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NHC Ref. No. 2004712

September 28, 2021

King County Water and Land Resources Division
201 S. Jackson St., Suite 600
Seattle, WA 98104

Attention: Judith Radloff

CC: Brian Reznick (Shannon & Wilson)

Re: Final Hydrologic and Hydraulic Approach - Lower Tolt River

This document presents the approach to the hydrologic and hydraulic analyses to be performed for the lower Tolt River as part of the Levee Breach Analysis Mapping and Risk Assessment Project (Project). This approach memorandum is one of the deliverables under King County contract E00670E20, Task 400, subtask 6.

1 GENERAL CONSIDERATIONS

Several recent hydraulic and hydrologic studies have been performed for the Tolt River, most notably the 2020 Level of Service (LOS) study (WSE, 2020). The approach outlined below re-uses the information developed in prior studies to the extent possible to avoid duplication of efforts and ensure consistency with prior King County efforts. This approach memorandum represents a tailored version of the "generic" approach memorandum developed by NHC for the Project, populated with information specific to the lower Tolt River.

2 HYDROLOGIC APPROACH

The hydrologic approach for the lower Tolt River study area will rely heavily on pre-existing analyses as discussed below.

2.1 Tolt-Snoqualmie Coincidence

A joint-coincidence analysis was completed for the Tolt and Snoqualmie Rivers to determine the degree of peak flow coincidence between those two rivers (WSE, 2018). The analysis utilized short interval (15-minute) data for the time period October 1987 to the present and excluded flows less than 10,000 cfs on the Snoqualmie and less than 1,000 cfs on the Tolt River. The analysis resulted in a scatterplot of Snoqualmie River flows for a given Tolt River flow (Figure 2.1). The x-axis represents the Tolt River at Carnation (USGS 12148500) flows transposed to a point immediately upstream of the confluence, assuming a 2-hr travel time. The y-axis represents the Snoqualmie River at Carnation (USGS 12149000) flows, transposed upstream to a point upstream of the confluence, assuming a 1-hr travel time and subtracting the Tolt River flows.

Previous modeling efforts by WSE were focused on levee design water levels and performance, and so conservatively assumed a worst-case Snoqualmie River boundary condition, represented by the red dashed “upper envelope curve” in Figure 2.1. The purpose of the present study is to obtain the most accurate estimates of flood risks and damages, so consideration was given to using Snoqualmie River hydrographs scaled to the “best fit” line in Figure 2.1 (blue line) rather than the worst-case envelope curve. After discussion with King County (pers. comm. Jay Smith, 8/5/21) it was decided that the Project will continue to use the WSE “envelope curve” Snoqualmie River hydrographs without further alteration. This decision considered previous findings that Snoqualmie River conditions have very limited impact on the Tolt River upstream of SR203 (the main area of interest), and the fact that smaller Snoqualmie River flows may be more conservative in some respects (velocity in the main channel) but less conservative in other respects (water level) and therefore there was no clear overriding reason to change from using the “upper envelope curve”.

While the WSE (2019 and 2020) hydrographs will be used in all of the primary model runs, we will also simulate the 10-, 100-, and 500-year existing condition Tolt River floods with coincident flows on the Snoqualmie River derived from the “best fit” line in Figure 2.1; these results will be used to inform the stage uncertainty functions in HEC-FDA where needed.

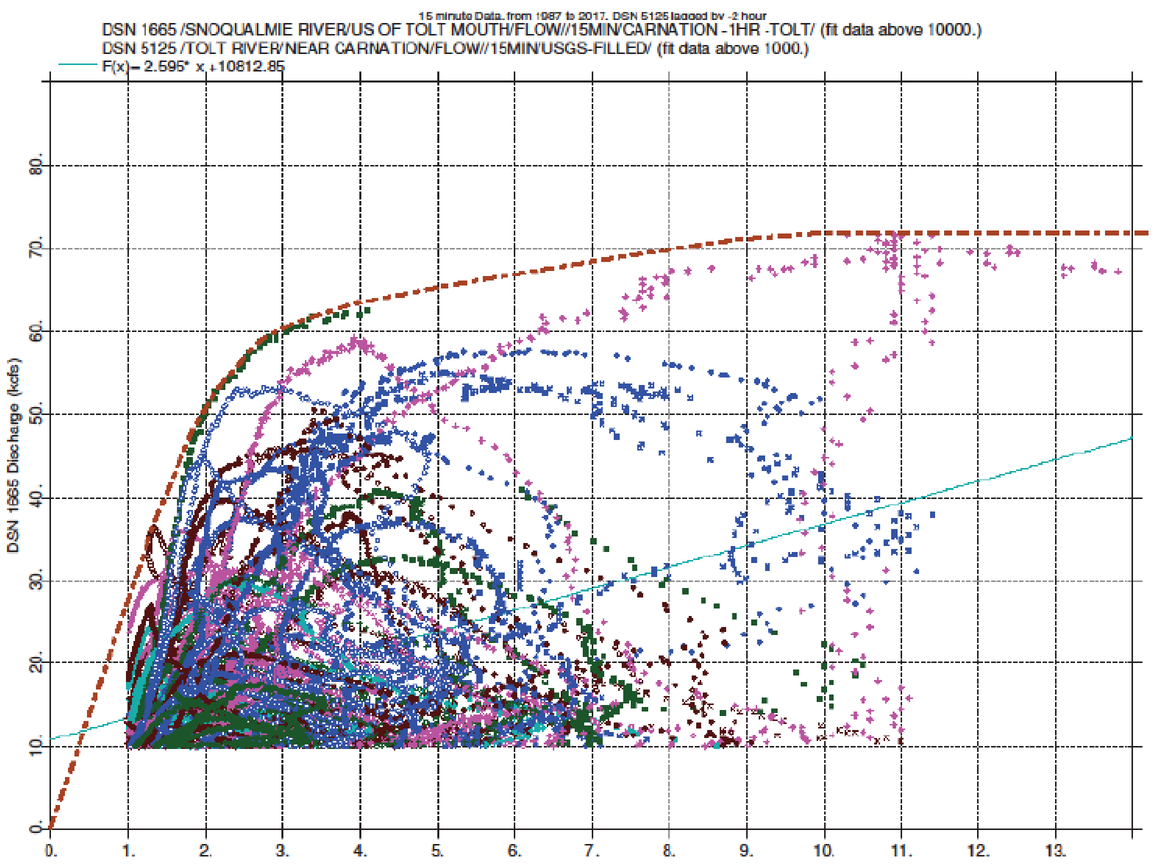

Figure 2.1 Snoqualmie River Pseudo Gage Location Upstream of Tolt River (y-axis) and Tolt River Upstream of Snoqualmie River (x-axis) flow coincidence (reproduced from WSE (2018)

2.2 Balanced Hydrographs

The Project will re-use recently developed synthetic flood hydrographs for the lower Tolt River study area (WSE, 2019 and 2020) with no further changes. These hydrographs span from the 2-year to the 500-year flood, so encompass the full range of Tolt River flows needed for the current study.

2.3 Future Hydrologic Conditions

The Project will re-use recently developed future conditions synthetic flood hydrographs for the lower Tolt River study area (WSE, 2019 and 2020) with no further changes. These hydrographs span from the 2-year to the 500-year flood with climate change, so encompass the full range of Tolt River flows needed for the current study.

3 HYDRAULIC APPROACH

3.1 Model Platform

The hydraulic model will be HEC-RAS version 6.0.0.

3.2 One-Dimensional (1D) vs. Two-Dimensional (2D)

A new full 2D model of the lower Tolt River and a portion of the Snoqualmie River will be developed. The 'classic' full momentum 2D solver will be used. The model area extents are shown in Figure 3.1 and discussed in greater detail below.

3.3 Model Extents

The model will encompass the Tolt River from approximately river mile 6.2 to the mouth at the Snoqualmie River. The Snoqualmie River will be represented from approximately two miles upstream of the confluence with the Tolt River to NE Carnation Farm Rd at the downstream end. The floodplain on either side of the Tolt River, including Carnation itself, will be included in the domain. Figure 3.1 shows the approximate model bounds that will be used; these bounds may change slightly as model development progresses (for example, to remove high ground areas).

The upstream extents along the Tolt and Snoqualmie Rivers were selected to coincide with the extents of the LOS model to allow seamless application of already developed boundary conditions. The downstream extent is approximately 0.6 miles further downstream than the LOS model, to the USGS Snoqualmie River near Carnation (12149000) gage. The main purpose of this extension is to include the cluster of homes between NE 55th and NE 60th St to capture all potential levee breach impacts. A secondary benefit of the extension is that placing the boundary at a gage location provides a convenient downstream boundary condition for this analysis as well as for future projects that utilize this model.

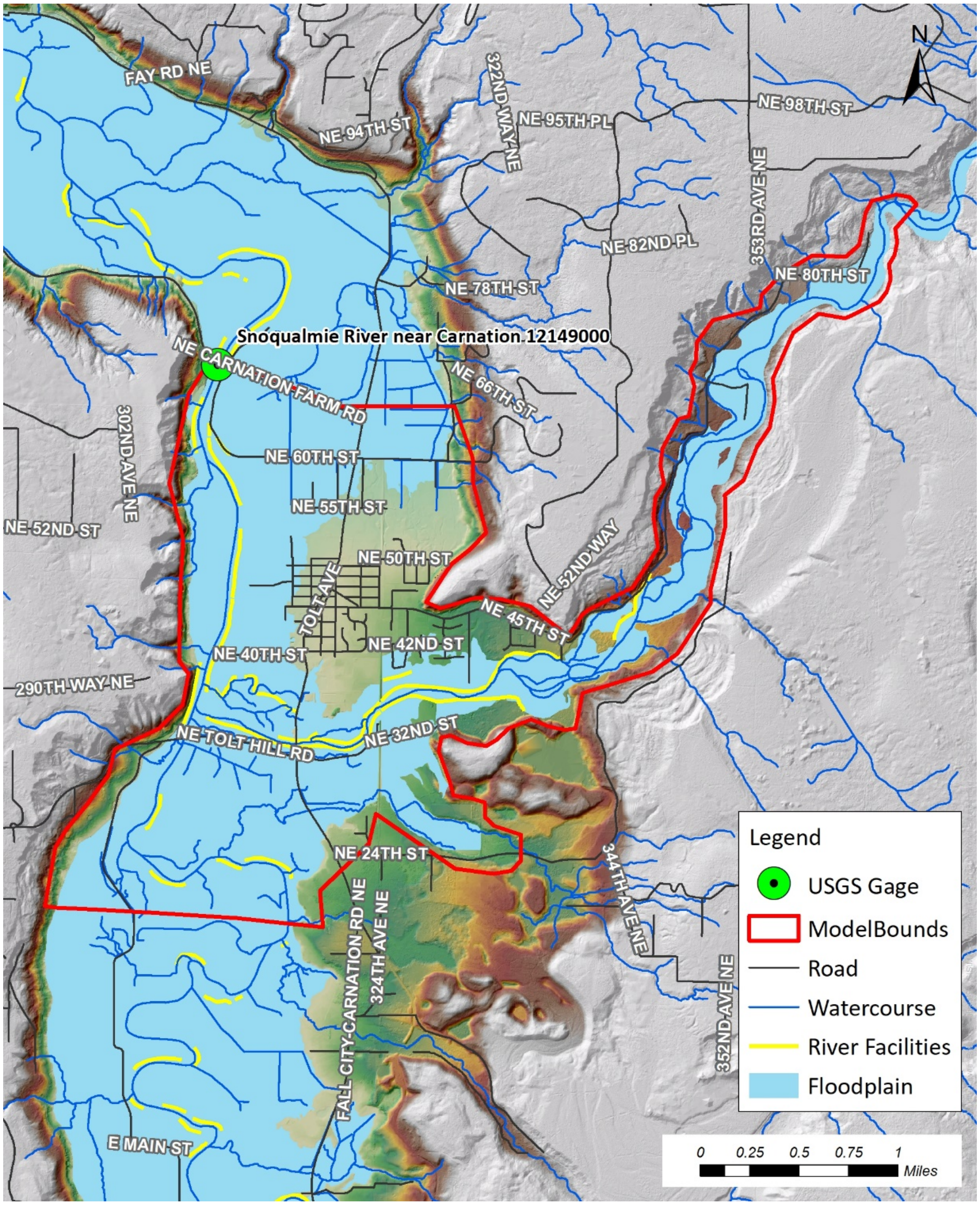

Figure 3.1 Proposed model extents (subject to refinement as development progresses)

3.4 Mesh Resolution and Timestep

The project purpose is to accurately characterize floodplain inundation depths and extents under various levee breach scenarios. In the main channel, accurate water surface elevations are required, but the ability to resolve fine-scale features such as eddies is not necessary. In addition, there are advantages in terms of both speed and stability to using larger mesh elements. Floodplain mesh elements can also be larger, as extensive use of breaklines will allow larger elements while still providing accurate routing of floodplain flows. For the lower Tolt River, consideration will be given to using small enough cells in the Carnation area that individual structures can be modeled accurately. For levees, a breakline will be placed along the crest of the levee and the cell on the landward side will extend beyond the levee toe; this is important for model stability and accuracy during breach simulations. An initial estimate of the number of mesh cells required to cover the proposed model domain in Figure 3.1 with cells small enough to resolve buildings in Carnation is approximately 500,000 with a nominal mesh size of 12 feet in developed areas. A HEC-RAS model with this number of cells would be pushing the limit of reasonable run-times; our first attempt at the mesh will include cells small enough to render individual buildings, but we may be forced to coarsen the mesh to obtain a workable model.

HEC-RAS 2D results are often sensitive to mesh size, so the mesh will be constructed to allow simulation of all floods and all potential breach locations in such a manner that no modification of the mesh will be required for any given flood event or breach scenario.

Timestep selection is related to the mesh resolution- finer meshes require smaller timesteps in general. The timestep will be selected such that Courant numbers in the area of interest are approximately two or less. The 'classic' full momentum 2D solver uses an implicit scheme that is stable and capable of giving good results with courant numbers greater than one, but the Courant number will be monitored to ensure it does not exceed reasonable bounds.

3.5 Surface Representation

The surface used for the LOS model (WSE, 2020) will be re-used for this study to maximize consistency with other recent modeling efforts. This surface combines data from numerous sources as documented in WSE (2020). The LOS surface will need to be extended slightly to the north to encompass the full Project domain. Digital ground model (DGM) tiles provided by King County will be used for this purpose. The tiles are composites that include Quantum Spatial 2019 LiDAR (floodplain) and 2020 topobathymetry (main channel). These DGM tiles match well with the LOS model surface at the point they will be joined.

Several of the levees in the lower Tolt River study area have informal (riprap) berms placed atop them. The underlying levees are represented in the LOS model terrain surface, however, the berms are not represented in the surface as they were instead represented as hydraulic structure (weirs). For the present study the same method of representing the berms will be used- they will be weirs in the model rather than included in the underlying terrain.

3.6 Landcover and Roughness

The landcover layer used for the LOS model (WSE, 2020) will be the starting point for the landcover layer used in the present study to help ensure consistency with other recent modeling efforts. A small expansion of the landcover layer will be necessary to cover the slightly larger domain that is proposed in Figure 3.1, which extends approximately 0.6 miles further north than the LOS model domain. Delineation of the landcover in the expanded area will be done using the most recent NAIP aerial imagery (consistent with LOS model development procedures) and will categorize the land using the landcover types already defined in the LOS model dataset.

In addition to the expanded area, modifications will be made to the interior of the LOS model landcover layer to include individual buildings in the landcover, rather than classifying all residential, commercial, and park area as “developed” as was done in the LOS model. A building database, including structure outlines, was developed by King County as part of the LOS study. This database includes structures within the future hydrologic condition 500-year floodplain, so some expansion of the database may be needed to encompass all structures affected by breaches during the largest floods. These additional buildings will be added to the database in accordance with the documented procedures used to develop the database (King County, 2020). This structure layer will be utilized by the economic analysis. If the selected grid resolution (see Section 3.4) supports typical building scale resolution, then the building outlines will be assigned an extremely high Manning roughness value, such as 5 to 10. This approach allows water to enter the buildings but not actively flow through them, while allowing extraction of depth at the building centroid for the HEC-FDA analysis. If the grid resolution is coarser than the typical building size, then the buildings in the landcover layer and the surrounding landscaping will be assigned roughness values that represent the average effects of building blockages and surrounding land.

Roughness values for each landcover type will use the LOS study values as a starting point for calibration but will likely require changes due to different calculation methodology used in HEC-RAS versus RiverFlow2d-Plus. Calibration is discussed further in Section 3.9.

3.7 Infrastructure

Review of the City of Carnation stormwater GIS data provided by King County reveals that the city has limited stormwater infrastructure. Newer residential areas have local drainage networks that service a cluster of homes and discharge to a ditch, swale, or stormwater pond such as the pond immediately north of the Swiftwater Berm. There is little to no connectivity between these local networks. These small, local networks (with nearly all pipes smaller than 24 inches) will not be included in the study model. Stormwater ponds will be represented through the terrain. While an interior drainage analysis is not part of this scope, we will estimate tailwater conditions at breach locations if necessary, such as at the Swiftwater Berm stormwater pond.

The Carnation stormwater GIS data does not include any river outfalls or levee penetrations. However, the team did observe two culverts in the field. One was a large squashed 48-inch (38” x 57”) diameter CMP pipe-arch culvert outfall through the Lower Frew Levee approximately 400 feet upstream of SR 203 (Figure 3.2). This culvert appears to drain a groundwater-fed side channel behind the Lower Frew Levee and will be included in the hydraulic model. A second, 12-inch diameter smooth walled HDPE culvert was observed in the Swiftwater Berm, which will also be included in the model. No other levee penetrations were observed during the site visit. The LOS report (WSE, 2020) also notes a five-foot diameter culvert through the SR 203 road prism approximately 600 feet north of the bridge. This culvert is not present in the Carnation GIS data but will be included in the model using dimensions and parameters from the LOS model.

Figure 3.2 Pipe arch culvert outfall in Lower Frew Levee not included in Carnation stormwater GIS.

There are four bridges within the proposed model domain: two on the Tolt River (SR 203, Snoqualmie Valley Trail) and two on the Snoqualmie River (NE Tolt Hill Road, NE Carnation Farm Road). The method in which the bridges will be represented will depend on the selected mesh size and whether the bridge decks interact with the flow during the largest flood events. If the bridge deck is well above the water surface in all flows to be modeled, then no specific bridge deck representation is necessary, but in-channel piers would still be represented by incorporating them into the terrain and forcing cell faces to align with pier centerlines to represent their energy losses. This is the approach taken by the LOS model, which included piers but no bridge decks. Where bridges may go into pressure flow (the LOS study report notes that the Snoqualmie Valley Trail and NE Tolt Hill Road bridges border on pressure flow) or the terrain size is not fine enough to accurately represent individual piers, the bridge deck and all piers will be added to the model as a bridge structure (rather than terrain edits) using surveyed information for low chords, piers, and railing elevations. Geometric data for the bridges will be taken from as-built plans, survey, or the LOS model.

Levees and embankments will be coded into the model as hydraulic structures. The choice of using the 2D equations or weir flow equations over the structure will be dictated by the height of the structure above natural ground and the expected tailwater conditions at the peak of the flood. For non-breaching levee segments with highly inundated tailwater conditions, the 2D flow equations will be used. Non-breaching levees that maintain a significant head difference at flood peak (approximately three feet or more) from the river to the floodplain will use the weir equations.

For breaching levee segments, the same guidelines will be used to select an initial breach flow equation. However, the 2D equations are generally much more stable for most breach scenarios, especially with high tailwaters and breaching below floodplain elevations. If results from breach modeling using the weir flow equations are not stable, a comparison run using the 2D equations will be performed and differences in results in terms of inundation depths and extents examined. If results are similar, the 2D equations will be used. More detailed information on levee breach methodology will be provided in the subtask 7 (Flood Hazard Analysis) memorandum.

The selected calculation method for a levee segment will be fixed for all flows (i.e., we will not switch between the weir equation and 2D equations for different floods). Once the levee breach locations are determined, a short unique hydraulic structure line will be created that covers only the breach area and a short distance on either side. This will enable better quantification of breach hydraulics versus potential levee overtopping nearby and allow the use of 2D equations for the breach even if the adjacent levees are using the weir flow equation. As noted above in Section 3.6, berms have been constructed atop the levees in certain locations. These berms will not be represented in the terrain but will be incorporated into the model using 2D hydraulic structures based on the surveyed berm crests conducted by King County in 2019.

3.8 Boundary Conditions

Inflow boundary conditions will be specified for both the Tolt and Snoqualmie Rivers. For the Tolt River, the balanced hydrographs developed as part of the LOS study will be used, including the local inflow from an unnamed creek at river mile 3.1 and miscellaneous distributed inflows. For the Snoqualmie River, the upstream inflow hydrographs will be identical to those used in the LOS study, with peak flows that match the upper envelope curve in Figure 2.1. For the downstream Snoqualmie River boundary, a stage rating curve will be used. The USGS Snoqualmie River Carnation gage is known to have issues at high flows including floodplain flows bypassing the gage and hysteresis effects; we will compare the USGS rating curve with a rating curve extracted from the Flood Insurance Study model and select one for use. The rating curve will be extrapolated to accommodate the largest flows in the Project study. We will investigate sensitivity of results in the area of interest to boundary condition assumptions during sensitivity testing; we expect given the low sensitivity of Tolt River stages above SR 203 to Snoqualmie River flows that lower boundary condition assumptions will have negligible impacts on the modeling results. If they do, we will use the sensitivity testing results in adjusting the stage uncertainty function in HEC-FDA.

3.9 Calibration

King County has expressed a desire for the Project model to produce results consistent with the LOS model to the extent possible. To help achieve this, the primary objective in model calibration will be to reproduce the (already calibrated) LOS main channel model water surface profiles for the two calibration flood events (January 2015 and November 2018) and the validation flood event (January 2009). Floodplain inundation patterns are driven primarily by the main channel water level, so matching main channel profiles should produce similar floodplain inundation patterns. Significant differences in floodplain inundation patterns will be investigated and the model mesh refined, if appropriate. If differences between the models cannot be satisfactorily reconciled, we will attempt calibration using the original observed data used for the LOS model. As mentioned previously, due to the different calculation methodologies used by the two models, it is anticipated that the final roughness values for individual landcover types will differ from those used in the LOS model.

3.10 Sensitivity Testing

Sensitivity testing will be performed on the calibrated model. Initial tests will determine optimum mesh resolution. Other sensitivity tests that will be run include:

1. Time step
2. Roughness
3. Downstream boundary condition
4. Weir flow coefficients (if using weir flow equations for levees)

The effects of these values on water surface elevations will be considered when entering stage uncertainty functions in HEC-FDA. Flow sensitivity will be evaluated by running the suite of balanced hydrographs needed for HEC-FDA.

3.11 Quality Control

A Quality Control (QC) check will be performed by an experienced HEC-RAS modeler not directly involved in the model development. This QC check will occur at key stages in model development: model geometry, hydrology and calibration, and calculation settings and results. The QC process will be documented in the subtask 6 Hydrology and Hydraulics Technical Memorandum. The Federal Highway Administration 2D model checklist provided by the King County will be adopted for QC purposes for this project.

3.12 Levee Breach Simulations

A detailed levee breach methodology for subtask 7 work, Flood Hazard Model, will be provided separately.

Sincerely,

Northwest Hydraulic Consultants Inc

Alex Anderson, PE
Senior Water Resource Engineer

4 REFERENCES

King County, 2020. Tolt River Level of Service Analysis – Structure Database Development for Flood Risk Analysis. Memorandum prepared by Seth Amrhein to Jay Smith, June 8, 2020.

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WSE, 2019. Task 308 – Lower Tolt Hydrologic Data Development Update – Tech memo. Memorandum prepared by Larry Karpack and Colin Butler of Watershed Science and Engineering, May 8, 2019.

WSE, 2020. Existing Condition Levee Level of Service Analysis – Contract E00228E11 Task 314 Report – Tolt River Levee Level of Service Analysis. Report prepared by Watershed Science and Engineering on behalf of King County, December 21, 2020.