I-405 MP 26.90 Queensborough Creek (WDFW ID): 993109 Final Hydraulic Design Report – NDC 152

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0 Revision Log

Revision		Description
A	4/5/2024	Preliminary Submittal
B	8/25/2024	Final Submittal
0	4/9/2025	RFC Submittal
1	5/1/2026	NDC 152

1 Introduction

This notice of design change (NDC) modifies the I-405 MP 26.90 Queensborough Creek Final Hydraulic Design Report (FHD). It presents updated bed material gradations and updated scour analyses associated with this change. This report addendum supersedes and replaces the following tables, sections, and figures as specified below.

- Section 4.1 Channel Design
  - Section 4.1.1 Channel Planform and Shape text revised to remove reference to previous type I and Type II Streambed Materials.
  - Updated Figure 4-2 and Figure 4-3.
- Section 4.2 Minimum Hydraulic Opening
  - Updated Figure 4-4.
  - Section 4.2.4 Hydraulic Length updated to include reference to DBIC 049 and discuss the updated hydraulic length.
- Section 4.3.1 Bed Material
  - Updated discussion of streambed material gradations.
  - Updated Table 4-5 and Table 4-6.
  - Table 4-7 deleted.
  - Subsection 4.3.1.1 retitled to “Stability Analysis of Streambed Material” and includes revised text.
- Section 4.3.2 Channel Complexity
  - Subsection 4.3.2.1 Design Concept, Figures 4-5, 4-6, and 4-7 revised.
  - Subsection 4.3.2.3 Meander Bars revised to remove reference to previous Type II Streambed Material and discuss meander bar material gradation.
    - Added Table 4-8 and Table 4-9.
  - Subsection 4.3.2.4 Deformable Grade Control revised to remove reference to previous Type II Streambed Material.
  - Subsection 4.3.2.5 Stability Analysis revised to remove reference to previous Type II Streambed Material.
- Section 7.2 Long-term Degradation of the Channel Bed
  - Updated armoring depth.
  - Text revised to remove reference to previous Type II Streambed Material.
- Subsection 7.4.3 Bend Scour revised.
- Section 7.5 Total Scour
  - Updated total scour values in text.
  - Updated Table 7-2.
- Section 9 Summary
  - Updated Table 9-1 potential channel degradation value.
  - Updated Table 9-1 crossing length values.
- Appendix C replaced in entirety
- Appendix D replaced in entirety
- Appendix K.1 and K.3 replaced in entirety

Refer to Revision 0 of the FHD report for sections or references not included in this addendum.

4 Water Crossing Design

4.1 Channel Design

4.1.1 Channel Planform and Shape

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

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

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

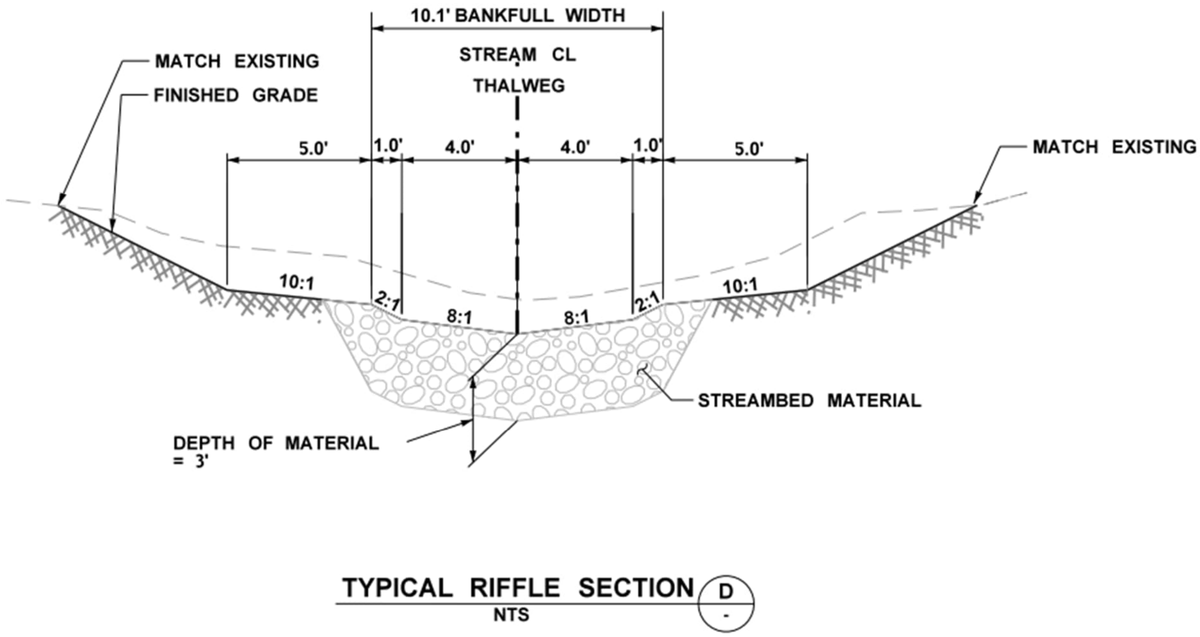

Figure 4-2: Typical riffle design cross section

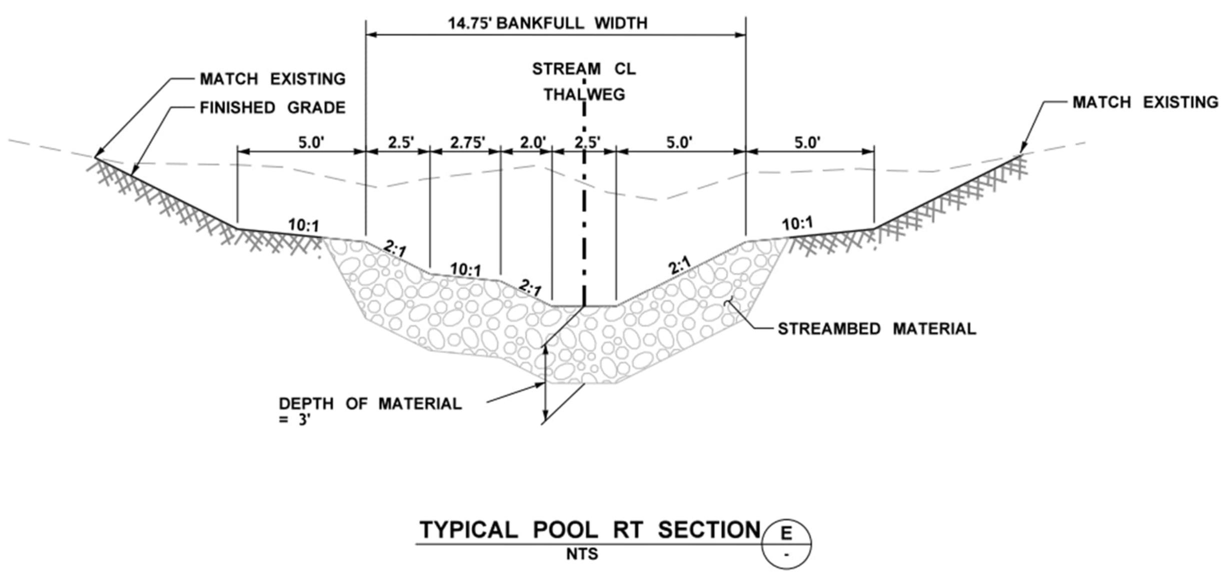

Figure 4-3: Typical pool design cross section

4.2 Minimum Hydraulic Opening

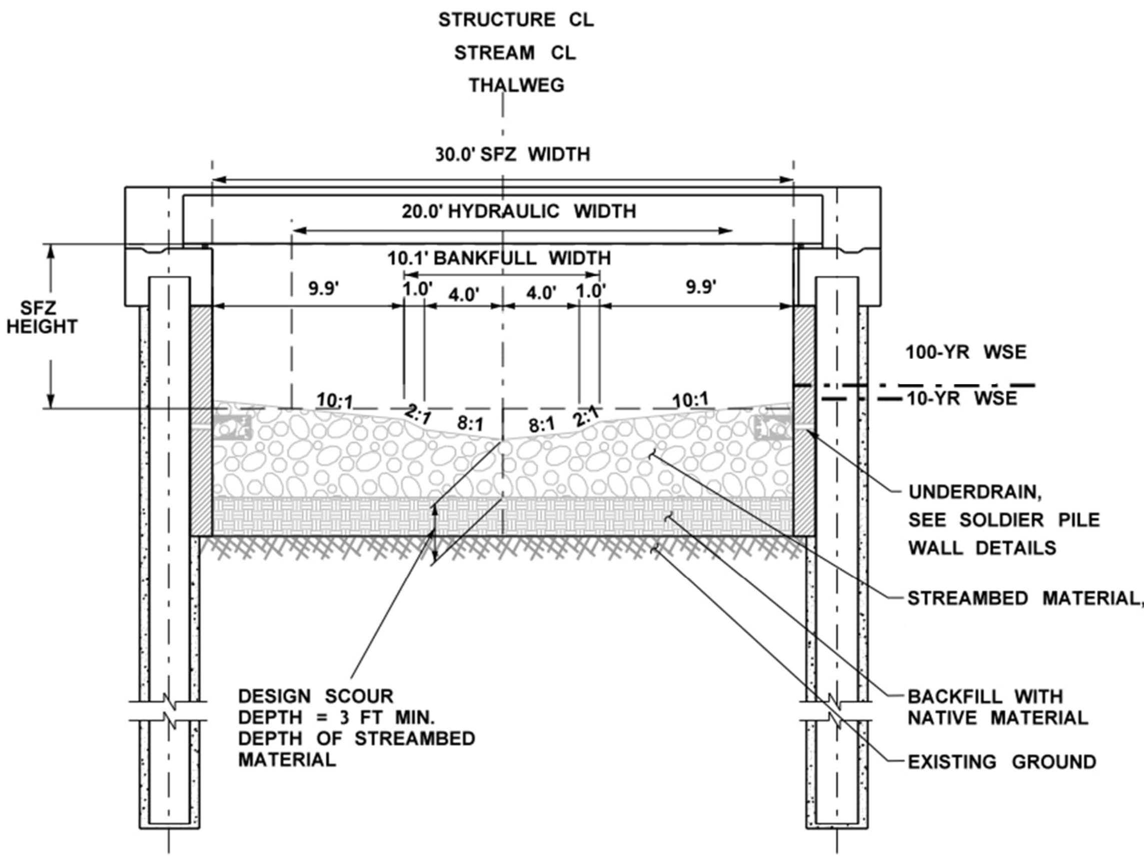

Figure 4-4: Illustration of minimum hydraulic opening and structure free zone

4.2.1 Hydraulic Length

As described in the Project Technical Requirements, hydraulic length is defined as including all structural elements of the crossing including wing walls. The structure length is defined as the length of the buried fish passage structure (excluding wing walls). The maximum allowable hydraulic length determined by WSDOT during preliminary design for the I-405 crossing of Queensborough Creek is 438.6 feet. This length did not, however, account for the length of wing walls and therefore represented the preliminary structure length and is documented in Table 2.30-B in the Project Technical Requirements. The actual hydraulic length of the preliminary design was 473 feet. The maximum allowable hydraulic length has since been updated to 505.3 feet and documented through design-builder initiated change (DBIC) 049 with justification described below.

The proposed structure length (not including wing walls) is 428 feet; 11 feet shorter than the preliminary design configuration provided by WSDOT. This structure length will be compliant with provision 93 of the revised project Hydraulic Project Approval, prepared by WSDOT.

The hydraulic length, as defined above, in AECOM's current design is 505.3 feet. The difference between the structure length and the hydraulic length in AECOM's current design is driven by wingwalls 1 and 3, which are oriented parallel to the structure's alignment. The hydraulic length of 505.3 feet does not represent a fatal flaw in the crossing's hydraulic design, and the restored stream connection meets the requirements of stream simulation criteria. Additionally, native plantings will be placed on the overbanks in front of wingwalls 1 and 3 to aid in bank stability. Live fascines will be placed at the approximate 2-year water surface elevation in the vicinity of the wingwalls to aid in plant establishment.

At wingwall 1, bioengineering, including brush mattressing, is also proposed where slopes exceed 3:1 to provide additional slope stabilization. There are no changes in base scope for the noted plantings, bank stabilization, erosion control, or construction footprint.

Because the hydraulic length has increased since the preliminary design, the hydraulic width and vertical clearance should be reevaluated. Based on the stream's bankfull width of 10.1 ft, Equation 3.2 of the WDFW 2013 Water Crossing Design Guidelines, and the fact that this crossing is defined as a "long culvert" by WDFW, the minimum hydraulic width was determined to be 20.0 ft. Proposed geomorphic features including large woody material, mobile woody material, and meander bars will be placed in the structure to provided habitat complexity and diversity. Considering the addition of these geomorphic features, a 30-foot structure free zone width was determined for the site.

The wingwall configuration allows for greater than a 30-foot structure free zone width outside of the structure, therefore, the stream will not be confined through the wingwalls. The width of flow during the 2-year storm (a proxy for the dominant channel forming flow) is not confined within the structure or wingwall layout.

The team notes that as part of DBIC 005, the vertical clearance of the I-405 MP 26.90 crossing has already been reevaluated and approved by WSDOT.

4.3 Streambed Design

4.3.1 Bed Material

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

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

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

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

Table 4-6: WSDOT standard streambed sediment

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

Source: Project Technical Requirements Section 2.30.5.3.1

4.3.1.1 Stability Analysis of Streambed Material

Consistent with engineering best practices, the Hydraulics Manual (WSDOT 2022), and the Water Crossing Design Guidelines (Barnard et al. 2013), stability of the proposed bed material has been investigated. The analysis indicates that the proposed streambed material is mobile at flows less than the 100-year discharge (see **Appendix C**).

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

- Alternative 1: Design a roughened channel with streambed material and configuration designed to be non-deformable up to the design discharge.
- Alternative 2: Design an overcoarsened channel with D_{84} sized to be stable at the 100-year flow with channel-spanning non-deformable boulder grade controls.
- Alternative 3: Design an overcoarsened channel with D_{84} sized to be stable at the 100-year flow, channel complexity features, and a deformable bedform.
- Alternative 4: Design a channel with streambed material size within 20 percent of the existing pebble-count size, and channel complexity features. (Note: Alternative 4 is consistent with the bed material presented above in Section 4.3.1.)

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

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

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

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

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

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

Bed Material	2-year	25-year
Alternative 3: D_{84} sized for stability at 100-year flow	42.0	55.0
Alternative 4: within 20% of existing size	100.0	100.0

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

4.3.2 Channel Complexity

4.3.2.1 Design Concept

The three channel complexity elements will be incorporated into the channel design to meet the functional goals, as described in more detail in the following subsections and seen in **Figure 4-5, Figure 4-6**, and **Figure 4-7** (see **Appendix D**).

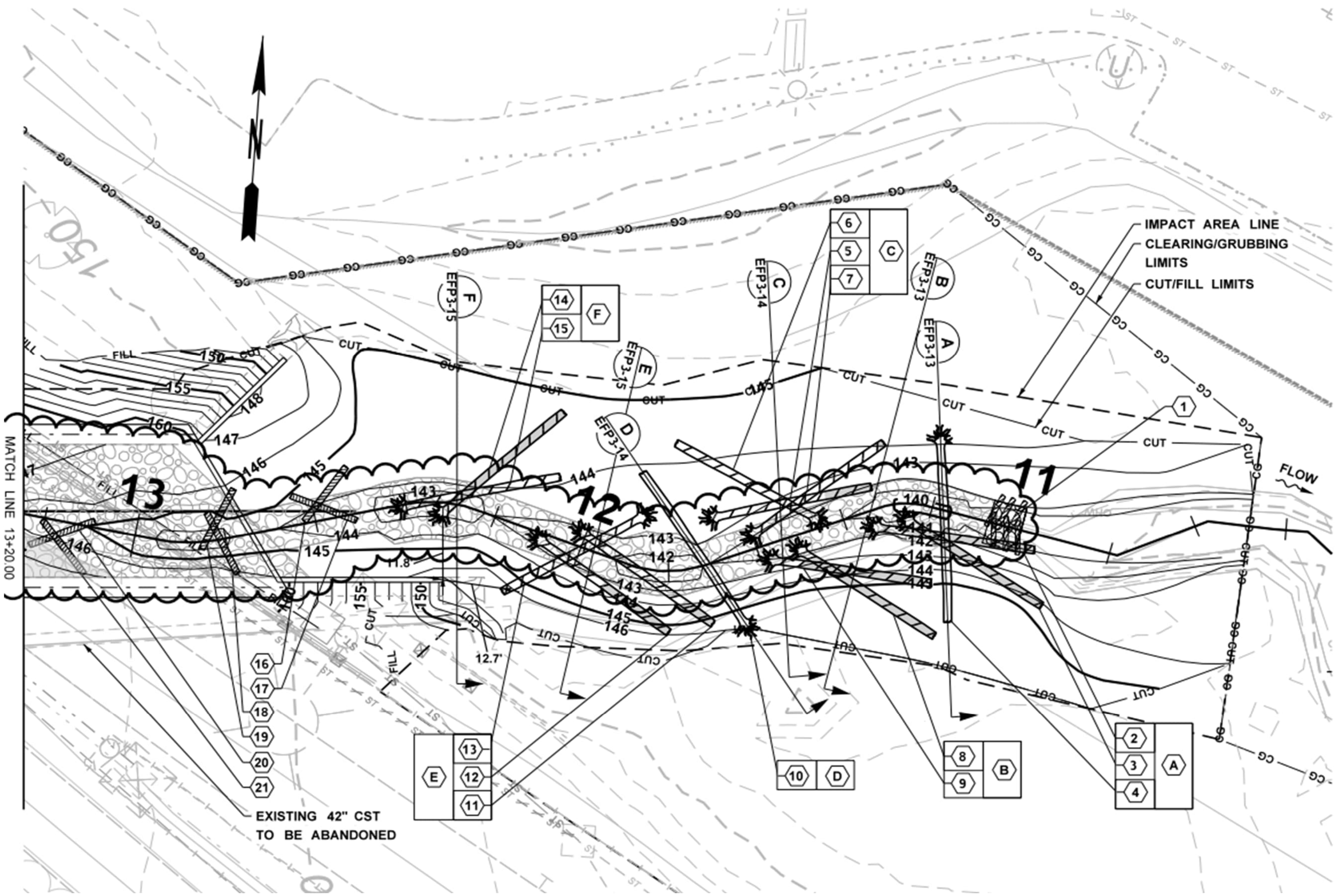

Figure 4-5: Downstream layout of habitat complexity features

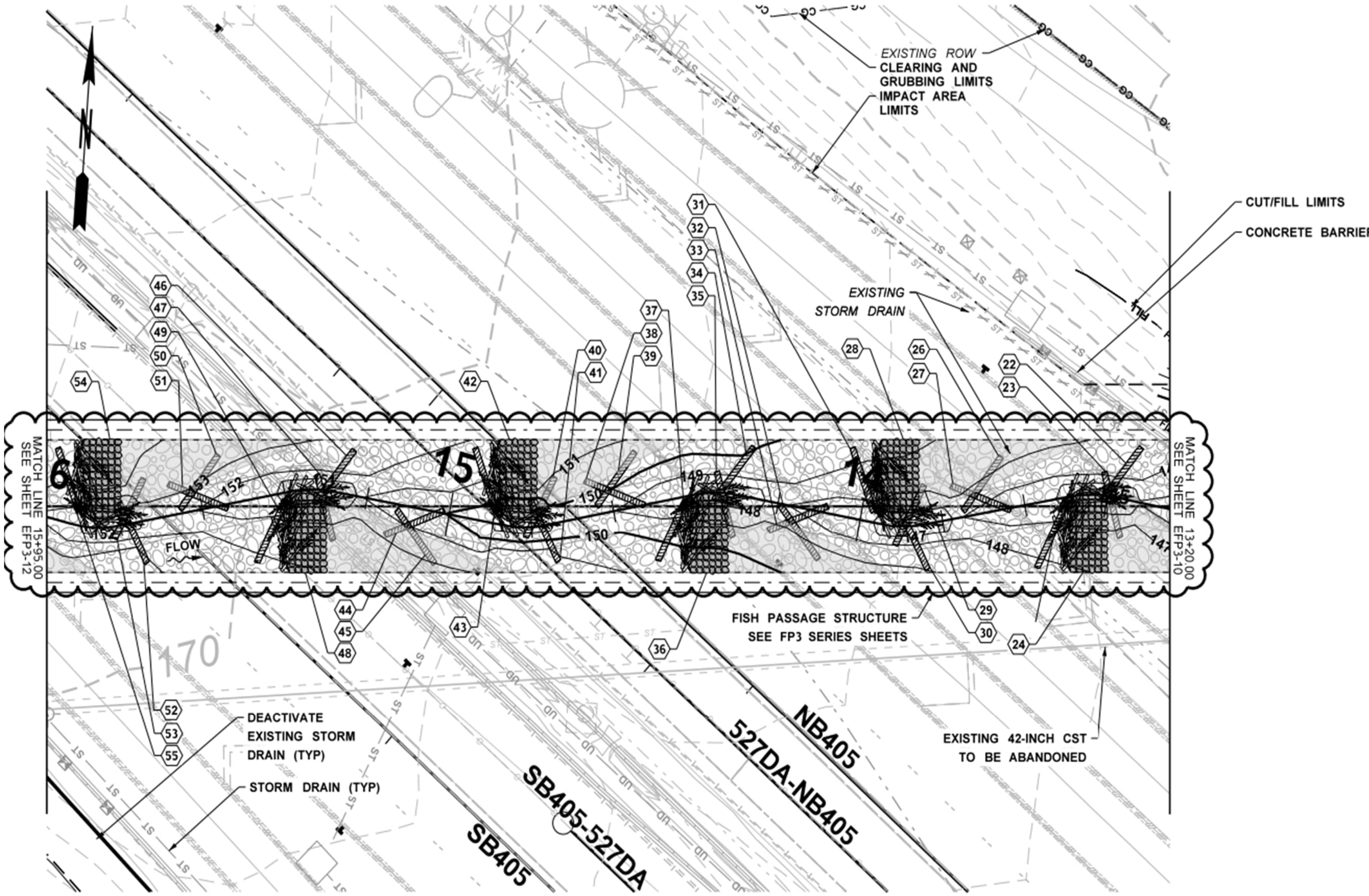

Figure 4-6: Structure layout of habitat complexity features

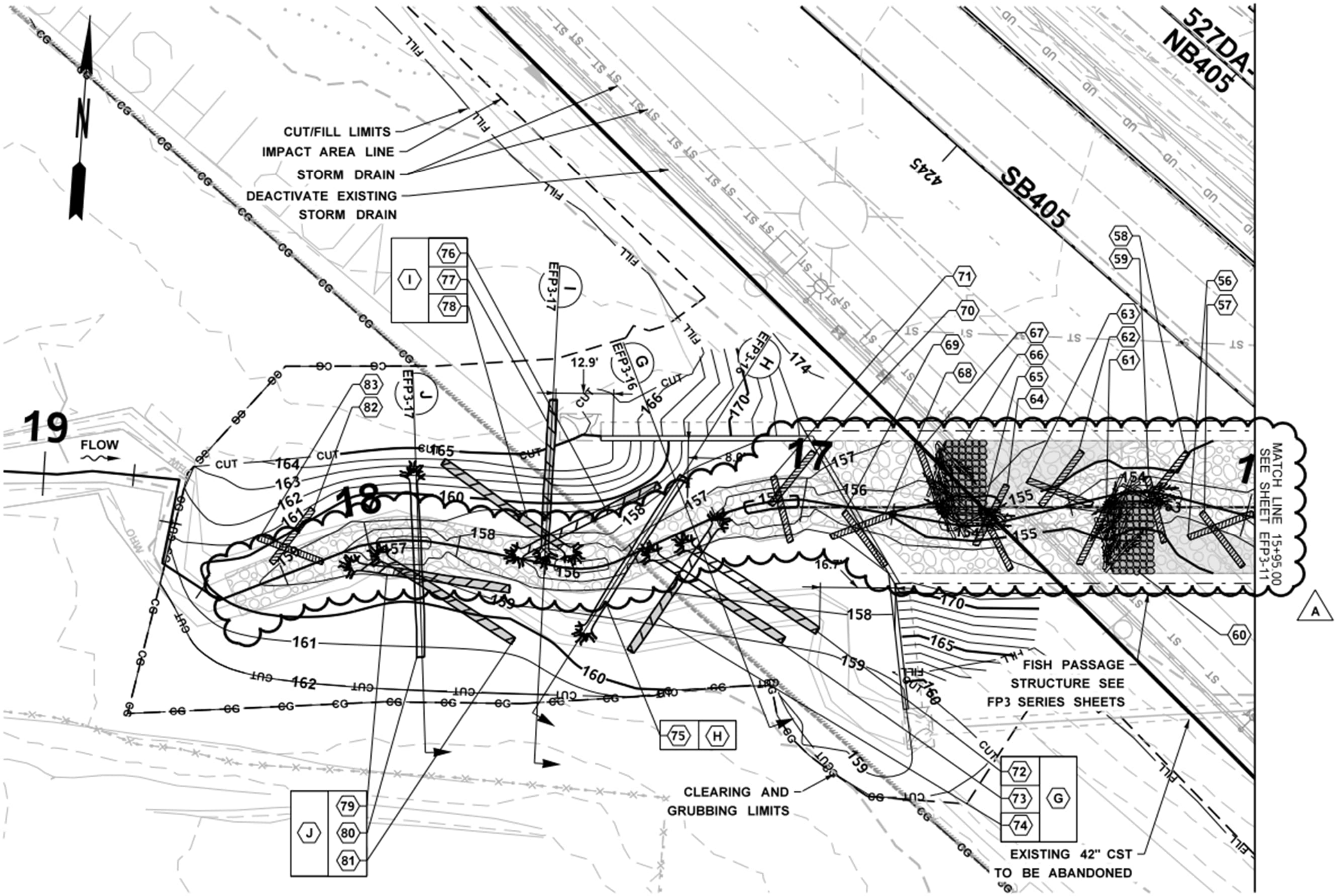

Figure 4-7: Upstream layout of habitat complexity feature

4.3.2.3 Meander Bars

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

The proposed meander bar composition follows WSDOT design guidance for three components of the meander bar: (1) structure head, (2) structure tail, and (3) other considerations (such as small wood material or slash placed in front of structure head rocks to encourage racking and add additional habitat complexity).To maintain channel shape, the apex of the meander bar height is set to the 10-year flow depth at the structure wall and the 2-year flow depth at the nose of the bar head, closest to the thalweg. Meander bars extend subgrade to the total scour depth and occupy a substantial portion of the cross-sectional area of the channel.

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

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

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

Table 4-8: Meander bar material gradation

Sediment Size	Proposed meander bar material diameter (inches)
D_{16}	1.2
D_{50}	3.9
D_{84}	9.9
D_{100}	18.0

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

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

Notes: WSDOT = Washington State Department of Transportation

[a] Source: Project Technical Requirements Section 2.30.5.3

[b] Source: WSDOT 2022b

4.3.2.4 Deformable Grade Control

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

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

4.3.2.5 Stability Analysis

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

7 Final Scour Analysis

7.2 Long-Term Degradation of the Channel Bed

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

Engineering stratigraphic units (ESU) 1B, 2A, and 3 discussed in **Section 7.1** overlay ESU 4, which corresponds to Glacial till (Q_{vt}), also known as hardpan; see **Section 2.3**. **Figure 7-2** shows the subsurface profile at the Queensborough Creek crossing of I-405. This layer does not support a definitive vertical limit to channel degradation.

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

Following the procedures presented in *Hydraulic Engineering Circular No. 20 - Stream Stability at Highway Structures* (HEC-20) (Lagasse et al. 2012) and the source material (Pemberton and Lara 1984), the long-term degradation for Queensborough Creek has been estimated using an armor analysis under bankfull conditions. As described in **Appendix K.1**, an armor layer would form at the Queensborough Creek crossing of I-405 after only 0.4 feet of degradation considering the proposed streambed material (see **Section 4.3.1**). This layer would likely arrest any further degradation of the streambed. Therefore, 0.4 feet is selected as the long-term degradation component of total scour.

7.4 Local Scour

7.4.3 Bend Scour

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

The bend scour equations used are empirical and were developed based on flows at or below the bankfull condition and are generally valid up to significant interaction between main channel and overbank flows (USACE 2025; WDFW 2012). Due to this, bend scour was evaluated using the 2-year flow. **Figure 7-3** shows the location of the bends analyzed.

The result of this analysis is summarized in **Table 7-1**. They represent an approximation of how deep meander bend would scour in a natural channel having a constant bankfull width. However, the proposed channel will have pre-scoured pools that dissipate hydraulic energy, resulting in a 1.0-foot residual pool depth at every meander bend. The estimated maximum bend scour, beyond the 1.0-foot residual pool depth, is 0.8 feet.

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

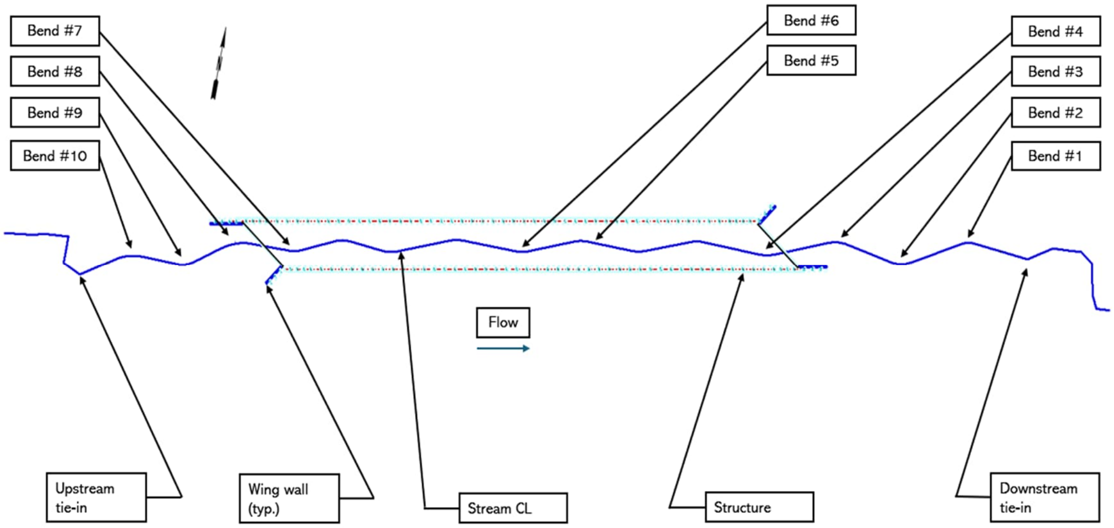

Figure 7-3: Location of meander bends evaluated for bend scour

Table 7-1: Depth of bend scour

	Thorne			USACE
Bend No.	**Depth of Scour Below Local Streambed Elevation (ft)**	**Residual Pool Depth (ft)**	**Estimated Scour Depth in Pre-Scoured Pool (ft)**	**Estimated Scour Depth in Pre-Scoured Pool (ft)**
1	1.8	1.0	0.8	-0.3
2	1.0	1.0	0.0	-0.7
3	0.8	1.0	-0.2	-0.9
4	0.6	1.0	-0.4	-1.1
5	0.9	1.0	-0.1	-0.9
6	0.7	1.0	-0.3	-1.2
7	0.8	1.0	-0.2	-0.9
8	0.5	1.0	-0.5	-1.0
9	1.5	1.0	0.5	-0.4
10	0.5	1.0	-0.5	-0.9

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

7.5 Total Scour

For Queensborough Creek, there are four components of total scour: long-term degradation, contraction scour, and local scour in the form of abutment scour and bend scour. Total depths of scour for the scour design flood and scour check flood at the proposed Queensborough Creek I-405 crossing are summarized in **Table 7-2**. Further details for scour calculations can be found in **Appendix K**. The *Hydraulics Manual* defines a minimum total scour depth of 3.0 feet; this is considered the total design scour for Queensborough Creek. Because the risk of lateral migration of the main channel is assumed across the entire SFZ width for this scour analysis (see **Section 7.1**), the thalweg is the starting elevation for total scour depths.

Table 7-2: Scour analysis summary

Calculated scour components and total scour for I-405 at Queensborough Creek		
Long-term degradation (feet)	0.4	
Bend scour (feet)	0.8	
	Scour design flood (2080 100-year)	**Scour check flood (500-year)**
Contraction scour (feet)	0.0	0.0
Local abutment scour (feet)	0.0	0.0
Estimated depth of total scour (feet)	1.2	1.2
Minimum depth of total scour (feet)	**3.0**	**3.0**

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

9 Summary

Table 9-1: Report summary

Stream crossing category	Element	Value	Report location
Channel degradation	Potential	0.4 feet	7.2 Long-Term Degradation of the Channel Bed
Crossing length	Existing structure length	439.0 feet	Refer to Revision 0 of the FHD report
	Existing hydraulic length	473.0 feet	4.2.1 Hydraulic Length
	Proposed structure length	428.0 feet	4.2.1 Hydraulic Length
	Proposed hydraulic length	505.3 feet	4.2.1 Hydraulic Length

Appendices

Appendix C: Streambed Material Sizing Calculations

Appendix D: Plan Set

Appendix K: Scour Calculations

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix K: Scour Calculations