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Engineering – Hydrology – Stream Restoration – Water Resources

TECHNICAL MEMORANDUM

Jeffrey K. Anderson

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Date: 2020.09.29 16:33:41 -07'00'

Date: 29 September 2020

To: Charles J. Striplen
North Coast Regional Water
Quality Control Board
5550 Skylane Blvd, Suite A
Santa Rosa, CA 95403-1072

From: Jeffrey K. Anderson, P.E., M.S.

REGISTERED PROFESSIONAL ENGINEER
JEFFREY K. ANDERSON
No. 50713
CIVIL
STATE OF CALIFORNIA

Expires: 30 Sep. 2021

Re: 1% Annual Chance Flood Elevation Estimates for the Lower Elk River, Humboldt County

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INTRODUCTION AND BACKGROUND

As part of the Action Plan for the Upper Elk River Sediment Total Maximum Daily Load (TMDL), the North Coast Regional Water Quality Control Board has initiated the Elk River Recovery Assessment and Community Stewardship Program (Stewardship). The Stewardship Program is being led by California Trout (CalTrout) with technical assistance from Northern Hydrology & Engineering (NHE) and Stillwater Sciences. As part of Stewardship, a number of public meetings and Elk River landowner meetings have occurred since early 2019. During these meetings, several landowners have voiced concerns regarding flooding and the accuracy of the Federal Emergency Management Area (FEMA) flood hazard zone mapping. Upon review of the FEMA Flood Insurance Rate Map (FIRM) Elk River panels it was noted that several residential structures that currently flood are mapped outside of the FEMA flood hazard zone. It also became evident, based on conversations with landowners, that the current extent, depth, and risk associated with extreme flood events in the Elk River, such as the 1% annual chance (or 100-yr) flood, may not be fully understood or appreciated. This even applies to landowners who lived in the Elk River watershed during the extreme flood events of the 1950s, 1960s and 1970s, a period when the Elk River had more flood flow capacity than it does today. Given the loss of channel capacity by sedimentation and vegetation changes that have occurred since the 1990s, the associated depth and risk from extreme flood events has significantly increased over conditions that existed in the Elk River during the 1950s to 1970s.

Following recommendations from agency project partners and interest expressed by landowners, the two-dimensional hydrodynamic and sediment transport model developed as part of the Elk River Recovery Assessment (California Trout et al., 2018) was expanded to model extreme flood events up to the 1% annual chance flood. The expanded model can be used to provide:

- A modeling tool to support future flood analysis of the restoration strategy developed as part of the Stewardship program.
- Existing condition fluvial and coastal flood elevations for the 1% annual chance flood event in the Lower Elk River Study area (as described below).

This technical memorandum (memo) provides a summary of the flood analysis conducted by NHE on the Elk River to provide 1% annual chance flood water surface elevation estimates for the Study area covered by the modeling domain. The Study area is defined as the lower portions of the North Fork (NF) Elk River and South Fork (SF) Elk River and the Elk River from the confluence of the NF and SF Elk Rivers to Humboldt Bay (Figure 1).

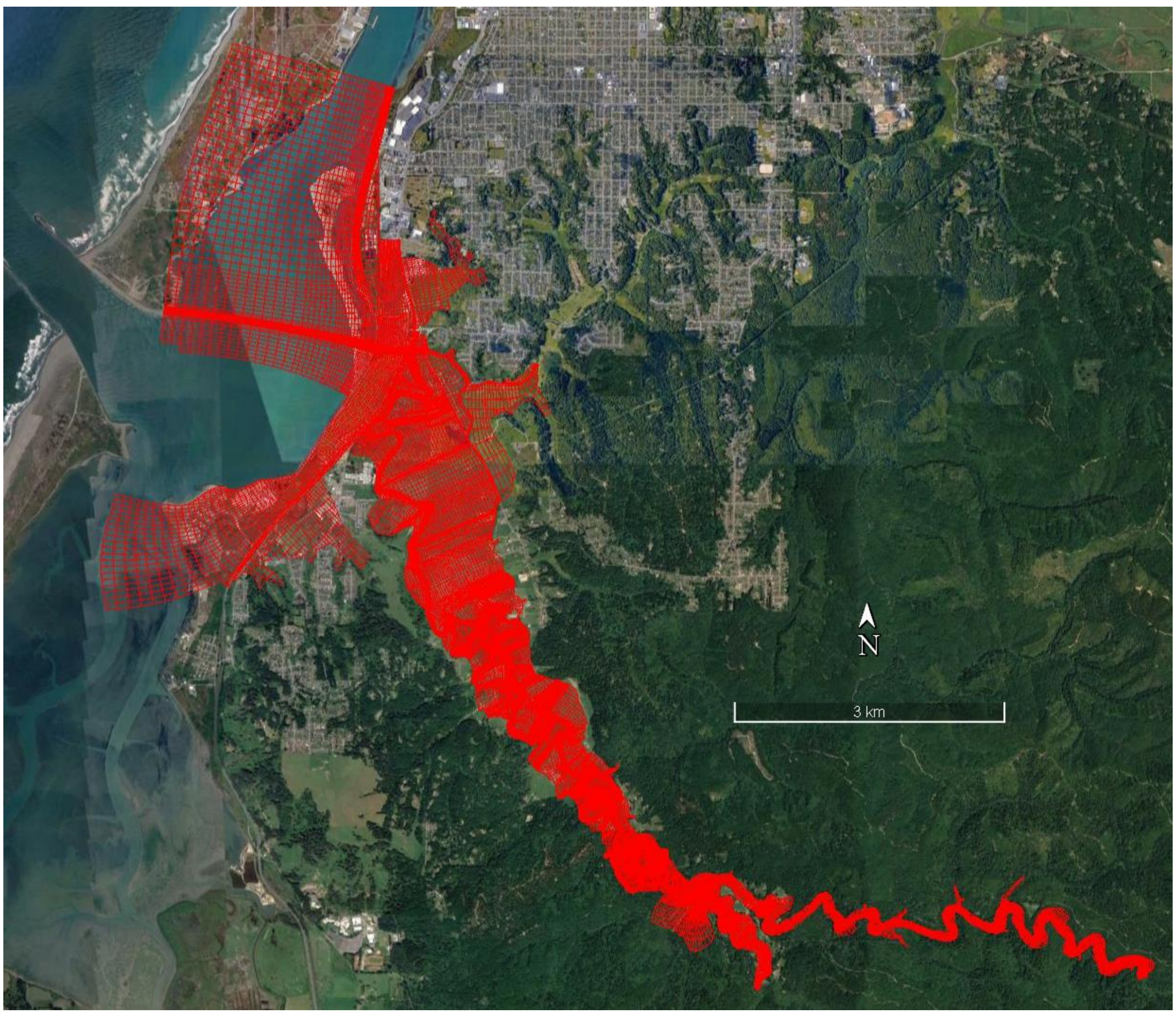

Figure 1. Location map showing the extent of the Elk River hydrodynamic expanded model (H-Exp Model).

The majority of the Study area is located within a FEMA Zone A special flood hazard area for which 1% base flood elevations (BFE) have not been determined, and Zone X special flood hazard area of minimal flood hazard and area of future conditions 1% annual chance flood hazard (FEMA, 2017; FEMA, 2018). The Zone A designation generally implies an unstudied area in which FEMA has not conducted a detailed hydrologic and hydraulic analysis. FEMA has conducted detailed studies at two locations within the Study area. These include a narrow strip of land adjacent to Humboldt Bay in which a detailed coastal hazard analyses provided 1% BFEs for both stillwater and wave runup elevations; and Martin Slough in which a detailed hydrologic and hydraulic analysis provided 1% BFEs in this area approximately 0.5 miles above its confluence with Swain Slough (FEMA, 2018). The Martin Slough hydraulic analysis consisted of a backwater analysis using the HEC-2 program assuming normal-depth downstream boundary conditions. The analysis did not consider backwater effects from the mainstem Elk River.

The 1% annual chance flood elevations determined in this work can be used to provide estimates of the 1% BFE in the Zone A areas of the Elk River. It should be noted that these 1% flood elevations have not formally been adopted by FEMA to represent 1% BFE but do provide the best available information for the Zone A areas of the Elk River covered by the model domain. FEMA, the County of Humboldt (Humboldt) or City of Eureka could pursue using this information and amending the Flood Insurance Study (FIS) and/or Flood Insurance Rate Map (FIRM) panels related to the Elk River.

The 1% flood elevations presented in this memo are a composite of the maximum water levels from either a riverine flood or a coastal stillwater extreme high-water (storm surge) level analysis within the Study area. These results do not account for sea-level rise effects, nor represent combined probabilities of riverine flood and coastal events occurring at the same time, which is beyond the scope and funds available for this work.

Units provided in this memo are a combination of U.S. customary and metric units. The modeling analysis was conducted in metric units. Elevations are referenced to the North American Vertical Datum of 1988 (NAVD88), and the horizontal coordinate system is Universal Transverse Mercator (UTM) Zone 10, North American Datum of 1983 (NAD83).

This memo supersedes a previous memo dated 30 March 2020.

GENERAL FLOOD ANALYSIS APPROACH

This study used an existing two-dimensional hydrodynamic and sediment transport model (HST Model) developed as part of the Elk River Recovery Assessment (California Trout et al., 2018). The existing HST Model was not configured to model 1% annual chance flood flows and it was necessary to expand the model grid in the lowest reach of the Elk River near Humboldt Bay. This expansion included extending the model grid into areas west of Highway 101 and Humboldt Bay on the both north and south sides of Elk River. The expanded HST Model will only model hydrodynamics and will be referred to as the H-Exp Model.

The Elk River Study area is subject to flood and inundation regimes from both riverine flooding and coastal extreme high-water events (storm surge). Two event conditions were analyzed, one for riverine flooding and the second for coastal flooding. For riverine flooding, the Study area includes the confluence of the NF and SF Elk Rivers (confluence). Based on available data, the backwater effects from the confluence on upstream flood levels needs to be considered in the analysis, which is a deviation from the typical FEMA approach for determining BFEs. The approach used in this study for determining 1% annual chance flood levels used coincident peaks for the NF and SF Elk River that consider backwater effects at the confluence of these river tributaries. This approach required two separate coincident flood cases be modeled within the riverine event condition. The two 1% annual chance flood event conditions analyzed are described as follows:

- Event Condition 1: Riverine flooding from the 1% annual chance flood event from upstream riverine sources with a representative existing condition spring tide level at the downstream boundary. The H-Exp Model was used to represent steady-state conditions for riverine flooding. Two coincident peak flood cases were simulated for Event Condition 1:
    - Case 1 consists of analyzing flood conditions assuming the NF Elk River discharge is at the 1% annual chance peak-flood, and the SF Elk River discharge is the difference between the 1% annual chance peak-flood for the Elk River below the confluence and the NF Elk River 1% annual chance peak-flood.
    - Case 2 is the opposing coincident flood condition and assumes the SF Elk River discharge is at the 1% annual chance peak-flood, and the NF Elk River discharge is the difference between the 1% annual chance peak-flood estimates below the confluence and SF Elk River.
- Event Condition 2: Coastal flooding based on a representative existing condition stillwater 1% annual chance extreme coastal event at the downstream boundary with winter median-flow from upstream sources. The H-Exp Model was used as a dynamic model for coastal flooding, with a tidal time series boundary condition and steady winter median-flows for all streams.

To account for the riverine and coastal flood events, the 1% annual chance flood elevation estimate was taken as the maximum water level from either Event Condition 1 (Case 1 and Case 2) or Event Condition 2.

HYDROLOGIC ANALYSIS

This section describes the hydrologic analysis conducted for determining 1% annual chance peak-flood flow estimates within the general Study area.

Background

Streamflow data on the Elk River is limited to two time periods. The USGS maintained a streamflow gaging station on the Elk River below the NF and SF Elk River confluence (USGS 11479700 Elk River near Falk, CA) for water year (WY) 1958 to 1967, and annual peak-flow data exist for this period-of-record (POR). Since WY 2003, Humboldt Redwood Company has maintained streamflow gaging stations on the Elk River below the NF and SF confluence (approximate location of the historic USGS gage), NF Elk River above the confluence, and SF Elk River above the confluence, and annual peak-flow estimates exist at these three locations for WY 2003 to current.

A review of USGS published peak-flood estimates (Gotvald et al., 2012) for the Elk River station demonstrates that the less frequent peak-flood estimates (e.g. 1% annual chance event) from a Bulletin 17B analysis (IACWD, 1982) using a Log-Pearson Type-3 distribution on the POR annual peak-flows are significantly lower than peak-flood estimates from the regional flood-frequency equations (Table 1). A condition that does not exist for other gaged streams in the local vicinity as the Elk River, such as the USGS gaging station on Jacoby Creek which is another tributary to Humboldt Bay, and the USGS gaging station on Little River that has a watershed area similar in size to the Elk River (Table 1).

Table 1. USGS Flood-frequency estimates for Elk River, Little River and Jacoby Creek (Gotvald et al., 2012) from a Bulletin 17B analysis (Log-Pearson Type 3 distribution) of the annual peak-flow station data and the regional flood-frequency equations. Not all flood-frequency estimates available in Gotvald et al. (2012) are provided.

Station Name	Basin Area (mi^2)	Flood-Frequency Estimate[1]	Percent (%) Annual Chance Flow (cfs)			
			50	10	1	0.2
Elk River near Falk, CA (USGS Sta: 11479700; POR: 1958-1967)	43.2	G	2,740	3,430	3,960	4,220
		R	2,880	6,730	11,900	15,400
		%Diff	5.1	96	201	265
Little River near Trinidad, CA (USGS Sta: 11481200; POR: 1953-2006)	40.5	G	4,990	8,840	12,700	14,900
		R	3,250	7,220	12,500	15,900
		%Diff	-34.9	-18	-2	7
Jacoby Creek near Freshwater, CA (USGS Sta: 11480000; POR: 1955-1974)	6.05	G	757	1,560	2,630	3,400
		R	606	1,390	2,450	3,170
		%Diff	-19.9	-11	-7	-7

1) G is estimate from the Bulletin 17B analysis using the annual peak-flows from each station; R is estimate from regional flood-frequency equations; %Diff is percent difference calculated as (R-G)/G x 100.

Review of Table 1 indicates that the Elk River Bulletin 17B peak-flood estimates for the 10%, 1% and 0.2% annual chance flows are approximately 96%, 201% and 265% lower than the regional flood-frequency equation estimates, respectively. However, the 10%, 1% and 0.2% annual chance flood-frequency estimates for Little River and Jacoby Creek only differ from each other by approximately 7% to -18%, indicating reasonable consistency between the Bulletin 17B and regional equation estimates. One possible explanation for this discrepancy is that the above-mentioned Elk River gaging sites are in an area with significant overbank flows during flood events (Figure 2). Not only is the site inaccessible during flood events due to road flooding, it appears that the gaged record may have only accounted for discharge within the channel and did not accurately account for the overbank flows. NHE has concluded that the observed annual peak-flow record for the historic USGS Elk River gage (USGS 11479700 Elk R. nr Falk CA) do not represent accurate annual peak-flows and conducting flood-frequency analysis with these data provide unreasonably low peak-flood estimates and should not be used. NHE has further concluded that this same condition applies for the three active Humboldt Redwood Company Elk

River gaging stations described above, and the annual peak-flows from these stations should not be used to provide peak-flow estimates. Consequently, NHE used the regional flood-frequency equations to estimate peak-flood flows for this study.

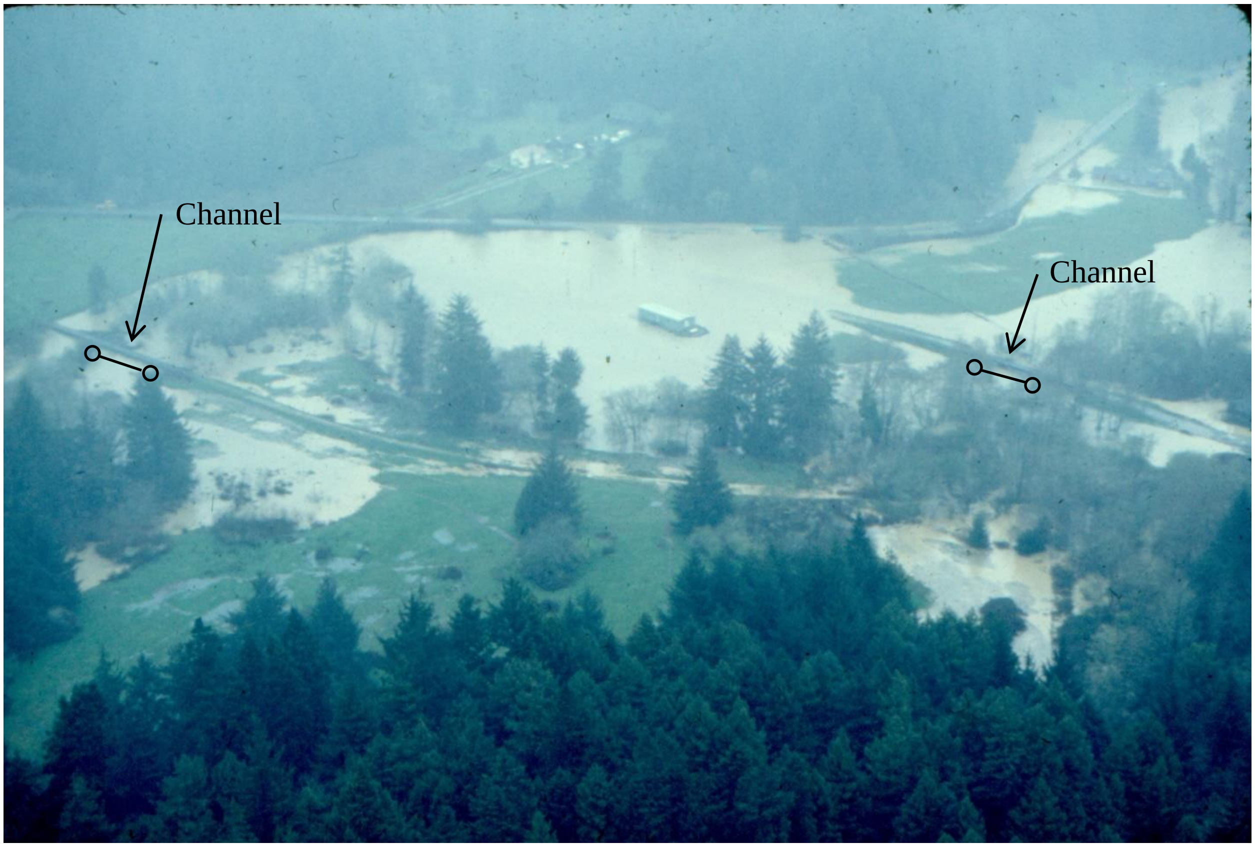

Figure 2. 1975 flood event on Mainstem Elk River showing large overbank floodplain flows. The photo is looking upstream and shows the Steel Bridge (center – right side of photo) and old railroad bridge (center – left side of photo). The approximate river channel width (o——o) is shown at both bridge locations and make up a small fraction of the total flood extents. Both bridge approaches encroach into the floodplain and the Steel Bridge road is covered by floodplain flow. The 1975 flood is the highest annual peak-flow event of record for Little River (POR: 1953 to 2019).

Methods and Results

Peak-Flood Estimates

The 1% annual chance peak-flood estimates for the Elk River study area were estimated using the regional flood-frequency equation for California (regional-equation) (Gotvald et al., 2012). Regional-equation parameters for the NF and SF Elk River, Elk River below the NF and SF Elk River confluence, and various Elk River tributaries (Table 2) were determined from the USGS online StreamStats program (http://water.usgs.gov/osw/streamstats/).

Table 2. Regional flood-frequency equation parameters for Elk River Study area (refer to Figure 3).

Parameter	Basin Area (mi^2)	Annual Precipitation (in)
NF Elk River below confluence with Lake Creek	18.5	57.0
NF Elk River below confluence with Browns Gulch	20.2	56.3
NF Elk River below confluence with Dunlap Gulch	21.0	55.9
NF Elk River below confluence with Unnamed Tributary 3	21.7	55.6
NF Elk River above SF Elk River	22.6	55.3
SF Elk River above NF Elk River[1]	19.4	57.8
Elk River below confluence of NF and SF Elk River[1]	42.0	56.5
Elk River below confluence with Railroad Gulch	43.2	56.3
Elk River below confluence with Clapp Gulch	44.2	56.1
Elk River below confluence with Unnamed Tributary 4	44.9	55.9
Elk River below confluence with Shaw Gulch	46.0	55.7
Elk River below confluence with Unnamed Tributary 1	47.3	55.4
Elk River below confluence with Unnamed Tributary 2	47.7	55.3
Elk River below confluence with Orton Creek	49.1	55.0
Elk River below confluence with Swain Slough (includes Martin Slough)	55.8	53.5

1) Adjusted parameter estimates by removing Railroad Gulch from SF Elk River.

Several tributaries to the NF Elk River and Elk River between the confluence and Humboldt Bay are included in the Elk River HST model (refer to Figure 3). Tributary flood flows were determined by calculating the 1% annual chance peak-flood estimate in the Elk River directly below the tributary confluence using the regional equation, and then subtracting the nearest upstream 1% annual chance peak-flood estimate. This approach provided tributary flood flows that were lower than the 1% annual chance peak-flood estimates from the regional-equation for each tributary but maintained upstream to downstream consistency in 1% annual chance peak-flood estimates along the Elk River.

As discussed earlier, two coincident flood cases were analyzed for Event Condition 1.

- Case 1 consists of analyzing flood conditions when the NF Elk River is at the estimated 1% annual chance peak-flood flow. The SF Elk River flood flow was taken to be the difference between the NF Elk River 1% annual chance peak-flood flow and the estimated 1% peak-flood flow below the confluence of the NF and SF Elk River. Under Case 1, the SF Elk River flood flow used in the analysis is lower than the estimated 1% annual chance peak-flood flow for the SF Elk River.
- Case 2 consists of analyzing flood conditions when the SF Elk River is at the estimated 1% annual chance peak-flood flow. The NF Elk River flood flow was taken to be the difference between the SF Elk River 1% annual chance peak-flood flow and the

estimated 1% annual chance peak-flood flow below the confluence of the NF and SF Elk River. Under Case 2, the NF Elk River flood flow used in the analysis is lower than the estimated 1% annual chance peak-flood flow for the NF Elk River.

Tributary flood flows downstream of the confluence were the same between Case 1 and Case 2.

Table 3 and Table 4 provide summaries of the Case 1 and Case 2, respectively, 1% annual chance peak-flood flow and coincident flood flow estimates for the NF and SF Elk River, Elk River below the NF and SF Elk River confluence, and Study area tributaries.

Table 3. Summary of Case 1 (Event Condition 1) 1% annual chance peak-flood flow and coincident flood flow estimates for the Elk River Study area (refer to Figure 3).

Parameter	Flood Estimate (cfs)	Note
Case 1 for Event Condition 1		
NF Elk River above confluence with SF Elk River	6,720	1% annual chance peak-flood estimate
NF Elk River below confluence with Lake Creek	5,934	NF Elk River blw Lake Creek 1% peak-flood adjusted to NF Elk River 1% peak-flood
Browns Gulch	426	Difference between NF Elk River blw Lake Creek and NF Elk River blw Browns Gulch 1% peak-flood flows adjusted to NF Elk River 1% peak-flood
Dunlap Gulch	192	Difference between NF Elk River blw Browns Gulch and NF Elk River blw Dunlap Gulch 1% peak-flood flows adjusted to NF Elk River 1% peak-flood
Unnamed Tributary 3	169	Difference between NF Elk River blw Dunlap Gulch and NF Elk River blw Unnamed Trib 3 1% peak-flood flows adjusted to NF Elk River 1% peak-flood
SF Elk River above confluence with NF Elk River	4,907	Coincident SF Elk River flow as difference between Elk River below confluence and NF Elk River 1% peak-flood flows
Elk River below confluence of NF and SF Elk River	11,627	1% annual chance peak-flood estimate
Railroad Gulch	268	Difference between Elk River blw NF & SF Elk confluence and Elk River blw Railroad Gulch 1% peak-flood flows
Clapp Gulch	214	Difference between Elk River blw Railroad Gulch and Elk River blw Clapp Gulch 1% peak-flood flows
Unnamed Tributary 4	142	Difference between Elk River blw Clapp Gulch and Elk River blw Unnamed Trib 4 1% peak-flood flows
Shaw Gulch	235	Difference between Elk River blw Unnamed Trib 4 and Elk River blw Shaw Gulch 1% peak-flood flows
Unnamed Tributary 1	267	Difference between Elk River blw Shaw Gulch and Elk River blw Unnamed Trib 1 1% peak-flood flows
Unnamed Tributary 2	80	Difference between Elk River blw Unnamed Trib 1 and Elk River blw Unnamed Trib 2 1% peak-flood flows
Orton Creek	286	Difference between Elk River blw Unnamed Trib 2 and Elk River blw Orton Creek 1% peak-flood flows
Martin Slough	1,313	Difference between Elk River blw Orton Creek and Elk River blw Martin Slough 1% peak-flood flows

Table 4. Summary of Case 2 (Event Condition 1) 1% annual chance peak-flood flow and coincident flood flow estimates for the Elk River Study area (refer to Figure 3).

Parameter	Flood Estimate (cfs)	Note
Case 2 for Event Condition 1		
NF Elk River above confluence with SF Elk River	5,592	Coincident NF Elk River flow as difference between Elk River below confluence and SF Elk River 1% peak-flood flows
NF Elk River below confluence with Lake Creek	4,938	NF Elk River blw Lake Creek 1% peak-flood adjusted to NF Elk River coincident flow
Browns Gulch	354	Difference between NF Elk River blw Lake Creek and NF Elk River blw Browns Gulch 1% peak-flood flows adjusted to NF Elk River coincident flow
Dunlap Gulch	159	Difference between NF Elk River blw Browns Gulch and NF Elk River blw Dunlap Gulch 1% peak-flood flows adjusted to NF Elk River coincident flow
Unnamed Tributary 3	140	Difference between NF Elk River blw Dunlap Gulch and NF Elk River blw Unnamed Trib 3 1% peak-flood flows adjusted to NF Elk River coincident flow
SF Elk River above confluence with NF Elk River	4,907	1% annual chance peak-flood estimate
Elk River below confluence of NF and SF Elk River	11,627	1% annual chance peak-flood estimate
Elk River tributaries below confluence of NF and SF Elk River	NA	All tributary flows below confluence of NF and SF Elk River are same as Case 1 (Table 3)

Winter Median-Flow

Winter median-flow estimates for Elk River and tributaries were necessary for the Event Condition 2 analysis. Winter median-flow estimates were determined for each tributary by scaling Little River near Trinidad (USGS 11481200) winter median-flow by tributary watershed area ratios. The winter median-flow estimate for Little River (243 cfs) was taken as the median flow for the months of November to April for the 64-year record (WY 1956 to 2019). The same general top-down approach used for the peak-flow estimates was used for estimating winter median-flows for the Elk River study area (Table 5).

Table 5. Summary of Event Condition 2 winter median-flow estimates for the Elk River Study area (refer to Figure 3).

Parameter	Winter Median-Flow Estimate (cfs)	Note
Event Condition 2		
NF Elk River above confluence with SF Elk River	135.4	Winter median-flow estimate for NF Elk River
NF Elk River below confluence with Lake Creek	115.4	NF Elk River blw Lake Creek winter median-flow adjusted to NF Elk River winter median-flow
Browns Gulch	10.6	Difference between NF Elk River blw Lake Creek and NF Elk River blw Browns Gulch winter median-flow adjusted to NF Elk River winter median-flow
Dunlap Gulch	5.0	Difference between NF Elk River blw Browns Gulch and NF Elk River blw Dunlap Gulch winter median-flow adjusted to NF Elk River winter median-flow
Unnamed Tributary 3	4.4	Difference between NF Elk River blw Dunlap Gulch and NF Elk River blw Unnamed Trib 3 winter median-flow adjusted to NF Elk River winter median-flow
SF Elk River above confluence with NF Elk River	116.2	Winter median-flow estimate for SF Elk River
Elk River below confluence of NF and SF Elk River	251.7	Winter median-flow estimate
Railroad Gulch	7.2	Difference between Elk River blw NF & SF Elk confluence and Elk River blw Railroad Gulch winter median-flow
Clapp Gulch	6.0	Difference between Elk River blw Railroad Gulch and Elk River blw Clapp Gulch winter median-flow
Unnamed Tributary 4	4.2	Difference between Elk River blw Clapp Gulch and Elk River blw Unnamed Trib 4 winter median-flow
Shaw Gulch	6.6	Difference between Elk River blw Unnamed Trib 4 and Elk River blw Shaw Gulch winter median-flow
Unnamed Tributary 1	7.8	Difference between Elk River blw Shaw Gulch and Elk River blw Unnamed Trib 1 winter median-flow
Unnamed Tributary 2	2.4	Difference between Elk River blw Unnamed Trib 1 and Elk River blw Unnamed Trib 2 winter median-flow
Orton Creek	8.4	Difference between Elk River blw Unnamed Trib 2 and Elk River blw Orton Creek winter median-flow
Martin Slough	40.1	Difference between Elk River blw Orton Creek and Elk River blw Martin Slough winter median-flow

HYDRAULIC ANALYSIS

This section summarizes the hydrodynamic model modification and further development used to estimate 1% annual chance flood elevations in the Elk River study area.

Elk River Hydrodynamic Model

The HST Model developed as part of the Elk River Recovery Assessment (California Trout et al., 2018) was used to simulate the hydrodynamics and sediment transport of the lower reaches of the Elk River for the observational period of Water Year (WY) 2003 to 2015. The HST model was developed using the Environmental Fluid Dynamics Code (EFDC) modeling framework, which solves the three-dimensional shallow water equations of motion and dynamically couples salinity, temperature, sediment transport and water quality transport modules. The EFDC model can be configured for one-, two- and three-dimensional simulations. The Elk River HST Model was configured as a two-dimensional model. The Windows-based EFDC_Explorer8.4 was used for a majority of the pre- and post-processing, and the enhanced EFDCPlus model was used in this assessment (Craig, 2018).

The HST Model grid domain covers approximately 18 mi (~29.5 km) of Elk River channel, with the upstream boundaries of the domain beginning just below Lake Creek on the NF Elk River and Toms Gulch on the SF Elk River, and the downstream boundary ending in Humboldt Bay (Figure 1 and Figure 3). The model grid was originally configured to achieve prediction goals and expectations at both the grid and reach scales and allow for long-term simulations (~13 years) within reasonable computer run times. The highest flood flow within the 13-yr simulation record (WY 2003 to 2015) was an approximate 10% annual chance flood event in December 2002. Upstream of Highway 101 (HWY101) the model domain includes the active 10% to 1% annual chance floodplain. However, downstream of HWY101 the model grid was confined to the Elk River channel which is confined by levees, a sand spit, and higher topographic areas which did not overtop during the peak flood events in the 13-yr simulation record. To model 1% annual chance flood events the HST Model grid was expanded in the downstream reaches to allow flood flows to cross HWY101, and flow south towards King Salmon and North towards the Eureka wastewater facility (Figure 1 and Figure 3). The expanded grid resolution diminishes in the north and south directions moving away from the Elk River channel. The coarser grid north and south areas may miss topographic features that could raise water levels above predicted values and under-estimate inundation in these areas. As mentioned earlier, the expanded model is referred to as the H-Exp Model to differentiate it from the original Elk River HST Model.

The H-Exp Model was configured as a two-dimensional (2D) model (Figure 3). The curvilinear-orthogonal grid consists of 41,246 horizontal segments and one complete mixed, depth-averaged vertical layer. Consistent with the original HST Model, the H-Exp Model contains thirteen (13) stream flow boundaries which includes the NF and SF Elk Rivers and eleven tributaries. Two different Humboldt Bay downstream open boundary condition regions were included to accommodate the expanded grid. In general, consistent grid elevations and model parameters (e.g. effective bottom roughness height (Z_0), vegetation drag coefficients, and eddy viscosity) from the calibrated and validated HST Model were used in H-Exp Model. For a more detailed discussion of the HST Model development, reference can be made to Elk River Recovery Assessment (California Trout et al., 2018).

Infrastructure components incorporated into the H-Exp Model domain include tide gate structures, drainage ditch features, bridge crossings and at-grade floodplain roads, which are briefly discussed in the following:

- The four largest tide gate structures and the major drainage ditch features located in the lower agricultural reaches of the domain were incorporated into the model grid.
- Six bridge crossings located on the NF Elk River (Concrete Bridge), SF Elk River (SF Bridge), and Mainstem Elk River (Elk River Courts Road, Berta's Road, Zanes Road, and HWY101) were incorporated into the model grid. The bridge crossing topographic constrictions were accounted for in the grid, but the bridge piers and decks were not.
- Six at-grade roads (NF Elk River Road, Steel Bridge Road, Elk River Courts Road, Bertas Road, Zanes Road and HWY101) that cross the floodplain perpendicular to the direction of flow were also incorporated into the model grid.

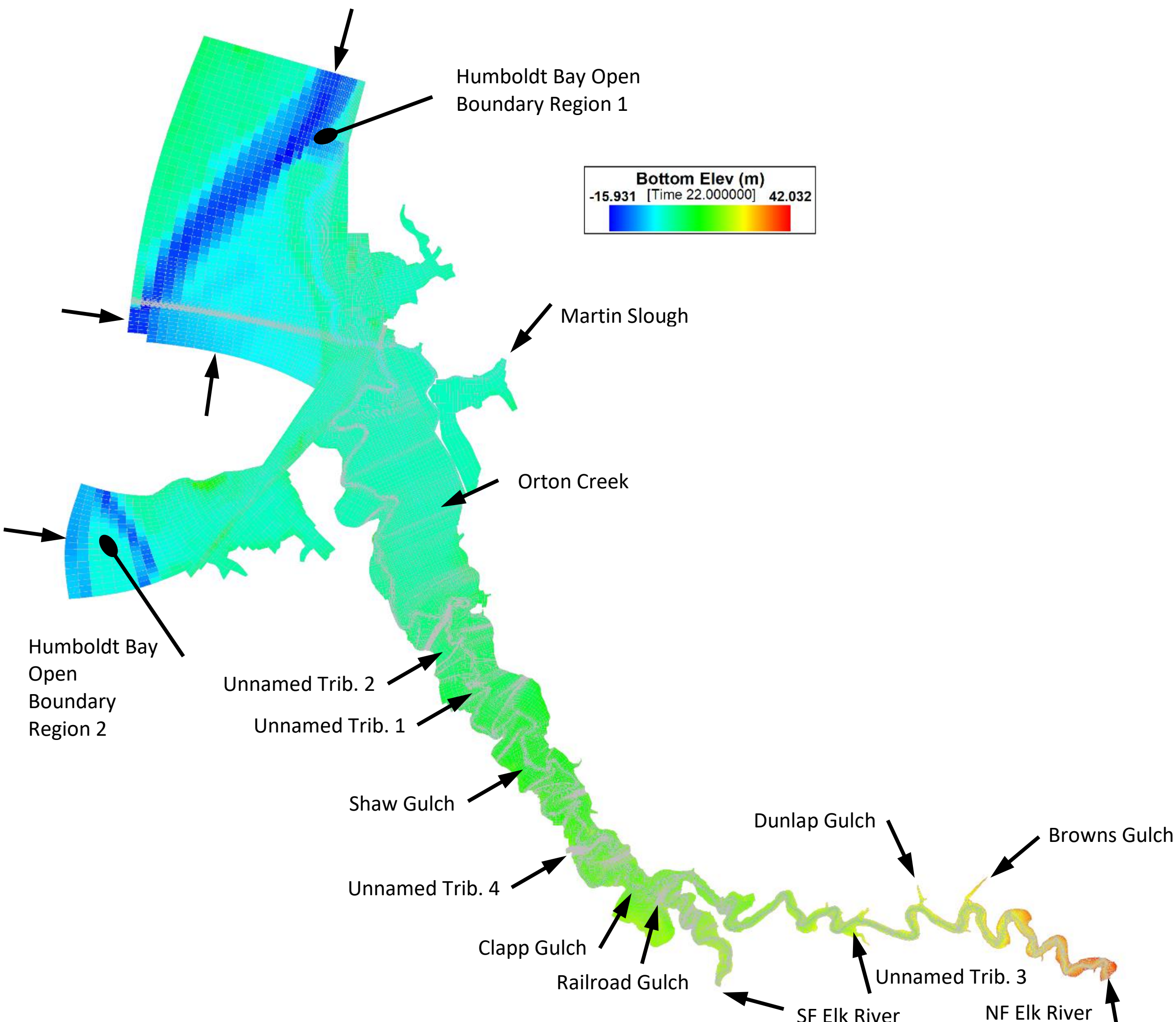

Figure 3. Elk River H-Exp Model grid, grid elevations and boundary conditions for Elk River, tributaries, and Humboldt Bay open boundary regions.

For this study, the H-Exp model only simulated hydrodynamics (i.e. depth and velocity) and not sediment transport. The original HST model was calibrated and validated to a large data set of water surface elevations, velocity, discharge, and suspended sediment concentration observations in the Elk River model domain study area for WY 2003 to 2015. The model calibration and validation results demonstrate high predictive capability for all simulated variables.

Correlation plots of water surface elevation for in-channel stage data (Figure 4) and floodplain high-water mark data (Figure 5) for the WY 2015 calibration period show high correlation of predictions to observations. The high correlation of predictions to observations indicate that the HST model and H-Exp Model have good to excellent predictive skill for water surface elevations over a large range of elevations. Only calibration results are provided in this memo, but validation results show similar correlation.

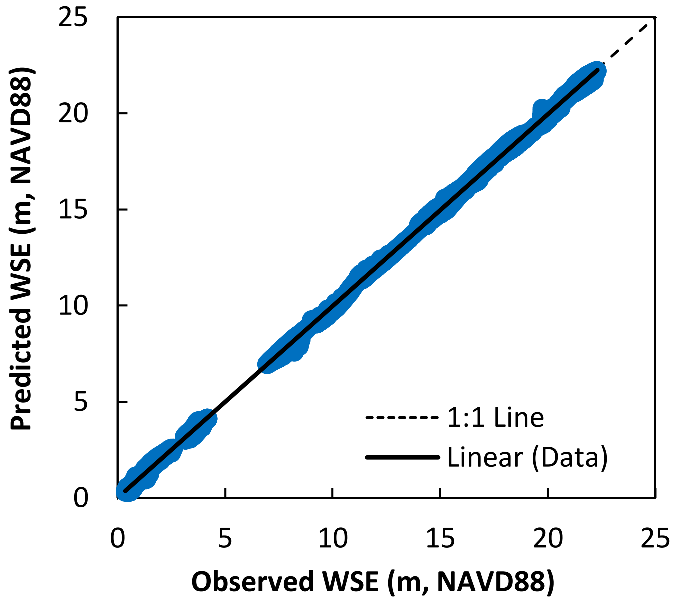

Figure 4. Observed and predicted WY 2015 water surface elevation (WSE) (in meters) for in-channel stage data [sample number = 13,088, correlation coefficient >0.999, average absolute error = 0.085 m (0.28 ft), root mean square error = 0.108 m (0.35 ft)].

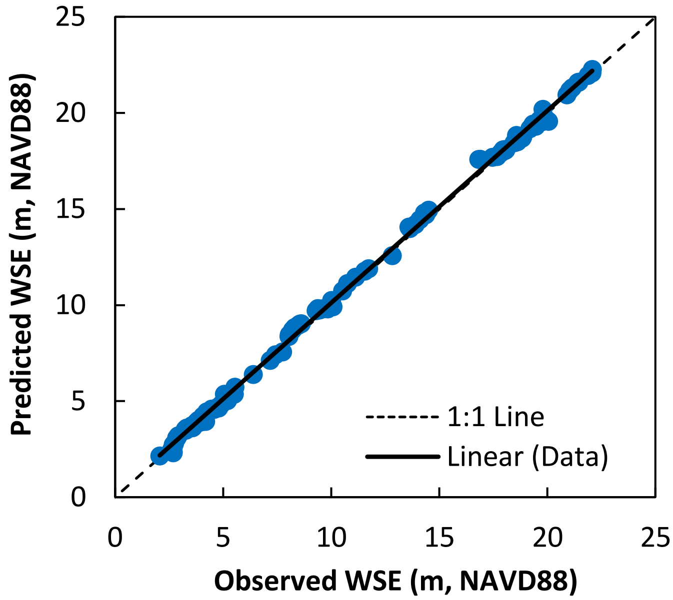

Figure 5. Observed and predicted WY 2015 water surface elevation (WSE) (in meters) for floodplain high water mark data [sample number = 112, correlation coefficient >0.999, average absolute error = 0.111 m (0.36 ft), root mean square error = 0.256 m (0.84 ft)].

Independence of Coastal (Surge) and Riverine Events

The Study area is subject to coastal extreme high-water level (storm surge) and riverine flood events. These processes can happen independently or simultaneously occur creating combined flood levels from both coastal and riverine events. Along much of the U.S. Pacific Coast, storm systems that produce extreme coastal surge events are not the same systems that produce extreme riverine flooding, and these events can generally be assumed independent (FEMA, 2005).

To verify the independence assumption, an evaluation of annual peak-flows for the Eel River at Scotia (USGS 11477000) and Little River near Trinidad (USGS 11481200), and the coincident maximum daily tide level from the Crescent City tide gauge (NOAA 94119750) on station datum was conducted (Figure 6). The intersection of these data is compared to the Eel River and Little River flood level probabilities from Gotvald et al. (2012), and the Crescent City extreme high-water level event probabilities and mean higher high water (MHHW) and mean monthly maximum water (MMMW) levels from NHE (2015).

Over the POR for both river locations simultaneous coastal and riverine events exceeding 10% annual chance probabilities have not occurred. Although a limited number of simultaneous events did occur between 50% and 10% annual chance probabilities at both locations. Results indicate that coastal and riverine extreme events generally appear independent or can be assumed widely separated in time.

Figure 6 also demonstrates that coastal water levels were between MHHW and the 50% annual chance event for most annual peak-flows at both river locations. This indicates that the assumption of using a MMMW tidal series as a typical downstream boundary condition for riverine flood events is reasonable.

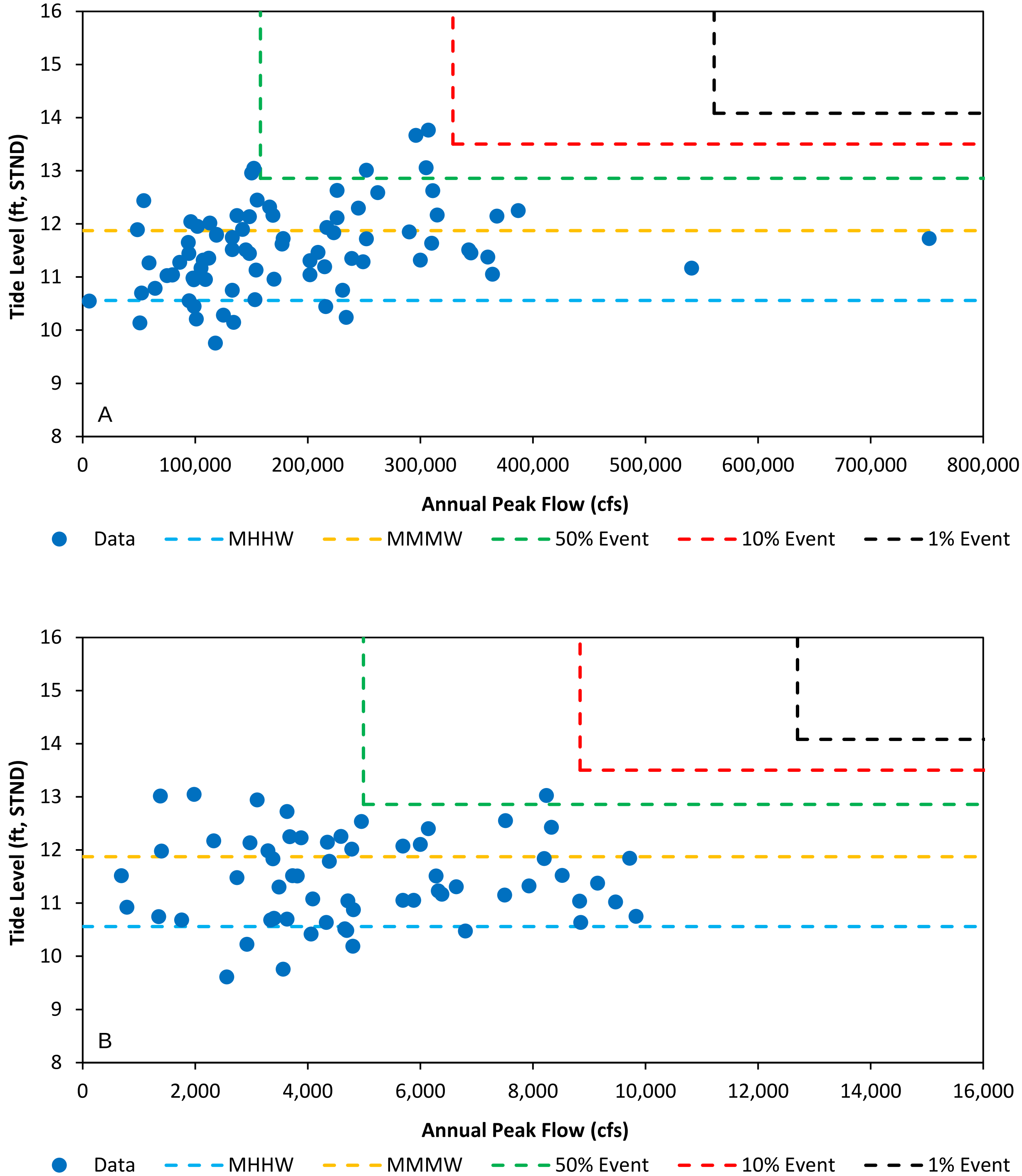

Figure 6. Comparison of (A) Eel River at Scotia (USGS 11477000) and (B) Little River near Trinidad (USGS 11481200) annual peak flows and coincident maximum daily tide levels for Crescent City (NOAA 94119750) tide gauge reported on station datum (STND). Extreme high-water level event probabilities and mean higher high water (MHHW) and mean monthly maximum water (MMMW) for Crescent City are from NHE (2015); and Eel River and Little River flood probabilities are from Gotvald et al. (2012). #% Event (e.g. 1% Event) represents the #% annual chance event (e.g. 1% annual chance event).

Boundary Conditions

This section provides an overview of the H-Exp Model upstream and downstream boundary conditions used for the Event Condition 1 and Event Condition 2 analysis.

Event Condition 1

Event Condition 1 analyzed the 1% annual chance flood from upstream riverine sources with a representative constant existing condition spring tide level at the Humboldt Bay downstream boundary regions. The H-Exp Model was used as a steady-state model with constant boundary conditions for Event Condition 1.

Due to backwater conditions at the NF and SF Elk River confluence, two cases were analyzed. For Case 1 the NF Elk River was at the 1% annual chance peak-flood flow, and the tributary peak-flows used in the analysis are summarized in Table 3. Case 2 assumes the SF Elk River is at the 1% annual chance peak-flood flow, and the tributary flows are summarized in Table 4.

The downstream boundary condition spring tide water level for Case 1 was represented as the mean monthly maximum (MMMW) tide level, which was taken from the Humboldt Bay sea-level rise 2D modeling work conducted by NHE (2015) for Year 2012. For this study the Year 2012 results from NHE (2015) represent existing conditions. The MMMW water levels were extracted at the corners of the two open boundary regions (Figure 3), and then interpolated along each boundary edge. MMMW water levels in open boundary region 1 ranged between 7.94 and 8.02 ft, and in region 2 between 7.99 and 8.01 ft.

Event Condition 2

Event Condition 2 analyzed the stillwater 1% annual chance extreme coastal event in Humboldt Bay with winter median-flow from upstream riverine sources. For Event Condition 2, the H-Exp Model was used as a dynamic model with tidal time series boundary conditions in Humboldt Bay and steady winter median-flows for all streams (Table 5).

The representative 1% annual chance tidal series were extracted from the Humboldt Bay sea-level rise 2D model results (NHE, 2015) for Year 2012. Like Event Condition 2, the tidal time series were extracted at the corners of each open boundary region and interpolated along the boundary region edges. Figure 7 shows a representative 1% annual chance tidal series used as one of the Humboldt Bay boundary conditions. It should be noted that the tidal series contains both the 1% and 0.2% annual chance extreme high-water level events.

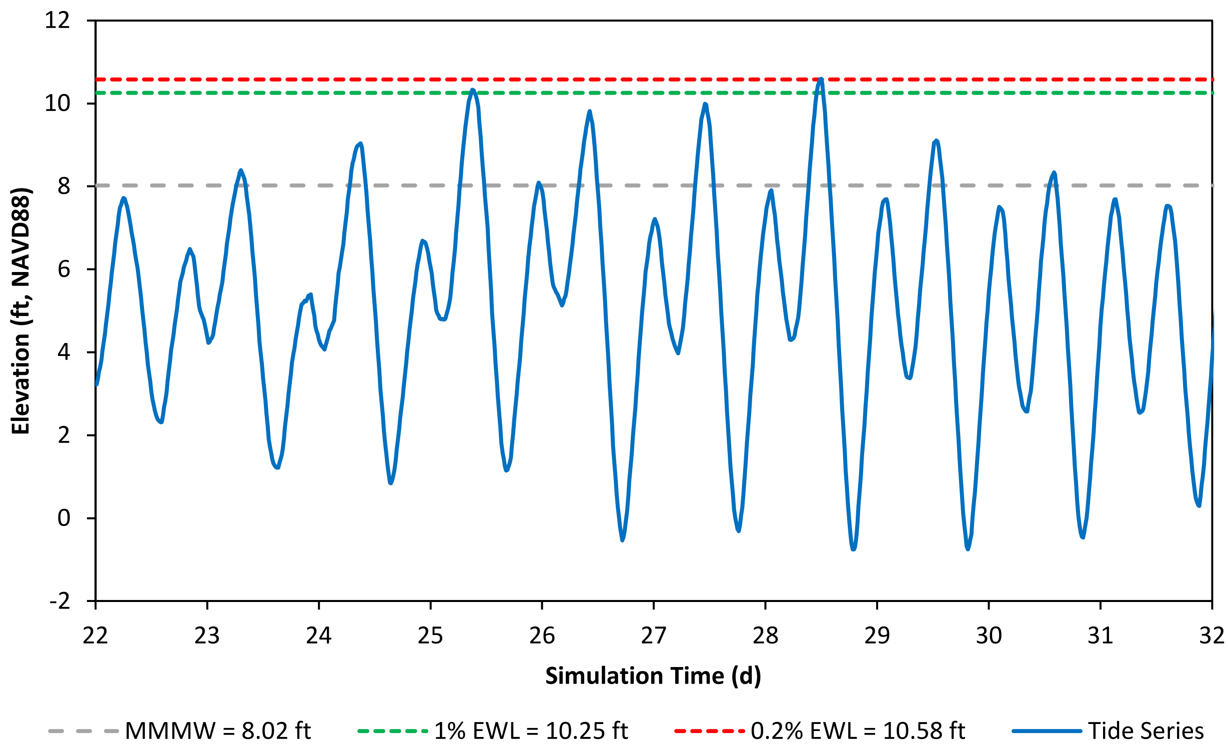

Figure 7. Representative tidal series for the H-Exp Model downstream boundary condition for the 1% annual chance extreme high-water level event. #% EWL (e.g. 1% EWL) represents the #% annual chance extreme high-water level (e.g. 1% annual chance extreme high-water level).

1% ANNUAL CHANCE FLOOD ELEVATION ESTIMATES

The H-Exp Model was used to estimate the 1% annual chance flood elevations within the Elk River Study area. To account for the effects of coincident flood flows for the NF and SF Elk River, and coastal and riverine flood events, the maximum water surface elevation at each grid cell from Event Condition 1 and Event Condition 2 runs were combined into a single layer representing the 1% annual chance flood elevations over the Elk River Study area.

The 1% annual chance flood levels in the Elk River Study area are provided in Attachments 1, 2 and 3, and include the following information on each attachment:

- FEMA special flood hazard zones that include 1% annual chance BFE for Zones AE and VE from the FEMA coastal analysis (blue text and blue polygons); and the Martin Slough detailed study information (red text and solid red BFE contour lines).
- FEMA flood hazard zone inundation extents (orange-red line) for all flood zones (Zones A, AE, and VE).
- Estimated 1% annual chance flood elevation contours (ft, NAVD88) from this study (black text and black dashed lines).
- Estimated 1% annual chance flood inundation extents from this study (black solid line).

These attachments provide 1% annual chance flood elevation estimates over much of the Elk River Zone A areas.

Attachment 2 shows the 1% annual chance flood elevation estimates compared to the FEMA BFE near Humboldt Bay. The FEMA FIS hydraulic analysis for Martin Slough assumed a normal-depth downstream boundary condition which resulted in a BFE of 13 feet over much of the lower Martin Slough area. The 1% annual chance flood elevation estimate from this study for the Elk River is above 15 feet near the confluence with Martin Slough, indicating that the FEMA BFE in lower Martin Slough could be over 2 feet low. Likewise, on the west side of HWY101, the 1% annual chance flood elevation estimates from this study for the Elk River are 1 to 4 feet higher than the FEMA BFE of 10 feet within the adjacent land areas to Humboldt Bay. The FEMA FIS and BFE accounted for Martin Slough flooding only without consideration of Elk River backwater flood effects, or coastal flooding only on the west side of HWY101 without the combined effects of coastal and fluvial flooding from Elk River. The developed H-Exp Model provides Elk River backwater flood conditions that can be considered in lower Martin Slough and combined coastal and Elk River fluvial flood conditions on the west side of HWY101.

These attachments also identify properties outside of the FEMA Zone A boundary that are vulnerable to 1% annual chance flood exposure. It appears this is the case for several residences near the NF and SF Elk River confluence area (Attachment 3).

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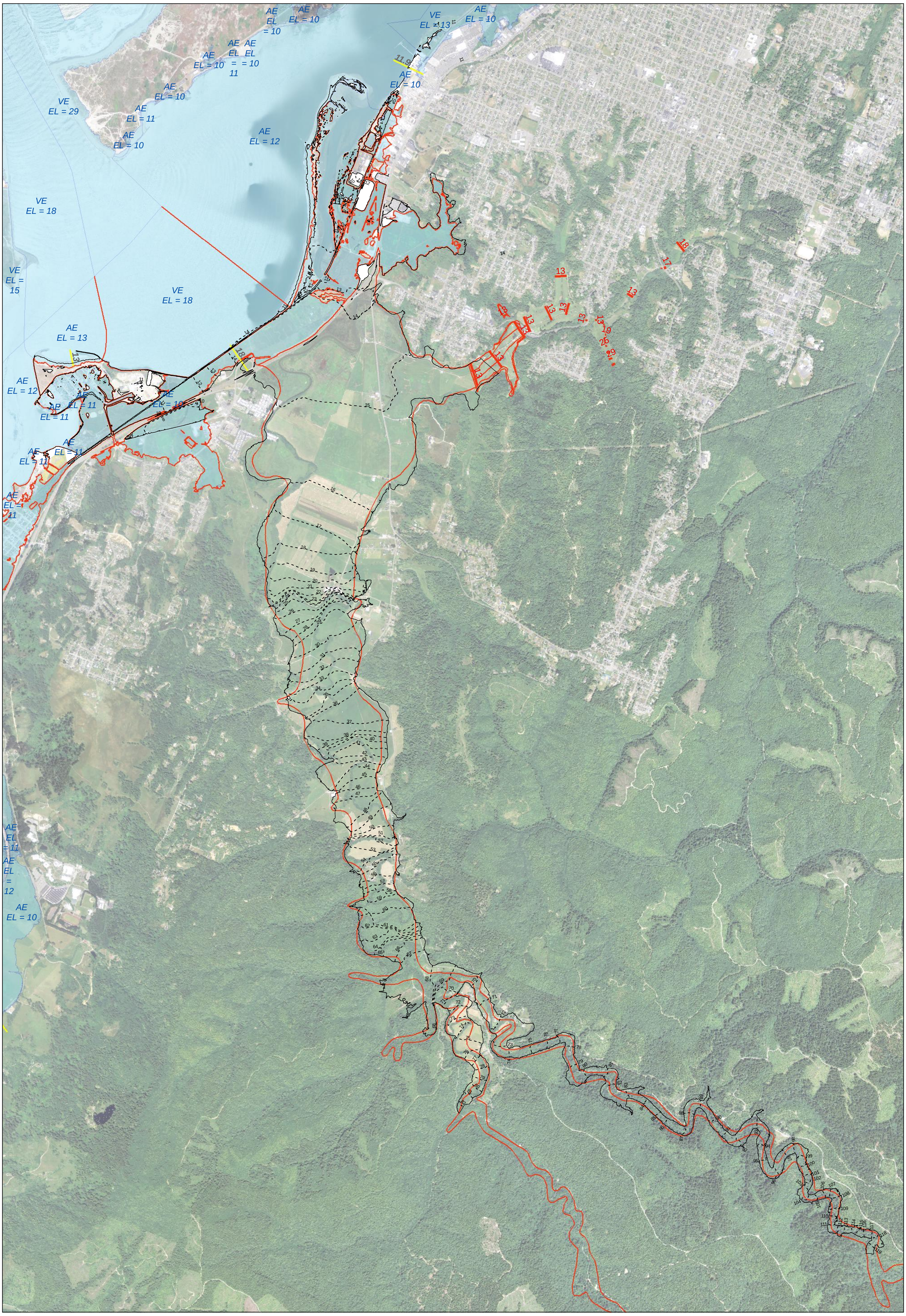
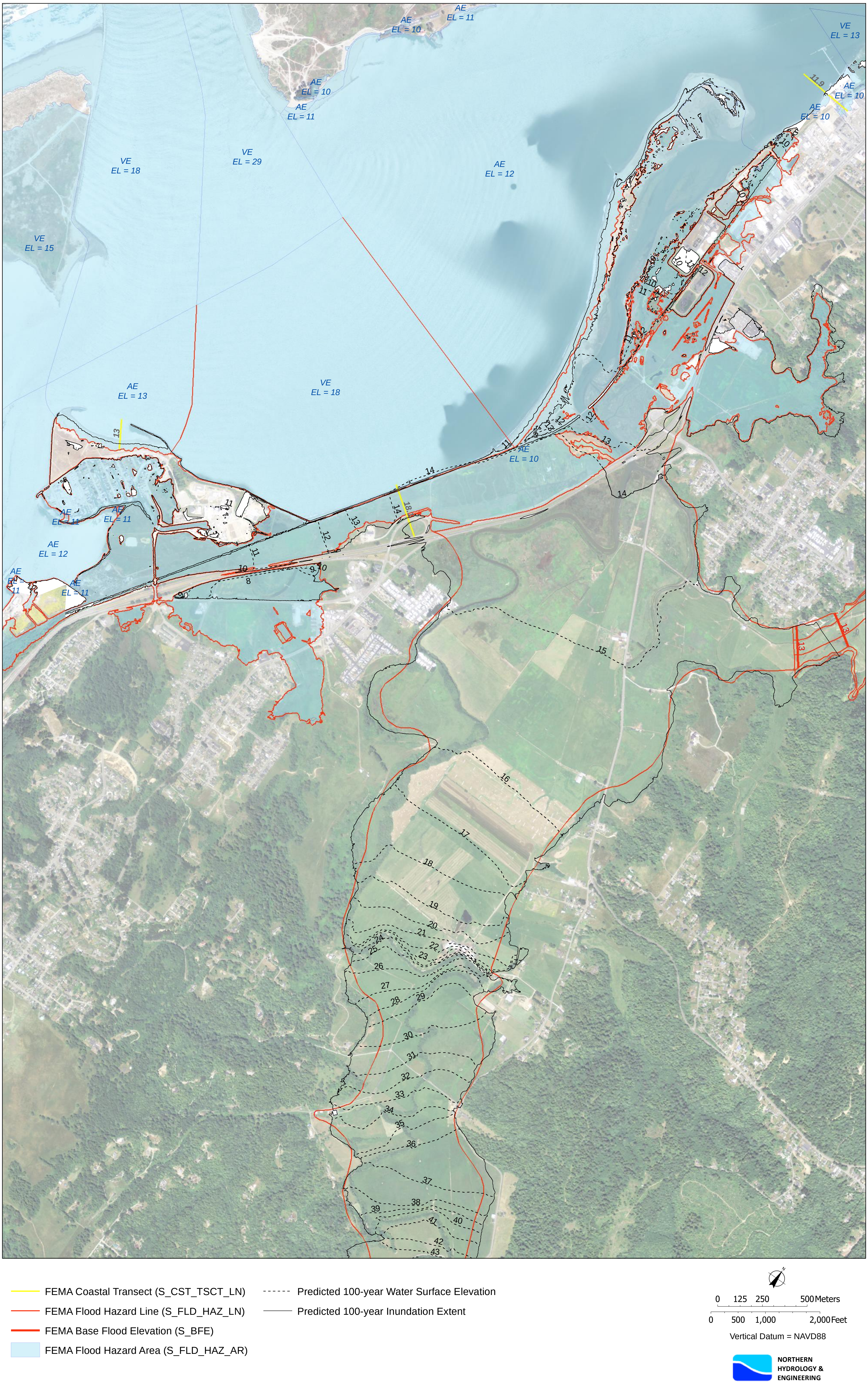


FEMA Coastal Transect (S_CST_TSCT_LN)
FEMA Flood Hazard Line (S_FLD_HAZ_LN)
FEMA Base Flood Elevation (S_BFE)
FEMA Flood Hazard Area (S_FLD_HAZ_AR)
Predicted 100-year Water Surface Elevation
Predicted 100-year Inundation Extent

0 250 500 1,000 Meters
0 1,250 2,500 5,000 Feet
Vertical Datum = NAVD88

NORTHERN HYDROLOGY & ENGINEERING

Attachment 1. 1% Annual chance flood elevation estimates in entire Elk River Study area.



Attachment 2. 1% Annual chance flood elevation estimates in the northern portion of Elk River Study area.

Attachment 3. 1% Annual chance flood elevation estimates in the southern portion of Elk River Study area.