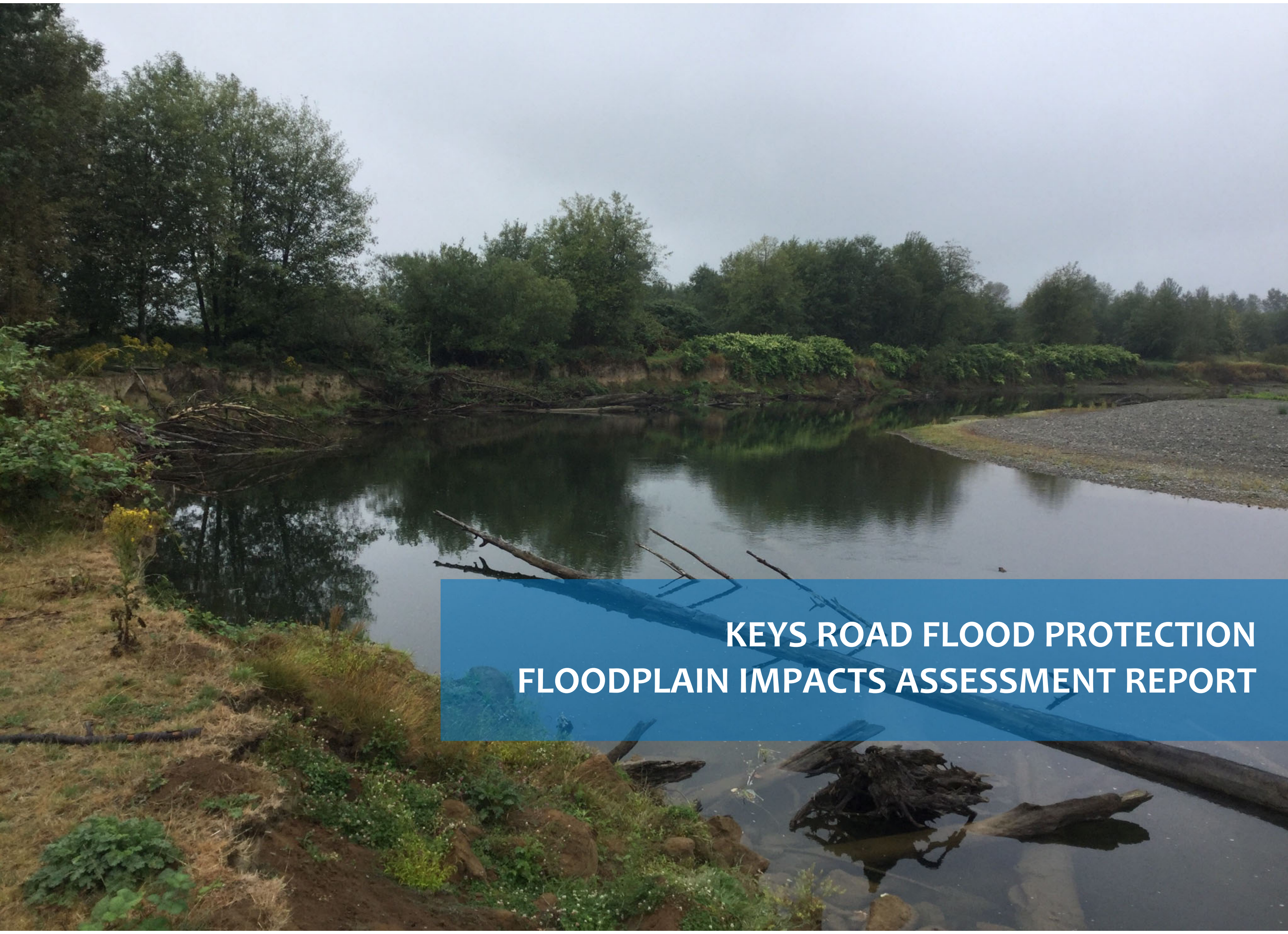

KEYS ROAD FLOOD PROTECTION FLOODPLAIN IMPACTS ASSESSMENT REPORT

March 10, 2020

Grays Harbor County
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Project Background

Natural Systems Design, Inc. (NSD) has prepared this floodplain impacts assessment report for use by Grays Harbor County (County) in its effort to gain construction permits for the proposed Keys Road Flood Protection Project (proposed project). Construction of flood protection in this reach of the lower Satsop River is being pursued by the County to provide protection of Keys Road and the Port of Grays Harbor's potable water well and to support the floodplain connectivity and restoration efforts Washington Department of Fish and Wildlife (WDFW) is pursuing in the project vicinity. This report specifically evaluates the impact of the proposed project on flood conveyance, water surface elevations and inundation extent for the lower Satsop River compared to existing conditions.

The project area is composed of two parts at River Mile (RM) 1.5 and at RM 0.5 along the western side of Keys Road, adjacent to the lower Satsop River near Satsop Washington. The goals of the proposed bank stabilization project are to distribute stream power across the floodplain, initiating processes towards a dynamic equilibrium that support successional riparian growth, aquatic habitat, and a restored historic channel migration zone. To achieve this goal, the proposed project focuses on stabilizing the floodplain, stabilizing river flow paths, and reducing rates of erosion along the approximate lower 2 miles of the Satsop River. Refer to the Keys Road Flood Protection Critical Areas Report (NSD, 2020) for more details on the proposed project and background information.

The Project Areas are located within a special flood hazard area of the Satsop River, as defined by Grays Harbor County Ordinance 448, Article IV, Sections 46 and 47. As such, the project is required to undergo floodplain review from Grays Harbor County Building and Planning Division. Additionally, the project is within a Federal Emergency Management Agency (FEMA) zone A and AE flood hazard area (effective February 3, 2017) which requires an analysis to demonstrate that proposed project activities do not significantly affect flood conveyance or increase flood levels during the occurrence of a base flood discharge (floodplain impacts assessment). Preliminary Flood Insurance Rate Maps (January 11, 2019) are currently in the FEMA approval process. The analysis documented in this report will consider the 2017 Effective Flood Insurance Study (FIS) and Maps, in accordance with Ordinance 448, Article IV, Section 44. A meeting with Grays Harbor County and NSD staff occurred on June 4, 2019 to discuss general project guidelines and specific requirements related to the floodplain impacts assessment.

NSD conducted a hydraulic analysis for the Satsop River between river miles (RM) 4.3 and 0.0 to assess impacts to main channel and floodplain hydraulics associated with existing conditions and proposed project design elements. This assessment uses state-of-the-art hydraulic modeling software and updated topographic data, which utilizes the best available science.

The approach to Floodplain Impact Assessment is as follows:

- Effective model (HEC-RAS), and FEMA Flood Insurance Study (Effective February 3, 2017)
- Duplicate Effective model (RiverFlow-2D)
- Proposed Conditions model (RiverFlow-2D)
- Comparison between Duplicate Effective and Proposed Conditions model

Existing Studies

Hydraulic studies have been performed within the project reach that include:

1. 2017 FEMA FIS, 53027CV000A for Grays Harbor County, WA and Incorporated Areas is effective as of February 3, 2017. Data from this FIS and associated FIRMs are considered as best-available science regarding hydraulic analyses, and are therefore considered as the Effective Model products.
2. 2019 Preliminary FEMA FIS, 53027CV000B for Grays Harbor County, WA and Incorporated Areas was revised as of January 11, 2019.
3. Chehalis Basin Ecosystem Restoration General Investigation Study Baseline Hydrology and Hydraulics Modeling by WEST Consultants (2014). Supporting documentation for development of the hydraulic model used in the 2019 Preliminary FEMA FIS.

Hydraulic Analysis

A hydraulic model of the Lower Satsop River was developed using Hydronia's RiverFlow-2D Plus GPU and Aquaveo SMS v12.3 computer software. RiverFlow-2D is a two-dimensional (2D) finite volume computer model by solving the shallow water equations resulting from integration of the Navier-Stokes equation. The Navier Stokes equation is derived from applying Newton's Second Law (Force = mass*acceleration) to fluid motion, and is generally expressed as:

$$\overbrace{\rho\left(\underbrace{\frac{\partial v}{\partial t}}_{\text{Unsteady acceleration}} + \underbrace{v \cdot \nabla v}_{\text{Convective acceleration}}\right)}^{\text{Inertia (per volume)}} = \overbrace{\underbrace{-\nabla p}_{\text{Pressure gradient}} + \underbrace{\mu \nabla^2}_{\text{Viscosity}}}^{\text{Divergence of stress}} + \underbrace{f}_{\text{Other Body forces}}$$

Where ρ# fluid density#
μ = dynamic viscosities#
s# pressure#
$\nabla = \ del\ operator$#(abbreviation for derivative (gradient) of 3D vector field)#
i# term representing body forces acting on the fluid (per unit volume)#

Output parameters such as depth and velocity are computed at the centroid of each grid cell. Two-dimensional (2D) models offer a more detailed representation of physical conditions and more intuitive flow routing in the channel and floodplain (hydraulic losses, individual flow paths) compared to a one-dimensional (1D) approach. The 2D approach allows for increased spatial resolution of analysis at the local scale, which can be critical for the design of instream structures.

Effective Model

The effective base flood elevations are computed from the U.S. Army Corps software, HEC-2 step-backwater program. Detailed methods to compute base flood elevations on the Satsop River extend from the confluence with the East and West Fork Satsop Rivers to 4,500 ft downstream of the U.S. Highway 12 bridge. Manning's n-value roughness coefficient was adjusted to calibrate the HEC-2 model to known water surface elevations recorded at USGS streamgage 12035000. The 100-year peak discharge for the Effective hydraulic model is 52,300 cfs. The Chehalis River, nor its influence on the Satsop River, is not included in the Effective model domain.

The Preliminary DFIRM database under current review reflects a 2019 update to the HEC-RAS hydraulic model (FEMA, 2019). The update primarily addresses baseline hydrology within the Chehalis River basin. Topographic updates include the lower two miles of the Satsop River, based on a previous modeling effort by WEST Consultants in 2004. Overbank topography in the Preliminary hydraulic model is updated from LiDAR data sources as recent as 2009. Calibration of the Preliminary model follows the same procedure as the Effective model. The 100-year peak discharge for the Effective hydraulic model is 58,459 cfs, and is influenced by interaction with the Chehalis River during the 100-year event.

Duplicate Effective Model

The best available data and scientific methods are used to analyze hydraulic conditions and impacts to floodplain areas from the proposed project design. NSD constructed a 2D hydraulic model using RiverFlow-2D. The purpose of the duplicate effective model is to reproduce effective model results for the 100-year discharge, using the same inputs defined in the 2018 HEC-RAS model with the RiverFlow-2D model. Refer to Attachment A for an inundation map and Effective FIRM special flood hazard areas.

The horizontal and vertical datum of all data utilized and referenced in this report is Washington State Plane Coordinates South Zone NAD83 ft and NAVD 88 ft, respectively.

Model Topography

Topographic data is referenced from multiple sources, including the 2017 topo-bathymetric green LiDAR and bathymetric and topographic surveys by NSD in 2019. In March of 2019, NSD collected bathymetric survey data from the recent channel avulsion, as well as land based topographic survey of the abandoned meander between RM 0.9 and 0.3. NSD conducted an additional bathymetric survey in August, 2019 of the Satsop River main channel between RM 1.6 and 1.2.

Computational Mesh

The RiverFlow-2D mesh consists of 1,344,642 grid cells and the 2018 HEC-RAS model includes 18 cross-sections in the same study area. The duplicate effective model begins at RM 4.3 and extends downstream to RM 0.0. The Riverflow-2D model extends to the Chehalis River approximately 5.5 RM and 2.2 RM upstream and downstream of the Satsop River confluence, respectively, which is sufficient distance to account for any artificial effects imposed by boundary conditions. There are 9 bridge openings defined in the model mesh for the Monte Elma Rd bridge, Puget Sound and Pacific Railroad bridge, and U.S. Highway 12 bridge across the main channel of the Satsop River and five crossings over overflow channels on the right bank floodplain.

In order to accurately capture the topography and yield results with fine enough detail in areas of interest, the model mesh was refined in the main and floodplain channels, with expanded mesh spacing in less topographically complex areas farther from the stream. Table 1 presents the mesh spacing used in the model.

Table 1. Mesh spacing applied to model breakline categories.

SURFACE TYPE	MESH SPACING (FT)
Thalweg	10
Bank Top and Toe	15
Gravel Bar	15
Floodplain Channel	30
Valley Grade Break	50
Outer Boundary	50

Boundary Conditions

The model domain begins at approximately RM 4.3 of the Satsop River and includes the Chehalis River approximately 5.6 RM upstream of the confluence with the Satsop River and 2.2 RM downstream of the confluence. The upstream boundary condition is defined as a steady state inflow of 52,610 cfs, which is within 0.60% the value used in the Effective model. Note that the difference in 100-year discharge between the Effective and Duplicate Effective models is due to an update of the 2017 peak flow analysis, resulting in a negligible difference. For the Chehalis River, a steady-state inflow is defined to the 10-year discharge (32,356 cfs). This is a conservative value to assess flood conditions that include backwater effects from the Chehalis River. The downstream boundary is defined as an open, uniform outflow boundary with a slope of 0.007 for the main channel and 0.00014 for the floodplain areas. Contributions from tributaries, or lateral inflows, are not included in the model.

Hydraulic Resistance (Roughness)

Hydraulic analyses require an assessment of the resistance (drag force) the ground surface and other physical features exert against the movement of water to incorporate bulk energy loss. This drag force is commonly referred to as roughness. The most accepted method to assess roughness uses the Manning's n resistance factor (Chow, 1959). Manning's n values for this project were assigned to different roughness categories using aerial imagery from the USDA National Agriculture Imagery Program (NAIP) and in accordance with standard hydraulic reference manuals (Chow, 1959; Barnes, 1967). Roughness values are shown in Table 2.

Table 2. Model roughness values.

SURFACE TYPE	MANNING'S n (0-9 ft depth)	MANNING'S n (>10 ft depth)
Logjam	0.15	0.15
Forest - Mature	0.08	0.06
Forest - Young	0.05	0.04
Scrub/Shrub	0.05	0.04
Standing Water	0.035	0.025
Pasture/Agriculture	0.03	0.02
Gravel bar	0.035	0.02
Channel	0.025	0.01
Road, gravel	0.025	0.01
Road, paved	0.02	0.01

2D Model Calibration

Extensive efforts were made to calibrate the RiverFlow-2D model to the 2017 Effective base flood elevations and comply with FEMA Region 10 policies. Model calibration was performed by adjusting Manning's roughness values to calibrate computed water surface elevation at RM 2.3 to within plus or minus 0.5-feet of the 2018 HEC-RAS model

NSD calibrated the existing conditions hydraulic model to USGS gage 12035000 for the November 2017 high flow event, peaking at approximately 33,500 cubic feet per second (cfs). To best match the rating curve across the full range of discharge, Manning's n-values are reduced according to computed depth (Table 2). Figure 1 shows the calibrated model results compared to the published rating curve for USGS gage 12035000.

Hysteresis in the computed water surface elevations is noted, but differences between the USGS 12035000 rating curve are agreeable to within 0.25 feet.

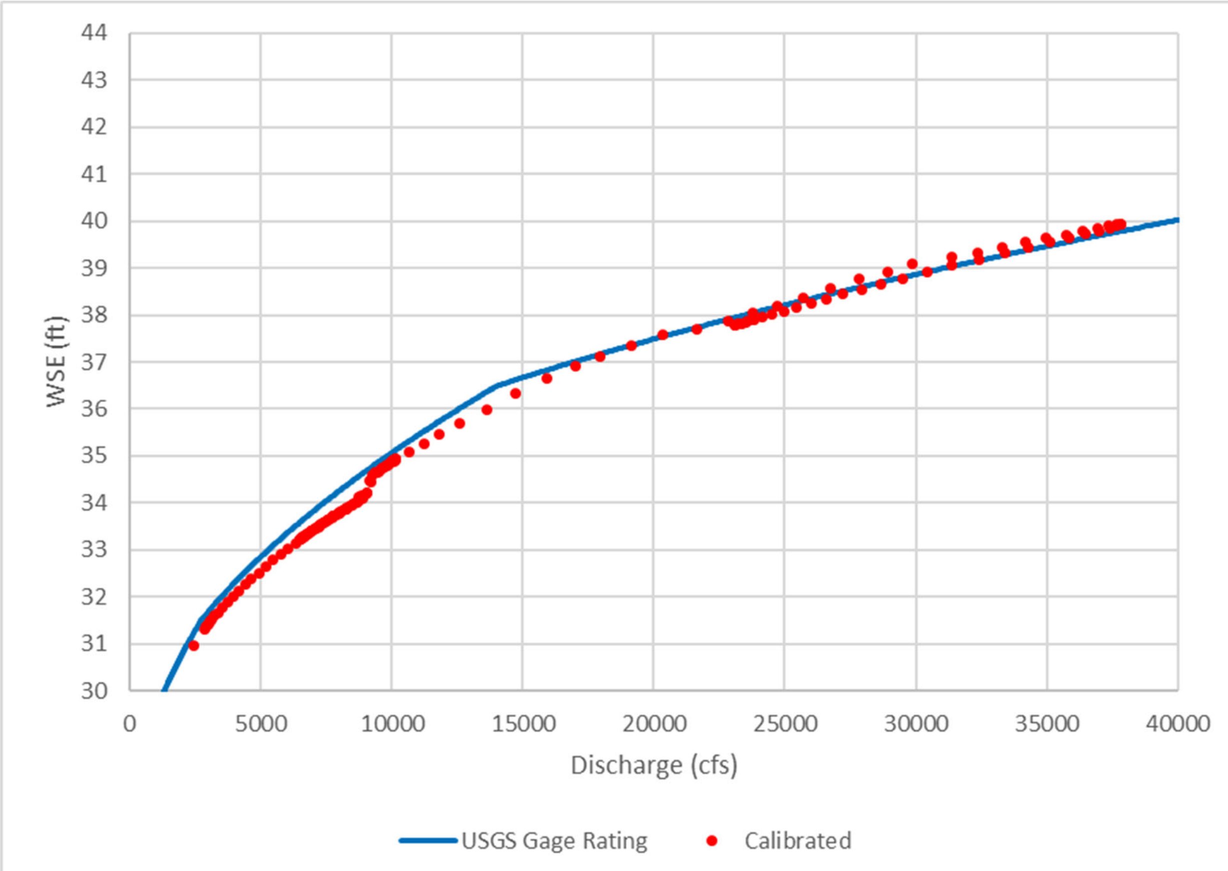

Figure 1. Calibration of Manning's n-values, computed versus USGS 12035000 rating.

Note that the calibration analysis for the Riverflow-2D model follows the same approach for the Effective HEC-RAS model. Both models compare computed water surface elevations to the published rating curve at USGS 12035000. The calibration analysis performed by NSD indicates that the Duplicate Effective model performs well in representing existing conditions at both low and high flow conditions. Inundated area extents mapped in Attachment A are slightly different from Effective FIRM boundaries. This difference can be attributed to the limitations of the 1D hydraulic model (HEC-2 and HEC-RAS), where the inundated areas are limited by the cross-section extent.

Proposed Conditions Model

The Duplicate Effective model serves as the base to compare changes to water surface elevation due to project related designs. Proposed conditions designs are incorporated into the hydraulic model by: 1.) modifying topography, 2.) adjusting roughness, and, 3.) refining the computational mesh. Note that the Proposed Conditions and Duplicate Effective model have identical mesh configurations.

Average water surface elevations were sampled across select cross sections within the project area to compare Proposed Conditions with Existing Conditions model results, as shown in Figures 2 through 7. Refer to Attachment B for an inundation map for Proposed Conditions.

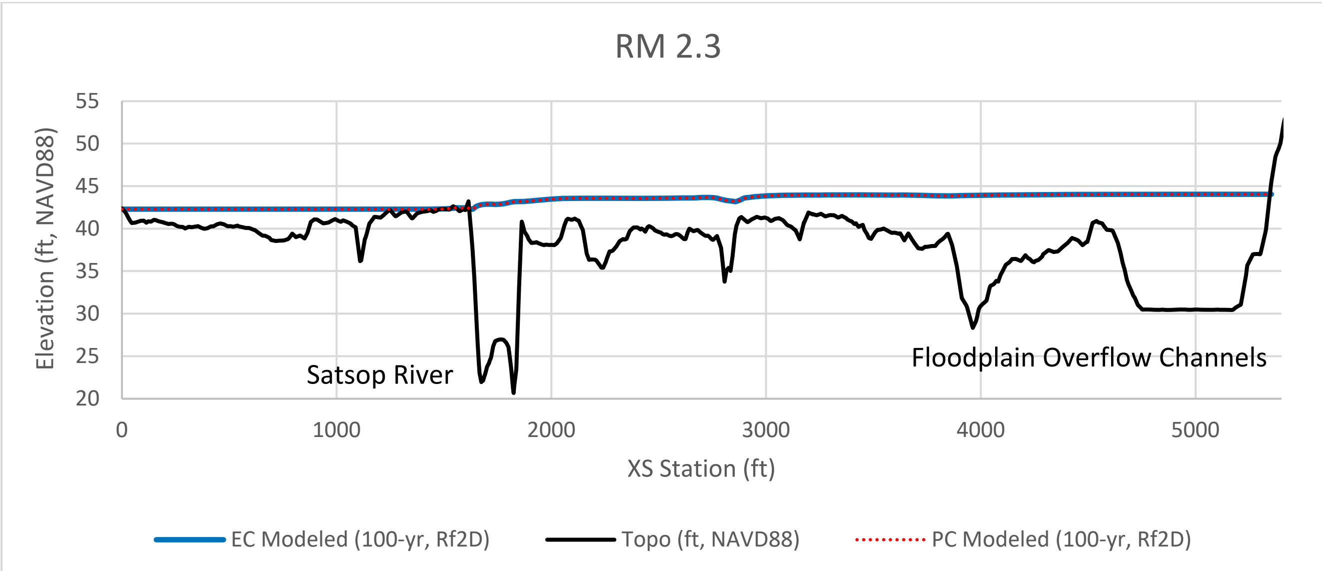

Figure 2. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 2.3. This location is above the U.S. Highway 12 bridge. Note that PC and EC model results show very little difference in computed water surface elevation, which indicate the proposed project does not have a significant influence on hydraulic conditions at the 100-year flow at this location.

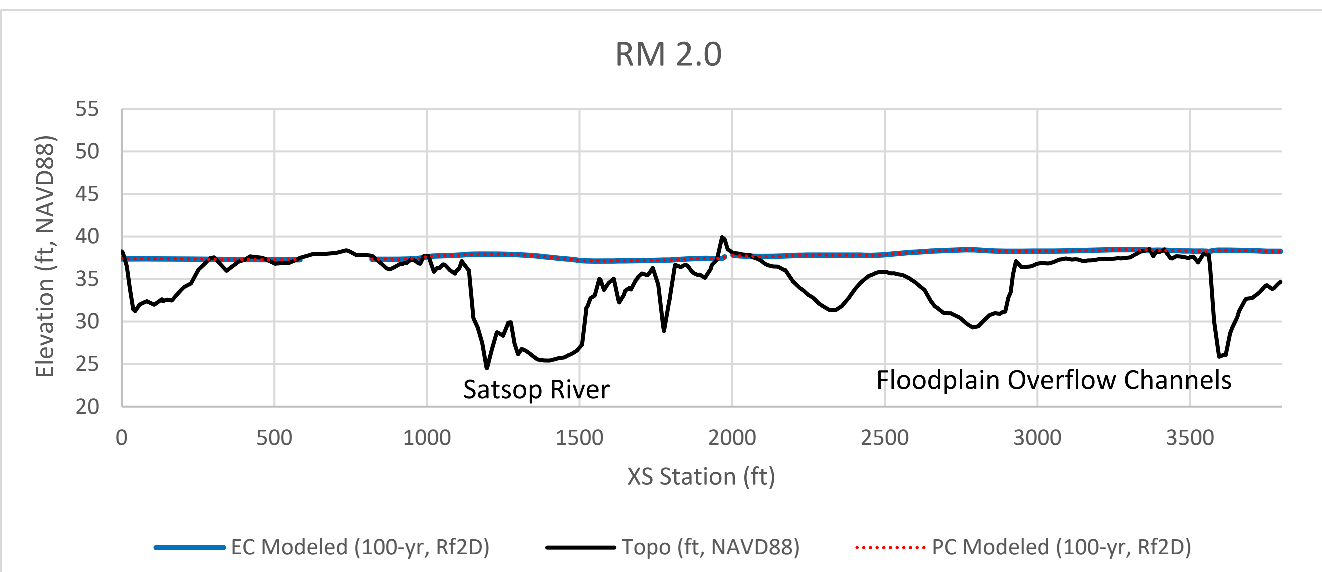

Figure 3. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 2.0. This location is below the U.S. Highway 12 bridge. Note that PC and EC model results show very little difference in computed water surface elevation, which indicate the proposed project does not have a significant influence on hydraulic conditions at the 100-year flow at this location.

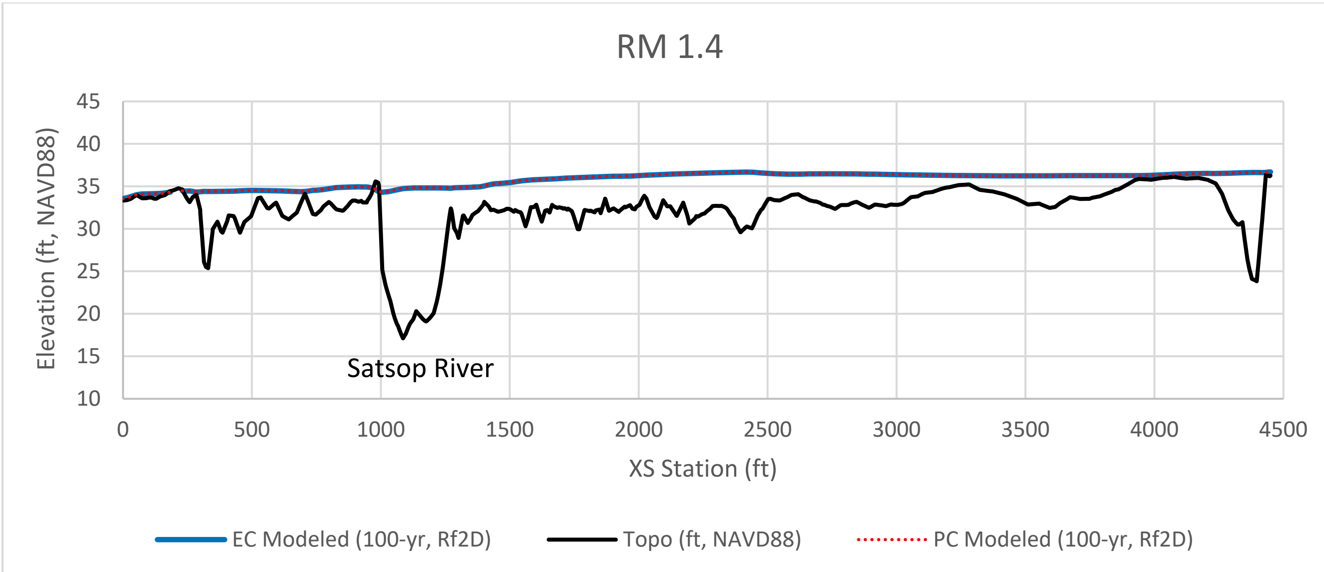

Figure 4. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 1.4. This location is downstream of the first proposed design site. Note that PC and EC model results show very little difference in computed water surface elevation, which indicate the proposed project does not have a significant influence on hydraulic conditions at the 100-year flow at this location.

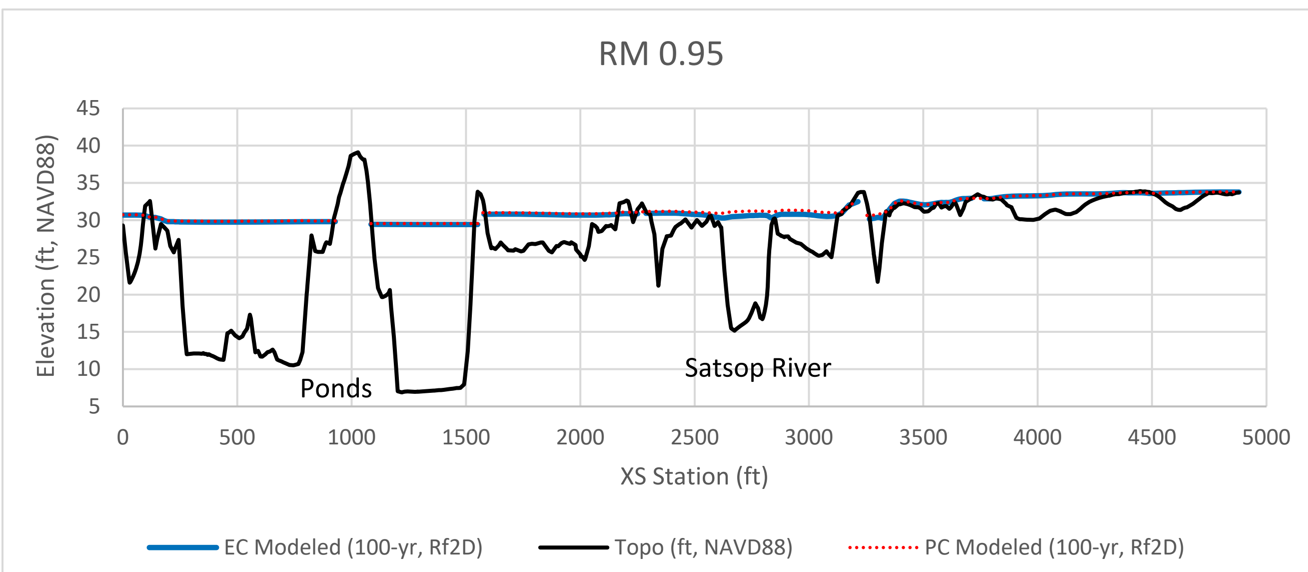

Figure 5. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 0.95. This location is at the upstream extent proposed design elements in the Satsop River main channel. PC model results show a slight increase in computed water surface elevation within the main channel of the Satsop River from engineered log jams. Note that the increase in water surface elevation is limited to the main channel and does not significantly influence flood conveyance at the reach scale.

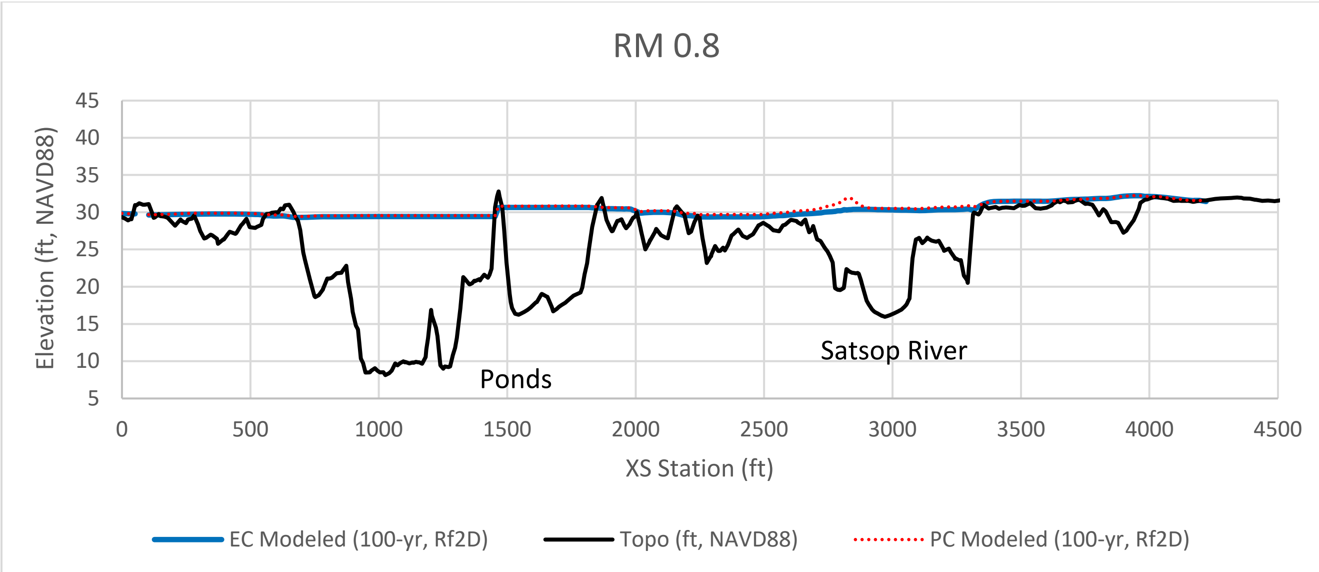

Figure 6. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 0.8. This location is at the proposed relief channel excavation and mainstem engineered logjams. PC model results show an increase in computed water surface elevation within the main channel of the Satsop River. Note that the increase in water surface elevation is limited to the main channel and does not significantly influence flood conveyance at the reach scale.

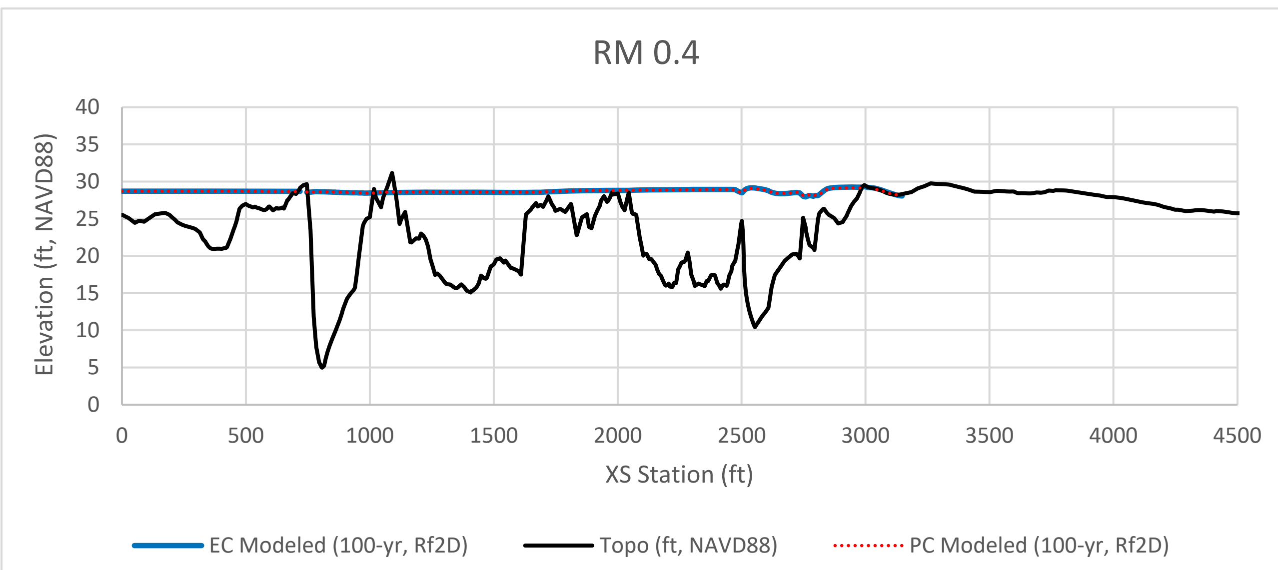

Figure 7. Proposed Conditions results (PC, red dotted line) plotted versus Duplicate Effective results (EC, blue line) at RM 0.4. This location is downstream of all proposed project elements. Note that PC and EC model results show very little difference in computed water surface elevation, which indicate the proposed project does not have a significant influence on hydraulic conditions at the 100-year flow at this location.

Proposed design elements are located in two segments of the Satsop River, at RM 1.5 and at RM 0.5. The Proposed Conditions model otherwise uses identical boundary conditions to the Duplicate Effective model. Results are shown in Table 3. Refer to Attachment C for a computed water surface elevation difference map and corresponding locations of comparison.

Table 3. Comparison of Proposed Conditions hydraulic model results with the Duplicate Effective hydraulic model.

RM[1]	Duplicate Effective Model WSEL (ft, NAVD88)	Proposed Conditions Model WSEL (ft, NAVD88)	Difference (ft)
2.3	43.36	43.36	0.00
2.0	37.32	37.34	0.02
1.4	35.62	35.63	0.01
0.95	30.51	30.72	0.21
0.8	30.21	30.44	0.23
0.4	28.72	28.71	-0.01

1: River Mile (RM) is relative to 2018 NHD dataset. Note that channel alignment has changed since its publication.

The Proposed Conditions model shows a minor effect on water surface elevations within the project area. A maximum average increase of 0.23 feet results from the project design. The "maximum average increase" refers to the difference in water surface elevation across the full cross-section width of wetted area. This is different than the "maximum local increase" in water surface elevation, which the latter refers to a single point-location. The maximum local increase in water surface elevation resulting from the Proposed Conditions design is 2.6 feet, and the corresponding average increase in water surface at this location is 0.23 feet. Increase in water surface elevation is within in the immediate vicinity of proposed design elements between RM 1.2 and 0.5, but does not affect flood conveyance or flood extents at the reach scale.

Note that the increases in water surface elevations are located within the main channel or in adjacent floodplain areas where grading is designed, and not in the vicinity of any structures or residences. There is no increase in 100-year inundation extent as a result of Proposed Conditions design. Also note that changes in water surface elevation for the 100-year discharge are limited to locations within the project areas. Refer to Attachment C for a map of computed water surface elevation changes.

Any variance in results between the RiverFlow-2D model and the HEC-2 model (Effective) can primarily be attributed to differences in main channel and floodplain topography. Channel topography in the HEC-2 model is derived from data sources compiled in 1985 and estimations of channel bed geometry below the water surface. This reach of the Satsop River is highly dynamic and can adjust its horizontal and vertical position significantly. The RiverFlow-2D model uses the 2017 topo-bathymetric LiDAR and 2019 bathymetric surveys, which includes the main channel and floodplain areas a spatial resolution of 3 feet. Furthermore, the HEC-2 model does not include the Chehalis River, which at flood conditions may influence water surface elevations in the Satsop River.

Conclusion

Analyses summarized in this report are consistent with Grays Harbor County Ordinance 448, FEMA Region 10 guidelines, and the standard of practice for floodplain analyses. Based upon the topographic data of the site, proposed design of the restoration project, and results from the hydraulic modeling, the project site and adjacent properties are expected to be reasonably safe from flooding and flood heights will not increase within the project area, meeting Grays Harbor County and FEMA Region 10 policies requirements. ELJs proposed as part of the project were designed and located to keep any rise in the 100-year flood levels as close to zero, as practically possible.

Hydraulic model results indicate that the restoration design within the project reach will cause a maximum of 0.23 feet rise in the average water surface elevation during the 100-year flow at the maximum point of rise. No increase in the 100-year WSEL occurs in an area with a residential structure within the modeled 100-year floodplain nor does the rise cause a residential structure or property that was not within the 100-year floodplain to be inundated during the modeled proposed condition. Given the results, we determine the project to be compliant with Grays Harbor County Ordinance 448 and FEMA Region 10 policies for habitat projects occurring within a FEMA regulated floodplain and floodway.

Attachments

Attachment A: Map –2D Hydraulic Model Output 100-year (52,610 cfs) Water Surface Elevations, Duplicate Effective.

Attachment B: Map –2D Hydraulic Model Output 100-year (52,610 cfs) Water Surface Elevations, Proposed Conditions.

Attachment C: Map – Change in 100-year Water Surface Elevation, Proposed Conditions versus Duplicate Effective Conditions.

Attachment D: Policy on Fish Enhancement Structures in the Floodway – FEMA Region 10

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Barnes, H.H., 1967. Roughness Characteristics of Natural Channels. U.S. Geological Survey, Water Supply Paper 1849, Washington, D.C.

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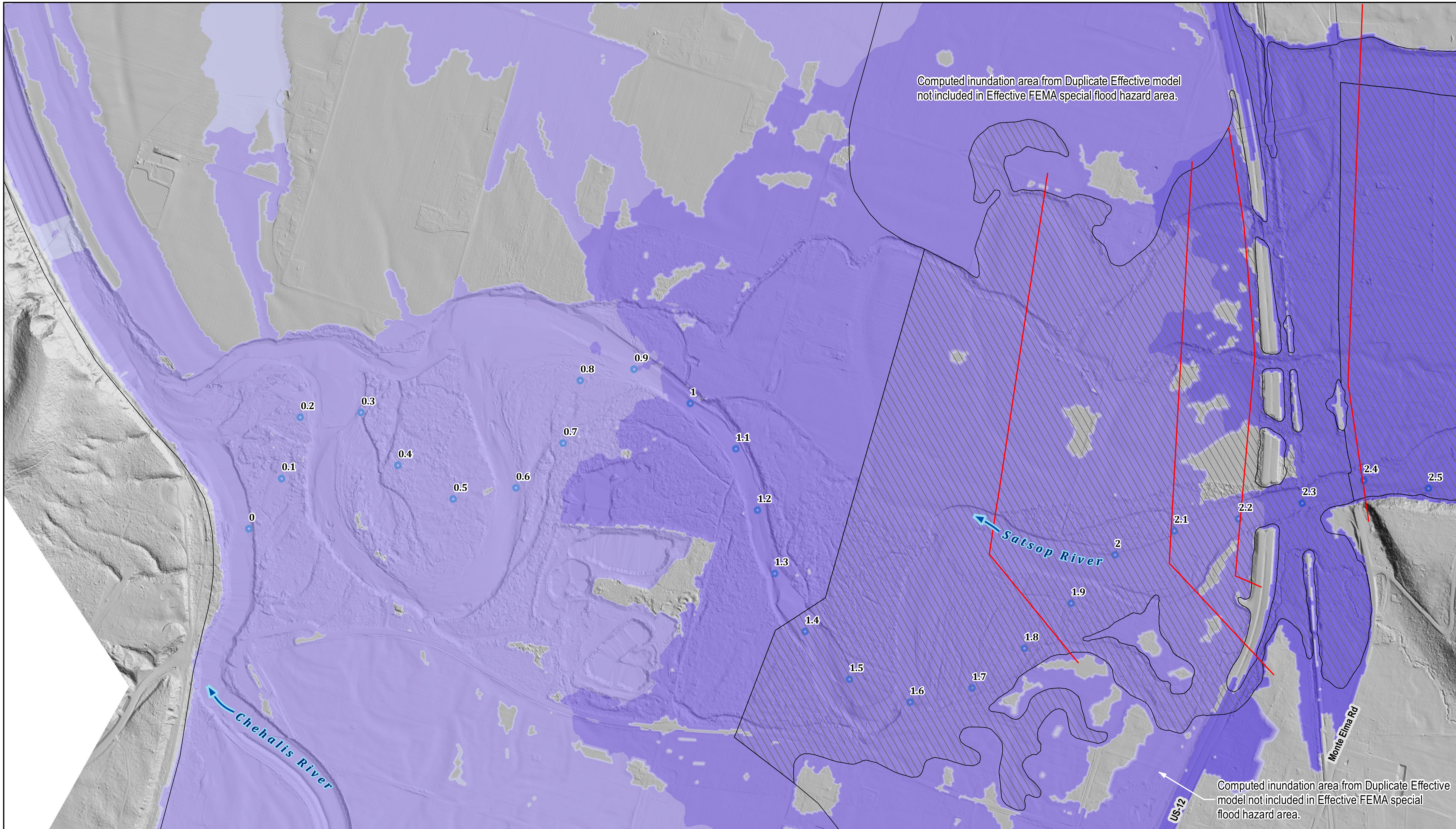

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Keys Road Flood Protection

Satsop River - RM 2.6 - 0.0

Duplicate Effective model results

100-yr flow (52,610 cfs)

0 250 500 1,000 Feet

Computed Water Surface Elevation (ft, NAVD88)

13-22
22-31
31-39
39-48
48-56

River Mile (NHD)

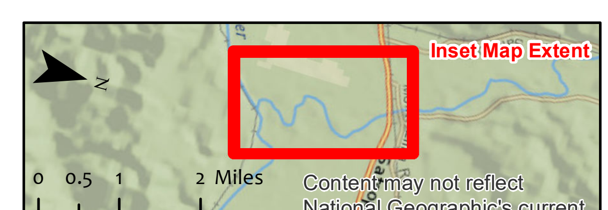
FEMA Zone AE (Effective)

FEMA Zone A (Effective)

HEC-2 Model XS (Effective)

Water surface elevation is computed using RiverFlow2D, performed by NSD (2020). FEMA Zone A and AE shown on map with base flood elevationsand DFIRM database (Effective 2/3/2017).

Topographic data sources: 2017 Green LiDAR (PSLC), March 2019 bathymetic survey (NSD), August 2019 bathymetric survey (NSD)



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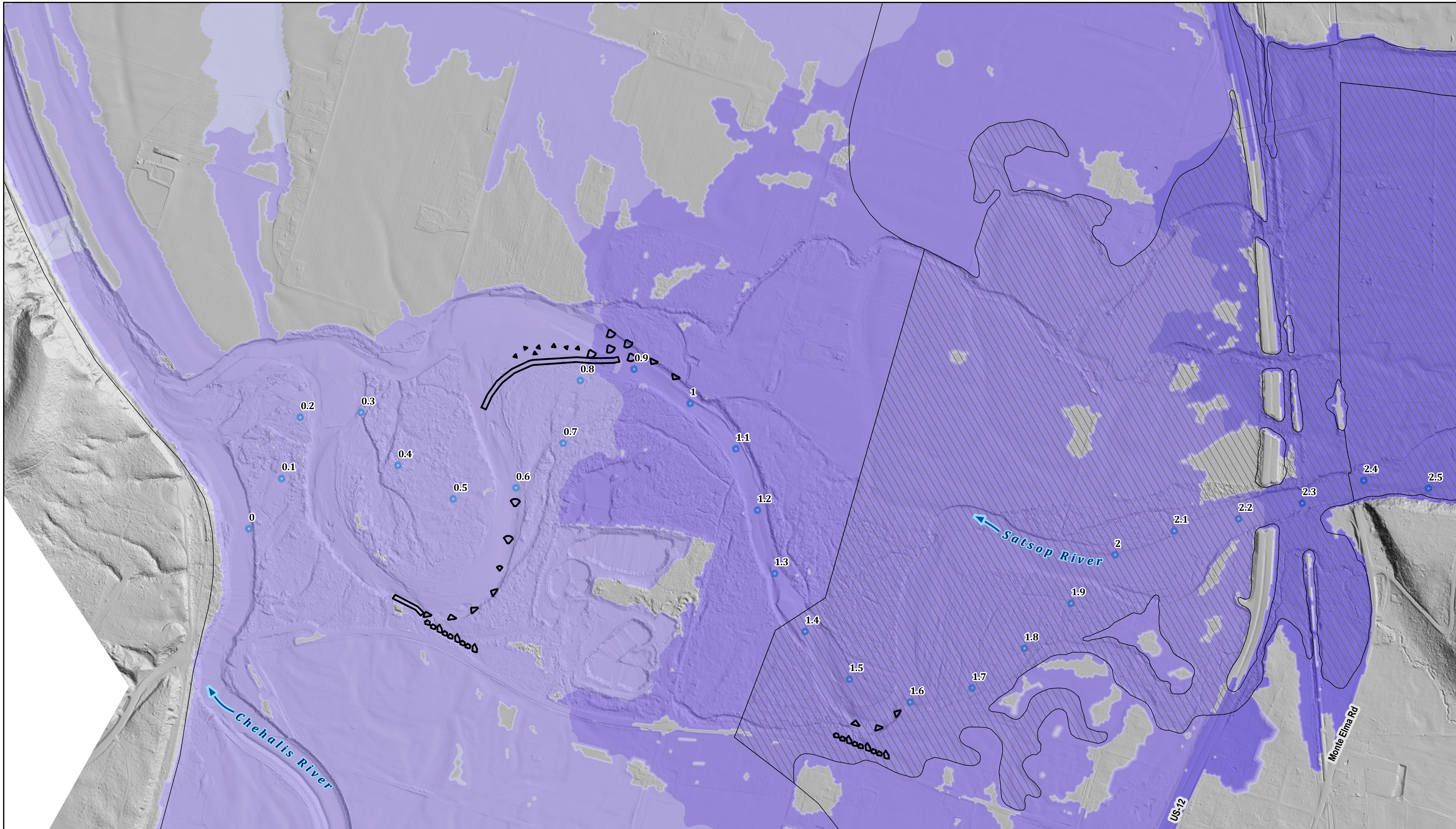

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Keys Road Flood Protection

Satsop River - RM 2.6 - 0.0

Proposed Conditions model results

100-yr flow (52,610 cfs)

0 250 500 1,000 Feet

Computed Water Surface Elevation (ft, NAVD88)

13-22
22-31
31-39
39-48
48-56

River Mile (NHD)

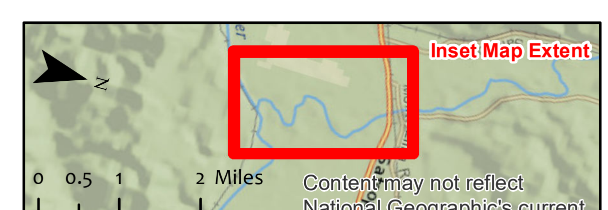
FEMA Zone AE (Effective)

FEMA Zone A (Effective)

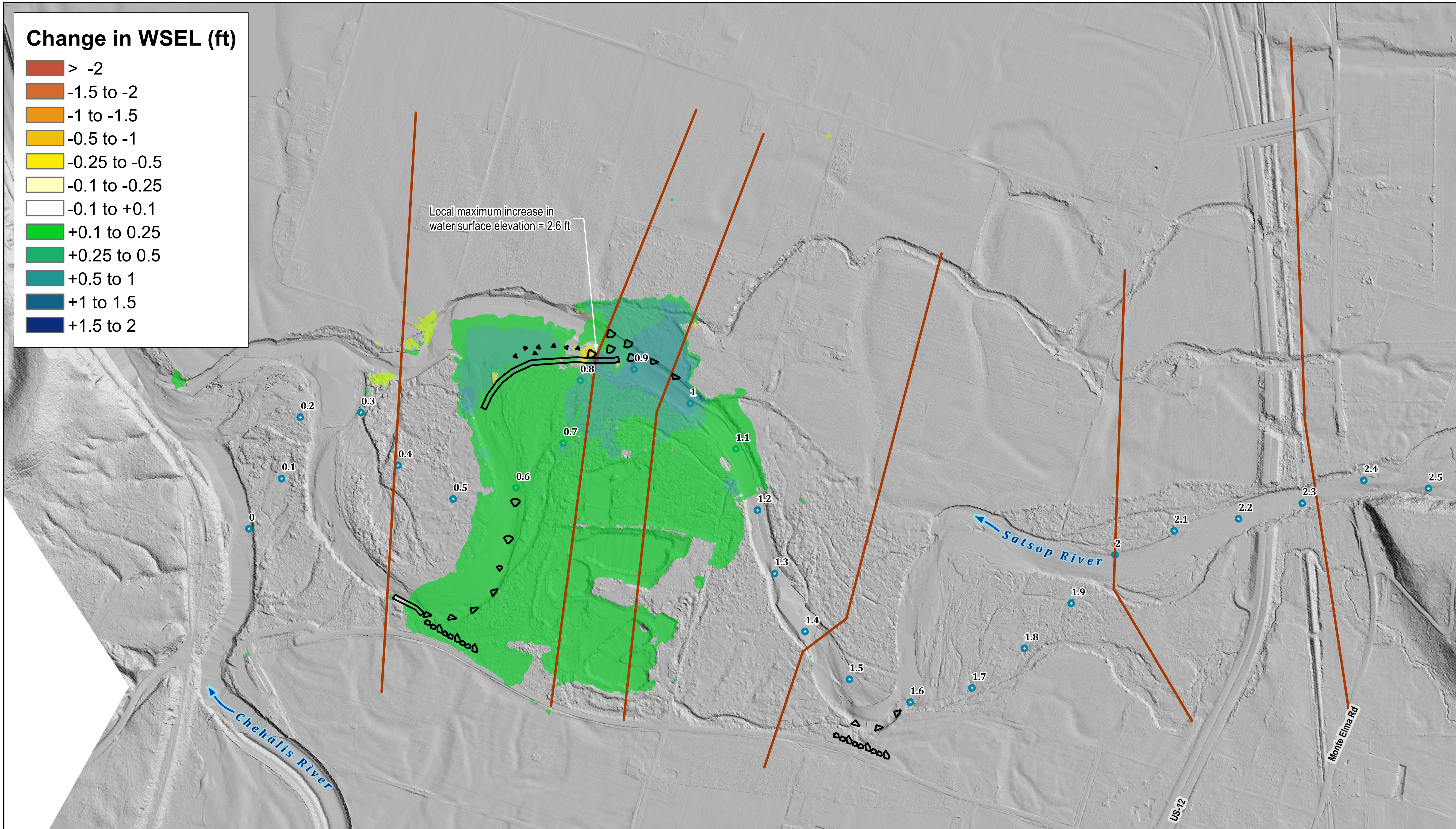
ELJ or Grading Footprint

Water surface elevation is computed using RiverFlow2D, performed by NSD (2020). FEMA Zone A and AE shown on map with base flood elevationsand DFIRM database (Effective 2/3/2017).

Topographic data sources: 2017 Green LiDAR (PSLC), March 2019 bathymetic survey (NSD), August 2019 bathymetric survey (NSD)



Natural Systems Design



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Keys Road Flood Protection

Satsop River - RM 2.6 - 0.0

Change in Water Surface Elevation from Proposed Conditions

100-yr flow (52,610 cfs)

0 250 500 1,000 Feet

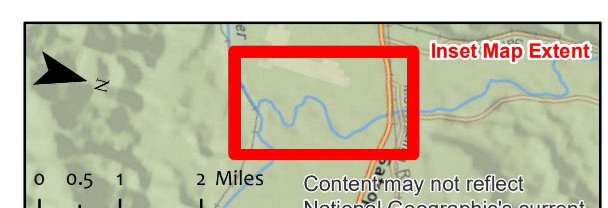
River Mile (NHD)

XS Comparison Locations

ELJ or Grading Footprint

Water surface elevation is computed using RiverFlow2D, performed by NSD (2020). FEMA Zone A and AE shown on map with base flood elevationsand DFIRM database (Effective 2/3/2017).

Topographic data sources: 2017 Green LiDAR (PSLC), March 2019 bathymetic survey (NSD), August 2019 bathymetric survey (NSD)



Natural Systems Design

APPENDIX E - POLICY ON FISH ENHANCEMENT STRUCTURES IN THE FLOODWAY

U.S. Department of Homeland Security
Region X
130 228th Street, SW
Bothell, WA 98021-9796

FEMA

Policy on Fish Enhancement Structures in the Floodway

The balance required between anadromous fish and the human environment is unique to the Northwest. Maintaining that balance often makes implementing regulations a challenge. Sometimes the local, State and Federal regulations contradict each other. This is the case with fish enhancement structures.

FEMA's regulations require communities to prohibit encroachments in regulated floodways unless provided with a no-rise analysis. The current listing and proposed listing of certain anadromous fish species as Threatened or Endangered requires the restoration of their habitat to ensure their survivability. Restoring that habitat often entails encroaching in the floodway. A strict interpretation of this standard could require a relatively expensive analysis that might exceed the cost of the enhancement project.

FEMA recognizes this. While we believe the best course of action is to preserve the floodway encroachment standard as it exists, an informed judgment regarding fish enhancement structures can be made as to exceptions for which less than the maximum hydraulic analyses are required. The community official often does not have the qualifications to make an informed judgment regarding the impacts of these structures on flood hazards. Therefore, FEMA will allow the community to defer to the "judgment" of a qualified professional regarding such impacts. Such qualified hydraulic or hydrology professionals would include staff of Rural Conservation and Development and the Natural Resource Conservation Service. It would also include similarly qualified staff of fisheries, natural resource, or water resources agencies.

The qualified professional should, as a minimum, provide a feasibility analysis and certification that the project was designed to keep any rise in 100-year flood levels as close to zero as practically possible and that no structures would be impacted by a potential rise. Additionally, routine maintenance of any project would be necessary to sustain conveyance over time and the community should commit to a long-term maintenance program in their acceptance of the project. FEMA also recommends a condition be placed on the projects emphasizing the dynamics of a river and, if the community deems necessary, further analysis be required.

We believe this is preferable to trying to specify in the ordinance language all the different types of "development" that need not comply with the "no rise" standard. Typically, any rise caused would require some offsetting action such as compensatory storage, channel alteration, or removal of existing encroachment. One of these alternatives would be appropriate to compensate for any rise and still preserve the integrity of the floodplain standards.

FEMA Region 10 feels this policy is in keeping with the concept of wise floodplain management which means enjoying the benefits of floodplain lands and waters while still minimizing the loss of life and damage from flooding and at the same time preserving and restoring the natural resources of floodplains as much as possible. If you have any questions regarding this policy, please contact the Mitigation Division at (425) 487-4737.

www.fema.gov