propose any modifications. The proposed condition would also include channel grading downstream of the Conway Hill Culvert that would continue through the crossing structure to replace Culvert CR2 and tie-in with the existing channel at the downstream end of the reach. A proposed conditions model was created to represent the proposed channel geometry and the selected crossing configuration, with the entire reach modeled as one reach. Cross sections were carried over from the pre-project conditions model for areas that propose no change. Cross sections were replaced in areas where the channel grading, stream daylighting, or culvert replacement are proposed in order to capture resulting changes in water surface elevations. The cross sections that were coincident between the existing and post-project conditions were maintained. The unique cross sections that were added in the proposed condition were located near existing cross sections. Additionally, the proposed channel features and regrading would result in a longer alignment.

The cross sections were exported from InRoads to a georeferenced GIS file using the "generate water surface data" output function and were then imported into HEC-RAS. The proposed culvert geometry was then built into HEC-RAS using information contained within the InRoads design files, which included the culvert dimensions and materials, invert elevations, and length. The geometry data was supplemented with roughness values (Manning's *n* coefficients) and applied to the model cross sections as described in Table 3. See Attachment F for supporting calculations of Manning's roughness coefficients for the proposed conditions. The roughness coefficients remained unchanged in portions of the reach that have no proposals for channel modifications, and the roughness values were updated in the cross sections that propose channel grading modifications or culvert redesign. Due to the presence of steep slopes in portions of the proposed conditions reach, the flow regime would pass from subcritical to supercritical, requiring the model to be run in a mixed flow regime mode. The proposed model was run using a mixed flow regime; therefore, it was necessary to enter both upstream and downstream boundary conditions. The upstream boundary condition was set to the critical WSE and the downstream boundary condition was set to the known WSE using the base flood elevation of the downstream SFHA Zone A2 of 9 feet (NGVD 29) associated with Carpenter Creek. The value was converted to a value of 12.701 ft (NAVD 88) using the same conversion factor as the existing model. Figure 6 depicts the proposed condition stream plan geometry, and Figure 7 depicts the HEC-RAS modeled post-project, 100-year water surface profile for the east and west reaches combined. The results of the post-project conditions HEC-RAS model are included in Attachment G.

Table 3. Manning's Roughness Coefficients Used in the Proposed Conditions Model by Cross-Section

HEC-RAS Cross Section	Left Overbank Area Manning's "n" Value	Main Channel Manning's "n" Value	Right Overbank Area Manning's "n" Value
1904.46	0.044	0.039	0.044
1877.21	0.044	0.039	0.044
1855.45	0.070	0.053	0.070
1823.20	0.070	0.053	0.070
1778.78	0.070	0.053	0.070
1738.81	0.070	0.053	0.070
1704.72	0.070	0.053	0.070
1666.64	0.070	0.053	0.070
1625.44	0.070	0.053	0.070
1604.76	0.070	0.053	0.070
1562.80	0.070	0.053	0.070
1550.83	0.044	0.039	0.044
1470.53	0.044	0.039	0.044
1453.26	0.044	0.039	0.044
1415.83	0.070	0.053	0.070
1381.21	0.070	0.053	0.070
1340.86	0.070	0.053	0.070
1305.75	0.070	0.053	0.070
1274.70	0.070	0.053	0.070
1251.00	0.070	0.053	0.070
1183.44	0.070	0.053	0.070
1151.34	0.070	0.053	0.070
1135.77	0.044	0.039	0.044
1103.10	0.044	0.039	0.044
1062.60	0.044	0.039	0.044
1039.48	0.044	0.039	0.044
1009.08	0.044	0.039	0.044

BASE FLOOD ELEVATION ANALYSIS DEMONSTRATING NO-RISE

Base flood elevations were determined at each modeled cross section along the length of the analyzed channel using the results of the hydraulic models described above. Pre-project and post-project cross sections and base flood elevations, are shown in Table 4 below. There are a number of unique cross sections within the reach that result from the lengthened alignment and the addition of natural meander features and culvert replacement. Eleven of the cross sections coincide between the pre-project and post-project models in terms of geometry and location within channel, in parts of the reach that have no proposed changes. The difference from pre- to post-project base flood elevations are also included in Table 4 for all coincident cross sections. Figure 8 depicts the cross sections for the Existing and Proposed Conditions to visually aid the comparison of the base flood elevation outputs generated by the HEC-RAS model.

HEC-RAS model results demonstrate that base flood elevation increases of greater than 1-foot are not expected to occur at any of the coincident cross sections from pre- to post-project conditions.

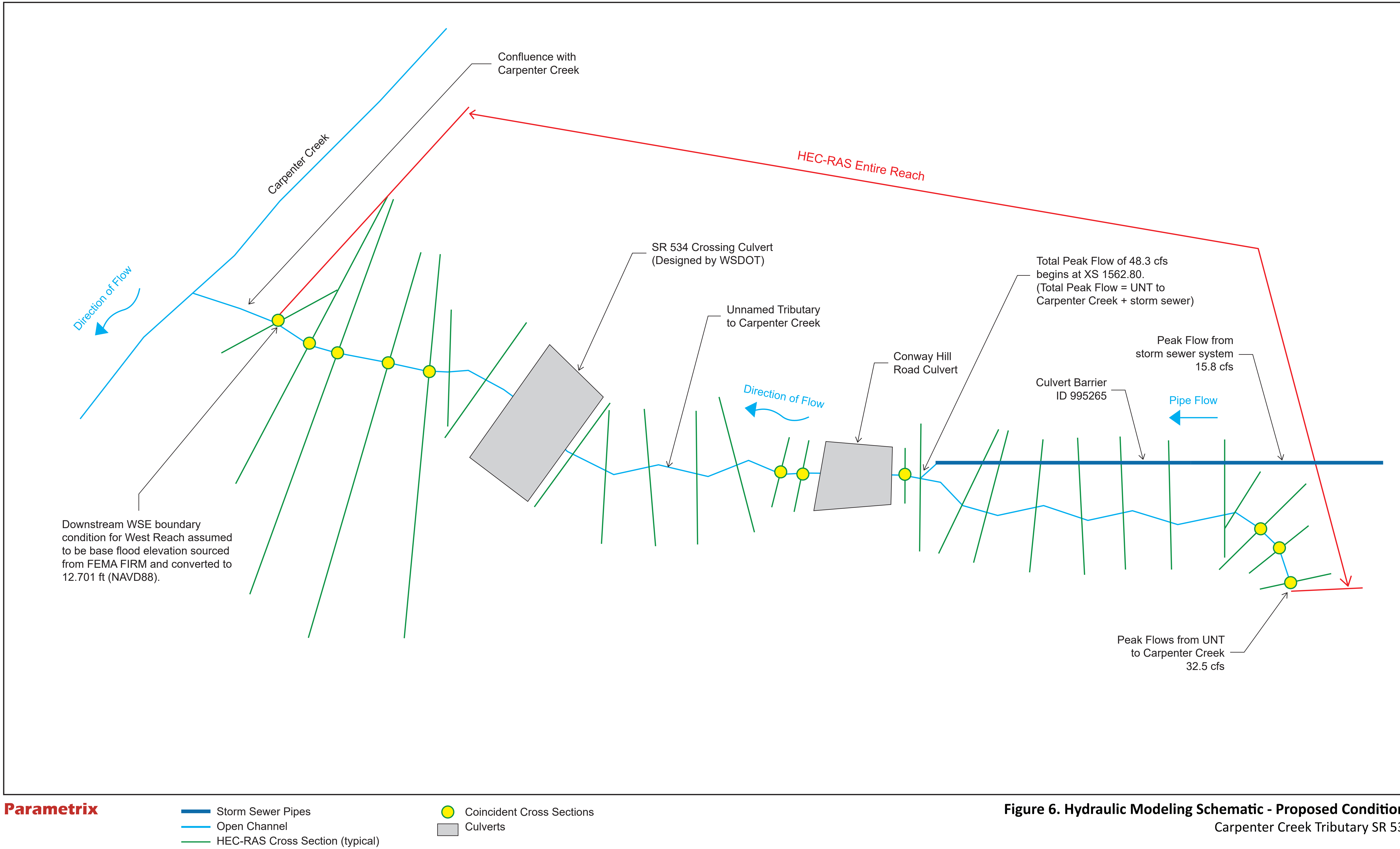

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Figure 6. Hydraulic Modeling Schematic - Proposed Conditions
Carpenter Creek Tributary SR 534

Skagit County, WA

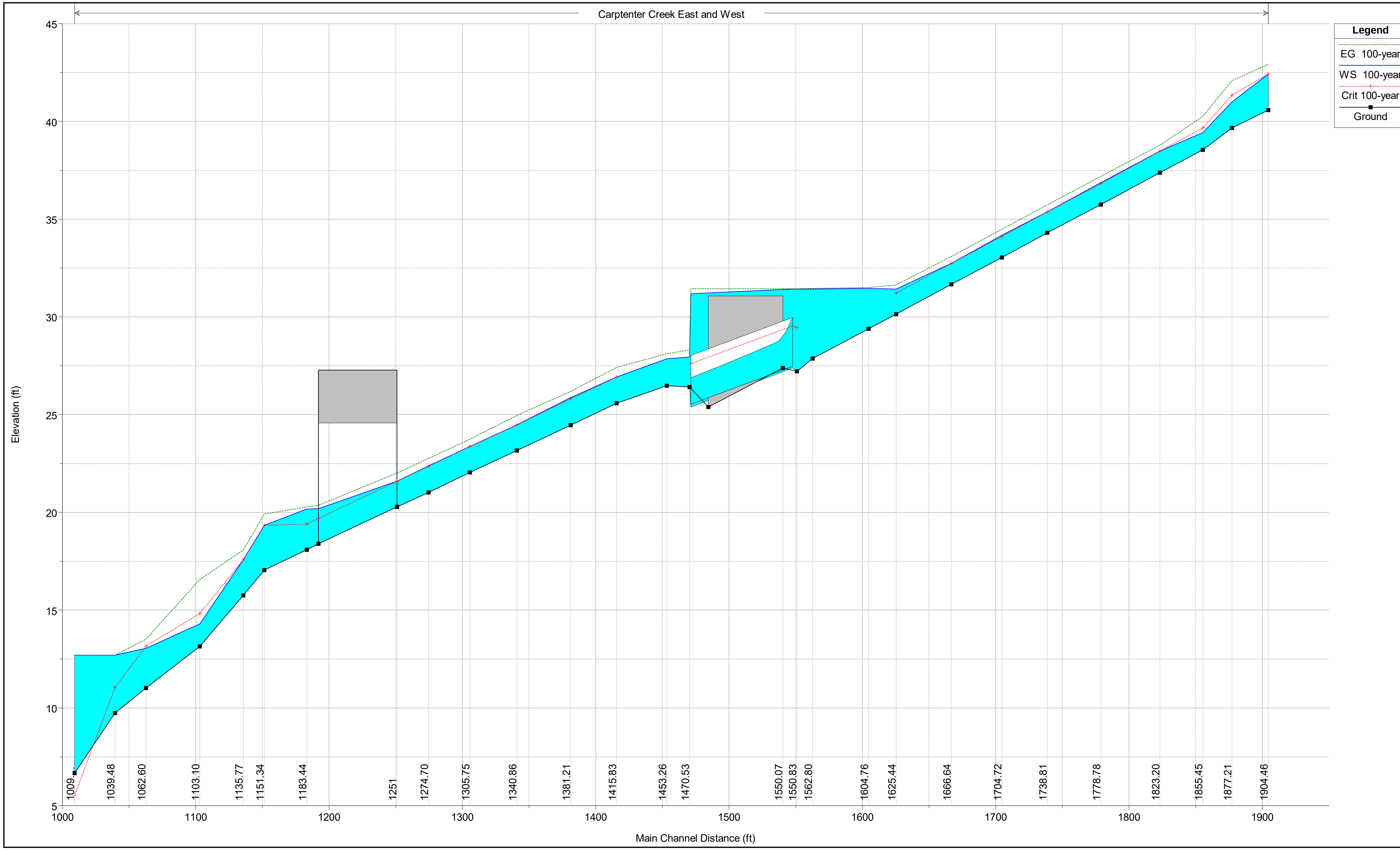

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Figure 7. Proposed Conditions Entire Reach Water Surface Profile
Carpenter Creek Tributary SR 534

Skagit County, WA

Table 4. Pre-Project and Post-Project Base Flood and Energy Grade Elevations and Deltas

Existing			Proposed			
Pre- and Post-Project Coincident HEC-RAS Cross Section River Station	**Unique HEC-RAS Cross Section River Station**	**Base Flood Elevation (feet)**	**Pre- and Post-Project Coincident HEC-RAS Cross Section River Station**	**Unique HEC-RAS Cross Section River Station**	**Base Flood Elevation (feet)**	**Base Flood Elevation Delta (feet)**
1009.08		12.70	1009.08		12.70	**0.00**
1039.48		12.70	1039.48		12.70	**0.00**
1062.60		13.04	1062.60		13.05	**0.01**
1103.10		14.47	1103.10		14.29	**-0.18**
1135.77		16.98	1135.77		17.58	**0.60**
				1151.34	19.35	
	1151.36	18.86				
	1168.75	21.79				
	1173.68	21.91				
				1183.44	20.17	
	1210.63	24.17				
	1217.09	24.19				
	1226.79	24.26				
	1234.12	24.29				
	1268.09	24.45				
				1274.70	22.39	
	1302.68	26.01				
				1305.75	23.38	
				1340.86	24.48	
	1345.89	26.86				
				1381.21	25.87	
				1415.83	26.92	
	1412.77	27.88				
1445.25		28.05	1453.26		27.85	**-0.20**

Table 4. Pre-Project and Post-Project Base Flood and Energy Grade Elevations and Deltas (continued)

Existing			Proposed			
Pre- and Post-Project Coincident HEC-RAS Cross Section River Station	**Unique HEC-RAS Cross Section River Station**	**Base Flood Elevation (feet)**	**Pre- and Post-Project Coincident HEC-RAS Cross Section River Station**	**Unique HEC-RAS Cross Section River Station**	**Base Flood Elevation (feet)**	**Base Flood Elevation Delta (feet)**
1462.52		28.09	1470.53		27.96	**-0.13**
1542.87		31.42	1550.83		31.42	**0.00**
	1552.55	31.33				
				1562.80	31.42	
				1604.76	31.46	
				1625.44	31.43	
				1666.64	32.73	
				1704.72	34.17	
				1738.81	35.38	
				1778.78	36.87	
	1789.29	37.50				
	1805.26	37.46				
				1823.20	38.49	
	1824.00	37.47				
1847.28		39.40	1855.45		39.43	**0.03**
1868.56		41.01	1877.21		41.01	**0.00**
1895.80		42.42	1904.46		42.42	**0.00**

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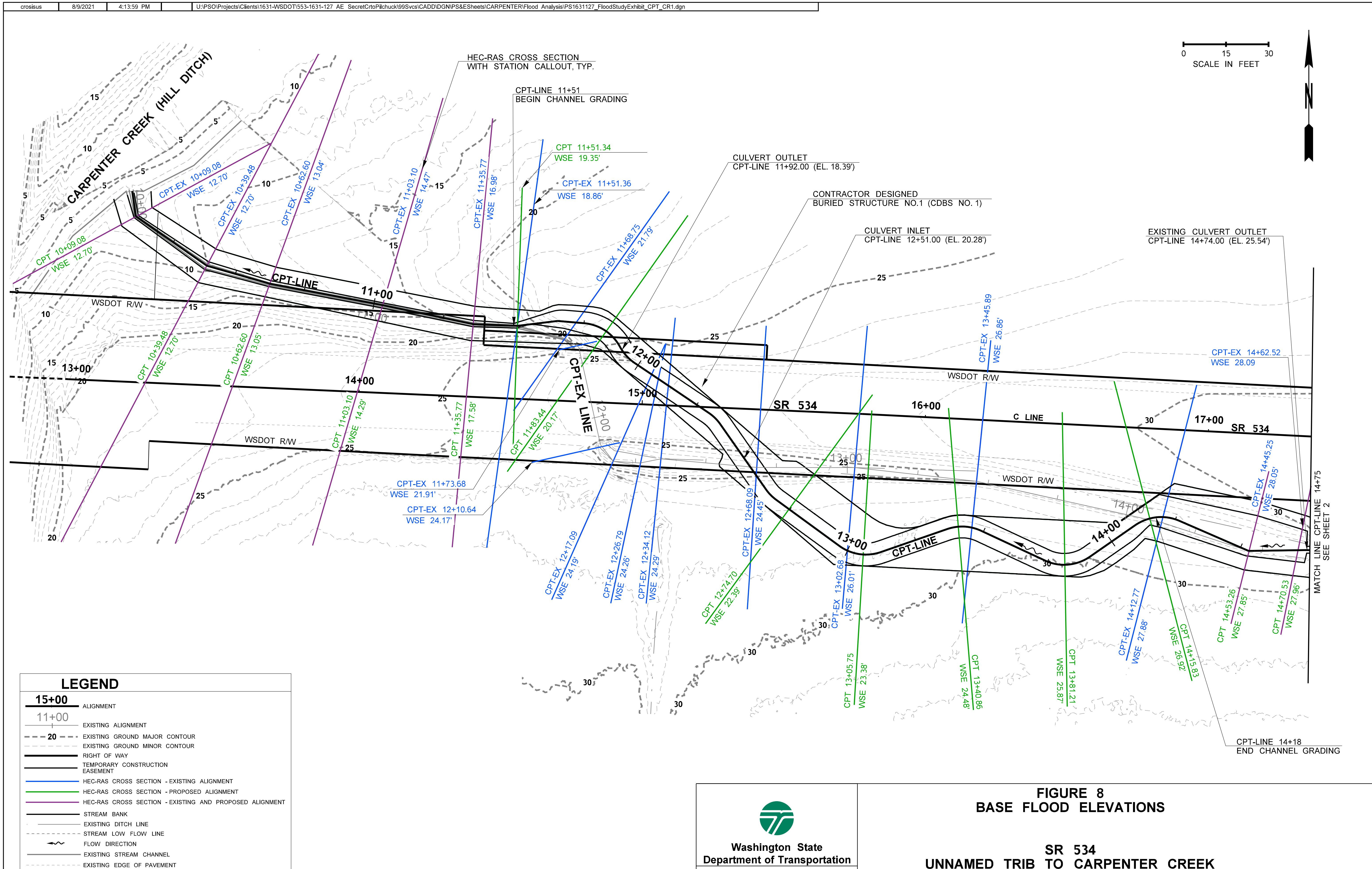

Washington State Department of Transportation

Parametrix

FIGURE 8
BASE FLOOD ELEVATIONS

SR 534
UNNAMED TRIB TO CARPENTER CREEK
FISH PASSAGE

SHEET 1 OF 2 SHEET(S)

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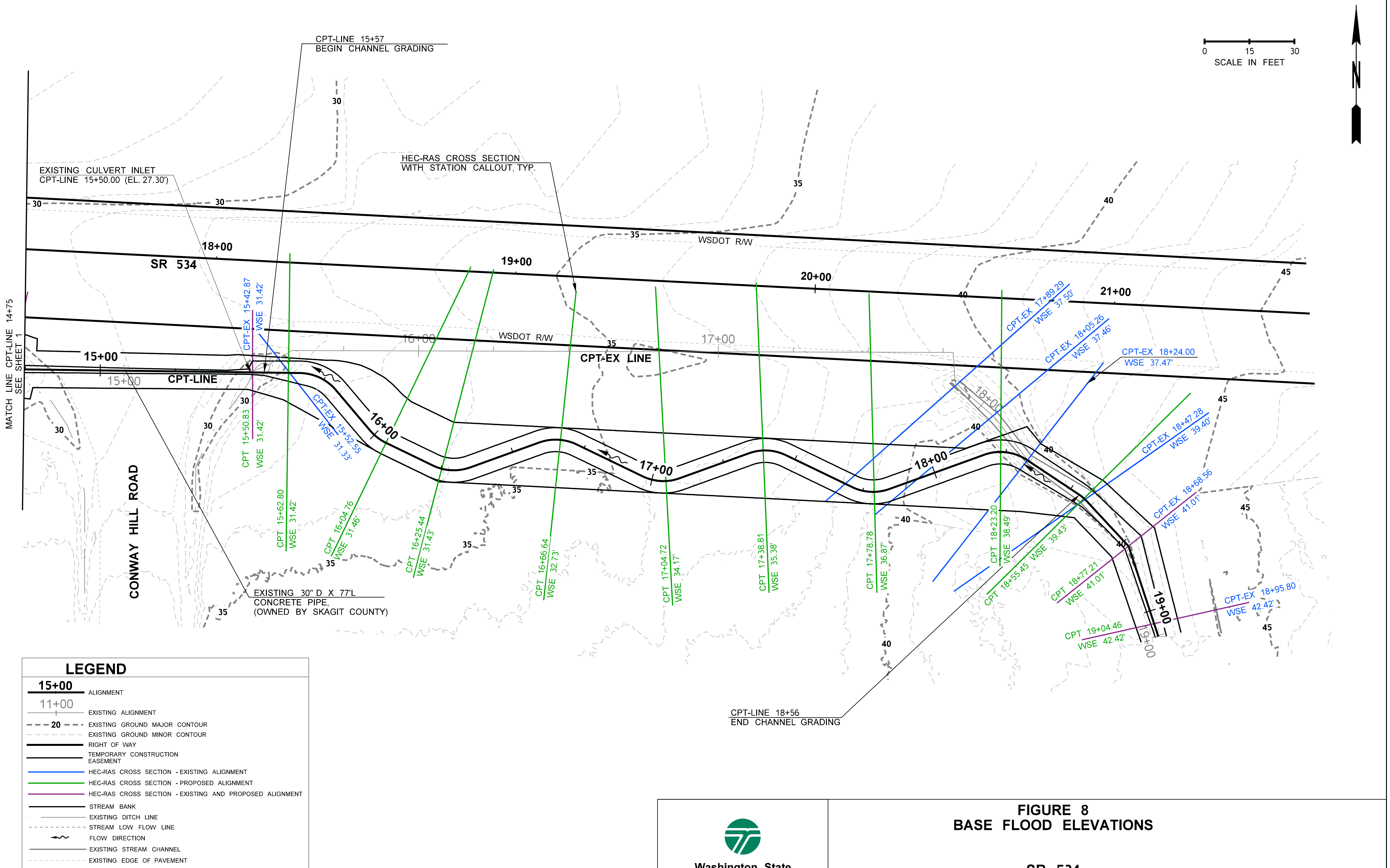

Washington State Department of Transportation

Parametrix

FIGURE 8
BASE FLOOD ELEVATIONS

SR 534
UNNAMED TRIB TO CARPENTER CREEK FISH PASSAGE

REFERENCES

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

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Mastin, M.C., C.P. Konrad, A.G. Veilleux, and A.E. Tecca. 2016. Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014 (version 1.2, November 2017). U.S. Geological Survey Scientific Investigations Report 2016-5118.

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ATTACHMENTS

Attachment A – FEMA FIRM

Attachment B – MGSFlood continuous-simulation Hydrologic Modeling Results

Attachment C – HY-8 Hydraulic Calculations

Attachment D – Calculation of Manning's Roughness Coefficients for Existing Conditions

Attachment E – Existing Conditions HEC-RAS Model Outputs

Attachment F – Calculation of Manning's Roughness Coefficients for Proposed Conditions

Attachment G – Proposed Conditions HEC-RAS Model Outputs

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Attachment A

FEMA FIRM

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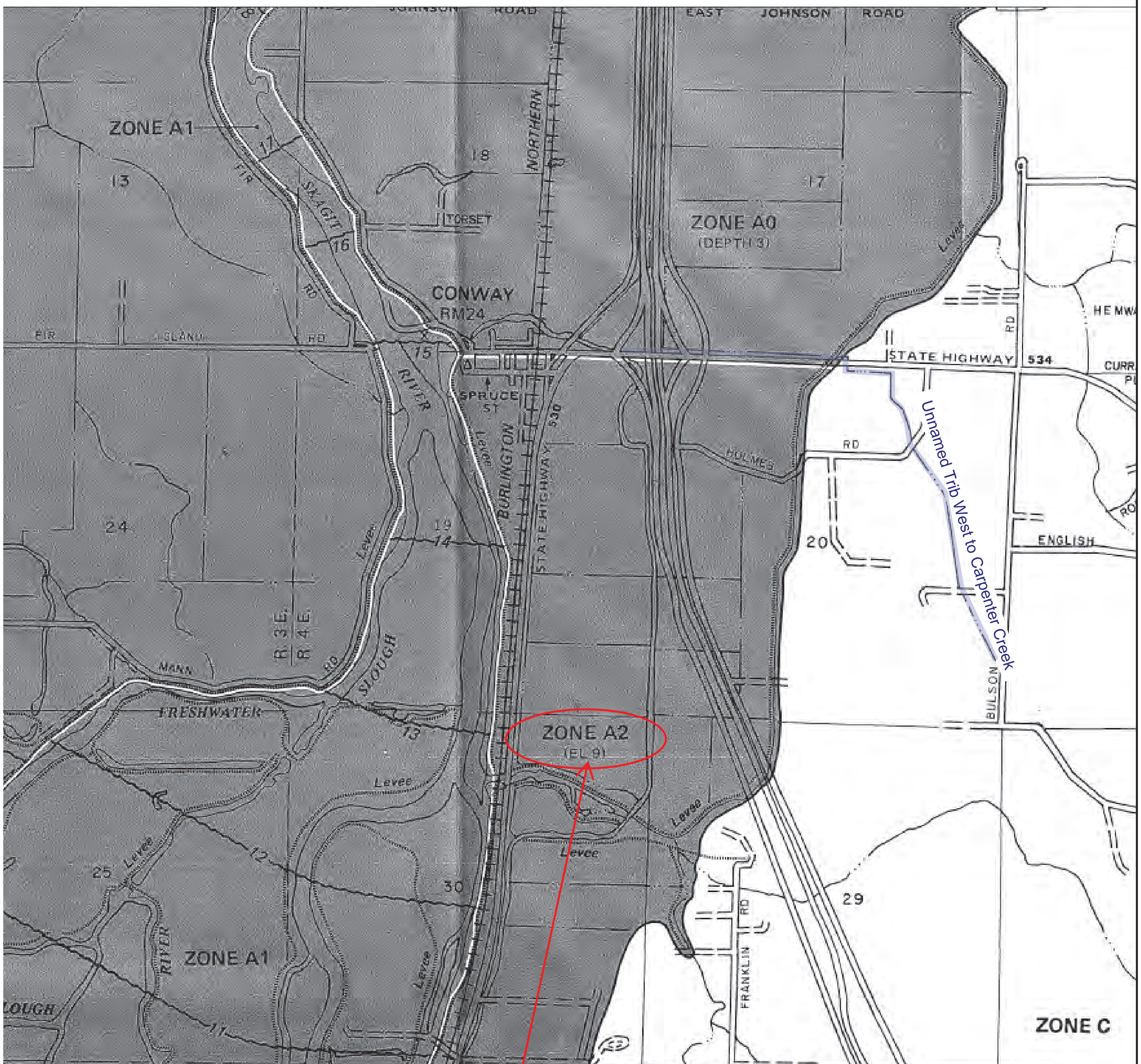

KEY TO MAP

500-Year Flood Boundary	ZONE B
100-Year Flood Boundary	ZONE A1
Zone Designations	ZONE A5
100-Year Flood Boundary	
500-Year Flood Boundary	ZONE B
Base Flood Elevation Line With Elevation In Feet**	513
Base Flood Elevation in Feet Where Uniform Within Zone**	(EL 987)
Elevation Reference Mark	RM7×
Zone D Boundary	
River Mile	•M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

SKAGIT COUNTY, WASHINGTON

(UNINCORPORATED AREAS)

PANEL 425 OF 550

(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER

530151 0425 C

EFFECTIVE DATE:

JANUARY 3, 1985

Federal Emergency Management Agency

Conversion: NAVD88 = NVGD 29 + 3.701 ft

EL 12.701 (NAVD 88). Used to define Boundary Condition of known WSE in HECRAS.

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Attachment B

MGSFlood Continuous-Simulation Hydrologic Modeling Results

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MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.52
Program License Number: 200510005
Project Simulation Performed on: 07/22/2021 11:28 AM
Report Generation Date: 07/22/2021 11:28 AM

Input File Name: SR534_MP0.53_UNTtoCarpenterCrk_CR2_995265_Watershed_BAK.FLD
Project Name: SR 534 Unnamed Tributary to Carpenter Creek Remove Fish Barrier
Analysis Title: Contributing watershed
Comments: SR 534 MP 0.53 Unnamed Tributary 1 (West) to Carpenter Creek (WDFW ID (CR2) and SR 534 ROW MP 0.60 Unnamed Tributary (east) to Carpenter Creek (WDFW ID 995265)

——— PRECIPITATION INPUT ———

Computational Time Step (Minutes): 15

Extended Precipitation Time Series Selected
Climatic Region Number: 15

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

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

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

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

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	299.318	299.318
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	299.318	299.318

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

---------- Subbasin : Subbasin 1 ----------

	-------Area (Acres) --------
Till Forest	42.385
Till Pasture	68.967
Till Grass	5.283

Outwash Forest	39.777
Outwash Pasture	64.725
Outwash Grass	4.958
Wetland	52.313
Impervious	20.910
Subbasin Total	299.318

----------------------SCENARIO: POSTDEVELOPED
Number of Subbasins: 1

---------- Subbasin : Subbasin 1 ----------

	-------Area (Acres) --------
Till Forest	0.331
Till Pasture	0.539
Till Grass	0.041
Outwash Forest	37.277
Outwash Pasture	60.655
Outwash Grass	4.646
Wetland	174.918
Impervious	20.910
Subbasin Total	299.318

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

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

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

----------------------SCENARIO: POSTDEVELOPED
Number of Links: 0

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

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

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

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

Total Predeveloped Recharge During Simulation
Model Element Recharge Amount (ac-ft)

Subbasin: Subbasin 1 65338.360

Total: 65338.360

Total Post Developed Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Subbasin 1	69518.460
Total:	69518.460

Total Predevelopment Recharge is Less than Post Developed
Average Recharge Per Year, (Number of Years= 158)
Predeveloped: 413.534 ac-ft/year, Post Developed: 439.990 ac-ft/year

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

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

Number of Links: 0

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

Number of Links: 0

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

Scenario Predeveloped Compliance Subbasin: Subbasin 1

Scenario Postdeveloped Compliance Subbasin: Subbasin 1

***** Point of Compliance Flow Frequency Data *****

Recurrence Interval Computed Using Gringorten Plotting Position

Predevelopment Runoff		Postdevelopment Runoff	
Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	11.889	2-Year	12.512
5-Year	19.289	5-Year	22.641
10-Year	24.227	10-Year	27.627
25-Year	37.263	25-Year	39.830
50-Year	45.143	50-Year	47.010
100-Year	49.453	100-Year	48.255
200-Year	49.774	200-Year	50.514
500-Year	50.089	500-Year	53.537

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

MGS FLOOD
PROJECT REPORT

Program Version: MGSFlood 4.52
Program License Number: 200510005
Project Simulation Performed on: 07/22/2021 11:32 AM
Report Generation Date: 07/22/2021 11:32 AM

Input File Name: SR534_MP0.53_UNTtoCarpenterCrk_StormPipe_BAK.FLD
Project Name: SR 534 Unnamed Tributary to Carpenter Creek Remove Fish Barrier
Analysis Title: Contributing watershed to existing SR 534 stormwater system
Comments: Storm pipe basin delineation for pipe that runs east to west along outside edge of eastbound SR 534

——— PRECIPITATION INPUT ———

Computational Time Step (Minutes): 15

Extended Precipitation Time Series Selected
Climatic Region Number: 15

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

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

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

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

Predevelopment/Post Development Tributary Area Summary

	Predeveloped	Post Developed
Total Subbasin Area (acres)	30.159	30.159
Area of Links that Include Precip/Evap (acres)	0.000	0.000
Total (acres)	30.159	30.159

---------------------SCENARIO: FORESTED CONDITION
Number of Subbasins: 1

---------- Subbasin : Forested condition ----------

	-------Area (Acres) --------
Till Forest	30.159
Subbasin Total	30.159

---------------------SCENARIO: EXISTING CONDITION
Number of Subbasins: 1

---------- Subbasin : Existing Condition ----------

	-------Area (Acres) --------
Till Forest	6.120
Till Grass	14.174
Wetland	1.536
Impervious	8.329
Subbasin Total	30.159

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

----------------------SCENARIO: FORESTED CONDITION
Number of Links: 0

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

----------------------SCENARIO: EXISTING CONDITION
Number of Links: 0

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

---------------------SCENARIO: FORESTED CONDITION
Number of Subbasins: 1
Number of Links: 0

---------------------SCENARIO: EXISTING CONDITION
Number of Subbasins: 1
Number of Links: 0

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

Total Predeveloped Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Forested condition	5200.285
Total:	5200.285

Total Post Developed Recharge During Simulation

Model Element	Recharge Amount (ac-ft)
Subbasin: Existing Condition	3116.500
Total:	3116.500

Total Predevelopment Recharge is Greater than Post Developed
Average Recharge Per Year, (Number of Years= 158)
Predeveloped: 32.913 ac-ft/year, Post Developed: 19.725 ac-ft/year

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

----------------------SCENARIO: FORESTED CONDITION

Number of Links: 0

----------------------SCENARIO: EXISTING CONDITION

Number of Links: 0

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

Scenario Forested Condition Compliance Subbasin: Forested condition

Scenario Existing Condition Compliance Subbasin: Existing Condition

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

Predevelopment Runoff		Postdevelopment Runoff	
Tr (Years)	Discharge (cfs)	Tr (Years)	Discharge (cfs)
2-Year	0.643	2-Year	4.471
5-Year	1.047	5-Year	6.023
10-Year	1.411	10-Year	7.903
25-Year	1.789	25-Year	10.775
50-Year	2.284	50-Year	13.949
100-Year	2.475	100-Year	15.810
200-Year	3.852	200-Year	16.468
500-Year	5.702	500-Year	17.291

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

Attachment C

HY-8 Hydraulic Calculations

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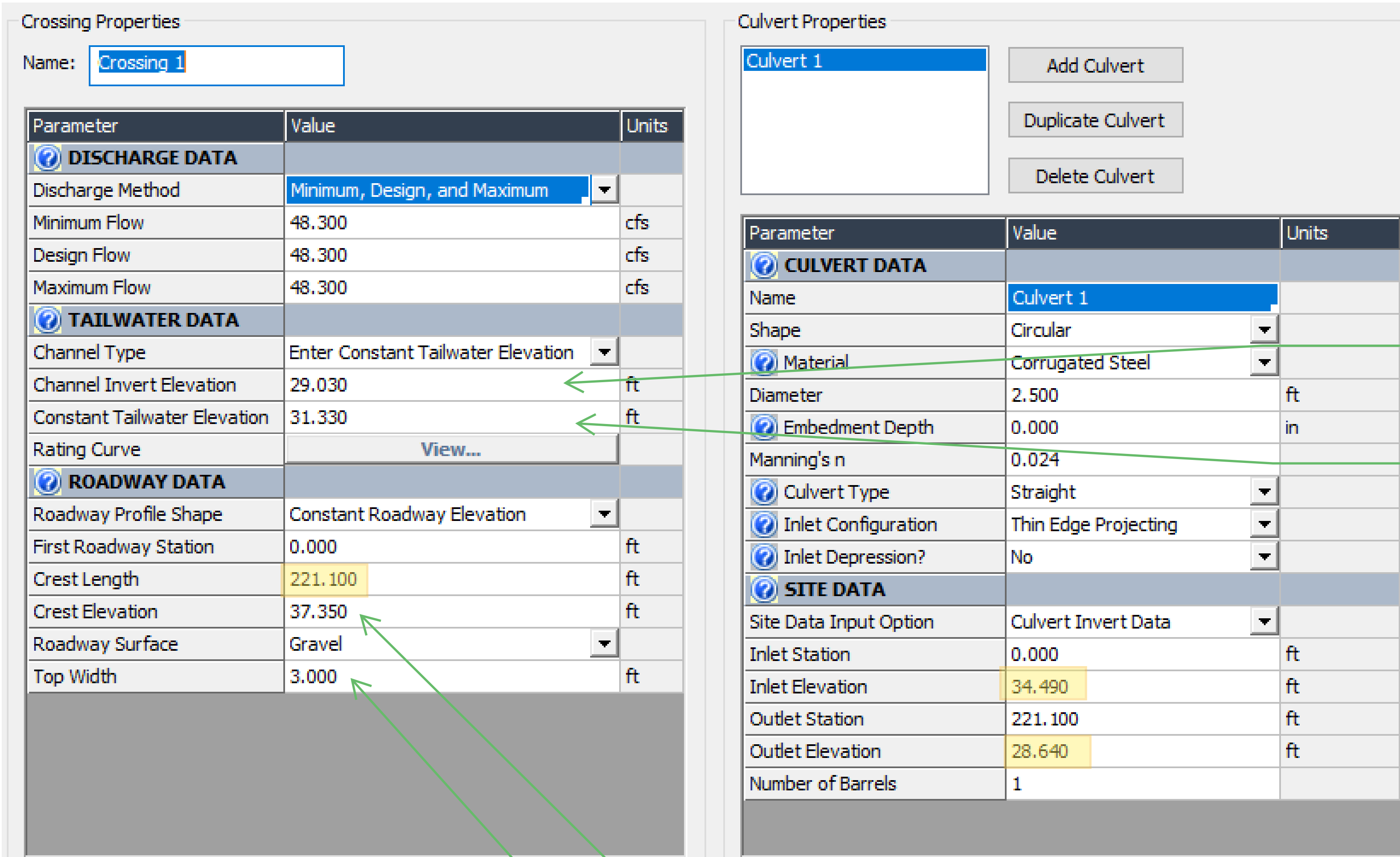


Crossing Properties

Name: Crossing 1

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	Minimum, Design, and Maximum	
Minimum Flow	48.300	cfs
Design Flow	48.300	cfs
Maximum Flow	48.300	cfs
TAILWATER DATA		
Channel Type	Enter Constant Tailwater Elevation	
Channel Invert Elevation	29.030	ft
Constant Tailwater Elevation	31.330	ft
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	221.100	ft
Crest Elevation	37.350	ft
Roadway Surface	Gravel	
Top Width	3.000	ft

Culvert Properties

Culvert 1

Add Culvert

Duplicate Culvert

Delete Culvert

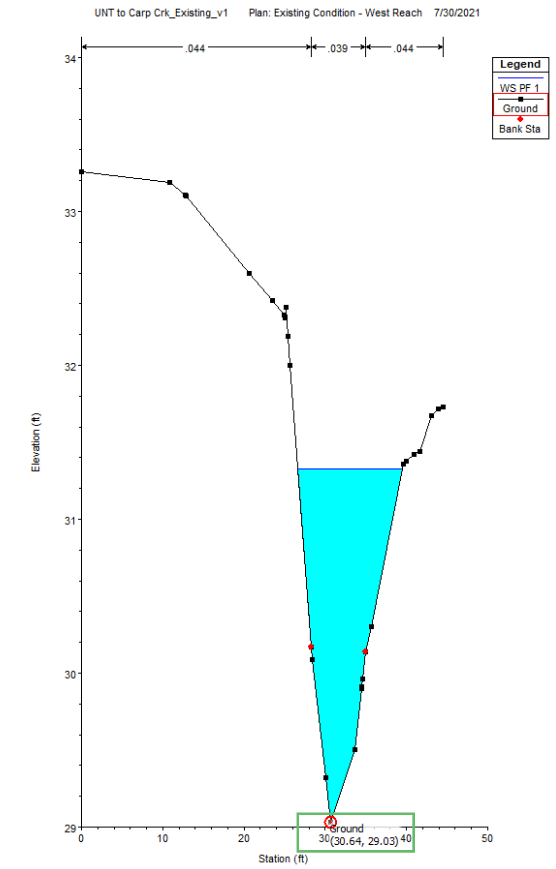
Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Circular	
Material	Corrugated Steel	
Diameter	2.500	ft
Embedment Depth	0.000	in
Manning's n	0.024	
Culvert Type	Straight	
Inlet Configuration	Thin Edge Projecting	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	34.490	ft
Outlet Station	221.100	ft
Outlet Elevation	28.640	ft
Number of Barrels	1	

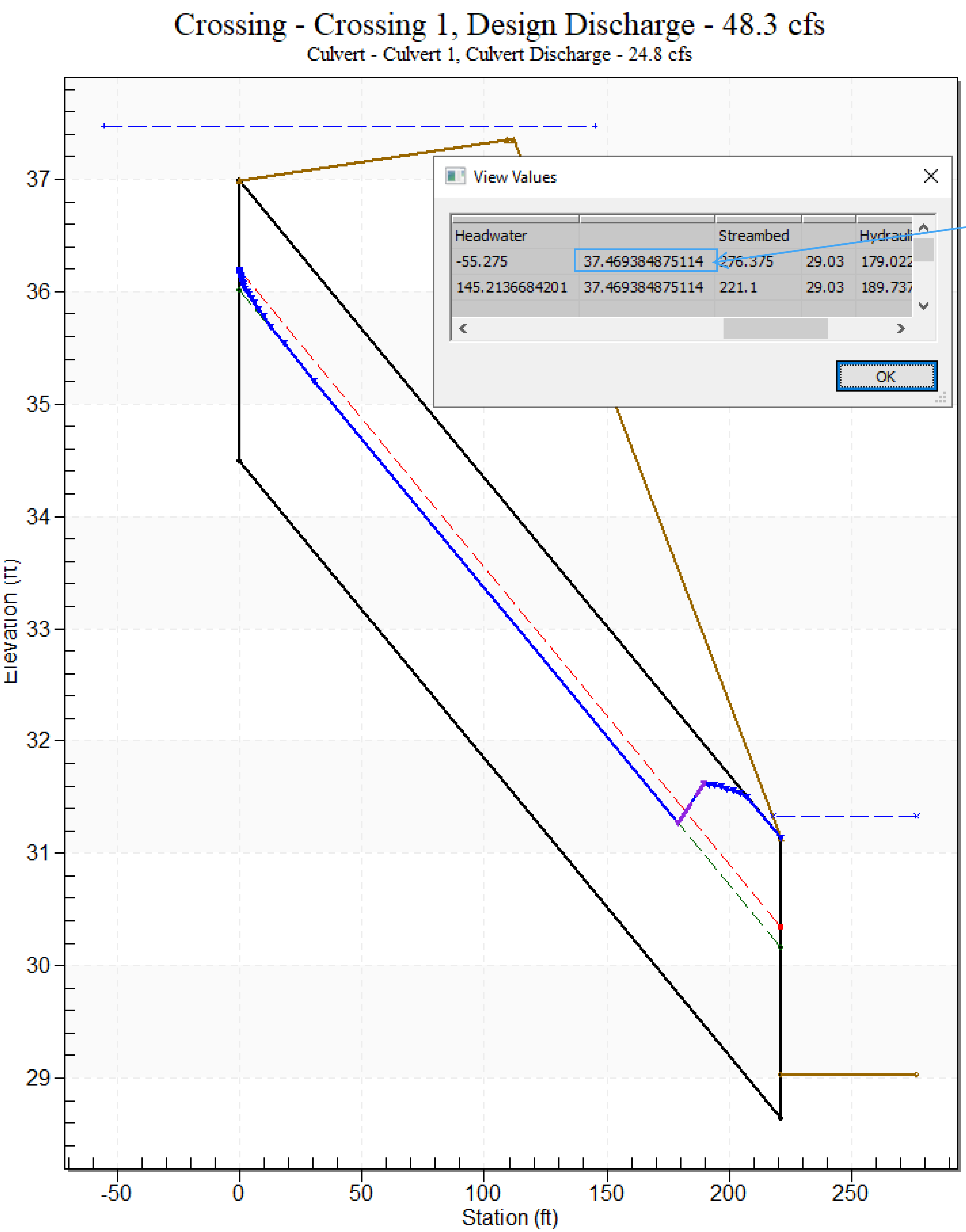
Thalweg Elevation Taken from Existing Model RS 1552.55

WSE Taken from Existing Model RS 1552.55

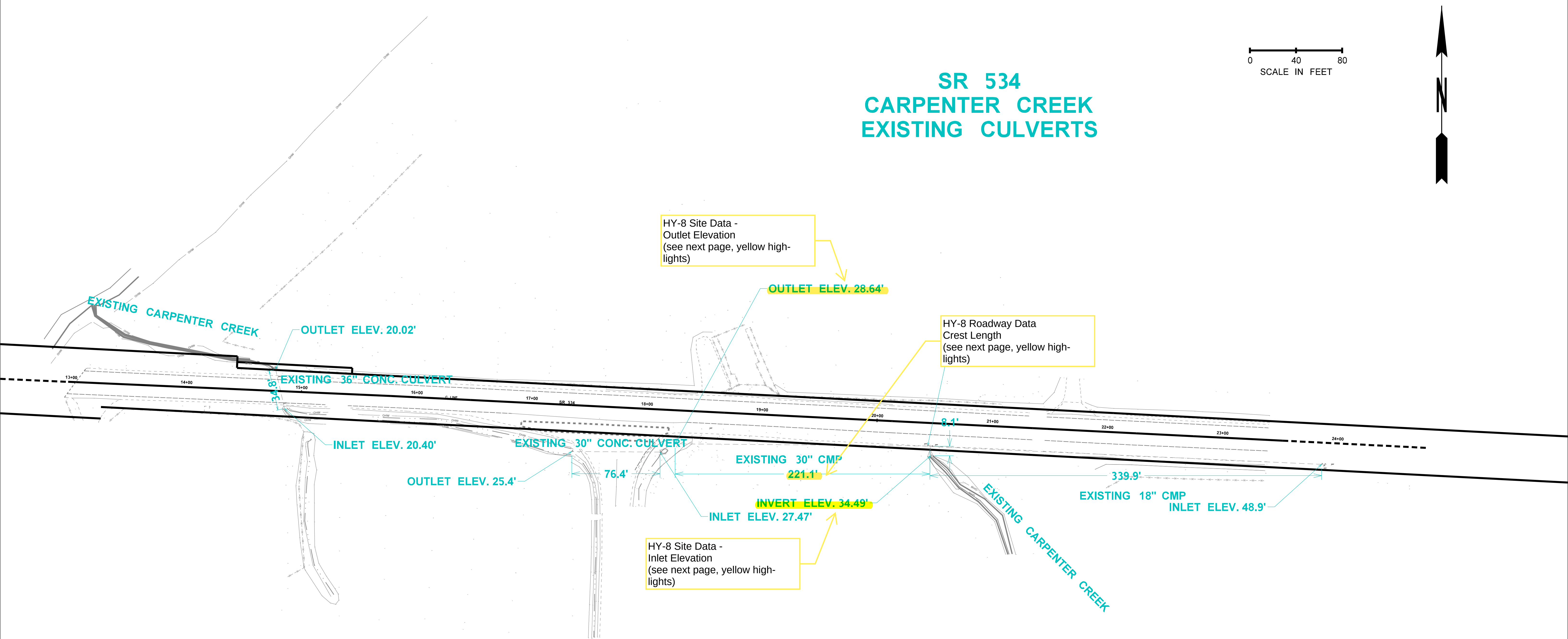
Estimated flow path width taken from In-Roads/ contours. Tyler N. reviewed 8.5.2021

Saddle elevation of roadway





Results:
Headwater Elevation:
37.47 feet



SR 534
CARPENTER CREEK
EXISTING CULVERTS
0
40
80
SCALE IN FEET
N
EXISTING CARPENTER CREEK
OUTLET ELEV. 20.02'
EXISTING 36" CONC. CULVERT
34.8'
INLET ELEV. 20.40'
HY-8 Site Data - Outlet Elevation (see next page, yellow high-lights)
OUTLET ELEV. 28.64'
HY-8 Roadway Data Crest Length (see next page, yellow high-lights)
8.1'
EXISTING 30" CONC. CULVERT
OUTLET ELEV. 25.4'
76.4'
EXISTING 30" CMP
221.1'
INVERT ELEV. 34.49'
INLET ELEV. 27.47'
HY-8 Site Data - Inlet Elevation (see next page, yellow high-lights)
339.9'
EXISTING 18" CMP
INLET ELEV. 48.9'
EXISTING CARPENTER CREEK

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Attachment D

Calculation of Manning's Roughness Coefficients for Existing Conditions

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Existing Condition - Main Channel

Carpenter Creek at SR 534 - Manning's n Calculation

T. Nabours
9/13/2019

Table 1: Values for the Computation of the Roughness Coefficient (Chow, 1959)	
Channel material (n0)	
earth	0.02
rock cut	0.025
fine gravel	0.024
coarse gravel	0.028
Degree of surface irregularity (n1)	
Smooth	0
Minor (e.g., dredged channel, slightly eroded side slopes)	0.005
Moderate	0.01
Severe (e.g., extensively sloughed banks of natural channel)	0.02
Variation in channel cross-section size or shape (n2)	
Gradual changes along channel	0
Alternating occasionally between large and small sections or shape such that flow shifts from side to side	0.005
Alternating extensive	0.01 to 0.015
Relative effect of obstructions (extent of water area occupied, degree to which obstructions are streamlined or induce turbulence in flow, position and spacing of obstructions) (n3)	
Negligible	0
Minor	0.010 - 0.015
Appreciable	0.020 - 0.030
Severe	0.040 - 0.060
Vegetation (n4)	
Low (e.g., flexible grasses, weeds, or seedlings where depth of flow is 3 times that of vegetation height)	0
Medium (e.g., grasses, weeds, or seedlings where depth of flow 2 times that of vegetation height or brush limited to channel side slopes and hydraulic radius greater than 2 ft)	0.010 - 0.025
High (e.g., emergent vegetation, trees in channel without foliage)	0.025 - 0.050
Very high (e.g., vegetation height 2 times that of flow, bushy willow with foliage)	0.050 - 0.100
Degree of meandering based on sinuousity (ratio of channel length to valley length) (m5)	
Minor (sinuousity < 1.2)	1
Appreciable (sinuousity 1.2 to 1.5)	1.15
Severe (sinuousity > 1.5)	1.3

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$$

n_0 =	0.024
n_1 =	0
n_2 =	0
n_3 =	0
n_4 =	0.015
m_5 =	1
n =	**0.039**

Existing Condition - Overbanks

Carpenter Creek at SR 534 - Manning's n Calculation

T. Nabours
9/13/2019

Table 1: Values for the Computation of the Roughness Coefficient (Chow, 1959)	
Channel material (n0)	
earth	0.02
rock cut	0.025
fine gravel	0.024
coarse gravel	0.028
Degree of surface irregularity (n1)	
Smooth	0
Minor (e.g., dredged channel, slightly eroded side slopes)	0.005
Moderate	0.01
Severe (e.g., extensively sloughed banks of natural channel)	0.02
Variation in channel cross-section size or shape (n2)	
Gradual changes along channel	0
Alternating occasionally between large and small sections or shape such that flow shifts from side to side	0.005
Alternating extensive	0.01 to 0.015
Relative effect of obstructions (extent of water area occupied, degree to which obstructions are streamlined or induce turbulence in flow, position and spacing of obstructions) (n3)	
Negligible	0
Minor	0.010 - 0.015
Appreciable	0.020 - 0.030
Severe	0.040 - 0.060
Vegetation (n4)	
Low (e.g., flexible grasses, weeds, or seedlings where depth of flow is 3 times that of vegetation height)	0
Medium (e.g., grasses, weeds, or seedlings where depth of flow 2 times that of vegetation height or brush limited to channel side slopes and hydraulic radius greater than 2 ft)	0.010 - 0.025
High (e.g., emergent vegetation, trees in channel without foliage)	0.025 - 0.050
Very high (e.g., vegetation height 2 times that of flow, bushy willow with foliage)	0.050 - 0.100
Degree of meandering based on sinuousity (ratio of channel length to valley length) (m5)	
Minor (sinuousity < 1.2)	1
Appreciable (sinuousity 1.2 to 1.5)	1.15
Severe (sinuousity > 1.5)	1.3

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$$

n_0 =	0.024
n_1 =	0
n_2 =	0
n_3 =	0
n_4 =	0.02
m_5 =	1
n =	**0.044**

Attachment E

Existing Condition HEC-RAS Model Outputs

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HEC-RAS Plan: East Reach (US)_Sub   River: UnnamedTribToCar   Reach: UnnamedTribToCar   Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Length Left	Length Chnl	Length Rght
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)	(ft)	(ft)
UnnamedTribToCar	1895.80	PF 1	32.50	40.58	42.42	42.42	42.91	0.016907	6.32	6.73	7.10	0.89	24.27	27.24	31.81
UnnamedTribToCar	1868.56	PF 1	32.50	39.67	41.01	41.35	42.09	0.053655	8.87	4.34	5.93	1.51	21.79	21.28	20.90
UnnamedTribToCar	1847.28	PF 1	32.50	38.56	39.40	39.74	40.57	0.098142	8.76	3.84	6.59	1.94	21.17	23.29	26.05
UnnamedTribToCar	1824	PF 1	32.50	36.25	37.47	37.85	38.68	0.067863	8.96	3.89	5.26	1.62	20.00	18.74	17.26
UnnamedTribToCar	1805.26	PF 1	32.50	35.76	37.46	37.06	37.67	0.006919	3.80	9.36	8.69	0.56	15.68	15.97	16.56
UnnamedTribToCar	1789.29	PF 1	32.50	34.52	37.50	36.52	37.59	0.001567	2.89	17.21	13.04	0.30			

HEC-RAS Plan: Trib 1 MP 0.60 (West) River: UnnamedTribtoCar Reach: UnnamedTribToCar Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Length Left	Length Chnl	Length Rght
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)	(ft)	(ft)
UnnamedTribToCar	1552.55	PF 1	48.30	29.03	31.33	30.69	31.50	0.004053	3.49	16.05	12.94	0.45	17.89	9.66	3.33
UnnamedTribToCar	1542.87	PF 1	48.30	27.21	31.42	29.46	31.45	0.000458	1.78	40.50	19.84	0.16	85.22	80.37	85.46
UnnamedTribToCar	1542.16		Culvert												
UnnamedTribToCar	1462.52	PF 1	48.30	26.42	28.09		28.39	0.008238	4.44	11.74	9.35	0.63	17.24	17.27	16.17
UnnamedTribToCar	1445.25	PF 1	48.30	26.48	28.05		28.23	0.005731	3.47	14.40	11.96	0.52	32.52	32.47	32.30
UnnamedTribToCar	1412.77	PF 1	48.30	25.78	27.88		28.07	0.004426	3.64	15.01	12.94	0.47	65.86	66.89	68.89
UnnamedTribToCar	1345.89	PF 1	48.30	25.32	26.86	26.86	27.48	0.020248	6.41	8.12	7.22	0.95	43.17	43.20	43.37
UnnamedTribToCar	1302.68	PF 1	48.30	24.29	26.01	26.02	26.65	0.018269	6.79	8.42	7.37	0.93	34.49	34.60	34.76
UnnamedTribToCar	1268.09	PF 1	48.30	23.05	24.45	24.81	25.62	0.049536	8.83	5.86	6.49	1.44	34.42	33.96	33.61
UnnamedTribToCar	1234.12	PF 1	48.30	21.80	24.29	23.26	24.44	0.002703	3.20	16.86	9.91	0.37	8.16	7.34	5.66
UnnamedTribToCar	1226.79	PF 1	48.30	21.65	24.26		24.42	0.002920	3.48	16.61	9.74	0.40	11.42	9.69	6.77
UnnamedTribToCar	1217.09	PF 1	48.30	21.46	24.19		24.39	0.003244	3.72	15.22	8.46	0.42	13.50	6.47	212.59
UnnamedTribToCar	1210.64	PF 1	48.30	20.58	24.17	22.44	24.32	0.001726	3.36	17.96	7.87	0.32	41.25	36.94	172.43
UnnamedTribToCar	1209.75		Culvert												
UnnamedTribToCar	1173.68	PF 1	48.30	20.10	21.91	22.06	22.75	0.024988	7.86	7.31	6.24	1.08	0.31	4.93	9.91
UnnamedTribToCar	1168.75	PF 1	48.30	19.72	21.79	21.95	22.64	0.024651	8.10	7.46	65.75	1.05	14.57	17.39	20.35
UnnamedTribToCar	1151.36	PF 1	48.30	17.06	18.86	19.55	21.51	0.195873	15.18	4.13	48.90	2.35	15.32	15.57	15.80
UnnamedTribToCar	1135.77	PF 1	48.30	15.75	16.98	17.58	19.06	0.113000	12.47	4.70	51.49	2.18	33.80	32.66	31.51
UnnamedTribToCar	1103.11	PF 1	48.30	13.15	14.47	14.83	15.60	0.085195	8.96	6.28	58.77	1.79	40.91	40.51	40.07
UnnamedTribToCar	1062.60	PF 1	48.30	11.02	13.04	13.17	13.52	0.029262	6.77	10.28	127.87	1.02	24.07	23.12	22.20
UnnamedTribToCar	1039.48	PF 1	48.30	9.73	12.70	11.05	12.70	0.000003	0.11	436.76	142.56	0.01	34.00	30.39	26.69
UnnamedTribToCar	1009.08	PF 1	48.30	6.67	12.70	5.53	12.70	0.000001	0.12	534.26	103.53	0.01			

Attachment F

Calculation of Manning's Roughness Coefficients for Proposed Conditions

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Carpenter Creek at SR 534 - Manning's n Calculation

T. Nabours
11/11/2019

Proposed Design - main channel

Table 1: Values for the Computation of the Roughness Coefficient (Chow, 1959)	
Channel material (n0)	
earth	0.02
rock cut	0.025
fine gravel	0.024
coarse gravel	0.028
Degree of surface irregularity (n1)	
Smooth	0
Minor (e.g., dredged channel, slightly eroded side slopes)	0.005
Moderate	0.01
Severe (e.g., extensively sloughed banks of natural channel)	0.02
Variation in channel cross-section size or shape (n2)	
Gradual changes along channel	0
Alternating occasionally between large and small sections or shape such that flow shifts from side to side	0.005
Alternating extensive	0.01 to 0.015
Relative effect of obstructions (extent of water area occupied, degree to which obstructions are streamlined or induce turbulence in flow, position and spacing of obstructions) (n3)	
Negligible	0
Minor	0.010 - 0.015
Appreciable	0.020 - 0.030
Severe	0.040 - 0.060
Vegetation (n4)	
Low (e.g., flexible grasses, weeds, or seedlings where depth of flow is 3 times that of vegetation height)	0
Medium (e.g., grasses, weeds, or seedlings where depth of flow 2 times that of vegetation height or brush limited to channel side slopes and hydraulic radius greater than 2 ft)	0.010 - 0.025
High (e.g., emergent vegetation, trees in channel without foliage)	0.025 - 0.050
Very high (e.g., vegetation height 2 times that of flow, bushy willow with foliage)	0.050 - 0.100
Degree of meandering based on sinuousity (ratio of channel length to valley length) (m5)	
Minor (sinuousity < 1.2)	1
Appreciable (sinuousity 1.2 to 1.5)	1.15
Severe (sinuousity > 1.5)	1.3

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$$

n_0 =	0.028
n_1 =	0
n_2 =	0.005
n_3 =	0.02
n_4 =	0
m_5 =	1
n =	0.053

Carpenter Creek at SR 534 - Manning's n Calculation

T. Nabours
11/11/2019

Proposed Design - overbanks

Table 1: Values for the Computation of the Roughness Coefficient (Chow, 1959)	
Channel material (n0)	
earth	0.02
rock cut	0.025
fine gravel	0.024
coarse gravel	0.028
Degree of surface irregularity (n1)	
Smooth	0
Minor (e.g., dredged channel, slightly eroded side slopes)	0.005
Moderate	0.01
Severe (e.g., extensively sloughed banks of natural channel)	0.02
Variation in channel cross-section size or shape (n2)	
Gradual changes along channel	0
Alternating occasionally between large and small sections or shape such that flow shifts from side to side	0.005
Alternating extensive	0.01 to 0.015
Relative effect of obstructions (extent of water area occupied, degree to which obstructions are streamlined or induce turbulence in flow, position and spacing of obstructions) (n3)	
Negligible	0
Minor	0.010 - 0.015
Appreciable	0.020 - 0.030
Severe	0.040 - 0.060
Vegetation (n4)	
Low (e.g., flexible grasses, weeds, or seedlings where depth of flow is 3 times that of vegetation height)	0
Medium (e.g., grasses, weeds, or seedlings where depth of flow 2 times that of vegetation height or brush limited to channel side slopes and hydraulic radius greater than 2 ft)	0.010 - 0.025
High (e.g., emergent vegetation, trees in channel without foliage)	0.025 - 0.050
Very high (e.g., vegetation height 2 times that of flow, bushy willow with foliage)	0.050 - 0.100
Degree of meandering based on sinuousity (ratio of channel length to valley length) (m5)	
Minor (sinuousity < 1.2)	1
Appreciable (sinuousity 1.2 to 1.5)	1.15
Severe (sinuousity > 1.5)	1.3

$n = (n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$

n_0 =	0.02
n_1 =	0
n_2 =	0.005
n_3 =	0.025
n_4 =	0.02
m_5 =	1
n =	0.070

Attachment G

Proposed Condition HEC-RAS Model Outputs

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HEC-RAS Plan: Proposed_EntireReach River: Carptenter Creek Reach: East and West Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Length Left	Length Chnl	Length Rght
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft)	(ft)	(ft)
East and West	1904.46	PF 1	32.50	40.58	42.42	42.42	42.91	0.016907	6.32	6.73	7.10	0.89	24.27	27.24	31.81
East and West	1877.21	PF 1	32.50	39.67	41.01	41.35	42.09	0.053655	8.87	4.34	5.93	1.51	21.74	21.77	22.92
East and West	1855.45	PF 1	32.50	38.55	39.43	39.68	40.26	0.132996	7.38	4.54	8.35	1.63	21.87	32.24	40.51
East and West	1823.20	PF 1	32.50	37.38	38.49	38.49	38.79	0.032505	4.48	8.38	18.43	0.85	42.02	44.42	43.40
East and West	1778.78	PF 1	32.50	35.75	36.87	36.82	37.19	0.034232	4.61	7.47	11.43	0.87	36.55	39.97	36.86
East and West	1738.81	PF 1	32.50	34.30	35.38	35.37	35.73	0.039277	4.80	7.22	12.02	0.93	32.89	34.08	33.14
East and West	1704.72	PF 1	32.50	33.05	34.17	34.12	34.49	0.033335	4.57	7.55	11.56	0.86	37.11	38.08	33.93
East and West	1666.64	PF 1	32.50	31.66	32.73	32.73	33.09	0.040291	4.84	7.12	11.85	0.94	39.14	41.36	36.06
East and West	1625.44	PF 1	32.50	30.15	31.43	31.22	31.64	0.017753	3.73	9.79	14.33	0.65	21.36	20.53	17.47
East and West	1604.76	PF 1	32.50	29.40	31.46		31.50	0.001924	1.79	24.18	22.90	0.23	35.36	41.96	43.57
East and West	1562.80	PF 1	48.30	27.87	31.42		31.46	0.000760	1.68	38.15	17.97	0.16	12.49	11.96	12.05
East and West	1550.83	PF 1	48.30	27.21	31.42	29.46	31.45	0.000458	1.78	40.50	19.84	0.16	85.22	80.30	82.33
East and West	1550.07		Culvert												
East and West	1470.53	PF 1	48.30	26.42	27.96		28.32	0.011298	4.90	10.53	9.01	0.73	17.24	17.27	16.17
East and West	1453.26	PF 1	48.30	26.48	27.85		28.11	0.009774	4.09	12.06	11.30	0.66	32.97	37.47	43.58
East and West	1415.83	PF 1	48.30	25.59	26.92	26.92	27.42	0.041222	5.72	8.84	9.60	0.98	36.35	34.59	31.00
East and West	1381.21	PF 1	48.30	24.47	25.87	25.81	26.19	0.024689	4.74	12.24	22.28	0.78	36.41	40.35	37.71
East and West	1340.86	PF 1	48.30	23.17	24.48	24.47	24.96	0.038332	5.59	9.04	10.13	0.96	35.12	35.11	34.33
East and West	1305.75	PF 1	48.30	22.04	23.38	23.38	23.74	0.029827	5.02	11.54	17.73	0.85	34.49	31.05	22.63
East and West	1274.70	PF 1	48.30	21.03	22.39	22.37	22.77	0.029812	5.08	11.09	16.92	0.85	23.69	23.69	23.69
East and West	1251		Bridge												
East and West	1183.44	PF 1	48.30	18.09	20.17	19.41	20.29	0.005021	2.91	19.63	14.61	0.38	27.65	32.10	36.07
East and West	1151.34	PF 1	48.30	17.05	19.35	19.35	19.91	0.031580	7.37	10.14	17.64	0.91	15.91	15.57	15.21
East and West	1135.77	PF 1	48.30	15.75	17.58	17.58	18.08	0.016328	6.47	9.96	61.68	0.90	33.80	32.66	31.51
East and West	1103.10	PF 1	48.30	13.15	14.29	14.83	16.57	0.230609	12.41	4.27	55.68	2.82	40.91	40.51	40.07
East and West	1062.60	PF 1	48.30	11.02	13.05	13.17	13.52	0.028308	6.69	10.43	128.07	1.00	24.07	23.12	22.20
East and West	1039.48	PF 1	48.30	9.73	12.70	11.05	12.70	0.000003	0.11	436.76	142.56	0.01	34.00	30.39	26.69
East and West	1009.08	PF 1	48.30	6.67	12.70	5.53	12.70	0.000001	0.12	534.26	103.53	0.01			

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