

## 7 Final Scour Analysis

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

### 7.1 Lateral Migration

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

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

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

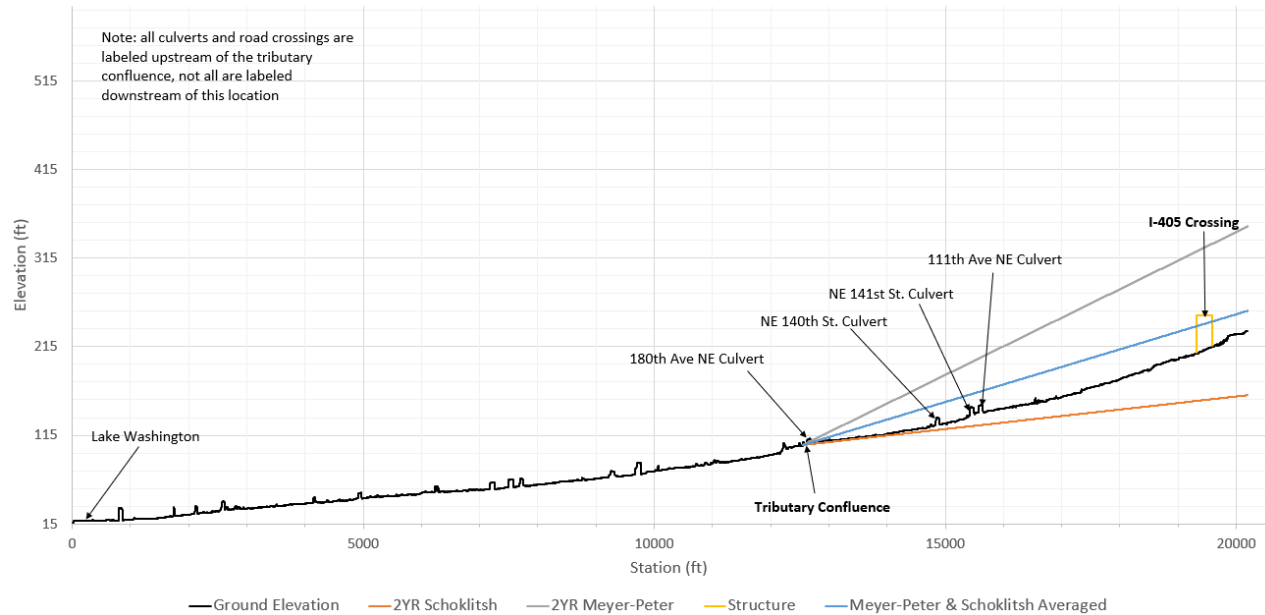
Although the risk for lateral migration is considered low to moderate, the risk in relation to the structure is assumed to occur for the purposes of scour analysis and estimation of total scour. The geotechnical data available at this time are not sufficient to exclude the risk of lateral migration from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

## 7.2 Long-term Degradation of the Channel Bed

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

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

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



**Figure 7-1. LTD Profile**

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

A degradation of 1.47 feet would be applied to total scour using existing conditions as degradation or incision is initiated downstream. For the proposed design, in order to provide a stable bed, the streambed material needs to be coarser than existing material as described in **Section 4.3**. This difference in size creates a more stable streambed and also acts as a profile stability measure. In order to quantify the effects of this coarser streambed, the same armor layer depth approach was used. Using the design riffle and meander bar gradation ( $D_{50} = 7.68$  inches), which will make up the majority of the streambed (and will be placed beneath the finer pool streambed sediment to a depth of 5 feet), the armoring depth for the proposed I-405 crossing is 0.12 feet (Table 7-1). This indicates that the riffle and meander bar sediments will act as an armor layer and not degrade significantly. Downstream of the proposed grading limits,

if a scour depth of 1.47 feet developed over time and began to headcut up to the downstream end of the proposed streambed, the proposed riffle material will stop the headcut from migrating further upstream to the structure. The proposed streambed material outside of the structure is placed to a depth of 3 feet and therefore would be protected down to the LTD depth of 1.47 feet and an additional 1.53 feet. If this condition (or greater degradation) were to occur, it would also not likely result in a fish passage barrier (due to water drop) because the proposed riffle material would respond by creating a ramp connecting the degraded portion of the stream to the proposed streambed. This would effectively function as a steeper riffle. The proposed bed material acting as a profile stability measure from this analysis has implications on applicable structural total scour.

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

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

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

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

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

**Table 7-1: LTD Summary table**

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

\*Included in estimate of total scour

### 7.3 Contraction Scour

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

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

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

### 7.4 Local Scour

#### 7.4.1 Scour at LWM

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

In order to estimate the potential scour from LWM, the *Hydraulic Engineering Circular No. 18* (HEC-18) pier scour equation will be used at LWM structures and at various flows. It is worth

noting that the HEC-18 pier scour equation is based on the Colorado State (CSU) equation (FHWA 2012); after development of this approach, Landers et al. concluded that the CSU equation frequently over-predicted the observed scour in laboratory studies, resulting in maximum scour depths (FHWA 2012). When applying the HEC-18 equation to geometries like LWM that differ from the pier shapes that the equation was developed for, caution needs to be taken with the resulting scour depths. Thus, the less conservative Julien 2002 equation will also be evaluated (USBR 2015). The U.S. Bureau of Reclamation *Bank Stabilization Guidelines* (2015) outline methods for the design of engineered log jams for bank stabilization that include the evaluation of local scour using the Julien equation, which generally provides less conservative results than the HEC-18 method. Thus, the less conservative Julian equation (USBR 2015) was also used to evaluate potential scour at LWM.

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

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

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

Table 7-2: Depth of local scour at LWM

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

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

#### 7.4.2 Pier Scour

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

#### 7.4.3 Abutment Scour

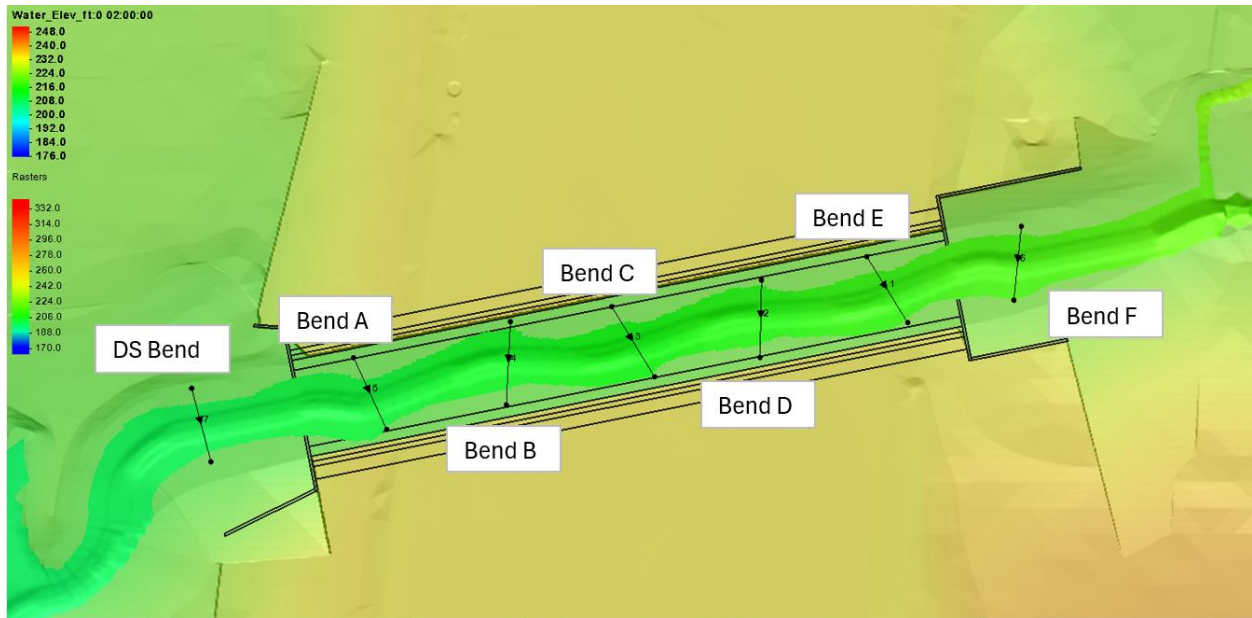
Abutment scour was estimated using the NCHRP 24-20 approach for all flood events up to the scour design flood and scour check flood using a clear-water condition. The NCHRP 24-20 method jointly evaluates contraction scour and abutment scour by applying an amplification factor to contraction scour. As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

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

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

#### 7.4.4 Bend Scour

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



**Figure 7-2. Bend scour locations**

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

**Table 7-3: Bend scour results**

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

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

The bend downstream of the I-405 crossing (denoted by DS Bend) was evaluated for bend scour because the stream at this location meanders and the outside of the bend is near existing fences and properties. Some property owners have already installed their own rock protection measures likely due to concerns of erosion. The more conservative estimated bend scour at this

location is approximately 1 foot using the Thorne Equation. Although this calculated bend scour is not excessive, a bank protection LWM structure is included at this location to help redirect flow and help protect adjacent properties from impacts due to realigning Juanita Creek.

## 7.5 Total Scour

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

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

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

**Table 7-4: Scour analysis summary**

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

## 8 Scour Countermeasures

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

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